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Poznan University of Technology
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Flexible Procedure for Ready Mix Concrete Production, Delivery, and Placement in Different Environmental Conditions by Monitoring and Learning

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STRESZCZENIE

Układanie betonu towarowego w warunkach wysokiej temperatury otoczenia stwarza znaczące wyzwania zarówno w procesie budowy, jak i jakości ostatecznego produktu. Podwyższona temperatura w betonie towarowym (RMC) może powodować problemy, takie jak pękanie termiczne i obniżenie wytrzymałości na ściskanie z powodu gradientów termicznych spowodowanych ciepłem hydratacji cementu. Skuteczne zarządzanie produkcją, transportem, układaniem i pielęgnacją RMC w zmiennych warunkach otoczenia, temperaturze mieszanki, poziomach wilgotności i czasie dostawy wymaga pełnego zrozumienia, jak te czynniki oddziałują i wpływają na właściwości betonu. Głównym celem jest osiągnięcie pożądanego poziomu jakości betonu towarowego (RMC), zwłaszcza jeśli chodzi o wytrzymałość na ściskanie betonu, aby sprostać oczekiwaniom klientów określonym przede wszystkim przez podanie klasy zamawianego betonu towarowego.

Rozprawa obejmuje kilka kluczowych aspektów, w tym budowę systemu zarządzania jakością w węźle betoniarskim (SCBP) poprzez połączenie przewodnika PMBOK z narzędziami zarządzania jakością w jednolity system. W ramach zarządzania procesami wykorzystuje się metodykę AHP (Analytic Hierarchy Process), która jest wdrażana za pomocą oprogramowania Expert Choice, co umożliwia elastyczną analizę kryteriów i wariantów, ułatwiając podejmowanie decyzji. W rozprawie wykorzystuje się różne narzędzia i metody, takie jak monitorowanie w czasie rzeczywistym, Six Sigma, symulację Monte Carlo oraz analizę FMEA (*Failure mode and effects analysis*). Metodę FEMA wykorzystano do oceny jakości materiałów stosowanych w produkcji betonu towarowego. Ocenie poddano właściwości wody, cementu, kruszywa drobnego i grubego. Badania miały na celu identyfikację renomowanych dostawców zdolnych do dostarczenia wysokiej jakości materiałów (surowców). Wdrożono także specjalne strategie, takie jak na przykład: stosowanie formuły z lodem w celu obniżenia temperatury mieszanki (uwzględniając zawartość wody w mieszance betonowej).

Podczas badań skoncentrowano się na poprawie właściwości mieszanki RMC poprzez monitorowanie w czasie rzeczywistym, co obejmowało kontrolowanie temperatury mieszanki betonowej, temperatury otoczenia, wilgotności względnej, prędkości wiatru i tempa parowania oraz czasów dostawy RMC, urabialności, zawartości powietrza, porowatości oraz określenie ich wpływu na wytrzymałość na ściskanie w różnych warunkach (pory roku).

Na zakończenie przeprowadzono badania w celu oceny wpływu różnych czynników przed i po wprowadzeniu usprawnień w mieszance, mając na celu osiągnięcie zerowych defektów. Wykorzystano techniki uczenia maszynowego, w szczególności sztuczne sieci neuronowe

ANN (Artificial Neural Network). Sieci te pozwalają na przewidywanie wytrzymałości na ściskanie betonu towarowego (RMC) na podstawie parametrów i warunków zmierzonych w poprzednich etapach, włącznie z całkowitym czasem dostawy.

Wyniki badań wskazują na znaczącą poprawę średniej wytrzymałości na ściskanie RMC, przekraczającą 50% po wprowadzeniu opisywanych usprawnień w produkcji, transporcie i układaniu mieszanki betonowej. Jak wykazano po wdrożeniu opisywanych usprawnień możliwe jest osiągnięcie wytrzymałości na ściskanie na poziomie 53 MPa w porównaniu do poprzednio osiąganych 25 MPa. Wynik ten uzyskano poprzez zastosowanie różnych strategii, takich jak: selekcja dostawców (co umożliwia zastosowanie surowców wysokiej jakości), usprawnienie produkcji mieszanki betonowej oraz właściwe zarządzanie procesami transportu, układania i pielęgnacji betonu towarowego (np. kontrola temperatury otoczenia, sterowanie temperaturą mieszanki betonowej).

W rozprawie wykorzystano modele sztucznych sieci neuronowych umożliwiające przewidywanie wytrzymałości na ściskanie RMC w oparciu o parametry mieszanki betonowej dotyczące węzła betoniarskiego (SCBP) i placu budowy, uwzględniające różne warunki środowiskowe w różnych porach roku. Modele te wykazują skuteczne możliwości predykcji, z wysokimi współczynnikami korelacji (R2) i niskim średnim błędem kwadratowym (RMSE). Z przeprowadzonych badań wynika, że wartości współczynnika korelacji R2 dla wytrzymałości na ściskanie betonu towarowego RMC wynoszą 91,9%, 99,7% i 94,3% w sezonie wiosennym, letnim i zimowym (odpowiednio) na placu budowy oraz 94,5%, 98,1% i 60,4% (odpowiednio) w wytwórni betonu towarowego (SCBP). RMSE dla wytrzymałości na ściskanie RMC jest różny i wynosi od 0,3662 do 1,534. Przedstawiony model, charakteryzujący się odpowiednią elastycznością, pozwala spełnić różne wymagania klienta.

Podsumowując, łącząc podejście numeryczne i eksperymentalne, rozprawa ta oferuje skuteczną i elastyczną procedurę doskonalenia jakości betonu towarowego w różnorodnych warunkach środowiskowych.

ABSTRACT

Placing ready-mix concrete under high ambient temperatures creates significant challenges both in the construction process and the quality of the final product. Elevated temperatures in ready-mix concrete (RMC) can cause problems such as thermal cracking and reduced compressive strength due to thermal gradients caused by the heat of hydration of the cement. Effectively managing the production, transportation, placement and curing of RMCs under varying environmental conditions, mix temperatures, humidity levels and delivery times requires a full understanding of how these factors interact and influence the properties of concrete. The main goal is to achieve the desired quality level of ready-mixed concrete (RMC), especially in terms of compressive strength of the concrete, in order to meet customer expectations determined primarily by the class of ready-mixed concrete ordered.

The dissertation covers several key aspects, including the construction of a quality management system for a concrete mixing plant (SCBP - Stationary Concrete Batching Plant) by combining the PMBOK guide with quality management tools into a unified system. Process management uses the AHP (Analytic Hierarchy Process) methodology, which is implemented using Expert Choice software, which enables flexible analysis of criteria and variants, facilitating decision-making. The dissertation uses various tools and methods, such as real-time monitoring, Six Sigma, Monte Carlo simulation and FMEA analysis (Failure mode and effects analysis). The FEMA method was used to assess the quality of materials used in the production of ready-mixed concrete. The properties of water, cement, fine and coarse aggregate were assessed. The research aimed to identify reputable suppliers capable of providing high-quality materials (raw materials). Special strategies have also been implemented, such as: using an ice formula to lower the mix temperature (taking into account the water content of the concrete mix).

This research focused on improving RMC mix properties through real-time monitoring, which included controlling concrete mix temperature, ambient temperature, relative humidity, wind speed and evaporation rates, and RMC delivery times, workability, air content, porosity and determining their effect on strength for compression in various conditions (seasons).

Finally, studies were conducted to evaluate the impact of various factors before and after making improvements to the mix, with the goal of achieving zero defects. Machine learning techniques were used, in particular artificial neural networks ANN (Artificial Neural Network). These networks allow the prediction of the compressive strength of ready-mix concrete (RMC)

based on the parameters and conditions measured in the previous stages, including the total delivery time.

The test results indicate a significant improvement in the average compressive strength of the RMC, exceeding 50% after introducing the described improvements in the production, transport, and placement of the concrete mix. As shown, after implementing the described improvements, it is possible to achieve a compressive strength of 53 MPa compared to the previously achieved 25 MPa. This result was achieved by using various strategies, such as: selection of suppliers (which enables the use of high-quality raw materials), improvement of the production of the concrete mix and proper management of the processes of transport, laying and care of ready-mix concrete (e.g. controlling the ambient temperature, controlling the temperature of the concrete mix).

In this dissertation artificial neural network models to predict the compressive strength of RMC based on concrete mix parameters related to the concrete mixing plant (SCBP) and the construction site, had been used taking into account different environmental conditions at different times of the year (seasons). These models demonstrate effective prediction capabilities, with high correlation coefficients (R^2) and low root mean square error (RMSE). The conducted research shows that the values of the correlation coefficient R^2 for the compressive strength of RMC ready-mix concrete are 91.9%, 99.7% and 94.3% in the spring, summer and winter seasons (respectively) at the construction site and 94.5%, 98.1% and 60.4% (respectively) in the ready-mix concrete plant (SCBP). The RMSE for the RMC compressive strength varies and ranges from 0.3662 to 1.534. The presented model, characterized by appropriate flexibility, allows it to meet various customer requirements.

In summary, by combining numerical and experimental approaches, this thesis offers an effective and flexible procedure for improving the quality of ready-mix concrete under a variety of environmental conditions.

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PUBLICATIONS AND CONFERENCES

1- "QUALITY MANAGEMENT TO CONTINUOUS IMPROVEMENTS IN THE PROCESS OF READY-MIX CONCRETE PRODUCTION"

By: Alaa Al-Saedi (1), Jerzy Pasławski (2), and Piotr Nowotarski(3).
Journal: "IOP Conference Series, Materials Science, and Engineering, "vol. 518, 2019.
https://iopscience.iop.org/article/10.1088/1757-899X/518/2/022019
2nd International Conference on Sustainable Engineering Techniques (ICSET 2019)

2-"INflUENCE OF STAKEHOLDERS AND COMMUNICATIONS MANAGEMENT IN CHOOSING THE BEST PRODUCT BY ANALYTIC HIERARCHY PROCESS METHOD"

By: AlaaAL-Saedi(1), and JerzyPasławski(2).
Journal: "IOP Conference Series, Materials Science and Engineering, "**June 2019**.
https://iopscience.iop.org/article/10.1088/1757-899X/518/2/022068
2nd International Conference on Sustainable Engineering Techniques (ICSET 2019)

3- "RISK MANAGEMENT BY MONITORING AND CONTROLLING RMC PRODUCTION, DELIVERY AND POURING BASED ON INDUSTRY 4.0, SIX SIGMA AND ISO 9000" (Poster).

By: Alaa AL-Saedi (1), and Jerzy Pasławski(2).
51st Conference and 4th Workshop at Poznan University of Technology, June10/11, 2019

4- "SUPPLIER RISK MANAGEMENT BY MONITORING AND CONTROLLING RMC PRODUCTION, DELIVERY, AND POURING BASED ON REAL-TIME MONITORING AND SIX SIGMA."

By: AlaaAL-Saedi(1), and JerzyPasławski(2).
Journal: Misan Journal of Engineering Sciences (MJES), **2023 (under evaluation)**

5- "REDUCE THE RAW MATERIALS QUALITY VARIATION AND BEST SUPPLIER BY MONITORING AND LEARNING"

By: AlaaAL-Saedi(1), and JerzyPasławski(2).
Journal: Construction and Building Materials, **2023 (under evaluation)**

LIST OF ABBREVIATIONS

RMC	Ready Mix Concrete
SCBP	Stationary Concrete Batching Plant
QM	Quality Management
TQM	Total Quality Management
QC	Quality control
QA	Quality Assurance
W/C	Water/Cement ratio
PMBOK Guide	Project Management Body of Knowledge
FMEA	Failure Mode & Effects Analysis
OCC	Occurrence probability
DET	Detection ease of the problem
SEV	The severity of the problem
RPN	Risk Priority Number
5 whys	5 whys analysis
Ishikawa Dia.	Ishikawa Diagram method of analysis
SM	Stakeholders Management
CM	Communication Management
AHP	Analytic Hierarchy Process
ASTM	American Society for Testing and Materials
B.S	British Standard
T.D.S	Total dissolved solids
PH	Degree of acidity
Cl	Chloride
O.W	Ordinary Water
P.W	Public Water
R.O.W	Reverse Osmosis Water
IST	Initial Setting Time
FST	Final Setting Time
B.L	Burning Loss
L.S.F	Limestone Saturation Factor
So_3	Cement Sulfate
f_{ci}	Compressive strength of the specimen at 28 days (MPa)
Fi	Maximum load applied to the specimen (N)
A_{ci}	The cross-sectional area of the specimen (mm^2)
Evap. rate	evaporation rate of ready-mix concrete
SPC	Statistical Process Control
6σ	Six Sigma
UCL	Upper Control Limit
LCL	Lower Control Limit
ANN	Artificial Neural Networks
LMS	Learning Management Systems
MLP	Multilayer Perceptron
R	Pearson's correlation coefficient
R^2	The correlation coefficient squared
RMSE	Root Mean Square Error

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CHAPTER 1 INTRODUCTION

1.1 General

The engineered mix design is called Ready-Mix Concrete in the context of stationary batching plant-produced concrete conforming to established standards. RMC offers several key benefits, including adherence to quality standards, cost efficiency, shorter production times compared to on-site mixing, and improved environmental sustainability through reduced waste generation. The definition of quality is to be suitable (fit) for its purpose and meet customer satisfaction, which may have a different understanding of subjective attributes [1]. The Quality Management principles implementation in the process is a planned decision for the organization to improve management implementation and deliver a solid foundation for growth sustainability [2]. It can be set up as a component of an improved path maintained by human resources management, management support, technology management, and strategy management [3]. Managing and controlling the crucial RMC properties and services is an essential assignment of the QM system and, consequently, quality management performance in the process [4]. Quality management decreases the non-quality costs and achieves customer expectations [5]. In contrast, the cost of non-quality can be caused by the impact of high or good quality in addition to advantages like delivery cost, delay, flexibility, and maintenance to deal with orders, problems, and customers [6][7].

The use of a socio-technical path to improve the processes and the system of the enterprise to attain the satisfaction of customers [8]. Therefore, if the processes and system improvement are insufficient, the next level will predict RMC parameters in real time. Technologies like Machine learning have been developing a solution with various benefits, quality of products, and reduction of cost [9][10]. It is essential to control, improve quality, and process [11]. The conventional meaning of quality has a more significant role later, which can be considered as the digitalization of Total Quality Management, and it affects the technology of quality, process, and production [12]. This combination assists in managing not just the production in SBPC but also the fast change of demands [13]. The benefit of evolving to manufacture is to increase their productivity and waste in the production [14]. Indeed, the term Industry 4.0 was announced in 2011 by the German Hannover Fair [15].

1.2 Problem description (origin of the work)

The RMC process, from a technological aspect, involves numerous components, like concrete mix design, production, delivery to the construction site, placement, and curing. Accurately implementing the actions mentioned above produces concrete customer satisfaction [16]. On the other hand, various factors like temperature and humidity, delivery process time, type of elements, and W/C ratio can affect the RMC quality. These factors can affect RMC properties, the $f$ci (MPa), durability, permeability, air content, and consistency, where [17]: -

- Increasing humidity caused a decrease in the $f$ci (MPa) and affected its durability.
- The safe limit temperature is 86-90 °F (30-32 °C), but thermal cracking can result from the temperature variance.
- Increasing RMC temperature can reduce the $f$ci (MPa) and decrease durability, where the $f$ci can determined as follows [17]:

$$f_{ci} = \frac{F_i}{A_{ci}}, f_{cm} = \frac{\sum_{n=1}^{n} f_{ci}}{n} \quad (1)$$

Where: -

$\boldsymbol{f}_{\mathbf{ci}}$ = compressive strength, ***Fi*** = maximum load, and $\boldsymbol{A_{ci}}$ = the area of a sample cross-section, ***n*** = samples number.

One of the reasons for that is the cement's faster hydration at higher temperatures and high humidity produces weak microstructural concrete due to the higher porosity because of cement hydration; therefore, several of these pores will never be filled [16].

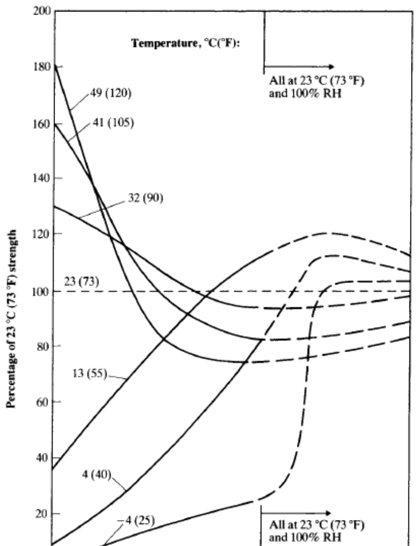


Figure 1.1 The temperature effect on concrete strength (in 28 days) where the water-cement ratio (W/C) is 0.4, Portland cement (ordinary), and the air content is 4.5 % [17].

Moreover, adding the wrong quantity of water, cement, aggregate, or other materials to the ready concrete mix, not consolidating it properly, and not engaging curing time and mixing time can cause many issues to the concrete, which must be adequate to make a standard concrete based on the mixer kind and the properties of concrete in a fresh matter where the concrete can be overmixing (entrapped air and water loss), undermixing (not homogeneous), and cracking, where can be caused by humidity, moisture air, and soil.

Table 1.1 Crack width is caused by different parameters to be reinforced concrete under loads [16].

No	*Exposure condition*	*Carack width*	
		in	*mm*
1.	*Dry air or protected member*	*0.016*	*0.41*
2.	*Humidity, moisture air, soil*	*0.012*	*0.3*
3.	*Deicing chemicals*	*0.007*	*0.18*
4.	*Seawater and Seawater spray, wetting, and drying*	*0.006*	*0.15*
5.	*Water-retaining structure*	*0.004*	*0. 10*

The figure below shows the sample, including surface, interfacial, internal cracks (cement), and voids. Many micropores (see Fig.1.2) appear on the interface of the aggregate cement. The large pores, which are comparatively large to the size of tiny pores, are recognized below (big pores mentioned in Fig.1.2). The preliminary cracks that appear on the concrete might also be produced in the process of concrete hardening or derived because of the process of sample preparation [18].

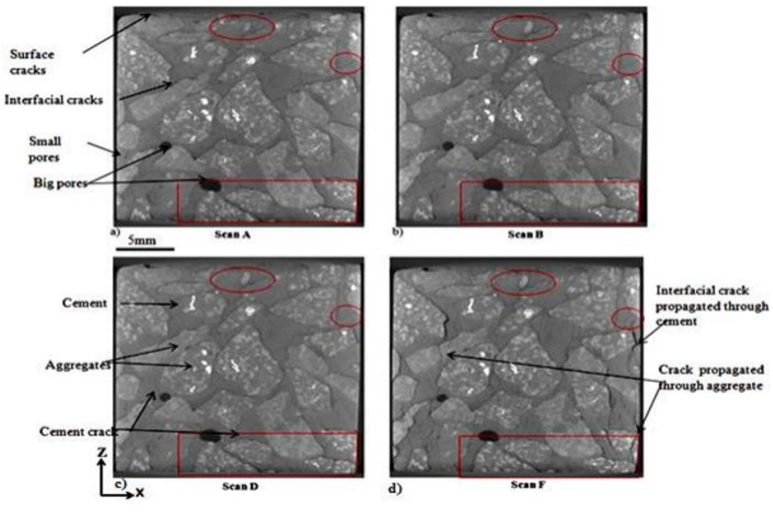


Figure 1.2 Single layer network [102]**.**

Moreover, the case study is in Iraq, where based on all 14 weather stations for the performance from 1949 to February 2020 were [19]:

- The hottest temperature measured in July 2016 at Basrah city was 53.8 °C.

- The coldest day was in Samawa city, and the temperature was -13.8 °C in January 2020.
- The hottest summer was in 2017; the temperature turns average was 38.4 °C, the minimum temperature average was 34.1°C, and the maximum temperature average was 47.5 °C.
- The coldest winter was daytime and nighttime, with an average of 9.7 °C.

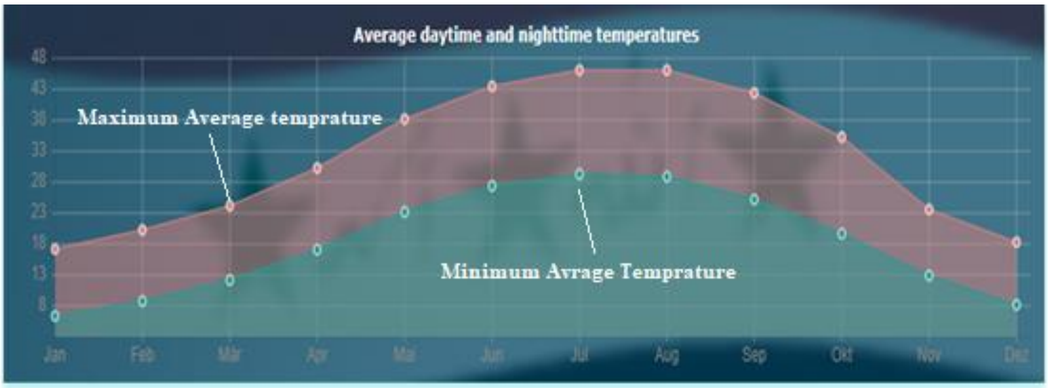


Figure 1.3 Average daytime and nighttime temperatures in 2021 (Iraq) [19].

The temperature variations can produce cracks on the concrete surface or go deep through the structure. The cracks on the surface occur with the high-temperature difference between the surface and the core during the expansion stage [20]. The hot weather suffers from two types of problems [12], where for hardened properties, the cracks mostly appear, occur in the expansion phase, and are associated with structure members or slabs [20]. It is decreased strength causes drying shrinkage, durability, and permeability. In contrast, for fresh properties, the interaction between the mix's ingredients causes a temperature increase inside the mix and leads to differences in temperature between the surface and core affected by stresses [20], where it is increased water demand, accelerated slump loss, faster setting times, rapid water evaporation, plastic shrinkage, and difficulty regulating entrained air enhanced thermal cracking potential if the temperature of concrete is high can cause reduce the sitting time due to cement's fast hydration and can lead to a decrease in the compressive strength. In addition to the high temperature, usually complained about the air's low humidity, which causes rapid evaporation of a part of ready-mix concrete and leads to workability loss, plastic shrinkage (higher), and then thermal cracking because of the tensile stresses induced by cooling subsequent [20].

Furthermore, there is a problem of air entrainment, which is increased when the temperature is high, where placing cool RMC at a high temperature permits expansion, and the voids caused by air expand to reduce the strength of RMC. The curing of hot weather (high-temperature dryer) can cause tensile stresses by hydration and evaporate the water of curing rapidly, which leads to cracking during RMC hardened shrinkage and development strength. The temperature of RMC must kept low in limitation(16℃ (60 ºF) to 32 ℃ (90 ºF)) [21].

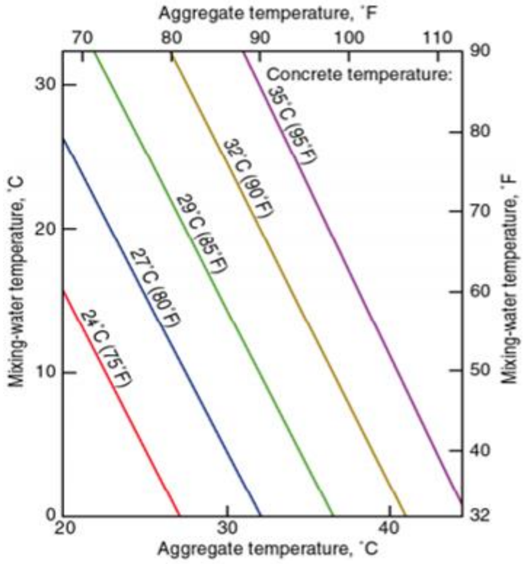


Figure 1.4 Effect of hot weather temperature on concrete freshly mixed by its ingredients temperature [21].

Based on the mentioned information previously, these issues lead to poor quality RMC due to changes in specifications during the delivery process and concrete different from The RMC of the SCBP, then the loss in cost, time, and effort of the manufacture and transportation.

Figure 1.5 Accelerated Slump Loss (Slump test failure) [22].

Figure 1.6 Faster Set Times Consistency & Air content failure [Researcher].

Figure 1.7 Decreasing strength Compressive Strength test failure [Researcher].

Moreover, the changing parameters and concrete strength are the central core of this study, leading to an inability to respond to client requirements at the construction site, including RMC temperature, slump, evaporation rate, air content, porosity, and compressive strength, taking into consideration the changes mix properties, temperature, humidity, wind speed, and delivery time.

1.3 The main goal and specific goals

The problem described in the previous section reveals that the dissertation has an extensive area of interest. The main objective of this study is:

The PhD work aims to improve of quality management system of RMC in a multistore building based on monitoring RMC delivery time, temperature, humidity, air content, and porosity, Learning (based on ANN) and generating flexible procedure, where the system can be used in any concrete plant and in any situation, to balance and improve the RMC conditions at the stationary concrete batching plant and construction site, to achieve the RMC quality level required (compressive strength) and meet with customer expectations. Moreover, specific goals are aimed at achieving the main goal; accordingly, will investigate 5 cases:

1. **Case (1): SCBP Express the quality system in SCBP:** by using a Flow chart, Ishikawa Diagram, cheek sheet, and 5 whys method where the areas of interest are: Row materials non-quality out of standards, Unstable parameters of RMC at SCBP (temperature, humidity, evaporation rate, and air content) and a high variety of parameters and Changing parameters of RMC during delivery to the construction site.
2. **Case (2): Quality of raw materials (finding the best suppliers for cement, water, and aggregates):** by investigating the improvement areas/tactics based on the processes of real-time monitoring, Six Sigma, Monte Carlo simulation and FMEA analysis for materials properties, suppliers, and RMC delivery time to define a library of reasonable procedures of different requirements in different conditions (This case of the work that go beyond the implementation of a quality management system in a specific concrete plant).
3. **Case (3): Improving production system :** by stable production - stable moisture content, stable temperature of concrete components, and accurate dosing**.**
4. **Case (4): Estimation of starting parameters of concrete mix (at plant) responding to client's requirements at the construction site :** by monitoring the changes/ improvements from the results by Monte Carlo simulation and FMEA Analysis based on the data of three seasons (spring, summer, and winter) for temperature, humidity, air content, workability, porosity, and RMC compressive strength (part of this case go beyond the implementation of a quality management system in a concrete plant).
5. **Case (5): Learning (based on ANN) and generating flexible procedure:** by the Artificial Neural Network and generating flexible procedure (SPSS software) of data analysis, training, testing, and prediction parameters as planned, reducing the number of

non-quality materials, stabilization RMC parameters, predicting RMC properties variables, and generating flexible procedure suitable at SBPC and the construction site.

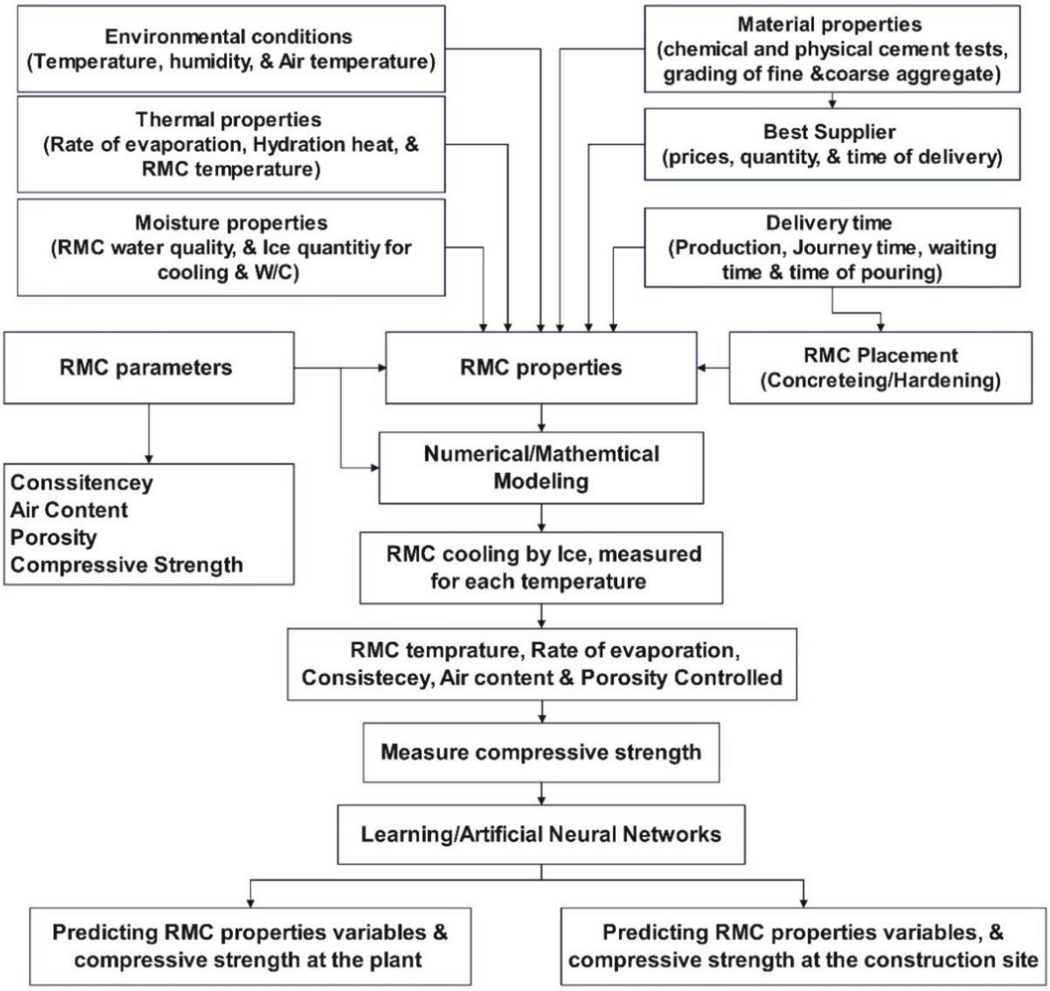


Figure 1.8 Theoretical and experimental works are attaining PhD dissertation objectives [Researcher].

Figure 1.8 illustrates the details of the theoretical and experimental works attained to achieve the dissertation's main objectives, where the outcomes will be accurately predicted ready mix concrete parameters at the SCBP and construction site and generate flexible procedures to manage RMC quality under variance environmental conditions where the properties of concrete and certain technological parameters, mainly regarding their variability, is important.

1.4 Scope of PhD work

The scope of the PhD dissertation incloud the work areas of RMC at the stationary concrete batching plant, stable production parameters, materials quality, and short-distance delivery. Mixing time, delivery time, total discharge time, temperature, and relative humidity can affect RMC parameters of compressive strength, workability, rate of evaporation, air content, porosity, and density.

1.5 Research Importance

The importance of this study as a new addition to the fields of knowledge as a gap in scientific work, the dissertation importance comes from the results of PhD work achieved: -

- The investigation of the change in parameters of RMC during the delivery process to minimize poor quality RMC.
- Monitoring and learning to estimate these parameters.
- Framing recommendations that manage the RMC production process.

1.6 Previous studies

Many studies discuss quality, management, process, RMC, performance, and ANN; this part will review an example of studies on the same subject as follows:

1. A study investigated 84 work cases linked to accidents for a period (2018 to 2020) in RMC production in Qatar, which helps companies to understand the accident attributes to improve solutions to reduce accident reappearance by M C Sario and Prasetyo [24] and is a study published in August 2020 discusses using of ANN have been assisting cost management on the Bayesian network for improving project management maturity [25].
2. The study discusses the relationship between highway quality and green construction; the study points out the impact of financial problems, codes of design specifications, and exposed eight elements that described 77.5% of differences in highway quality, 2019 [26].
3. A study addressing the scope, cost, and time problems for the infrastructure by management interviewed 32 experts and 85 managers by questionnaire about their completed projects to obtain improvements by Khattak and Mustafa, published in Pakistan 2019 [27].
4. A Paper digs into finding deviations in time for a project plan, delivers a schedule controlled reliably using the quality control charts process, and apply changes to the project duration published in 2016 by Yousefi. The study results consider the time delay value, money, and use the Earned value management schedule to estimate the project's final budget [28].
5. A study discusses the possibility of correcting RMC producers' condition by executing a quality plan in Riyadh published in September 2014 by Alhozaimy and Al-Negheimis. The result was the execution of a touchable development plan in the RMC and quality [29].
6. A study examines the impact of a planned diagram of a process of RMC chart and kind of fly ash on performance in the city of western Maharashtra in 2013 by Naiknavare. The results were executed to evaluate the compressive concrete strength at RMC plants, showing that what could be concluded from the RMC process performance is extensively in the licensed schematic process of the RMC chart, and the kind of fly ash used [30].

7. The study compares the outcomes of a linear fuzzy software simulation and four suggested grey linear software simulations and finds the efficient results for production alternatives in Turkey, published in 2020 by Yılmaz. The results provide a more efficient plan to use a manufacturing solution based on a linear fuzzy software model [31].
8. A study of quality control in RMC production, as a result, this paper contains a characteristic model required to be applied for QC, published in 2013 by Naiknavare [32].
9. A study that adapted Neural network theory evolution as an innovative factor in economic systems' successful and dynamic development was published in 2018 [33].
10. A study investigates establishing systematic multiscale models to predict the compressive strength containing a high volume of fly ash by a 450 tested HVF experimental data and ANN where the sensitivity investigation concludes that curing time is the most dominating parameter for predicting the compressive strength of HVFA published in 2021 [34].
11. An article uses ANN for modulization of compressive strength of SCC based on rheological parameters found during tests. The results showed that the architecture of the optimum with two hidden layers model is 5-50-50-1 with a Pearson's correlation R = 97.58 [35].
12. An article discusses identifying the compressive strength of concrete based on non-destructive criteria, and The findings demonstrate that artificial neural networks are well suited for evaluating in situ validation of the neural identification compressive strength [36].
13. A study proposes a method to forecast 28-day compressive strength using multilayer feedforward based on the insufficiency of approaches dealing with variables and nonlinear issues. The results show that the ANN models provide high prediction accuracy and the utility and value of utilizing ANNs to forecast concrete strength [37].
14. A study aims to validate the different possibilities of utilizing an ANN to identify the characteristics of SCC when Portland pozzolana cement is partly replaced with biowaste such as Bagasse Ash and Rice Husk Ash, where the results show that the correlation coefficient (R) and root mean square error (RMSE) produced by ANN were used to verify the findings, yielding an acceptability range of 97 percent to 99 percent [38].

1.7 Research Methodology

The research methodology for this study will involve the following steps:

1) **Data collection:** Gathering data on the RMC parameters of compressive strength, RMC workability, rate of evaporation, air content, porosity, and density will be collected at different stages of the RMC production process, including mixing, delivery time, and total discharge time, data of temperature, relative humidity, and other environmental conditions.

2) **Data analysis:** The data will be analyzed to determine the effect of time, temperature, and relative humidity on the RMC parameters, which will be used to identify any patterns or trends in the RMC production process that affect RMC quality.
3) **Real-time monitoring:** Real-time monitoring will be developed based on the data analysis and modelling results, where this method will balance and improve the RMC conditions at the stationary concrete batching plant and the construction site.
4) **Evaluation:** The effectiveness of the real-time method will be evaluated by comparing the compressive strength based on changes in temperature, consistency, and air content.
5) **Artificial Neural Network (ANN) modelling:** An ANN used to learn based on the RMC parameters and the environmental conditions. It is trained to predict the compressive strength-based temperature, humidity, air content, porosity, and density.

1.8 Structure of the dissertation

As a description of the generic dissertation structure and layout, the structure starts through the significant image step by step, then digs into every chapter to summarise the discussion of the contents. The structure of the dissertation was as follows:

1.8.1 Chapter One: Introduction

The first chapter provides a dissertation introduction, including the research subject, and defines the research problem, the objectives, methodology, and previous studies.

1.8.2 Chapter Two: Definition and Concepts

It provides definitions for the terms and concepts used in decoration. It explains the essential terms of RMC, quality, Six Sigma, monitoring, management, and Artificial Neural Networks.

1.8.3 Chapter Three: Process Of Production Management

It provides a comprehensive and accurate description of process production, product description, manufacturing process description, and problem description.

1.8.4 Chapter Four: Management Of Improvements In RMC Production Process

It identifies and analyses problems and clarifies the group to which they belong. It analyses the root causes to find the main reason and execute solutions by managing the knowledge areas.

1.8.5 Chapter Five: Reduce Raw Materials Quality Variation And find the best supplier

It provides monitoring of changes by Six Sigma, Monte Carlo simulation, and Failure Modes and Effects Analysis for RMC mix water quality tests (18 test samples), and the 93 tests of materials properties (Cement 33 test samples, Fine aggregate 30 test samples, Coarse 30 test samples supplied by three different suppliers, and mixing time, delivery time and total discharge time for 81 delivery time cases to stable production at SCBP.

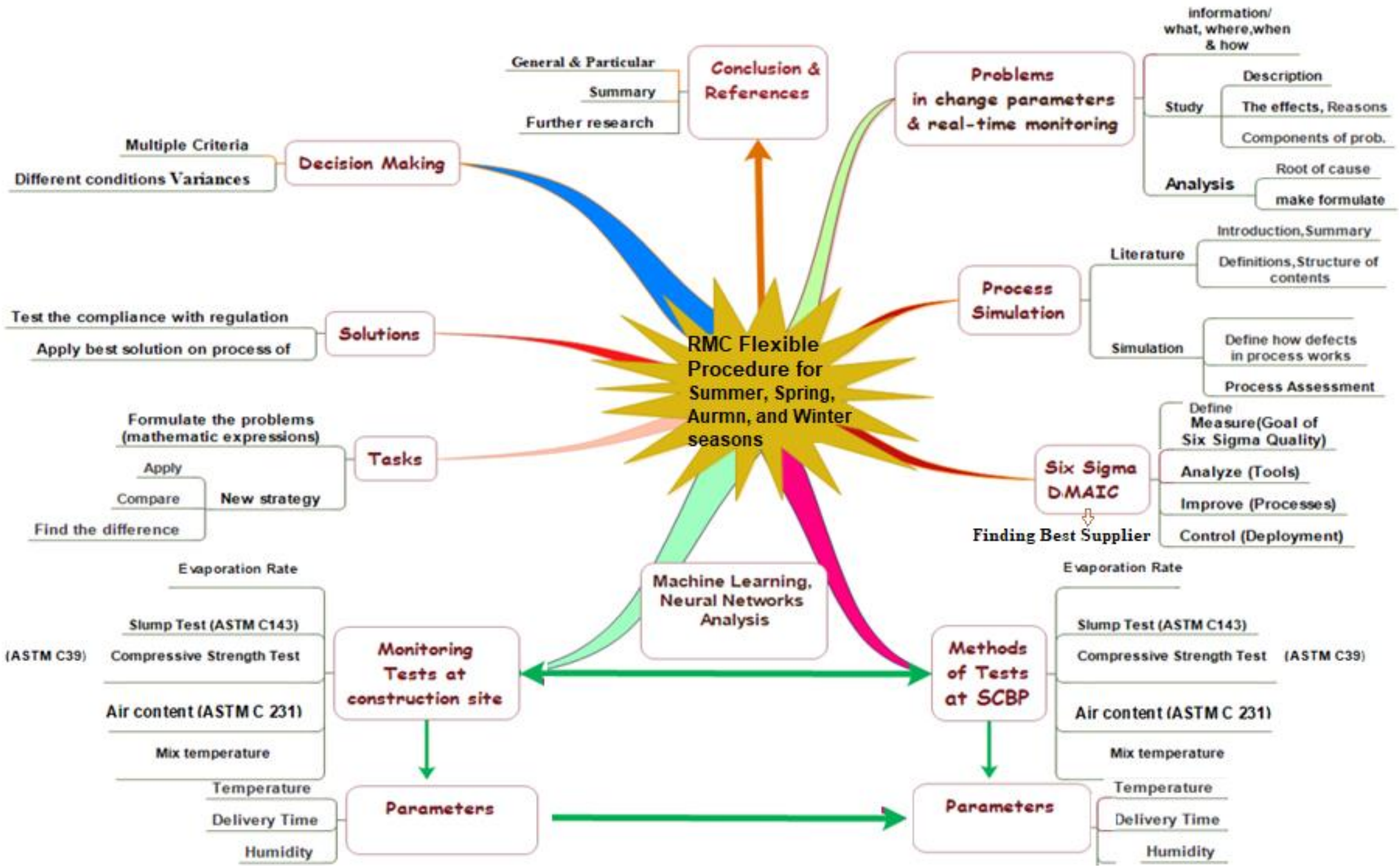


Figure 1.9 Research Methodology (essential tasks to be performed as a work plan) [Researcher].

1.8.6 Chapter Six: The Stability Of Delivery Time, Production, And Placemen

It provides real-time monitoring for 18 samples of RMC water mixing tests and 48 samples of RMC before making the mix improved by the fact half samples at SCBP and the other half at the work site by making slump test, air content, porosity, and compressive strength for three different seasons (spring, summer, and winter).

1.8.7 Chapter Seven: RMC Mix Improvements and Parameters Stabilization

It describes the real-time monitoring procedure of 80 samples of the RMC mixture, weather temperatures, relative humidity, wind speed, and the rate of evaporation at the stationary concrete batching plant and the construction site after RMC delivered to the site of the construction with different air temperatures and surrounding conditions. The real-time monitoring for 48 samples after making mix improvements by the fact of half samples at the SCBP and half at the work site, by RMC slump, air content, porosity, RMC density, and compressive strength, make a comparison between the results of compressive strength before and after the improvements, and results for three seasons.

1.8.8 Chapter Eight: Learning and Generating Flexible Procedure

It provides two cases: the first is for predictors/variables drawn from the quality of materials to the material's properties in a Moodle-based 93 tests made in 2021.

The second case is to predictors/variables, drawn from delivery cases of RMC from the SCBP to a construction site in a Moodle-based 81 delivery cases (7 independent variables) as inputs with one dependent variable RMC delivery cases time outcome.

Moreover, two cases for three seasons to predictors, drawn for prediction of the parameters: RMC temperature, consistency, air content, porosity, density, and compressive strength for each season at SCBP and construction site in a Moodle for each season, as inputs to make an ANN capable of predicting the parameters.

1.8.9 Chapter Nine: Key findings and conclusions

This chapter provides a conclusion of the work carried out in the research for each chapter, recommendations for future work, and further research than the references.

9.1.General Conclusions

9.2.Detailed Conclusions

9.3.Future works.

CHAPTER 2 DEFINITIONS AND CONCEPTS

2.1 General definitions of Quality and environmental conditions

Shewhart derived the concept of Quality Management at a laboratory in the 20s industrial concepts of interaction and growth betterment [32]. Joseph Juran and Deming were the first scientists to adopt the management concept and trained the Japanese (in the fifties) on executing management [39]. W. Edwards Deming continued to teach Japanese management as a consultant, where he supported the industries of Nihon to take management standards that make these industries' management [40]. Dependably following his philosophy, "character should be aimed at the needs of the client," Deming's experience as a consultant skill provided or summarized perfect 14 principles of management, which are the foundation of what is now titled Total Quality Management, industrial some of the direction tools and concepts [39]. The attribute has been established as a strategic magnitude by new enterprises businesses that can be affected by fast changes [39]. This section will present several definitions and concepts mentioned in the dissertation. Defining the environmental conditions in Iraq is essential to understanding the unique challenges and opportunities RMC faces in construction sites. One of Iraq's most defining environmental conditions is the country's hot weather and arid climate; summers in Iraq can be hot, with temperatures reaching up to 50°C, while winter are mild, but there can be occasional frost and snow in the country's northern parts.

2.1.1 Process, Product, and Standard

The process is a set of interrelated resources and activities that transform inputs into outputs, and resources may include personnel, finance, facilities, equipment, techniques, and methods [41]. Management process investigates the most critical components of the company's process management, including the most important product, service, and organizational processes for delivering customer and future performance and investors. The category includes all essential processes and job units [42], where for customers, quality means that businesses will define quality using specifications and standards. This means the quality can be defined and measured [43], the product is a result of the activities or processes, and it may include service, hardware, processed materials, and software where it can be tangible or intangible, or a combination [41]. At the same time, the standard is a document that establishes methods, norms, practices, and processes. The formal document has developed through sound practices of project recognition and management, where they contribute to developing or updating these standards [44].

2.1.2 Stationary Concrete Batching Plant (SCBP)

It can be described as a stationary machine mixer for mixing concrete ingredients and transferring them to another place by equipment (truck mixers) for RMC delivery. This truck mixer transporting can operate as a top open truck body and be an agitator. The slop and rotation of the truck body can help prevent concrete from segregating. The variations between SCBP are brought about by factors such as rising production rates and substituting human judgment with equipment functioning within predetermined limits [45]. If the agitator is used in the truck mixer, the limits of ASTM (No. C 94) tell us that the RMC volume uploaded in the truck is around 80% of the truck drum or the volume of the truck. The concrete is partially mixed in SCBP, and a final mixing stage will be done during transporting in a truck mixer with a revolving (rotating) drum [46]. The ASTM C 94 standard limits show that when using the Shrink mixing concept, the concrete charged the volume in the truck mixer reduced to 63% of the truck mixer (drum) volume [21]. The stationary mixers use a sample of the RMC by collecting two or more samples at evenly spaced intervals through the middle section of the batch's discharge, with no more than 15 minutes passing between the first and last sample for testing reasons, and combine samples into a single composite. The sampling should not be before or after 10% or 90% of the batch has been discharged due to collecting samples that indicate widely spaced areas rather than the beginning or ending of the load [47].

2.1.3 The concrete trucks (truck-mixer)

It is the equipment to transfer the RMC by process of which previously concrete ingredients from SBPC into the RMC truck mixer for the final mixing stage to deliver it to the worksite of the project, to guarantee thorough mixing of the absolute volume of RMC ingredients in a rotating (drum) truck body mixer that has not exceeded the upper limit (63%) of the volume of the truck drum [21]. Truck agitators are often used to transport fresh RMCs from the plant to the construction site by a spinning drum within the vehicle on its journey to the construction site, where it collects ingredients at the plant and combines them into new concrete [48].

2.1.4 The process of mixing and charging

The sequence and the method of loading (charging) mixers are crucial in estimating whether the RMC will be thoroughly mixed. The SBCP gains a mixing (ribboning) impact by loading the cement and fine or coarse aggregates together as the flow of materials stream at the mixer is crucial. Into the truck of the mixer, the charging process must be planned to obviate the material packing, the sand particularly, and the cement in the top of the truck drum over the loading. The possibility of packing can be decreased by probing around 10% from the coarse aggregate and the water in the truck mixer before the fine aggregate and the cement. Generally, around 1/4 or 1/3 of the water must be added into the mixer when the truck drum is unloaded and the other ingredients mixed and charged correctly. The charging of water by pipes is a suitable design to enter at the time, and a point is located well inside the RMC mixer, and the loading is done at the beginning of 25% from the time of mixing [21].

2.1.5 Quality Definition

The search for a universal quality definition has yielded unstable outcomes, but various definitions are suitable for numerous circumstances [49]. Quality has different definitions for use or people; the ASQ (American Society of Quality) has defined quality as "The subjective concept for every employee or person who might own his/her position or meaning," where the spect of technical use, the definition of quality might have more than one definitions [50]. Edward defined 'quality' as the potential of a product or service to meet the customer's needs [51]. The fitness encompasses product design features and adherence to the design [52].

The organization (international) of standardization, which is known as ISO,19 describes quality (QM) as the "Principals wholeness of the existence which can endure on its capability for purposes satisfying requirement stated [53]. Then, in 1994, Pyzdek considered that not exist to the general (single) accepted quality definition [54], where he produced or found five standard procedures for defining and then discussed through Garvin as follows [50]:

The first one is the transcendent: "The Quality cannot find a definition but can find a way or method to determine what it is," The second aspect is the Product "according to the quality differences, the location amounts to these differences in the desired quantity of attribute or products," the third aspect is the user " according to the Quality to its capability to meet the required needs," the fourth aspect is manufacturing "according to the tools of quality to the requirements meeting" [55]. The fifth aspect is value: "according to the quality is the level of perfection at the acceptable prices and the cost the variability control." The quality can mean the best conditions for customers [56]. Deming defined quality as "should be designed (planned) into the process and the product, where it can be expected the level of the reliability and homogeneity meeting with the possible lowest cost and that comply with the demands of the market" [50]. Juran's quality definition "the fitness for the use or usefulness of service and product" [57]. John Oakland's definition "the customer requirements conformance" [50]. The quality definition by Kaoru Ishikawa "the quality of services and products after the process of sales, the quality management of the human and the company" [50].

2.1.6 Quality System

The system of quality can be defined as the organization's procedure, responsibilities, structure, and the reason for the execution of quality management (QM). It is the way or method to maintain components of quality to result in good-quality products to provide the services that could meet with or exceed, if possible, customer satisfaction or their needs [58].

2.2 Quality Management (QM)

Quality Management has many definitions for each person. W.E.Deming "Quality should be designed into both product and the process. It is the expected degree of homogeneity and reliability at the lowest possible cost and matched to market requirements" [50]. Joseph Juran said quality is the fitness of product and service for use" [6]. Philip B. Crosby defines quality as a conference of the requirements. [59]. In addition, Quality means the best conditions for customers, such as the selling price of products and actual usage [56]. Pyzdek produced five principal procedures for defining quality, which Garvin has viewed as follows [50]:

The transcendent "Quantity cannot be defined, but you can find a way to know what is it" The product according to quality differences, quantity located to variances for products, the user is according to the ability of the quality to meet the requirements, manufacturing is according to tools quality to meet needs [55], and the value is according to the level of Fineness at the best satisfactory price and control of cost variability [60].

2.2.1 Quality Control (QC)

The operational strategies and actions utilized to meet quality criteria [60]. The inspection and the process monitoring outputs determine the level of compliance with standards to identify the causes of the non-conformance to standards performance. The QC is the organization's unit that determines the quality responsibilities [61]. In addition, it can be described as a part of three fundamental management processes quality might manage, where quality planning is the second basic management process, and quality improvement is the third basic [57]. It may be broadly described as a system that keeps a product or service at a desired standard by monitoring its performance and taking corrective action if it falls short. Three possible subfields are offline quality control, statistical process control, and acceptance sampling plans [62].

2.2.2 Quality Assurance (QA)

The planned and systematic procedures required to offer appropriate assurance to management that a product or service will meet specific quality criteria [60]. The guessing process of all performance of the process on a reasonable basis to provide confidence to flow of the process can fulfill the quality standard, where the QA can be described as a unit of the organization assigned assurance to quality responsibility [61]. Quality assurance's primary goal is to put in place a formal system that routinely assesses how well the business's quality is being implemented, so the quality assurance team conducts audits across all departments and provides minimal support to ensure that everyone is doing their part to ensure a high-quality result [62]. As standard deals with the quality key concepts of assurance, the ISO: 9000 contains the responsibilities and the objectives of the expectations of stakeholders and quality, where the process concept has a role in the quality system, the training, and documentation as an application of standards, where, there is more than one type of ISO standard, where, ISO 9004 is another type of guide to the process of quality system execution and development [63].

2.3 Total Quality Management

Various definitions have been set for the concept of Total Quality Management during the past years to the present [64]. An organization-wide initiative to enhance performance that engages everyone. It prioritizes quality as a strategic goal, where TQM is accomplished by an organized approach through workers at all levels to maximize client satisfaction through continual performance improvement [60]. As a description of the meaning of TQM, the word Total refers to each employee (everyone) in the process of the value chain, which has a role in the process of production or involvement, including the suppliers, customers, and employees. The meaning of the second word, Quality, refers to services and products that comply with customers' needs. The third word, Management, means that management has to be encouraged and committed to each employee to keep the conscious quality [65]. Quality management works at each level of the process, from the planning phase to the design, by personal inspection to monitor continual improvement opportunities [66]. The TQM concepts can be classified into two parts or categories; the first is social, described as a normal TQM (the social TQM), which uses human resource management to build leadership involvement empowerment work. The second type (the technical TQM) refers to the process of production optimization methods for building an excellent process to clarify, and the procedures that can provide the ability to improve consideration for the serval the products to achieve TQM goals must be implemented using sophisticated QM strategies to create a strong partnership with suppliers, quality control would also extend beyond the company's internal structure [67].

2.4 The concept of the PMBOK Guide 7th Edition

This guide provides the Management of projects or the best standard (guidelines) for the individual management of projects and defines project management with related concepts. This standard refers to the life cycle of project management connected to the project's processes and life cycle. It provides a good vocabulary according to the project profession to apply the project's management concepts [68]. The PMBOK standard is contained at the beginning of the two sections (parts), introducing the fundamental concepts of the project field management. The third part of section 3 summarizes the group's process and gives the process overview interactions for all Areas of Knowledge. The five process groups sections or parts 4 to 13 are described as the guide for the project management, where these parts or sections extend to information of the guide by referring to the type of inputs and the outputs added to the techniques and tools used in the process managing [68]. Project management acceptance indicates a profession that describes the knowledge application, tools, skills, techniques, and processes that can hugely impact the project's success. It is identified as the subset of project management usually deemed worthy of practice [68]. It included the description of managing processes used for managing the procedure or the project to gain results more successfully [61].

2.5 Quality management tools

There are many tools of quality management have been used in the dissertation, which can be described as follows:

2.5.1 Check-sheet

It is used for case checking when gathering data and organizing the facts to effectively collect valuable data about a potential quality problem. It is beneficial for gathering attribute data while performing inspections to identify defects [61]. In the quality improvement cycle, a unique form created may be helpful for inspections [67].

2.5.2 FMEA Analysis (Failure Modes and Effects Analysis)

An analytical procedure in which each potential failure mode in every component of a product is analyzed to determine its effect on the reliability of that component, by itself or in combination with other possible failure modes, on the reliability of the product and the required function of the component; or examination of a product [61]. The FMEA technique is a systematic approach to analyzing the potential for failure in designed systems. The failure modes, root causes, consequences, and preventative measures are all rolled into one convenient document in an FMEA. The risk associated with each failure mode may be assessed, and the failure modes can be rated by recasting the FMEA in a probabilistic framework by measuring the probability of occurrence of each failure mode and measuring the severity of the impact of each failure mode [69]. An FMEA is a systematized set of actions designed to:

a) Identify and analyze the possible failure of a product/process and its causes.
b) Identify steps that might remove or lessen the possibility of failure occurring.
c) Record the process complements procedure must do to please the consumer [70].

In addition to a table categorizing the failure modes according to their RPN, another beneficial depiction of FMEA findings is a color-coded matrix known as the risk characterization matrix, with a probability of occurrence and consequence severity [69]. As a result, the phases of an FMEA are:

- It is recognizing the many sources of potential failure. The list must include every potential source of failure. If there are any residual failure modes, the FMEA procedure uses the RPN to find the severity of those failures. This procedure will make it possible to eliminate minor failure modes [69].
- Developing the chance of each failure mode occurring and the corresponding scale for measuring its likelihood, the case with qualitative evaluation, the level of likelihood may be derived from quantitative metrics like statistics [69].
- They are creating a scale to quantify the overall severity of repercussions connected to each failure style. The repercussions are determined by qualitative or quantitative measures [69].

2.5.3 Risk Priority Number (RPN)

The Risk Priority Number (RPN), which represents the product of a likelihood measure and the severity measure, is used to determine the order of importance for each potential failure, and an RPN is determined [69]. It is the number that describes the risk in the process of production; where calculate this number (RPN) by the FMEA method or technique through three fundamental factors used, as follows:

a. The occurrence probability.
b. The detection of probability.
c. The consequent incident severity.

Where the calculation of RPN can be as follows [70]:

$$\mathrm{RPN} = \mathrm{D} * \mathrm{O} * \mathrm{S} \qquad (2)$$

Where (S) refers to the consequent severity to the scope or extent of damage that can be caused due to the incident. Estimating the consequences of the incident's severity where the formula above reflects the priority number risk, which is a result of the combination of the occurrence, severity, and detection. The higher levels (number) of risk of the priority numbers accrue for the estimated priority condition indicates correlation action active for these defect (hazard) conditions. Risk priorities (RPN) are scaled from 1 to 10 to sort the corrective action necessary to eliminate potential defects. These defect modes might have the highest score number of risk (RPN). The severity level investigation is very crucial if the level of severity scales as a number from 9 or maybe 10. This means the number of risks (RPN) can affect and must be inspected directly. The improvements or the correction will continue till a new RPN extent to the level can be accepted for failure modes. The description or the mean of the number has a value (10) referring to a complete failure, the number 9 means or refers to intense damage(failure) in the process, the value 8 means or refers to the damage (failure)in the process is extremely high, the value 7 is referred to that the damage or failure high, the value 6 means that the damage (failure) in the process is in level can be described a medium level damage, the value 5 is referred to the damage in the system can be described as low-level damage, the value 4 means that the damage in the system can be very low, the value of 3 means minor failure in the process, the value 2 means it has minor failure or damage to the process and the value (1) means there is no damage in processor [21].

2.5.4 Ishikawa diagram

It is the quality management tool used to help identify, explore, and display all possible causes related to a problem, discover the root causes, and show dependencies amongst causes and underlying drivers. In other words, it is the graphic illustration of the relationship between a problem and its underlying contributors [61]. The idea behind the diagram is that the stated causes lead to the result, which is the quality issue that needs to be fixed [67]. Ishikawa devised a method for visually illustrating the sources of any quality issue. His approach is known by many names, including the Ishikawa diagram or cause and effect diagrams, which are well-known quality assurance techniques that can be used to investigate the source of defects [71].

2.5.5 5 Whys Analysis

It is a system analysis to optimize productivity by reducing waste and maintaining an orderly workplace [72]. It could be an essential tool that requires a more profound understanding where the fundamental cause of an issue is unknown [73].

2.5.6 Flow Chart

It is a diagram or illustrative exemplification that explains the solutions in process phases. It helps to understand and manage the process for numerous fields [64]. It is a tool l to understand the situation's complexity and how several entities and systems relate to each other, showing a clear view and the context of a process situation [61]. Creating and using flow charts is one of the most crucial steps in introducing process control to administrative and industrial operations. The most effective method to comprehend a process is to make a picture of it [67]. Moreover, it depicts the nature and flow of a process using visual symbols, and it assists in determining if the process stages are rational, identifying issues, defining the limits of a process, and developing a shared basis of knowledge about a process. The sequence of steps links the symbols and may be used in the project's life cycle [73].

2.5.7 Solution-effect analysis

An inversion of the fishbone diagram is the solution-effect analysis where the possible solution is placed in a box on the left and draws a horizontal line from it towards the right, with lines leading to display possible consequences and effects [73].

2.6 Cost of Quality and Quality Improvement

It is a kind of methodology that permits the organization to locate the extent of the resources that can be used for the activities to prevent poor quality, that asses the organization's quality of the services or products and can result in internal failures or external failures. The concept of quality can be split into four parts: the costs appraisal, added to the costs of prevention, the costs of internal (failure), and finally, the costs of external [74]. The cost quality can contain the whole cast during the product lifecycle. The costs of failure are distributed into the external and internal levels and can be set by the project. The cost contains planning for quality, control assurance quality for service, product, and cost of rework [61]. This built-in cost is avoided by Six Sigma (DMAIC) or Define, Measure, Analyze, Improve, and Control [75].

Moreover, quality improvement is responsible for making management changes that will apply appropriately for manufacturing, service, operations software and hardware, support activities, and processes [57]. The capacity to meet or exceed consumer expectations while minimizing needless costs is the basis of value enhancement [77]. The construction industry is a field of economy that revealed different opportunities for quality improvement, such as the activities, procedures, machine learning, and the environment to dominate the cost criterion minimization in construction projects [78].

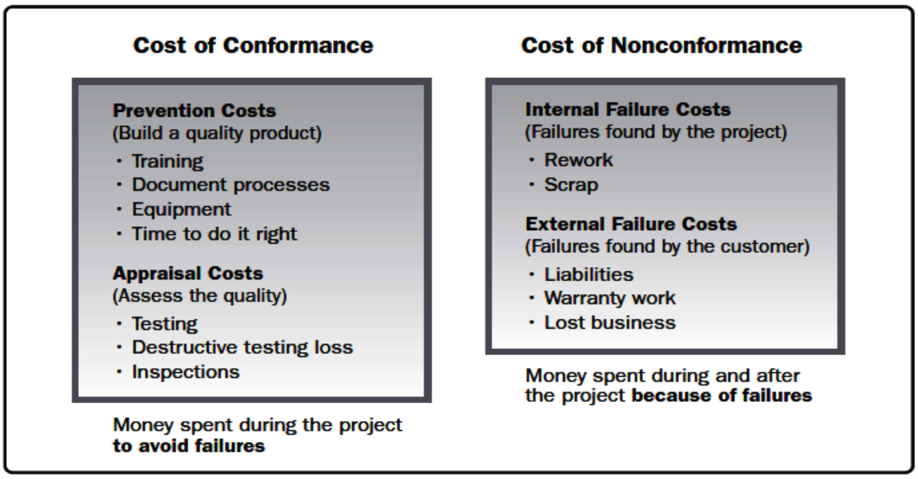


Figure 2.1 Cost of quality [44].

There are five stages to the cost management cycle for a contractor: setup/estimate preparation, estimate correction post-buyout, estimate input into cost control/accounting system, recording/monitoring of costs, a framework if cost goals are not met, as-built estimate preparation, and estimate input back into company database for use in subsequent estimate [76].

2.7 Communication and Stakeholders Management (SM)

The managers communicate with members of teamwork and stakeholders, whether inside or outside the company. Communicating effectively affects a project, according to the PMBOK of the communications management processes [68]. In contrast, stakeholder management is essential to define the companies that could influence the investigation of stakeholder expectations and the effect on the process to improve proper management approaches for professionally attractive stakeholders in the decision-making and execution [61]. The stakeholder identifies persons and organizations essential to the firm's existence and is actively involved in decision-making processes or arbitration [79]. It includes the processes required to identify the people, groups, or organizations that could influence or be impacted by the project, analyze stakeholder expectations and their impact on the project, and develop appropriate management strategies for effectively engaging in the project decisions and execution. It focuses on communication with stakeholders to understand their needs and expectations, addressing issues as they occur, managing conflicting interests, and fostering stakeholder engagement in decisions and activities [61].

2.7.1 Stakeholder map table and stakeholder analysis

A stakeholder map is a powerful tool during the set-up phase of a project as it helps to understand the bigger picture. The stakeholders are part of the scope and belong to specific interest groups; they must be involved in the initiative [68]. The stakeholder analysis refers to reorganizing and acknowledging stakeholders’ needs, concerns, authority, typical relationships, and interfaces and aligns this information within the Stakeholder Matrix [61].

2.7.2 Stakeholders Engagement Assessment Matrix

It is used to document the current engagement level of all stakeholders, which needs to be compared to the planned engagement levels required for successful project completion [61]. A requirements review aims to ensure that the team has developed the requirements to their highest level of quality and gain agreement among the stakeholders that the requirements are correct and complete; an ambiguity checklist exposes the most common mistakes [80].

2.8 The Analytic Hierarchy Process method (AHP)

The AHP Analytic Hierarchy Process method, a multiple-objective ranking procedure proposed by Saaty [9], focuses on the hierarchical analysis of the decision problem. It is based on a multi-attribute utility theory and allows the rank of a finite set of variants [81]. The AHP effectively decomposes complicated decision-making situations and reduces decision-makers cognitive strain [82].

2.9 Ready Mix Concrete properties

The properties of RMC in different environmental conditions for the case of study, the weather conditions that tend to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration or causing detrimental results: high ambient temperature, concrete temperature, low humidity; and high wind speed [83]. This part will provide a short description or definition for several variables as follows:

2.9.1 Water/Cement ratio (%)

It is the percentage of water to cement, defined as the water weight divided by the cement weight in the concrete mix. A lower limit of this ratio can result in higher compressive strength, workability, and durability. In addition, it may cause) The concrete mix requires hard effort to deal with and form the concrete. Cement paste hydration processes are susceptible to the initial water/cement ratio. The water-to-cement ratio in concrete is low, and much of the cement remains unhydrated [84]. This ratio means the quantity of water in the mix relayed on the cementitious materials. The cementitious materials refer to several materials such as cement, fly ash, furnace slag, or the blast of ground granulated, pozzolans, and silica fume. The w/c ratio can be estimated from Abram’s law [48]. Hydration is the chemical reaction between water and cement, which leads to heat, and concrete hardens; as a result, the heat generated during the production is the heat of the hydration reaction. The limit tries to make hydration reactionaries around 0.35kg or 0.35 pounds, the same for the other corresponding weight unit of cement, and around 0.35 kg, pounds, or any other corresponding weight unit of water [21]. Interference between processes and reciprocal interaction between distinct clinker phases entering the reaction with water make cement hydration very complex [85].

2.9.2 Compressive strength (ƒci)

The primary criterion for measuring ready mix concrete's quality is its compressive strength. Traditionally, mix design has included creating a mixture with a particular strength in mind. In contrast, strength is often not the most significant criterion; the rationale for its usage as a performance criterion is evident in the phase that follows its selection in the majority of techniques for mixed design [86]. The compressive strength can be described as the maximum stress of compressive caused by the applied load on a square area unit to give a solid mass elasticity material that can carry the load without deforming the formula to calculate the following formula used [87]:

$$f_{ci} = \frac{F_i}{A_{ci}}, f_{cm} = \frac{\sum_{n=1}^{n} f_{ci}}{n} \quad (3)$$

Where: -

$\boldsymbol{f_{ci}}$ = compressive strength, $\boldsymbol{F_i}$ = maximum load, $\boldsymbol{A_{ci}}$ = the area of a sample cross-section, and $\boldsymbol{n}$ = sample number. The ASTM C109/C109M−16a and BS EN12390-3:2002 test methods cover the determination of the compressive strength of hydraulic cement mortars [88] [89]. The test of ƒci is done in a laboratory with compressive instruments by using an applied load equal to the crossectional area unit of concrete, which can be a cube or cylinder where the ƒci calculated at the age of *t* (days), usually after 7 or 28 days [21].

2.9.3 Compressive stress (σcu) and ultimate compressive strain (Ɛcu)

It is the force applied perpendicular to a material's cross-sectional area. The unit of measurement for compressive stress is typically Pascals (Pa) or pounds per square inch (psi) [90]. Moreover, the ultimate compressive strain (Ɛcu) refers to the maximum deformation a material can withstand in compression before it fails. It is measured as a decimal fraction or percentage and is determined through material testing [90]. Neville (1987) viewed concrete compressive strength as the foundation for its adoption as the cause of durability issues 25 years ago. He added, “My submission is that we should have decreased our concern with strength long since, and we should have concentrated on developing practical criteria for durable concrete which could be used in the specification.” In most projects, the compressive strength of standard cubes or cylinders is frequently evaluated for compliance [86]. It is often used to determine the strength and durability of materials to evaluate a wide range of structures and components, such as bridges, buildings, and mechanical parts [91].

2.9.4 Cooling Ready Mix Concrete with ice

In order to reduce the temperature of the mixing water, ice might be substituted for some of the water. The ice must be weighed for precise measurements. A crusher/slinger device is used to smash a block of ice into small pieces before blowing it into the mixer for efficient cooling in many places; the lack of a reliable supply of block ice is a significant barrier to its usage. The cost of utilizing block ice consists of the ice's purchase price, delivery cost, cold storage, crushing and handling equipment, workforce, and maybe scales. Making ice includes weighing, crushing, and transporting it to the mixer, which may be manufactured and used as flake ice [83]. The concrete must be compacted after it is poured to release any air pockets. Manual tamping, rodding, or mechanical vibrators are all viable options for compaction [48].

2.9.5 Real-time monitoring and Quality management

It refers to continuously monitoring and quality managing a system or process as it is happening. It involves collecting and analyzing data from various sources in real-time and using that data to make decisions and take actions that can help optimize performance, improve efficiency, and mitigate risks. Real-time monitoring and management can be applied in various industries, such as manufacturing, transportation, and finance. In manufacturing, real-time monitoring can track production processes, identify bottlenecks, and make adjustments. In transportation, monitoring can track the location and status of vehicles, identify traffic congestion, and optimize routes. In finance, real-time monitoring can be used to make investment decisions. It is supported by sensors and big data analytics, allowing for collecting and analyzing large amounts of data in near real-time [92].

2.9.6 Air entrainment (content) of RMC

The objective is to estimate the air content of fresh ready mix concrete containing relatively thick particles by watching the change in volume of the concrete in response to a change in pressure, as described in ASTM C173 [93]. It refers to the amount of air present in freshly mixed concrete, typically measured as a percentage of the total volume of the concrete. Air content is an essential parameter in concrete production as it affects the workability and strength of the concrete. The air content is measured by the pressure method, where a sample of concrete is placed in a sealed container, and air pressure is applied until the concrete reaches a specific density; the air content is calculated from the pressure difference. The air content should be within limits specified in the concrete mix design to ensure that the concrete has the desired strength, durability, and workability [94]. ASTM C231 – 08c provides a test method to estimate the air content of the freshly mixed by monitoring the change in RMC volume with a pressure difference [95]. It significantly affects the workability, where it enhances slump for each 1% of added air, equating to around 2.5 cm of slump, while less air than intended will negatively impact operability [96].

2.9.7 Workability (Slump test)

The precise definition of workability is the amount of internal beneficial work required to achieve complete compaction. The usable internal work is a physical attribute of concrete alone and is the effort or energy necessary to overcome the internal friction between concrete particles. More energy is necessary to overcome the surface friction between the concrete, formwork, and reinforcement. Consistency is another word that describes the condition of new concrete: the hardness of a substance's shape or the ease with which it flows. In the concrete context, which is often interpreted as the degree of wetness within certain limitations, wet concretes are more workable than dry concretes. However, the workability of the same consistency may vary, where the strength of concrete is substantially and negatively influenced [17]. The factors helping concrete to have a more lubricating effect of reducing internal friction for helping easy compaction are water content, mix proportions, size of aggregates, shape of aggregates, surface texture grading of aggregate, and use of admixtures [97]. It indicates the consistency of an individual concrete batch [96]. The commonly used method of measuring consistency can be employed in a laboratory. If the concrete slumps evenly, it is called a true slump. If one-half of the cone slides down, it is called a shear slump. In the case of a shear slump, the value is measured as the difference in height between the mold's height and the subsidence's average value [97].

2.9.8 Porosity of concrete

It is an essential characteristic that affects many aspects of RMC behavior: transport properties, mechanical properties, and durability [86]. It refers to the amount of space or voids within a sample. It is measured as a percentage of the total volume of the sample and can be affected by factors such as mix design, curing conditions, and aggregate properties. It can impact the durability and strength of RMC and its ability to resist water and types of penetration [98].

2.10 Six Sigma (6σ)

Six Sigma is a methodology for process improvement and a statistical concept that seeks to define the inherent variation in any process. The overarching premise of Six Sigma is that variation in a process leads to opportunities for error; opportunities for error lead to risks for product defects. By reducing variation and opportunities for error, the Six Sigma method reduces process costs and increases customer satisfaction [99]. It is an improvement technique that focuses a company on Identifying and managing customer expectations [71]. Moreover, it is a high-performance management method for implementing corporate strategy. It is a top-down approach that assists firms in aligning their business strategy with crucial improvement objectives [71] to organize teams to tackle high-impact initiatives, accelerate better business outcomes, and manage efforts. It focuses on leadership principles, integrated approaches, engaged teams, and analytic tools [71].

2.11 Monte Carlo simulation

It is a statistical modeling method that uses random sampling to obtain numerical results, where random processes are used in gambling games. In a Monte Carlo simulation, many random samples are generated, and statistical analysis is applied to the samples to estimate an unknown quantity of interest, such as the probability of an event or the expected value of a variable. These simulations are used in various fields, such as finance, engineering, physics, and computer science, to model complex systems and predict their behavior. It is helpful for problems where a closed-form solution is not available or is too complex to compute [100].

2.12 Pouring concrete at a high ambient temperature

Pouring concrete at a high ambient temperature poses several issues due to the elevated concrete temperature and, in many instances, the increased rate of water evaporation from the mix. These issues pertain to the production, delivery, and placement of concrete. Concreting during hot weather is not a rare or specialized procedure; it necessitates adopting known techniques to limit or regulate the impacts of high ambient temperature, high concrete temperature, low relative humidity, high wind speed, and high solar radiation. It is essential to standardize the process [85]. Under ASTM C 403-03, the setting time of concrete is sped up by an increase in temperature; whenever the temperature of the concrete was increased from 28° to 46°C, tests on cement mortar with a ratio of 1:2 revealed that the first setting time was roughly halved and the actual setting time decreased as the water/cement ratio decreased. The high ambient temperature raises the need for water, and the temperature of fresh RMC causes an increase in the slump loss rate and quicker cement hydration, resulting in a rapid setting and a decrease in the concrete's compressive strength over time [85]. Fast evaporation may result in plastic shrinkage fractures and cracks, and the following cooling of the hardened concrete might result in tensile strains. Observations indicate that cracks that grow underneath water are scarcely evident after drying. Plastic shrinkage may generate profound fissures, ranging from 0.1 to 3 mm in diameter and up to 1 m in length [87]. A reduction in the relative humidity of the environment promotes the growth of these types of fissures. According to ACI 305 R-91, the probability of plastic cracking at the below relative humidity and temperature combinations is 41°C with 90%, 35°C with 70%, and 24°C with 30% [83], wind speeds above 4.5 meters per second aggravate the situation. In hot weather, additional problems involved with concrete placement may be rectified by increasing the quantity of air-entraining. Relatedly, if the cooled concrete can expand at a higher temperature, the air spaces rise in volume, and the bale's strength diminishes [87].

2.13 Placement of large concrete masses

The ACI defines mass concrete as concrete that must account for the development of heat and associated volume changes to prevent cracking in a drastic temperature difference between the RMC interior, where cement hydration generates a high increase in temperature, and its exterior, where that heat is dissipated into the air cracking may also be caused by shrinkage [85]. Many options exist for reducing the heat of RMC by cooling its constituents, like lower thermal cement, minimal cement content, and water-reduction admixtures [85], where if there is a heat dissipation somewhere at the exterior, the RMC interior of a mass would generate heat at such a faster than the outside. A significant temperature gradient between the inside and outside can cause cracking. If this happens while the temperature rises, the cracks will form within; if it happens when the temperature is falling, the cracks will form outside [17].

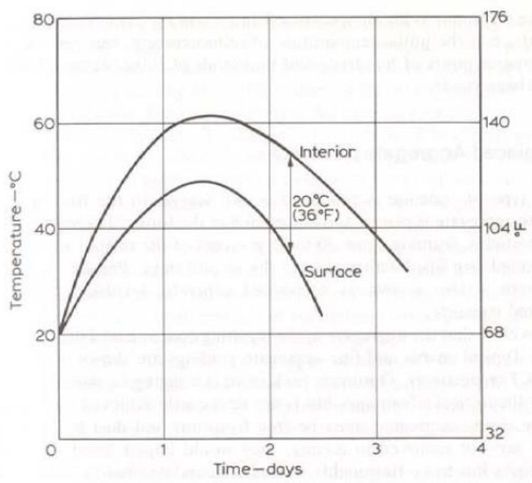


Figure 2.2 The pattern of temperature change which causes internal cracking [17].

Figure 2.2 shows the effect of the temperature differential in causing internal cracking where the 20 ℃ (critical) temperature difference occurs during heat generation, but the crack would open only when the concrete interior cooled more than the RMC exterior part [17]. The issue may be solved not by reducing the internal temperature increase but by stopping heat dissipation at the exterior. This allows the whole mass of RMC to heat to the same temperature, increase without being confined, and then cool to its ultimate proportions without any more adjustment. The construction framework and the upper part must be well insulated to avoid a significant heating loss [85]. The insulation should be kept in place till the temperature difference is no more than 10 degrees Celsius (18 °F) [85].

2.14 Artificial Neural Network

An artificial neural network (ANN) is a computer model influenced by the information-processing biological neural networks within the human brain. Neural networks can " learn " and connect vast experimental or simulated data sets. The trained neural network is an analytical tool for making accurate predictions and outcomes. It is an efficient technique for their training and validation and can provide predictions with a high degree of accuracy [101].

The neural net is a highly parallel processor composed of basic processing units with a natural predisposition for accumulating and making accessible experience information. It is similar to the brain in two main ways [102]:

1. The network acquires knowledge from surroundings via learning. Synaptic weights, referred to as interneuron-weighted connections, store learned information.
2. The ANN is a mechanism that replicates how the brain accomplishes a specific activity; the network is often constructed using electrical components. ANN acquires high performance via the vast interconnection of essential computer cells known as "neurons" [102].

Developing learning approaches allows for the prediction of RMC compressive strength. The ANN has already been utilized to estimate the compressive strength of RMC [103].

2.15 Principal Artificial Neural Network Architectures

The ANN consists of three parts, known as layers, which can be described as follows:

2.15.1 Input layer

This layer collects the necessary data, signals, and characteristics. These inputs were usually normalized inside these limit values generated via activation functions. This improves the numerical accuracy of performed mathematical computations [102].

2.15.2 Hidden layers (intermediate)

These layers consist of neurons identifying patterns related to the examined system or process. These layers do the majority of such internal operations [102].

2.15.3 Output layer

In addition to being constituted of neurons, each layer is responsible for producing and displaying the overall network outputs, which are the consequence of such processing conducted by neurons as in preceding layers [102]. The designs for ANN may be categorized according to the neuron placement, their interconnections, and the composition of their layers:

(i) Single-layer feedforward network,

The ANN has only one layer input, a single layer (neural), and an output layer [104].

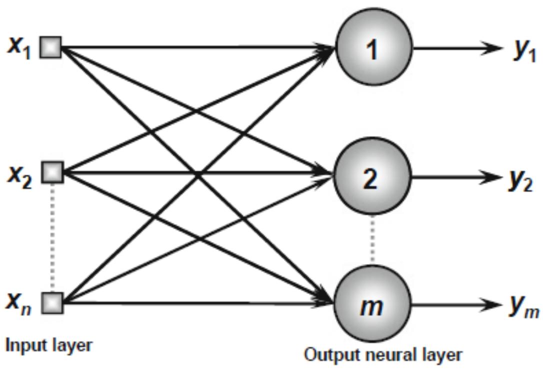


Figure 2.3 Single layer network [102].

The data flows in a unidirectional way and reaches the output layer from the input layer. In networks with this topology, the network outputs will equal the number of neurons [102].

(ii) Multilayer feedforward networks,

Unlike networks of a preceding design, feedforward networks with many layers consist of one or more hidden neural layers [104].

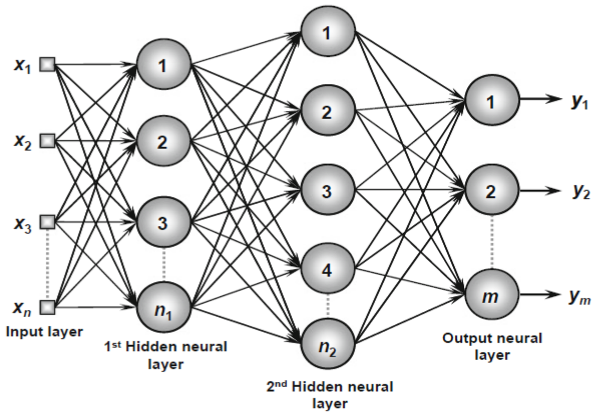


Figure 2.4 Multilayer feedforward networks [102].

The ANN model solves various issues, including compliance, pattern classification, system identification, control activities, optimization, and robotics. Figure 2.4 depicts a backpropagation network with many layers, including an input layer having n samples, two hidden neural layers with n1 and n2 neurons, and an output neural layer with m neurons reflecting the problem's output values. Multilayer Perceptron (MLP) and Radial Basis Function (RBF) are two of the most prominent networks employing multiple-layer feedforward topologies, with training methods depending on the generalized function approximation and the competitive/delta rule, respectively. In figure 2.3, one can deduce that the number of neurons differs from the amount of signals comprising the input layer [102].

(iii) Recurrent networks

In these networks, neuronal outputs are the feedback inputs for all other neurons. The feedback qualifies the networks for dynamic processing; therefore, they may be used for time-variant systems like timing prediction, dynamical systems, optimization, and process control, among others. Among the most crucial feedback networks are Hopfield and Perceptron, featuring feedback among neurons from various layers, whose training methods are built upon energy function reduction and generalized delta rule, respectively [102].

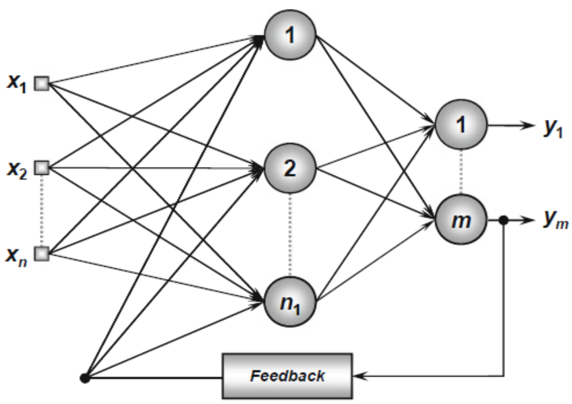


Figure 2.5 Recurrent layer (feedforward) networks [102].

Figure 2.5 illustrates an example of the perceptron network within feedback; it shows that one of the outputs can give feedback towards a middle layer, considering a previous output.

(iv)Mesh networks.

The primary characteristics of networks using mesh structures are the spatial organization of neurons with pattern extraction; the spatial positioning of neurons was directly connected to modifying their synaptic weights and thresholds. Artificial networks serve a wide variety of applications and are used to solve issues involving data grouping, pattern recognition, system optimization, and graphing; the Kohonen network is the most prominent example of mesh designs, and i

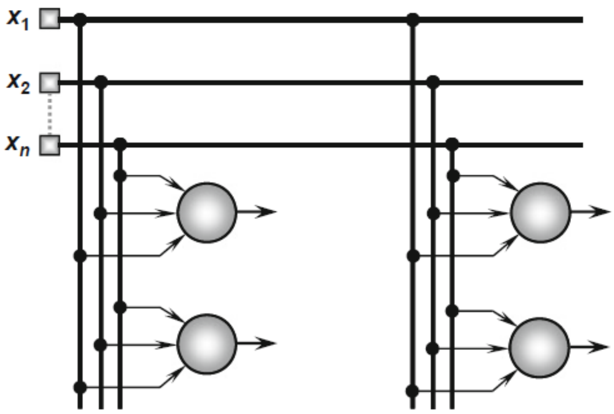


Figure 2.6 Mesh layer networks [102].

Figure 2.6 illustrates the example of a Kohonen network, showing that the neurons were arranged for the two spaces (dimensional).

2.16 Artificial Neuron

The architecture of ANN was derived from models of biological nerve systems and the human brain. Artificial neurons are simplified representations of organic neurons. The research on how a neuron's cell membrane produces and propagates electrical impulses inspired these models (Hodgkin and Huxley 1952). Artificial neurons used in neural networks are also nonlinear, typically provide continuous outputs, and perform simple functions like assembling signals available on their inputs, assembling individuals as per their operational functions, and producing a response considering their inherent activation functions [105].

2.17 Artificial Neuron behavior (Functions)

The behavior of the neurons as functions that convert (transduce) an unbounded activation input ***x(t)*** at the time ***t*** into an output signal ***f(x(t)),*** which is a sigmoidal curve usually. The function (*f*) is the activation function [106]. The following activation functions are more often encountered in practice:

2.17.1 Logistic: The function of the logistic function is the most used and is described as:

$$f(a) = \frac{1}{1+e^{-ca}} \quad (4)$$

Where *C* >0, *C* refers to the constant (the favorable scaling). The activation derivative is *f* =*df* /*da* = *cf* (1- *f*), and so *f* is the monotone increasing (*f* > 0), And the activation function f is applied to the result a. The neuronal output is taken to be *f(a)*, while for each input, xi is weighted by a factor wi, and the sum of inputs is calculated by [106]:

$$\sum_{\text{All inputs}} w_i x_i = a \quad (5)$$

2.17.2 Hyperbolic-tangent:

The sigmoid neurons in the hidden layer are represented by hyperbolic tangent transfer functions and the output layer's linear (positive) transfer functions [106].

$$f(a) = \tanh(ca) = \frac{e^{ca} - e^{-ca}}{e^{ca} + e^{-ca}} \quad (6)$$

where c > 0; c = const. is a positive scaling constant. The activation derivative is $f = df/da = c(1 - f^2) > 0$, and so f is monotone increasing ($f < 1$).

2.18 Network learning function and learning strategies

The process of learning is described as unsupervised. The time is considered as a discrete *t* = 1; 2. The weights are time-dependent *W* = *W(t).* The learning networks are loaded with data described as *x(t).* At the time (symbol) *t* = 0 (weights) starts with random (tiny) values, where the weights at the time *t* updated as follows [106]:

$$dW = (dW/\ dt).dt \quad (7)$$

which in discrete time approximation (dt= t- (t-1) = 1) becomes:

$$\Delta W = W(t) - W(t\text{-}1) = dW/\ dt \quad (8)$$

The learning strategy is an algorithm that can be used to change and thereby train the ANN so that the network produces a desired output. Although it is the most reasonable solution, it does not apply to all issues. The network attempts to discover similar patterns and categorize them into comparable groups based on the input patterns. The training set comprises input patterns, attempts to identify commonalities, and produces pattern classes independently [105].

CHAPTER 3 PROCESS OF PRODUCTION MANAGEMENT

3.1 Introduction

The key benefits of Ready-Mix Concrete (RMC) are good quality, lower Life cycle cost, the speed of work, and friendliness of the environment concrete. However, when the quality of RMC is below, the threat of several causes resulting in poor quality or useless concrete; therefore, this investigates the use of quality management to improve the process of production and study the impacts of quality control (QC) and quality assurance (QA) on the company by introducing them to the process. The idea of the work depends on finding the relationship between the Project Management Body of Knowledge (PMBOK) Guide and quality management to achieve the best results as soon as possible, higher product work, increased customer satisfaction, increased profitability and sustainability by finding company's problems and achieving it through guidelines and instructions of PMBOK Guide also the principles, the tools and the techniques of Quality Management, to achieve that, it has been used techniques and tools of management such as Flow Chart it has been used for a process, Ishikawa diagrams to define seven groups, Check Sheet to the problems occurring FMEA Analysis for thirty-five problems, 5 Whys Analysis to find sources of the problems, Solution effect Analysis to propose the possible solutions. The most important results from this section are the main reasons for the absence of management methodology in the company: a defect in the Quality system, lack of management experience, and communication. The thoughtful scientific methodology for managing the production process and developing the RMC production system is based on the PMBOK Guide. Adopting a quality management system is a strategic decision that can help improve its performance and provide a basis for sustainable development initiatives [107].

3.2 Process defects

It reviews the fundamental problem of RMC companies that are non-compliance, applies quality management to the required degree, and applies only a fraction of quality standards to match with regulations, which led to the fact that most RMC companies suffering from no transparent quality management system in the company, problems in the processes of production, production process needs continuous improvements and updating.

Moreover, to understand the nature of the problem, take into consideration that there is no single accepted definition of quality [54], and it should be designed into both the product and the process; it is the expected degree of homogeneity and reliability at the lowest possible cost and matched to market requirements, where, it is fitness for use or the usefulness of a product and service [50]. The data are provided by the RMC production company (Sert company and AL-Snaf company) through interviews with the head of the company, employees, and the field visiting the plant work site. As a result of inception, it has been noticed that in the past two years, the production rate has reduced from 1000 to 200-100 cubic meters per three days, and consequently, the company began to lose skilled employees. The company was dealing with a reliable contractor and started to lose them. In addition to the cost of maintenance of the parts of the plant and trucks that deliver concrete to the worksite due to fuel losses because of equipment, there is a need to predict the expected problems in the process based on data analysis and find solutions. The plant is (an MB-100W) Stationary Concrete Batching Plant, which has a wet mixer system, and the technical information is shown below.

Table 3.1 Technical information of the concrete batching plant [Researcher].

No	*Technical Data*	*Value*	*Unit*	*Employee*	*No*
1	*Capacity*	*80*	*m^3 /hr*	*Civil Engineer*	*2*
2	*Mix Type*	*wet*	--	*Water Treatment Engineer*	*1*
3	*Mix Capacity*	*1.5*	*m^3/min*	*Mechanical Engineer*	*1*
4	*Aggregate Compartments*	*4*	*Quantity*	*Electrical Engineer*	*1*
5	*Aggregate Weighing Conveyor*	*800x14.350*	*mm*	*Mechanical Technicians*	*20*
6	*Mixer Feeding Conveyor*	*800x29.000*	*mm*	*Electrical Technicians*	*5*
7	*Aggregate Weighing Capacity*	*2.200*	*kg*	*Supervisor*	*6*
8	*Cement Weighing Capacity*	*500*	*kg*	*consultative lawyer*	*1*
9	*Water Weighing Capacity*	*250*	*kg*	*consultative Accountant*	*1*
10	*Additives Weighing Capacity*	*20*	*kg*	*Hygiene worker*	*1*
11	*Cement Screw Conveyor*	*3*	*No*	*Officials' administration*	*4*
12	*Cement Silo Capacity*	*100× 3*	*Ton*	*Guardian man*	*1*

Moreover, the Stationary Concrete Batching Plant (SCBP) inclouds batching station, conveyor belt, admixtures tank, storage bucket and discharge gate, cement silos and cement scale, water tank, water scale, and control concrete. The company produces all types of concrete based on orders, in addition to Ready-Mix Concrete, pre-stressed concrete, precast members, and concrete piles.

3.3 Quality Management (implementation)

It contains the procedures and actions of the company performance, which define the rules, aims, and responsibilities of quality; thus, the process drive fulfils the requirements aimed at which it was accepted. It uses rules and processes within the process set, and the company's quality management system fits with the process improvement activities undertaken on behalf of the performing organization. Quality Management ensures that the process desires, including product needs, are met and validated [44]. It complies with the customer's requirements according to the PMBOK Guide principles. The procedure is as follows:

3.3.1 Plan for Quality Management

The quality reference for our management plan is the PMBOK Guide (seventh edition). It is desirable to investigate possible improvements in drying efficiency in terms of efficiencies [61]. The QM plan recognizes the necessity of quality for the process deliverables, detailing how the process will validate acquiescence with quality requirements to deliver supervision. The plan for QM starts with identifying the product producer applying QC by changing the company's structure and then displaying the problems. The Ishikawa diagram is used to locate a point of cause. Moreover, identify the occurrence of problems by check-sheet for thirty days, analyses these problems by FMEA and 5whys analysis, and propose solutions by the solution effect analysis and the Flow Chart after applying QC and QA in the process to understand the quality performance it must identify the current quality system. Therefore, the process begins with the structure of the company, where the company structure is the functional type of organization. It is a grading where every member is the only supervisor [61].

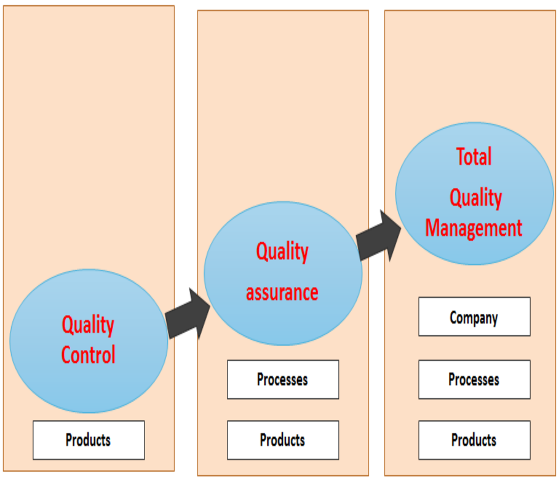


Figure 3.1 Quality control, Quality Assurance [50].

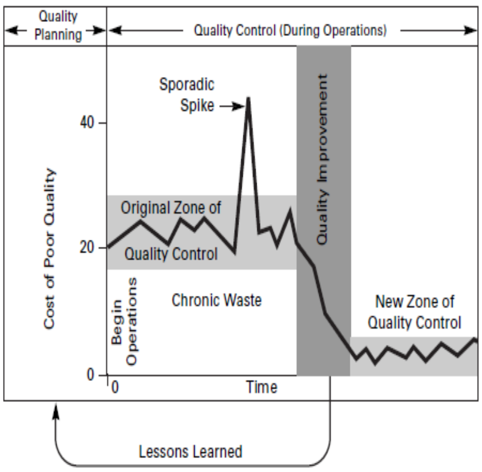


Figure 3.2: Juran trilogy diagram [57].

3.3.2 Perform performers from quality.

Specialty persons like engineering, accounting, production, and marketing collect teamwork members. The functional manager is an entity that can role the management with the functional zone of production, human resource, finance, and account or procurement. Therefore, the changes the structure of the company from a functional organization to a composite organization type, as shown in the following table:

Table 3.2 Organizational Structures Influence from Functional to Composite [Researcher].

No	*Organization Project Structure characteristics*	*Functional Organization*	➞	*Composite Organization*
1	*The authority of the Project Manager*	*None of Little*	➞	*High to nearly Total*
2	*The Availability of resources*	*None of Little*	➞	*High to nearly Total*
3	*The responsibility of the project budget (Manager)*	*Functional*	➞	*Project*
4	*The role of the Project Manager*	*Part of time*	➞	*All-time*
5	*The administrative staff of the project management*	*Part of time*	➞	*All-time*

Table 3.2 shows that the company might manage a maximum of its procedures by the strong matrix. However, permit some work to manage the functional management zone. In a composite organization, the company's resources are the PM takes countless duties individuality. The divisive can report to the PM or deliver different products to projects.

3.3.3 Process Quality Control

Quality Control is a single of the fundamental three administrative procedures by the quality which can be managed process, the second is quality planning, and the third is quality improvement, as shown in Juran’s diagram of the mutual relation of these procedures [57]. It is a procedure for documenting, designing, analysing, and managing several fields [64]. To improve the effectiveness of the company's processes that produce the service or products [39]. It starts with materials and services we would like to purchase from organizations and suppliers, then check these offers and agree with the specifications. The suppliers will deliver the raw materials to the plant, and when they arrive and are received without inspection, check whether the quantity is complete; where if there is a shortage of quantity, the stakeholder will communicate with the supplier to complete its t, which delivers late and poor quality, where the materials go into the company's stores, the design and planning department perform the mixing formula after considering the engineers' judgment and testing the formula, the mixing phase where the inputs is the materials, water, and mix additives to produce RMC as outcomes.

3.4 Fishbone or Cause-effect tool (Ishikawa diagram)

It illustrates the relationship between the problem effect and its contributors to root causes [61]. The fishbone diagram (sometimes called Ishikawa) offers an optical diagram of the roots (the factors) that are linked to a specific problem (the effect) and are best used while discovering a specified problem at an early or during the process of the analysis phase to dig deeper. It is assistance in discovering recommended probable size reasons connected to the problem, discovering the source causes, and showing the dependencies of causes and underlying drivers.

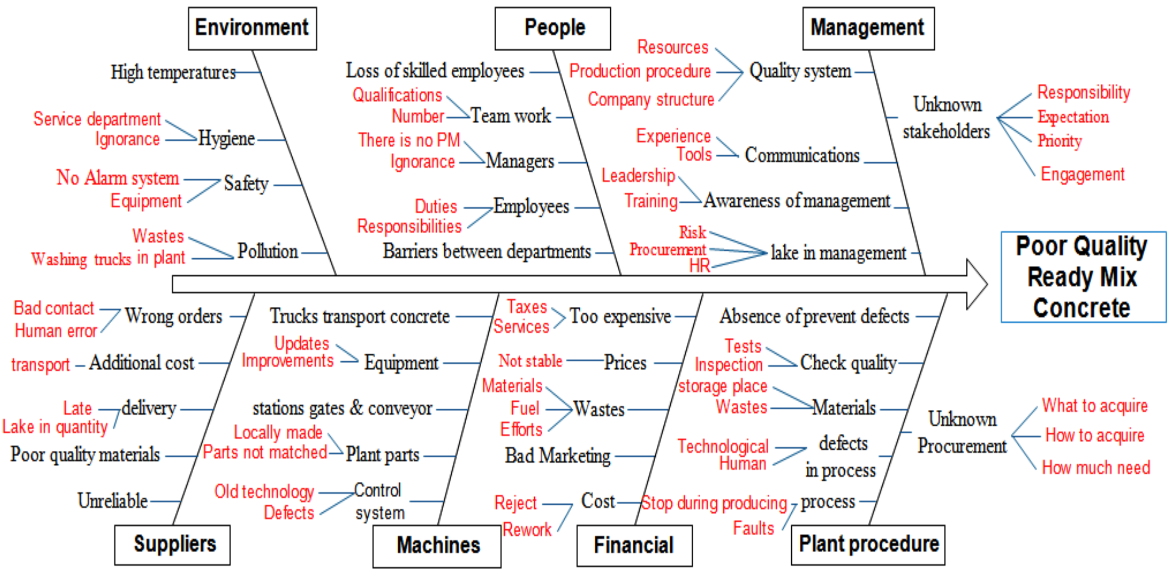


Figure 3.3 Ishikawa diagram indicates the problems [Researcher].

Figure 3.3 was used to identify and review all likely reasons linked to problems to discover the root causes and show dependencies amongst causes and underlying drivers where the main categories of problems were management, people, procedure, financial, machines, suppliers, and environment as shown in figure 3.4 where it shows the causes related to the problems, which are identified and displayed by seven categories related to 34 secondary causes.

3.5 Check-sheet

The check sheet recorded the number of problem occurrences for over thirty days. It is mentioned that not all problems can be measured due to the system used. A check-sheet table is an efficient method to collect and organize data on problems, which can help identify patterns and trends and inform decision-making to improve the plant's overall performance.

Table 3.3 Check-sheet of Ready Mix Concrete batching plant for 30 days [Researcher].

<table>
<tr><th>No</th><th>Defect type</th><th>10 days</th><th>10 days</th><th>10 days</th><th>Total</th></tr>
<tr><td>1.</td><td>Late delivery of materials or total quantity</td><td>|</td><td>|</td><td>||</td><td>4</td></tr>
<tr><td>2.</td><td>Additional cost (transportation loading cost)</td><td>||</td><td>|</td><td>|</td><td>4</td></tr>
<tr><td>3.</td><td>Wrong orders due to bad communication or errors</td><td>|</td><td>|</td><td></td><td>2</td></tr>
<tr><td>4.</td><td>Provide poor-quality materials.</td><td>|</td><td>||</td><td>|</td><td>4</td></tr>
<tr><td>5.</td><td>The faults stop the plant during production.</td><td>||</td><td>|||</td><td>||</td><td>7</td></tr>
<tr><td>6.</td><td>Wastes of materials and fuel</td><td>||</td><td>|</td><td>|||</td><td>6</td></tr>
<tr><td>7.</td><td>Materials place storage</td><td></td><td>|</td><td>|||</td><td>4</td></tr>
<tr><td>8.</td><td>Defects in test inspection</td><td>||</td><td>|</td><td>|</td><td>4</td></tr>
<tr><td>9.</td><td>Gates &conveyor defects</td><td>|</td><td>|</td><td>|</td><td>3</td></tr>
<tr><td>10.</td><td>Equipment transportconcretee.</td><td></td><td></td><td>|||</td><td>3</td></tr>
<tr><td>11.</td><td>Bad communications</td><td>||</td><td>|||</td><td>||</td><td>7</td></tr>
<tr><td>12.</td><td>Lack of awareness of management</td><td>||</td><td>||</td><td>||</td><td>6</td></tr>
<tr><td>13.</td><td>Loss skilled employees</td><td></td><td>||</td><td>|</td><td>3</td></tr>
<tr><td>14.</td><td>Lake of numbers team of work</td><td>||</td><td>||</td><td>||</td><td>6</td></tr>
<tr><td>15.</td><td>Lake of qualifications team of work</td><td>|</td><td>|</td><td>||</td><td>4</td></tr>
<tr><td>16.</td><td>Employee's awareness of responsibilities</td><td>|</td><td>|</td><td>||</td><td>4</td></tr>
<tr><td>17.</td><td>Bad Marketing and service after the sale</td><td>|</td><td>|</td><td>||</td><td>4</td></tr>
<tr><td>18.</td><td>Cost loss because of rejection, return, or rework.</td><td>|||</td><td>|||</td><td>|||</td><td>3</td></tr>
<tr><td>19.</td><td>Prices are not stable (materials, fuel, and products)</td><td>|</td><td>|</td><td>||</td><td>4</td></tr>
<tr><td>20.</td><td>Services (electricity & water) & taxes (expensive)</td><td></td><td></td><td>|||</td><td>3</td></tr>
<tr><td>21.</td><td>High temperatures</td><td>||</td><td>||</td><td>||</td><td>6</td></tr>
<tr><td>22.</td><td>Environment issues due to the wastes</td><td>|</td><td>|</td><td>|||</td><td>5</td></tr>
</table>

Table 3.3 represents the check sheet for RMC production in 30 days monitoring to understand and record the defects numbers, type, where it happened and how many times happened, where the most significant occurrence numbers, the faults or stops of the plant during the production of ready mix concrete and harmful communications and management awareness.

3.6 FMEA Analysis

It is the systematic way to monitor and represent the reasons and impacts of constituent defects and includes the quantitative evaluation of the essential results of defect type [61]. The obstacles will require analysis in expressions of the occurrence probability, the detection ease, and the significant influence on the entire company process. The analysis method prioritizes possible defects depending on the detection, occurrence, and severity of management.

$$RPN = X1 \times X2 \times X3 \qquad (9)$$

Where X1= Ease of detection, X2= Probability of occurrence, X3= Severity of the problem, and RPN= Risk Priority Number.

The Risk Priority Number (RPN) is calculated by multiplying detection by occurrence by the Severity of problems, where a higher RPN is the most significant performance of the company [20]. The scale number is (1 to 10), where 10 is the most significant impact. A higher RPN indicates a higher priority problem requiring more resources. The defects can be described as Management defects in the quality system, which are crucial for maintaining the consistency and reliability of products and services. Defects in the quality can lead to nonconformance and customer dissatisfaction. Stakeholders play an essential role in the success of an organization.

Table 3.4 FMEA analysis for Ready Mix Concrete [Researcher].

No	Subject	Problem	X_1	X_2	X_3	RPN
1	Management	Defects in Quality System	9	9	9	729
2		Unknown stakeholders	5	5	5	125
3		Lack of awareness of QM	8	6	6	288
4		Experience Communicate	7	7	9	441
5		HR management	6	5	5	150
6	Financial	Risk management	8	5	5	200
7		Wastes due to defects	9	6	3	162
8		Bad Marketing	8	4	5	160
9		Reject or Rework.	4	3	5	60
10 `		Prices not stable	7	4	3	84
11		Services & taxes	3	3	3	27
12	People	Loss skilled employees	8	3	5	120
13		Qualifications of worker	6	4	4	96
14		Barriers & departments	4	3	5	60
15		Numbers of TeamWork	5	6	6	180
16		Responsibility and Duties	6	5	4	120
17	Machines	Old Technology & C. S	7	4	6	168
18		The Plant is locally made	4	3	5	60
19		Gates &conveyor defects	8	3	5	120
20		Updates of process	2	3	4	24
21		Equipment transport con.	3	3	3	27
22	Procedure	Stop during production	9	7	8	504
23		Wastes materials	7	6	5	210
24		Materials place storage	6	4	5	120
25		Defect Test & Inspection	6	4	8	192
26		Absence prevent defect	7	3	5	105
27	Suppliers	Unreliable	4	4	6	96
28		Poor quality materials	7	4	8	242
29		Late delivery&quantity	6	4	8	192
30		Additional cost	4	4	3	48
31		Wrong orders	3	2	7	42
32	Environment	High temperatures	3	6	3	54
33		Hygiene	3	4	4	48
34		Safety	5	3	8	120
35		cleaning trucks inside	4	5	3	60

Table no.3.4 represents the FMEA analysis of the RMC process of production, where the primary group of the defects related to management, finances, people, machines, procedure, supplier, and environment, based on the defects recorded in the previous step (check sheet) and the scale was (1 to 10). X_1 represents the ease of detection, X_2 represents the probability of occurrence, X_3 refers to the severity of the problem, and RPN is the RPN of RMC production.

Moreover, Identifying and engaging with unknown stakeholders can help meet their needs and expectations. A lack of awareness of QM can lead to poor quality products and services, negatively impacting customer satisfaction and the organization's overall performance. Good communication is essential for effective teamwork, customer service, and problem-solving. The communication experience can help ensure that important information is shared and understood by all relevant parties; recruiting, training, and skilled employees can help ensure the organization meets its goals. Risk management is an essential aspect of business management. Identifying and managing risks can help minimize adverse events' impact and ensure the organization can operate effectively. Unstable prices can make it difficult for organizations to plan and budget effectively, negatively impacting their financial performance.

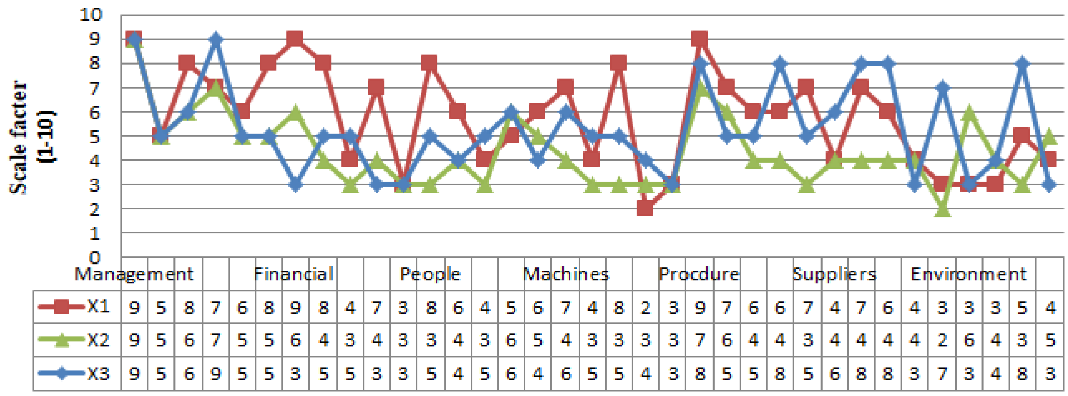


Figure 3.4 The Detection, Occurrence, and Severity of Problems [Researcher].

The detection evaluates the real opportunity of finding the deficiency before it happens. The scale number (1) means we have comprehensive controls for finding the deficiency. The occurrence probability evaluates the real opportunity to the failure mode that appears (the more significant number means a higher opportunity). The severity evaluates the likely loss or damage that might occur during the production or due to human usage (a more significant number means a higher possible loss).

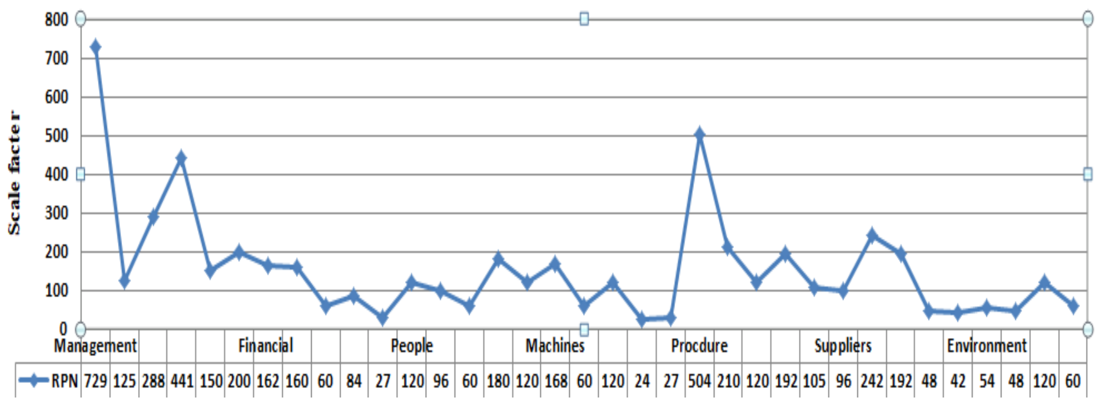


Figure 3.5 The Risk Priority Number [Researcher].

In the table of FMEA analysis, the numbers of occurrences of problems used are taken from check sheet results and multiplied by detection and severity to give a risk priority number of the results. The most significant number was for the defects in the quality system (729).

3.7 5 Whys Analysis

This an effective technique when it requires a systematic way to lead a group to understand why a problem is/has occurred. It could also be an essential tool in all the information-gathering activities that require a more profound understanding [73]. The author used why 5 analyses to find sources of the problems, as shown in the figure below:

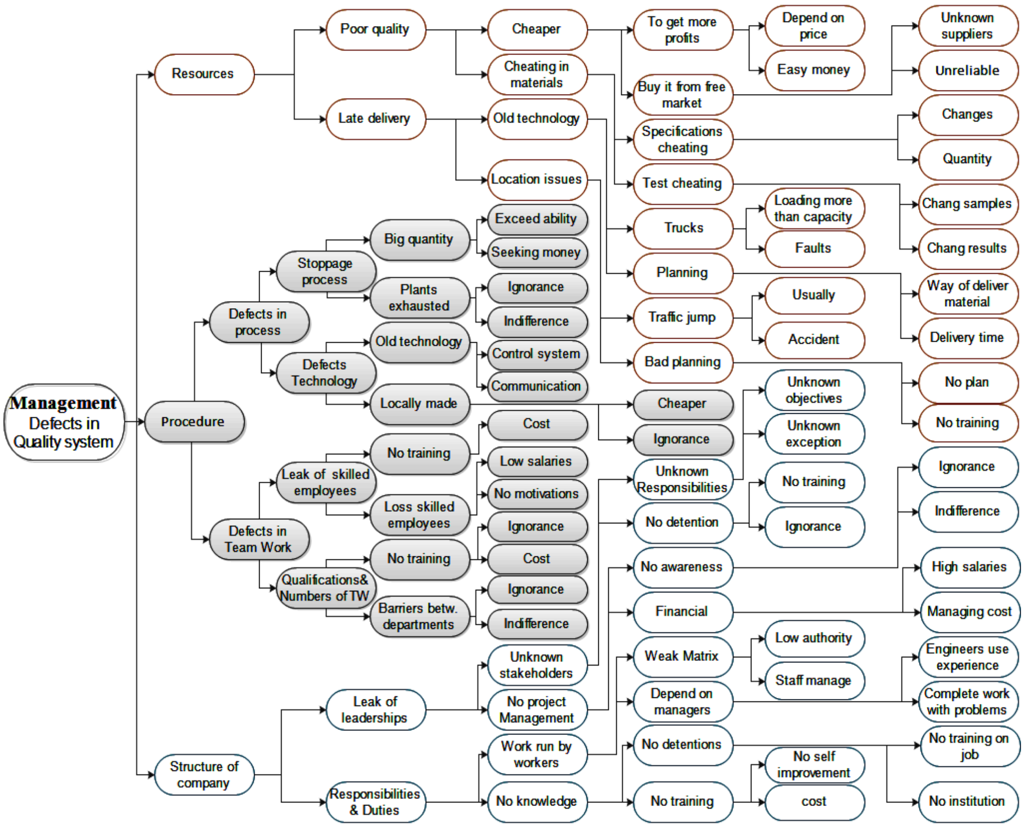


Figure 3.6 The 5 whys analysis for Management /Defect in the Quality System [Researcher].

The author systematically understood the real reasons why problems occur in the plant; the most crucial point, according to the outcomes of the FMEA Analysis, is the quality system defect based on Quality tools to meet requirements [55]. The sources of problems are unreliable or unknown suppliers, deception or change in specifications and quality, manipulation of the samples and results of tests, errors in planning for the way of the delivery of the product, errors in delivery, lack in training and development plan, ignorance loss of the skilled staff due to low salaries or cost. In addition, there is no project manager, producing a defender and efficient structure, low authority, and a lack of leadership.

3.8 Solution-effect analysis

An inversion of the fishbone is the solution-effect analysis where the possible solution is in a box on the left and a horizontal line from it towards the right, with further lines leading from this to display possible consequences and effects [73].

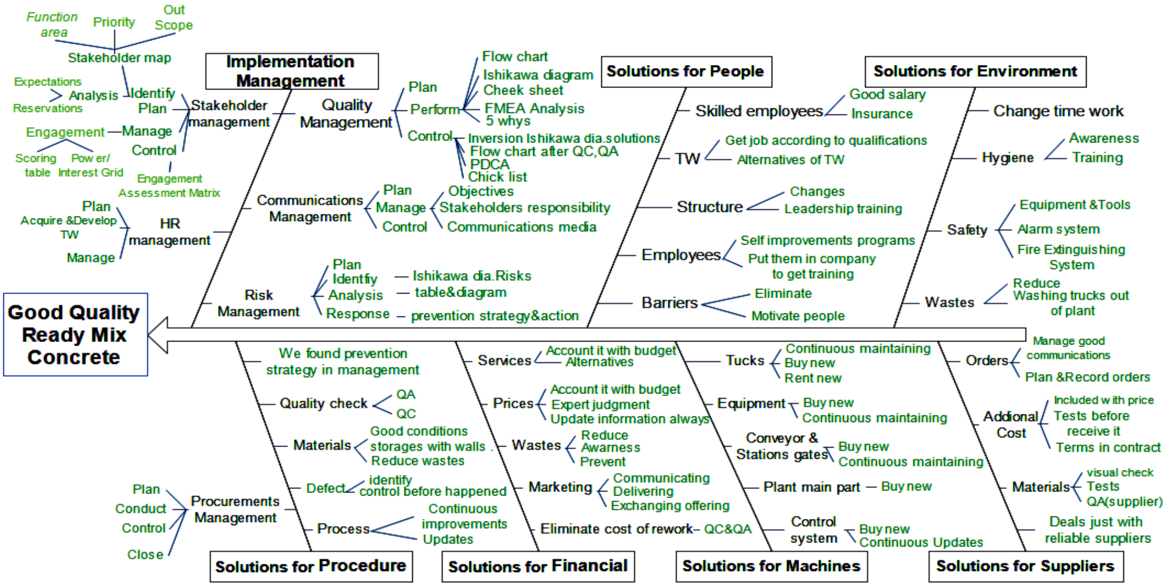


Figure 3.7 The solution-effect analysis [Researcher].

Figure 3.7 shows what the researcher proposed as solutions to all problems in the company. The researcher suggested (1- 4) solutions for each problem, some of which would be applied through quality control and assurance. In addition, the tools and techniques used before help cover other knowledge areas like human resources communications, procurement, risks, and stakeholders to reach Total Quality Management. Quality control deals with products; therefore, the author applies quality control found: The product enters the inspection department to quality control where the results are three cases:

a) The first is a mandatory report on the quality control and production process.
b) The second is that the product conforms to the specifications and delivery.
c) The third is the product not conforming to specifications, resulting in four cases:

Accepted with permission, then accepted request and report, repair request and report, then return to process, type change: the requested change and report, then return to process, and Reject products, then reject the report, then dispose of the products.

3.9 Quality Assurance

It is the procedure of predicting the whole process execution on a good foundation to guarantee that the process will comply with the suitable standards of quality; it is also the company unit responsible for ensuring the quality [61].

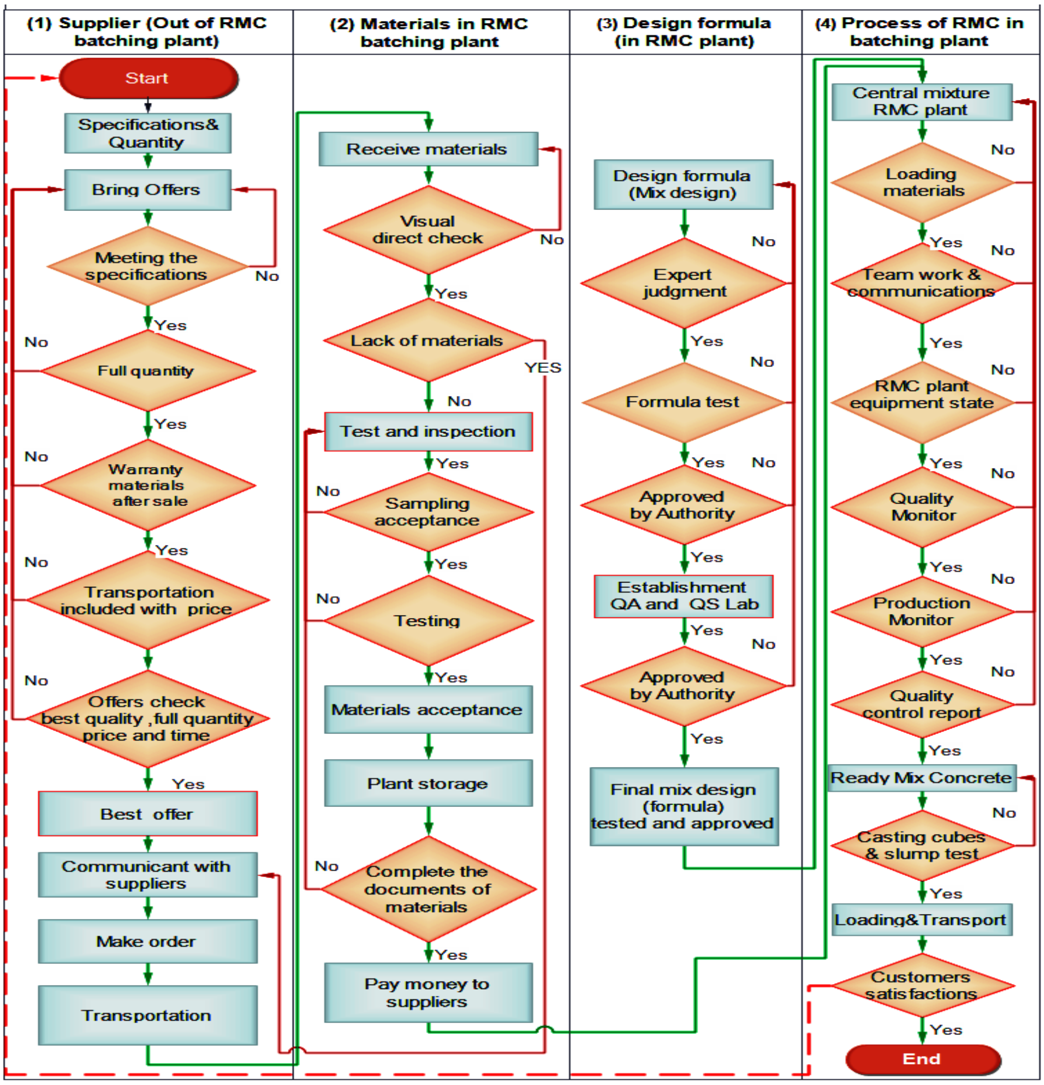


Figure 3.8 The Flow chart of the RMC plant after applying QC and QA [Researcher].

Maintaining quality-processed products at levels and tolerances acceptable to the consumer is essential. It also ensures meeting government regulations, reducing the probability of spoilage, minimizing the cost of production, and raising product value [109]. The quality systems will deliver the base to meet customers' expectations, satisfaction, work teams, and repetitive improvements. The prevention action of the defect exists in quality assurance, which is different from the detection and rejection of defects in quality control, which has been mentioned as it focuses on quality at the earlier level of the process. It deals with processes and products where, from the beginning, the materials must be of good quality, complete quantity delivery on time, and the price of transportation and loading. The primary criterion for accepting the offer must be quality, not price, and quality assurance of the material by the supplier, putting monitors production and Quality monitors in a process and considering many other factors (team of work, communications, equipment, quality, and production reports) as shown in the flowchart and figure below, and Inspection and test materials' arrival at the plant is a prerequisite for acceptance, completing paperwork, and paying the money. The test outcomes show that when the quantity discarder of the mix is more significant, the compressive strength will reduce [110]. The temperature is also a significant factor that affects RMC quality [29]. Use expert judgment in the mixing formula, then test it practically, and establish QA and QS Lab in a plant to test the formula and products. Receive production and Quality Control reports, making a final inspection [111].

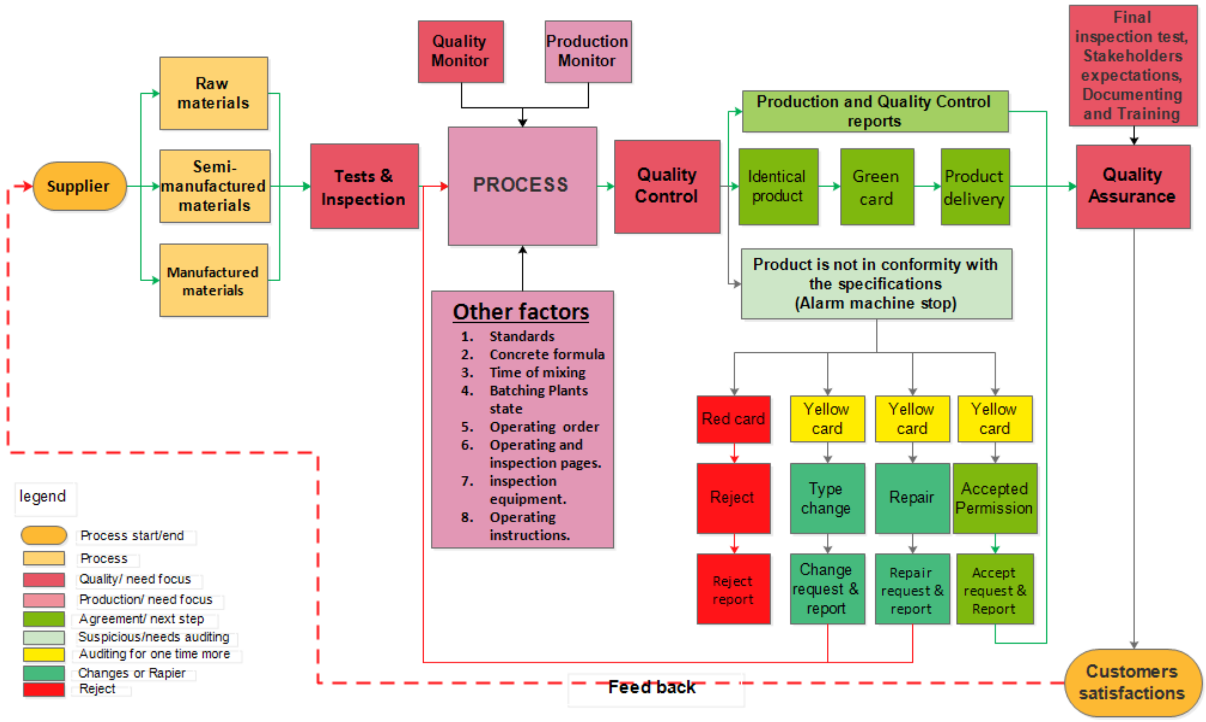


Figure 3.9 The QC and QA are in the process of RMC production [Researcher].

Figure 3.9 provides a comprehensive overview of a production process, detailing the various steps involved, from procuring materials and components from suppliers to delivering the final product to customers and providing after-sales service. The introduction of Quality Control (QC) into the process is highlighted, with the figure showing how QC and Quality Assurance (QA) are integrated into the production of RMC. The figure clearly illustrates the outcomes and impacts of QC and QA on production, including identifying and eliminating defects, improving quality, and reducing rework and waste costs. Overall, the figure provides a clear and detailed understanding of the importance of QC and QA in the RMC production process and how it ensures the final product's quality and customer satisfaction.

CHAPTER 4 MANAGEMENT OF IMPROVEMENTS IN THE RMC PRODUCTION PROCESS

4.1 Introduction

The Analytic Hierarchy Process (AHP) is the way of study that tries to provide vision makers with a group of means and tools needed to solve problems because rank reversal also occurs in the AHP [112]. This section examines an analytical examination of stakeholder and communications management within concrete. The objective is to determine the suitable product for achieving quality using the AHP Process to compare criteria and variances through pairwise comparison. The selection of the optimal product impacts the effectiveness of our actions, as it will minimize the expenses incurred in updating the progress of other products in production, thereby conserving time, effort, and resources. The Expert Choice software is utilized to enter goal criteria, make pairwise criteria comparisons, and submit alternatives. The analysis of results based on sensitivity criteria, performance sensitivity, dimensional sensitivity, dynamic sensitivity, and expert opinions shows that RMC is better than other primary products at achieving superior quality. The software that carried out an assessment was represented as scores, making it possible to conduct a cross-case analysis to assess factors affecting the success of large quality [113]. The final decision is based on the synthesis results and sensitivity analysis [114]. It supports decision-making and enables him/her to advance in solving the so-called multiple criteria decision problems. Its methodology helps to structure and solve the unstructured, complex problem and reach the final compromise solution [115].

4.2 Process of production description

The production process of RMC, undertaken by Sert Company for RMC production, encompasses generating various concrete types by specific demands. However, this process encounters challenges for stakeholders and communication. The primary commodities encompass ready-mix concrete, pre-stressed concrete, precast elements, and concrete piles. Over the years, the company's accumulated experience has facilitated the acquisition of numerous favorable contracts, perhaps leading to increased income for various reasons. The concrete batching plant under investigation replicates the MB-100W stationary concrete batching plant. This conclusion is drawn based on data gathered from the company, interviews conducted with the company's chief executive officer, individuals responsible for overseeing the production process, and employees.

4.3 Stakeholder Management

It is essential to define the persons and companies that could influence and investigate stakeholder expectations and the effect on the process to improve proper management approaches for professionally attractive stakeholders in decision-making and execution. The stakeholder management procedure is described in the following:

4.3.1 Identify the stakeholders

Stakeholders are individuals with a vested interest in a particular outcome, and this outcome has a reciprocal relationship with them, as they can both influence and be influenced by it. The main goal is to recognize stakeholders, including identifying relevant information, assessing it, and classifying stakeholders accordingly.

Table 4.1 Stakeholder map table [Researcher].

NO	*Stakeholders*	*Function/ area*	*Priority (First)*	*Second Priority*	*Our Scope*
1		*The owner*	*Chief of plant*	*allocates capital*	---------
2		*Project Manager*	*Managing all*	*Manage & Director of all operations*	---------
3		*Engineers*	*Manage the process*	*Employees need*	*Legal issues*
4		*Design &Planning*	*Manage the formula*	*Manage of planning*	*marketing*
5		*Production*	*Manage Production*	*Manage process*	*Distribution*
6		*Legal*	*Manage legal issues*	*Manage contract*	*Design*
7		*Financial*	*Finance managing*	*Finance Director*	*Vendor*
8	*Internal*	*Sales & product service*	*Managing Call Centre, Procurement Director of sales*	*Manage After Sales Service*	*maintenance*
9		*Marketing*	*Head of Marketing & Communications*	*Director Sales*	*Salesforce*
10		*Human resource*	*Managing employees' record system*	*Notifications of HR issues*	*Design*
11		*Inspection &Testing*	*Manage of QM*	*Manage Inspection*	---------
12		*Customers*	*Corporate clients*	*Current clients*	*New clients*
13		*Investor*	*Seeking information to mitigate risks*	*seeking IT to get benefits of investing.*	-----------
14	*External*	*Sellers*	*Customer satisfaction& Deliver on time.*	*Sell as many as possible/products.*	*Human resource*
15		*Suppliers*	*Dealing with reliable people*	*Provide as much possible material*	*company Structure*

Table 4.1 presents a stakeholder map that provides insights into internal and external stakeholders and their functional areas. It is essential to analyze which groups are within the defined boundaries and ensure their active involvement. The stakeholder map represents the initial stage of the process and is used for a comprehensive understanding of the expectations

and concerns of relevant stakeholders, as shown in the provided table. This map outlines the actions and processes used to understand the impact of quality on processes and outcomes, including documentation, assessments, highlights, and preventive measures. Therefore, it is crucial to establish a set of quality indicators [116], as seen in the earlier table, which are based on audit data for management purposes [117].

4.3.2 Plan for stakeholder management

The analysis of stakeholders’ requirements, interests, and the impact on process success to develop the next step, a suitable strategy for effective engagement of stakeholders throughout the process through the use of a stakeholder scoring table and the Power Interest Grid with Stakeholders to intermingle with the process to support its interests with stakeholders to intermingle the process to support its interests.

4.3.3 Manage the engagement of stakeholders

Managing the engagement includes interactive and operational with the stakeholders to meet the expectations and encourage suitable engagement in process activities. The researcher used the table of stakeholder scoring to manage which stakeholder group influences the process and how its intended outcome affects the stakeholder group.

Table 4.2 Stakeholder scoring table [Researcher].

No	*Stakeholders*	X_1	X_2	X_3	X_4	X_T
A.	*The Chief of investment (owner)*	*5*	*4*	*5*	*5*	*19*
B.	*Project Manager*	*5*	*5*	*5*	*4*	*19*
C.	*Engineers (Manager)*	*4*	*3*	*4*	*3*	*14*
	Design and Planning Manager	*3*	*3*	*3*	*2*	*11*
D.	*Production Manager*	*4*	*3*	*4*	*2*	*13*
E.	*Legal Manager*	*2*	*2*	*4*	*1*	*9*
F.	*Financial Manager*	*4*	*3*	*4*	*3*	*14*
G.	*Sales & Product Service Manager*	*3*	*2*	*3*	*3*	*11*
H.	*Marketing Manager*	*4*	*2*	*3*	*1*	*10*
I.	*Human Resource Manager*	*2*	*1*	*2*	*2*	*7*
J.	*Inspection and Testing Manager*	*5*	*3*	*5*	*2*	*15*
K.	*Services & Equipment Manager*	*3*	*2*	*4*	*2*	*11*
L.	*Customers*	*4*	*2*	*3*	*1*	*10*
M.	*Investor*	*2*	*2*	*2*	*3*	*9*
N.	*Sellers*	*2*	*1*	*3*	*1*	*7*
O.	*Suppliers*	*4*	*3*	*4*	*2*	*13*

Table 4.2 show the results were the most considerable Level of interest of the owner and project manager, the most significant influence and impact of the project manager, owner, and inspection manager. The formula of the scarfing table the matrix is:

$$X_T = X_1 + X_2 + X_3 + X_4 \tag{10}$$

X_1 means the interest, X_2 means the influence, X_3 means the impact, X_4 means the support, and X_T means the total or summation of the grade. Moreover, the number (1) is the score factor that refers to the importance, and (5) the excellent or the higher score factor means more important a valuable stakeholder and a higher level of required attention. It is worth using the Power influence or impact grid, gathering stakeholders according to the phase of the authority (authorization power) and the active involvement of its impact in the procedure.

4.3.4 Control the engagement of stakeholders

It is a classification of stakeholders according to the degree of authority, which can call power and the degree of interest regarding the production results. It is a process of observing the relations process of stakeholders and regulating the strategies for involving stakeholders. The benefits can be to preserve the competence and the ability of stakeholders involved.

Figure 4.1 presented based on the results of the stakeholder scoring table used Power/Interest Grid with Stakeholders were found that the A, B, C, E, G, K, and O manage closely. The D, H, I, J, Q, and P keep informed. The N and F are satisfied. The L monitors.

The stakeholder's engagement phase can be categorized as follows: The neutral path, the aware position of stakeholders in the procedure is to resend and not support. The unaware was the watchful position in the process and the potential consequences. In the supportive phase, the conscious position in the production impacts and changes are supportive.

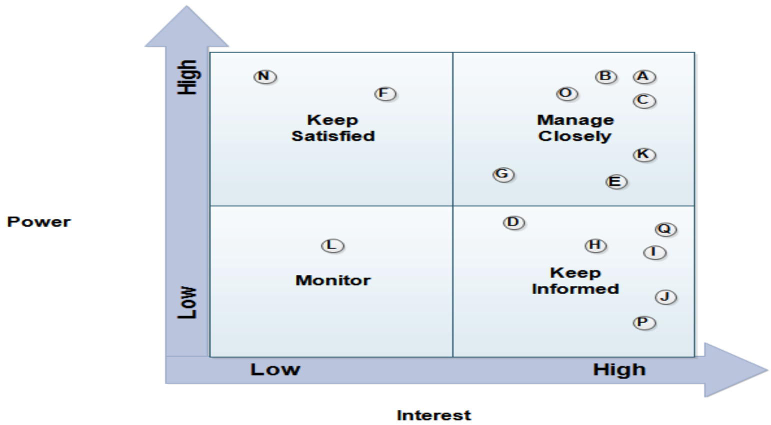


Figure 4.1 Power/Interest Grid with Stakeholders [Researcher].

The resistant were cognizant of their position in the procedure and possible influences change in resistance. The present engagement can be identified using the Engagement Assessment Matrix of Stakeholders, as explained in the table below, where 1 means the indicator of the current position engagement, and 2 means the indication of the desired engagement. Table no.4.3 shows us the Engagement Assessment Matrix of Stakeholders.

Table 4.3 Stakeholders Engagement Assessment Matrix [Researcher].

No	*Stakeholder*	*Neutral*	*Unaware*	*Resistant*	*Supportive*	*Leading*
1	*The Chief of invest*		*1*		*2*	
2	*Project Manager*			*1*		*2*
3	*Engineers (Manager)*				*1*	*2*
4	*Design and Planning*	*1*			*2*	
5	*Production Manager*	*1*				*2*
6	*Legal Manager*			*1*	*2*	
7	*Financial Manager*				*1, 2*	
8	*Sales/product service*	*1*			*2*	
9	*Marketing Manager*				*1*	
10	*HR Manager*				*2*	*2*
11	*Inspection/Testing*				*1*	*2*
12	*Services/Equipment*				*1, 2*	
13	*Customers*	*1*			*2*	
14	*Investor*			*1*	*2*	
15	*Sellers*			*1*	*2*	
16	*Suppliers*		*1*		*2*	

Table 4.3 has identified the present engagement and the anticipated engagement for each stakeholder in the process, where the matrix results show the big difference between current and desired engagement for stakeholders, causing a general malfunction.

4.4 communications Management

The managers spent time communicating with members of teamwork and stakeholders, whether from inside or outside of the company, communicating effectively at work. According to the PMBOK Guide of the Communications Management processes, as follows:

4.4.1 Identify and plan communications management

The communication plan needs a stakeholder map to describe the plans of management based on the reasons, objectives, or intentions behind the contact, the person who was required to reach the message, the time of sending and place, the intended frequency of the communication, the official owner of the message, and the end date of the communication period. The communication tools used are interactive communication, interviews, video conferences, distribution of printed and displayed means, status reports, brochure wares, the project newspaper, reports, electronic communications means, electronic newsletters, web-based surveys, interactive multimedia platforms or portals, intranet or mixed and group presentation and hotlines, the activities involve the internal and external activities, such as internal with the process and external with the clients, suppliers, and public initiatives, the formal state is like reports, a vertical state like up or down the company or horizontal with employees, and the written way, verbal like inflections of the voice, or nonverbal.

4.4.2 Manage communications

The company information process is to manage and spread using many means, which are, for example, Documents managed hard copies like press releases, notes, reports, and letters, electronic means of communications management like phone, e-mail, speaker, video and journal, online conferencing, websites, tools of administration like scheduling and electronic version folders, the software of project, management, and collaborative management tools.

4.4.3 Control communications

The procedural requisites involve engaging in dialogue and fostering collaboration within a cohesive team to determine the optimal means of communicating the company's operational processes as a response to the requirements articulated by stakeholders. These consultations and deliberations are commonly facilitated through meetings, which may be conducted in various formats, including face-to-face, virtual, or across disparate geographical locations, such as the corporate office and the supplier's premises. These meetings encompass negotiations and dialogues with clients, suppliers, and other pertinent parties. Consequently, the ensuing table elucidates the intricate interplay between communication tools and stakeholders, delineating the respective roles of stakeholders in utilizing these tools.

Table 4.4 Control communications (tools and stakeholders) and communicate type [Researcher].

No	*Name of the Communication tool*	*Stakeholder role*												
		Project Manager	*Engineers*	*Design and Planning*	*Production*	*Legal*	*Financial*	*Sales Service and Marketing*	*Inspection*	*Human resource*	*Services*	*Customers*	*Suppliers*	*Investor*
1	*Comm. plan*	*WM*	*AM*	*AM*						*AM*				
2	*Newsletter.*							*a o*	*a o*			*AM*	*AM*	*AM*
3	*Email*	*a o*	*AM*	*a o*	*a o*	*a o*	*a o*	*a o*	*a o*	*a o*	*a o*	*AM*	*AM*	*AM*
4	*Execu. plan*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*			
5	*Lett. &Mem*	*a o*	*AM*	*a o*	*a o*	*a o*	*a o*	*a o*	*a o*	*AM*	*a o*		*AM*	*a o*
6	*Proj. report*	*wo*	*wo*	*a o*	*WM*	*a o*	*AM*	*WM*	*WM*	*a o*	*AM*			*mm*
7	*Meetings*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*a*	*AM*		*a o*	*a o*
8	*Proj. chart*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*			
9	*Project plan*	*BW*	*BW*	*BW*	*mm*	*BW*	*mm*	*MM*	*MM*	*mm*	*MM*			
10	*Prog. report*	*WM*	*WM*	*AM*	*AM*			*MM*	*WM*	*WM*	*WM*			
11	*Risks plan*	*AM*	*AM*	*a o*	*a o*	*a o*	*a o*	*a o*	*a o*	*a o*	*a o*			*AM*
12	*Test plan*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*	*AM*			*AM*		*a o*
13	*Train. plan*	*a o*	*a o*	*AM*	*AM*	*mm*	*a o*	*AM*	*AM*	*AM*	*AM*			

Table 4.4 in the ensuing discussion presents an elaborate delineation of communication frequencies, organized into weekly, bi-weekly, monthly, and as-needed categories. In this context, the abbreviations used are as follows: "WM" denotes "Weekly Mandatory," "WO" represents "Weekly Optional," "BW" signifies "Bi-weekly Mandatory," "bw" indicates "Bi-

weekly Optional," "MM" corresponds to "Monthly Mandatory," "mm" stands for "Monthly Optional," "AM" designates "As Needed Mandatory," and "AO" stands for "As Needed Optional.". Controlling is typically achieved through meetings, which can occur in person.

4.5 The AHP (Analytic Hierarchy Process) method

It is the procedure of the comparisons (pairwise) that encourages the design of numerous decision-making approaches. Its extensive approval shaped some substantial ensure for the theoretical besides actual aims. The AHP in the standard model is extensively considered through the numerous features as the high reliability for decision-makers according to Saaty's comparisons were used to define the virtual importance of every variance in terms of standard; therefore, take care of the judgment on the result of each comparison, where the essential steps in decision means are the precise valuation of the relevant information. Saaty suggested that the decision makers have to exclude variances from the contemplation based on the score of 10 factors for the variances, which means the intensity of importance is (1-9) as follows [112].

- The importance intensity (1), defined as identical importance, means two actions participate similarly to the goals.
- The importance intensity (3) weak importance means that experience and judgment somewhat prefer action more than others.
- The importance intensity (5) vital or power importance means the experience is a favour in the first place and the judgment favour in the second place.
- The intensity (7) confirmed the importance, meaning the action and control explanation in training are powerfully preferred.
- The importance intensity (9) absolute importance is a proof of preferring action over another, which is the highest assertion instruction.
- The importance intensity (2, 4, 6, and 8) is a middle value between two similar judgments.
- The inverse of the above nonzero in case the activity (I) has a number overhead nonzero factor allocated to it once when compared to action (J), where it has inverse factor once compared to (I) activity.

4.5.1 Introduction of Expert Choice software

In our case, Expert Choice (software), the decision-making software, executes the AHP. It is an intensive implementation program that can result in improved delivery and slightly improved outcomes and quality. It has been used in manufacturing, environmental management, and agriculture quality strategies as tools, procedures, or activities aimed at improving [118].

4.5.2 Structuring of the AHP model

The structure of the AHP model includes the main aim or goal of work at the first level, the criteria evaluation will be in the second level (middle), and the variances will be down in the third level (bottom). The company structure is flexible, dynamic, self-oriented, reliable, and competitive for each phase hierarchically.

Figure 4.2 The decision hierarchy chooses the best product to achieve quality [Researcher].

i. The definition of the Criteria

Quality management systems are interacting activities, methods, and procedures used to monitor, control, and improve quality [119]. Therefore, we can describe a family of criteria for the company of Ready-Mix Concrete (RMC) following:

a. Cost

It is the sum of costs incurred by a company in preventing poor quality, the cost incurred to ensure and evaluate the quality requirements being met, and any other cost incurred due to poor quality being produced [74]. However, the costs must be allowable, allocable, and reasonable. The cost of quality for different technologies of construction varies widely.

b. Meet with standards

The organizational unit is assigned responsibility for quality assurance [61]. The quality control monitoring and inspection of the process results to evaluate if it meets associable standards of quality and define ways to remove causes of non-conformance performance. Also, it includes quality assurance, guessing the whole process to trust that it will meet suitable standards. Maintaining quality-processed products at levels and tolerances acceptable to the consumer is crucial. It also assures meeting government regulations, reducing the probability of spoilage, minimizing the cost of production, and raising the product value.

c. Experience of the functional managers

It refers to the experience of the persons with authority to do the management tasks within the administrative zone of the work, like procurement and human resources.

d. Reliability of Engineering System

Reliability describes the ability of a system to function under stated conditions for a specified period. It is described as the capability of a constituent of the system to task for a moment of a long time. Reliability may be defined as the thought of the system being able to achieve its aims with time or the capability of the system to do as required concerning time.

e. Quality of Human Resource

It contains the procedures to organize and manage the process. The process contains allocated duties or tasks to finish the process for allocated employees. The participation of the team members in the process preparation is helpful. The employees' contribution during preparation increases their knowledge and supports their commitment.

f. Safety

Safety typically concentrates on conserving life, and there is more than cost. Safety factor levels also result from sound engineering and attention to detail [120].

ii. The definition of the Variances

The improvement by Expert Choice software at this level required finding alternatives, so the variances can describe the variances as follows:

a) Ready Mix Concrete

It is the type of concrete made in a batching plant based on the engineering design of the mix formula. It is usually sold in two shapes: dry or wet. The wet type is loaded in the truck to supply it in a plastic shape to the customers. The dry-state concrete is delivered and then mixed at the site.

b) Pre-stressed concrete

It is a concrete place under compression before supporting loads beyond its dead weight. It is usually used in different types of high structures, and long spans reduce the thicknesses of the structural members and decrease material waste.

c) Precast member

It is produced by casting concrete in a reusable form, cured in a controlled environment, and transported to the worksite. Its building components and site amenities are used architecturally as fireplace mantels, cladding, trim products, accessories, and curtain walls.

d) Concrete Piles

It is made with steel bars and pre-stress tendons to get the required strength of tensile, providing and carrying satisfactory deflection resistance by giving the strength required.

4.5.3 Using AHP software and getting results

It develops decisions as professionals to choose the best product through the support, management, and effective use of available resources. The variances' imports are acquired mutually as a standard summation to know the criterion value to build the priorities for all variances. The following is a procedure to compare the alternatives based on the respect criterion and generate respect matrixes for variables to compare the relative performance concerning variables. The variances which have the highest priority is the best product.

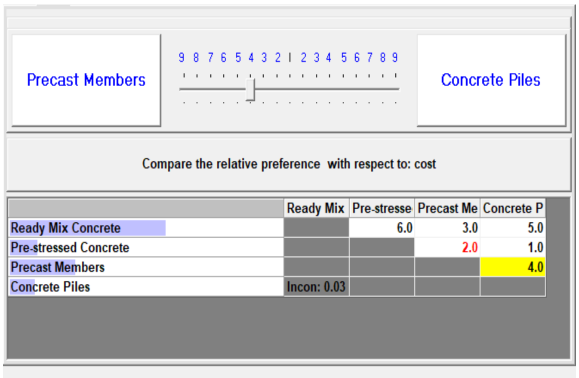


Figure 4.3 The comparison of alternatives with cost [Researcher].

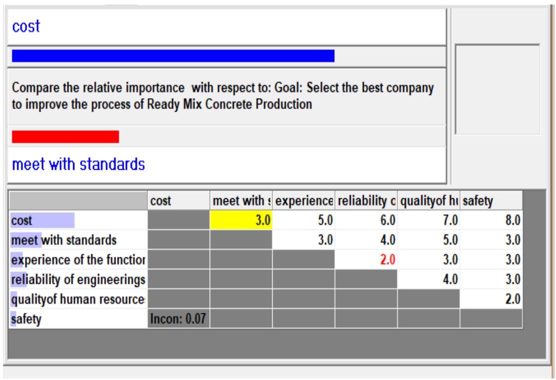


Figure 4.4 Pairwise comparison of criteria [Researcher].

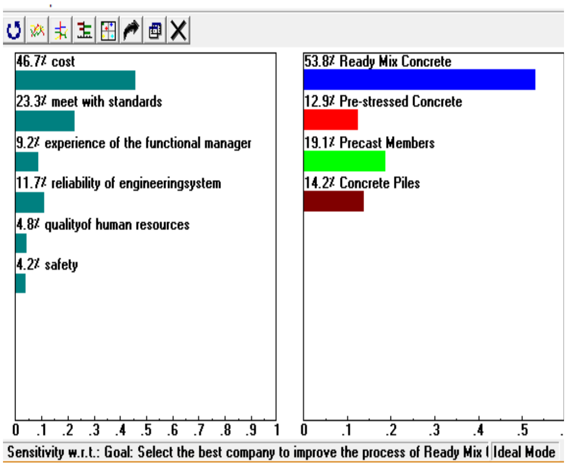


Figure 4.5 Dynamic sensitivity [Researcher].

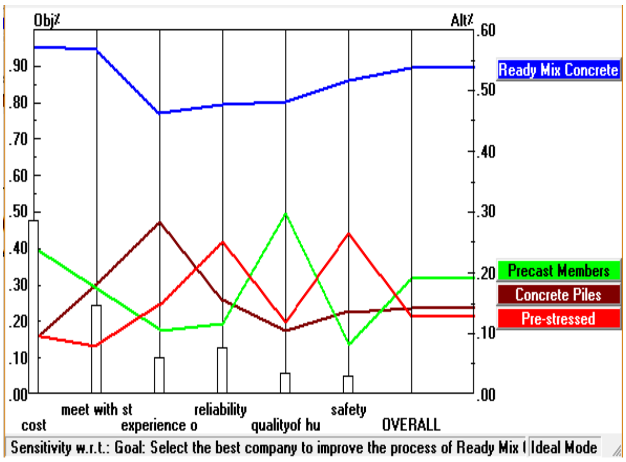


Figure 4.6 Performance sensitivity [Researcher].

The figures above illustrate that the highest quality output is attained by employing matrices and effectively managing stakeholder responsibilities and communication. This approach involves utilizing software by Saaty's pairwise comparisons method, as implemented through the AHP. The selection of the optimal choice is contingent upon several factors, including adherence to cost requirements, the functional manager's expertise, the reliability of the engineering system, the quality of human resources, and safety considerations. The matrices yield performance sensitivity, dynamic sensitivity, and dimensional sensitivity as indicators, collectively indicating that RMC is the most favorable option.

CHAPTER 5 REDUCE THE RAW MATERIALS QUALITY VARIATION AND BEST SUPPLIER

5.1 Introduction

The concrete placement in challenging environmental conditions, such as high ambient temperatures, low humidity, increased wind speed, and elevated RMC temperature, necessitates a comprehensive understanding of their impact on RMC properties during real-world construction scenarios. Effective strategies must be employed to minimize these adverse effects. These strategies include material selection, proportioning, ingredient state, batching methods, mixing times, pre-placement RMC temperature assessment, and rigorous testing and inspection protocols tailored for hot weather conditions. These responsibilities' overarching objective is optimizing their ability to achieve service objectives efficiently to involve continuous monitoring and improvement processes guided by information from results in both the first and second cases. These results are obtained by meticulously applying Monte Carlo simulation and Failure Modes and Effects Analysis (FMEA), drawing from data collected across various seasons. This chapter explores the strategic utilization of real-time monitoring management, Six Sigma, Monte Carlo simulation, and Failure Modes Effects Analysis to provide an integrated framework for addressing the challenges posed by adverse conditions during hot weather concrete placement. This approach offers a robust solution to enhance the efficiency and reliability of concreting operations in demanding weather conditions.

5.2 Real-time monitoring and Six Sigma procedure

In project management, the initial step is to define and assign responsibilities [121]. This process encompasses tracking time management against schedules, optimizing Ready Mix Concrete (RMC) activities for workload balance, enhancing response times, and identifying the root causes of response delays and service levels. Real-time monitoring offers immediate visibility and facilitates issue resolution, resulting in data-driven decisions [122]. This approach expedites decision-making and enables timely actions. It is also an efficient means to improve response, performance, and safety through process optimization and waste management [123]. Six Sigma, introduced by Bill Smith at Motorola in 1986 [124], has become a pivotal strategy for process improvement in large organizations aiming to enhance quality [125]. At its core, Six Sigma addresses the impact of process variation on errors and defective products, directly influencing customer satisfaction. By reducing this variation, Six Sigma enhances efficiency profitability, and reduces overall process costs [99]. It serves two primary purposes: enhancing the quality control of RMC ingredients and improving financial efficiency by minimizing waste, defects, and process variation in RMC production. The DMAIC methodology, encompassing five stages—Define, Measure, Analyze, Improve, and Control offers a structured approach for measuring process performance and achieving superior outcomes.This chapter provides an overview of the composite procedure, focusing on the influence of material properties and suppliers on RMC ingredient quality in the context of real-time monitoring for a multistore building project (Peral Maysan). It specifically examines the stationary concrete batching plant (SCBP) of the Sert company for RMC production, which is supplied by three different material suppliers. The study entails 93 laboratory tests for material properties and 18 tests for water properties used in RMC mixing, comparing them against ASTM and BS standards. This research investigates the primary impact of raw material suppliers on RMC production. It explores how suppliers influence material quantity, delivery time, and quality. Additionally, it identifies parameters affecting the production process and customer satisfaction while pinpointing any suppliers negatively impacting production and material quality. Furthermore, the study employs Monte Carlo simulation to assess the impact of suppliers on the RMC process. It considers factors such as the number of materials, delivery time, and the probability of delivering the required quantity on time for companies supplying materials to the SCBP. This simulation is conducted over 1000 trials. Additionally, Monte Carlo simulation is used to analyze production costs and revenues (over 500 trials) and the probability of revenues based on the required mixing ratio. These analyses help compare suppliers, revenues, delivery efficiency, total quantity, material quality, and monitor improvements through Failure Mode and Effects Analysis (FMEA) to enhance the continuous improvement cycle.

5.3 RMC Materials Suppliers

The production of RMC at the plant (SCBP) operated by the Sert Company involves sourcing raw materials such as sand, gravel, and cement from various suppliers. The company maintains an inventory of these materials and procures them based on RMC orders and the required quantities for production. The information regarding the suppliers and their contractual agreements for material supply to the SCBP is as follows:

a) Maysan Moon company will refer to it as supplier No. 1

b) Majra Al Khairat company will denote it as supplier No. 2

c) Al-Rafd company for general contracting will represent it as supplier no.3.

The raw materials will be used later after the inspection phase in the production of RMC according to the quantities, quality, and times required (order), which will be done later through the real-time monitoring process of the RMC production and recorded by the researcher personally present at the batching plant, in addition to the observation of the reliability of the suppliers through supplies specified raw materials at the times and quantities and required (ordered) by the SCBP company. It noticed that the suppliers did not comply with the times and quantities ordered, recorded as a conditional term in the legal contracts concluded between the two sides. The most crucial point of view is the difference in the quality of the materials supplied by the three suppliers; where this focus point will be discussed at the next step through the 93 tests for the properties of the raw materials and included in the production of RMC where the tests made at the construction laboratory of the Engineering union in 2021, therefore, this lead us to monitor the process in real time, identify the supplier with the most significant negative impact on the production, and make a recommendation to exclude from the process by analyzing the results of laboratory tests, comparing them with standard limitations, and use Monte Carlo simulation by SPSS software.

5.4 Materials properties

The choice of RMC mixes is virtually infinite; therefore, the selection cannot be made without a sound knowledge of the properties and behavior of RMC materials. The competence of the designer and the specifier determines the potential qualities of concrete by monitoring the properties of materials and the competence of the contractor and the supplier that controls the quality of the materials. The interaction of hydraulic cement and water produces this typical medium. The section is limited to combinations of cement, water, aggregate, and admixtures, where there are three potential connections between the components of this mixture:

a) Aggregate serves as a low-cost diluting agent, while the cementing medium, the by-product of cement hydration, is the primary construction ingredient.
b) The coarse aggregate may be considered little masonry pieces held together by mortar, hydrated cement, and a fine aggregate combination.
c) The third option is to acknowledge that, roughly speaking, concrete has two stages:
    1) The qualities of the two phases and the interfaces between them determine the properties of concrete, which consists of hydrated cement paste and aggregate.
    2) The arguments for the second perspective have considerable validity, where the cement paste is diluted due to aggregate.

5.4.1 Quality of water

The critical influence of the RMC water quantity in the mixture can be evident when considering the RMC compressive strength. This chapter primarily focuses on the RMC elements, namely the cement, aggregate, and water comprising the concrete mix. Impurities in the water may prevent the cement from setting, reduce the concrete's strength, and lead to reinforcement corrosion. For these reasons, the suitability of water for mixing should be considered with a water/cement ratio of 0.5 by mass. The influence of common solids would be minimal if the total dissolved solids (T.D.S.) were below 500 ppm [126]. However, the criterion of potability of water is not absolute; water fit for drinking may not be fit for mixing when the water has a high concentration of sodium or potassium, and there is the risk of an alkali-aggregate reaction, where the alkali-silicate gel formed attracts water by absorption and thus tends to increase in volume. The cement paste holds the gel in place, and internal stresses cause the paste to expand and crack. Concrete may experience a potentially highly disruptive reaction known as an alkali-silica reaction. The reaction between alkali hydroxides with a high PH and silica is known as ASR [127]. As a rule, any water with a PH of 6.0 to 8.0, which does not taste saline, is suitable for use but is a dark color. Natural waters that are slightly acidic are harmless, but water containing organic acids may adversely affect the hardening of concrete; such water and highly alkaline water should be tested.

Figure 5.1 The water properties test samples with tools and the chemical materials test them at the laboratory of the Maysan Environment Directorate[Researcher].

Figure 5.1 shows the instruments, tools, and chemical materials for testing water properties for three types of water used in RMC at the SCBP at the Maysan Environment Directorate laboratory, where the test is done for 18 samples of mixed water. Another attitude inherent in quality in a high-technology setting is the development of long-term partnerships with a few high-quality suppliers rather than merely picking those with the lowest initial cost [77].

Table 5.1 Standard Limits of RMC impurities in the mixing water (mg per liter) [128] [126].

No	*Impurity*	*BS 3248:1980*	*BS EN 1008:2002*	*ASTM C1602/C1602M-18*
1.	***T.D. S***	*< 500*	*< 500*	*< 500*
2.	***PH***	*≥ 6.0*	*≥ 6.0*	*6-8*
3.	***alkali***	*< 1000*	*< 1500*	*< 600*
4.	***Chloride***	*≤ 500*	*≤ 1000*	*≤ 500*

The results comparison has been made according to the standards described in BS EN 1008:2002, which is compatible with BS 3148:1980 and ASTM C 1602-06, C 1602M-18 for the results of the water properties tests, were made for 18 samples of water for three types of water for four main topics, which are total dissolved solids (T.D.S.), degree of acidity (PH), alkali, and chloride, according to dates and time of real-time monitoring, as follows:

Table 5.2 The quality of water test for samples taken in concreting dates for properties of total dissolved solids, PH, Alkali, and Chloride [Researcher].

No	*Water type*	*Time (hr)*	*Date (dd/mm/yy)*	*T.D.S (ppm)*	*PH*	*alkali (Mg./l)*	*Chloride (Mg./l)*
1.	*O. W*	*10:12 am*	*06/07/2020*	*974*	*7.77*	*168*	*268*
2.	*O. W*	*08:50 am*	*20/07/2020*	*866*	*7.76*	*170*	*254*
3.	*O. W*	*09:14 am*	*29/07/2020*	*974*	*7.53*	*140*	*277*
4.	*P. W*	*10:32 am*	*07/12/2020*	*994*	*7.88*	*176*	*275*
5.	*P. W*	*11:09 am*	*14/12/2020*	*1022*	*6.58*	*190*	*249*
6.	*R.O. W*	*09:45 am*	*08/04/2021*	*55*	*6.76*	*36*	*38*
7.	*R.O. W*	*10:3 am*	*12/04/2021*	*57*	*6.71*	*32*	*43*
8.	*R.O. W*	*10:15 am*	*26/04/2021*	*53*	*6.88*	*33*	*46*
9.	*R.O. W*	*09:10 am*	*01/07/2021*	*51*	*6.62*	*33*	*45*
10.	*R.O. W*	*09:30 am*	*14/07/2021*	*56*	*6.67*	*34*	*51*
11.	*R.O. W*	*09:30 am*	*27/07/2021*	*53*	*6.56*	*30*	*47*
12.	*R.O. W*	*08:32 am*	*08/12/2021*	*50*	*6.82*	*37*	*40*
13.	*R.O. W*	*08:30 am*	*09/12/2021*	*55*	*6.79*	*35*	*43*
14.	*R.O. W*	*11:10 am*	*04/04/2022*	*54*	*6.63*	*30*	*39*
15.	*R.O. W*	*09:05 am*	*05/04/2022*	*52*	*6.81*	*34*	*41*
16.	*R.O. W*	*09:00 am*	*24/04/2022*	*50*	*6.73*	*33*	*42*
17.	*R.O. W*	*10:12 am*	*01/07/2022*	*53*	*6.82*	*31*	*45*
18.	*R.O. W*	*0943 am*	*04/08/2022*	*51*	*6.45*	*37*	*40*

Moreover, it is found that the water used for the RMC production is of three types: the first type is ordinary water (O.W.), where the RMC company used a tank (sedimentation purposes) for water taken from the Tigris River and then used in the RMC mix, as shown in the results of the water properties test shown in figure 5.2. Sometimes, it may be challenging to obtain enough fresh water, and only brackish water is available, which contains chloride. At the same time, BS 3148: 1980 suggests a maximum of 500 mg/l, BS EN 1008: 2002, and ASTM C 1602-06 based on the concrete's intended use. The tests of water properties show that the results can be compared with the chloride and alkali limits based on the standards. The tests were done at the Ministry of Environment/Directorate of Protecting and Improving the Environment laboratory in the southern region of Missan and the construction laboratory of the Iraqi Engineers Union.

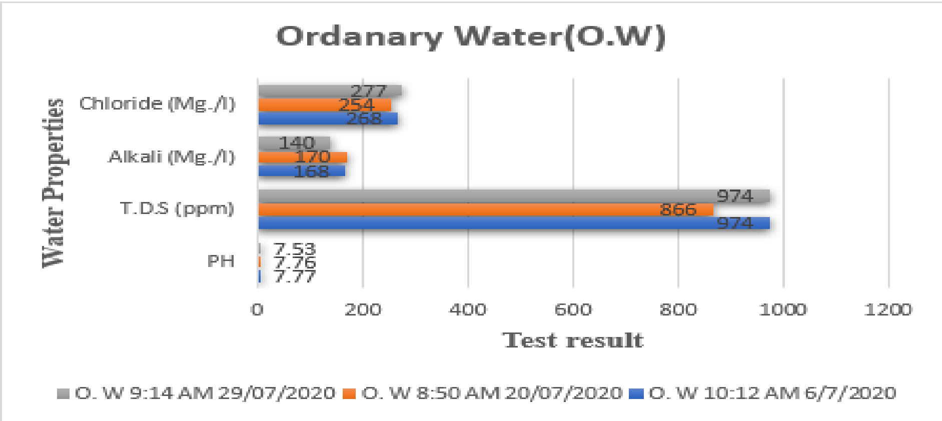


Figure 5.2 The expected water properties test results for the samples taken on 06/07, 20/07, and 29/07/2020 for PH, T.D.S, Alkali, and chloride [Researcher].

The results show that the values of the water properties meet BS 3248:1980, BS EN 1008:2002, and ASTM C1602/C1602M-18 for the chloride less than 500 mg/l and alkali less than 600 mg/l, but for the total dissolved solids (T.D.S.) exceed the limitations (less than 500 mg/l). The PH is between 6 and 8 for the samples taken from concreting dates in the limitations.

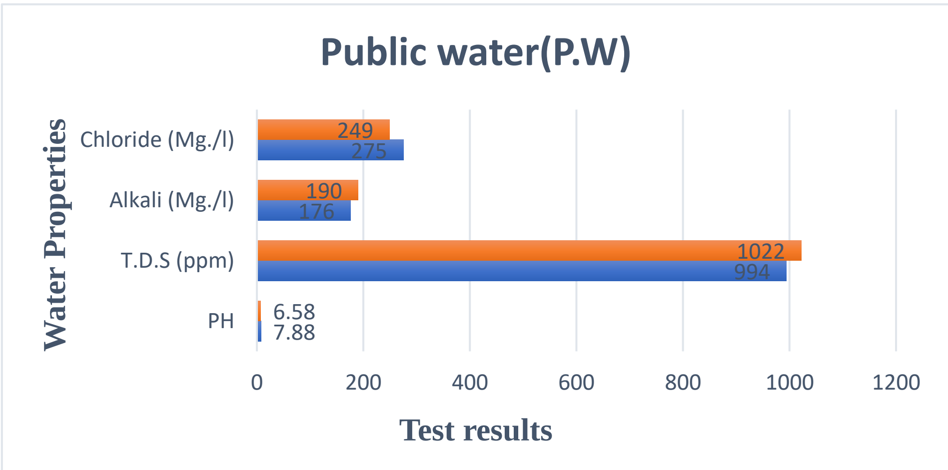


Figure 5.3 The public water properties test results for the samples taken on 07/12 and 14/12/2020 for PH, T.D.S, Alkali, and chloride [Researcher].

The second type of water used is public water (P.W.), provided by public network pipes for human use. As shown in Figure 5.3, the tests of water properties meet with BS 3248:1980, BS

EN 1008:2002, ASTM C1602/C1602M-18 for the chloride less than 500 mg/l, Alkali less than 600 mg/l, and the PH are between (6-8), in the limitations, total dissolved solids (T.D.S) 944 and 1022 Mg/l exceed the limitations (less than 500). The third type of water used in the RMC mix is reverse osmosis water (R.O.W), which is transported to the SBCP site by tanker water; through the observations in real-time monitoring, the R.O.W because the RMC company uses it only when their inspection process by the engineers of the project ordered the RMC. The reverse osmosis water results meet with standards of BS 3248:1980, BS EN 1008:2002, and ASTM C1602/C1602M-18 for the chloride less than 500 mg/l, the alkali less than 600 mg/l, and the degree of acidity (PH) between 6 and 8, but for the total dissolved solids (T.D.S.) less than 500 mg/l for the samples taken from dates, as shown in the figure below. The results show that the values of the water properties meet BS 3248:1980, BS EN 1008:2002, and ASTM C1602/C1602M-18 for the chloride less than 500 mg/l and alkali less than 600 mg/l, but for the total dissolved solids (T.D.S.) mg/l exceed the limitations (less than 500 mg/l). The PH is between 6 and 8 for the samples taken from concreting dates in the limitations.

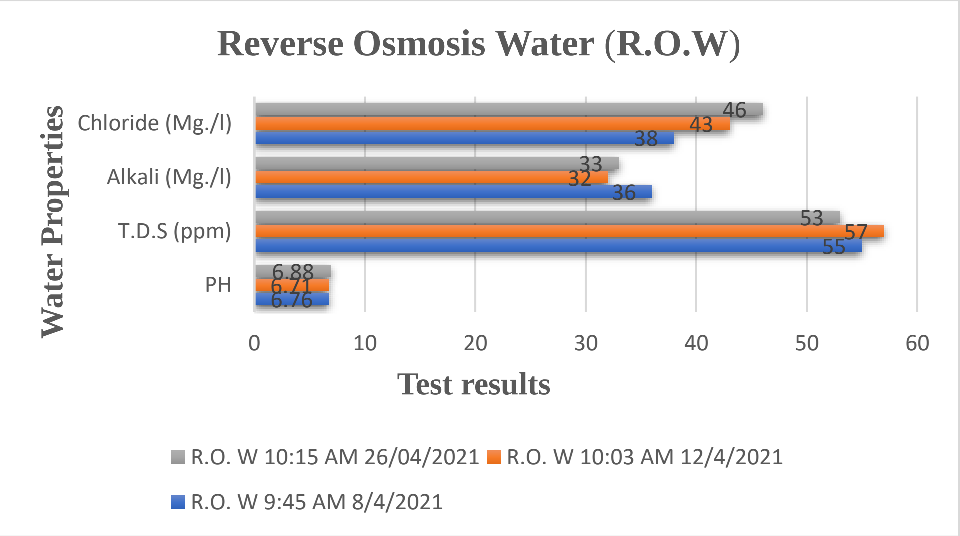


Figure 5.4 The properties of reverse osmosis water test results for the samples taken on 08/04, 12/04, and 26/04/2021 for PH, T.D.S, Alkali, and chloride [Researcher].

Moreover, the tests were conducted to ensure RMC quality using various water types, comparing them against industry standards (ASTM C1602/C160M-06, BS EN 3148:1980, and BS EN 1008:2002). Reverse osmosis water (R.O.W) proved the most efficient, leading to its exclusive use in subsequent 18 tests. These tests evaluated water properties during production at Sert company's SCBP. The results below demonstrate that water acidity remains within limits, with an average PH of 6.69, ensuring quality control in RMC production.

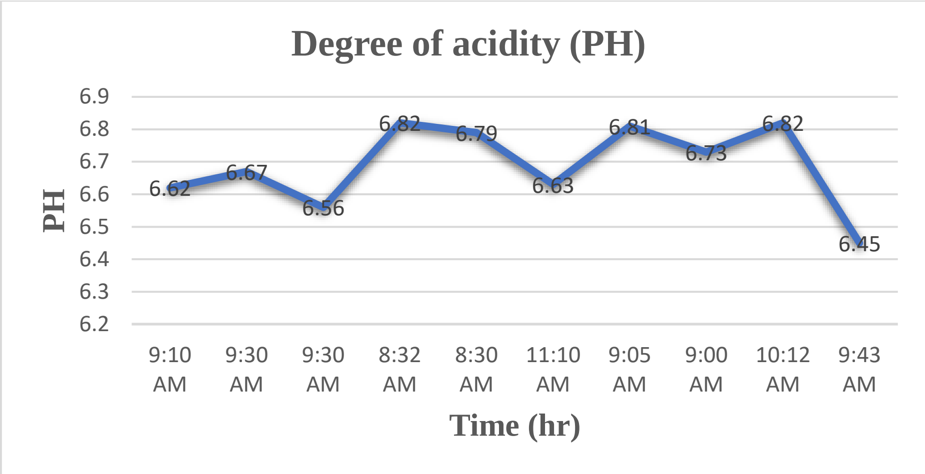


Figure 5.5 The PH for ten reverse osmosis water (R.O.W) water tests in 2021-2022 [Researcher].

The average T.D.S was 52.5 Mg/l; the lowest value was 50 ppm, and the highest value was 56 Mg/l were, less than 500, while the Alkali average was 33.4 mg/l, the maximum value 37, and the minimum value 30 mg/l (all the results were met with the limitations less than 600 mg/l ASTM and less than 1000 BS 3148:1980 and less than 1500 according to BS EN 1008:2002.

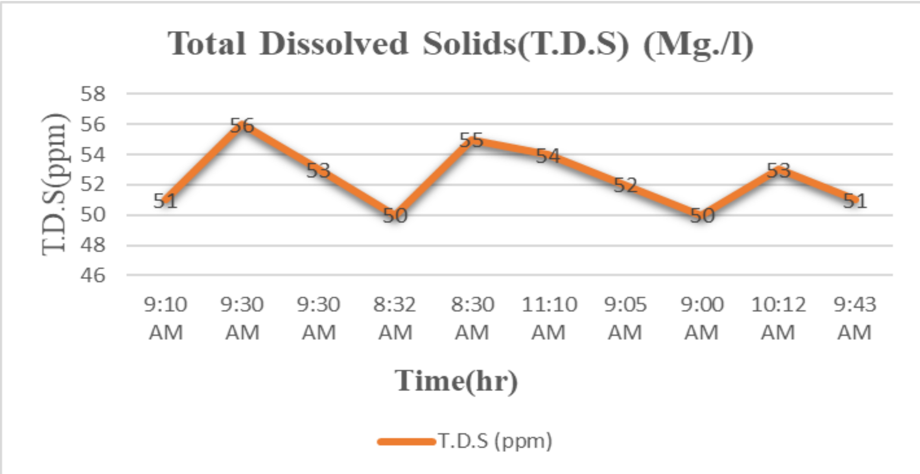


Figure 5.6 The T.D.S for ten reverse osmosis water water tests in 2021-2022 [Researcher].

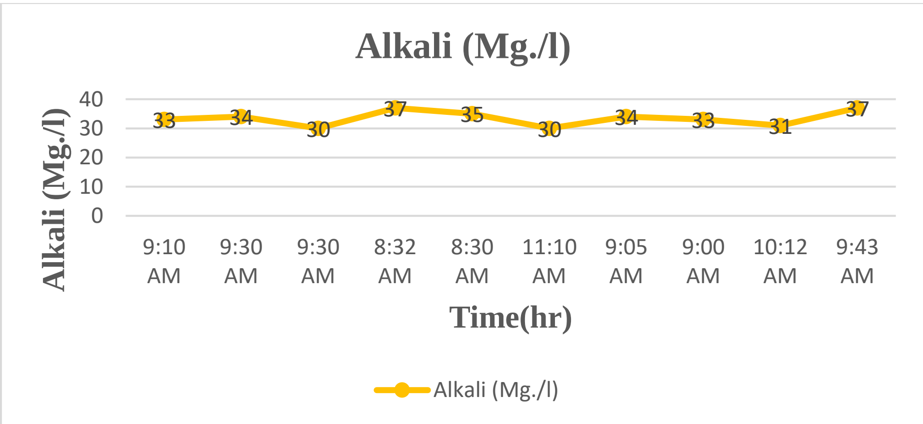


Figure 5.7 Alkali (Mg/l) for ten reverse osmosis water (R.O.W) water tests[Researcher].

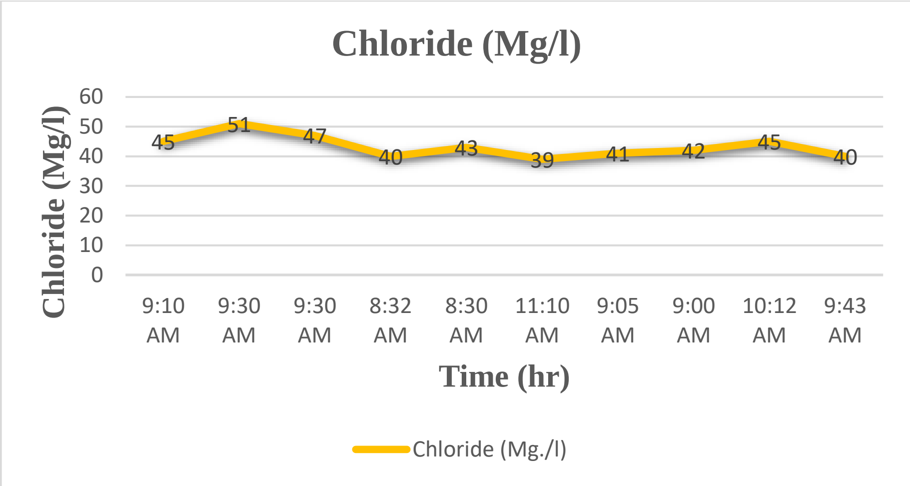


Figure 5.8 Alkali (Mg/l) for ten reverse osmosis water (R.O.W) water tests[Researcher].

Moreover, the chlorides average was 43.3 Mg/l, The maximum value was 47 mg/l, and the minimum was 39 mg/l, where the values meet the limitations of BS EN 3148:1980 and BS EN 1008:2002 and ASTM C1602/C160M-06, which is less than 500 mg/l as the results of test for 18 samples of water properties for three types of water used for RMC by the SCBP for the PH, the T.D.S, Alkali, and Chloride show that the best type is Reverse Osmosis Water.

5.4.2 Define cement properties

The calcareous and argillaceous or other silica-, alumina-, and iron oxide-bearing materials are thoroughly combined, burned at a clinkering temperature, and ground into a powder, where the portland cement is composed of a mix of calcareous elements like limestone, silica, and alumina from clay or shale. Clinker is produced by grinding raw materials into a fine powder, combining them in precise amounts, and then burning the mixture in a giant rotating kiln at about 1400 °C until the material sinters and partly fuses. The final product is Portland cement after the clinker has cooled and been crushed into a fine powder and some gypsum added. There is no way to use cement only in RMC instead of aggregate; cement paste is about ten times bigger than the shrinkage of concrete containing 250 kg per cubic meter. The buyer must conduct such inspections of the Material as the Seller may reasonably require [129].

5.4.3 Measure of cement properties

The method of measuring the opportunities represented in the testing of the cement properties physical and chemical test (33 samples of the test), for the Fineness, initial time setting, final time setting, compressive strength at three days, and compressive strength at seven days, SiO2, AI2O3, Fe2O3, Cao, So3, burning loss, C3O, and lime saturation factor, for the three companies supplies the materials to the SCBP, and the defects are the lake of quality of the raw materials for each supplier according to the cement properties that have mentioned, where, F means Fineness, I.S.T means initial setting time, F.S.T is final setting time, *fc* at 3 and *fc* at 7 refers to compressive strength at three days, and at seven days, respectively, B.L. refers to burning loss. L.S.F means the limestone saturation factor.

Table 5.3 Physical and chemical cement tests for 33 samples of three suppliers provide materials to the SCBP [Researcher].

No	F (%)	IST (Min)	FST (hr)	f_c at 3 (MPa)	f_c at 7 (MPa)	Sio_2	Al2O3	Fe2O3	CaO	SO_3	B.L	C_3a	LSF
Supplier No.1													
1.	0.02	112	4.32	12	19.6	----	-------	--------	------	----	--	---	------
2.	0.02	93	4.35	14.2	19.3	7.2	3.2	3.5	1.8	0.7	3.5	3	0.77
3.	0.02	180	5.42	13.2	20.8	7.1	3.5	4.2	2.3	2.3	3.4	3.2	0.201
4.	0.03	172	5.34	16.2	23.3	18.9	6.4	4.6	4.2	2.2	2.5	4.4	0.616
5.	0.02	167	5.2	15.7	22.1	10.1	5.8	4.1	3.9	2.1	2.3	4.3	0.366
6.	0.03	171	5.4	14.3	23.2	15.2	4.3	4	4.1	2.4	2.3	4.1	0.434
7.	0.02	133	5.2	11.2	19.2	14.8	2.48	2.1	4.5	2.1	1.1	3.2	0.854
8.	0.02	123	4.51	14.1	20.2	8.2	3.4	3.1	2.6	2.2	3.4	3.7	0.634
9.	0.03	135	4.11	13.8	19.9	8	3.2	2.9	2.2	1.7	2.5	3.6	0.565
10.	0.03	99	4.84	14.9	19.8	9.2	3.7	3.4	2.9	2.1	3.4	3.9	0.653
11.	0.03	136	5.1	16	23.2	11	4.6	5	4.17	2.3	2.7	4.5	0.091
Supplier No. 2													
12.	0.02	100	5.11	10.5	16.7	9.4	3.4	4.3	3.6	2.3	3.4	3.5	0.432
13.	0.02	120	4.23	13.5	17.5	8.8	3.6	4.1	2.6	1.8	3.1	3.4	0.654
14.	0.02	124	4.66	11.1	22.4	7.9	4.9	4.6	2.7	2.8	3.3	3.4	0.355
15.	0.02	139	5.17	10.9	20.6	17.6	5.9	3.4	3.6	2.5	3.6	3.3	0.456
16.	0.02	162	4.56	14.1	24.7	12.4	4.7	3.9	4.5	2.8	2.7	3.9	0.544
17.	0.02	145	5.33	13.5	25.6	13.8	4.9	4.7	3.1	2.1	3.4	4.5	0.688
18.	0.03	167	4.89	12.6	20.4	15.9	3.4	3.9	4.2	2.3	2.1	4.2	0.794
19.	0.03	113	4.99	13.8	24.1	10.4	3.9	2.7	3.5	1.8	2.7	3.8	0.544
20.	0.02	143	5.19	14.6	17.4	9.9	3.8	3.7	2.3	2.9	3.6	3.9	0.574
21.	0.02	115	5.73	13.7	20.4	11.3	4.7	3.5	2.8	2.6	2.8	4.4	0.864
22.	0.03	94	4.91	12.5	20.1	12.5	5.8	4.8	3.8	2.2	3.7	4.2	0.985
Supplier No. 3													
23.	0.03	98	6.34	10.5	19.2	14.2	4.2	4.6	2.7	2	2.1	3.9	0.546
24.	0.03	97	5.23	9.9	20.3	10.1	5.1	4.7	2.9	2.7	2.9	3.7	0.575
25.	0.02	101	5.11	12.3	22.3	9.8	4.7	4.9	4.9	2.5	2.7	5	0.434
26.	0.03	104	5.16	10.2	21.9	15.6	5.7	4.3	4.8	2.6	2.8	4.6	0.646
27.	0.02	130	5.24	12.7	24.1	12.6	5.2	3.9	4.3	2.8	3.5	4.9	0.651
28.	0.03	153	5.09	13.1	20.4	11.9	6.3	4.3	4.7	2.9	1.8	4.1	0.650
29.	0.02	130	5.15	15.5	18.9	14.8	4.8	3.1	3.9	2.3	2.9	4.2	0.351
30.	0.02	127	4.27	14.1	23.4	13.5	5.7	4.2	3.1	2.4	3.1	4.5	0.766
31.	0.03	125	5.51	13.7	25.6	9.5	4.4	4.8	2.7	2.5	3.5	4.6	0.469
32.	0.02	116	4.28	14.8	20.8	15.9	4.3	3.9	4.5	2.9	2.6	3.8	0.362
33.	0.03	104	5.77	12.6	23.5	13.8	4.9	4.3	3.8	2.8	3.1	4.6	0.264

Table 5.3 shows the results of the physical and chemical cement test for 33 test samples of materials, where the tests are done based on BS 12 or ASTM C-187-04 and ASTM C 349 in the laboratory of the Technical Institute of Omara at Maysan/the Southern Technical University.

5.4.4 Analysis of results and comparison

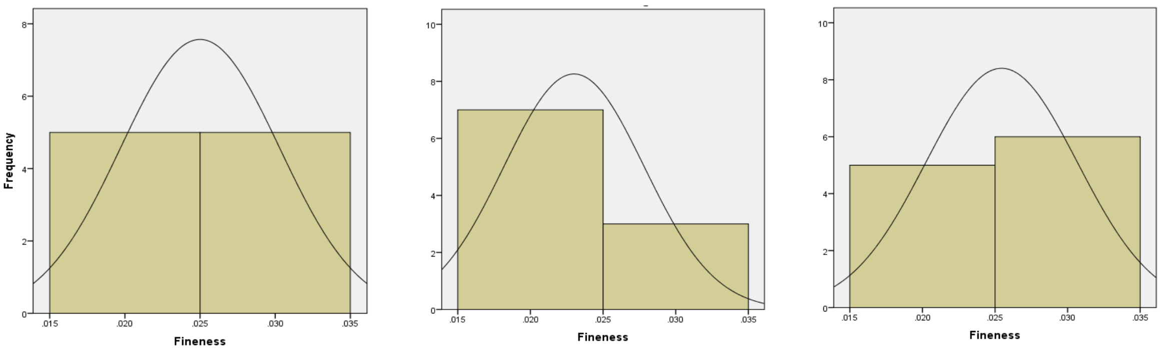
Finding the supplier effect on the process of RMC production and the type of effects it has on the process, the comparison has been made between the results of materials tests cement for the three suppliers for each specific topic of cement test based on the results of the cement test for 33 cement tests (32 cement chemical test and one cement physical test), where the standard deviation was determined (by SPSS software) to be the most consistent measure of variability:

$$\text{Standard Deviation } (\sigma) = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \qquad (11)$$

Where: x_i= the value of ith point in the data set, $(\bar{x})$= the mean of the set data values, n= a number of the data in a data set taken. Furthermore, standard deviation or (σ) provides an understanding of the variance of a procedure for the three suppliers' values as follows.

a) Fineness (%)

ASTM C 115 – 96a outlines a method for assessing cement fineness, measured as the total surface area per gram (in square centimeters) or per kilogram (in square meters) of cement [130]. The prescribed standard for fineness percentage necessitates a value equal to or below 5% for all three suppliers, where the test results indicated values less than 0.05 for each supplier. The mean fineness values for the three suppliers are as follows: Supplier No. 1 had a mean value of 0.025 with a 95% confidence interval ranging from 0.022 to 0.028 (representing a trimmed mean of 5%) and a standard deviation of 0.00527. Supplier No. 2 exhibited a mean value of 0.023 with a 95% confidence interval between 0.020 and 0.026 and a standard deviation of 0.00483. Lastly, for Supplier No. 3, the mean value was 0.0255, accompanied by a 95% confidence interval spanning from 0.022 to 0.029 and a standard deviation of 0.00522.



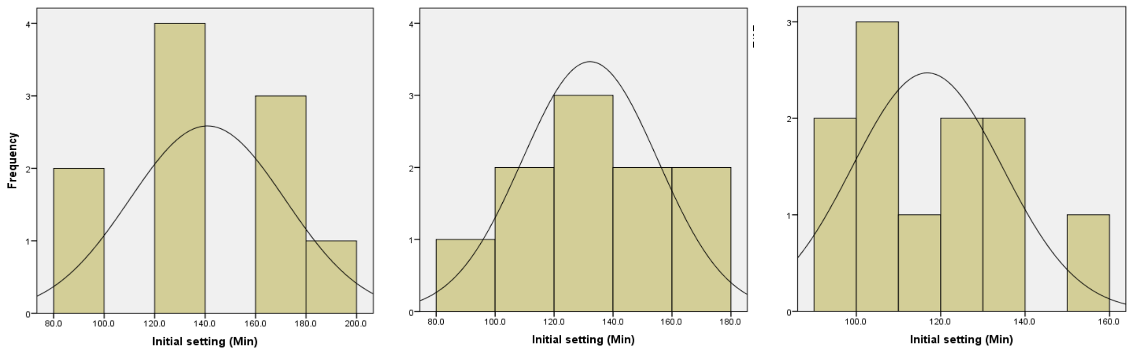
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.9 Cement fineness test results for the three suppliers with 11 test samples [Researcher].

Figure 5.9 displays a histogram illustrating the distribution of test results among suppliers. Regarding standard deviation, Supplier No. 1 exhibited 0.00527, Supplier No. 2 demonstrated 0.00483, and Supplier No. 3 showed 0.00522. This comparison highlights that Supplier No. 1 positively influences the RMC production, whereas Supplier No. 2 has the most adverse impact.

b) Initial setting time

The standard requirement for the initial setting time stipulates a minimum duration of 45 minutes, which all three suppliers in our study have successfully met.



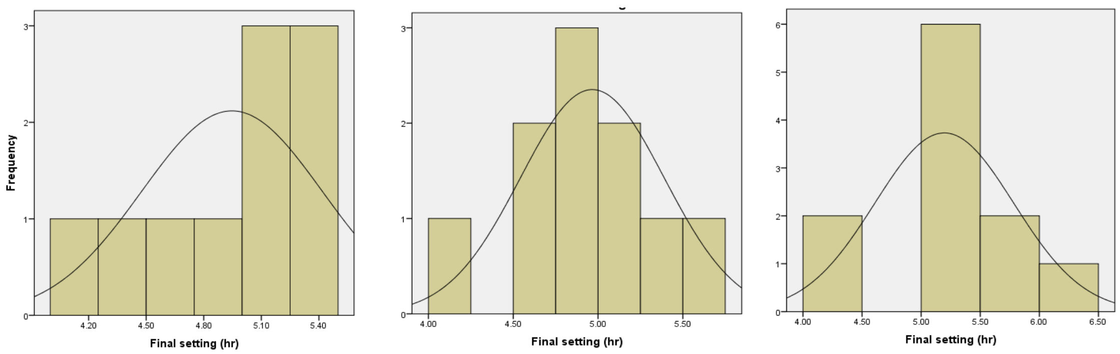
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.10 Cement initial setting time results for the suppliers with 11 tests for each [Researcher].

Figure 5.10 depicts a histogram illustrating the distribution of test results among suppliers. Regarding standard deviation, Supplier No. 1 exhibited 30.8669, Supplier No. 2 showed 23.0111, and Supplier No. 3 displayed 17.7585. This comparison reveals that Supplier No. 2 has the most favorable impact on production (Supplier No. 1 has the most negative impact).

c) Final setting time

The standard for the final setting time is less than or equal to 10 hr for the suppliers, where the results of the tests were met with limitations (all results for suppliers are less than 10 hr).



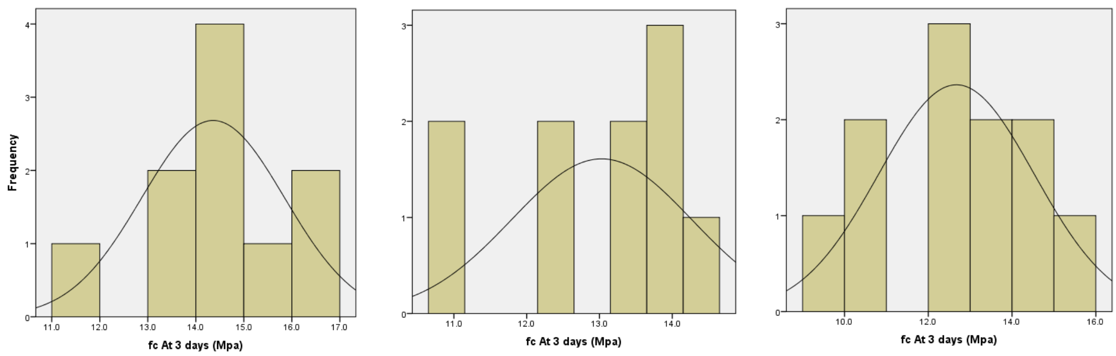
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.11 Cement final setting time tests for the three suppliers with 11 tests for each [Researcher].

Figure 5.11 illustrates a histogram displaying the distribution of test results among suppliers. The standard deviations were 0.47072 for Supplier No. 1, 0.42395 for Supplier No. 2, and 0.58809 for Supplier No. 3; this comparison indicates that Supplier No. 2 has the most favorable impact on the production process, while Supplier No. 3 has the least favorable impact.

d) Compressive strength (*fc*) at three days (MPa)

The standard mandates that the three suppliers achieve a minimum compressive strength of 8 MPa in three days, which all suppliers have successfully met.



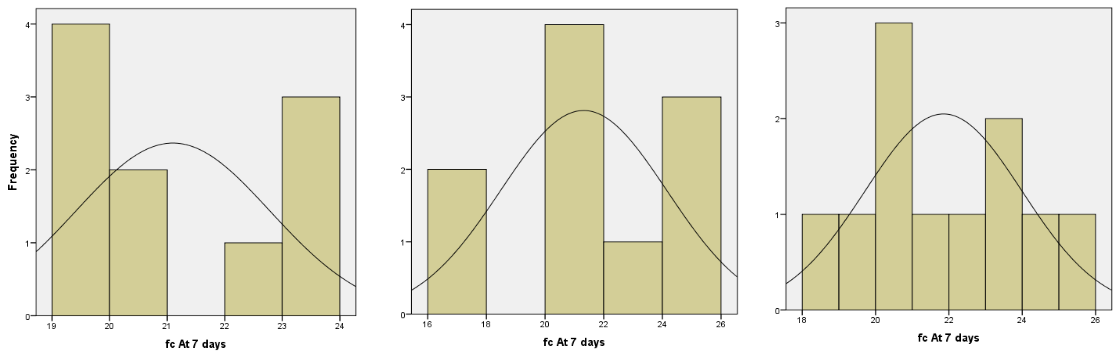
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.12 Cement compressive strength at three days for the suppliers with 11 tests [Researcher].

Figure 5.12 presents a histogram depicting the distribution among suppliers. The standard deviations were 1.4871 for Supplier No. 1, 1.2392 for Supplier No. 2, and 1.8564 for Supplier No. 3. Regarding the compressive strength at three days, Supplier No. 3 has the most positive impact, while Supplier No. 2 has the least favorable impact.

e) Compressive strength (*fc*) at seven days (MPa)

The standard stipulates that the compressive strength at seven days must be equal to or greater than 15 MPa. All test results from the suppliers have adhered to these specified limits.



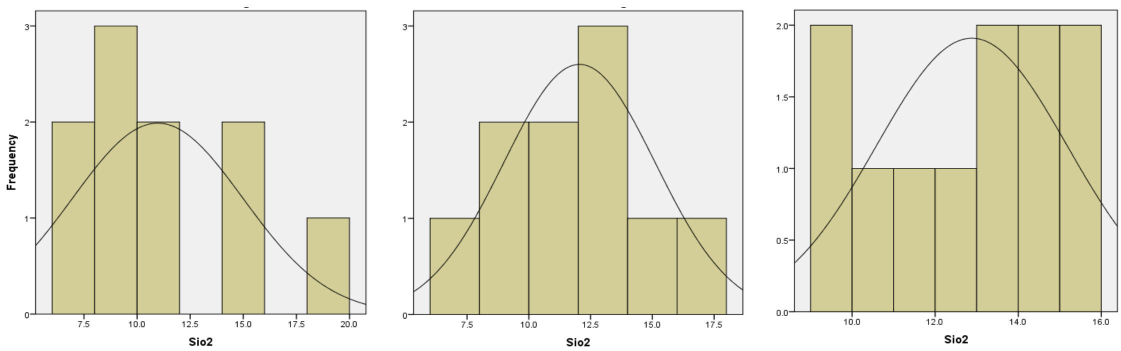
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.13 Cement compressive strength at 7 days for the three suppliers [Researcher].

Figure 5.13 presents a histogram displaying the distribution of test results among suppliers. The standard deviations were 1.685 for Supplier No. 1, 2.836 for Supplier No. 2, and 2.142 for Supplier No. 3. In the context of compressive strength at seven days, Supplier No. 2 has the most favorable impact, while Supplier No. 1 has the least favorable impact.

f) SiO_2

The SiO_2 standard requires a maximum value of 24 for all suppliers, and all test results from the suppliers have consistently exceeded this threshold, registering values greater than 15 MPa.



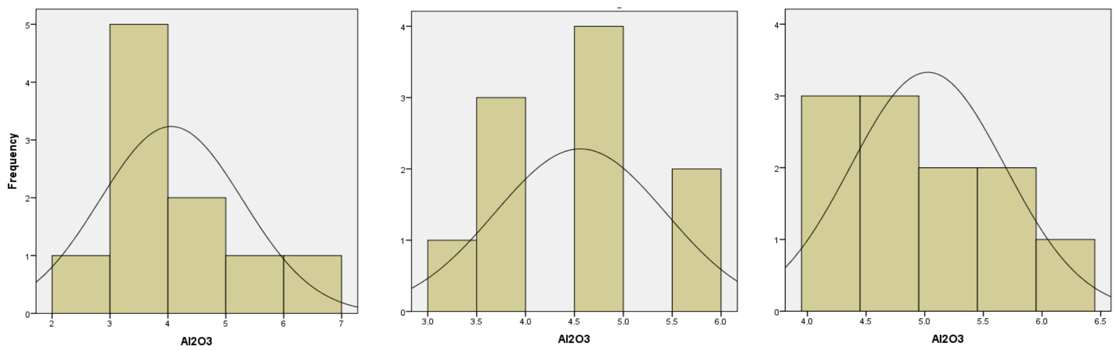
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.14 Cement Sio_2 results for the suppliers with 11 test samples for each [Researcher].

Figure 5.14 depicts a histogram representing the distribution of test results among suppliers. The standard deviations were 4.014 for Supplier No. 1, 3.0678 for Supplier No. 2, and 2.299 for Supplier No. 3. Regarding SiO_2 comparison, Supplier No. 2 has the most favorable impact. In contrast, Supplier No. 1 has the least favorable impact.

g) Al_2O_3

The Al_2O_3 standard requires values within the range of 3 to 8 for all three suppliers, and all test results from these suppliers have consistently adhered to this specified range.



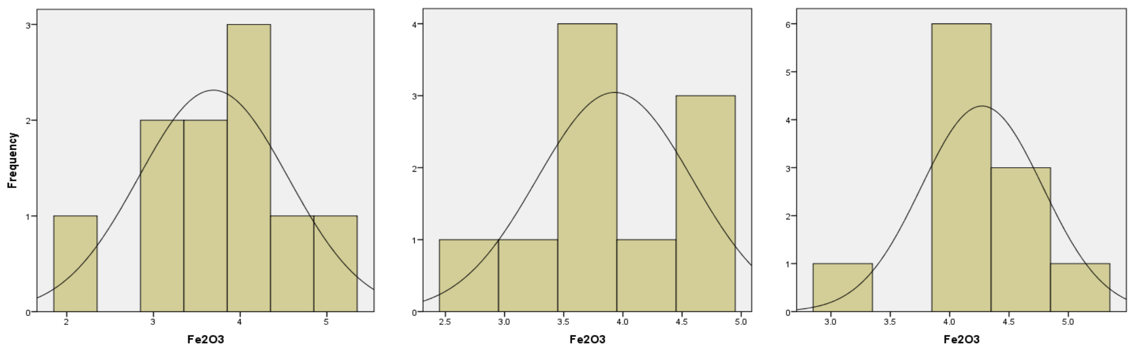
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.15 Al_2O_3 test results for the suppliers with 11 test samples for each supplier [Researcher].

Figure 5.15 displays a histogram illustrating the distribution of cement test results among three suppliers. The standard deviations were 1.234 for Supplier No. 1, 0.8746 for Supplier No. 2, and 0.6589 for Supplier No. 3. Regarding the Al2O3 comparison, Supplier No. 3 had the most favorable impact. In contrast, Supplier No. 2 had the least favorable impact.

h) Fe_2O_3

The standard for the Fe_2O_3 value is from 3 to 8 for the three suppliers, where the results of the tests were met with limitations, as shown in the figure below:



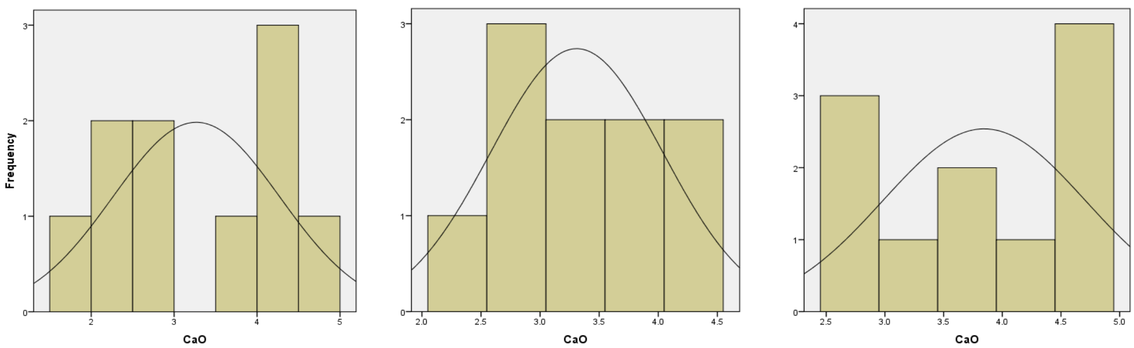
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.16 The Fe_2O_3 test results for the suppliers with 11 test samples for each [Researcher].

Figure 5.16 presents a histogram depicting the distribution of results among suppliers, with standard deviations of 0.862 for Supplier No. 1, 0.655 for Supplier No. 2, and 0.512 for Supplier No. 3. In terms of Fe2O3 comparison, Supplier No. 1 exhibited the most favorable impact.

i) Cao

The results for CaO were observed to conform to specified limits, as depicted in Figure 5.17:



Supplier No.1 Supplier No.2 Supplier No.3

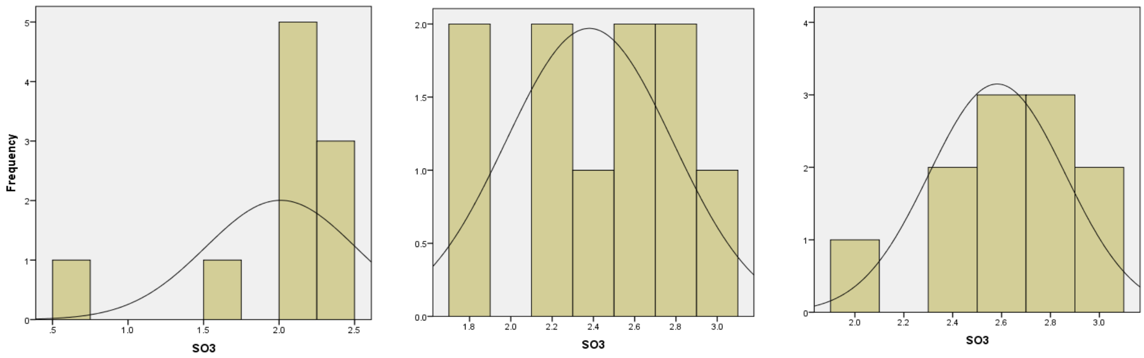
Figure 5.17 Cement Cao test results for suppliers with 11 test samples for each [Researcher].

Figure 5.17 displays a histogram depicting the distribution of test results among suppliers, with standard deviations of 1.006 for Supplier No. 1, 0.7279 for Supplier No. 2, and 0.8641 for

Supplier No. 3. In terms of CaO comparison, Supplier No. 2 exhibited the most favorable impact. At the same time, Supplier No. 3 had the least favorable impact.

j) So_3

The standard for the So3 value is less than or equal to 2.5% for the three suppliers, where the results of the tests were met with limitations, as shown in the figure below:



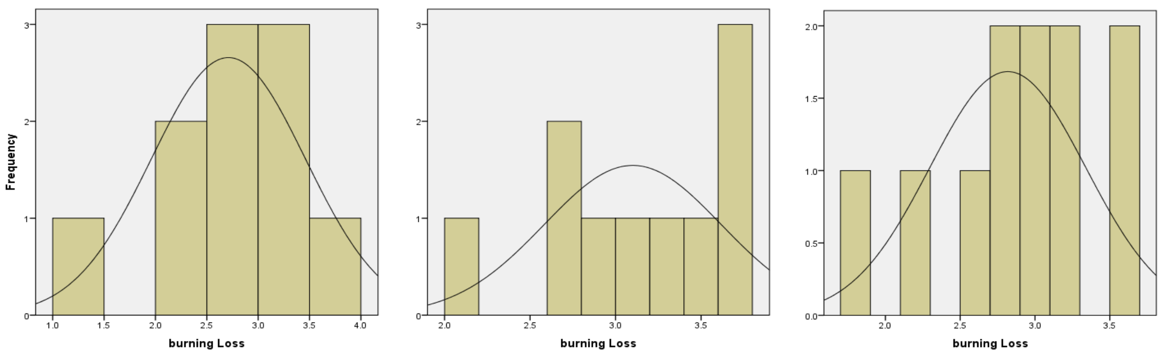
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.18 Cement So_3 test results for suppliers with 11 test samples for each [Researcher].

Figure 5.18 illustrates a histogram depicting the distribution of results among suppliers, with standard deviations of 0.498 for Supplier No. 1, 0.405 for Supplier No. 2, and 0.2786 for Supplier No. 3. In terms of SO3 comparison, Supplier No. 2 demonstrated the most favorable impact. At the same time, Supplier No. 1 had the least favorable impact.

k) Burning loss

The burning loss must adhere to limitations of less than or equal to 4% for all three suppliers, and the test results have consistently met these specifications, as indicated in the figure below:



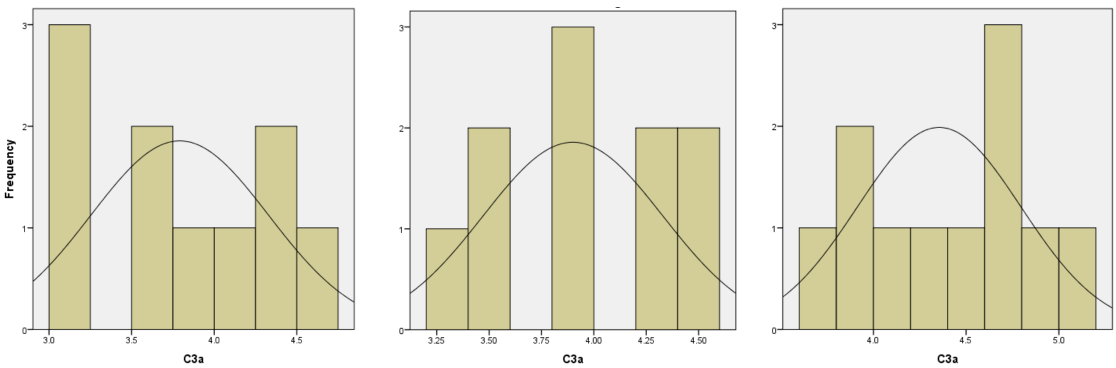
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.19 Cement burning loss test results for suppliers with 11 tests for each [Researcher].

Figure 5.19 presents a histogram depicting the distribution of test results among suppliers, with standard deviations of 0.75 for Supplier No. 1, 0.5164 for Supplier No. 2, and 0.5212 for Supplier No. 3. In terms of SO_3 comparison, Supplier No. 1 demonstrated the most favorable impact. At the same time, Supplier No. 2 had the least favorable impact.

l) C_3a

The test results for C3a were within specified limits, as indicated in the figure below:



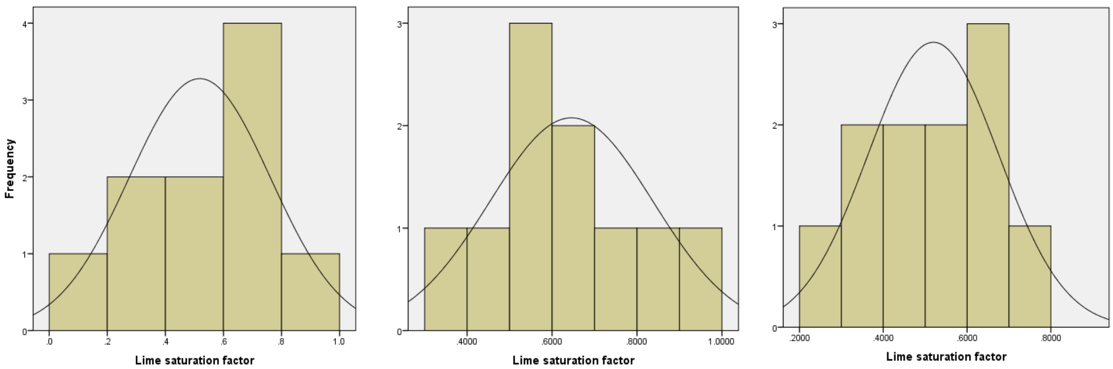
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.20 Cement C_3a test results for suppliers with 11 test samples for each [Researcher].

Figure 5.20 depicts a histogram displaying the distribution of test results among suppliers, with standard deviations of 0.537 for Supplier No. 1, 0.4295 for Supplier No. 2, and 0.4413 for Supplier No. 3. In terms of C3a comparison, Supplier No. 3 exhibited the most favorable impact. At the same time, Supplier No. 2 had the least favorable impact.

m) Lime saturation factor

The specified range for the lime saturation factor is from 0.66 to 1.02 for all three suppliers. The test results consistently adhere to these limits, as demonstrated in the accompanying figure:



Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.21 Cement lime saturation factor for the suppliers with 11 tests for each [Researcher].

Figure 5.21 presents a histogram portraying the distribution of test results among suppliers, with standard deviations of 0.243 for Supplier No. 1, 0.1921 for Supplier No. 2, and 0.1557 for Supplier No. 3. In terms of the lime saturation factor comparison, Supplier No. 3 (with a standard deviation closer to the mean) exerts the most positive influence on the RMC production process. At the same time, Supplier No. 2 has the most adverse impact.

5.4.5 Improve the process of cement supplying

The optimization of the current production process is closely linked to the quality of raw materials, specifically cement, as determined by the analysis of 33 tests encompassing various parameters, including fineness, initial time setting, final time setting, compressive strength at three days, compressive strength at seven days, SiO_2, Al_2O_3, Fe_2O_3, CaO, SO_3, burning loss, C_3O, and lime saturation factor. These tests were conducted on materials supplied by three companies to the SCBP. Considering the results of comparisons among these three suppliers, Supplier No. 2 has demonstrated the most favorable impact on the RMC production process regarding material quality (cement). Supplier No. 3 is the second-best option, while Supplier No. 1 is recommended for exclusion due to material quality concerns.

5.4.6 Control and look up the Sigma process

The final step in the Six Sigma process involves controlling improvements within the case study. This control is exercised over cement quality through Statistical Process Control (SPC), a method to measure uniformity and ensure predictability in production processes. It achieves this by maintaining values within the range defined by the Upper Control Limit (UCL) and the Lower Control Limit (LCL), representing desired quality parameters. For instance, in the control chart generated for the fineness percentage, the values consistently fall within the specified range, with the UCL at 0.407 and the LCL at 0.0053.

Figure 5.22 displays various quality parameters. The initial setting time falls within the range defined by the Upper Control Limit (UCL) of 285.635 and the Lower Control Limit (LCL) of 5.765. Similarly, the final setting time remains within the UCL (7.58) and LCL (2.35), while the compressive strength at three days adheres to the UCL (19.8) and LCL (6.3). The compressive strength at seven days also falls within the UCL (39.4) and LCL (3.2). Additionally, SiO_2 values are maintained within the UCL (28.5) and LCL (-4.434). These control limits ensure the quality and consistency of the production process, while the C_3a values are in between 5.554 and 2.246, where they are the UCL and the LCL, respectively, and the Lime Saturation Factor values are in between the UCL which was 1.49 and the LCL – 1.97.

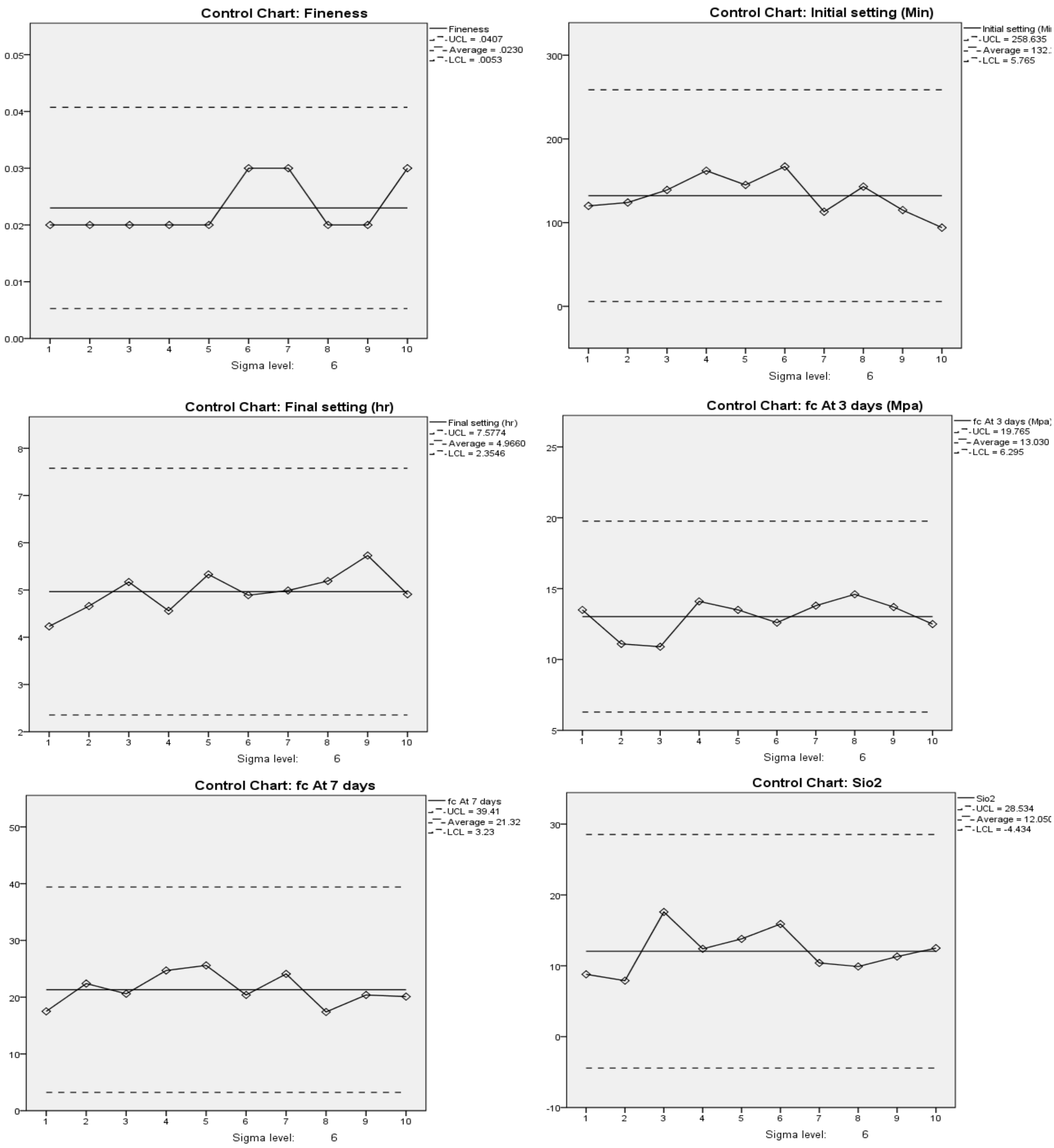


Figure 5.22 Six Sigma control chart for the Fineness, initial setting time, final setting time, compressive strength at three days, seven days, and Sio_2 for 33 cement tests [Researcher].

Figure 5.22 illustrates the quality parameters. The Al2O3 values fall within the range defined by the Upper Control Limit (UCL) of 9.168 and the Lower Control Limit (LCL) of -0.048. Similarly, the Fe2O3 values remain within the UCL (8.361) and LCL (-0.501), while the CaO values fall within the UCL (7.918) and LCL (-1.298). The SO_3 values are also maintained within the UCL (5.216) and LCL (-0.456). These control limits ensure the consistency and quality of the production process. Moreover, the burning loss values are between the UCL, 6.999, and the LCL –0.779.

5.4.7 Define the aggregate properties.

Aggregates constitute a significant portion (three-quarters) of the concrete volume, making it crucial to assess their quality. Aggregate properties substantially impact the compressive strength, durability, and overall performance of Ready-Mix Concrete (RMC) structures. Although aggregate is typically regarded as a cost-effective material that augments the volume of concrete, it is economically advantageous to utilize a mixture with a higher aggregate-to-cement ratio. The grading of aggregate offers an opportunity to enhance quality by aligning it with specified standards. It involves comparing the sieve analysis results of aggregates from three different suppliers. Moreover, defects in aggregates, such as variations in shape, surface texture, and size, can significantly influence concrete strength, with flexural strength being more sensitive than compressive strength. A rougher texture promotes better adhesion and a stronger bond between cement and aggregate particles. In contrast, larger surface areas and greater angularity of aggregate particles contribute to a more robust bond.

5.4.8 Measure the aggregate properties.

Sieve analysis tests serve as a pivotal indicator of aggregate quality. This analytical process involves the subdivision of aggregate samples into distinct fractions based on particle size, thereby revealing the size distribution of the aggregate. Aggregate gradation significantly influences various concrete properties, including the workability of freshly placed concrete and the ultimate compressive strength, durability, and resistance to abrasion in hardened concrete [131]. The aggregate grading samples are subjected to vibrational separation through a set of sieves, with the sieve featuring larger openings positioned at the top. The material retained by each sieve characterizes the corresponding percentage of the aggregate composition. ASTM Standard C 33 – 03 delineates fine and coarse aggregate grading and quality assessment criteria [132]. The sieve sizes typically employed for grading adhere to standards such as BS 812-103.1: 1985, BS EN 933.2: 1996, and ASTM C 136-06. Notably, the 4 to 5 mm (3/16 in., No. 4 ASTM) sieve size demarcates the boundary between fine and coarse aggregate. The impact of aggregate shape becomes more effective in the modulus of rupture test compared to uniaxial compressive or tensile tests. This discrepancy may be attributed to stress gradients that impede crack propagation, thereby influencing the eventual failure mode [17]. Consequently, concrete incorporating angular-shaped aggregates exhibits higher flexural strength, especially in mixtures with low water-to-cement ratios. However, rounded-shaped aggregates demand less water than their angular counterparts in practical mixes with equivalent workability.

5.4.9 Fine aggregate tests

The measurement method employed to assess opportunities is evident in the sieve analysis test, which encompassed 30 tests for the properties of fine aggregates. These tests covered a range of sieve sizes, including sieve no.10, no.4.75, no.2.36, no.1.18, no.0.6, sieve no.0.3, no.0.15, and SO_3, relating to materials supplied by three different companies to the SCBP. Conducted within the construction materials laboratory at the Southern Technical University in Maysan City, this testing initiative involved the examination of 30 acceptable aggregate samples. These samples were collected and monitored in real time throughout 2021.

Table 5.4 Fine aggregate test for 30 samples from materials supplied to the SCBP [Researcher].

No	***Sample Passing Percentage***	***Sieve No.***							
		10	***4.75***	***2.36***	***1.18***	***0.6***	***0.3***	***0.15***	***SO3 %***
				Supplier No.1					
1.	*Test 1*	*100*	*97*	*88*	*70*	*46*	*16*	*7*	*0.038*
2.	*Test 2*	*100*	*98*	*87*	*68*	*44*	*17*	*2*	*0.025*
3.	*Test 3*	*100*	*97*	*87*	*71*	*47*	*16*	*7*	*0.031*
4.	*Test 4*	*100*	*96*	*86*	*69*	*48*	*16*	*5*	*0.023*
5.	*Test 5*	*100*	*98*	*86*	*70*	*43*	*15*	*4*	*0.023*
6.	*Test 6*	*100*	*98*	*89*	*72*	*48*	*15*	*6*	*0.0891*
7.	*Test 7*	*100*	*97*	*88*	*68*	*47*	*16*	*6*	*0.022*
8.	*Test 8*	*100*	*98*	*87*	*89*	*48*	*29*	*5*	*0.029*
9.	*Test 9*	*100*	*100*	*100*	*94*	*63*	*28*	*3*	*0.023*
10.	*Test 10*	*100*	*97*	*88*	*69*	*45*	*15.3*	*5.7*	*0.023*
				Supplier No. 2					
11.	*Test 1*	*100*	*99*	*79*	*82*	*42*	*14*	*5*	*0.042*
12.	*Test 2*	*100*	*93*	*84*	*73*	*41*	*16*	*8*	*0.051*
13.	*Test 3*	*100*	*96*	*86*	*76*	*39*	*17*	*4*	*0.053*
14.	*Test 4*	*100*	*95*	*84*	*59*	*50*	*16*	*6*	*0.036*
15.	*Test 5*	*100*	*98*	*82*	*83*	*53*	*20*	*7*	*0.027*
16.	*Test 6*	*100*	*96*	*87*	*77*	*38*	*18*	*3*	*0.046*
17.	*Test 7*	*100*	*98*	*83*	*66*	*37*	*24*	*8*	*0.026*
18.	*Test 8*	*100*	*96*	*90*	*79*	*54*	*25*	*6*	*0.029*
19.	*Test 9*	*100*	*99*	*95*	*88*	*45*	*19*	*5*	*0.034*
20.	*Test 10*	*100*	*96*	*87*	*67*	*47*	*17*	*8*	*0.035*
				Supplier No. 3					
21.	*Test 1*	*100*	*96*	*75*	*50*	*41*	*15*	*8*	*0.032*
22.	*Test 2*	*100*	*97*	*78*	*63*	*42*	*27*	*6*	*0.037*
23.	*Test 3*	*100*	*97*	*85*	*83*	*41*	*29*	*9*	*0.029*
24.	*Test 4*	*100*	*98*	*91*	*75*	*47*	*27*	*3*	*0.031*
25.	*Test 5*	*100*	*98*	*88*	*76*	*57*	*19*	*6*	*0.037*
26.	*Test 6*	*100*	*96*	*87*	*79*	*55*	*17*	*7*	*0.028*
27.	*Test 7*	*100*	*98*	*87*	*82*	*49*	*21*	*3*	*0.029*
28.	*Test 8*	*100*	*97*	*90*	*87*	*53*	*14*	*8*	*0.047*
29.	*Test 9*	*100*	*99*	*83*	*81*	*47*	*19*	*9*	*0.043*
30.	*Test 10*	*100*	*97*	*92*	*59*	*49*	*27*	*7*	*0.054*

The stress at which significant cracking commences is affected by the shape of the aggregate: smooth gravel leads to cracking at lower stresses than rough and angular crushed aggregate, other things being equal. The effect is similar in tension and compression due to a better bond and less microcracking with an angular crushed aggregate.

5.4.10 Analysis of the results and the comparison of fine aggregate

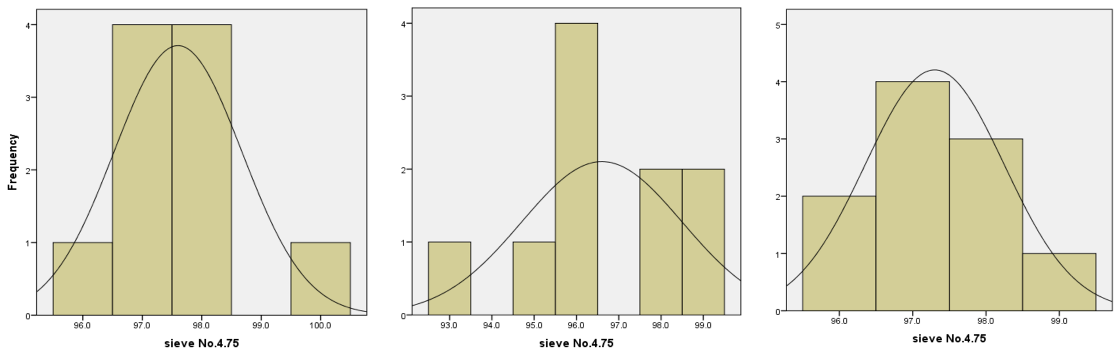
The results were obtained using the SPSS software in order to identify the suppliers that have an impact on the RMC production process and determine the specific effects they have. The comparison of test results was conducted for each supplier. These tests were conducted on 30 aggregate test samples, following the guidelines outlined in the ACI code E1-16. The grading of the samples is determined according to the standards set by ASTM C136/C136M and involves assessing the percentage of the samples that pass through several sieves, including sieve no.10, sieve no.4.75, sieve no.2.36, sieve no.0.6, sieve no.0.3, sieve no.0.15, and So_3.

a) Sieve No. 10

The samples passing through sieve no.10 were 100% (constant values); therefore, it has been omitted, but it is met with the limitations (equal to 100%) according to ASTM C136/. C136M.

b) Sieve No.4.75

The passing percentage of samples through sieve no. 4.75 was assessed per industry standards, ranging from 90% to 100% for three suppliers. The analysis revealed that for Supplier No. 1, the mean passing percentage through sieve no. 4.75 was 97.6, with a 95% confidence interval ranging from 96.831 to 98.369. The trimmed mean, representing the central tendency while excluding 5% of values, was calculated as 97.556. The standard deviation for this dataset was 1.075. Supplier No.2 mean passing percentage was 96.6, with a 95% confidence from 95.243 to 97.957. The trimmed mean was 96.677, and the standard deviation was 1.8974. Likewise, for Supplier No. 3, the mean passing percentage was 97.3, with an interval of 96.621 to 97.179. The trimmed mean was 97.275, and the standard deviation was 0.9487.



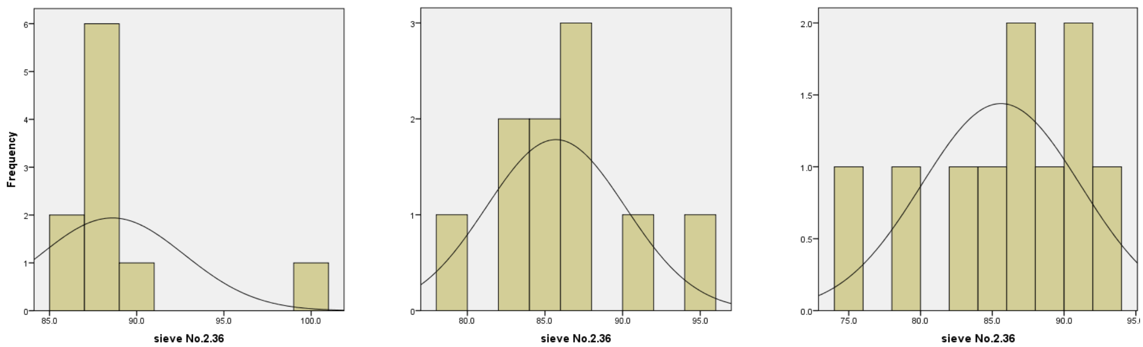
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.23 Samples of fine aggregate passing through sieve no.4.75 results [Researcher].

The histogram and distribution curve above depicts the three suppliers' test result distributions. In comparing these suppliers, their respective standard deviations were 1.075, 1.8974, and 0.9487 for Supplier No. 1, Supplier No. 2, and Supplier No. 3. Notably, Supplier No. 1 exhibited the most favorable impact on the production process.

c) **Sieve No.2.36**

The standard for the passing percentage of samples through sieve no. 2.36 encompassed a 75% to 100% range for all three suppliers, albeit with encountered test limitations.



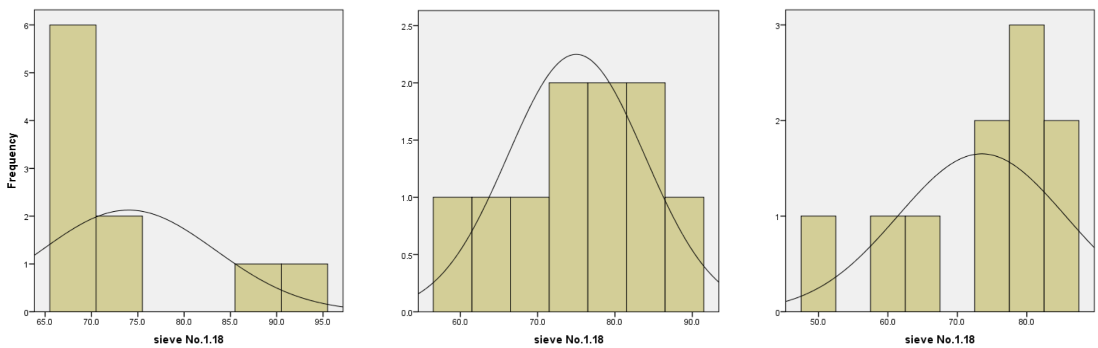
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.24 Samples of fine aggregate passing through sieve no.2.36 results [Researcher].

Figure 5.24 illustrates histograms and distribution curves of test results among three suppliers. The standard deviations for Supplier No. 1, Supplier No. 2, and Supplier No. 3 were 4.115, 4.4734, and 5.5418, respectively. Notably, Supplier No. 3 had the most significant positive impact on the production process.

d) **Sieve No.1.18**

The established standard for sample passage through sieve no. 1.18 ranged from 55% to 90% for all three suppliers, albeit with certain limitations encountered during the average test results.



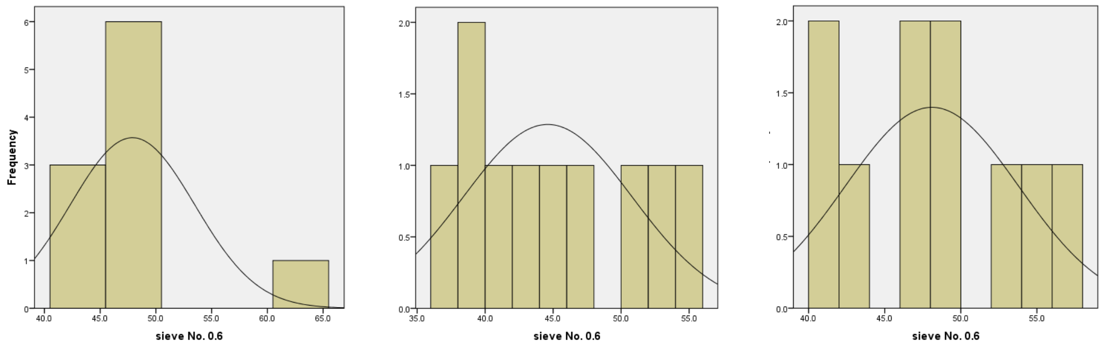
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.25 Samples of fine aggregate passing through sieve no. 1.18 results [Researcher].

Figure 5.25 depicts histograms of test results for three suppliers, with standard deviations of 9.3808, 8.8699, and 12.0761 for Supplier No. 1, Supplier No. 2, and Supplier No. 3, respectively. Notably, Supplier No. 2 had the most favorable impact.

e) **Sieve No.0.6**

The standard for the passage percentage of samples through sieve no. 0.6 ranged from 35% to 59% for all three suppliers, albeit with encountered limitations in the test results.



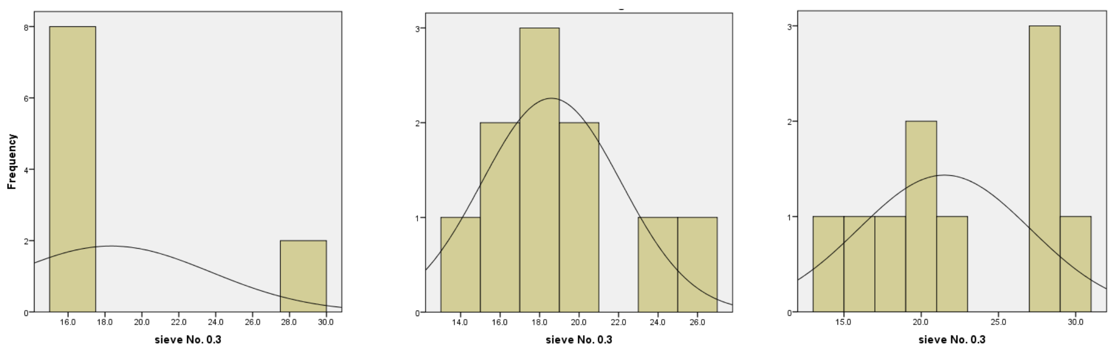
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.26 Samples of fine aggregate passing through sieve no.0.6 results [Researcher].

Figure 5.26 illustrates histograms of supplier test results, revealing standard deviations of 5.5867, 6.2039, and 5.7048 for Supplier No. 1, Supplier No. 2, and Supplier No. 3, respectively. Notably, Supplier No. 2 had the most positive impact, while Supplier No. 1 exhibited the most negative effect.

f) **Sieve No.0.3**

The standard for sample passage through sieve no. 0.3 ranged from 8% to 30% for all three suppliers, although limitations constrained the test results.



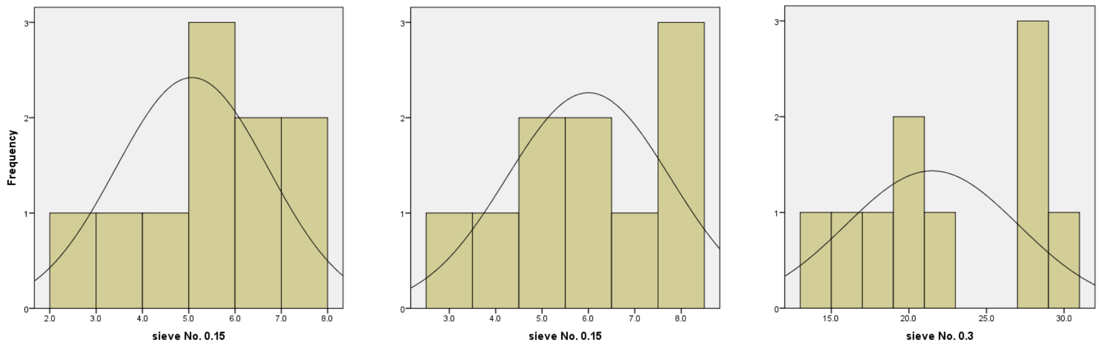
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.27 Samples of fine aggregate passing through sieve no.0.3 results [Researcher].

Figure 5.27 displays histograms of test results with standard deviations of 5.3975, 3.534, and 5.5628 for Supplier No. 1, Supplier No. 2, and Supplier No. 3, respectively. Notably, Supplier No. 2 had the most positive impact, while Supplier No. 1 exhibited the most negative effect.

g) **Sieve No.0.15**

The standard for sample passage through sieve no. 0.15 ranged from 0% to 10% for all three suppliers, with results subject to limitations.



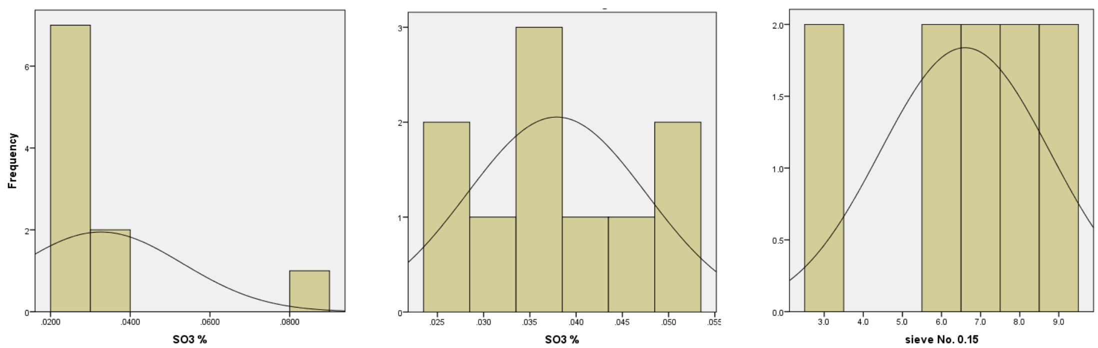
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.28 Fine aggregate samples pass through sieve no.0.15 with 10 tests for each [Researcher].

Figure 5.28 displays histograms of test results with standard deviations of 1.6479, 1.7638, and 2.1705 for Supplier No. 1, Supplier No. 2, and Supplier No. 3, respectively. Notably, Supplier No. 1 had the most positive impact, while Supplier No. 3 exhibited the adverse effect.

h) **SO_3**

Despite limitations in the test results, the standard for SO3 ranged from 0.002 to 0.06 across the three suppliers. The standard deviations for Supplier No. 1, Supplier No. 2, and Supplier No. 3 were 0.0204822, 0.009712, and 0.008782, respectively. Supplier No. 3 had the most positive impact on the production process, while Supplier No. 1 had the most negative impact.



Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.29 Fine aggregate test of the SO_3 for suppliers with 10 samples for each [Researcher].

5.4.11 Improve the current process of Sigma

In order to optimize the existing production process, which encompasses the utilization of materials of fine aggregate tests as outlined in the ACI code E1-16, grading was determined using ASTM C136/C136M for samples passing through various sieves (no.10, no.4.75, no.2.36, no.0.6, no.0.3, no.0.15) and SO_3 for materials supplied by different companies to SCBP. The comparison of these suppliers from various angles reveals that Supplier No. 2 has the most beneficial impact on the production of ready-mix concrete (RMC) due to the superior quality of fine aggregate properties. Supplier No. 3 follows closely in second place, while Supplier No. 1 is recommended for exclusion from the process due to its inferior material quality.

5.4.12 Control sigma process of fine aggregate

The final stage for fine aggregate in the Six Sigma process entails controlling improvements to involve employing statistical process control to maintain the uniformity and predictability of fine aggregate properties, which is achieved by ensuring that the values remain within the defined upper control limit (UCL) and lower control limit (LCL), thereby aligning with the desired quality characteristics, as represented by the following equations:

$$UCL = x — L * \sigma \qquad (12)$$

Or

$$\text{LCL} = x - (\text{L}^{*}\sigma) \qquad (13)$$

Where: x = Control means, σ = Control standard deviation, and L = Control limit want to evaluate (the lines of sigma dispersion from the mean controlled). Sieve no. 4.75 values are between the UCL 111.37 and the LCL 81.83, sieve no. 2.36 values are between the UCL 109.333 and the LCL 62.067, sieve no. 1.18 values are between the UCL 141.762 and the LCL 8.238, sieve no. 0.6 values are in between the UCL, 84.64, and the LCL, 8.65, as follows:

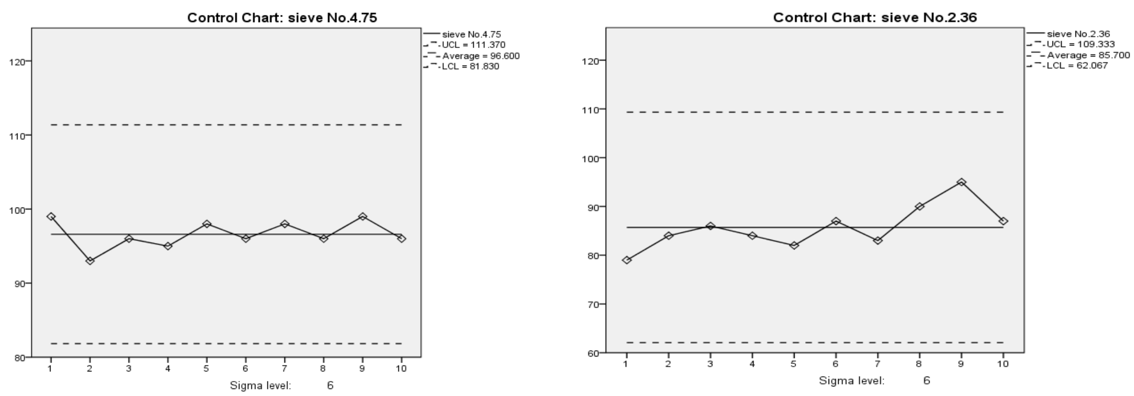


Figure 5.30 Six-Sigma control chart for the samples passing through sieve no. 4.75, no. 2.36**,** and sieve no. 1.18 for 30 fine aggregate tests of materials supplie**d** to the SCBP [Researcher].

Furthermore, for sieve no. 0.3, values are within the range defined by the upper control limit (UCL) of 33.37 and the lower control limit (LCL) of 3.83. In the case of sieve no. 0.15, the values fall between the UCL of 20.77 and the LCL of 8.77. Regarding SO3 percentage, the values are within the interval delineated by the UCL of 0.088 and the LCL of 0.0123.

5.4.13 Coarse Aggregate Tests

The present study focuses on assessing opportunities given by the sieve analysis test, specifically for coarse aggregate qualities. A total of 30 tests were conducted, evaluating the performance of sieve no.37.5, sieve no.20, sieve no.10, sieve no.5, and the SO3 %. These measurements were carried out on the materials supplied by three different companies.

Table 5.5 Coarse aggregate 30 tests for materials supplied to the SCBP [Researcher].

No	*Suppliers*	*Sample Passing Percentage*	*Sieve No.*				
			37.5	*20*	*10*	*5*	*SO_3 %*
1.	*Supplier No.1*	*Test 1*	*100*	*97*	*34*	*0.5*	*0.1*
2.		*Test 2*	*100*	*97*	*35*	*0*	*0.1*
3.		*Test 3*	*100*	*98*	*43*	*3.2*	*0.1*
4.		*Test 4*	*100*	*97*	*33*	*2.1*	*0.1*
5.		*Test 5*	*100*	*95*	*37*	*0.9*	*0.1*
6.		*Test 6*	*100*	*99*	*45*	*1.5*	*0.1*
7.		*Test 7*	*100*	*97*	*34*	*0.5*	*0.1*
8.		*Test 8*	*100*	*97*	*40*	*4.3*	*0.1*
9.		*Test 9*	*100*	*96*	*34*	*0.8*	*0.08*
10.		*Test 10*	*100*	*97*	*54*	*6.2*	*0.1*
11.	*Supplier 2*	*Test 1*	*100*	*98*	*42*	*3*	*0.1*
12.		*Test 2*	*100*	*98*	*47*	*2.5*	*0.1*
13.		*Test 3*	*100*	*96*	*39*	*3.7*	*0.1*
14.		*Test 4*	*100*	*97*	*43*	*3.5*	*0.1*
15.		*Test 5*	*100*	*97*	*38*	*4.2*	*0.1*
16.		*Test 6*	*100*	*98*	*44*	*2.5*	*0.1*
17.		*Test 7*	*100*	*97*	*46*	*3.6*	*0.1*
18.		*Test 8*	*100*	*97*	*35*	*3.8*	*0.1*
19.		*Test 9*	*100*	*97*	*38*	*2.8*	*0.1*
20.		*Test 10*	*100*	*97*	*48*	*6*	*0.1*
21.	*Supplier 3*	*Test 1*	*100*	*97*	*43*	*1.7*	*0.1*
22.		*Test 2*	*100*	*97*	*46*	*4.6*	*0.1*
23.		*Test 3*	*100*	*97*	*47*	*3.9*	*0.1*
24.		*Test 4*	*100*	*99*	*35*	*4.8*	*0.09*
25.		*Test 5*	*100*	*96*	*46*	*2.8*	*0.1*
26.		*Test 6*	*100*	*97*	*58*	*6.5*	*0.09*
27.		*Test 7*	*100*	*96*	*51*	*7.1*	*0.1*
28.		*Test 8*	*100*	*97*	*53*	*6.4*	*0.1*
29.		*Test 9*	*100*	*98*	*45*	*0.7*	*0.1*
30.		*Test 10*	*100*	*99*	*58*	*8.3*	*0.1*

Table 5.5 displays test results for coarse aggregate supplied by three different suppliers. These tests were conducted over 12 months in 2021 at the Construction Materials Laboratory of the Southern Technical University in Maysan City.

5.4.14 Analysis of the results and the comparison

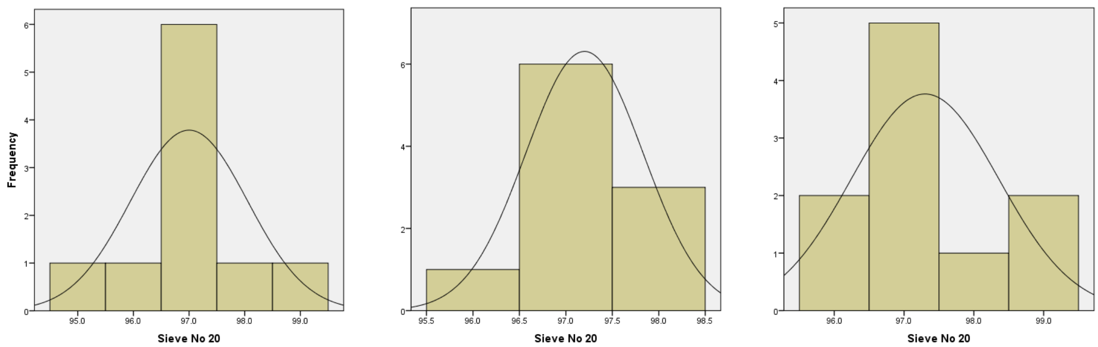
The analysis, conducted using SPSS software, aimed to identify the supplier with the most significant influence and the nature of that influence on the production process. Comparative assessments were made initially against established standards and subsequently between suppliers. This assessment was carried out for each aspect of the materials tests, comprising 30 tests based on ACI code E1-16. The grading criteria were determined using ASTM C136/C136M for samples passing through various sieves, including no.10, no.4.75, no.2.36, no.0.6, no.0.3, no.0.15, and SO3 percentages.

a) Sieve No. 37.5

The samples passing through sieve no.37.5 were 100% of samples (constant); therefore, it has been omitted, but it is met with the limitations according to ASTM C136/. C136M.

b) Sieve No. 20

The standard for sample passage through sieve no.20 ranged from 95% to 100% for the suppliers. However, it is essential to note that limitations constrained the test results. Supplier No. 1 exhibited a mean passing percentage of 97, with a 95% confidence interval ranging from 96.246 to 97.754. The trimmed mean represented the central tendency while excluding 5% of values, and the standard deviation was 1.0541. For Supplier No. 2, the mean was 97.2, with an interval of 96.748 to 97.652. The trimmed mean was 97.22, and the standard deviation was 0.6325. Supplier No. 3 demonstrated a mean of 97.3, with an interval ranging from 96.542 to 98.058. The trimmed mean was 97.278, and the standard deviation was 1.0593.



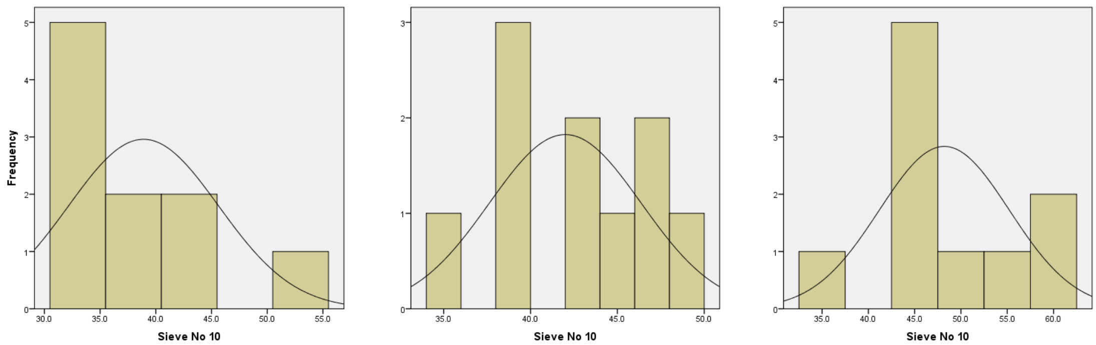
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.31 Coarse aggregate test of the samples passing through sieve no.20 results [Researcher].

Figure 5.31 depicts a histogram and distribution curve illustrating test results among suppliers. Standard deviations of 1.0541, 0.6325, and 1.0593 were observed for Supplier No. 1, Supplier No. 2, and Supplier No. 3, respectively. Supplier No. 2 had the most favorable impact, while Supplier No. 1 had the most adverse effect on the process.

c) **Sieve No. 10**

The standard for the samples passing percentage through the sieve no. 20 is from 30 to 60 for the three suppliers, where the results of the tests were met with limitations.



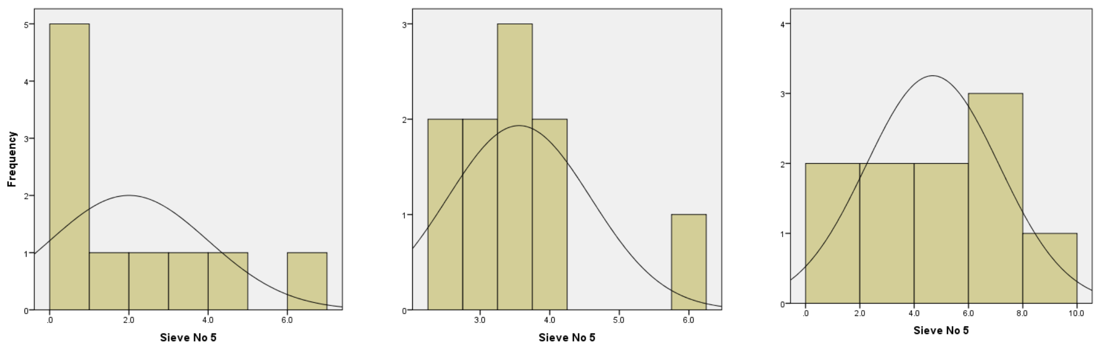
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.32 Coarse aggregate test of the samples passing through sieve no.10 results [Researcher].

Figure 5.32 illustrates a histogram and distribution curve presenting test results among suppliers. The standard deviations of 6.7404, 4.3716, and 7.0364 were observed for Supplier No. 1, Supplier No. 2, and Supplier No. 3, respectively. Supplier No. 2 had the most favorable impact on the process, while Supplier No. 1 had the most adverse effect.

d) **Sieve No. 5**

The standard for sample passage through sieve no. 20 ranged from 0% to 10% for all three suppliers, yet the test results were subject to limitations.



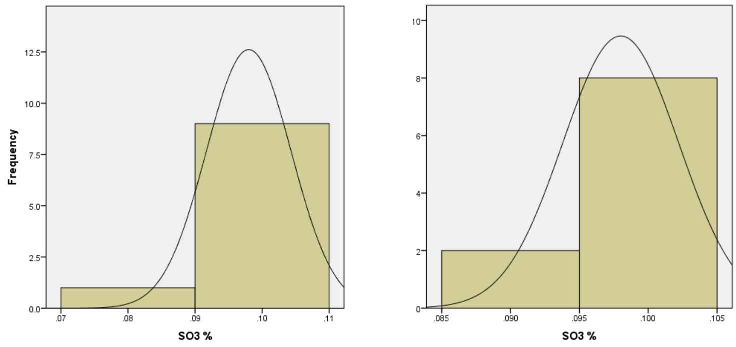
Supplier No.1 Supplier No.2 Supplier No.3

Figure 5.33 Coarse aggregate test of the samples passing through sieve no.5 results [Researcher].

Figure 5.33 displays a histogram and distribution curve depicting test results among suppliers. Standard deviations of 1.9939, 1.0319, and 2.4521 were observed for Supplier No. 1, Supplier No. 2, and Supplier No. 3, respectively. Supplier No. 3 had the most positive impact on the process, while Supplier No. 1 had the most adverse effect.

e) **So_3 (%)**

The standard for SO3 content ranged from 0% to 0.10% for all three suppliers, with the test results being constrained by limitations.



Supplier No.1 Supplier No.3

Figure 5.34 Coarse aggregate of SO_3 results for 10 test samples for each supplier [Researcher].

Figure 5.34 presents coarse aggregate results and a distribution curve for the three suppliers. The standard deviations observed for Supplier No. 1 and Supplier No. 3 were 0.00632 and 0.00422, respectively. Notably, Supplier No. 2 had the most positive impact on the process.

5.4.15 Improve sigma process

To optimize the current production process involving materials and based on the analysis of fine aggregate tests (30 tests) conducted according to ASTM C136/C136M standards, we examined samples passing through various sieves, including no.37.5, no.20, no.10, no.5, and SO_3, supplied by different companies to SCBP. A comprehensive comparison of these results revealed that Supplier No. 2 had the most favorable impact on ready-mix concrete (RMC) production. Supplier No. 3 was the second-best choice, while Supplier No.1 is recommended for exclusion due to material quality concerns.

5.4.16 Control sigma process

The final step in the Six Sigma process for coarse aggregate involves controlling the coarse aggregate properties using Statistical Process Control (SPC), which is achieved by maintaining these properties within the range defined by the Upper Control Limit (UCL) and Lower Control Limit (LCL) to ensure the desired quality standards are met. An analysis using SPSS software generated control charts for different sieve sizes. Sieve no. 3.75 displayed constant values with no deviation. For sieve no. 20, values fell within the range of the UCL (100.154) and LCL (97.2). Sieve no. 10 exhibited values within the UCL (73.97) and LCL (10.09). Lastly, sieve no. 5 displayed values within the UCL (9.35) and LCL (-2.23).

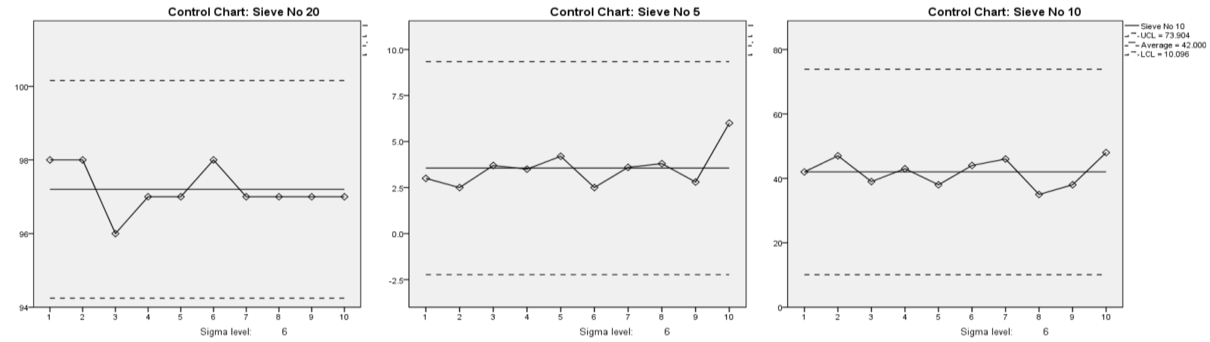


Figure 5.35 Six-Sigma control chart for the samples passing through sieve no. 20, sieve no.10, and sieve no.5, of 30 fine aggregate tests of supplier no. 2, supplies to SCBP [Researcher].

The outcomes of 93 material tests conducted over 12 months, encompassing cement (33 tests), fine aggregate (30 tests), and coarse aggregate (30 tests), within the context of Six Sigma for material supply to SCBP, reveal that Supplier No. 2 consistently delivers the highest-quality materials, exerting a positive influence on the process. Conversely, Supplier No. 1 has the most adverse impact on RMC due to subpar material quality. Consequently, it is recommended to discontinue the involvement of Supplier No. 1 in the material supply process.

5.5 Monte Carlo simulation by SPSS software

Monte Carlo methods encompass mathematical problem-solving techniques that rely on random sampling [133]. These methods involve creating stochastic simulations to investigate complex phenomena [134]. It is characterized by repeated random sampling and subsequent statistical analysis to derive results. In this context, we will briefly discuss the significance, methodology, and mathematical prerequisites for conducting these simulations. The primary aim is to employ Monte Carlo simulations for quantitative risk analysis, specifically in supplier selection for production. These simulations are predicated on the assumption of typical disruptions in numerical data. Moreover, the simulated quantities of materials are determined based on previously established test results. The Monte Carlo simulation is approached from two perspectives:

A. Probability of Risks: It seeks to determine the likelihood of risks influencing the supplier selection process.
B. Material Quantities: It involves simulating material quantities based on test data.

5.5.1 Time of supplying the total amount of materials

The simulation focused on suppliers' performance concerning material quantities and delivery times for the production of RMC. Specifically, this pertained to fulfilling an order of 1100 cubic meters of RMC with a grade of 25 MPa for the Pearl of Maysan Multistore building project. This requirement encompassed 419 tons of cement, 580 cubic meters of fine aggregate, and 835 cubic meters of coarse aggregate.

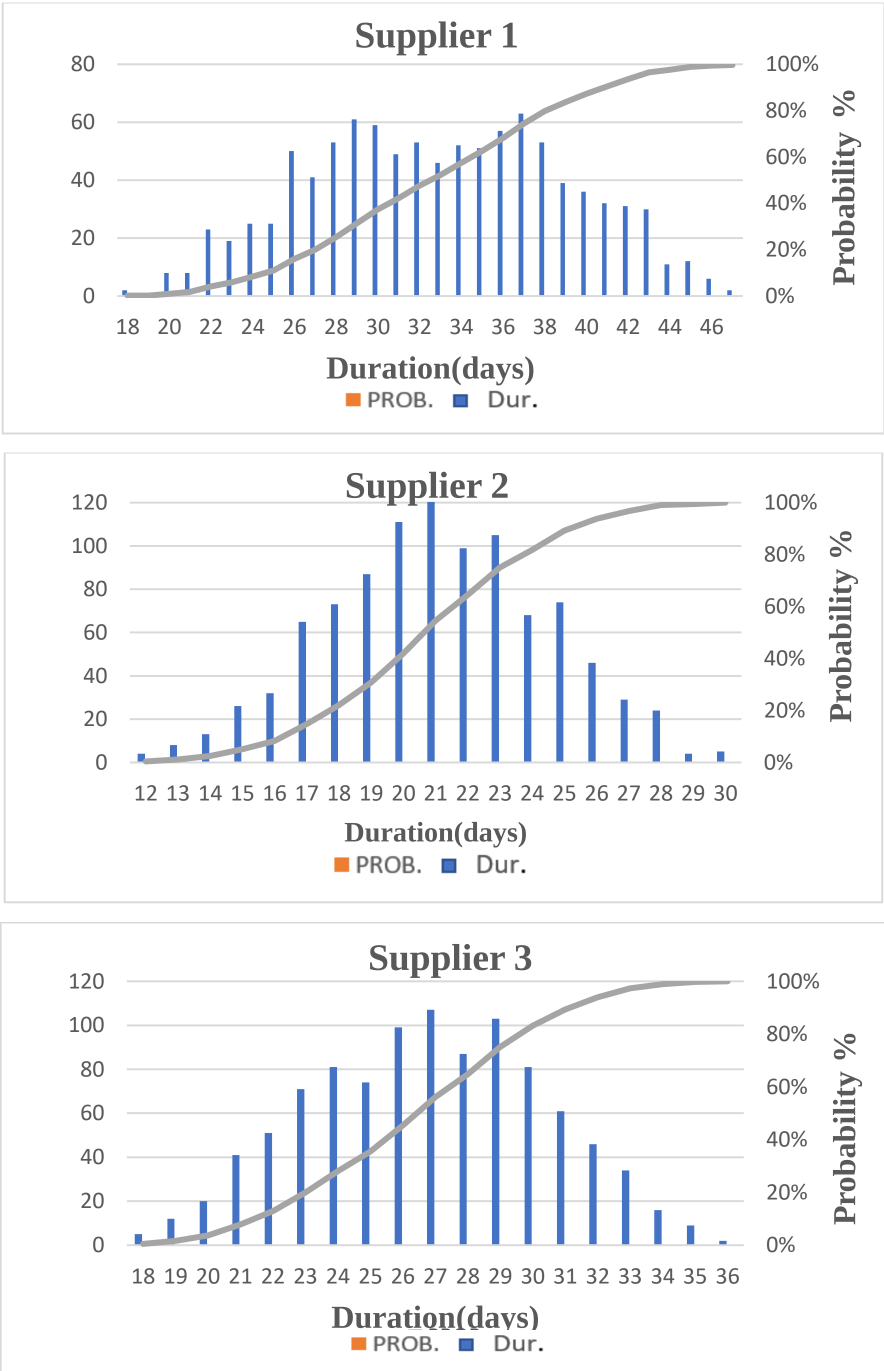


Figure 5.36 Monte Carlo simulation for the amount of materials and duration required to supply it for the three companies(suppliers) supplying the materials to the SCBP [Researcher].

Figure 5.36 illustrates the outcome of a Monte Carlo simulation employing the central limit theorem, which naturally results in a normal distribution [134]. Based on historical interactions with three suppliers and their established supply periods, one thousand simulations were conducted to analyze material deliveries. These simulations assumed a normal distribution of delivery durations to estimate the most likely duration for material supply to the RMC company. The objective was to compare the simulation outcomes and determine the supplier capable of delivering the entire quantity quickly. The first simulation for Supplier 1 (Maysan Moon company) indicated a probability exceeding 85% for supplying the total quantity within 37 days, aligning with the company's historical data. In the case of Supplier 2 (Majra Al Khairat company), the simulation demonstrated a probability exceeding 100% for providing the total quantity within 21 days. Conversely, for Supplier 3 (Al-Rafd company), the third simulation indicated a probability exceeding 87% for delivering the total quantity within 27 days. Based on these simulation results, Supplier 2 emerged as the most efficient choice, guaranteeing a 100% probability of supplying the total quantity in the shortest time.

5.5.2 Costs and revenues are based on materials, marketing, and transportation.

In the second phase of the simulation, cost and revenue considerations for RMC production are addressed. This analysis is based on data and the specified mixing ratios, which dictate that for each cubic meter of RMC, 380.25 kg of cement, 0.528 cubic meters of fine aggregate, and 0.758 cubic meters of coarse aggregate are required. To illustrate cost monitoring in a real-time scenario, let us consider an order to supply 1100 cubic meters of RMC for a construction project at the Pearl of Maysan. The materials needed from the suppliers include 419 tons of cement, 580 cubic meters of fine aggregate, and 835 cubic meters of coarse aggregate. Additionally, each supplier provides their pricing for the required materials as follows:

Table 5.6 Materials prices offered by the suppliers [Researcher].

No	*Topic*	*Price ($)*		
		Cement (ton)	*Fine Aggregate(m^3)*	*Coarse Aggregate(m^3)*
1.	*Supplier 1*	*92*	*87.5*	*19*
2.	*Supplier 2*	*90*	*86*	*17*
3.	*Supplier 3*	*90.6*	*87.2*	*16.8*

Table 5.6 displays the material prices from three suppliers for use in RMC production. The subsequent step involves a Monte Carlo simulation to ascertain the most cost-effective supplier for the process. It is known for their flexibility and utility, are frequently employed when dealing with intricate problems that resist more mathematically elegant solutions[135].

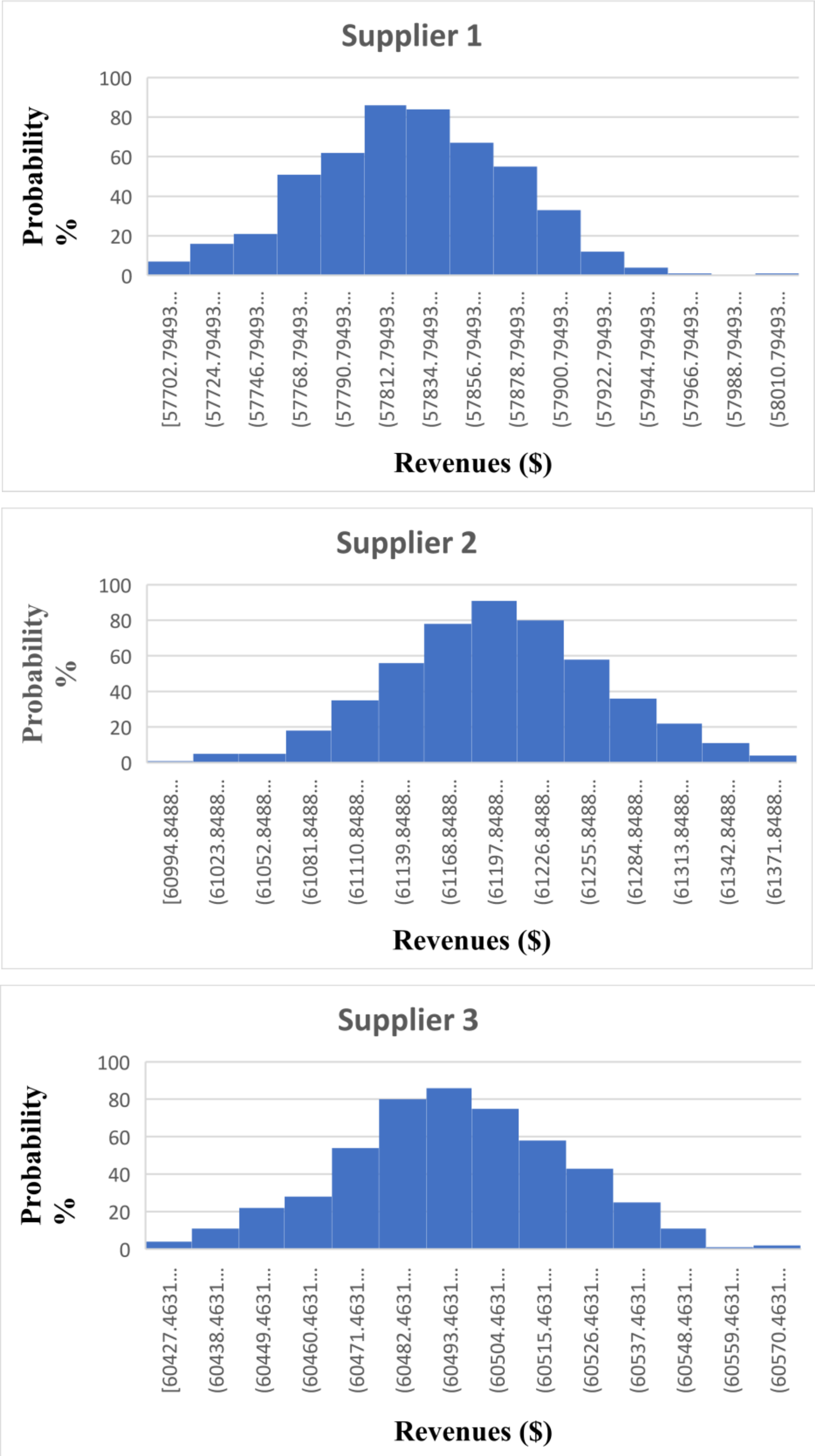


Figure 5.37 Monte Carlo simulation for the RMC cost (materials, marketing, payroll, and transportation) and revenues for the three materials suppliers [Researcher].

Figure 5.37 illustrates a Monte Carlo simulation for the cost of RMC production, encompassing materials, marketing, payroll, and transportation expenses associated with RMC pricing. The RMC price is $160 per cubic meter for grade 25 MPa, resulting in a total order cost of $176,000 for 1100 cubic meters. Material costs vary among the three suppliers due to their pricing differences: $105,163 for supplier no. 1, $101,785 for supplier no. 2, and $102,565 for supplier no. 3. Additionally, salaries and transportation costs amount to $11,000, with marketing expenses totaling $2,000. The simulation, conducted over 500 trials, aims to determine the most probable revenue within the simulation framework. Notably, the results indicate that for the first supplier (Maysan Moon company), the revenue is $57,812, with an 83% probability, making it the most efficient choice in 500 trials. In the second simulation, focusing on supplier no. 2 (Majra Al Khairat company), the revenue is $61,197 with a 90% probability, demonstrating its efficiency over 500 trials. The third simulation, involving supplier no. 3 (Al-Rafd company) yields a revenue of $60,493 with an 82% probability, making it the most efficient choice over 500 trials.

In conclusion, after comparing the simulation results for the three material suppliers to the SCBP, it is evident that the second supplier (Majra Al Khairat company) stands out as the most efficient choice for RMC production, with a revenue of $61,197 and a 90% probability.

5.6 FMIA Analysis

Design-responsible engineers or teams typically employ a Design Potential Failure Mode and Effects Analysis (FMEA) to comprehensively assess and address potential failure modes and their underlying causes or mechanisms in the design process. This analysis encompasses final products, associated systems, subassemblies, and individual components. FMEA represents a compilation of the engineer's and team's insights, drawing from prior experiences, to anticipate potential issues [136]. The primary objective is to proactively identify and assess the likelihood of encountering specific failure modes before they manifest [137]; as discussed in Chapter 2, FMEA serves as a systematic approach for scrutinizing the origins and consequences of various constituent defects, incorporating a quantitative evaluation of their actual impact [61].

$$RPN = X_1 \times X_2 \times X_3 \qquad (14)$$

Where:

X_1= Ease of detection, X_2= Probability of occurrence, X_3= Severity of problem, PPN= Problem Priority Number.

The supplier's risk priority number (RPN) is calculated by multiplying the severity, occurrence, and detection values, with a higher RPN indicating a more significant impact on RMC production. The scale ranges from 1 to 10, with ten signifying the highest priority. This section presents an updated FMEA analysis for suppliers, considering real-time monitoring, Six Sigma, and Monte Carlo simulations to reduce defects. Minitab software is used for this analysis, which is divided into two parts. In this part, we assess the current situation, covering key process inputs, potential failure modes, effects, severity (SEV), causes, occurrence (OCC), current controls, detection (DET), and RPN prior to improvements. For reliability, RPN is 96, with SEV at 6, OCC at 6, and DET at 4. Materials quality yields an RPN 244 with SEV at 8, OCC at 4, and DET at 7. Delivery and quantity issues result in an RPN of 192, SEV at 8, OCC at 4, and DET at 6. Cost issues have an RPN of 48, SEV at 3, OCC at 4, and DET at 6. Order-related problems have an RPN of 42, SEV at 7, OCC at 2, and DET at 3; see Table 5.7.

Table 5.7 FMEA Analysis for the suppliers of the RMC stationary concrete batching plant (the current situation) done by companion by Minitab (version 5.2) software [Researcher].

No	*Key process input*	*Potential Failure Mode*	*Potential Failure Effects*	*SEV*	*Potential Causes*	*OCC*	*Current Controls*	*DET*	*RPN*
1.	*Reliability*	*Unreliable, cheating in prices, quality, and quantity*	*RMC company's reputation for providing orders on time, specified quantity, and specified prices*	*6*	*trying to sell cheap or low-quality materials with the same prices as suitable quality materials, late delivery, and not the total quantity*	*4*	*no control*	*4*	*96*
2.	*Materials*	*Poor quality materials*	*RMC compressive strength reduced*	*8*	*cheap materials, ignorance of material properties, and dealing with three suppliers provide different materials quality without evaluating their performance based on quality.*	*4*	*inspection, a few tests for large quantities in some cases, without test (only visual inspection) if the orders were a lot.*	*7*	*244*
3.	*delivery and quantity*	*Late delivery and uncomplete d quantity*	*late order or loss of RMC orders, company reliability*	*8*	*there is no evaluating system for suppliers' performance based on quantity and delivery time*	*4*	*deals for the quantity, delivery time*	*6*	*192*
4.	*cost*	*Additional costs and different prices*	*prices of RMC*	*3*	*there is no evaluating system for suppliers' performance based on prices.*	*4*	*Price negotiation*	*4*	*48*
5.	*orders*	*Wrong orders*	*waste of time, effort, and money, issues with customers*	*7*	*Human mistakes and bad communications*	*2*	*no control*	*3*	*42*

Figure 5.7 illustrates the FMEA analysis conducted on the material suppliers for SCBP, focusing on supplier reliability, material quality, delivery, quantity, cost, varying prices, and

incorrect orders. Among these, the highest RPN corresponds to material quality, while the lowest is 42, about incorrect orders.

A better version of the Failure Mode and Effects Analysis (FMEA) has been made after the post-analysis phase and implementing improvements made possible by real-time monitoring, Six Sigma methods, and Monte Carlo simulations to fix problems. This updated iteration demonstrates a discernible reduction in the severity of problems and corresponding RPN values. However, it is essential to note that these issues have not been entirely eradicated. The revised FMEA incorporates recommended actions to improve supplier reliability, material quality, delivery and quantity, cost efficiency, and order accuracy. Additionally, it encompasses vital information concerning accountable stakeholders, actions undertaken, projected completion dates for these actions, and the updated values of problem severity (SEV), occurrence probability (OCC), ease of detection (DET), and RPN.

Furthermore, in our assessment criteria, RPN values exceeding 90 are classified as high-risk and are visually denoted in red, while values below 40 are categorized as low-risk priorities and are highlighted in green. Likewise, a severity (SEV) rating of 6 or higher on a scale of 10 indicates high severity, represented in red. In contrast, a rating of 5 or lower denotes low severity and is depicted in green.

Table 5.8 The SEV and RPN values for each condition display a color [Researcher].

Severity (SEV)		
If SEV ≥	*6*	
Otherwise		
If SEV ≤	*5*	

Risk Priority Number (RPN)		
If RPN ≥	*90*	
Otherwise		
If RPN ≤	*40*	

Furthermore, the improvement takes real-time monitoring data (tests, quality, quantity, and prices) collected for 12 months from January 2020 to December 2021. The second part of the FMEA analysis can describe the action recommended, the responsibility, the action taken, and the actual end of the action. Revised metrics for the situation after making improvements by choosing the best water type for the mix of RMC through 18 water properties tests, determining the best materials supplier through 93 tests, tests results in comparison, applying the Six Sigma method for cement, fine aggregate, and coarse aggregate, Monte Carlo simulations for the suppliers to provide the materials in total quantity, within the schedule, and the third simulation for the costs and revenues.

Table 5.9 FMEA Analysis for the suppliers by companion by Minitab [Researcher].

No	Actions Recommended	Responsibility	Actions taken	Actual end date	Revised Metrics			
					SEV	OCC	DET	RPN
1.	Choose the best supplier for RMC production based on the recorded history of supplying materials.	The project manager, the company stakeholder	Choose the supplier by evaluating the degree of reliability of each supplier based on their performance and history recorded of previous supplying and excluding unreliable suppliers.	12/1/2021	4	3	3	36
2.	More tests, Evaluating the supplier's performance, according to materials quality by real-time monitoring and Six Sigma methodology.	Project manager at the stationary concrete batching plant (SCBP)	Choose the best supplier for the process of RMC production, based on real-time monitoring and Six Sigma methodology according to materials quality	11/25/2021	5	2	3	30
3.	recorded contract with penalties for each day late or incomplete quantity, and deals only with a reliable supplier	Project manager, the company stakeholder.	Recording contracts and penalties for each day late or insufficient quantity and choosing the best supplier based on real-time monitoring and Monte Carlo simulation results.	12/1/2021	5	2	4	40
4.	Evaluating the suppliers' price offers by Monte Carlo simulation and deciding about the best and excluding the worst	The project manager, the company stakeholder, and the financial employee.	Choose the best supplier, based on real-time monitoring and Monte Carlo simulation according to price, and excluding the most supplier have a negative effect on the RMC production	12/25/2021	3	4	3	36
5.	Recorded contracts for supplying RMC orders, training, empowerment, and performance evaluation.	Project manager and communication employees	supplying contracts with fixed recorded details, online forms orders, updating the communications network, conformation the supplying orders	12/31/2021	4	1	2	8

Table 5.9 presents an updated FMEA analysis for SCBP's material suppliers, addressing the previously mentioned issues. The revised analysis reflects reductions in the risk priority numbers (RPNs) due to the implemented improvement measures outlined in the preceding table. Notably, the highest RPN stands at 40 for material quality, while the lowest is 8 for order-related issues.

CHAPTER 6 THE STABILITY OF DELIVERY TIME, PRODUCTION, AND PLACEMENT

6.1 Introduction

Ready mix concrete is made at a stationary concrete batching plant according to a set proportion and then delivered to a construction site in a truck mixer. The delivery time of ready-mix concrete can vary depending on several factors, including the distance from the batching plant to the construction site, traffic conditions, and the availability of the truck mixer. In general, the delivery time of ready-mix concrete can range from a few hours to a few days, depending on the specific needs of the construction project. It is essential to coordinate with the supplier to ensure that the concrete is delivered on time and in the required quantity. It is also essential to consider the time required for the concrete to reach its design strength and be ready for use, which will depend on the type of concrete being used, the ambient temperature and humidity, and the curing conditions. Moreover, this chapter will discuss the process of disclosure of the significant impact of the delivery time on RMC compressive strength and the problems of the delay, the amount of delay time, where it occurs, the reason, the amount of excess of the determinants, the proposed actions, and the distance between the construction work site and SBPC site through 81 cases of delivery from the beginning process of the RMC mixing until returning to SBPC site after concrete placing includes truck mixers wash time, the return journey time, and make 48 tests of compressive strength for the current situation in real-time monitoring.

6.2 RMC delivery time real-time monitoring

The process of real-time monitoring of RMC is the practice of routinely monitoring the methods and customer service representatives throughout the day, which involves steps like tracking time management compared, optimizing activities and improving response times, and identifying the problem's root causes in the response time and service, for producing and transporting RMC from SCBP to the construction site journey, to conduct the monitoring time process in real-time for 81 delivery cases of RMC starting from the first moment of production at SCBP to the final step in the process of delivery to the work site, for the Sert Stationary Concrete Batching Plant (SCBP) is 11 km away from the construction site, which is a multi-story building, (Maysan Peral) Building.

6.2.1 RMC delivery time and total discharge time

The monitoring of the RMC production in real-time from a perception of the time factor should take into consideration recording the time of the arrival of the truck mixers to the SCBP, the actual time of starting the SCBP to work, and starting to load the materials into the mixer of plant, the time required to finish loading the materials into the mixer, the time necessary to the process of mixing materials in the mixer of the SCBP to produce RMC, and record at which time the process of materials mixing is completed, then record the actual time for the truck mixer leaving SCBP to the construction site the moment of recording the time of the truck mixer arriving at the construction site and calculating the difference between the arrival and departure to determine the exact amount of the time required to reach the work site.

Furthermore, the precise duration for the truck mixer to initiate the process of loading ready-mix concrete (RMC) at the construction site was meticulously documented to accurately record the entire period from the moment the RMC was poured until the completion of the loading process, including the time taken for washing. In addition, the actual time taken to wash the mixing trucks was recorded, which started from the first moment of the truck washing process to the time of completion (wash process ends) and preparing to return to the SCBP again, and the time required for casting RMC ultimately, and the delay time for the truck mixers inside the construction site before and after the casting process and the washing process before leaving to return to the plant. Thus, it can cover the whole parts of the product delivery process, monitoring time for the process from the moment the truck mixers arrive to the SCBP and materials loading in the mixer of the plant to the moment they reach the site, pour them in real-time to the construction site and return to the stationary concrete batching plant.

The purpose of the process of real-time monitoring of the parts mentioned above in this stage is to give us an accurate perception of the work in terms of the time taken for each part of this process, and therefore controlling these times and managing, guarantees us control and preservation of the properties of the existing concrete and ensuring its quality to achieve customers satisfaction. The calculations were made considering the surrounding environmental conditions, traffic jams, weather conditions, peak hours, and the most appropriate way to reach the work site in a short time and the best ways far away from the city center, thus avoiding the traffic jam that occurs, where the real-time monitoring was done for three different months:

1. The first month was on Monday 09/21/2021 for 26 delivery cases of the RMC delivery, from mixing the concrete inside the SCBP to placing it at the construction site and return journey time. The time was recorded and calculated accurately, with the average weather temperature (36.7 °C) and the average relative humidity at 19 % from 7 a.m. to 6 pm.

2. The second month was on Monday 04/10/2021 for 31 delivery cases where the average temperature was (32.7 ℃), and relative humidity averaged 15 % from 7 am to 9 pm.
3. The third month was on Thursday, 11/25/2021, when the average weather temperature was (20.3 ℃), and the average relative humidity was 41 % from 7 am to 5 pm.

The work was divided into two phases: the first phase, through the attached tables of the delivery cases at the SCBP, and the second phase at the construction site. The SCBP company used five truck mixers to transport the RMC to the construction site, represented with I.D. numbers TM1, TM2, TM3, TM4, and TM5 for truck mixer no. 13541 Erbil/ construction, the truck mixer no. 3235 Baghdad/ construction, the truck mixer no. 48246 Sulaymaniyah / construction, the truck mixer no. 12778 Baghdad/ construction, and the truck mixer no. 12615 Erbil/ construction, respectively, as shown in the following:

Table 6.1 Real-time monitoring for 81 RMC delivery cases from the production at SCBP to delivery to the construction site and placing it for 26 cases on Mon 20th September 2021 [Researcher].

No	*ID*	*Get plant*	*Start load.*	*Time load*	*Finish load*	*Dep. to site*	*Time del.*	*Arrive site*	*Start to unload*	*Unload time*	*Finish unload ing*
1.	TM1	7:10	8:00	0:10	8:10	8:12	0:21	8:33	8:38	0:08	8:46
2.	TM2	7:15	8:12	0:13	8:25	8:28	0:24	8:52	8:58	0:08	9:06
3.	TM3	7:22	8:31	0:12	8:43	8:47	0:22	9:09	9:19	0:09	9:28
4.	TM4	7:35	8:46	0:11	8:57	9:12	0:25	9:37	9:40	0:10	9:50
5.	TM5	7:48	9:15	0:15	9:30	9:33	0:23	9:56	10:01	0:12	10:13
6.	TM1	9:11	9:36	0:14	9:50	9:55	0:24	10:19	10:23	0:10	10:33
7.	TM2	9:34	9:53	0:15	10:08	10:11	0:26	10:37	10:45	0:14	10:59
8.	TM3	9:58	10:18	0:14	10:32	10:38	0:21	10:59	11:07	0:09	11:16
9.	TM4	10:13	10:34	0:12	10:46	10:48	0:28	11:16	11:28	0:10	11:38
10.	TM5	10:46	11:00	0:14	11:14	11:17	0:26	11:43	11:50	0:10	12:00
11.	TM1	10:59	11:17	0:14	11:31	11:47	0:23	12:10	12:13	0:10	12:23
12.	TM2	11:34	11:45	0:15	12:00	12:04	0:24	12:28	12:35	0:12	12:47
					Rest time						
13.	TM3	11:47	13:00	0:10	13:10	13:12	0:27	13:39	13:42	0:08	13:50
14.	TM4	12:07	13:12	0:08	13:20	13:23	0:25	13:48	14:02	0:10	14:12
15.	TM5	12:32	13:25	0:15	13:40	13:44	0:28	14:12	14:22	0:09	14:31
16.	TM1	12:52	13:42	0:11	13:53	14:01	0:29	14:30	14:42	0:10	14:52
17.	TM2	13:18	13:53	0:13	14:06	14:09	0:27	14:36	15:02	0:08	15:10
18.	TM3	14:17	14:20	0:14	14:34	14:49	0:26	15:15	15:23	0:10	15:33
19.	TM4	14:53	14:52	0:10	15:02	15:08	0:27	15:35	15:45	0:09	15:54
20.	TM5	15:25	15:27	0:11	15:38	15:40	0:23	16:03	16:07	0:10	16:17
21.	TM1	15:25	15:40	0:10	15:50	15:54	0:24	16:18	16:27	0:09	16:36
22.	TM2	15:41	15:52	0:15	16:07	16:16	0:22	16:38	16:48	0:10	16:58
23.	TM3	16:07	16:10	0:13	16:23	16:27	0:23	16:50	17:09	0:09	17:18
24.	TM4	16:22	16:32	0:15	16:47	16:50	0:25	17:15	17:27	0:10	17:37
25.	TM5	16:44	16:50	0:19	17:09	17:12	0:27	17:39	17:50	0:11	18:01
26.	TM1	17:02	17:22	0:13	17:35	17:40	0:26	18:06	18:12	0:10	18:22

Table 6.1 represents the 26 RMC delivery cases, where the time is recorded in hours and minutes for Monday, 20 September 2021. Moreover, the rest time of employees starts from 12 for one hour.

Table 6.2 Real-time monitoring for 81 RMC delivery cases from the production process at SCBP to delivery to the construction site and placing it for 31 cases on Mon 04th October 2021 [Researcher].

No	***ID***	***Get plant***	***Start load.***	***Time load***	***Finish load***	***Dep. to site***	***Time del.***	***Arrive site***	***Start to unload***	***Unload time***	***Finish unloading***
27.	*TM4*	*7:24*	*8:00*	*0:10*	*8:10*	*8:14*	*0:21*	*8:35*	*8:40*	*0:10*	*8:50*
28.	*TM5*	*7:30*	*8:21*	*0:14*	*8:35*	*8:38*	*0:20*	*8:58*	*9:00*	*0:16*	*9:16*
29.	*TM1*	*7:42*	*9:26*	*0:12*	*9:38*	*9:50*	*0:26*	*10:16*	*10:19*	*0:14*	*10:33*
30.	*TM2*	*7:59*	*9:52*	*0:11*	*10:03*	*10:05*	*0:35*	*10:40*	*10:42*	*0:08*	*10:50*
31.	*TM3*	*8:00*	*10:23*	*0:10*	*10:33*	*10:32*	*0:20*	*10:52*	*10:55*	*0:09*	*11:04*
32.	*TM4*	*9:16*	*10:46*	*0:11*	*10:57*	*10:59*	*0:23*	*11:22*	*11:26*	*0:09*	*11:35*
33.	*TM5*	*9:48*	*11:08*	*0:10*	*11:18*	*11:20*	*0:25*	*11:45*	*11:48*	*0:11*	*11:59*
34.	*TM1*	*11:01*	*11:30*	*0:11*	*11:41*	*11:43*	*0:23*	*12:06*	*12:08*	*0:09*	*12:17*
35.	*TM2*	*11:19*	*11:50*	*0:10*	*12:00*	*12:02*	*0:21*	*12:23*	*12:26*	*0:12*	*12:38*
						Rest time					
36.	*TM3*	*11:32*	*13:00*	*0:10*	*13:10*	*13:12*	*0:22*	*13:34*	*13:38*	*0:10*	*13:48*
37.	*TM4*	*12:02*	*13:21*	*0:11*	*13:32*	*13:34*	*0:26*	*14:00*	*14:02*	*0:08*	*14:10*
38.	*TM5*	*12:29*	*13:50*	*0:11*	*14:01*	*14:03*	*0:22*	*14:25*	*14:29*	*0:08*	*14:37*
39.	*TM1*	*12:43*	*14:15*	*0:10*	*14:25*	*14:27*	*0:29*	*14:56*	*14:58*	*0:09*	*15:07*
40.	*TM2*	*13:08*	*14:36*	*0:11*	*14:47*	*14:50*	*0:27*	*15:17*	*15:19*	*0:11*	*15:30*
41.	*TM3*	*14:15*	*14:49*	*0:12*	*15:01*	*15:03*	*0:23*	*15:26*	*15:41*	*0:15*	*15:56*
42.	*TM4*	*14:39*	*15:05*	*0:15*	*15:20*	*15:22*	*0:27*	*15:49*	*16:10*	*0:15*	*16:25*
43.	*TM5*	*15:08*	*15:25*	*0:30*	*15:55*	*15:58*	*0:35*	*16:33*	*16:38*	*0:12*	*16:50*
44.	*TM1*	*15:40*	*16:05*	*0:13*	*16:18*	*16:32*	*0:28*	*17:00*	*17:05*	*0:10*	*17:15*
45.	*TM2*	*16:09*	*16:22*	*0:15*	*16:37*	*16:45*	*0:24*	*17:09*	*17:17*	*0:12*	*17:29*
46.	*TM3*	*16:29*	*16:40*	*0:12*	*16:52*	*17:27*	*0:26*	*17:53*	*17:56*	*0:10*	*18:06*
47.	*TM4*	*16:53*	*16:55*	*0:14*	*17:09*	*17:34*	*0:30*	*18:04*	*18:16*	*0:09*	*18:25*
48.	*TM5*	*17:29*	*17:31*	*0:15*	*17:46*	*18:04*	*0:26*	*18:30*	*18:36*	*0:10*	*18:46*
49.	*TM1*	*17:46*	*17:48*	*0:15*	*18:03*	*18:30*	*0:24*	*18:54*	*18:58*	*0:09*	*19:07*
50.	*TM2*	*18:02*	*18:26*	*0:14*	*18:40*	*18:49*	*0:25*	*19:14*	*19:19*	*0:10*	*19:29*
51.	*TM3*	*18:42*	*19:01*	*0:13*	*19:14*	*19:17*	*0:20*	*19:37*	*19:40*	*0:08*	*19:48*
52.	*TM4*	*19:00*	*19:16*	*0:14*	*19:30*	*19:32*	*0:24*	*19:56*	*20:01*	*0:08*	*20:09*
53.	*TM5*	*19:19*	*19:32*	*0:10*	*19:42*	*19:44*	*0:29*	*20:13*	*20:21*	*0:09*	*20:30*
54.	*TM1*	*19:36*	*19:45*	*0:12*	*19:57*	*20:10*	*0:26*	*20:36*	*20:42*	*0:10*	*20:52*
55.	*TM2*	*19:58*	*20:05*	*0:15*	*20:20*	*20:25*	*0:28*	*20:53*	*21:04*	*0:11*	*21:15*
56.	*TM3*	*20:19*	*20:23*	*0:15*	*20:38*	*20:41*	*0:30*	*21:11*	*21:28*	*0:12*	*21:40*
57.	*TM4*	*20:40*	*20:45*	*0:20*	*21:05*	*21:08*	*0:29*	*21:37*	*21:50*	*0:13*	*22:03*

Table 6.2 shows the 31 RMC delivery cases, where the time was recorded in hours and minutes for Monday, 04th October 2021. Moreover, the rest time of employees starts from 12 for one hour, and the stationary concrete batching plant stopped for 47 minutes.

Table 6.3 Real-time monitoring of 81 delivery cases from the production process at SCBP to delivery to the construction site and placing it for 24 cases on Thu, 25th November 2021[Researcher].

No	ID	Get plant	Start load.	Time load	Finish load	Dep. to site	Time del.	Arrive site	Start to unload	Unload time	Finish unloading
58.	TM3	7:14	8:00	0:10	8:10	8:12	0:20	8:32	8:34	0:09	8:43
59.	TM4	7:20	8:12	0:13	8:25	8:27	0:23	8:50	8:54	0:11	9:05
60.	TM5	7:34	8:29	0:11	8:40	8:42	0:22	9:04	9:17	0:10	9:27
61.	TM1	7:47	8:44	0:14	8:58	9:05	0:25	9:30	9:39	0:09	9:48
62.	TM2	7:53	9:02	0:12	9:14	9:21	0:29	9:50	10:00	0:09	10:09
63.	TM3	9:10	9:18	0:12	9:30	9:34	0:31	10:05	10:20	0:10	10:30
64.	TM4	9:33	9:35	0:15	9:50	10:09	0:23	10:32	10:42	0:08	10:50
65.	TM5	9:57	10:10	0:14	10:24	10:30	0:23	10:53	11:02	0:08	11:10
66.	TM1	10:22	10:29	0:15	10:44	10:48	0:24	11:12	11:23	0:09	11:32
67.	TM2	10:40	10:49	0:14	11:03	11:09	0:26	11:35	11:45	0:10	11:55
68.	TM3	11:05	11:06	0:15	11:21	11:29	0:28	11:57	12:05	0:10	12:15
69.	TM4	11:20	11:24	0:13	11:37	11:49	0:27	12:16	12:27	0:08	12:35
70.	TM5	11:40	11:48	0:12	12:00	12:10	0:25	12:35	12:47	0:11	12:58
						Rest time					
71.	TM1	12:02	13:00	0:10	13:10	13:12	0:21	13:33	13:36	0:10	13:46
72.	TM2	12:25	13:13	0:11	13:24	13:26	0:23	13:49	13:58	0:13	14:11
73.	TM3	12:44	13:26	0:15	13:41	13:43	0:32	14:15	14:23	0:10	14:33
74.	TM4	13:07	13:43	0:15	13:58	14:00	0:29	14:29	14:45	0:14	14:59
75.	TM5	13:30	14:10	0:12	14:22	14:24	0:31	14:55	15:09	0:09	15:18
76.	TM1	14:19	14:35	0:11	14:46	14:50	0:27	15:17	15:31	0:11	15:42
77.	TM2	14:42	14:51	0:27	15:18	15:20	0:24	15:44	15:54	0:12	16:06
78.	TM3	15:04	15:22	0:10	15:32	15:34	0:27	16:01	16:18	0:11	16:29
79.	TM4	15:33	15:37	0:10	15:47	15:49	0:41	16:30	16:41	0:10	16:51
80.	TM5	15:48	15:57	0:16	16:13	16:15	0:26	16:41	17:02	0:09	17:11
81.	TM1	16:15	16:21	0:15	16:36	16:38	0:32	17:10	17:23	0:09	17:32

Table 6.3 represents the 24 RMC delivery cases, where the time was recorded in hours and minutes for Thursday, 25th November 2021, in addition to the rest time of employees starting from 12 for one hour. Moreover, the times recorded for the 81 cases at the stationary concrete batching plant from getting to the plant site to the departure to the construction site, time of journey to the construction site, the RMC unloading to the concrete pump to place it, and the time take to unload the concrete, as have been described in this stage.

Furthermore, the following phase at the construction site starts with the truck mixers arriving for the same 81 RMC delivery cases and pouring the RMC into frameworks. The time required to finish RMC pouring in clouds, the wash time for the truck mixers, the delay time of loading due to the concrete pump situation, the downtime at the construction site, and the return journey time to the SCBP.

Table 6.4 Real-time monitoring of 81 delivery cases from the production process at SCBP to delivery to the construction site and placing it for 26 cases on Mon 20th September 2021 [Researcher].

No	ID	Start wash	Wash time	Finish Wash	Start return	Ret. Time	Delay Time loading	Start pour-ing	Pour Time	Finish pour-ing	Down Time at site
1.	TM1	8:48	0:03	8:51	8:51	0:20	0:05	8:38	0:18	8:56	0:02
2.	TM2	9:09	0:04	9:13	9:13	0:21	0:06	8:58	0:19	9:17	0:03
3.	TM3	9:31	0:04	9:35	9:35	0:23	0:10	9:19	0:19	9:38	0:02
4.	TM4	9:52	0:05	9:57	9:57	0:20	0:03	9:40	0:18	9:58	0:02
5.	TM5	10:15	0:06	10:21	10:22	0:24	0:05	10:01	0:20	10:21	0:02
6.	TM1	10:35	0:03	10:38	10:38	0:21	0:04	10:23	0:20	10:43	0:02
7.	TM2	11:01	0:06	11:07	11:09	0:25	0:08	10:45	0:19	11:04	0:02
8.	TM3	11:18	0:05	11:23	11:23	0:24	0:08	11:07	0:19	11:26	0:02
9.	TM4	11:40	0:04	11:44	11:45	0:22	0:12	11:28	0:20	11:48	0:02
10.	TM5	12:03	0:06	12:09	12:11	0:21	0:07	11:50	0:21	12:11	0:03
11.	TM1	12:25	0:05	12:30	12:30	0:22	0:03	12:13	0:20	12:33	0:02
12.	TM2	12:51	0:04	12:55	12:55	0:23	0:07	12:35	0:19	12:54	0:04
						Rest time					
13.	TM3	13:52	0:03	13:55	13:55	0:22	0:03	13:42	0:18	14:00	0:02
14.	TM4	14:14	0:06	14:20	14:20	0:23	0:14	14:02	0:20	14:22	0:02
15.	TM5	14:33	0:05	14:38	15:00	0:25	0:10	14:22	0:19	14:41	0:02
16.	TM1	14:55	0:04	14:59	14:59	0:26	0:12	14:42	0:20	15:02	0:03
17.	TM2	15:12	0:05	15:17	15:19	0:23	0:26	15:02	0:18	15:20	0:02
18.	TM3	15:36	0:05	15:41	15:43	0:24	0:08	15:23	0:19	15:42	0:03
19.	TM4	15:57	0:03	16:00	16:00	0:22	0:10	15:45	0:20	16:05	0:03
20.	TM5	16:19	0:04	16:23	16:23	0:21	0:04	16:07	0:18	16:25	0:02
21.	TM1	16:38	0:04	16:42	16:42	0:20	0:09	16:27	0:18	16:45	0:02
22.	TM2	17:00	0:05	17:05	17:05	0:21	0:10	16:48	0:19	17:07	0:02
23.	TM3	17:21	0:05	17:26	17:27	0:21	0:19	17:09	0:18	17:27	0:03
24.	TM4	17:39	0:04	17:43	17:43	0:23	0:12	17:27	0:20	17:47	0:02
25.	TM5	18:03	0:03	18:06	18:06	0:21	0:11	17:50	0:19	18:09	0:02
26.	TM1	18:25	0:04	18:29	18:31	0:23	0:06	18:12	0:21	18:33	0:03

Table 6.4 represents the real-time monitoring for 26 RMC delivery cases at the construction site, where the time was recorded in hours and minutes for Monday, 20th September 2021. Moreover, the rest time of employees starts from 12 for one hour.

Table 6.5 shows the 31 RMC delivery cases at the construction site, where the time was recorded in hours and minutes for Monday, 04th October 2021. Moreover, the rest time of employees starts from 12 for one hour, and the stationary concrete batching plant stopped for 47 minutes at 8:35 am.

Table 6.5 Real-time monitoring of 81 delivery cases from the beginning production process at SCBP to delivery to the construction site and placing it for 31 cases on Mon 04th October 2021 [Researcher].

No	ID	Start wash	Wash time	Finish Wash	Start return	Ret. Tim e	Delay Time loading	Start pour-ing	Pour. Time	Finish pour-ing	Down Time at site
27.	TM4	8:52	0:04	8:56	8:56	0:20	0:05	8:40	0:18	8:58	0:02
28.	TM5	9:18	0:05	9:23	9:23	0:25	0:02	9:00	0:26	9:26	0:02
				The stationary Batching Plant stopped for 47 minutes.							
29.	TM1	10:35	0:04	10:39	10:39	0:22	0:03	10:19	0:19	10:38	0:02
30.	TM2	10:52	0:03	10:55	10:55	0:24	0:02	10:42	0:18	11:00	0:02
31.	TM3	11:06	0:05	11:11	11:11	0:21	0:03	10:55	0:18	11:13	0:02
32.	TM4	11:38	0:04	11:42	11:42	0:20	0:04	11:26	0:19	11:45	0:03
33.	TM5	12:01	0:05	12:06	12:06	0:23	0:03	11:48	0:21	12:09	0:02
34.	TM1	12:19	0:03	12:22	12:22	0:21	0:02	12:08	0:18	12:26	0:02
35.	TM2	12:40	0:06	12:46	12:46	0:22	0:03	12:26	0:18	12:44	0:02
						Rest time					
36.	TM3	13:50	0:05	13:55	13:55	0:20	0:04	13:38	0:19	13:57	0:02
37.	TM4	14:13	0:04	14:17	14:17	0:22	0:02	14:02	0:19	14:21	0:03
38.	TM5	14:40	0:05	14:45	14:45	0:23	0:04	14:29	0:18	14:47	0:03
39.	TM1	15:09	0:04	15:13	15:14	0:26	0:02	14:58	0:18	15:16	0:02
40.	TM2	15:35	0:06	15:41	15:43	0:26	0:02	15:19	0:21	15:40	0:05
41.	TM3	16:02	0:05	16:07	16:07	0:22	0:15	15:41	0:28	16:09	0:06
42.	TM4	16:27	0:03	16:30	16:30	0:23	0:21	16:09	0:20	16:29	0:02
43.	TM5	16:52	0:05	16:57	16:58	0:31	0:05	16:38	0:21	16:59	0:02
44.	TM1	17:17	0:04	17:21	17:21	0:25	0:05	17:05	0:19	17:24	0:02
45.	TM2	17:32	0:05	17:37	17:37	0:25	0:08	17:17	0:22	17:39	0:03
46.	TM3	18:09	0:06	18:15	18:15	0:27	0:03	17:56	0:19	18:15	0:03
47.	TM4	18:27	0:03	18:30	18:33	0:27	0:12	18:16	0:18	18:34	0:02
48.	TM5	18:48	0:06	18:54	18:54	0:25	0:06	18:36	0:20	18:56	0:02
49.	TM1	19:11	0:05	19:16	19:16	0:20	0:04	18:58	0:19	19:17	0:04
50.	TM2	19:33	0:03	19:36	19:36	0:22	0:05	19:19	0:18	19:37	0:04
51.	TM3	19:52	0:04	19:56	19:56	0:23	0:03	19:40	0:19	19:59	0:04
52.	TM4	20:11	0:04	20:15	20:15	0:25	0:05	20:01	0:18	20:19	0:02
53.	TM5	20:33	0:05	20:38	20:38	0:26	0:08	20:21	0:19	20:40	0:03
54.	TM1	20:54	0:04	20:58	21:00	0:23	0:06	20:42	0:20	21:02	0:02
55.	TM2	21:18	0:05	21:23	21:23	0:25	0:11	21:04	0:21	21:25	0:03
56.	TM3	21:42	0:05	21:47	21:47	0:23	0:17	21:28	0:20	21:48	0:02
57.	TM4	22:05	0:06	22:11	22:11	0:22	0:13	21:50	0:23	22:13	0:02

Table 6.6 represents the 24 RMC delivery cases at the construction site, where the times recorded in hours and minutes on Thursday, 25th November 2021, in addition to the rest time of employees starting from 12 for one hour, for divers of truck mixers are one after back to the SCBP.

Table 6.6 Real-time monitoring of 81 delivery cases from the production process at SCBP to delivery to the construction site and placing it for 24 cases on Thu, 25th November 2021, [Researcher].

No	ID	Start wash	Wash time	Finish Wash	Start return	Ret. Time	Delay Time loading	Start pour-ing	Pour. Time	Finish pour-ing	Down Time at site
58.	TM3	8:45	0:05	8:50	8:50	0:20	0:02	8:34	0:18	8:52	0:02
59.	TM4	9:07	0:05	9:12	9:13	0:22	0:04	8:54	0:21	9:15	0:02
60.	TM5	9:30	0:04	9:34	9:34	0:23	0:13	9:17	0:20	9:37	0:03
61.	TM1	9:51	0:07	9:58	9:59	0:23	0:09	9:39	0:18	9:57	0:03
62.	TM2	10:12	0:05	10:17	10:19	0:21	0:10	10:00	0:19	10:19	0:03
63.	TM3	10:34	0:06	10:40	10:40	0:25	0:15	10:20	0:19	10:39	0:04
64.	TM4	10:52	0:05	10:57	10:57	0:23	0:10	10:42	0:18	11:00	0:02
65.	TM5	11:12	0:05	11:17	11:19	0:21	0:09	11:02	0:19	11:21	0:02
66.	TM1	11:34	0:04	11:38	11:38	0:24	0:11	11:23	0:20	11:43	0:02
67.	TM2	11:58	0:05	12:03	12:05	0:20	0:10	11:45	0:18	12:03	0:03
68.	TM3	12:18	0:03	12:21	12:21	0:23	0:08	12:05	0:20	12:25	0:03
69.	TM4	12:37	0:04	12:41	12:43	0:24	0:11	12:27	0:18	12:45	0:02
70.	TM5	13:00	0:05	13:05	13:05	0:25	0:12	12:47	0:21	13:08	0:02
71.	TM1	13:48	0:04	13:52	13:52	0:27	0:03	13:36	0:20	13:56	0:02
72.	TM2	14:13	0:04	14:17	14:17	0:25	0:09	13:58	0:21	14:19	0:02
					Rest Time						
73.	TM3	14:35	0:05	14:40	14:42	0:22	0:08	14:23	0:20	14:43	0:02
74.	TM4	15:05	0:03	15:08	15:10	0:23	0:16	14:45	0:22	15:07	0:06
75.	TM5	15:21	0:06	15:27	15:27	0:21	0:14	15:09	0:19	15:28	0:03
76.	TM1	15:44	0:05	15:49	15:52	0:23	0:14	15:31	0:21	15:52	0:02
77.	TM2	16:09	0:05	16:14	16:14	0:22	0:10	15:54	0:22	16:16	0:03
78.	TM3	16:31	0:04	16:35	16:35	0:21	0:17	16:18	0:20	16:38	0:02
79.	TM4	16:53	0:04	16:57	16:59	0:23	0:11	16:41	0:19	17:00	0:02
80.	TM5	17:13	0:05	17:18	17:20	0:25	0:21	17:02	0:19	17:21	0:02
81.	TM1	17:35	0:05	17:40	17:40	0:21	0:13	17:23	0:18	17:41	0:03

6.2.2 Real-time monitoring analysis

According to the ASTM C95/C95M-15a/ 12.10, the concrete discharge must be finished within 90 Min of the water of the RMC mixture being introduced to the other ingredients or the loading time of cement introduced to aggregates.

The customer may waive this limitation if the RMC has attained such a slump after 90 Min that it may be placed in the batch without adding water. Hot weather conditions that contribute to quick RMC hardening. The results of the analysis of the delivery time found that the total time of the delivery process from the loading materials in the hooper of the SCBP to the end of RMC pouring in the construction site exceeds limitations (less than 1:30hr) except the times as follows:

1) Monday, the 20th of September 2021, for truck mixer, truck mixer no. 3235 Baghdad/ construction (TM2) was (92 Min),

2) Monday, 04th October 2021, truck no. 48246 Sulaymaniyah/construction (TM3) 93 Min, truck no. 12778 Baghdad/construction (TM4) 98 Min, truck no. 12615 Erbil/ construction (TM5) 103 Min, and truck no. 48246 Sulaymaniyah/construction (TM3) 94 Min.

Figure 6.1 Real-time monitoring of delivery time from the SCBP to the construction site cases on Mon 20th September 2021, Mon 04th October 2021, and Thu, 25th November 2021 [Researcher].

3) Thursday, 25th November 2021, truck no.12778 Baghdad/construction (TM4) 96 Min, truck no. 3235 Baghdad/construction (TM2) 95 Min, truck no. 12778 Baghdad/construction (TM4 again) 91 Min, no. 12615 Erbil/construction (TM5) 91 Min.

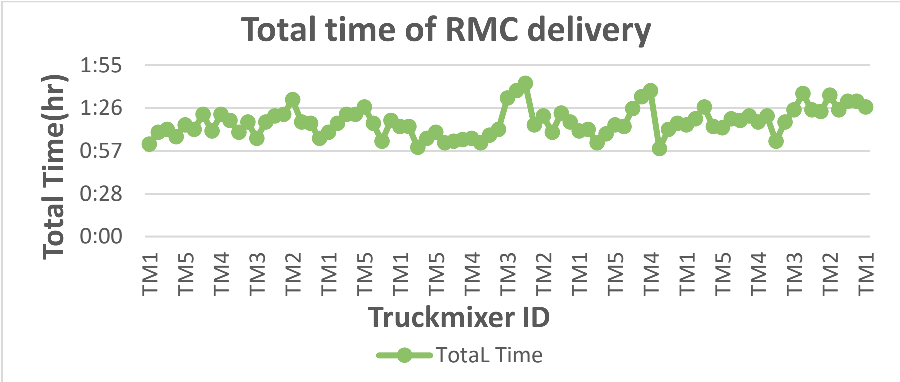


Figure 6.2 RMC total delivery time for 81 cases in real-time monitoring for the three dates on 20th September, 04th October, and 25th November 2021 [Researcher].

The following part describes the real-time monitoring process through the loading time, RMC unloading time, the journey time to the site and return time to the SCBP, truck mixers waiting time at the site before RMC pouring, the pouring time, the truck mixer washing time, and the downtime at the construction site.

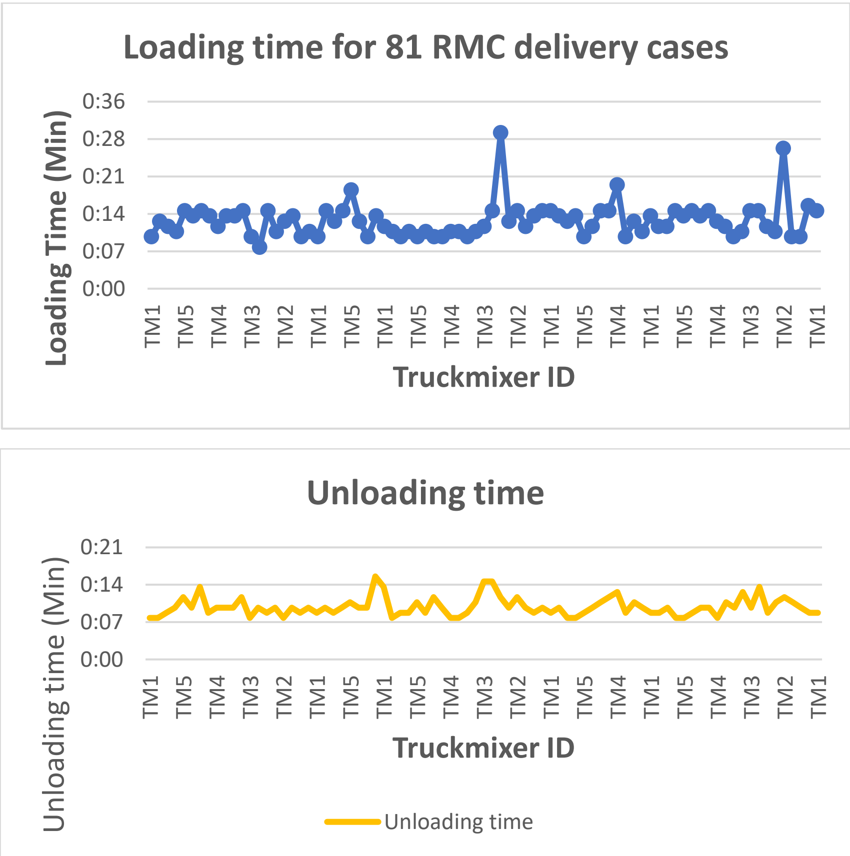
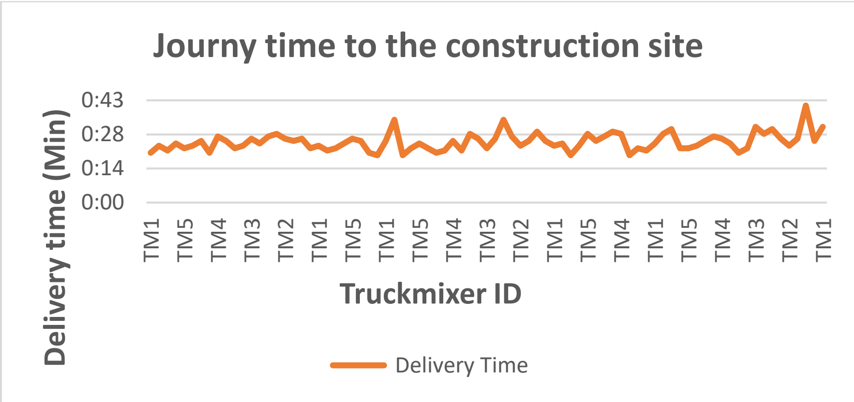


Figure 6.3 The loading time of materials in the SCBP and the RMC unloading time in the concrete pump in real-time monitoring [Researcher].

Figure 6.3 represents the time of the loading materials in the hooper of the SCBP and the RMC unloading time at the site, where the average loading time was 13 Min, the minimum loading time was 8 Min at 1:20 pm on 20th September 2021, and maximum loading time was 30 Min at 4:18 pm on 04 October 2021. Furthermore, 10 Min is the average RMC unloading time at the construction site, the minimum unloading time recorded is 8 Min at 8:46, 9:06 am, and 1:50, 3:10 pm on Monday, 20 September 2021, in addition to 10:50 am, and 2:10, 2:37, 7:48, 8:09 pm on Monday, 04 October 2021, moreover 10:50, 12:35 pm on 25 November, and the maximum unloading time is 16 Min at 9:16 am on Monday, 04 October 2021.



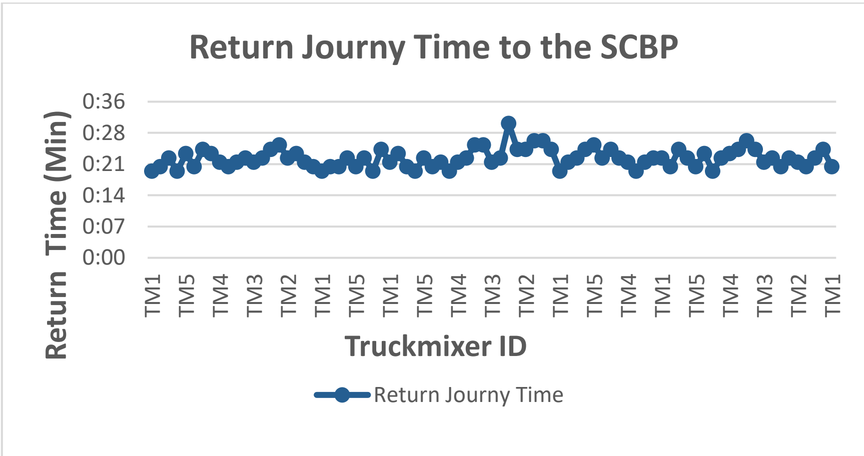


Figure 6.4 Real-time monitoring of journey time to the construction site and SCBP [Researcher].

Figure 6.4 represents the time of the journey time to the construction site and the return journey time to the SCBP, where the average journey time to the site was 25 Min, the minimum journey time to the construction site recorded was 20 Min at 8:58 am on 04th October 2021, and maximum journey time to the site was 41 Min at 4:30 pm on 25th November 2021. Moreover, the average return journey time to the SCBP is 22 Min, and the minimum return journey time recorded is 20 Min at 8:51, 9:57 am, and 4:42 pm on 20th September 2021, in addition to 8:56 am, and 1:55, 7:16 pm on 04th October 2021, and the maximum return journey time is 31 Min at 4:58 pm on 04th October 2021 due to the traffic jam.

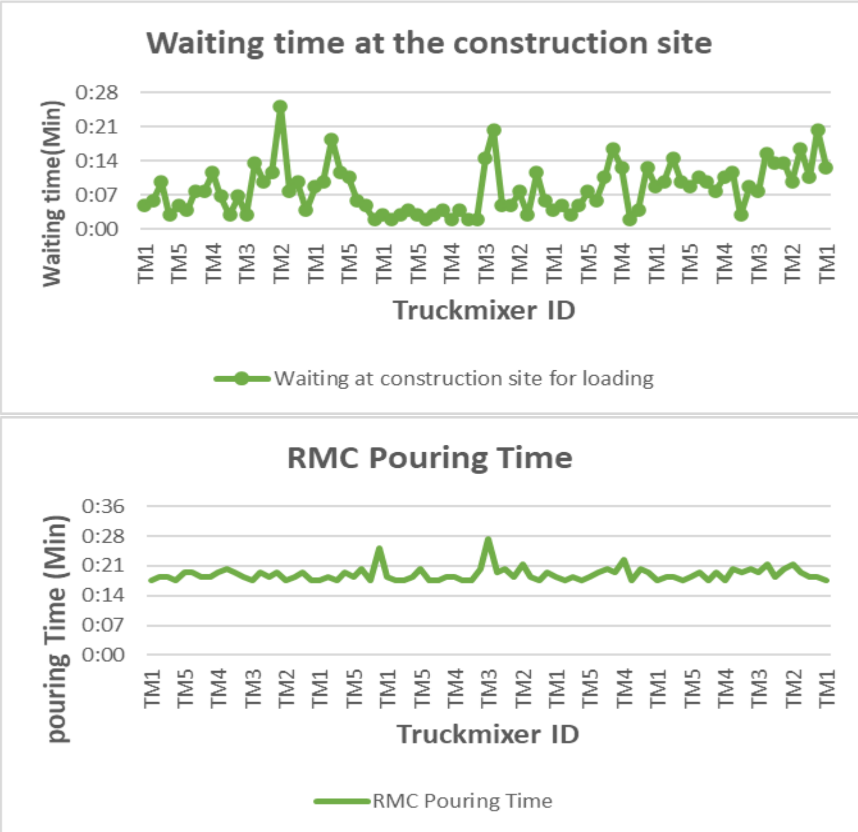


Figure 6.5 Waiting time at the construction before unloading and the RMC pouring time [Researcher].

Figure 6.5 shows the time of truck mixers waiting time at the construction site for loading in the concrete pump hopper and RMC pouring time at the construction site, where the average waiting time was 8 Min, the minimum waiting time recorded was 2 Min at 9:00, 10:42 am, and 12:08 2:02, 3:19 pm on 04 October 2021, and 8:34 am on 25 November. The maximum waiting time was 26 Min at 3:02 pm on 20 September 2021. Furthermore, 19 Min is the average RMC pouring time at the construction site, and the minimum unloading time recorded is 18 Min at 8:56, and 4:45 pm on Monday, 20 September 2021, in addition to 8:58, 11:00, 11:13 am, and 12:26, 7:37 pm on 04 October 2021; moreover 8:52, 9:57, 11:00 am, and 12:03, 5:41 pm on 25 November, and maximum pouring time is 28 Min at 4:09 am on 04 October 2021 Moreover, the truck mixer washing time and the downtimes at the construction site, where the average truck mixer washing time was 4 Min, the minimum washing time recorded was 3 Min at 8:58, , and 1:55, 6:06 pm on 20 September 2021, in addition to 10:55 am, 6:30 pm on 04 October 2021, and 12:21,3:08pm on 25 November. The maximum washing time was 7 Min at 9:58 am on Thursday, 25 November 2021. Furthermore, 2 Min is the average downtime at the construction site, and the minimum downtime recorded is 2 Min on 20 September, 04 October, and 25 November 2021and maximum downtime is 6 Min at 4:09 pm on Monday, 04 October 2021 and 3:07 pm on Thursday, 25 November 2021.

6.3 Concrete compressive strength (f_c)

One of the critical properties of RMC is compressive strength, which measures its resistance to crushing or collapsing under a load. The compressive strength of RMC can be managed by controlling various factors, including workability, air content, and porosity, where workability refers to the ease with which the concrete can be mixed, delivered, and placed. A greater degree of workability indicates a higher fluidity and ease of manipulation in concrete, while a lower degree of workability suggests a more rigid consistency. Air content refers to the air entrapped in RMC, which can be controlled by the amount of water used in the mix. Porosity refers to the number of voids in the concrete, where a higher porosity can reduce the compressive strength.

6.3.1 Slump test

The test method was initially devised to offer a means of assessing the uniformity of unhardened concrete. Its purpose is to give users a systematic approach to determining the slump of (hydraulic-cement) concretes. The test technique described above is within the purview of ASTM Committee C09 on Concrete Aggregates and is specifically overseen by subcommittee C09.60, which is responsible for testing fresh concrete. In Europe, this procedure is also governed by BS EN12350-2. In laboratory settings, where there is meticulous control over all tangible components, it is commonly observed that the slump of a specific concrete mixture tends to grow in direct proportion to the water content. The mold dimensions are specified as the sidewall of a cone frustum, with a base diameter of 20 cm, a top diameter of 10 cm, and a height of 30 cm. The rod used for tamping is a cylindrical steel rod with a diameter of 16 mm ± 2 mm. The tamping rod's length should exceed the depth by a minimum of 100 mm while not exceeding 600 mm during the rodding process. [138].

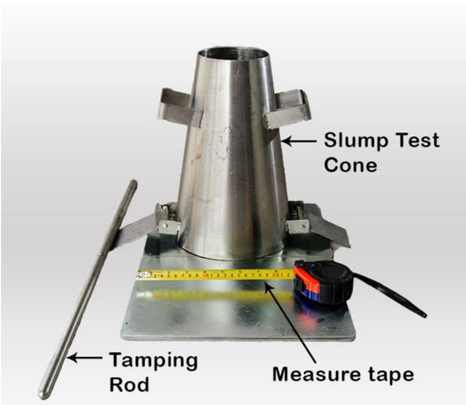


Figure 6.6 slump test cone and test tools [139].

The slump test is defined as the vertical displacement of the middle of the surface (top) of the concrete from its original location. The test was made to observe the RMC mix workability by the determination and comparison of the amount type of slump and compare the results with the limitations according to the type of construction member and required concrete grade (for our case, 25 MPa) for beams, columns, and foundations. The RMC slump is affected by materials properties, mixing method, the ratio of water /cement, and admixtures. The slump test was carried out for RMC under the conditions to which it is exposed to temperature, relative humidity, wind speed, mixing time, delivering time, and water added to the truck mixers.

The samples taken at the construction site were before the employees added the admixture for durability purposes as one percent of the RMC mix before unloading, where some of the results of failure due to the water added into truck mixers, which is an effect on the RMC properties, air content, and porosity which effects on the compressive strength as a final result.

Table 6.7 Slump test results for 16 samples taken on dates in Spring, Summer, and Winter seasons at the stationary concrete batching plant and at the construction site[Researcher].

No.	*Date / Season*	*location*	*Slump (cm)*
1.	*2021/04/08 (Thursday) Spring*	*SCBP*	*7.5*
2.		*Worksite*	*22.5*
3.	*2021/04/12 (Monday) Spring*	*SCBP*	*8.1*
4.		*Worksite*	*7.9*
5.	*2021/04/26 (Monday) Spring*	*SCBP*	*6.9*
6.		*Worksite*	*7.5*
7.	*2020/12/07 (Monday) Winter*	*SCBP*	*8.6*
8.		*Worksite*	*9.7*
9.	*2020/12/14 (Monday) Winter*	*SCBP*	*9*
10.		*Worksite*	*20.4*
11.	*2020/07/06 (Monday) Summer*	*SCBP*	*10.1*
12.		*Worksite*	*21.3*
13.	*2020/07/20 (Monday) Summer*	*SCBP*	*7.8*
14.		*Worksite*	*25.5*
15.	*2020/07/29 (Wednesday) Summer*	*SCBP*	*11.5*
16.		*Worksite*	*22.9*

Table 6.7 shows the results of the slump tests for 16 RMC samples taken as eight samples at the stationary batching concrete (SCBP) and eight samples at the construction site, where the results show two types of RMC slump: actual and shear slump, where the true slump was for the cases almost all cases at the stationary concrete batching plant (SCBP) except slump sample

11.5 cm(shear slump)which is tested on 2020/07/29 (Monday)in Summer season, in addition to the slump samples at the construction site on 2021/04/12 (Monday), 2021/04/26 (Monday) in Spring season, 2020/12/07 (Monday) in Winter season was true slump type, and the rest samples at the worksite are shear slump type. The slump test results of the RMC samples compared with the limitations recommended slump for various types of construction according to the ASTM C143/C 143M, as follows:

Table 6.8 The recommended slump for various t types of construction according to the ASTM C 143/C 143M [138].

No	*Type of construction*	*Slump (cm)*	
		Maximum	*Minimum*
1.	*Reinforced foundation, wall, and footing*	*7.5*	*2.5*
2.	*Plain footing and substructure walls*	*7.5*	*2.5*
3.	*Beams and reinforced walls*	*10*	*2.5*
4.	*Building columns*	*10*	*2.5*
5.	*Slabs Mass concrete*	*7.5*	*2.5*

The comparison of slump results with the limitation shows that the slump test results at the SCBP for April 2021, for the slab RMC of the ground floor of the building (less than or equal to 7.5 cm limitation) are met in limitations on 8th April 2021 at the SCBP, and exceed the limitation in the rest dates on April 2021 in December 2020 at the construction site, the RMC slump for the building's columns (less than or equal 10 cm limitation) results are met with limitations except the slump on 14th December 2020 did not meet the requirement, and in July 2020 where the RMC was for the reinforced foundation of the building (7.5 cm limitation) the slump results did not meet with a limitation for all dates in July 2020. Furthermore, the slump test results of the RMC at the construction site did not meet with limitations for almost all samples taken on the exact concreting dates at the worksite except the slump test results taken on 12th April 2021 (Monday) Spring was 7.9 cm, and on 26th April,2021was 7.2 cm, which meets with limitation for columns. It was observed that the standard deviation varied with the slump values and was, therefore, the most reliable measure of variability for both cases at the SCBP and construction site by the equation:

$$\text{Standard deviation } (\sigma) = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \tag{15}$$

Where:

x_i= the value of ith point in the data set, ($\bar{x}$)= the mean of this value of the data set, n=the number of data points in the data set. In comparison between both cases, the standard deviations were determined for both, as shown in Fig. 6.7.

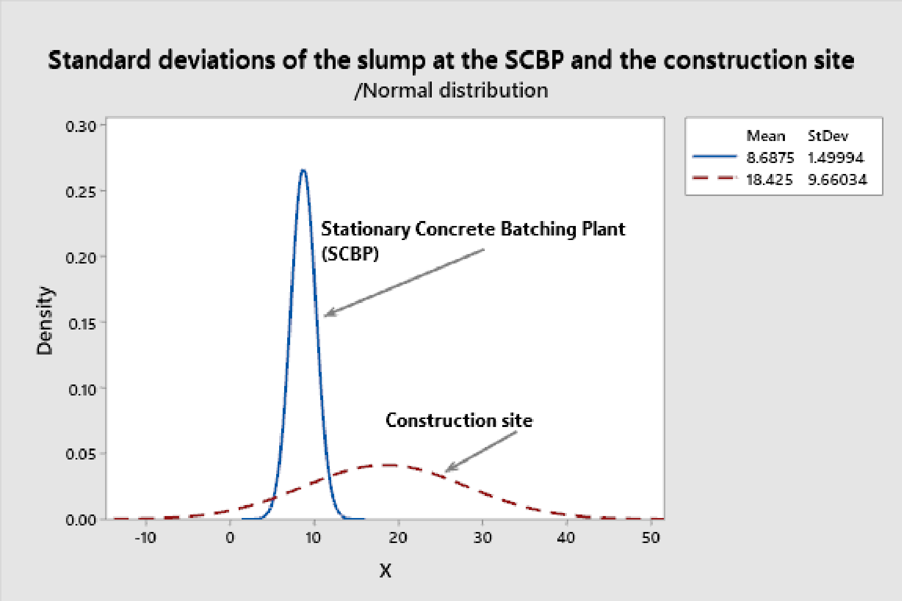


Figure 6.7 The standard deviations of the slump test at the SCBP and construction site [Researcher].

Figure 6.7 illustrates the comparison of the standard deviation for both cases: first, at the SCBP, where it was 1.5, and the mean was 8.69, and second, at the construction site was 9.66, and the mean was 18.43. Moreover, it is clear from the figure that the standard deviation at the SCBP means that the standard deviation value of 1.5 is close to the mean of 8.69 more than the standard deviation at the construction site, which is 9.66, far away from the mean 18.43 taking bell shape, due to several factors, such as the level of control and consistency in the production process at the batching plant compared to the variable conditions at the construction site. It is essential to strive for low standard deviations in any process, as it indicates a higher level of quality control and a more consistent product. It may be worth considering ways to improve the standard deviation at the construction site, such as implementing more consistent processes, addressing any potential sources of variability in the production process, real-time monitoring management to the delivery process time, and controlling the process of keeping water/cement ratio (preventing adding water at the work site) as it is designed for the required concrete grade.

6.3.2 Air content

Usually, in construction cases, it is impossible to expel all the air from the concrete, whether the concrete was fully compacted or not, still some of the entrapped air voids. For our case study, we assume the concrete is fully compacted and taken at a known age to be proportional inversely to the ratio of water/cement.

It is straightforward to determine the air content of fresh ready mixed concrete using a conventional test procedure using the pressure method.; the test is described in ASTM C 231 [140], and there is another standard for determining air content like BS 1881-107: 1983 and BS 12350-6: 2000, Furthermore, test procedure C 138/C 138M and C 173/C 173M offer distinct methodologies, namely pressure, gravimetric, and volumetric, which can determine the air content of recently mixed concrete. The reason for using the pressure method is that it covers determining the air content percentage of RMC (fresh) based on monitoring the volume changes of RMC with pressure changes, which applies to the case of study due to RMC orders, which means changing the RMC volume for different times with a change in pressure. The test results estimate the air content percentage of fresh mixed, excluding the air that may reside due to aggregate particle voids. An air meter (as a meter type) comprises a measuring bowl and a lid assembly. The operational mechanism of this meter involves the introduction of water at a designated elevation above a concrete sample of known volume, followed by the application of a pre-determined air pressure on the water. This measurement is calibrated in relation to the percentage of air present in the concrete sample. The apparatus's components are a cover assembly, Calibration Vessel, Tamping Rod, Mallet, Trowel, and Strike-Off Plate [17].

Furthermore, If the meter's design calls for inserting the calibration vessel into the measuring bowl to confirm calibration, the measure must be cylindrical and have an interior depth of 13 mm less than the bowl. The tamping rod utilized in this experiment should adhere to specific specifications.. The tamping end of the rod should be rounded, forming a hemispherical tip. A mallet with a rubber head weighing approximately 0.57±0.23 kg is recommended for evaluations of 0.5 ft3 or less. For measurements exceeding 0.5 ft3 (14 L), a mallet weighing around 1.02±0.23 kg is more suitable. A strike-off plate is a planar, rectangular metal plate with a minimum thickness of 6 mm. Its length and width should exceed the length of the measuring instrument by at least 50 mm. Furthermore, the edges of the plate should be level and uninterrupted, with a tolerance of 1.5 mm. [17].

The experimental protocol commences by moistening the inside of the determining bowl and positioning it over a stable, even solid substrate. Subsequently, the concrete is carefully placed within the determining bowl in three uniform layers of an equal quantity. Each layer of

RMC is then compacted by applying 25 strokes of a tamping rod, ensuring even distribution across the entire cross-section. Following the compaction of each layer, the sides of the determining bowl are firmly tapped between ten and fifteen times with the a mallet to eliminate any voids that may have been created during the compaction process.

Moreover, it is necessary to turn off the valve that is part of the air chamber bleeder located in the air chamber. Proceed by pumping air into the chamber until the hand of the pressure gauge stabilizes. Allow the compressed air to cool down for a few seconds to reduce its temperature. Finally, ensure that the hand of its pressure gauge remains stable along the pressure line. through air bleeding-off as required, by hand lightly tap on the gage, by the cover close petcocks (both) on the two holes, now open the valve of air between measuring bowl and the chamber of air, followed by numerous pump strokes to blow away the final traces of water. The nominal maximum aggregate size is 45mm, and the limitations for air content are 4% (moderate) and 5.5% (severe), but the total air content determined was higher than the limitations, which may reduce strength without any further improvement of durability as well as compressive strength test [141].

Table 6.9 Air content percent of the RMC mixture with 0.5 a ratio of water/ cement for samples taken in the different seasons at the SCBP and the construction site [Researcher].

No	***Date***		***Air content (%)***	***No***	***Date***		***Air content (%)***
1.	*2021/04/08 Thursday (Spring)*	*SCBP*	*2.5*	***25.***	*2020/12/14 Monday (Winter)*	*SCBP*	*6.1*
2.			*2.3*	***26.***			*3*
3.			*2.4*	***27.***			*5.7*
4.		*Work site*	*7.5*	***28.***		*Works ite*	*5.8*
5.			*7.2*	***29.***			*6.5*
6.			*5.6*	***30.***			*7.6*
7.	*2021/04/12 Monday (Spring)*	*SCBP*	*6.2*	***31.***	*2020/07/06 Monday (Summer)*	*SCBP*	*5.7*
8.			*5.5*	***32.***			*7.1*
9.			*2.4*	***33.***			*2.5*
10.		*Work site*	*3*	***34.***		*Works ite*	*7.1*
11.			*7.3*	***35.***			*5.7*
12.			*3.2*	***36.***			*7*
13.	*2021/04/26 Monday (Spring)*	*SCBP*	*2.5*	***37.***	*2020/07/20 Monday (Summer)*	*SCBP*	*2.4*
14.			*6.3*	***38.***			*5.6*
15.			*7.4*	***39.***			*6.6*
16.		*Work site*	*2.8*	***40.***		*Works ite*	*6.3*
17.			*5.5*	***41.***			*8.5*
18.			*6.9*	***42.***			*7*
19.	*2020/12/07 Monday (Winter)*	*SCBP*	*5.5*	***43.***	*2020/07/29 Wednesday (Summer)*	*SCBP*	*6.9*
20.			*5.7*	***44.***			*2.6*
21.			*2.5*	***45.***			*6.6*
22.		*Work site*	*7.8*	***46.***		*Works ite*	*6.5*
23.			*2.5*	***47.***			*7.7*
24.			*5.8*	***48.***			*5.6*

Table 6.9 illustrates the air content for 24 samples at the SCBP and 24 other samples at the construction site for the exact dates of the concreting days for the Spring, Summer, and Winter seasons as a part of the RMC real-time monitoring to study the effects of the water added to the RMC mixture in the truck mixers at the construction site to accelerate the RMC pouring process, in addition to, the short time of the RMC mixing in the SCBP mixer due to the large quantity ordered, Alkali content more than 0.8 percent due to the low-quality mixing water used as the water tests showed previously, and the RMC delivery time and the date it occurs.

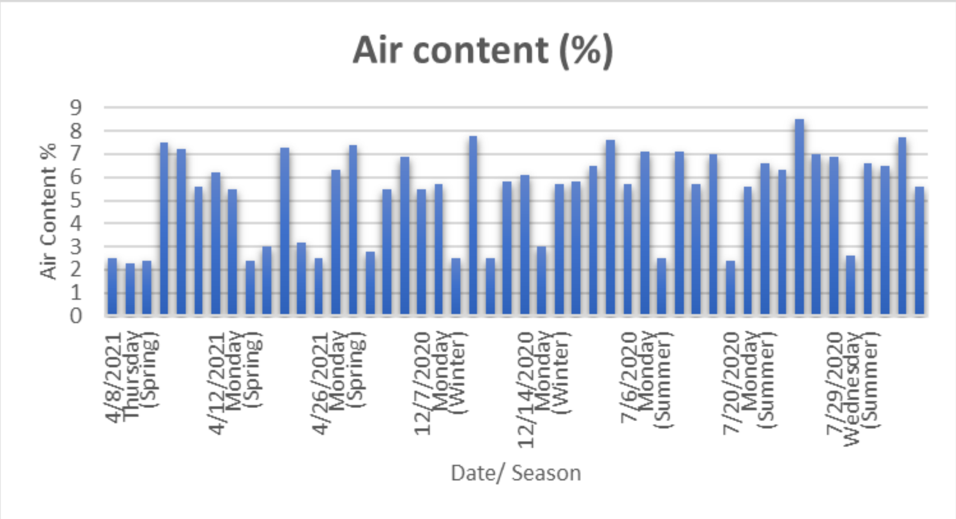


Figure 6.8 Air content percent of the RMC mixture with a 0.5 ratio of water/ cement for 48 samples taken at the SCBP and construction site [Researcher].

Figure 6.8 represents the percentage of air content according to date, days, and season; it was noticed that the air content percentage for the samples at the SCBP was less (values) than the air content percentage at the construction site, due to the water added to the RMC at the truck mixers at the construction site which is increasing the air content percentage, as shown in the figure above, where the maximum percentage of air content is 8.5 % was at the construction site on Monday in 2020/07/20, in Summer season. In the Spring season, the minimum air content percent was 2.3 % at the SCBP in 2020/04/08.In general, the process of the real-time monitoring for the 48 samples of RMC air content percent taken at the stationary concrete batching plant(SCBP) and at the construction site has shown that their diversity in the air content percentage, even if the delivery time of the RMC or the total time discharge of RMC was less than 90 Min according to the ASTM C95/C95M-15a/ 12.10, and that provides us with an idea about the effects of the short time of mixing in the SCBP mixer. These mixed water properties contain Alkali of more than 0.8 percent, as the previous chapter shows the water test and the quantity of water added to the mixture in the truck mixers before the unloading process in the concrete pump or the RMC pouring in the frameworks at the construction site.

6.3.3 Porosity

Fresh cement paste is a plastic network of cement particles in water, but once set, the paste's apparent or gross volume stays essentially constant. The paste is made up of hydrates of different cement compounds and Ca (OH)2, and the gross volume available for all these hydration products is equal to the sum of the absolute volume of the dry cement and the volume of the mix water (assuming that there is no loss of water due to bleeding or evaporation). As a result of hydration, the mixture water assumes one of three forms: combined water, gel water, and capillary water. The hydrated cement, also known as cement gel, is made up of the solid products of hydration as well as water that is physically retained or adsorbed on the enormous surface area of the hydrates; this water is known as gel water and is found between the solid products of hydration in so-called gel pores. These are pretty little since it has been shown that the volume of gel water is 28% of the amount of cement gel.

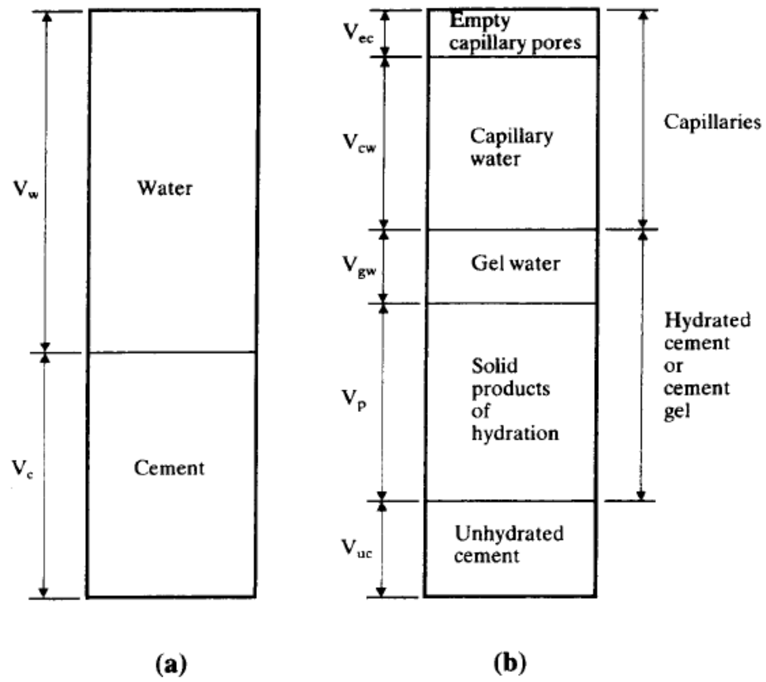


Figure 6.9 Diagrammatic representation of the volumetric proportions: (a) before hydration (degree of hydration h=0), and (b) during hydration (degree of hydration, h) [17].

Figure 6.9 illustrates the volume proportions of cement paste elements before and after cement hydration. In addition to gel water, water has been chemically or physically coupled with hydration agents and is, therefore, exceptionally tightly held. The amount of mixed water may be calculated as the non-evaporable water content, which accounts for about 23% of the dry cement mass in completely hydrated cement. The solid products of hydration now occupy a volume less than the absolute volume summation of the original dry cement (which has hydrated) and the combined water; thus, a residual space exists within the paste's gross volume.

This residual area comprises about 18.5% of the initial volume of dry cement for completely hydrated cement with no extra water beyond that necessary for hydration. The remaining space is represented by voids or capillary holes, which may be empty or filled with water depending on the initial mix. If the mixture included more water than required for complete hydration, there would be more capillary pores. Consider the volume changes caused by the hydration of cement. Remember that combined water is 23% of the mass of completely hydrated dry cement. Therefore, if the proportion of hydrated cement, the degree of hydration is h, the mass of combined water is 0.23 C*h* for the mass of original cement C when a volume of cement *Vc* has completely hydrated, a volume of empty capillary pores *Vec* equal to 0.185 *Vc* is produced. About 3.15 is the specific gravity of dry cement [17]. The cement's fineness directly affects the rate at which cement hydrates. Finer cement hydrates more quickly and thus causes a more rapid generation of heat and more significant strength gain, particularly during the early hydration period [143]. Therefore, the solid *Vc* occupies a mass of 3.15 *Vc*. Consequently, for a given hydration level, h, the volume of capillary pores that are empty equals:

$$V_{ec} = 0.185 V_c h = 0.185 \frac{C}{3.15} h = 0.059 Ch. \tag{16}$$

Hence, a combined water volume is less than the empty capillary pores volume.

$$(0.23 - 0.059) Ch = 0.171 Ch \tag{17}$$

The solid product volume of the hydration is calculated from the sum of the volumes of the combined water and the cement hydrated only for empty capillary pores as follows:

$$V_p = \frac{Ch}{3.15} + 0.171 Ch = 0.488 Ch \tag{18}$$

To find the water gel based on the truth that it always occupied 28 percent of the cement gel, which means the gel porosity is:

$$p_g = 0.28 = \frac{V_{gw}}{V_p + V_{gw}} \tag{19}$$

From the substations, the formula becomes

$$V_{gw} = 0.190 Ch \tag{20}$$

Now, the volume occupied by the capillary water, V_{cw}, can be derived as

$$V_{cw} = V_c + V_w - \left[V_{uc} + V_p + V_{gw} + V_{ec}\right] \tag{21}$$

From the compensation where the *V.C.* is the volume of the dry cement, which is equal to (C/3.15), and the Vuc is the volume of the unhydrated cement, which is equal to (*V.C.* (1-*h*)), the formula becomes:

$$V_{cw} = V_w - 0.419\text{Ch}. \qquad (22)$$

The capillary pores assist in determining the concrete's hardened properties.

$$V_{cw} + V_{cc} = V_w - 0.36Ch = \left[\frac{W}{C} - 0.36h\right]C. \qquad (23)$$

The formula now (in terms of) the ratio of water/cement by mass, which represents a fraction of the total volume of the hydrated cement, which is called the capillary porosity Pc:

$$p_c = \frac{\left[\frac{W}{C} - 0.36h\right]C}{V_c + V_w} \qquad (24)$$

The calculation of the cement paste P_t can be determined as the sum of capillary pores volumes to the volume (total) of the cement paste.

$$p_t = \frac{0.190Ch + \left[\frac{W}{C} - 0.36h\right]C}{0.317 + \frac{W}{C}} \qquad (25)$$

Hence

$$p_t = \frac{\frac{W}{C} - 0.17h}{0.317 + \frac{W}{C}} \qquad (26)$$

The equation demonstrates that porosity depends upon the ratio of water/cement and hydration degree, where the porosity decreases with an increase in the degree of hydration[17]. The expression for porosity derived earlier assumes that the fresh cement paste is fully compacted. It contains no accidental or entrapped air. If such air is present or if air entrainment is used, then the equation becomes, respectively,

$$p_t = p_t = \frac{\frac{W}{C} + \frac{a}{C} - 0.17h}{0.317 + \frac{W}{C} + \frac{a}{C}} \qquad (27)$$

The volume of pores and entrapped air is a proportion of the volume of cement gel, including voids. However, the volume of voids as a concrete proportion is also attractive. Let us consider concrete having mixed proportions by mass of the cement, coarse aggregate, and fine aggregate of C, A.C., A.F. Moreover, through the ratio of w/c by a mass and the volume of entrapped air of the total volume of voids Vv, it is given by:

$$V_v = V_{gw} + V_{cw} + V_{sc} + a \qquad (28)$$

Moreover, the total volume of RMC is given by:

$$V = \frac{C}{3.15} + \frac{A_f}{\rho_f} + \frac{A_c}{\rho_c} + W + a \qquad (29)$$

In our case study, the total voids of the RMC proportions (RMC porosity) for the volumetric proportion (1:2:2.87), water/cement ratio is 0.5, and the specific gravity is 2.6, 2.65, 3.15 for fine, coarse aggregate, and cement, respectively. Moreover, let us consider that the degree of hydration is 0.7. Moreover, the average of RMC air entrapped for all samples is 5.83 %, given by:

$$P = \frac{V_v}{V} = \frac{\frac{W}{C} - 0.17h + \frac{a}{C}}{0.317 + \frac{1}{\rho_f}\frac{A_f}{C} + \frac{1}{\rho_c}\frac{A_c}{C} + \frac{W}{C} + \frac{a}{C}} \qquad (30)$$

And

$$\frac{a}{V} = \frac{\frac{a}{C}}{3.15 + \frac{2}{2.6} + \frac{2.87}{2.65} + 0.5 + \frac{a}{C}} = \frac{5.83}{100} \qquad (31)$$

The entrapped air per unit mass of cement is $\frac{a}{C} = 0.34$, where the hydration degree is 0.7, which can describe the proportions of RMC volumes, the corresponding situation with water/cement ratio 0.5, specific gravity are 3.15 for cement, 2.6 for fine aggregate, and 2.65 coarse aggregates. Consider the cement is 20 kg, with a ratio of water/cement of 0.5, so the cement mass is 3.41kg, 1.71 kg water, 6.81kg fine aggregate, and 9.87 kg coarse aggregate.

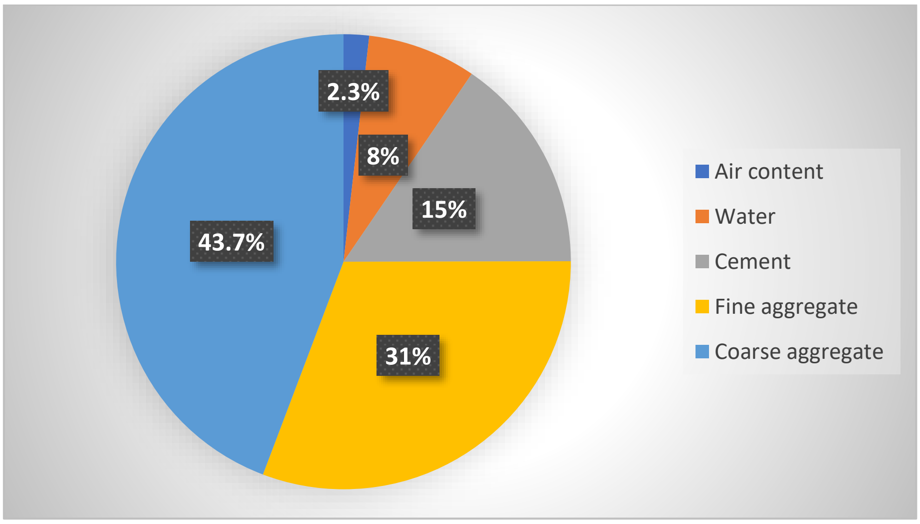


Figure 6.10 The volumetric proportion of RMC mixture before hydration with water/cement ratio 0.5 and entrapped air content 2.3 percent kg/m^3 [Researcher].

As indicated in Figure 6.10, the volumetric proportion of air entrapped in ready-mixed concrete before the hydration process is 2.3%, followed by 8% water, 15% cement, 31% fine aggregate, and 43.7% coarse aggregate. Moreover, to compare results before and after the hydration (for the maximum and average of the air content) considering that the volume changes during the hydration process where the cement and water percent change, as shown below:

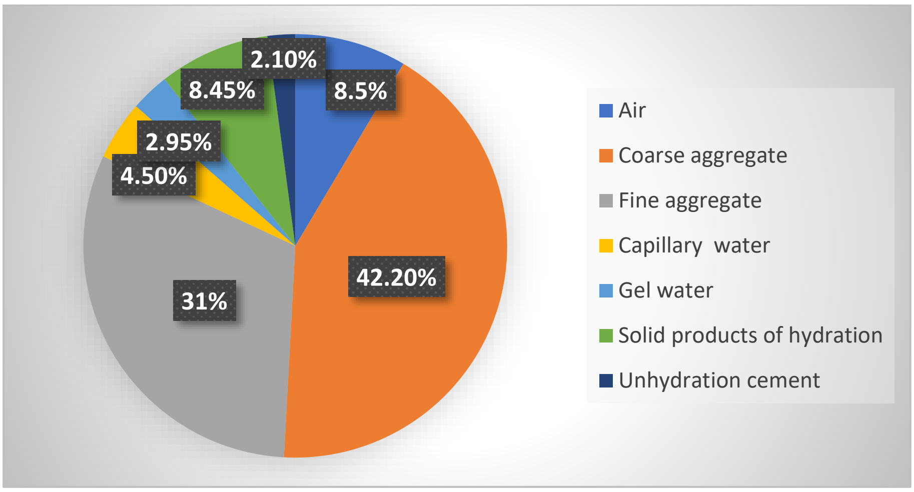


Figure 6.11 The volumetric proportion of RMC mix with a degree of hydration 0.7, maximum air content 8.5 percent, and cement specific gravity 2.6 kg/m^3 [Researcher].

Figure 6.11 represents the values (volumetric proportion) of RMC mix percent; it was noticed that the ratio of water/cement has changed (due to water added to truck mixers). The capillary water was 4.5 percent, and the gel water was 2.95 percent due to the water added more than required to the hydration process and truck mixers at the construction site, which caused an increase in air content of 8.5 percent, while the solid products of hydration were 8.45 percent and un hydrated cement 2.1 percent as average air content of the RMC mix proportion.

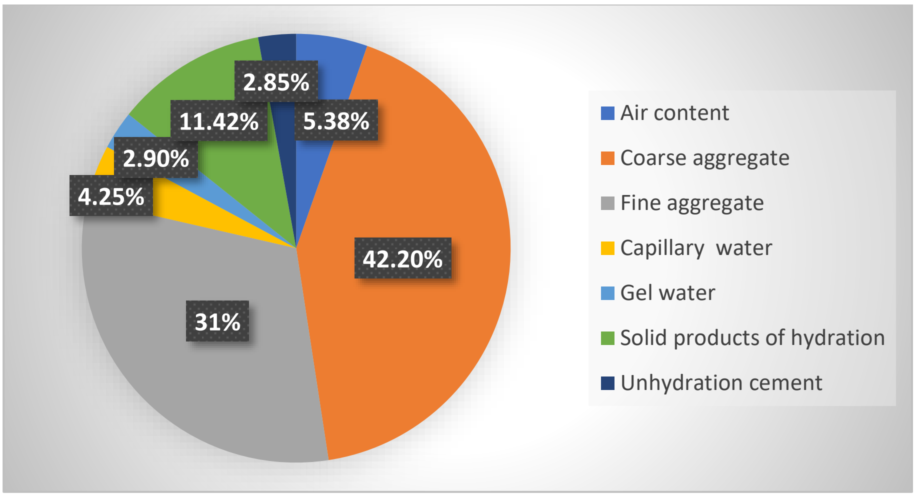


Figure 6.12 The volumetric proportion of RMC mix with a degree of hydration of 0.7, a ratio of water/cement of 0.5, and an air content average of 5.38 percent [Researcher].

Figure 6.12 represents the values proportion of the RMC mix percent was noticed that the capillary water was 4.7 percent and the gel water 2.9 percent due to the water added more than required to the hydration process and truck mixers at the construction site, which caused increasing in air content 3.8 percent, while the solid products of hydration were 11.5 percent and un hydrated cement 2.4 percent. Moreover, for real-time monitoring of the effects of volume percentage changes due to the hydration process on the RMC mix at the stationary concrete batching plant(SCBP) and the construction site, the entrapped air per unit mass of cement (a/c) and the RMC porosity can be determined by the equations mentioned previously.

Table 6.10 Porosity percent and volume of entrapped air per unit mass of cement of the RMC mixture for samples taken in the Spring, Summer, and Winter seasons at SCBP and the work site [Researcher].

No	Date		$\frac{a}{C}$	Porosity (%)	No	Date		$\frac{a}{C}$	Porosity (%)
1.	2021/04/08 Thursday (Spring)	SCBP	0.14	18.64	25.	2020/12/14 Monday (Winter)	SCBP	0.36	24.58
2.			0.13	18.35	26.			0.17	19.51
3.			0.135	18.5	27.			0.33	23.82
4.		Work site	0.45	26.77	28.		Work site	0.34	24.08
5.			0.43	26.29	29.			0.38	25.08
6.			0.33	23.82	30.			0.46	27
7.	2021/04/12 Monday (Spring)	SCBP	0.36	24.58	31.	2020/07/06 Monday (Summer)	SCBP	0.33	23.82
8.			0.32	23.57	32.			0.42	26.05
9.			0.135	18.5	33.			0.14	18.64
10.		Work site	0.17	19.51	34.		Work site	0.42	26.05
11.			0.43	26.29	35.			0.33	23.82
12.			0.18	19.79	36.			0.41	25.81
13.	2021/04/26 Monday (Spring)	SCBP	0.14	18.64	37.	2020/07/20 Monday (Summer)	SCBP	0.135	18.5
14.			0.37	24.83	38.			0.34	24.08
15.			0.44	26.53	39.			0.39	25.32
16.		Work site	0.16	19.22	40.		Work site	0.37	24.83
17.			0.32	23.57	41.			0.51	28.15
18.			0.41	25.81	42.			0.41	25.81
19.	2020/12/07 Monday (Winter)	SCBP	0.32	23.57	43.	2020/07/29 Wednesday (Summer)	SCBP	0.41	25.81
20.			0.33	23.82	44.			0.15	18.93
21.			0.14	18.64	45.			0.39	25.32
22.		Work site	0.46	27	46.		Work site	0.38	25.08
23.			0.14	18.64	47.			0.46	27
24.			0.34	24.08	48.			0.34	24.08

Table 6.10 represents the values of the porosity percentage. The volume of entrapped air per unit mass of cement (a/c) for the samples taken at the stationary concrete batching plant (SCBP) and the construction site for the dates mentioned above for Spring, Summer, and Winter seasons, where the maximum porosity was at the construction site 28.15% in Summer on 20/07/2020. The minimum porosity percentage was 18.35% on 08th April 2021 in the Summer season; the increasing porosity for the samples taken at the work site is due to the water added to the RMC mix to truck mixers at the construction site.

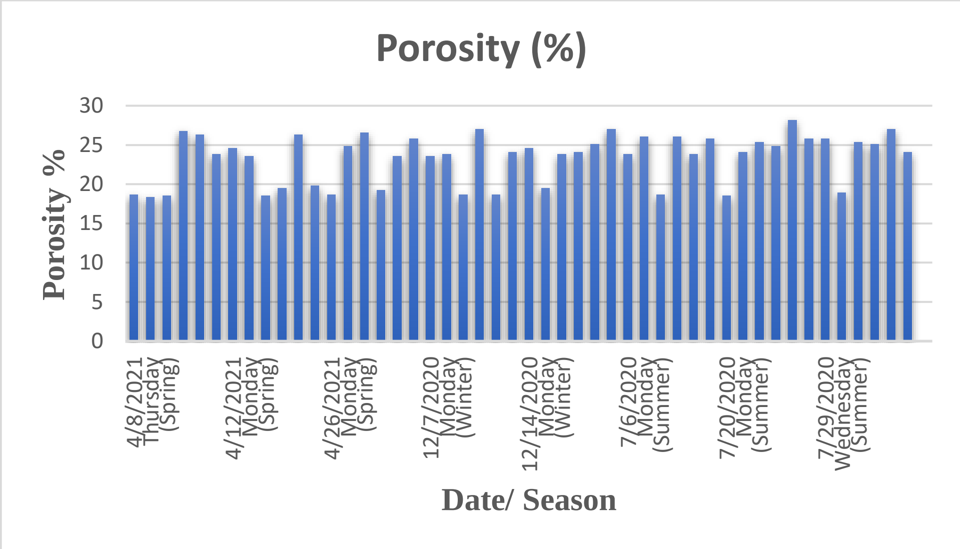


Figure 6.13 The porosity percent of the RMC mixture with a ratio of water/ cement of 0.5 for samples taken in the Spring, Summer, and winter seasons at the SCBP and the construction site [Researcher].

In general, the porosity percentage values in Figure 6.13 represent that the RMC has a high porosity percent for the samples taken on the dates mentioned in the previous table for the Spring, Summer, and Winter seasons due to the effects of the conditions on RMC mixture, such as changing in the water/cement ratio due to water added to truck mixers at the construction site, Moreover, the delay in the transport time because of traffic jam, waiting time at the work site, the distance between the SCBP and the construction site which is 11 km, in addition to the effects of the weather conditions temperature, humidity, which is the effect on the rate of the evaporation the water of the RMC mix causes increasing in porosity percentage. The values of porosity percent at the work site are higher than those at the SCBP; these values provide us with an accurate view and prove the condition's effects on the compressive strength.

6.3.4 Concrete compressive strength (f_c) test

Since strength is a variable, while creating a concrete mix, we must strive for a mean strength more significant than what is necessary from a structural standpoint so that we may anticipate that every component of the structure will be formed with strong enough concrete [141]. The test results of the laboratory for samples collected from the RMC precisely for each mixing process, recorded as part of the monitoring process for RMC in real-time monitoring for 96 test samples collected for each mixing process (day) for two phases; the first one was 48 samples before making the adjustments by the fact of six samples for each date with three samples at the SCBP and three samples at the work site and the second phase is 48 samples after making adjustments for the production process. The testing of 48 samples taken before making the improvements (24 at the SCBP, the 24 cubes at the construction site), described in table 6.11, where the samples were taken as a part of real-time monitoring without consideration for effects of the surrounding conditions like temperature. Humidity and delivery time, quality of materials, and suppliers, where the 24 test samples taken at the worksite are as follows:

1. The test samples (9 cubes) were taken for the foundation casting for the building as a whole; the foundation was raft foundation, which is cast in three stages: the first stage to the right side to the location of the elevator, the second is the middle part of the foundations, and the third is the left side of the foundation of the building with (3 cubes for each stage), where the reason for dividing the concreting of the building into three stages was for financial reasons were the enterpriser was buying ready mix concrete from SCBP.

Figure 6.14 RMC compressive strength samples for foundations (six cubes) at 28 days [Researcher].

2. The RMC test samples (9 cubes) were taken from the concrete for the columns of the first floor from the RMC casting at the construction in real time, where the columns were cast in three stages, with 3 test samples for each stage.

Figure 6.15 RMC compressive strength samples for the columns (six cubes) at 28 days [Researcher].

3. The RMC test samples (6 cubes) of the ground floor slab are cast in two stages, the first to the right side and the second to the left side of the building with (3 cubes for each stage).

Figure 6.16 RMC compressive strength test samples for the ground floor slab (3 cubes for the first stage) at 28 days [Researcher]

Figure 6.17 RMC compressive strength test samples for the ground floor slab (3 second-stage cubes) at 28 days [Researcher].

Furthermore, the other 24 cubes were taken at the stationary concrete batching plant (SCBP)for ready-mixed concrete (RMC) before the truck mixers journey to the construction site, which is 11 km away from the site of the stationary concrete batching plant (SCBP). The tests were done in the Engineers Union/ Iraq/ Misan construction laboratory, according to ASTM C31, where the results represent the test for the RMC samples before making improvements, where the mean compressive strength required 25 MPa.

The average of the compressive strength for the cases chosen for 48 test samples for various seasons was 25.3 MPa, as shown in the figure below, where the samples of tests were taken directly after the mixing in the SCBP (three cubes the size of the mold is 150 x 150 x150mm for each mixing date) and at the construction site with three cubes for each mixing date.

Figure 6.18 The compressive strength fc (MPa) of RMC at the laboratory at 28 days age [Researcher].

The RMC samples are taken in the current situation without any improvements or adjustments to RMC mixture ingredients, representing RMC compressive strength under the variables parameters and conditions that affect the compressive strength.

Table 6.11 RMC compressive strength test results for samples at SCBP and construction site at age 3, 7, and 28 days for real-time monitoring during Spring, Summer, and Winter seasons [Researcher].

No	***Date***		***f_c* at 3 days**	***f_c* at 7 days**	***f_c* at 28 days**	***No***	***Date***		***f_c* At 3 days**	***f_c* At 7 days**	***f_c* At 28 days**
1	*2021/04/08 Thursday (Spring)*	*SCBP*	*10.5*	*19.7*	*26.3*	***25***	*2020/12/14 Monday (Winter)*	*SCBP*	*10.1*	*18.9*	*25.2*
2			*10.8*	*20.3*	*27.1*	***26***			*10.7*	*20*	*26.7*
3			*10.6*	*19.9*	*26.5*	***27***			*10.2*	*19.1*	*25.4*
4		*Worksite*	*9.6*	*18.1*	*24.1*	***28***		*Worksite*	*10.1*	*18.9*	*25.2*
5			*9.8*	*18.4*	*24.5*	***29***			*9.9*	*18.6*	*24.8*
6			*10.3*	*19.3*	*25.7*	***30***			*9.6*	*17.9*	*23.9*
7	*2021/04/12 Monday (Spring)*	*SCBP*	*10.1*	*18.9*	*25.2*	***31***	*2020/07/06 Monday (Summer)*	*SCBP*	*10.1*	*18.9*	*25.2*
8			*10.4*	*19.4*	*25.9*	***32***			*9.8*	*18.4*	*24.5*
9			*10.6*	*19.9*	*26.5*	***33***			*10.4*	*19.5*	*26*
10		*Worksite*	*10.2*	*19.2*	*25.6*	***34***		*Worksite*	*9.8*	*18.4*	*24.5*
11			*9.7*	*18.2*	*24.3*	***35***			*10.2*	*19.2*	*25.6*
12			*10.2*	*19.1*	*25.4*	***36***			*9.8*	*18.5*	*24.7*
13	*2021/04/26 Monday (Spring)*	*SCBP*	*10.8*	*20.2*	*26.9*	***37***	*2020/07/20 Monday (Summer)*	*SCBP*	*10.8*	*20.3*	*27*
14			*10.1*	*18.9*	*25.2*	***38***			*10.2*	*19.2*	*25.6*
15			*9.7*	*18.2*	*24.3*	***39***			*9.9*	*18.6*	*24.8*
16		*Worksite*	*10.6*	*19.8*	*26.4*	***40***		*Worksite*	*10.1*	*18.9*	*25.2*
17			*10.3*	*19.4*	*25.8*	***41***			*9.5*	*17.9*	*23.8*
18			*9.8*	*18.5*	*24.6*	***42***			*9.8*	*18.5*	*24.6*
19	*2020/12/07 Monday (Winter)*	*SCBP*	*10.4*	*19.4*	*25.9*	***43***	*2020/07/29 Wednesday (Summer)*	*SCBP*	*9.8*	*18.4*	*24.6*
20			*10.2*	*19.2*	*25.6*	***44***			*10.7*	*20*	*26.7*
21			*10.5*	*19.7*	*26.3*	***45***			*9.9*	*18.5*	*24.7*
22		*Worksite*	*9.6*	*18*	*24*	***46***		*Worksite*	*10*	*18.7*	*24.9*
23			*10.4*	*19.6*	*26.1*	***47***			*9.6*	*17.9*	*23.9*
24			*10.1*	*18.9*	*25.2*	***48***			*10.2*	*19.1*	*25.5*

Table 6.11 shows that the results of compressive strength exceeded the compressive strength required (25 MPa) for both cases at SCBP and the construction work site for the 48 samples tested at the construction laboratory of the Engineers Union/ Iraq/ Misan according to ASTM C39 and ASTM C31, 318 Building Code; concrete testing, and the EN Eurocodes.

Moreover, the highest RMC compressive strength value was 27.1 MPa at SCBP in Spring 2021(April), where the daily maximum temperature was (25.5°C), wind speed (8 mph), and maximum humidity (was 84%), and the lowest RMC compressive strength value was 23.8 at a construction site in Summer 2020 (July) where the maximum daily temperature was (35°C), maximum wind speed (79 mph), and maximum humidity (79%). Furthermore, the results show that some RMC test samples fail to reach the compressive strength required (25 MPa) individually, but they manage the required compressive strength by the average (but the failure is in limitations less than 3.5 MPa based on ASTM).

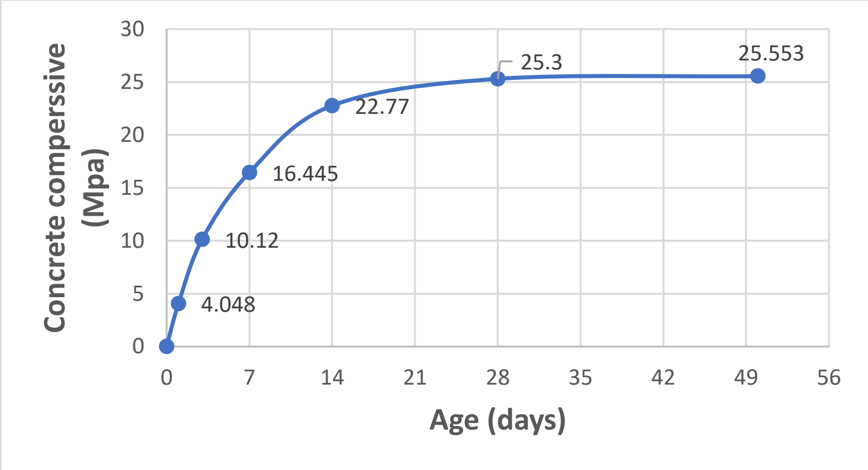


Figure 6.19 Average of RMC compressive strength test results at age 28 days for the samples at SCBP and the construction site [Researcher].

Therefore, the main challenge was to improve the quality of RMC for this project under these circumstances only by monitoring and improving the compressive strength of RMC at the lowest possible cost and overcoming concrete quality problems. So, to improve the quality of RMC at the minimum possible cost, with less time required and lower workforce efforts, it has been proposed several improvements to the RMC production and the RMC mixture itself, based on the monitoring in real-time in different seasons in the daytime and at nighttime according to data, the calculation of the parameters and take its effects before and after these adjustments for both cases at SCBP and then at the construction site. Furthermore, as a compersion between the quality of RMC at the SCBP and a construction site, it found that the average compressive strength at age 28 days at the SCBP was 25.75 MPa, 16.74 MPa at seven days, and 10.3 MPa at three days, where the concrete are mixed in the planetary concrete mixer of the SCBP under the average speed of the mixer paddles, and the time of RMC mixing.

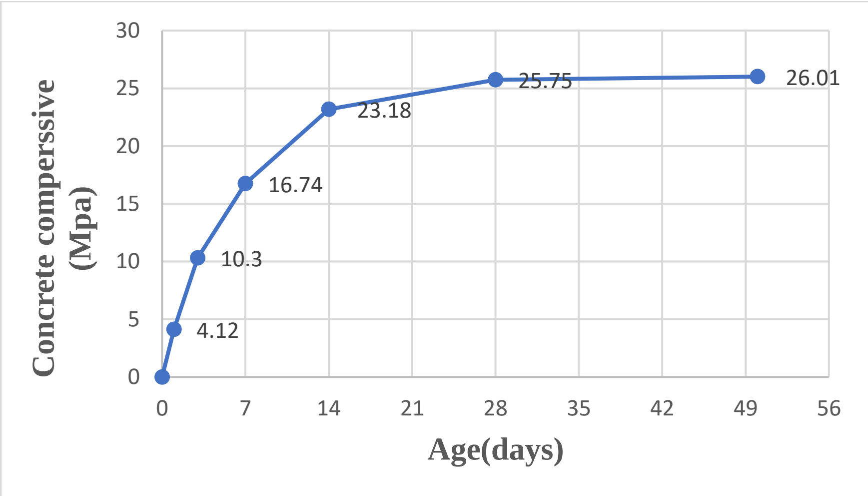


Figure 6.20 The average RMC compressive strength test results at age 28 days for the samples at SCBP [Researcher].

The second case is the quality of RMC at the construction site, where the results show that the average of the compressive strength at age 28 days at the SCBP was 24.93 MPa, 16.2 MPa at 7 days, and 9.97 MPa at 3 days, which is less ths n than the comperassive strength at the SCBP, in addition to water quantity added to the mix, and the effect of the Alkali per cent more than 0.8 percent which is comes from the low quality mixig water (P.W, and O.W) as the water testsed in prevoiouse chapter, where the RMC are transported to construction site by truck mixers undre the conditions of the RMC time of delivery (traffic, peak hours, and time waiting at construction site before RMC pouring), Mix tempertuer, weather conditions like temperture, relative humidity, wind speed, evaporation rate, air content, and porosity, all theses conditions with no control contribute in the comperassive strength reduction less than required which is 25 MPa as an average, but it is meet with the requiremed comperassive strength by the average of the samples taken for each date espcially in Summer season, whenever temperuture increased more water added, minimum comperassive strength reslts which is 23.8 MPa at 20th July,2020.

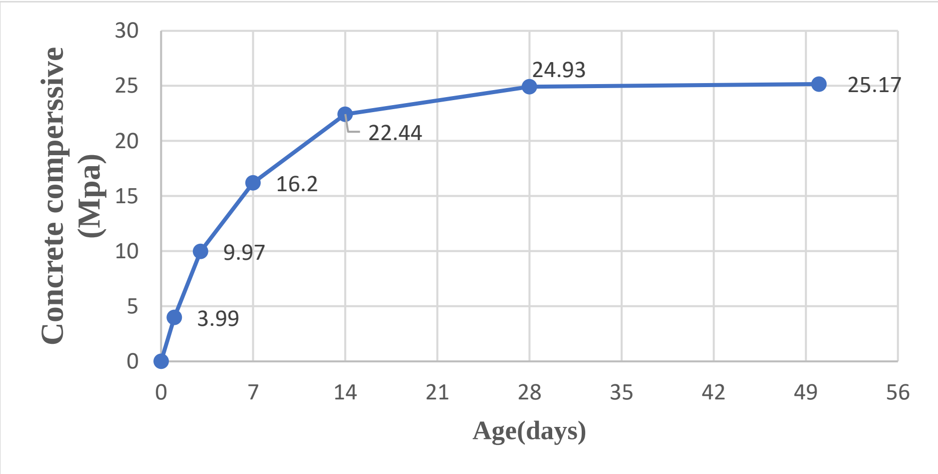


Figure 6.21 The average RMC compressive strength *fc* (MPa) test results at age 28 days for the samples at the construction site [Researcher].

Figure 6.21 represents the RMC compressive strength by different ages in days at the construction site for 24 samples taken on dates mentioned previously.

6.4 Results and relationships

As analysis for the effects of the results values of the real-time monitoring for materials quality (93 tests), RMC delivery time (81cases), air content (48 test samples), and porosity samples (48 test samples) on the compressive strength and determination the relationship of each factor with the compressive strength, as following:

1) The compressive strength is in direct proportion with an increase in the quality of the materials for each topic of the tests for water, cement, fine aggregate, and coarse aggregate, which means that the values of these factors, whenever close to the limitations are good

quality, and compare between these results, where the second supplier have the best quality of materials, to achieve zero defects in RMC, it is essential to use high-quality ingredients, monitoring the RMC mixing, delivery, and implement strict quality control.

2) The RMC delivery time (total discharge time) to the construction site is inversely proportional to the compressive strength, where if the time of delivery increases, then the RMC compressive strength decreases.

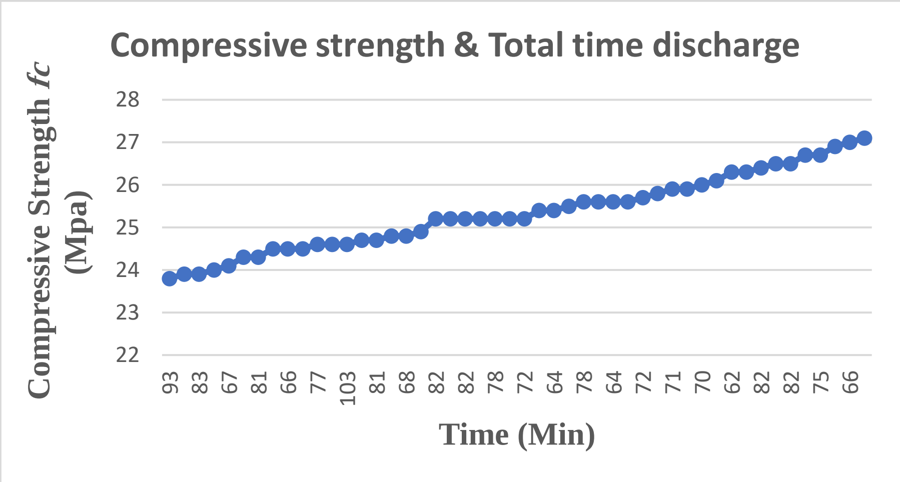


Figure 6.22 The compressive strength is inversely proportional to total discharge time [Researcher].

Figure 6.22 illustrates the relationship between the compressive strength and the RMC time of delivery based on the assumption that the same conditions of delivery time happened at the concreting dates mentioned previously, where it shows decreasing the compressive strength with increasing the time of delivery, where the maximum discharge time was 93 Min (which exceeds the limitation of 90 Min based on ASTM). In contrast, the compressive strength is 23.8 MPa (minimum), which is less than the compressive strength required (25 MPa), and the maximum compressive strength is 27.1 MPa, while the RMC delivery time is 66 Min (minimum). It is essential to ensure that the concrete is mixed, transported, and placed within a specified delivery time to maintain workability and prevent water loss from the mix. If the transit time is too long, the concrete may begin to set before it can be placed, reducing compressive strength.

3) An inverse proportion relationship between the compressive strength and the air content of RMC, where the compressive strength decreases with an increase in the air content of RM:

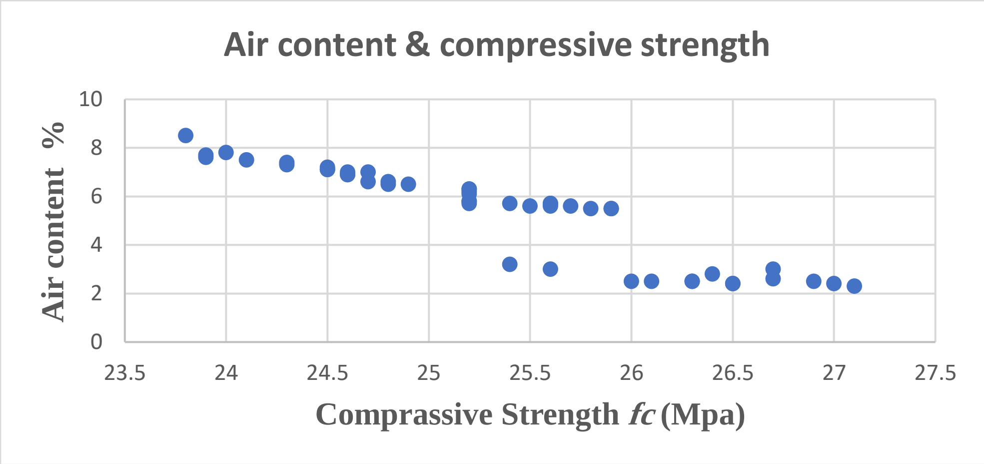


Figure 6.23 The relationship of the Air content percent with the compressive strength [Researcher].

Figure 6.23 represents the relationship between the RMC compressive strength and the Air content of RMC (direct proportion); in general, the increase of the percentage of air content decreases the RMC compressive strength, where the air content was 8.5% (maximum air content) the compressive strength was 23.8 MPa which is the minimum compressive strength because the capillary water pores and gel water pores in the RMC mix reduce the amount of contact between the aggregate particles, which reduces the compressive strength, on the other hand, if the air content percent decreased the compressive strength will increase, where, for the RMC samples the minimum air content was 2.3%, the compressive strength of the RMC was 27.1 MPa as mentioned previously.

4) The porosity of the RMC is inversely proportional to the compressive strength, where if the porosity of the RMC decreases, then compressive strength increases; see Figure 6.26.

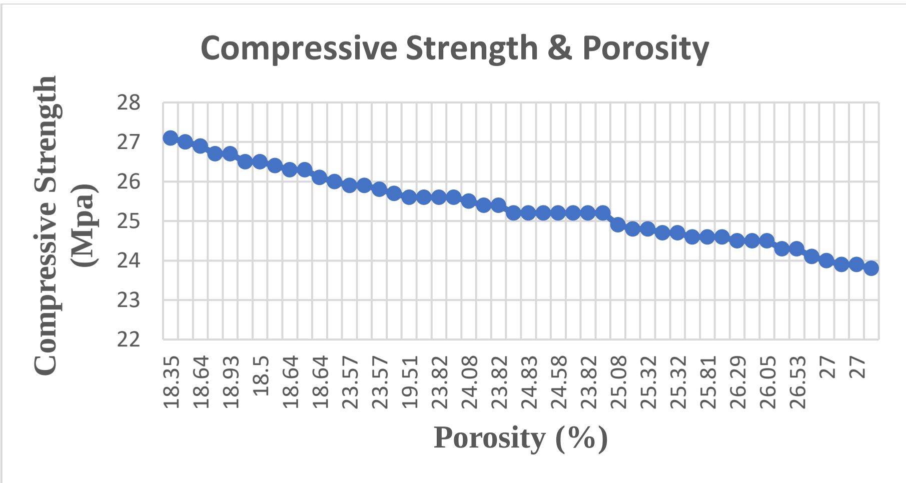


Figure 6.24 The compressive strength *fc* (MPa) relationship with RMC porosity percent [Researcher].

Figure 6.24 represents the inversely proportional relationship between the compressive strength and porosity percent, which shows that increasing the porosity percent reduces the compressive strength fc (MPa). Moreover, the maximum compressive strength fc was 27.1 MPa, determined at a minimum porosity percent of 18.35%; on the other hand, the minimum compressive strength (*fc*) was 23.8 MPa, occurring at the maximum porosity was 28.15 %, which is the maximum porosity percentage.

5) The direct proportional relationship between the air content percentage and the porosity percent, where the porosity percent increases with the air content percent increases, the lowest air content percentage is 2.3%, and the minimum porosity is 18.35%.

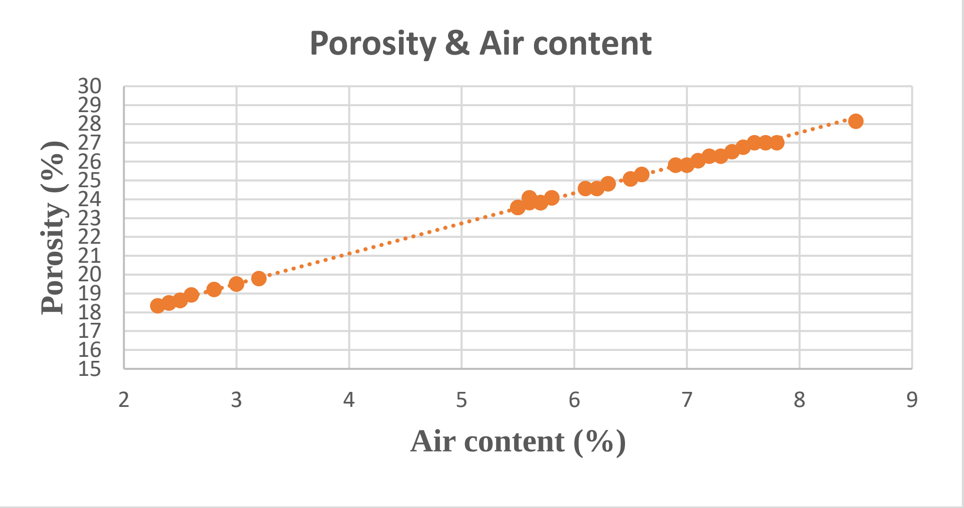


Figure 6.25 Direct proportional relationship of the RMC Porosity with Air content [Researcher].

The characterizing values of the porosity and the air content of the RMC in Figure 6.25 have shown us the direct relationship between them, where the maximum air content value was 8.5%, and the porosity was 28.15% of the RMC sample.

High porosity in ready-mix concrete can be caused by adding too much water during the hydration process, which can occur if the water-to-cement ratio is too high or if the water is not correctly distributed throughout the mix. The presence of high porosity in the concrete can have several negative impacts on the RMC, where the high porosity can decrease compressive strength and make it more susceptible to cracking, as shown below, in addition to the effect on durability. The high porosity effect can be addressed; it will be essential to identify and correct the underlying cause, which may involve adjusting the water-to-cement ratio to ensure proper mixing and distribution of the water.

Furthermore, to see the effect of porosity on RMC test samples, the slices from cubes of RMC made with 4 cm x 4cm dimensions were taken to photographed with accuracy one millimeter by a camera specialized in scientific research, where the slices were taken for samples for 28 days aged after the mixing date, as shown below:

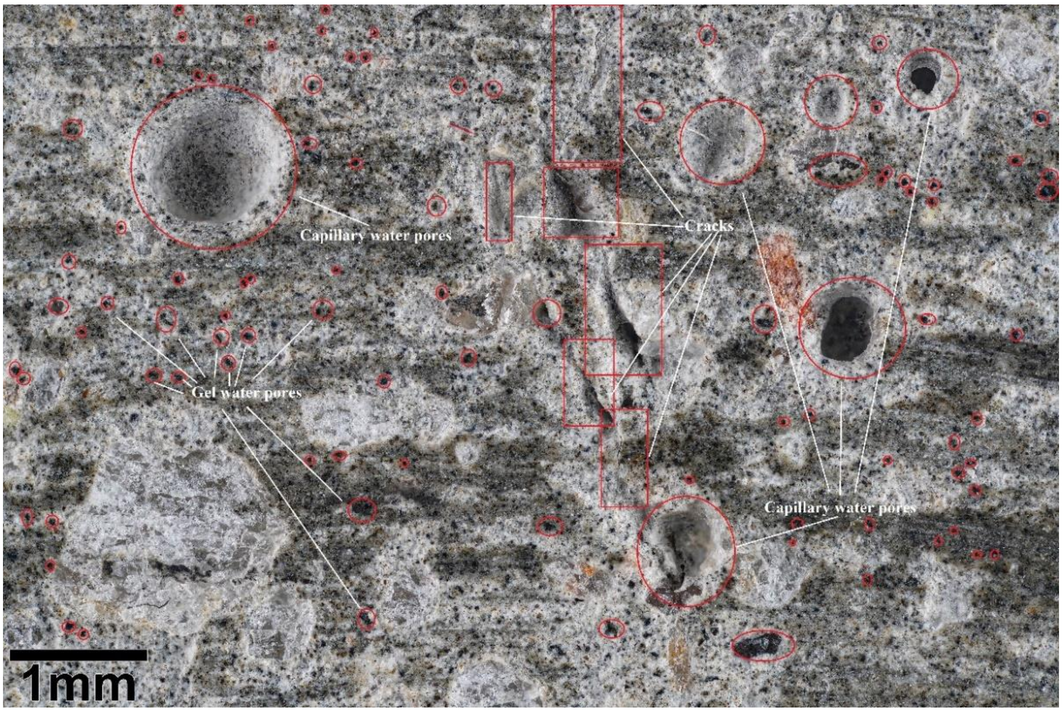


Figure 6.26 The RMC sample photographed with an accuracy of one millimeter shows the capillary water pores, gel water pores, and shrinkage cracks, with priority 28.15 % (maximum) and air content 8.5% (maximum), providing 23.8 MPa compressive strength (minimum *fc*) [Researcher].

Figure 6.26 shows the capillary water pores, gel water pores, and shrinkage cracks, which are caused by the water added more than is needed for hydration with the dry components, such as sand, cement, and an aggregate of the RMC mix, where most of the water will eventually evaporate, causing shrinkage cracks, for the capillary water pores which are increased by the increase of the water added to RMC mix more than required.

In addition to the gel water pores, they are smaller than the capillary water pores and have an irregular shape (size) of these pores, with a maximum porosity of 28.15 % and a maximum air content of 8.5% for RMC mix with water/ cement ratio (0.7) more than planned ratio (0.5) due to water added to the truck mixers causes increase in percent of air content and decreased the compressive strength where the RMC compressive strength tests results were 23.8 MPa which is a minimum compressive strength recorded which is less than fc required (25 MPa).

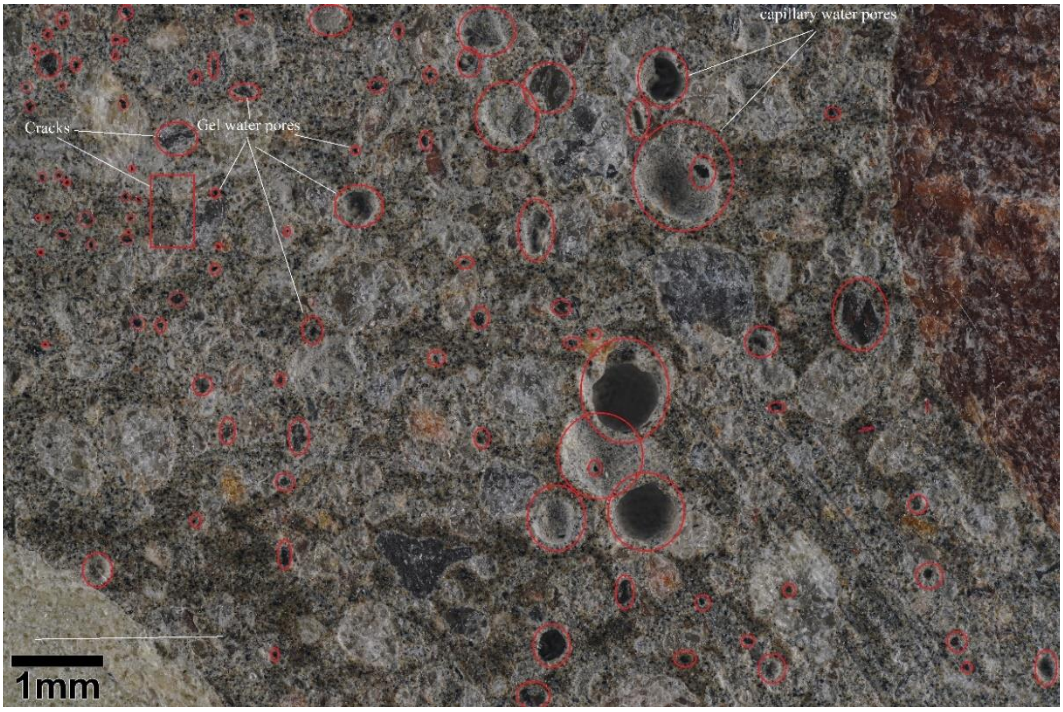


Figure 6.27 The RMC sample photographed with an accuracy of one millimeter shows the capillary water pores, gel water pores, and cracks, with porosity of 25.81 % and air content of 6.9 %, providing 24.6 MPa RMC compressive strength [Researcher].

Figure 6.27 shows the second slice sample, which was taken on Wednesday, 29th July 2020, in the summer season from the RMC sample, with mix water/cement ratio more than planned ratio because the air content percent exceed limitations (5.5% for the maximum nominal aggregate size 45mm) due to water added to truck mixers, with 25.81 %, porosity percent and 6.9% air content percent for RMC mix where the RMC compressive strength tests results were 24.6 MPa which is a moderate compressive. Furthermore, the picture shows that the capillary water pores, gel water pores, and shrinkage cracks are reduced, but still, porosity percent and air content percent are high, and the RMC compressive strength is less than required (25 MPa). The third slice sample, as shown below taken on Thursday, 08th April 2021, in the Spring season, from the RMC sample (cube) with a mixed water/cement ratio of 0.5, where the porosity is 18.35% (the minimum percentage in all sample), and air content 2.3 % (the minimum percent), for RMC mix, provide 27.1 MPa which maximum compressive strength recorded meet with (more than)the RMC compressive strength required (25MPa), the picture shows that the capillary water pores, gel water pores, and shrinkage cracks are reduced more than the first and second slice samples.

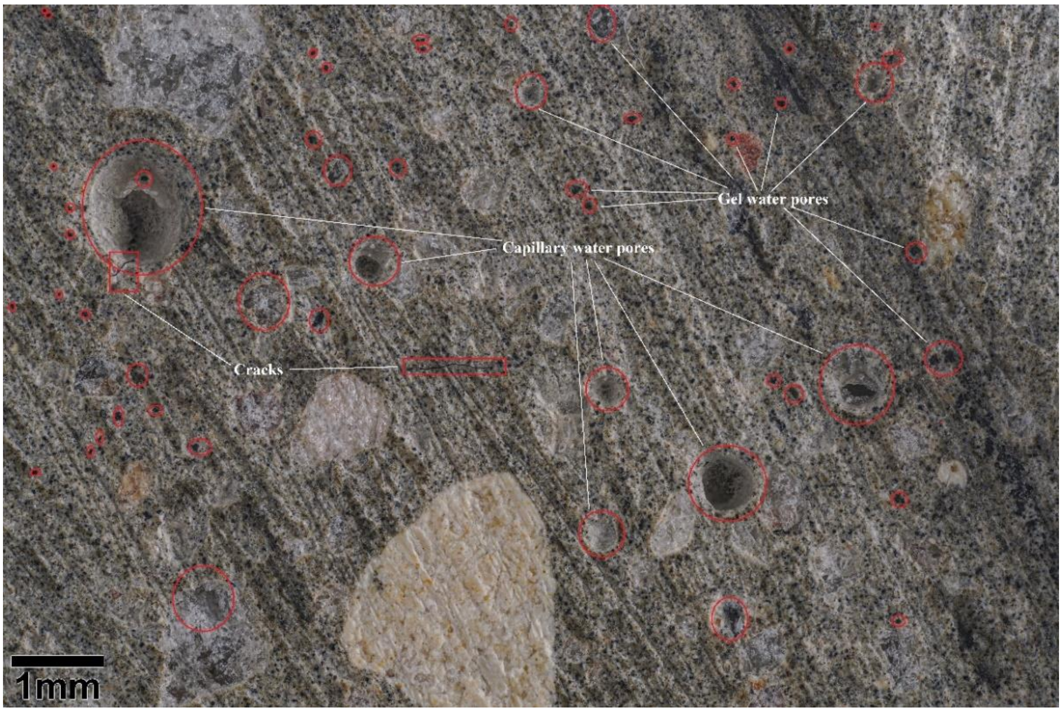


Figure 6.28 The RMC sample photographed with an accuracy of one millimeter shows the capillary water pores, gel water pores, and cracks, with porosity of 18.35 % (minimum percent) and air content of 2.3 % (minimum percent), for the RMC mix with water/ cement ratio 0.5 provide 27.1 MPa compressive strength (maximum *fc*) [Researcher].

Figure 6.28 represents the RMC sample's capillary water pores, gel water pores, and cracks, with minimum porosity of 18.35 % and minimum air content of 2.3 %, for RMC mix with water/ cement ratio 0.5 provide 27.1 MPa (maximum compressive strength).

Generally, it is concerning to see that the porosity of the ready-mix concrete is more than 20 percent. High porosity can indicate several potential issues with concrete.

The high porosity can lead to a reduction in the strength and durability of the concrete. Pores within the concrete can fill with water, leading to the potential for corrosion of the reinforcing steel. In addition, high porosity can also lead to a reduction in the overall service life of the concrete, as it may be more susceptible to cracking and other forms of deterioration, as shown above. It is also important to note that the presence of both capillary and gel water pores may contribute to the high porosity. Capillary water pores are formed when water is drawn into the concrete through tiny pores, while gel water pores are formed when excess water is trapped within the concrete during curing. Moreover, both types of pores can lead to an increase in porosity and a reduction in the strength and durability of the concrete.

CHAPTER 7 RMC MIX IMPROVEMENTS AND PARAMETERS STABILIZATION

7.1 Introduction

Concreting in hot weather presents several challenges due to the high RMC temperature under many circumstances and accelerating the RMC evaporation rate of the fresh mixture. In the event of large volumes, the issues are probable cracking caused by a temperature spike and subsequent decrease caused by the cement hydration heat, as well as the simultaneous restricted volume variations. This chapter studies the effects of the temperature, rate of evaporation, and the percentage of air content of the mix on the RMC compressive strength for seasons (Spring, Summer, and Winter) through a real-time monitoring procedure of 80 samples of temperatures, relative humidity, wind speed, and evaporation rate at the SCBP and the construction site after RMC delivered to the site with different air temperatures and surrounding conditions. In addition, determining the precise quantity of ice melted required to reduce the RMC mix temperature for cases exceeds the limitations. Moreover, study the effects of these variables on the compressive strength, their ability of real-time monitoring of the RMC production to make improvements on the RMC compressive strength, and make decisions to prevent a defect before it shows up and make recommendations based on the results.

7.2 Real-time monitoring process

A higher temperature of fresh concrete in hot weather than expected results in more rapid cement hydration, leading to accelerated setting and a decreased compressive strength, where, if high temperature is accompanied by a low relative humidity of the air, rapid evaporation of some mixed water occurs, causing a higher loss of workability and increasing the plastic shrinkage. The rapid acceleration of the cement hydration heat induces tensile stresses, which may cause thermal cracking. Another problem is that air entrainment is more challenging to control at higher temperatures. If relatively RMC-cooled concrete is allowed to expand at a higher air temperature, air pores expand, and the concrete's strength is diminished. This part of monitoring is executed in real-time, where the effect of variables on the quality is as follows:

1) Calculate the temperature of fresh RMC by its ingredients using the equation below and two types of digital thermometers with a measuring range (-50 °C to +300 °C, - 40 °C to +250 °C respectively, and accuracy +1 °C) to ensure the accuracy of the calculations.

2) Measuring the air temperature is based on ACI 305. R- 99, NRMCE-PCA monograph, accurate data for each truck mixer at relative humidity wind speed and find the air temperature above RMC surface in real-time and based on ACI 305. R- 99.

3) Determine the precise evaporation rate of RMC (Ready-Mix Concrete) above the RMC surface at the SCBP (Stationary Central Batching Plant) and the work site. This investigation also includes the two points before and after balancing the RMC ingredients, as well as variations in the type and percentage of additive material and the cooling temperature of the RMC. A total of 80 samples were collected from RMC truck mixers for analysis.
4) Control the RMC temperature mixture through the quantity of ice required to decrease the mixture temperature and calculate the new evaporation rate after considering the surrounding conditions for each RMC quantity, like air temperature, relative humidity, RMC temperature, and wind speed.
5) Find the RMC compressive strength for the samples taken from truck mixers for both cases at SCBP and the construction worksite by laboratory testing.
6) Find the air entrapping the RMC through Abrams' 'law,' which is formulated by Feret:

$$f_c = K\left[\frac{V_c}{V_c+V_w+a}\right]^2 \tag{32}$$

7) The purpose of the points above is to monitor the improvements variances after balancing the RMC temperature, humidity, and air entrapped or changing chemical additive present based on the data gathered in the site and at SCBP for different seasons (Spring, Autumn, Winter, and Summer) with different variables as a loop for cyclical improvements.

7.2.1 RMC mixture temperature monitoring

The RMC transported to the construction site should be stored at a cool temperature, ideally 32 degrees Celsius (90 degrees Fahrenheit). A simple statement is all that is needed to determine the temperature of newly mixed concrete given its component temperatures [144]:

$$T = \frac{0.22(T_a W_a + T_c W_c) + T_w W_\text{w} + T_a W_\text{wa}}{0.22(W_a + W_c) + W_w + W_\text{wa}} \tag{33}$$

Where Ti (i=a, c, and w) denotes temperature (°C or °F), Wi (i= a, c, w, and wa) is ingredients are measured by their mass per unit volume of concrete, where a refers to dry aggregate, (c) cement, (w) additional water, and (wa) water absorbed by the aggregate. The dry components' specific heat ratio to the specific heat of water is around 0.22. As a result of the concrete's early development, the heat of hydration of cement and the mechanical labor involved in mixing the concrete's actual temperature will be greater than that suggested by the above formula; nevertheless, the formula is usually sufficiently accurate. Since we often have a certain degree of control over the temperature of at least some RMC ingredients, it is helpful to consider the relative influence of changing their temperature. For instance, for a water/cement ratio of 0.5 and an aggregate/cement ratio of 5.6, it may reduce the temperature of new concrete by one degree Celsius (2 °F) by reducing the temperature of either the cement (by 9 °C) or the water (3.5 °C). Thus, cement requires a more significant temperature decrease than other components because of its comparatively modest proportion in the mix.

Moreover, it is much easier to cool water than cement or aggregate. Therefore, for accurate temperature measurements, two types of thermometers are used to find the RMC temperature in real-time monitoring. To have an idea about how the calculations of the RMC temperature is done by using two methods, the first one by using two kinds of digital thermometer; the first one is a digital thermometer (Aswar TP- 300) with a temperature range from -50 °C (-122 °F) to +300 °C(+572 °F), accuracy ±1 °C. The second type is a digital thermometer (Lpn) with a temperature range from -40 °C (-104 °F) to +250 °C(+482 °F), Accuracy of ±1 °C as shown in the figure below, and the second method is through the temperature of the ingredients of RMC by the expression mentioned previously.

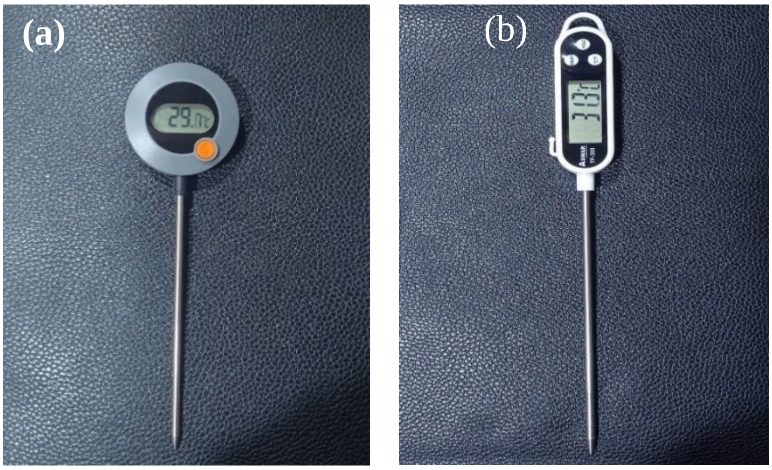


Figure 7.1 Digital thermometers have two types: (a) Lpn 0967 and (b) Aswar TP-300 [Researcher].

The measurements of the RMC temperature are done by using two types of thermometers for RMC made in SCBP with water cement ratio of 0.5, cement Portland (type I), cement 380 kg, 190-liter water, 0.53 m^3 fine aggregate, and 0.76 m^3 coarse aggregate for different weather temperature with diverse humidity's percent at SCBP and after delivering it to the construction site (a multistory building) by trucks mixers for two cases first before making adjustments to

RMC ingredients temperature and change the percent of the chemical additive material to keep fresh concrete durability in limitation and reduced the quantity of water cement ratio.

Figure 7.2 RMC temperature samples were measured by two thermometers with water-cement of ratio 0.5 Portland cement (type I) and different weather temperatures [Researcher].

The rapid increase of the rate of evaporation on the surface due to delivery time (as we approved and discussed before) and the environmental situation, which is affected by weather conditions, air temperature, relative humidity, wind speed, RMC temperature, and wind velocity, as results will lead to increase the air content of the total mixture, fast sitting time and decrease the compressive strength as we see in following pages.

The second case is after adjusting or balancing to RMC temperature at SCBP and the worksite before placing. The table above has shown the measurements of RMC temperature records in real-time monitoring by using two methods of calculations:

a) RMC temperature is measured by taking concrete samples from each truck mixer finish loaded in SCBP and ready to travel to the work site; the other measurements are from the same truck mixers after arriving at the construction worksite taken from the samples record and measure the actual temperature of concrete in real-time (as shown in the table below) by two types of thermometers to gain more accurate temperature measurements which effected by the environmental circumstances (weather conditions).

b) The expression determines the RMC temperature (fresh concrete) (temperatures of RMC ingredients (cement type I, sand, aggregate, and water) based on the equation above), also from each truck mixer finish loaded in SCBP and ready-to-travel to the work site, the other measurements are from the same truck mixers after arriving to construction worksite.

Table 7.1 The RMC mixture temperature measured in real-time based on the time of RMC production at the stationary concrete batching plant and the construction site [Researcher].

No	*Date*	*RMC Temp. at SCBP °C*	*RMC Temp. /worksite °C*	*No*	*Date*	*RMC Temp. at SCBP °C*	*RMC Temp. /worksite °C*
1.	*2022/04/04 Monday*	*30.1*	*32.9*	*41.*		*25.2*	*28*
2.		*35.1*	*38*	*42.*		*23.4*	*26.4*
3.		*38*	*40.1*	*43.*		*30.1*	*32.2*
4.		*40*	*43.3*	*44.*		*26.7*	*28.8*
5.		*41.2*	*44*	*45.*		*28.3*	*31.8*
6.		*46.3*	*48.1*	*46.*		*30.5*	*33.1*
7.	*2022/04/05 Tuesday*	*28.3*	*31.8*	*47.*		*30.1*	*32.9*
8.		*30.1*	*32.2*	*48.*		*30.1*	*32.2*
9.		*34.7*	*36.2*	*49.*	*2021/07/1 Thursday*	*32.6*	*35.1*
10.		*35.1*	*38*	*50.*		*33.4*	*36.6*
11.		*35.7*	*38.3*	*51.*		*46.3*	*48.1*
12.		*37.2*	*39.5*	*52.*		*47.6*	*49.7*
13.		*38*	*40.1*	*53.*		*48.1*	*50.2*
14.		*42.2*	*45.3*	*54.*		*49.7*	*51.9*
15.		*39.8*	*43.2*	*55.*		*50.2*	*52.8*
16.	*2022/04/24 Sunday*	*32.6*	*35.1*	*56.*		*50.2*	*52.8*
17.		*30.1*	*32.2*	*57.*		*53.1*	*55.7*
18.		*30.1*	*32.9*	*58.*		*52.3*	*54.9*
19.		*34.7*	*36.2*	*59.*		*53.1*	*55.7*
20.		*35.7*	*38.3*	*60.*		*54.2*	*56.5*
21.		*35.7*	*38.3*	*61.*	*2021/07/07 Wednesday*	*54.2*	*56.5*
22.		*37.2*	*39.5*	*62.*		*55.2*	*57.8*
23.		*38*	*40.1*	*63.*		*40*	*43.3*
24.		*40*	*43.3*	*64.*		*42.2*	*45.3*
25.		*42.8*	*44.7*	*65.*		*44.3*	*46.8*
26.	*2021/12/08 Wednesday*	*21*	*23.7*	*66.*		*47.6*	*49.7*
27.		*21*	*23.7*	*67.*		*48.7*	*50.4*
28.		*24*	*26.6*	*68.*	*2021/07/27 Tuesday*	*50.2*	*52.8*
29.		*23.4*	*26.4*	*69.*		*55.2*	*57.8*
30.		*24*	*26.6*	*70.*		*44.3*	*46.8*
31.		*30.1*	*32.2*	*71.*		*46.3*	*48.1*
32.		*30.5*	*33.1*	*72.*		*48.1*	*50.2*
33.		*30.1*	*32.9*	*73.*		*50.2*	*52.8*
34.		*32.6*	*35.1*	*74.*		*50.3*	*52.8*
35.		*32.6*	*35.1*	*75.*		*52.3*	*54.9*
36.		*33.4*	*36.6*	*76.*		*53.1*	*55.7*
37.	*2021/12/09 Thursday*	*21*	*23.7*	*77.*		*53.1*	*55.7*
38.		*21.7*	*23.4*	*78.*		*54.2*	*56.5*
39.		*24.3*	*26.4*	*79.*		*55.2*	*57.8*
40.		*25.2*	*28*	*80.*		*55.3*	*57.5*

Table 7.1 illustrates the RMC mixture temperature measured in real time based on the time of RMC production at the stationary concrete batching plant and the construction site.

7.2.2 Air temperature, relative humidity, and wind speed measurement

The effect of the weather conditions measurement on the fresh RMC helps to understand the relationship between them; accurate measurements have been done for the specific time of each truck mixer used in the table above for the two locations at the SCBP, and a construction worksite measure at the actual time for both locations weather temperature, relative humidity and wind speed for each time truck mixer finished loaded at both locations. Moreover, based on the ACI-305.R-99, the air temperature above the surface of RMC is measured for each truck mixer at both locations according to RMC temperature measurement times. The purpose of finding the weather temperature, RMC temperature, relative humidity, and wind speed from truck mixers at both locations is to find the evaporation rate for samples taken at accurate time and weather conditions according to the nomograph in ACI-305.R-99.

Table 7.2 The surrounding environmental conditions taken in real-time monitoring [Researcher].

No	Date	Time	Weather temp. °C	Relative humidity %	Wind speed km/h	Air temp. at SCBP °C	Air temp. /worksite °C
1.	2022/04/04 Monday	7:58	26	28	15	25	27
2.		8:33	31	31	15	29	32
3.		9:07	33	26	15	30	34
4.		9:30	35	22	14	34	35
5.		10:17	36	16	20	35	37.3
6.		11:00	41	12	24	40.3	42.1
7.	2022/04/05 Tuesday	7:30	23	40	24	25	28
8.		8:15	24	29	23	25	27
9.		8:37	29	26	21	29	32
10.		9:00	31	20	40	29	32
11.		9:26	30	18	21	31	34
12.		10:12	32	16	27	35	37
13.		11:00	33	14	25	35	36
14.		12:10	37	7	42	36.2	39.3
15.		13:00	34	7	38	32	37.2
16.	2022/04/24 Sunday	7:22	27	32	21	27	29
17.		7:50	24	36	16	24	27
18.		8:10	26	39	20	24	27
19.		8:39	29	34	20	28	29
20.		9:11	30	28	21	29	32
21.		9:42	30	25	28	29	32
22.		10:10	32	25	19	32	33
23.		11:1	33	22	22	32	34
24.		12:00	35	18	23	34	37.3
25.		12:36	37	16	18	36.8	38.7
26.	2021/12/08 Wednesday	7:25	16	66	4	16	19
27.		7:40	16	66	4	16	19
28.		8:22	19	40	4	19	21
29.		9:00	21	39	3	19	21
30.		9:17	19	34	7	19	21
31.		10:12	24	34	14	25	27
32.		11:09	25	34	14	25	28

33.		*11:45*	*26*	*29*	*16*	*25*	*28*
34.		*12:00*	*27*	*29*	*11*	*27*	*29*
35.		*12:43*	*27*	*32*	*13*	*27*	*29*
36.		*14:00*	*28*	*37*	*15*	*28*	*30*
37.		*7:45*	*16*	*100*	*15*	*16*	*19*
38.		*8:05*	*17*	*100*	*16*	*16*	*19*
39.		*8:38*	*19*	*88*	*21*	*19*	*21*
40.		*9:00*	*20*	*88*	*23*	*20*	*22*
41.		*9:21*	*20*	*88*	*21*	*20*	*23*
42.		*9:46*	*21*	*88*	*19*	*19*	*21*
43.	*2021/12/09*	*10:08*	*24*	*88*	*18*	*25*	*27*
44.	*Thursday*	*10:30*	*22*	*88*	*16*	*21*	*24*
45.		*10:52*	*23*	*88*	*17*	*24*	*27*
46.		*11:12*	*25*	*88*	*17*	*25*	*26*
47.		*11:40*	*26*	*36*	*17*	*25*	*27*
48.		*13:30*	*24*	*39*	*16*	*25*	*27*
49.		*14:11*	*27*	*34*	*16*	*27*	*29*
50.		*15:00*	*28*	*34*	*12*	*28*	*30*
51.		*7:20*	*41*	*30*	*3*	*40.3*	*42.1*
52.		*7:47*	*42*	*24*	*3*	*41.6*	*43.7*
53.		*8:11*	*43*	*24*	*4*	*42.1*	*44.2*
54.		*8:35*	*45*	*20*	*4*	*43.7*	*45.9*
55.		*9:00*	*46*	*16*	*6*	*44.2*	*45.8*
56.	*2021/07/01*	*9:38*	*46*	*10*	*8*	*44.2*	*45.8*
57.	*Thursday*	*10:00*	*48*	*9*	*7*	*47.1*	*49.7*
58.		*10:30*	*47*	*8*	*7*	*46.3*	*48.9*
59.		*10:46*	*48*	*6*	*7*	*47.1*	*49.7*
60.		*11:10*	*49*	*6*	*8*	*48.2*	*50.5*
61.		*11:30*	*49*	*6*	*7*	*48.2*	*50.5*
62.		*12:00*	*50*	*5*	*9*	*49.2*	*51.8*
63.		*8:00*	*35*	*12*	*24*	*34*	*37.3*
64.		*8:15*	*37*	*11*	*26*	*38.2*	*39.3*
65.	*2021/07/07*	*8:49*	*39*	*9*	*24*	*38.3*	*40.8*
66.	*Wednesday*	*9:00*	*42*	*9*	*29*	*41.6*	*43.7*
67.		*11:22*	*44*	*7*	*28*	*42.7*	*44.4*
68.		*12:00*	*46*	*7*	*30*	*44.2*	*46.8*
69.		*13:00*	*50*	*7*	*25*	*49.2*	*51.8*
70.		*7:45*	*39*	*70*	*10*	*38.3*	*40.8*
71.		*8:00*	*41*	*70*	*9*	*40.3*	*42.1*
72.		*8:19*	*43*	*70*	*16*	*42.1*	*44.2*
73.		*8:57*	*46*	*57*	*31*	*44.2*	*46.8*
74.		*9:19*	*46*	*57*	*25*	*44.3*	*46.8*
75.	*2021/07/27*	*9:43*	*47*	*47*	*26*	*46.3*	*48.9*
76.	*Tuesday*	*10:10*	*48*	*45*	*28*	*47.1*	*49.7*
77.		*10:40*	*48*	*44*	*29*	*47.1*	*49.7*
78.		*11:12*	*49*	*44*	*30*	*48.2*	*50.5*
79.		*12:00*	*50*	*39*	*26*	*49.2*	*51.8*
80.		*12:21*	*51*	*100*	*10*	*49.3*	*51.5*

Table 7.2 represents the actual values of the surrounding environmental conditions in real-time monitoring, showing that the maximum weather temperature was (51 °C) on Tuesday, 2021/07/27, at 12:21 pm. Minmum weather temperature was (16 °C) on Wednesday,

2021/12/08, at 07:25, maximum relative humidity was 100 % on Tuesday, 2021/07/27, at 12:21 pm, and minimum relative humidity was 5 % on Thursday, 2021/07/01, at 12:00 pm, maximum wind velocity was (31 km/h) on Tuesday 2021/07/27 at 8:57 am, the minimum wind velocity was (3 km/h) on Wednesday 2021/12/08 at 9:00 am, maximum air temperature at SCBP (49.3°C) on Tuesday 2021/07/27 at 12:21 pm, the minimum air temperature at SCBP (16 °C) on Thursday 2021/12/09 at 7:45 and maximum air temperature at construction worksite (51.8°C) on Wednesday 2021/07/07 at 1:00 pm, minimum air temperature at construction worksite (19 °C) on Wednesday 2021/12/08 at 7:25,7:40 am. Accordingly, based on values measured by the samples, July 2021 has the maximum temperature degrees and minimum relative humidity percent, minimum wind velocity, maximum air temperature at SCBP, and maximum air temperature at a construction site. In contrast, December 2021 has minimum temperature wind speed at SCBP and air temperature at the construction site, as shown below.

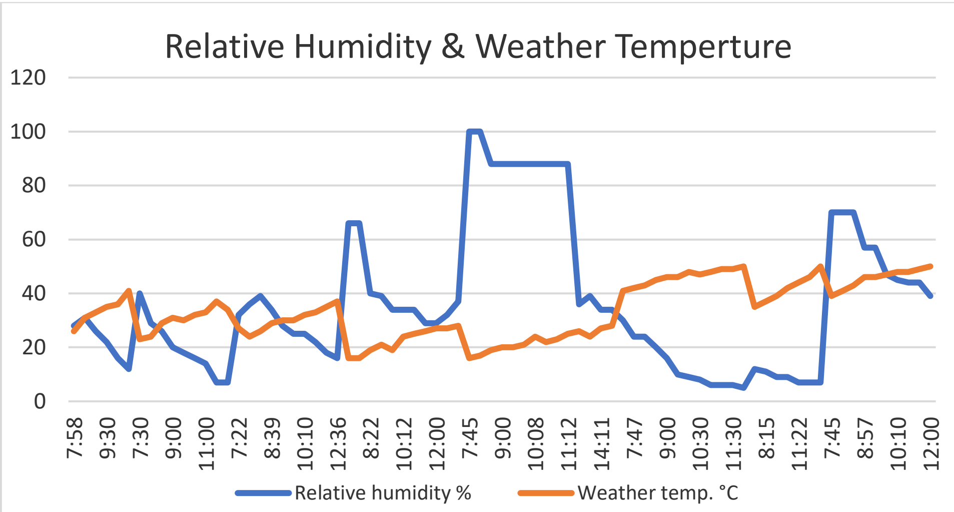


Figure 7.3 Relative humidity and Weather temperature taken during concreting dates [Researcher].

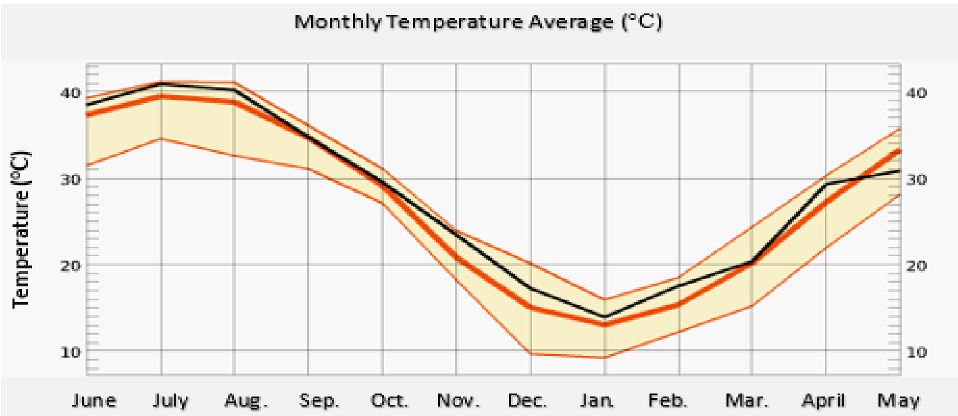


Figure 7.4 Average temperature for the last 21 months (the black line) and the climate for the last three years for Misan city [Researcher].

Figure 7.4 represents the weather temperature average for the period of the last 21 months, and the black line represents the weather temperature and the climate for three years for Misan city (32.00 °N/47.34 °E, 10 meters above the datum) in Iraq, where the place of our case of study is done. As standard to compare and inspect the accuracy of the measurement values for RMC temperature, air temperature, and critical evaporation rate, the ACI 305.R-99 shows the limitations for the factors mentioned, NRMCA-PCA nomograph, results scaled to closest 5%, unless the relative humidity, which evaporation rate exceed the critical values provided in the table below, will assume air temperature 10 F (6°C) lower than concrete temperature and a constant wind speed of 10 mph (16 km/h)[144].

7.2.3 Evaporation Rate of the RMC

The nomograph in ACI 305.R-99 has been used to estimate the rate of evaporation on the surface of concrete because it is the most accurate way to do so and is based on accepted hydrological methods for measuring the rate of water evaporation. Contrarily, that area is soaked with blood (RMC cube samples are covered with bleed water). This monograph is the best tool for determining the surrounding environment's evaporation potential by accurately depicting the rate at which water evaporates from a concrete surface.

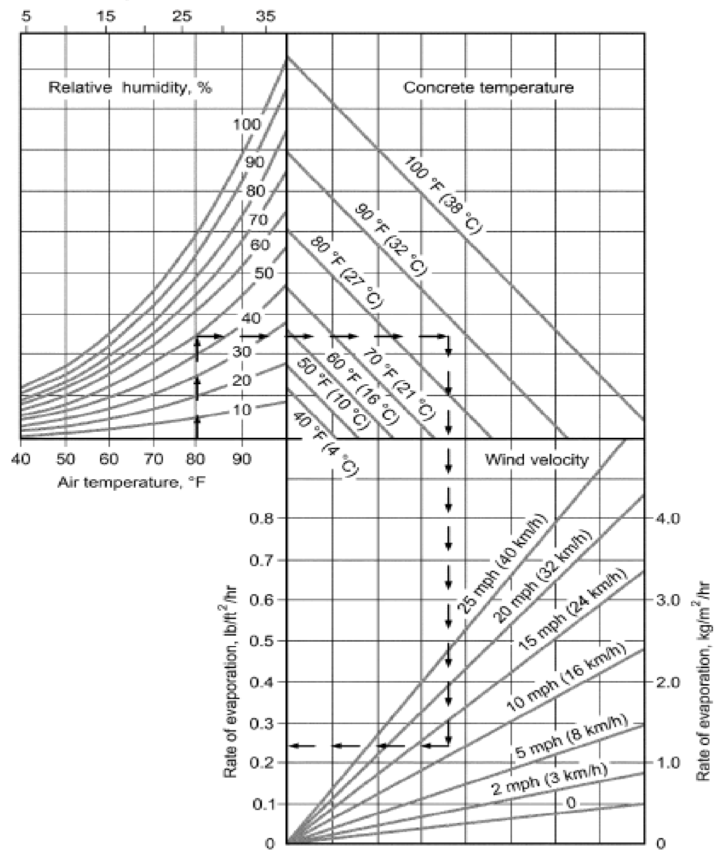


Figure 7.5 Effect of concrete and air temperature, relative humidity, and wind velocity on the evaporation rate of the surface moisture from concrete [83].

Table 7.3 The RMC mixture temperature before reducing the temperature for samples measured at the SCBP and the construction site for the Spring, Summer, and Winter seasons [Researcher].

No	Date	Time	Rate of evap.at SCBP	Rate of evap. at worksite	No	Date	Time (hr.)	Rate of evap.at SCBP	Rate of evap. at worksite
1.		7:58	1	1.3	41.		9:21	0.4	0.4
2.		8:33	1.1	1.5	42.		9:46	0.15	0.6
3.	2022/04/04 Monday	9:07	1.6	1.9	43.		10:08	0.14	0.5
4.		9:30	1.5	1.9	44.		10:30	0.16	0.4
5.		10:17	2.4	2.8	45.	2021/12/09 Thursday	10:52	0.25	0.7
6.		11:00	3.1	3	46.		11:12	0.8	0.8
7.		7:30	1.5	1.6	47.		11:40	1.5	1.1
8.		8:15	1.7	1.8	48.		13:30	1.4	1.5
9.		8:37	1.6	2	49.		14:11	1.5	1.6
10.		9:00	3.7	4.8	50.		15:00	1.1	1.2
11.	2022/04/05 Tuesday	9:26	2	2.5	51.		7:20	0.8	0.8
12.		10:12	2.9	3.2	52.		7:47	0.8	0.8
13.		11:00	2.8	3.1	53.		8:11	0.9	0.9
14.		12:10	4.9	3.5	54.		8:35	0.9	0.9
15.		13:00	4.7	3.7	55.		9:00	1	1
16.		7:22	1.9	2	56.	2021/07/01 Thursday	9:38	1.2	1.2
17.		7:50	1.4	1.4	57.		10:00	1.1	1.1
18.		8:10	1.9	1.5	58.		10:30	1.1	1.1
19.		8:39	2	1.8	59.		10:46	1.1	1.1
20.	2022/04/24 Sunday	9:11	2	2.1	60.		11:10	1.2	1.2
21.		9:42	2.5	2.2	61.		11:30	1.1	1.1
22.		10:10	2.2	2.1	62.		12:00	1.3	1.3
23.		11:1	2.3	2.3	63.		8:00	3.1	3.1
24.		12:00	2.4	2.6	64.		8:15	3.2	3.15
25.		12:36	2.1	2.2	65.		8:49	3.1	3.1
26.		7:25	0.25	0.25	66.	2021/07/07 Wednesday	9:00	3.3	3.6
27.		7:40	0.25	0.25	67.		11:22	3.4	4.7
28.		8:22	0.5	0.21	68.		12:00	3.5	4.8
29.		9:00	0.26	0.15	69.		13:00	3.1	3.2
30.	2021/12/08 Wednesday	9:17	0.6	0.15	70.		7:45	1.4	1.4
31.		10:12	1	0.9	71.		8:00	1.3	1.1
32.		11:09	1	1.1	72.		8:19	2.1	1.7
33.		11:45	1.2	1.3	73.		8:57	3.7	3.3
34.		12:00	1.3	1.1	74.		9:19	3.2	3.1
35.		12:43	1	1.2	75.	2021/07/27 Tuesday	9:43	3.1	3.3
36.		14:00	1.1	1.3	76.		10:10	3.4	2.5
37.		7:45	0.15	0.25	77.		10:40	3.5	3.6
38.		8:05	0.16	0.3	78.		11:12	3.6	3.1
39.		8:38	0.4	0.4	79.		12:00	3.1	3.3
40.		9:00	0.5	0.45	80.		12:21	1.3	1.4

Table 7.3 shows that the RMC rate of evaporation was high due to the hydration process increased in the extended delivery distance (11 km) to the construction site and in high-temperature weather where in July the weather temperature exceeded 50°C, where the maximum rate was 4.8 at the construction site on 07th July 2021.

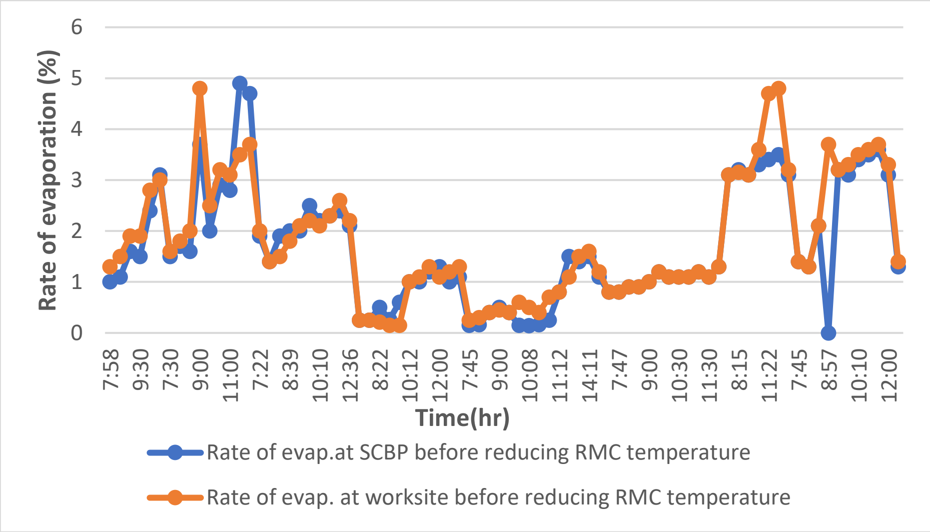


Figure 7.6 RMC evaporation rate at the SCBP and construction site for samples taken for Spring, Winter, and Summer seasons before reducing the temperature of the mix [Researcher].

Figure 7.6 shows RMC evaporation rate is relatively high, especially during the summer season when the RMC temperature is high (reaching even more than 50), which is likely because higher temperatures can increase the evaporation rate. It indicates that the RMC mixture's temperature exceeds the recommended limits, particularly during the summer season, which could adversely affect the strength and durability of the concrete product. Furthermore, it is suggested that real-time temperature management may be necessary to ensure that the RMC mixture is within the desired temperature range, where it may involve the use of ice or other cooling methods to keep the temperature of the mixture within the recommended limits, where reducing the RMC temperature by ice (melted) help to decrease and stabilize the rate of evaporation and keep the RMC mix temperature under control and meet with limitations.

7.2.4 Control the RMC mixture temperature

The temperature of the ready-mix concrete (RMC) mixture can significantly affect the properties and quality of the RMC. It is essential to keep the temperature of the RMC mixture under control and within recommended limits to ensure optimal strength and durability and meet these limitations; it may be necessary to reduce the mixture's temperature. One way to do this is by adding ice (melting water). Moreover, to determine the ice amount necessary to decrease the RMC temperature, measure the amount of ice and water after subtracting the ice, using a calculated formula that considers the mixture's specific temperature and evaporation rate goals. By carefully controlling the temperature of the RMC mixture, it is possible to improve the quality and performance of the finished concrete product.

7.2.5 The quantity of ice required to decrease the RMC mix temperature.

In order to determine the amount of ice per cubic meter of RMC, an equation can be derived based on the initial temperature of the RMC mixture. This estimation is achieved by applying the energy conservation principle during the heat transfer. The equation considers the temperatures of the RMC components and the mixing process, which are based on the principles of energy balancing and calculations using heat conduction theory and convective heat transfer. This method is executed based on Japanese Concrete Institution standards. The formula to find the initial temperature of RMC mixture with 0.5 water/ cement ratio, cement 380 kg, 190-liter water, 0.53 m^3 fine aggregate(sand), 0.76 m^3, and coarse aggregate [145]:

$$T_O = \frac{c_1(m_C T_C + m_a T_a + m_S T_S) + c_2 m_W T_W}{c_1(m_c + m_a + m_s) + c_2 m_W} \quad (34)$$

Where:

m= mass of RMC components mixture(kg/m3) accounted per cubic meter.

i= for c, s, a, and w are the symbols that refer to cement, sand, coarse aggregate, and water.

T= temperature of RMC mixture for cement, water, sand, and coarse aggregate, respectively.

c_1 = heat capacity(specific) for dry volume (cement, aggregate)

c_2 = the water heat capacity (specific) kcal/(kg. ^oC).

where the values of (c) for cement, sand, and coarse aggregate are approximately equal ≈ 0.2 kcal/(kg. oC), and c2 ≈ 1.0 kcal/(kg. oC), now the expression may be rewritten [18]:

$$T_o = \frac{0.2(m_c T_c + m_a T_a + m_s T_s) + m_w T_w}{0.2(m_c + m_a + m_s) + m_w} \quad (35)$$

The standard referenced that to make the RMC temperature lower by one °C, it is required to reduce the cement temperature by about eight °C, aggregate temperature by about two °C, and mixing water by about four °C, Where the use of ice to make water cooler, the temperature of RMC mixture will drop (ΔT), which can be found by the following expression [18]:

$$\Delta T = \frac{m_{ice}\{79.6 + (T_O - 0)\}}{0.2(m_c + m_a + m_s) + m_w} E_f \quad (36)$$

Where:

m_{ice} = the ice mass (kg/m^3), Ef = the cooling efficiency (the value can used between 0.7-0.8).

Nevertheless, the quantity of ice required to lower the starting temperature of the concrete mixture has not been calculated, and the equation above does not consider the nature of energy transfer nature. Therefore, there is a method to estimate the ice amount required to lower the

RMC mixture temperature by considering RMC mixture thermal balancing. Through the unit masses by volume (α) of each RMC mixture component and their thermal properties, let us take (x) as the unknown ice amount in kilograms used to reduce the mixture temperature. Moreover, the quantity of water required as the allowable value according to the water-to-cement ratio will be the water volume subtracted from the ice quantity (α×mc - x).

Let us assume that the ice temperature is 0°C, and the particular heat of ice melting λ= 81.26 (kcal/kg) [18], where after mixing, the mixture temperature is indicated To, and before mixing, each RMC mixture component has its temperature Ti. The thermal energy amount when RMC components temperature decreases to initial temperature *To,* represented as follows [145]:

$$Q_A = \sum_i c_i m_i (T_i - T_o) \quad (37)$$

Substituting the cement, aggregate, sand, and water symbols in the equation (5):

$$Q_A = c_c m_c (T_c - T_o) + c_a m_a (T_a - T_o) + c_s m_s (T_s - T_o) + c_w (\alpha m_c - x)(T_w - T_o) \quad (38)$$

If the heat needed to melt the ice and the temperature water formed change from 0°C to T_o temperature applied, the expression would be as follow:

$$Q_B = \lambda \cdot m_{\text{ice}} + c_w m_{\text{ice}} (T_o - 0) = \lambda \cdot x + c_w \cdot x \cdot T_o \quad (39)$$

Based on the heat balance principle (equality), which is written as:

$$QA = QB \quad (40)$$

or

$$c_c m_c (T_c - T_o) + c_a m_a (T_a - T_o) + c_s m_s (T_s - T_o) + c_w (\alpha m_w - x)(T_w - T_o) = \lambda x + c_w x T_o$$

By using the equation above, the required ice amount is replaced by the mixture water partially to find the RMC mixture temperature; the equation will be:

$$x = \frac{c_c m_c (T_c - T_o) + c_a m_a (T_a - T_o) + c_s m_s (T_s - T_o) + c_w \alpha m_w (T_w - T_o)}{\lambda + c_w T_w} \quad (41)$$

Assuming that the RMC mixture components temperature is equal to air temperature *T* (cement, aggregate, sand, water, and air) and the c (cement, aggregate, and sand) ≈ 0.2 kcal/(kg. °C), c water ≈ 1.0 kcal/(kg. °C), so the expression will be written as follows:

$$x = \frac{[0.2(m_c + m_a + m_s) + \alpha m_c](T_{air} - T_o)}{\lambda + T_{air}} \quad (42)$$

In our case of study the average temperature at SCBP and worksite $T_{\text{air}} = 34.3$ °C, , λ= 81.26 (kcal/kg), m_c =380.2 kg, m_a=1216 kg, m_s= 742 kg.

To find the ice water (milted) amount required to achieve RMC initial temperature mixture at the safe limit initial temperature is 30-32 °C (lower safe limit 30 °C used).

Table 7.4 RMC mix properties, including the ice amount required for RMC temperature of mix reduction [Researcher].

Mixture properties	*W/C %*	*Cement (kg)*	*Aggregate (kg)*	*Water (Liter)*	*Ice*
	0.5	*380.2*	*1958*	*190 - x*	*x*

$$x = \frac{[0.2(380 + 1958) + 0.5\ x\ 380](34.3 - 30)}{81.26 + 34.3} = 24.46$$

Thus, RMC water volume at the initial temperature equals the air temperature (34.3℃), which is 190 -24.46 = 165.54 kg. Let us find the temperature of water under the circumstances taken into consideration, where the heat amount essential to decrease the water of RMC mixture temperature of the minimum mixture temperature recorded (T_{air}), which is 21℃ to T_{W}:

$$Q_1 = c_w m_w (T_{air} - T_w) = 165.54(21 - T_w) \quad (43)$$

The heat essential to ice melting amount and raises the temperature of RMC from 0℃ to T_{w} as follow:

$$\boldsymbol{Q_2 = \lambda . m_{ice} + c_w m_{ice}(T_w - 0) = 81.26 \times 24.46 + 24.46T_w = 1987.6 + 24.46T_w} \quad (44)$$

According to the heat energy principle of balancing the $Q_1 = Q_2$

$$165.5(21 - T_w) = 1987.6 + 24.46T_w \quad (45)$$

Then the T_{w} =7.8 ℃

Moreover, for the dates that have a high average RMC mixture initial temperature (exceeding the limitations) in April 2022 and July 2021, the amount of ice, its quantity from mixing water, and the heat required to melt the ice which is required to reduce the temperature and keep it at the safe limit initial temperature (32℃), can be determined by using same equations, where, the amount of ice is calculated in kilograms through the density law, where the weight of ice is equal to the density of ice for pure water (drinkable according to ACI code) used in RMC mix, which is 1 kg/m^3, multiplied by the volume of concrete for each cubic meter which is one cubic meter. Thus, the weight of ice per liter equals one kilogram, so it is possible to find the amount of ice in kilogram to reduce the temperature, as shown in the table below:

Table 7.5 The ice amount to reduce RMC initial temperature for one cubic meter [Researcher].

No.	***Date***	***Ave.Temperate (SCBP) °C***	***Ice (kg)***	***Water (Liter)***	***the heat required to melt ice (°C)***
1.	*2022/04/04*	*38.45*	*46*	*144*	*5.45*
2.	*2022/04/05*	*35.67*	*31*	*159*	*7.03*
3.	*2022/04/24*	*35.69*	*32*	*158*	*7*
4.	*2021/07/01*	*47.56*	*89.64*	*100.36*	*0.63*
5.	*2021/07/07*	*47.45*	*89.15*	*100.85*	*0.68*
6.	*2021/07/27*	*51.36*	*105.91*	*84.09*	*0*

The results in the table7.5 show that on 04/24/2022, the average temperature was 38.45℃, which was taken at RMC SCBP, as the ice amount required to decrease the RMC temperature of the mixture to allowable limits according to ACI code was 46 liters; this result represents the amount of melted snow (water); therefore, it is measured in liters. Thus, the amount of water in the mixture equals the total amount of the mixing water minus the melting ice water.

The last column of the table represents the quantity of heat (℃) essential to ice melting used to reduce RMC mixture temperature for each date, where the results were taken for two seasons (Spring and Summer) because the temperatures were higher than the allowable limitations which are (32℃) according to ACI code, while in Winter season (December 2021), the average of RMC mixture temperature was in limitations(28.5℃) this is the reason not to mention it.

The maximum average temperature in Summer on (27/7/2021), was (51.36 ℃); it was noticed that it does not need time to melt (it required zero Celsius degrees to melt in the mixture), which means the ice amount (in the crushed state) can melt in weather temperature. In contrast, the minimum average temperature (for the seasons required temperature reduction) was (35.67℃) on Spring (5/4/2022), as the ice amount required to reduce RMC temperature was (31 liters), and the amount of water (159 liters) and the temperature it requires to melt is seven degrees celsius.

7.2.6 The RMC mixture, after reducing the temperature

As mentioned before, a higher RMC mixture temperature than typical results, in addition to cement hydration, leads to acceleration of the setting time and affects the strength long term of hardened RMC; moreover, if the RMC mixture high temperature (exceeds limitations) combined with a low percentage of relative humidity and rapid rate of evaporation of RMC mix water occur producing a higher loss of workability, and higher plastic shrinkage[17]. Therefore, adding the amount of ice to the RMC mixture, the temperature will reduce (change) according to the heat required to melt the ice (℃). Table 7.6 shows the RMC mixture temperature measured by two types of digital thermometers after cooling with ice and according to the mentioned quantities per cubic meter of RMC, where the temperature will be as follows:

Table 7.6 The RMC mixture temperature after reducing the temperature of the RMC mix for samples measured at the SCBP and at the construction site for the Spring, Summer, and Winter seasons [Researcher].

No	***Date***	***RMC Temp. at SCBP °C***	***RMC Temp. at worksite °C***	***No***	***Date***	***RMC Temp. at SCBP °C***	***RMC Temp. at worksite °C***
1.	*Monday 4th April 2022*	*30.1*	*30.1*	***41.***	*Thursday 9th Dec. 2022*	*25.2*	*28*
2.		*29*	*31.3*	***42.***		*23.4*	*26.4*
3.		*30*	*31.2*	***43.***		*30.1*	*32.2*
4.		*31*	*31.3*	***44.***		*26.7*	*28.8*
5.		*31.5*	*31.6*	***45.***		*28.3*	*31.8*
6.		*31.2*	*31.5*	***46.***		*30.5*	*28.2*
7.	*Tuesday 5th April 2022*	*28.3*	*31.8*	***47.***		*30.1*	*28.4*
8.		*30.1*	*29*	***48.***		*30.1*	*28.4*
9.		*30.4*	*30.2*	***49.***		*31*	*28.6*
10.		*30.1*	*29.9*	***50.***		*31*	*29*
11.		*30.3*	*31*	***51.***	*Thursday 1st July 2021*	*31.4*	*30.4*
12.		*30.1*	*30*	***52.***		*31.2*	*30.5*
13.		*30*	*30.5*	***53.***		*30.4*	*31.3*
14.		*31*	*30.2*	***54.***		*30.3*	*31.2*
15.		*30.1*	*30*	***55.***		*30.8*	*31.6*
16.	*Sunday 24th April 2022*	*30*	*30*	***56.***		*31.7*	*31.8*
17.		*30.1*	*28.4*	***57.***		*30.5*	*31.8*
18.		*30.1*	*30*	***58.***		*31*	*31.6*
19.		*29*	*30.1*	***59.***		*31.9*	*31.7*
20.		*28*	*30.3*	***60.***		*31.7*	*31*
21.		*30.2*	*30.3*	***61.***		*32*	*31.9*
22.		*30.5*	*30.5*	***62.***		*31.4*	*31.9*
23.		*30*	*30.2*	***63.***	*Wednesday 7th July 2021*	*30*	*29.1*
24.		*29.8*	*30.5*	***64.***		*31.2*	*29.3*
25.		*29.5*	*31*	***65.***		*30*	*29.3*
26.	*Wednesday 8th Dec. 2022*	*21*	*23.7*	***66.***		*30.6*	*29.1*
27.		*21*	*23.7*	***67.***		*30.7*	*31*
28.		*24*	*26.6*	***68.***		*31*	*31.6*
29.		*23.4*	*26.4*	***69.***		*31.9*	*31.8*
30.		*24*	*26.6*	***70.***	*Tuesday 27th July 2021*	*29.2*	*29.3*
31.		*30.1*	*28.6*	***71.***		*29*	*29.6*
32.		*30.5*	*28*	***72.***		*30.1*	*31.1*
33.		*30.1*	*28.9*	***73.***		*31.6*	*31.2*
34.		*32.6*	*35.1*	***74.***		*31.8*	*31.3*
35.		*32.6*	*28.7*	***75.***		*31.9*	*31.1*
36.		*33.4*	*28.6*	***76.***		*31*	*31*
37.		*21*	*23.7*	***77.***		*31.8*	*31.8*
38.		*21.7*	*23.4*	***78.***		*32*	*31.7*
39.		*24.3*	*26.4*	***79.***		*31.9*	*31.8*
40.		*25.2*	*28*	***80.***		*31.9*	*31.6*

It is essential to control the mixture's temperature, as variations can significantly impact the strength and workability, where high temperatures can lead to rapid cement hydration and accelerate the setting time, which can negatively affect the long-term strength of the hardened RMC. In addition, high temperatures combined with low relative humidity and rapid evaporation can lead to a loss of workability and increased plastic shrinkage.

To address these issues, adding ice to the RMC mixture may be necessary to reduce the temperature. It is essential to notice that adding ice to the RMC mixture can also affect the mix design and may require adjustments to the proportions of cement, water, and aggregates.

Moreover, the amount of ice added was only for the samples that exceeded the limit for the maximum temperature, which is (30- 32 °C) according to ASTM and based on the amount of ice calculated for each date according to the average of the temperature previously. It noticed that all temperatures in the seasons that exceed ACI code limitations (32°C) in the Spring and Summer seasons had reduced using the amount of ice to meet ACI code limitations. It was found that the minimum temperature in the winter season was 21°C, whereas, in this season, the mix temperature was not changed, and the temperature met with limitations (there is no need to add ice to the mixture), and the maximum mixture temperature was on 24/07/2022. The process of adding ice to the RMC mixture was according to the quantities mentioned previously based on the equations used. In addition, this quantity of ice is subject to a specific temperature to melt inside the mixture, which was found according to the mixture temperature, which is affected by the external air temperature, relative humidity, and delivery time, where it noticed that the RMC temperature is more than the air temperature by 2-5 °C.

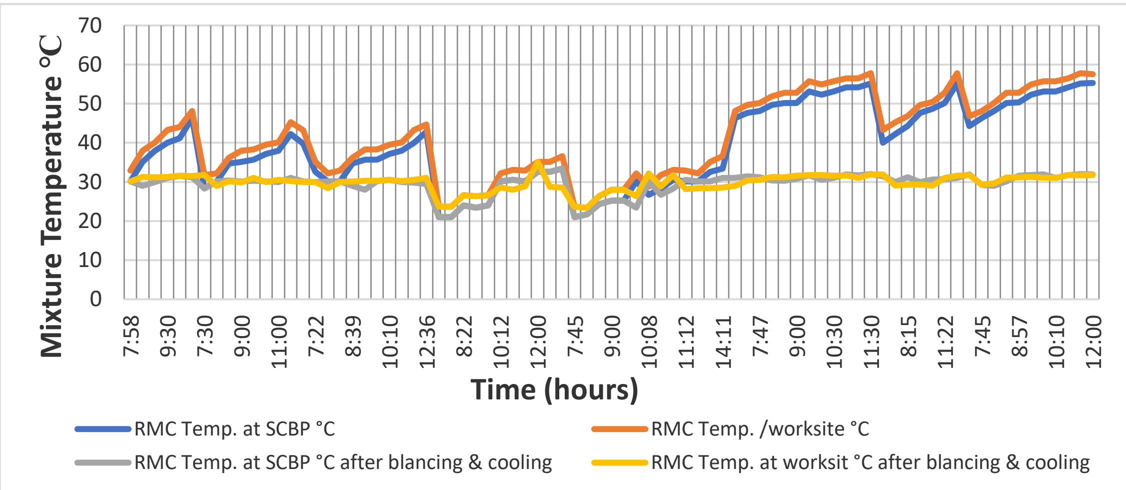


Figure 7.7 RMC mixture real-time temperature monitoring before and after reducing the mix temperature at the SCBP at the construction site [Researcher].

The relationship between the temperature of the ready-mix concrete (RMC) and the elapsed time can be analyzed by monitoring the properties of the mixture during various seasons and on specific sampling dates. This analysis should consider the influence of surrounding conditions, including temperature, relative humidity, wind speed, air temperature, and evaporation rate. Real-time monitoring techniques should ensure that no additional expenses are incurred during production. The maximum average of the temperature difference on 2021/07/27 Tuesday is 51.3℃ (before cooling by ice) and 31.07 ℃ (after cooling by ice) in the summer season, where a quantity of ice essential to decrease the temperature (ΔT) 20 ℃ for each cubic meter was as follow:

$$\Delta T = \frac{m_{ice}\{79.6 + (T_o - 0)\}}{0.2(m_c + m_a + m_s) + m_w} E_f \tag{46}$$

Substituting the mass of cement 380 kg, aggregate 1216 kg and sand 742 kg, and water values 84.09 liters in addition to the efficiency of cooling (0.75) in the equation above:

$$20 = \frac{m_{ice}\{79.6 + (51.3 - 0)\}}{0.2(380 + 1217 + 741) + 84.09} 0.75,\ m_{ice} = 112.4\ \mathrm{kg/m3}$$

The weight of each block of ice used (size 25cm x 25cm x 48 cm) is 23 kg, which requires 5.62 kg for each cubic meter of RMC to reduce the mixture temperature to 1℃.

This value is specific for the average temperature (51.3℃) in July 2021 in the summer season and can be changed based on the average temperature of each month of the season and the quantity of water (liter). However, still, the same calculation, for example, in the spring season, the average temperature at SCBP and work site is 37.6℃, (ΔT) 5 ℃, and water required 152 liters, so the $m_{ice} = 37.59\mathrm{kg/m3}$, which required 1.6 blocks of ice to reduce the one cubic meter of RMC temperature 5℃, and 7.82 kg to reduce the mixture temperature 1℃.

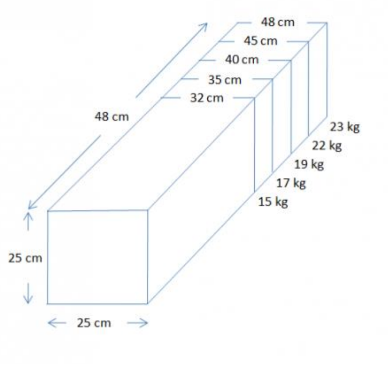


Figure 7.8 The ice blocks' dimensions and weight [Researcher].

The mixture temperature average after the cooling procedure by ice met with limitations, where the maximum temperature was less than 32℃ in the summer season, and the minimum RMC temperature was in the winter season 21℃. It is worth mentioning that the process of temperature reduction in the construction site is done by using ice block purchases from the local factory, where it is smashed and placed inside the truck mixers, while ice is added into the mixer of SCBP with the ingredients and measured as a subtraction from the total water amount.

7.2.7 The rate of evaporation after reducing the RMC mixture temperature

The RMC evaporation rate can be affected by several factors, including the mixture's temperature. It is well known that increasing the temperature of a substance can increase its evaporation rate. Conversely, reducing the temperature of a substance can decrease its evaporation rate.

The rate of ready-mix concrete evaporation is an essential consideration in construction, as excess water evaporation can reduce the finished product's strength and durability. By reducing the mixture's temperature, it is possible to reduce the evaporation rate and improve the concrete's final properties.

The ready-mix concrete's evaporation rate can be calculated by considering the mixture's temperature and other factors affecting the evaporation rate. One of the methods to reduce the evaporation rate of ready-mix concrete is adding ice (melting water) to the mixture. The ice amount required to reach (achieve) the desired reduction in evaporation rate can be calculated using the appropriate formula mentioned previously.

However, It is essential to carefully control the amount of ice added to the mixture, as too much ice can cause reverse effects and reduce the RMC compressive strength. By accurately calculating the ice amount required to reach (achieve) the desired reduction in evaporation rate, it is possible to optimize the strength and durability of the finished concrete product. Additionally, a calculated formula to determine the amount of ice needed can help ensure consistency in the final RMC, which is essential in the work site.

Moreover, the next step will be to determine the effects of the rate of evaporation improvements through the control steps by reducing the RMC mix temperature and time of delivery to the construction site on the workability(slump test), air content, porosity (accounts for the effect of the over-all voids volume on compressive strength, gel pores, capillary pores, and entrapped air with an increase in age, the degree of hydration increases so that strength increases; this effect is for RMC produce with using of cement Type I (ordinary Portland), density, and the compressive strength.

Table 7.7 RMC evaporation rate at the SCBP and construction site for samples taken for different seasons, after reducing the temperature of the mix by ice calculated as RMC mix water [Researcher].

No	***Date***	***Time (h)***	***Rate of evap.at SCBP***	***Rate of evap. at worksite***	***No***	***Date***	***Time (h)***	***Rate of evap.at SCBP***	***Rate of evap. at worksite***
1.		*7:58*	*1*	*1.2*	**41.**		*9:21*	*0.4*	*0.4*
2.		*8:33*	*0.7*	*0.9*	**42.**		*9:46*	*0.15*	*0.6*
3.	*2022/04/04 Monday*	*9:07*	*1.1*	*1.1*	**43.**		*10:08*	*0.4*	*0.3*
4.		*9:30*	*1.15*	*1.16*	**44.**		*10:30*	*0.16*	*0.4*
5.		*10:17*	*1.7*	*1.8*	**45.**		*10:52*	*0.25*	*0.7*
6.		*11:00*	*2*	*2.1*	**46.**		*11:12*	*0.5*	*0.4*
7.		*7:30*	*1.5*	*1.7*	**47.**		*11:40*	*1.5*	*1*
8.		*8:15*	*1.7*	*1.4*	**48.**		*13:30*	*1.4*	*1*
9.		*8:37*	*1.5*	*1.6*	**49.**		*14:11*	*1.5*	*1.5*
10.	*2022/04/05 Tuesday (Spring)*	*9:00*	*3*	*2.6*	**50.**		*15:00*	*0.7*	*0.8*
11.		*9:26*	*1.5*	*1.13*	**51.**		*7:20*	*0.3*	*0.3*
12.		*10:12*	*1.5*	*1.8*	**52.**		*7:47*	*0.3*	*0.3*
13.		*11:00*	*2*	*2.3*	**53.**		*8:11*	*0.4*	*0.4*
14.		*12:10*	*1.6*	*2.6*	**54.**		*8:35*	*0.5*	*0.5*
15.		*13:00*	*1.7*	*1.6*	**55.**	*2021/07/01 Thursday (Summer)*	*9:00*	*0.9*	*1*
16.		*7:22*	*1.6*	*1.5*	**56.**		*9:38*	*1*	*1*
17.		*7:50*	*1.2*	*1.1*	**57.**		*10:00*	*0.8*	*0.9*
18.		*8:10*	*1.6*	*1.5*	**58.**		*10:30*	*0.8*	*0.8*
19.	*2022/04/24 Sunday (Spring)*	*8:39*	*1.4*	*1.4*	**59.**		*10:46*	*08*	*0.9*
20.		*9:11*	*1.3*	*1.4*	**60.**		*11:10*	*0.8*	*0.9*
21.		*9:42*	*2*	*2*	**61.**		*11:30*	*0.9*	*0.9*
22.		*10:10*	*1.4*	*1.4*	**62.**		*12:00*	*1*	*1.1*
23.		*11:1*	*1.6*	*1.7*	**63.**		*8:00*	*1.7*	*1.8*
24.		*12:00*	*1.5*	*1.7*	**64.**		*8:15*	*2.1*	*2.2*
25.		*12:36*	*1.5*	*1.6*	**65.**	*2021/07/07 Wednesday (Summer)*	*8:49*	*1.6*	*1.9*
26.		*7:25*	*0.25*	*0.25*	**66.**		*9:00*	*2.2*	*2.2*
27.		*7:40*	*0.25*	*0.25*	**67.**		*11:22*	*2.7*	*3.3*
28.		*8:22*	*0.5*	*0.21*	**68.**		*12:00*	*2.8*	*3.6*
29.		*9:00*	*0.26*	*0.15*	**69.**		*13:00*	*2.4*	*2.4*
30.	*2021/12/08 Wednesday (Winter)*	*9:17*	*0.6*	*0.15*	**70.**		*7:45*	*0.2*	*0.25*
31.		*10:12*	*1*	*0.8*	**71.**		*8:00*	*0.15*	*0.16*
32.		*11:09*	*1*	*0.9*	**72.**		*8:19*	*0.2*	*0.25*
33.		*11:45*	*1.2*	*1*	**73.**		*8:57*	*0.5*	*0.5*
34.		*12:00*	*1.2*	*1*	**74.**	*2021/07/27 Tuesday (Summer)*	*9:19*	*0.3*	*0.3*
35.		*12:43*	*1.4*	*1.2*	**75.**		*9:43*	*0.9*	*0.9*
36.		*14:00*	*1.4*	*1.1*	**76.**		*10:10*	*0.95*	*0.95*
37.		*7:45*	*0.15*	*0.25*	**77.**		*10:40*	*1.1*	*1.1*
38.	*2021/12/09 Thursday (Winter)*	*8:05*	*0.16*	*0.3*	**78.**		*11:12*	*1.1*	*1.1*
39.		*8:38*	*0.4*	*0.4*	**79.**		*12:00*	*1.4*	*1.4*
40.		*9:00*	*0.5*	*0.45*	**80.**		*12:21*	*0.15*	*0.15*

Table 7.7 shows that the RMC rate of evaporation improvements due to the control of the hydration process by reducing the RMC mix temperature by adding ice to the RMC mix and controlling the time of delivery to the construction site by real-time monitoring management, as shown in the figure below:

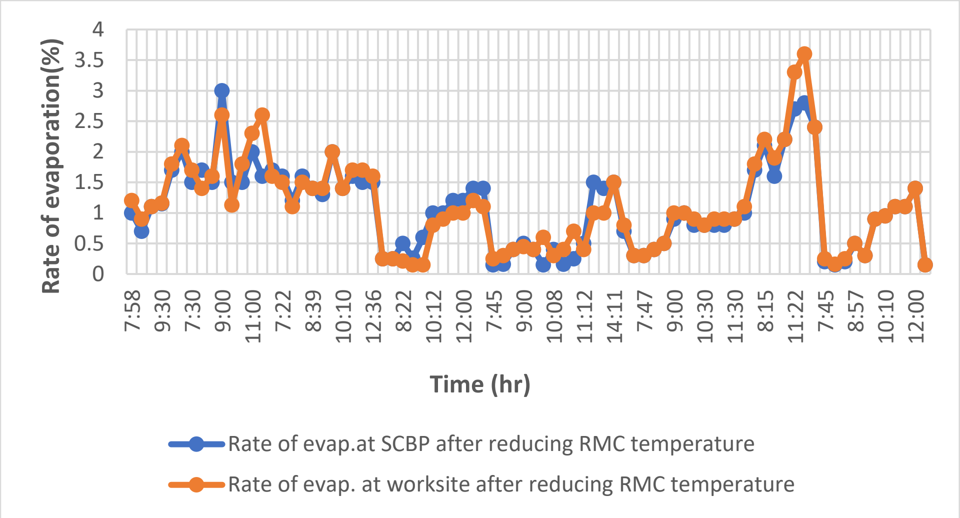


Figure 7.9 RMC evaporation rate in real-time monitoring at the SCBP and construction site for samples taken for different seasons after reducing the temperature of RMC mixture [Researcher].

Figure 7.9 represents the RMC rate of evaporation after reducing the mix temperature, where it shows that both values of the evaporation rate are stable for the samples taken at the SCBP and construction site meets with limitations for the seasons, where the maximum rate of evaporation was 3.6 % at the construction site on 7th July 2021. The minimum evaporation rate was 0.15 percent on 09th December 2021 at the stationary concrete batching plant.

7.2.8 Slump test

The RMC samples used to make test specimens must represent the whole batch. It must be acquired following ACI C172; the test procedure is outlined in ASTM C143/C143M; the test falls within the purview of ASTM Committee C09 on Concrete and Concrete Aggregates; and the direct responsibility of subcommittee C09.60 on testing fresh concrete and BS EN12350-2 in Europe.

The samples were taken from the mix directly and tested by two samples for each casting date, one in the SCBP and the second at the construction work site. The test was made to observe the RMC mix workability and compare it in both cases (at SCBP and worksite) through the determination and comparison of the amount and type of slump occurring and comparing the results with the limitations according to the type of construction member and the required concrete grade. The test was carried out for RMC in its current situation under controlled conditions. The samples taken as exist at the construction site were before the employees added the admixture for durability purposes as one percent of the total RMC mix (before unloading), where the results of the slump show improvement in the RMC mix properties like workability, air content, and porosity, which effects on the compressive strength *fc* in total as a final result.

Figure 7.10 The slump test of the RMC mix at the construction site for the samples taken on 27th July 2021 after reducing the temperature of the RMC mix [Researcher].

Figure 7.10 shows the slump test method carried out by the researcher of the RMC mix at the construction site for the samples taken on 27 July 2021. after reducing the temperature of the RMC mix, reducing the rate of evaporation, controlling the quality of materials, and controlling the delivery time of the RMC fresh mix to the construction site, where the slump test results of the RMC samples compared with the limitations recommended slump for various types of construction according to the ASTM C143/C 143M, as follows:

Table 7.8 Recommended slump for various types of construction based on ASTM C 143M [138].

No	*Type of construction*	*Slump (cm)*	
		Maximum	*Minimum*
6.	*Reinforced foundation, wall, and footing*	*7.5*	*2.5*
7.	*Plain footing and substructure walls*	*7.5*	*2.5*
8.	*Beams and reinforced walls*	*10*	*2.5*
9.	*Building columns*	*10*	*2.5*
10.	*Slabs Mass concrete*	*7.5*	*2.5*

The results of RMC slump tests performed on 16 samples of ready-mix concrete (RMC). The samples were collected from two different locations: a stationary concrete batching plant (SCBP) and a construction site. Moreover, controlling the slump of mixtures is essential to ensure the workability characteristics of the production of high-quality RMC with the desired compressive strength; where the test results were as follows:

Table 7.9 The slump test results for 16 samples taken on dates in the Spring, Summer, and Winter seasons at the stationary concrete batching plant and the construction site [Researcher].

No.	*Date / Season*	*location*	*Slump (mm)*
1.	*2022/04/04 (Monday) Spring*	*SCBP*	*6.2*
2.		*Worksite*	*7.3*
3.	*2022/04/05 (Tuesday) Spring*	*SCBP*	*6.7*
4.		*Worksite*	*6.5*
5.	*2021/04/24 (Sunday) Spring*	*SCBP*	*6.8*
6.		*Worksite*	*7*
7.	*2021/12/08 (Wednesday) Winter*	*SCBP*	*6.3*
8.		*Worksite*	*6.9*
9.	*2021/12/09(Thursday) Winter*	*SCBP*	*7.2*
10.		*Worksite*	*7.5*
11.	*2021/07/01 (Thursday) Summer*	*SCBP*	*6.6*
12.		*Worksite*	*8.3*
13.	*2021/07/07 (Wednesday) Summer*	*SCBP*	*5.9*
14.		*Worksite*	*7.2*
15.	*2021/07/27(Tuesday) Summer*	*SCBP*	*7.8*
16.		*Worksite*	*8.5*

Table 7.9 shows the results of the slump tests for 16 RMC samples taken as half at the SCBP and the other half at the construction site, where the results show two types of RMC slump: actual and shear slump, where the true slump was for the almost all cases at the SCBP except slump 8.5 cm (shear slump) which is tested on 2021/07/27 (Tuesday)in Summer season.

Moreover, The standard deviation measured and compared at the SCBP was 0.6, and the mean was 6.69, while at the construction site, the standard deviation was 0.687, and the mean of 7.4. It is calculated as the square root of the variance and is a valuable tool for understanding how much the data points in a set differ from the mean. In the first case, the standard deviation of 0.6 indicates that the data points are relatively close to the mean of 6.69, which suggests that there is not much variation in the data. On the other hand, in the second case, the standard deviation of 0.687 is more significant, indicating that the data points are more spread out and there is more variation in the data. The mean of 7.4 in the second case is also higher than the mean in the first case, which could also contribute to the more significant standard deviation, but they are close generally, and there is no significant variance, as shown in Figure 7.11.

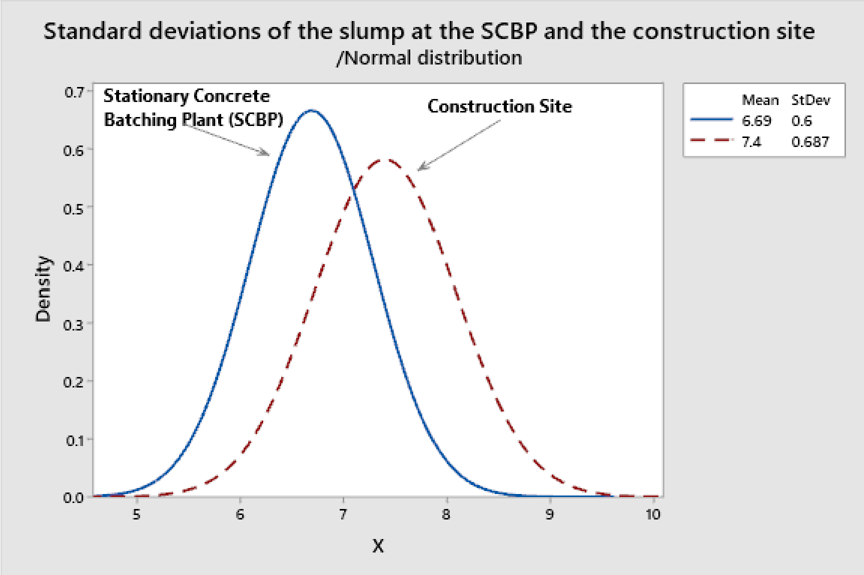


Figure 7.11 The standard deviations and the means of the slump test results at the SCBP and the construction site drawn by Minitab software version 2019 [Researcher].

Figure 7.11 illustrates the comparison of the standard deviations for both cases: first, at the SCBP, where it was 0.6, and mean of 6.69, and second, at a construction site was 0.687, and mean of 7.4 for the RMC samples.

7.2.9 Air content

The fresh concrete (compacted) air content can usually be determined when testing the air content of freshly compacted RMC. It is possible to find the air content of fresh RMC using a conventional test procedure like the pressure method.; the test is described in ASTM C 231 [140], and there are other standards for determining air content like BS 1881-107: 1983 in addition to test Method C 138/C 138M and C 173/C 173M provide pressure procedures for air content determining of RMC lets assuming that the concrete is fully compacted, and the concrete is taken at a known age to be proportional inversely to the ratio of water/cement.

The reason for using the pressure method is that it covers determining the air content of concrete based on the changes in RMC volume observation with a change in load (pressure), which applies to the case of the study due to changes in RMC order, which means changing the RMC volume for different times with a change in pressure. The test provides the air content of fresh RMC, excluding any percent of the air that may reside within aggregate particle voids.

The air content tests have been made at the SCBP and the construction site for 48 samples taken for casting dates in different seasons (Spring 2022, winter 2021, and Summer 2021). the samples have been tested at the SCBP, and the mixer arrives at the construction site after the truck. The mixture in this phase has been improved, including controlling and managing the quality of materials control, time of mixing, time of delivery, water/cement ratio, mixture temperature, ice amount required, and evaporation rate, using an acceptable ingredient with a particle size of 20 microns, and with a maximum coarse aggregate of 45mm.

Table 7.10 The air content percent of the RMC mixture with a 0.5 ratio of water/ cement for samples taken in the Spring, Winter, and Summer seasons at the SCBP and the construction site [Researcher].

No	***Date***		***Air content (%)***	***No***	***Date***		***Air content (%)***
1.	*2022/04/04 Monday (Spring)*	*SCBP*	*3.4*	**25.**	*2021/12/09 Thursday (Winter)*	*SCBP*	*3.4*
2.			*3.8*	**26.**			*3*
3.			*3.7*	**27.**			*2.8*
4.		*Work site*	*2.8*	**28.**		*Work-site*	*3.9*
5.			*3*	**29.**			*3.6*
6.			*3.4*	**30.**			*3.2*
7.	*2022/04/05 Tuesday (Spring)*	*SCBP*	*3.6*	**31.**	*2021/07/01 Thursday (Summer)*	*SCBP*	*3*
8.			*3.4*	**32.**			*2.8*
9.			*3.6*	**33.**			*3.8*
10.		*Work site*	*3.5*	**34.**		*Work-site*	*3.1*
11.			*3.9*	**35.**			*2.7*
12.			*3.7*	**36.**			*4.4*
13.	*2022/04/24 Sunday (Spring)*	*SCBP*	*3.7*	**37.**	*2021/07/07 Wednesday (Summer)*	*SCBP*	*3.6*
14.			*3.5*	**38.**			*3.3*
15.			*3.2*	**39.**			*3.3*
16.		*Work site*	*4.3*	**40.**		*Work-site*	*3.7*
17.			*3.1*	**41.**			*3.6*
18.			*3.4*	**42.**			*4.1*
19.	*2021/12/08 Wednesday (Winter)*	*SCBP*	*3.3*	**43.**	*2021/07/27 Tuesday (Summer)*	*SCBP*	*4.3*
20.			*3*	**44.**			*4.2*
21.			*3.3*	**45.**			*4.9*
22.		*Work site*	*3.2*	**46.**		*Works ite*	*4*
23.			*3.6*	**47.**			*4.3*
24.			*3.6*	**48.**			*3.7*

Table 7.10 represents the air content percentage for 24 samples at the SCBP and 24 samples at the construction site for the dates of the concreting days for the spring, autumn, summer, and winter seasons, where the nominal maximum aggregate size is 45mm, the air content limitations are 4 % (moderate) and 5.5% (severe), to improve cohesiveness and workability, decrease the bleeding rate, and decrease water added to mix for a specified consistency [142].

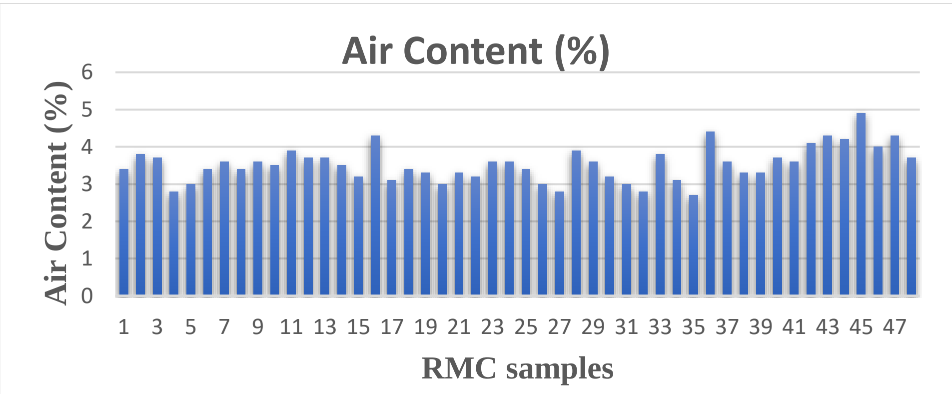


Figure 7.12 The RMC air content percent with a 0.5 ratio of W/C for 48 samples [Researcher].

Figure 7.12 represents air content according to the date of RMC casting; it was noticed that the air content percentage for the samples at the SCBP was close to the values of the air content percentage at a construction site due to the controlling and managing of the quality of materials, time of mixing process, time of delivery, water/cement ratio, mix temperature, ice amount required, evaporation rate, as shown in the figure 7.12, where the maximum percentage of air content is 4.9 % was at the SCBP on 27th July 2021 which is met with limitations according to ASTM, in summer season, and the minimum air content percent was 2.7 % at the construction site on 1st July 2021, in summer season. In general, monitoring 48 samples of RMC air content percent taken at the SCBP and at a construction site has shown that the diversity in the air content percentage is reduced based on the previous improvement steps.

7.2.10 Porosity

Several factors, including the mix design, casting and curing process, and quality of raw materials, can influence the porosity. The mix design should be tailored to the project's specific requirements, considering the strength and durability requirements and the ambient conditions at the construction site. The ratio of water/cement, type, amount of cement, gradation of aggregate, and casting and curing process are all factors that can affect the porosity of RMC, where proper casting techniques can help reduce porosity. Furthermore, the quality of the raw materials used in the production can affect the porosity. In the case of the study, the total voids of the RMC for 0.5 a ratio of water/cement, and the specific gravity is 2.6, 2.65, and 3.15 for fine aggregate, coarse aggregate, and cement, respectively, with the degree of hydration is 0.7, average of air entrapped 3.54 %, and the porosity of the sample calculated by the following:

$$P = \frac{V_v}{V} = \frac{\frac{W}{C} - 0.17h + \frac{a}{C}}{0.317 + \frac{1}{\rho_f}\frac{A_f}{C} + \frac{1}{\rho_c}\frac{A_c}{C} + \frac{W}{C} + \frac{a}{C}} \tag{47}$$

And

$$\frac{a}{V} = \frac{\frac{a}{C}}{\frac{1}{3.15} + \frac{2}{2.6} + \frac{2.87}{2.65} + 0.5 + \frac{a}{C}} = \frac{3.54}{100} \tag{48}$$

Hence, the entrapped air per unit mass of cement $\frac{a}{c} = 0.2$, the porosity for the average air content is 20.35 percent for 48 samples of RMC taken at the stationary concrete batching plant and the construction site for the casting dates, as shown in the table below:

Table 7.11 The porosity percent and air entrapped per unit cement mass with 0.5 W/C ratio for samples taken at the SCBP and construction site [Researcher].

No	Date		$\frac{a}{c}$	Porosity (%)	No	Date		$\frac{a}{c}$	Porosity (%)
1.	2022/04/04 Monday (Spring)	SCBP	0.19	20.07	25.	2021/12/09 Thursday (Winter)	SCBP	0.19	20.07
2.			0.22	20.91	26.			0.17	19.51
3.			0.21	20.63	27.			0.16	19.22
4.		Work site	0.16	19.22	28.		Work site	0.22	20.91
5.			0.17	19.51	29.			0.205	20.49
6.			0.19	20.07	30.			0.18	19.79
7.	2022/04/05 Tuesday (Spring)	SCBP	0.205	20.49	31.	2021/07/01 Thursday (Summer)	SCBP	0.17	19.51
8.			0.19	20.07	32.			0.16	19.22
9.			0.205	20.49	33.			0.22	20.91
10.		Work site	0.199	20.32	34.		Work site	0.178	19.73
11.			0.22	20.91	35.			0.15	18.93
12.			0.21	20.63	36.			0.253	21.8
13.	2022/04/24 Sunday (Spring)	SCBP	0.21	20.63	37.	2021/07/07 Wednesday (Summer)	SCBP	0.205	20.49
14.			0.199	20.32	38.			0.187	19.99
15.			0.18	19.79	39.			0.187	19.99
16.		Work site	0.25	21.72	40.		Work site	0.21	20.63
17.			0.178	19.73	41.			0.205	20.49
18.			0.19	20.07	42.			0.235	21.8
19.	2021/12/08 Wednesday (Winter)	SCBP	0.187	19.99	43.	2021/07/27 Tuesday (Summer)	SCBP	0.25	21.72
20.			0.17	19.51	44.			0.24	21.45
21.			0.187	19.99	45.			0.28	22.52
22.		Work site	0.18	19.79	46.		Work site	0.23	21.18
23.			0.205	20.49	47.			0.25	21.72
24.			0.205	20.49	48.			0.21	20.63

Table 7.11 shows the RMC porosity, the entrapped air volume per unit mass of cement (a/c) for the RMC samples taken for the dates mentioned for different seasons, where the maximum porosity was at the SCBP 22.52 % in summer on 27/07/2021, and minimum porosity was 18.93 % in the spring season at the construction site in the summer on 01/07/2021.

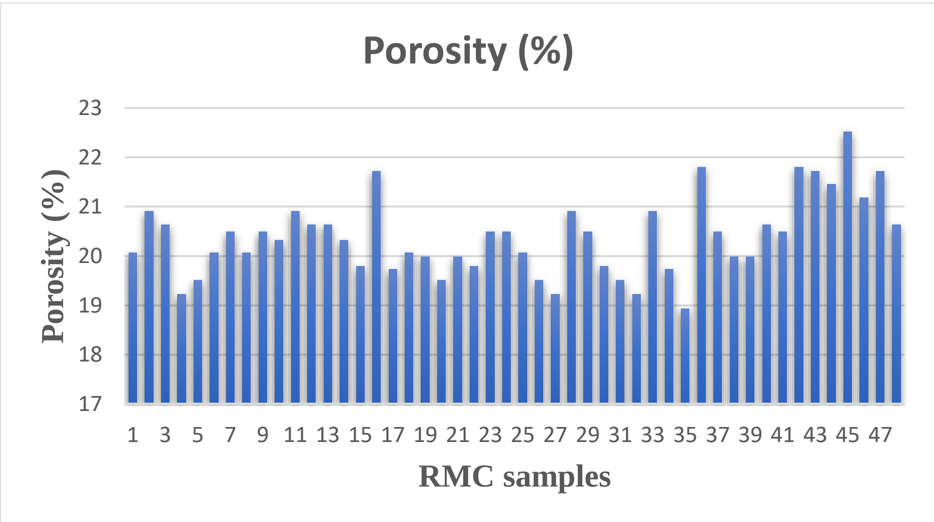


Figure 7.13 RMC porosity percent with a 0.5 ratio of water/ cement for samples taken in different seasons at the SCBP and the construction site [Researcher].

Figure 7.13 illustrates the porosity for samples taken at the SCBP and construction site. The maximum porosity was 22.52 % at the SCBP in the summer season on 27/07/2021, and the minimum porosity percent was 18.93% in summer on 01/07/2021 at the construction site. The porosity percentages at the SCBP and the construction site are generally close, which may be due to the mixed temperature control to reduce the evaporation rate and decrease the percentage of entrapped air, reducing the porosity of the RMC samples.

7.2.11 Concrete compressive strength (f_c) test

The results of laboratory tests for RMC samples were taken precisely from each batch mixing process in the stationary concrete batching plant and recorded as part of the monitoring process for concrete in real-time monitoring for the second phase of 48 samples after making adjustments for the production process. For the mixing, components were taken into account the weather conditions (temperature, relative humidity, air temperature, wind speed, delivery time, truck mixer waiting time before RMC pouring, placing time, downtime at the site, truck mixers washing time, and the journey time from the SCBP to the construction site, in addition to the factors such as the surrounding environment conditions, quality of mixing water, mixing ingredient type, W/C ratio, rate of evaporation, air content, additive material percent, size of particles of aggregate, and the porosity. The tests were done in the construction laboratory of the Engineers Union/Iraq/Misan, according to ACI Code 301-20, ASTM C39, ASTM C31, and IS 5816-1999 were the results of tests for the samples taken for the phase one before improvements, where the compressive strength required 25 MPa, where the equation gives it:

$$f_{ci} = \frac{F_i}{A_{ci}}, f_{cm} = \sum_{n=1}^{n} f_{ci}/n \qquad (49)$$

Where: $f$ci= Compressive strength of the specimen (MPa), Fi= Maximum load applied to the specimen (N), and Aci= Cross-sectional area of the specimen (mm^2) = 22500 (mm^2); the specimens of dimensions (150 x150 x150 mm) were prepared. The testing samples are 48 cubes, where the 24 tests were taken at SCBP before the truck mixers journey to the construction site, which is 11 m away from the site of the SCBP; where mentioned above, the tests were made in the construction laboratory of the Engineers union/ Misan. Furthermore, the 24 test samples at the construction site, described according to the dates mentioned in the table below, where the samples were taken in real-time as a part of real-time monitoring for the effects of the surrounding environment conditions and delivery time. The quality of materials and suppliers, where the 24 test samples taken at the worksite are as follows:

1. The test samples for the RMC of the first-floor columns (six samples), cast in two stages, are a good quality control measure. This approach allows for proper evaluation of the mixture at different locations and stages of the construction. The division into two stages, with three cubes per stage, further ensures a comprehensive evaluation of the concrete quality. This approach helps ensure the structural integrity and durability of the building.

Figure 7.14 RMC compressive strength test samples for the building columns of the first floor, six test samples at age 28 days [Researcher].

2. The test samples (six samples) taken from the RMC of the reinforced beams and the slab of the first floor which is cast in two stages; the first is for the left and right sides of the buildings, in addition to the columns of the middle part of the first floor (did not take samples and leave them until the columns casting was complete). The second stage is for the right side of the building, taking during the RMC placing, in frameworks of the reinforced beams and reinforced slab of the first floor.

Figure 7.15 RMC compressive strength test samples for the first-floor reinforced beams and slab, six test samples at age 28 days [Researcher].

3. The test samples (six cubes) were taken from the RMC columns of the second floor, which is cast in three stages; the first stage is to the right side to the location of the elevator, the second is the middle part with round beams, and the third is the left side of the building with (2 cubes for each stage). The division into three stages also allows for a more detailed evaluation of RMC quality and helps to ensure the reliability and safety of the building.

Figure 7.16 RMC compressive strength *fc* (MPa) test samples for the building columns of the second floor, six test samples at age 28 days [Researcher].

Figure 7.17 The RMC compressive strength fc (MPa) test samples for the building columns of the second floor, six test samples at age 28 days [Researcher].

4. The RMC test samples (six samples) are taken from a reinforced slab of the second floor, which is cast in two stages, with each stage covering half of the building. Six samples were taken for testing, with three samples for each stage of the RMC casting. These tests were conducted in real time to ensure the quality of the RMC used in the construction.

Figure 7.18 The RMC compressive strength *fc* (MPa) test samples for the reinforced beams and slab of the second floor, six tets samples at age 28 days [Researcher].

Figure 7.19 The RMC compressive strength fc (MPa) test samples for the reinforced beams and slab of the second floor, six test samples at age 28 days [Researcher].

The figure of the RMC compressive strength (*fc*) test samples for the reinforced beams and slab of the second floor shows the results of six tests taken at 28 days. The compressive strength of RMC is an essential parameter in determining the quality and durability of the concrete. The concrete has reached a significant stage of curing, and the compressive strength test provides valuable information about the RMC's ability to withstand the loads and stresses it will be subjected to during its service life. The results of these tests help to determine if the RMC used in the construction meets the required standards for strength and durability.

Figure 7.20 RMC compressive strength (MPa) test results for the sample at a construction site on 4th April 2022 for the reinforced beams and slab of the second floor, at age 28 days [Researcher].

Figure 7.20 shows RMC samples taken on 4th April 2022 and tested at age 28 days at the construction site for the RMC use for the reinforced beams and slab of the second floor of the building for the first stage of the RMC casting for the left side and the middle parts of the building is essential to test the quality and strength of RMC at various stages of the construction process to ensure that it meets the necessary specifications and will be able to support the weight and structural requirements of the building, where the compressive strength was 43.7 MPa.

Figure 7.21 RMC compressive strength *fc* (MPa) test results for the sample at the SCBP on 24th April 2022, for the reinforced beams and slab of the second floor, at age 28 days [Researcher].

Figure 7.21 shows the RMC test samples taken on 24th April 2022 at age 28 days at the stationary concrete batching plant and the construction site and tested for the RMC use for the reinforced beams and slab of the second floor of the building for the second stage of the RMC casting for the right side of the building, where the compressive strength was 38.9 MPa, the test made based on ASTM C39, ASTM C31.

Figure 7.22 RMC compressive strength (MPa) test results for the sample at the construction site on 8th December 2021 for the second-floor reinforced columns at age 28 days [Researcher].

The compressive strength fc test results in the figure above show the RMC samples taken on 8th December 2021at the construction site and tested at age 28 days for the RMC use for the reinforced columns of the second floor of the building, for the first and the second stages of the

RMC casting for the columns middle part (circular columns) and the rectangular columns in the left side of the building, where the compressive strength was 44.9 MPa. The RMC mix arrives at a construction site by truck mixers (controlled delivery time) and directly unloads the RMC in the concrete pump's hooper to transport it to the building's columns.

Figure 7.23 RMC compressive strength (MPa) test results for the sample at the SCBP on 9th December 2021, for the second-floor reinforced columns, at age 28 days [Researcher].

Figure 7.23 represents the compressive strength fc test results of the RMC samples taken on December 8, 2021, at the SCBP and tested at the age of 28 days for the RMC use for the reinforced columns in the second floor for the third stage of casting for the rectangular columns in the right side of the building, where the compressive strength was 43.3 MPa.

Figure 7.24 The RMC compressive strength (MPa) test results for the sample at the SCBP on 1st July 2021 for the reinforced beams and slab of the first floor at age 28 days [Researcher].

Figure 7.24 shows the RMC test samples taken on 1st July 2021 at age 28 days at the stationary concrete batching plant (SCBP) and tested for the RMC use for the reinforced columns of the first floor of the building, which is cast in two stages that it is meet the compressive strength fc requirement (25 MPa), where the compressive strength was 35.4 MPa, the test made based on ASTM C39, ASTM C31.

Figure 7.25 RMC compressive strength fc (MPa) test results for the sample at the SCBP on 7th July 2021, for the reinforced beams and slab of the first floor, at age 28 days [Researcher].

Figure 7.25 shows the RMC test samples taken on 7th July 2021 at age 28 days at the construction site and tested for the RMC use for the reinforced beams and slab of the first floor of the building for the first stage of the RMC casting for the left side of the building, where the compressive strength was 35.2 MPa, the test made based on ASTM C39, ASTM C31 in the laboratory. Furthermore, the samples were taken on 27th July 2021 for the ready-mix concrete (RMC) of the reinforced beams and slab of the first floor of the building for the second stage of the RMC casting for the right side of the building, which is cast in two stages, (three samples (cubes) at the SCBP, and three at construction site). It is essential to regularly test the RMC quality used in constructing the reinforced columns on the first floor of the building. By taking samples on 27th July 2021 and testing them both at the stationary batching plant and on the construction site, it ensures that the RMC meets the specifications and standards for the project. Regular testing is crucial in ensuring the strength and durability of the finished structure. This comprehensive testing process provides a comprehensive understanding of the quality of the RMC used in the reinforced beams and slab of the first floor of the building. The quality of the RMC used in the construction is being regularly monitored and tested to ensure that it meets the specifications and standards required for the project.

The results of the compressive strength tests on 27th July 2021 for the RMC of the reinforced beams and reinforced slab of the first floor of the building for the second stage of the RMC casting for the right side of the building, which is cast in two stages that it is meet the compressive strength requirement (25 MPa) of the project, where for the figure 7.26 (RMC sample taken on 27th July 2021) the compressive strength was 33.4 MPa at the stationary concrete batching plant (SCBP) and 33.3 MPa at the construction site.

Figure 7.26 RMC compressive strength (MPa) test results for the sample at the SCBP on 27th July 2021, for the reinforced beams and slab of the first floor, at age 28 days [Researcher].

Moreover, the test results for the RMC samples showed previously are a sample from the 48 tests of the compressive strength that have been made at the construction laboratory of the Engineers union of Iraq in Misan city; for this phase, after the controlling the temperature, and relative humidity effects during the mixing process, delivery time, truck mixer waiting time, placing time, downtime at the construction site, and the journey time from the SCBP to the construction site, in addition to the quality of materials, and water, mixing type, rate of evaporation, air content, the additive material percent, the size of particles of aggregate, and the porosity percent where the results of the compressive strength for both cases at the stationary concrete batching plant (SCBP) and at the construction site, as shown in the table 7.12, where it presents the results of 48 RMC samples taken at the stationary batching plant (SCBP) and the construction site during the summer of 2021, the winner of 2021, and the spring of 2022. The samples were tested for compressive strength at ages 3, 7, and 28 days. The results show that the maximum compressive strength of 53 MPa was achieved at the construction site on 7th July 2021, while the minimum compressive strength of 32 MPa was achieved at the construction site on 27 July 2021.

Table 7.12 RMC compressive strength (MPa) test results for samples at the SCBP and construction site at age 3, 7, and 28 days for monitoring during Spring, Summer, and Winter seasons [Researcher].

No	**Date**		***fc* at 3 days**	***fc* at 7 days**	***fc* at 28 days**	**No**	**Date**		***fc* at 3 days**	***fc* at 7 days**	***fc* at 28 days**
1	*2022/04/04 Monday (Spring)*	*SCBP*	*15.5*	*25.2*	*38.8*	**25**	*2021/12/09 Thursday (Winter)*	*SCBP*	*15.7*	*25.5*	*39.2*
2			*14.2*	*23.1*	*35.6*	**26**			*16.2*	*26.3*	*40.4*
3			*14.9*	*24.2*	*37.2*	**27**			*17.3*	*28.1*	*43.3*
4		*Work site*	*17.5*	*28.4*	*43.7*	**28**		*Work site*	*13.8*	*22.4*	*34.5*
5			*16.4*	*26.6*	*40.9*	**29**			*15*	*24.3*	*37.4*
6			*15*	*24.3*	*37.4*	**30**			*15.6*	*25.3*	*38.9*
7	*2022/04/05 Tuesday (Spring)*	*SCBP*	*14.8*	*24.1*	*37.1*	**31**	*2021/07/01 Thursday (Summer)*	*SCBP*	*16.4*	*26.7*	*41*
8			*15.7*	*25.5*	*39.2*	**32**			*17*	*27.6*	*42.5*
9			*14.8*	*24*	*36.9*	**33**			*14.2*	*23*	*35.4*
10		*Work site*	*15.4*	*25.1*	*38.6*	**34**		*Work site*	*16.6*	*27.0*	*41.6*
11			*13.7*	*22.3*	*34.3*	**35**			*21.2*	*34.5*	*53*
12			*14.6*	*23.7*	*36.4*	**36**			*13*	*21.2*	*32.6*
13	*2022/04/24 Sunday (Spring)*	*SCBP*	*14.8*	*24.1*	*37.1*	**37**	*2021/07/07 Wednesday (Summer)*	*SCBP*	*15.1*	*24.5*	*37.7*
14			*15.6*	*25.3*	*38.9*	**38**			*15.5*	*25.2*	*38.7*
15			*15.8*	*25.7*	*39.5*	**39**			*15.2*	*24.8*	*38.1*
16		*Work site*	*13.5*	*22*	*33.8*	**40**		*Work site*	*14.1*	*22.9*	*35.2*
17			*15.8*	*25.7*	*39.6*	**41**			*15.2*	*24.7*	*38*
18			*16.4*	*26.7*	*41.1*	**42**			*13.7*	*22.2*	*34.2*
19	*2021/12/08 Wednesday (Winter)*	*SCBP*	*16*	*26*	*40*	**43**	*2021/07/27 Tuesday (Summer)*	*SCBP*	*13.2*	*21.4*	*32.9*
20			*16.6*	*27*	*41.6*	**44**			*13.4*	*21.7*	*33.4*
21			*15.7*	*25.5*	*39.2*	**45**			*12.8*	*20.8*	*32*
22		*Work site*	*16.1*	*26.1*	*40.2*	**46**		*Work site*	*13.8*	*22.4*	*36.5*
23			*15.3*	*24.9*	*38.3*	**47**			*13.3*	*21.6*	*33.3*
24			*18*	*29.2*	*44.9*	**48**			*14.4*	*23.5*	*36.1*

Moreover, the overall average compressive strength of 48 RMC samples was 38.2 Mpa, which means that the RMC used meets the standards, an essential factor in determining the quality and durability of the concrete. It is crucial to notice a range of results, with some samples having higher or lower strengths than the average, so further analysis may be necessary to determine if any action is required to ensure the RMC quality.

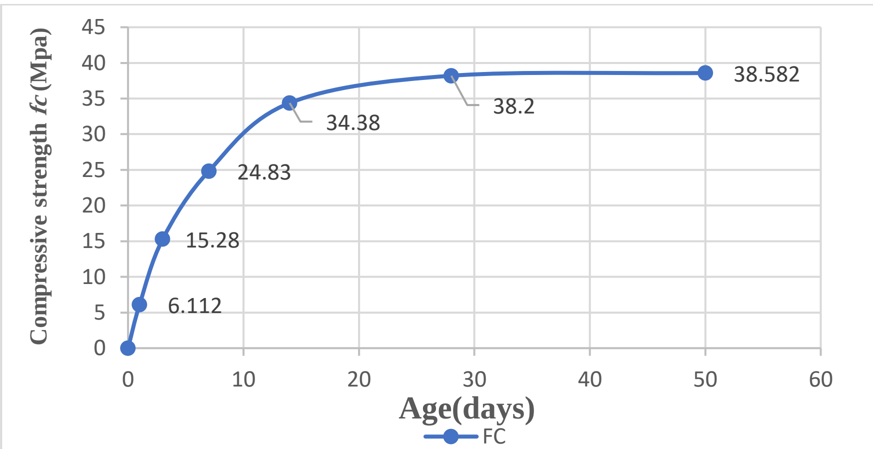


Figure 7.27 Average of RMC compressive strength at age 28 days for the second phase (48 samples) after the RMC improvements at the SCBP and the construction site [Researcher].

Figure 7.27 illustrates that the overall average compressive strength for 48 samples was 15.3 MPa at 3 days of age, 24.8 MPa at 7 days of age, and 38.2 MPa at 28 days of age, which means that the results exceed the compressive strength required (25 MPa), which represent the 99% of the final RMC compressive strength.

The results of RMC tests have shown that there is an improvement in the values of compressive strength after a group of adjustments made to the RMC production process and mixture ingredients quality concerning the factors (water-cement ratio, size of aggregate, percent of quantities of ingredients, additive materials percent, rate of evaporation, air content, and porosity, in addition to delivery time, temperature, humidity, and environmental circumstances that it is have taken in consideration. The impact of all these factors can be managed in an earlier phase (in our case study, these effects are monitored and controlled or managed by a procedure of real-time management monitoring through reducing the RMC temperature by adding ice to the mixture to keep it in limitations according to ASTM (30-32℃) accounted as a percent from the water used in the mixture when temperatures decrease, increase the quantities of the fine material such as cement, fine aggregate. The improvement steps lead to an increase in the surface area for interaction with water, which affects the rest of the components during the hydration process and reduces the pores in RMC that exist in between the ingredients, the changes in the ingredients (additive materials, the ratio of water to cement to find the porosity to increase the density, control air entrapped percent to meet the limitations, reduced the rate of evaporation and control delivery time, where for the variance between the compressive strength at the SCBP, and the construction site are reduced to minimum possible value, due to the steps of the monitoring and controlling have made previously, where all the samples met with the required compressive strength for the project which is 25 MPa.

Moreover, the comparison between the average of the compressive strength of the RMC for the first phase (48 samples) before the real-time monitoring and controlling process and the second phase (48 samples) after the improvements for both cases at the batching plant and at the construction site, where the comparison was as following:

1. The comparison between the total average of the compressive strength results at age 28 days for the samples taken at the SCBP and at the construction site for the first phase 48 samples before the improvements and second phase 48 samples after the improvements, in addition to the comparison with the compressive strength required, as shown in the figure below:

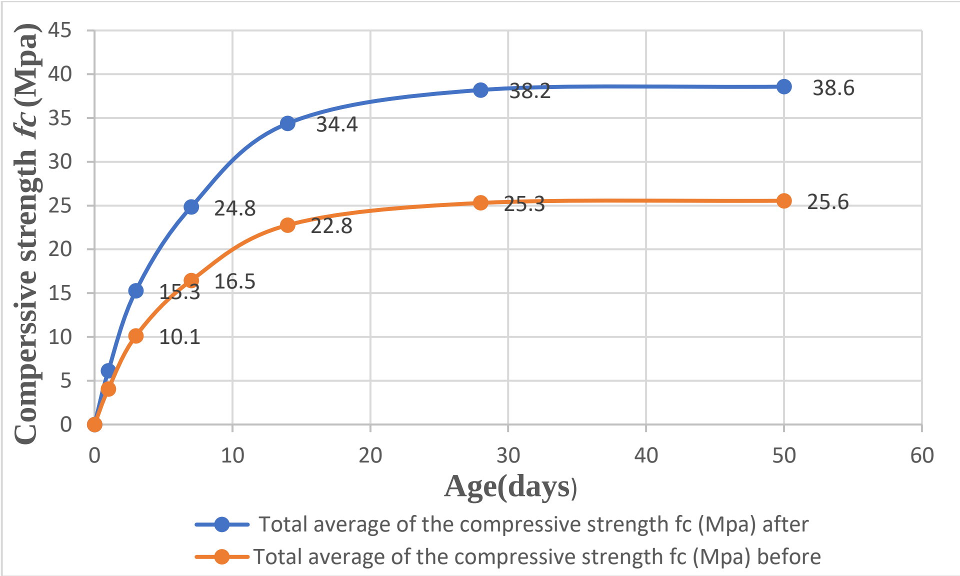


Figure 7.28 Average RMC compressive strength at 28 days compared between the initial phase (48 samples) and the improved phase (48 samples) at the SCBP and construction site [Researcher].

Figure 7.28 shows the total average of the compressive strength test results at age 28 days for the first phase (48 samples) before the improvements and the second phase (48 samples) after improvements at the SCBP and at the construction site, where the results show that there is an improvement in the compressive strength in the second phase around 51% more than the compressive strength in the first phase before the improvements at the SCBP and at construction site, where the total average of the strength at the second phase was 38.2 MPa, while for the first phase was 25.3 MPa, both results are meet with the compressive strength required. However, there is a clear difference between the quality of concrete barely passing the compressive strength test by an average (some of the samples failed to meet with strength required) and the RMC exceeding the results required with confident quality.

2. The comparison between the compressive strength test results at the stationary batching concrete (SCBP) for the first phase (24 samples) before the improvements and the second phase (24 RMC samples) after the improvements, where it is noticed that there is an improvement in the average of the compressive strength of the RMC samples for the second phase of the RMC around 35% more than the average of the compressive results for the first phase before the improvements as shown below:

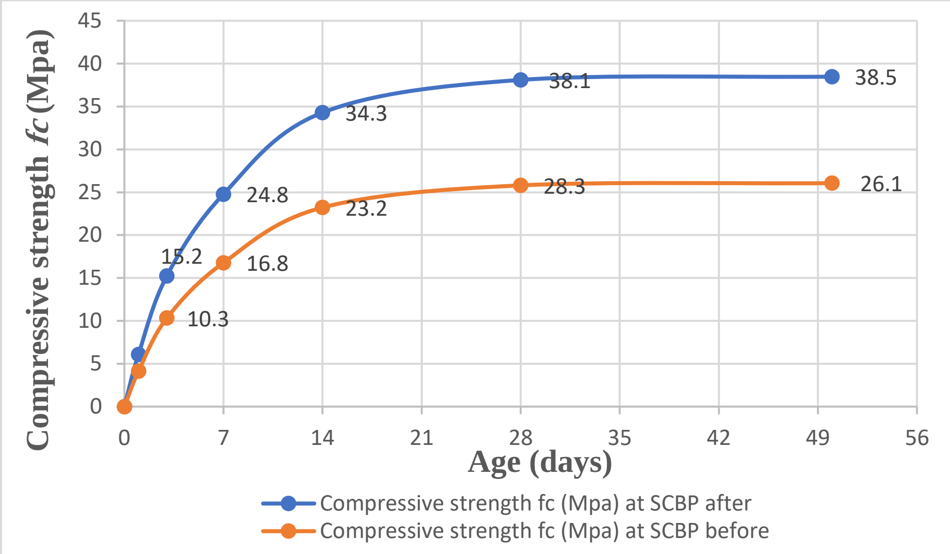


Figure 7.29 Average of RMC compressive strength test results at age 28 days for the first phase (48 samples) before improvements and the second phase (48 samples) after at the SCBP [Researcher].

Figure 7.29 represents the average of the compressive strength at the SCBP of 24 samples for the first phase before the improvements, where the strength at age 28 days was 28.3 MPa, and the average compressive strength of 24 samples for the second phase after the improvements was 38.1 MPa, taken at the batching plant (SCBP).

3. The comparison of the RMC compressive strength test results for samples taken at the construction site (48 samples) showed that there was an improvement in the average compressive strength of the 24 samples for the second phase after the RMC improvements of around 54% more than the average of the compressive results values for the first phase for 24 RMC samples before the improvements as shown in follows:

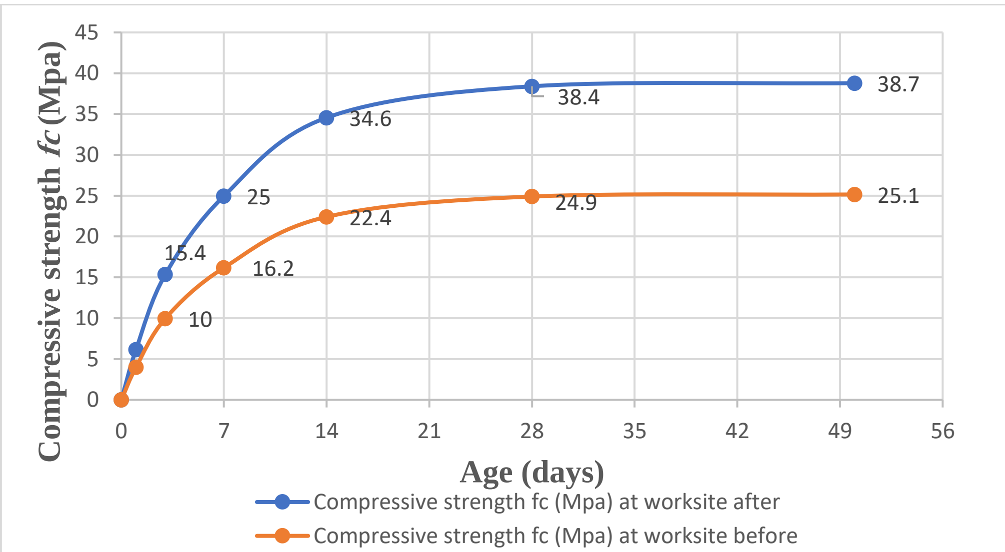


Figure 7.30 Average of RMC compressive strength test results at age 28 days for the first phase (48 samples) before and the second phase (48 samples) after at the construction site [Researcher].

Figure 7.30 illustrates the average compressive strength for 24 samples taken at the construction site for the first phase before the improvements, where it was 24.9 MPa at age 28 days. The average compressive strength of 24 samples for the second phase after improvements was 38.4 MPa taken at the construction sites, where the samples were taken for different seasons for the dates mentioned previously to control the properties in variance conditions and mitigate the effect of these conditions on RMC quality.

4. The final compression for compressive strength results for the seasons to have an idea about the effects of the real-time monitoring and controlling process steps used to improve the quality of the RMC compressive strength in our case study; it is possible to make a comparison based on the compressive strength test results between the seasons summer 2020, winter 2022, spring 2021, for the first phase before the improvements for 48 test samples, and the three seasons summer 2021, winter 2021, spring 2022, for the second phase after the improvements for 48 test samples, both samples of the two phases taken on dates mentioned previously at the SCBP and the construction site, see the figure below:

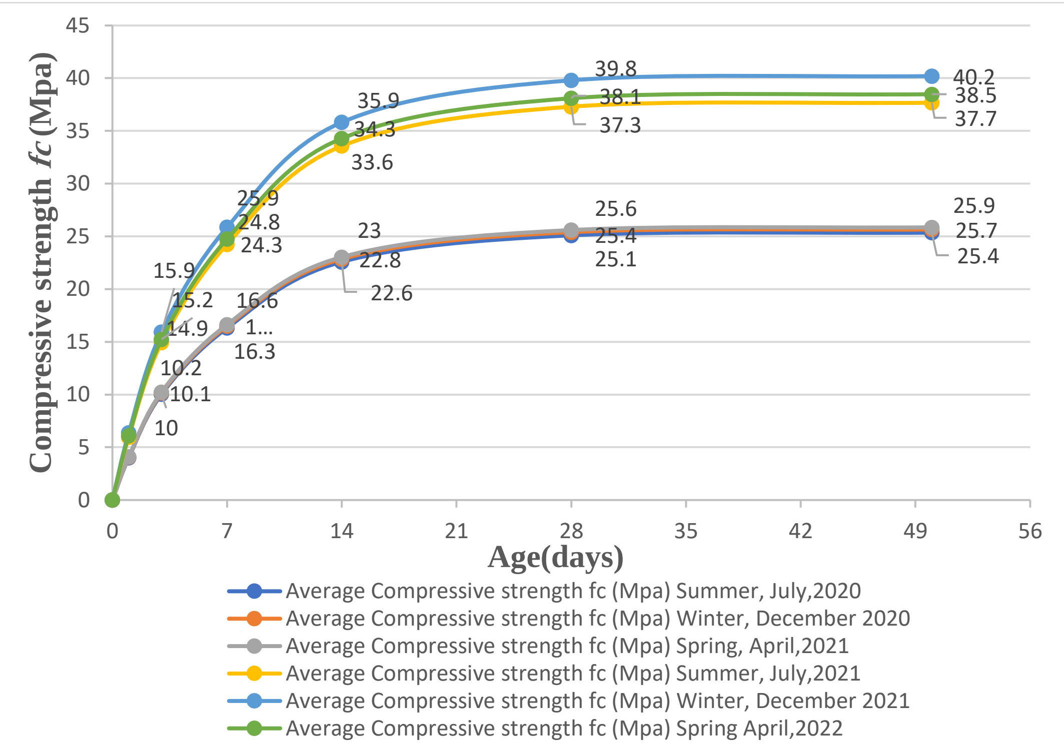


Figure 7.31 Comparison of RMC compressive strength: Before and after improvements at SCBP and construction site, across 96 season samples [Researcher].

Figure 7.31 shows that the compressive strength of RMC exceeded the compressive strength required (25 MPa) for both cases before and after the RMC improvements; the focus point was to improve the quality of RMC at the lowest possible cost, with the minimum amount of time required and less effort, for 96 samples of tests taken at the

SCBP and at the construction site, where the average compressive strength of RMC at 28 days of age for the first phase (48 RMC samples) before making the improvements on the RMC for the summer season in July 2020 was 25.1 MPa and the winter season in December 2020 was 25.4 MPa. In the spring season, April 2021 was 25.6 MPa. The average compressive strength at 28 days of the second phase (48 RMC samples) after making improvements to the RMC for the summer season in July 2021 was 37.3 MPa, the winter season in December 2021 was 39.8 MPa, and the spring season in April 2022 was 38.1 MPa. Therefore, based on the results of the average compressive strength of the three seasons that samples were taken in, it was noticed that the compressive strength for the summer seasons, July for the second phase (after the improvements), is 37.3 MPa, and for the first phase, July 2020 (before the improvements), is 25.1 MPa, which means that the RMC compressive strength improved 49% more than the RMC compressive strength before RMC mix improvements in the first phase. Moreover, the compressive strength for the winter season, December 2021, for the second phase (after the improvements) is 39.8 MPa. For the first phase, December 2020 (before the improvements), it is 25.4, which means that the RMC compressive strength is around 57% more than the compressive strength before the improvements in the first phase. Furthermore, the compressive strength for the spring season, April 2022, for the second phase (after the improvements) is 38.1 MPa. For the first phase of the spring season, April 2021 (before the improvements) is 25.6, which means that the RMC compressive strength is around 49% more than the compressive strength before the improvements in the first phase.

7.1 Results and relationships

The analysis of the effects of the results values of monitoring for RMC quality provides us with an idea about the nature of the relationships between the parameters through 80 samples of the RMC mix temperature, 80 cases of the environmental conditions (weather temperature, relative humidity percent, wind speed, and the air temperature) for the same time of the RMC temperature samples taken, the rate of evaporation (80 samples) for the same RMC samples were temperature of mix taken, 16 samples of the slump test for RMC fresh mix, air content percent for 80 samples for the same samples taken for the rate of evaporation (after reducing the mix temperature), porosity samples (48 test samples), and 48 compressive strength tests for the exact sample taken at the stationary concrete batching plant (SCBP) and at the construction site, where the relationships were as follows:

1) An inverse relationship exists between compressive strength and air content, whereby an increase in air content leads to a decrease in compressive strength. It is widely acknowledged that the presence of air can substantially impact the strength and durability of the material. Air voids in concrete can weaken the concrete matrix and reduce its strength, making it more susceptible to cracking and other forms of damage. Therefore, it is essential to control the air content to ensure that the concrete reaches its maximum strength and durability, as shown in the figure below:

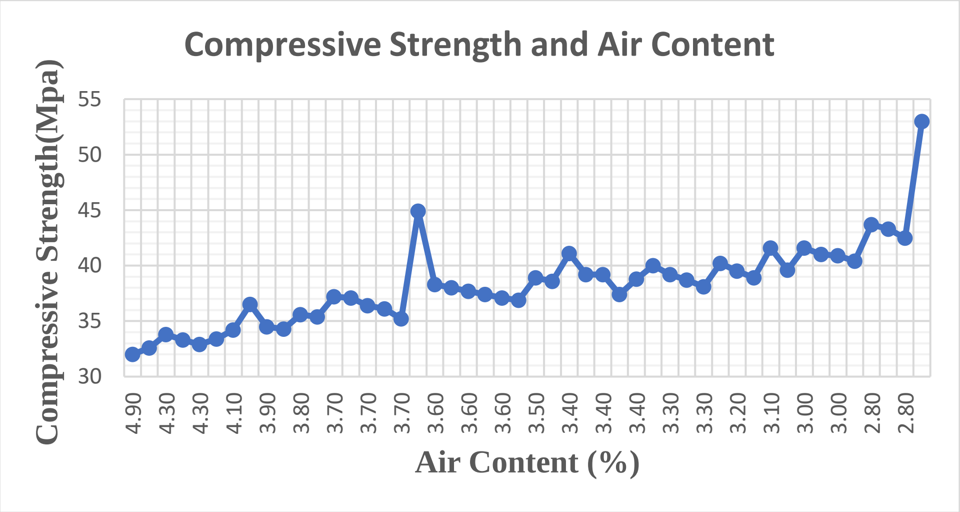


Figure 7.32 Air content percent relationship with the compressive strength (*fc*) for 48 samples after RMC improvements taken at the SCBP and the construction site [Researcher].

Figure 7.32 represents the relationship between the RMC compressive strength and the air content (direct proportion); in general, the increase in the percentage of air content decreases the compressive strength, where the maximum air content was 4.9% of the compressive strength was 32 MPa which is the minimum compressive strength because the increasing number of the capillary water pores and gel water pores in the mix reduces the amount of contact between the aggregate particles, which reduces the strength, on the other hand, if the air content percent decreased the compressive strength will increase, where, the minimum air content was 2.7%, the compressive strength was 53 MPa for 48 samples after RMC improvements taken at the SCBP and the construction site.

2) An inverse relationship between the porosity and compressive strength of RMC means that as the porosity decreases, its compressive strength increases, and vice versa. In the case of RMC, lower porosity results in higher compressive strength, making it more resistant to crushing and deformation under load; see Figure 7.33.

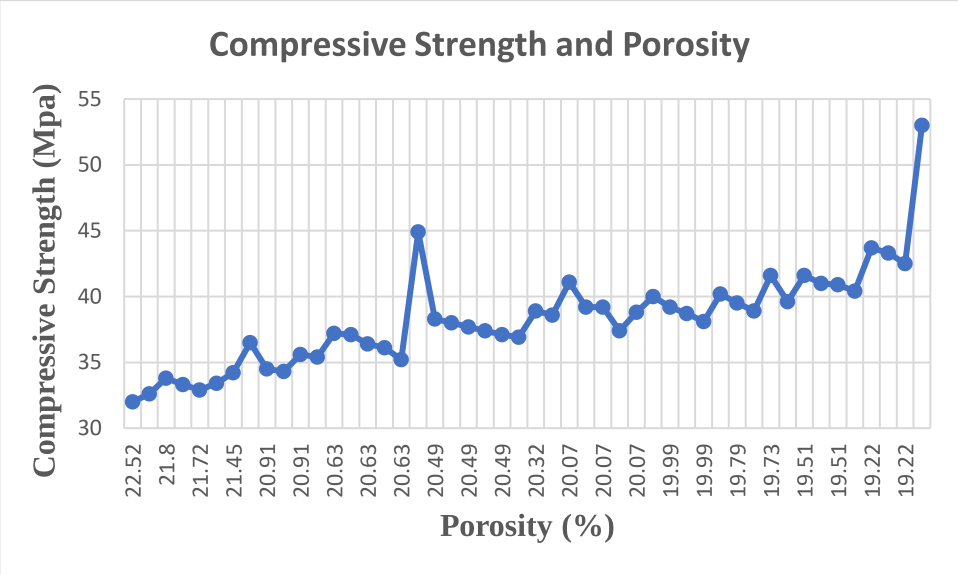


Figure 7.33 An inverse porosity relationship with the compressive strength for 48 samples after RMC improvements taken at the SCBP and the construction site [Researcher].

Figure 7.33 illustrates the inverse relationship between compressive strength and porosity (as porosity percent increases, the compressive strength decreases). The results show that the maximum compressive strength of 53 MPa was achieved at a minimum porosity of 18.93%, while the minimum compressive strength of 32 MPa was observed at a maximum porosity of 22.52 %. These findings indicate the importance of controlling porosity in RMC production, as it directly affects the material's compressive strength. Notably, the results were obtained from 48 samples taken from the SCBP and construction site after improvements were made in the production process, highlighting the efforts made to improve the quality of RMC.

3) The density of ready-mix concrete and its air content percentage have an inverse relationship, meaning that as air content increases, concrete density decreases. This relationship is established through RMC compressive strength tests, revealing that higher air content leads to lower density and vice versa, underscoring air content's influence on RMC density and strength.

Moreover, these findings highlight the variability in air content and density of RMC in different seasons and locations, emphasizing the importance of continuous monitoring and improvement efforts to ensure the quality of RMC.

The inversely proportional relationship highlights the importance of controlling air content levels in RMC production to ensure consistent density and strength.

Table 7.13 The entrapped air percent and the density of the RMC for samples taken at the stationary concrete batching plant (SCBP) and the construction site [Researcher].

No	Date	Air (%)	Density (Kg/mm^3)	No	Date	Air (%)	Density (Kg/mm^3)
1	2022/04/04 Monday (Spring)	3.4	2364	25.	2021/12/09 Thursday (Winter)	3.4	2435
2		3.8	2340	26.		3	2458
3		3.7	2352	27.		2.8	2387
4		2.8	2346	28.		3.9	2207
5		3	2375	29.		3.6	2263
6		3.4	2255	30.		3.2	2381
7	2022/04/05 Tuesday (Spring)	3.6	2235	31.	2021/07/01 Thursday (Summer)	3	2479
8		3.4	2411	32.		2.8	2384
9		3.6	2291	33.		3.8	2345
10		3.5	2361	34.		3.1	2416
11		3.9	2275	35.		2.7	2492
12		3.7	2202	36.		4.4	2215
13	2022/04/24 Sunday (Spring)	3.7	2301	37.	2021/07/07 Wednesday (Summer)	3.6	2267
14		3.5	2375	38.		3.3	2272
15		3.2	2415	39.		3.3	2379
16		4.3	2119	40.		3.7	2204
17		3.1	2314	41.		3.6	2320
18		3.4	2428	42.		4.1	2175
19	2021/12/08 Wednesday (Winter)	3.3	2434	43.	2021/07/27 Tuesday (Summer)	4.3	2193
20		3	2462	44.		4.2	2189
21		3.3	2420	45.		4.9	2113
22		3.2	2388	46.		4	2211
23		3.6	2374	47.		4.3	2130
24		3.6	2480	48.		3.7	2305

Table 7.13 provides valuable information on the air content percent and density of samples taken at 28 days for 48 samples from the SCBP and construction site. The results show a range of air content percentages, from a low of 2.7% to a high of 4.9%. The maximum air content of 4.9% was found at the SCBP on July 27, 2021, and the corresponding density was 2113 kg/m3. On the other hand, the lowest air content percent of 2.7% was found at the construction site on July 1, 2021, with a density of 2492 kg/m3.

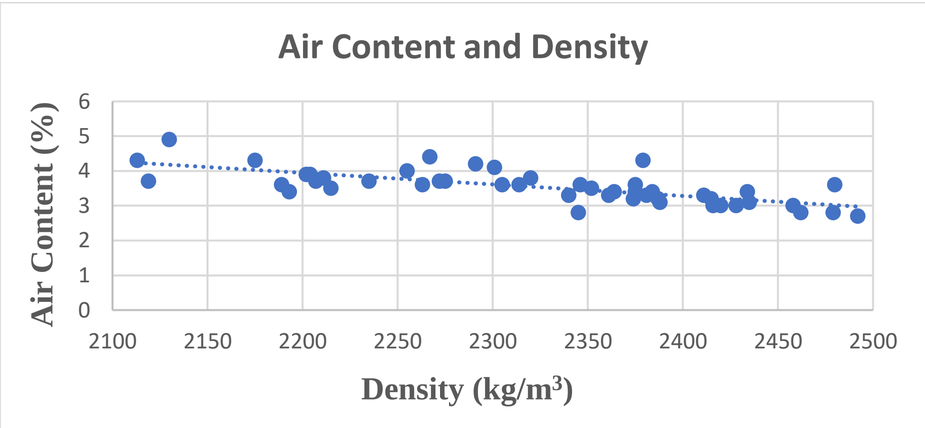


Figure 7.34 The relationship between air content percentage and concrete density was studied using 48 samples after RMC improvements at SCBP and the construction site [Researcher].

Figure 7.34 illustrates an inverse relationship between air content percentage and RMC density. Results indicate that as air content increases, density decreases. The study recorded a maximum of 4.9% air content with a density of 2113 kg/m3 and a minimum of 2.7% air content of 2492 kg/m3 among the 48 RMC samples, emphasizing air content's role in determining RMC density.

4) A direct proportionate link exists between the percentage of air content and the percentage of porosity, whereby an increase in the percentage of air content leads to a corresponding increase in the percentage of porosity.

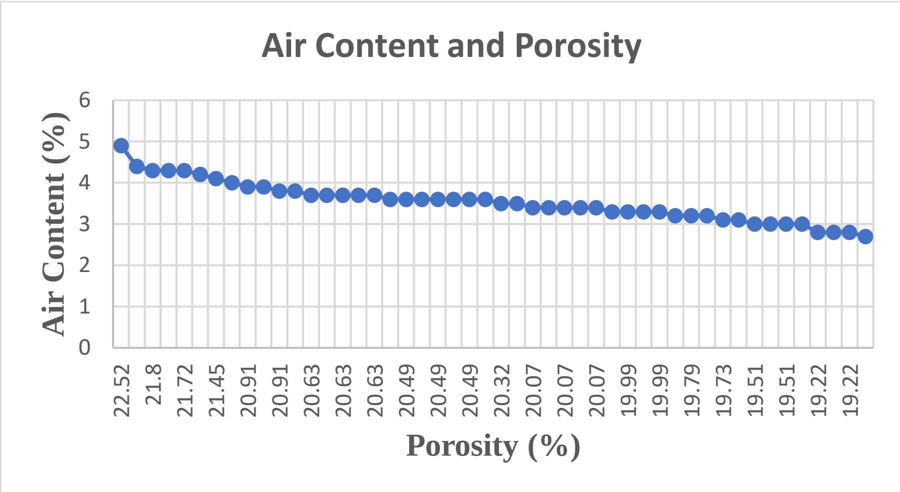


Figure 7.35 The relationship between the percent of Porosity and air content percent in 48 samples after RMC improvements were taken at the SCBP and the construction site [Researcher].

Figure 7.35 depicts a direct relationship between RMC porosity and air content, with a maximum of 3.1% air content resulting in 16.92% porosity for RMC samples. In the second phase, after RMC improvements, air content and porosity decreased among the 48 samples, increasing density and compressive strength. Reducing variability between the plant and construction site samples helps control and ensure concrete quality control.

Furthermore, to observe the effect of porosity and air content on RMC test samples, the slices from cubes of RMC samples made with 4cm x 4cm dimensions were photographed with an accuracy of one millimeter by an endoscope (a rigid viewing device) and a specialized camera, where the slices were taken for samples at 28 days of age for 48 samples after the quality improvement steps have been done. Also, the purpose of taking slices of the RMC samples for different construction members placed on different dates in different seasons after the improvements is to get an idea of how porosity and air content affect compressive strength, which is the size and distribution of the capillary water pores and the gel water pores in the samples, and to compare them to the samples before the RMC improvements, where the slices were as follows:

a) The sliced sample was taken from the RMC produced on July 27, 2021, at the stationary concrete batching plant used for the reinforced beams and slabs of the first floor of the building during the second stage of casting for the right side of the building. This sample provides valuable information on the RMC's properties and helps determine if it meets the required standards and specifications. Overall, the sliced sample is essential for ensuring the quality and integrity of the RMC used in construction projects.

Figure 7.36 RMC sample photographed with 1mm accuracy, showing a maximum porosity of 22.52% and maximum air content of 4.9% in a mix with a water/cement ratio of 0.5, achieving a minimum compressive strength of 32 MPa [Researcher].

Figure 7.36 shows the capillary water pores and gel water pores for the RMC sample photographed with an accuracy of one millimeter for RMC mix with a 0.5 ratio of water to cement, taken at the stationary concrete batching plant on July 27, 2021, where the sample taken from the ready-mix concrete for the reinforced beams and slab of the first floor of the building for the second stage of the RMC casting for the right side of the building Moreover, the gel water pores are smaller in size than the pores of capillary water and have an irregular shape (size) of these pores, with a maximum porosity of 22.52% and a maximum air content of 4.9% for the RMC mixture. The RMC compressive strength test results were 32 MPa, the minimum compressive strength recorded, and they meet the compressive strength test results of 32 MPa, which is the minimum compressive strength recorded and meets the compressive strength required (25 MPa).

b) The sliced sample piece is taken from the RMC sample produced on 4th April 2022 for the reinforced beams and slab of the second floor of the building and tested at age 28 days at the construction site, as shown in the figure below:

Figure 7.37 RMC sample photographed with 1mm accuracy, showing porosity of 19.22 % and air content of 2.8% in a mix with a water/cement ratio of 0.5, achieving a compressive strength of 43.7 Mpa [Researcher].

Figure 7.37 shows the slice sample taken on April 4, 2022, and tested at age 28 days at the construction site for the RMC use for the reinforced beams and slab of the second floor of the building for the first stage of the casting for the left side and the middle parts of the building in the spring season from the RMC sample (cube), with a 0.5 ratio of water to cement, with 19.22 % porosity percent, and 2.8% air content percent for the RMC mix, where the RMC compressive strength test results were 43.7 MPa. It also shows that the capillary and gel water pores are tiny but spread out evenly among the RMC ingredients, and the compressive strength is less than required (25 MPa).

c) The sliced sample taken from the RMC sample produced on 8th December 2021, taken at the construction site, and tested in the winter season for the RMC use for the reinforced columns of the second floor of the building, for the first and the second stages of the RMC casting, as shown in the figure below:

Figure 7.38 RMC sample photographed with 1mm accuracy, showing porosity of 20.49 % and air content of 3.6 %, in a mix with a water/cement ratio of 0.5, achieving a compressive strength 44.9Mpa [Researcher].

Figure 7.38 shows the slice piece from the sample taken on 8th December 2021, in the winter season from the RMC cube, taken at the construction site and tested at age 28 days, for the RMC use for the reinforced columns of the second floor of the building, for the first and the second stages of the casting for the columns middle part (circular columns) and the rectangular columns in the left side of the building, with 0.5 W/C ratio, with 20.49 %, porosity percent, and 3.6 % air content percent for RMC mix where the compressive strength tests results were 44.9 MPa, where we notice that the pores start to be smaller and less than the samples with less compressive strength, where the purpose from taking a slice to the from the sample is to compare the size, number, and distribution of the capillary water pores, and gel water pores, in the sample of RMC for different stages of concrete pouring for different construction members in a multistory building.

d) The sliced sample is taken from the RMC sample produced on 1st July 2021, where the sample was taken from the concrete for reinforced columns of the first floor (first phase) for the right side of the multistory building, as shown in the figure below:

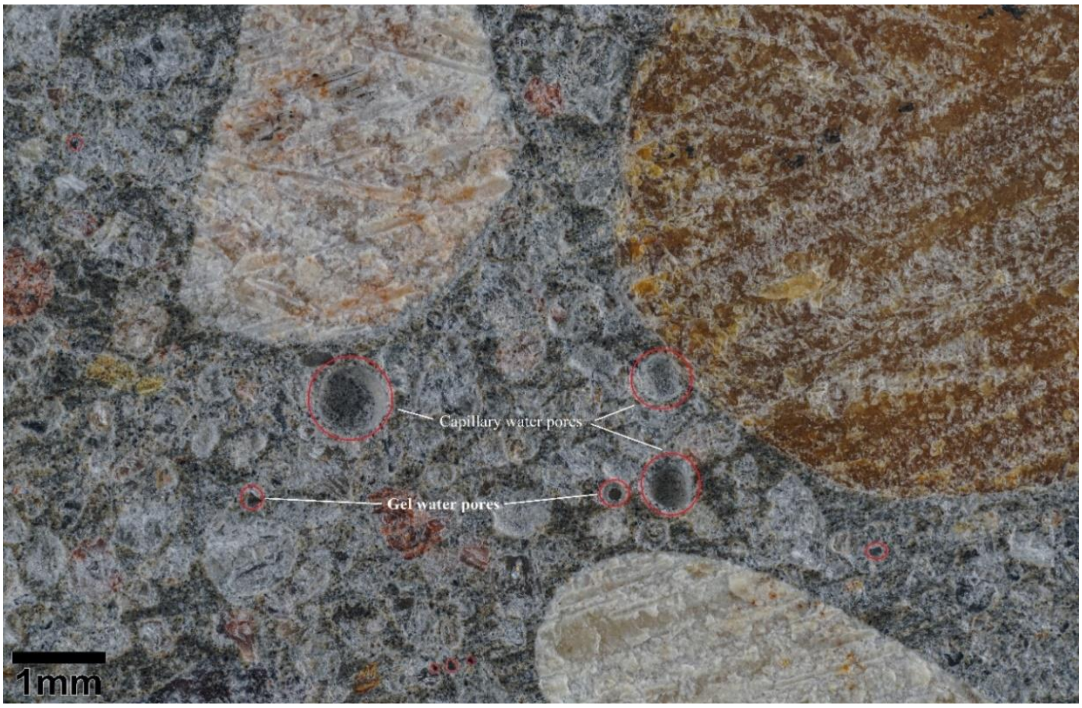


Figure 7.39 RMC sample photographed with 1mm accuracy, showing minimum porosity of 18.93 % and minimum air content of 2.7 % in a mix with a water/cement ratio of 0.5, achieving a maximum compressive strength **of** 53 Mpa [Researcher].

Figure 7.39 provides valuable information on the Ready-Mix Concrete sample's structure at the construction site on 1 July 2021. The sample was taken from the reinforced columns of the first floor (first phase) for the right side of the multistory building. The photograph shows the capillary and gel water pores with an accuracy of one millimeter. The gel water pores are smaller than those of capillary water and have an irregular shape.

The sample had a porosity of 18.93%, the minimum porosity percent for all samples, and an air content of 2.7%, the minimum air content for all samples. The RMC mix had a water/cement ratio of 0.5, and the RMC compressive strength test results were 53 MPa, the maximum compressive strength recorded and meets the required RMC compressive strength of 25 MPa. These findings highlight the importance of controlling the pore structure of RMC to ensure its quality and integrity. The sample's minimum porosity, air content, and maximum compressive strength indicate that the RMC was well-mixed and produced to meet the desired standards. These results can also be used to identify potential issues and make necessary adjustments to the RMC production process to improve the quality of the material.

CHAPTER 8 LEARNING AND GENERATING FLEXIBLE PROCEDURE

8.1 Introduction

The term "Neural" pertains to the domain of the nervous system. Neural networks, specifically known as Artificial Neural Networks (ANNs), are designed to emulate the functioning of human brain neurons. Like the human brain, these networks can acquire new knowledge through learning. It is particularly advantageous in the context of Learning Management Systems (LMS) [146][147], where access to related information has been greatly facilitated. Reducing the prediction error of the target variable is a notable attribute of predictor variables, comprising both independent input vectors and the dependent output variable. A neural network operates as a highly parallel distributed processor and exhibits an inherent capacity for storing and retrieving experiential knowledge. Analytics and data mining methodologies enable project managers to explore extensive datasets to identify patterns related to compressive strength behavior and learning [148].

This section of the study delves into the concept of artificial neural network learning implemented within the Moodle platform. This process utilizes inputs derived from 93 material property tests conducted in Moodl (2021). The subjects of these tests serve as inputs to construct an ANN model capable of predicting material quality. The model is designed to categorize outcomes as either (0) for failure or (1) for success, thereby adhering to specified criteria.

Furthermore, the study extends to predicting various RMC (Ready-Mix Concrete) parameters under different production, delivery, and placement conditions. This predictive approach establishes flexible procedures for forecasting variables such as RMC temperature, consistency, air content, porosity, density, and compressive strength. These predictions apply to both the stationary concrete batching plant and the construction site, spanning different seasons and conditions, and are facilitated through the Moodle platform using parameter values.

8.2 Artificial Neural Networks

The ANN is a computational method that can tackle complicated issues by simplifying human brain operations [149]. Artificial neurons are information processing units stacked in layers and coupled by the synaptic weights in perceptron-type neural networks. The ANN model consists of three layers of linked nodes: input, hidden, and output. The nodes may create one or any number of hidden layers between the input and output. Each neuron for every layer is connected to the next layer with each neuron of it. However, the input layer takes data from outside data, a hidden layer processes data, and the output layer generates class labels or forecasts of the continuous values. The input layer reaching the hidden node (values) was multiplied by the weights, and a preset set multiplication of numbers produces a numerical value. This value is supplied as an input to the activation function, a nonlinear function that yields a value between 0 and 1 [146].

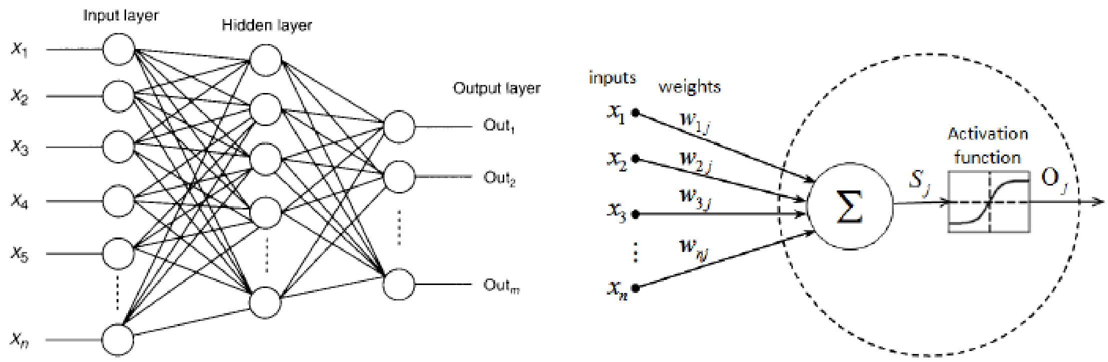


Figure 8.1: The Artificial Neural network's architecture and the Neural network's active node [150].

Figure 8.1 presents the weight of net sum inputs arriving at node *j*. The expression can describe the activation function of output that changes the weight of neuron input to its activation output (where a sigmoid function is most used). [150]:

$$S_j = \sum_{i=1}^{n} x_i w_{ij} \tag{50}$$

And

$$O_j = \frac{1}{1 + e^{S_j}} \tag{51}$$

The ANN and the neuron operate in two modes: the training mode and the testing mode. In training mode (phase), the data set with actual inputs, hidden layers, and outputs can be used as samples to learn how prediction outputs to the system. The learning is supervised and begins randomly with a weight using slope descent algorithms search such as the backpropagation. The variance between the values obtained and the output's targeted values drives learning as an error function [146]. This function (error function) is dependent on the weights, which must be adjusted to reduce error for the training given set {((x1, t1), (x2, t2) …, (xk, tk))} containing k pairs of ordered of n inputs and m for vectors dimensional, where it is known as the input. The output patterns, the error of every neuron, can be determined as the output by the expression:

$$E_j = \frac{1}{2}\left(O_j - t_j\right)^2 \tag{52}$$

Moreover, the network error function that should be reduced is:

$$E_j = \frac{1}{2}\sum_{j=1}^{k} \left(O_j - t_j\right)^2 \tag{53}$$

Where Oj refers to the produced output, the x j is the input pattern for the training set to network, and the tj symbol is the target output value [150]. Every weight is reformed throughout the training by adding weight value to the value quantity in the previous step.

$$\Delta w_{ij} = -\gamma \frac{\partial E}{\partial w_{ij}} \tag{54}$$

The γ refers to the constant that gives the learning rate, whereas a higher rate of learning means the convergent will be faster. Accordingly, the path of searching might be trapped near an optimal solution and result in an impossible convergence. Therefore, when the good weights set has been determined, the ANN model will use another data set with unknown output values and automatically predict the outputs. The data were randomly assigned to training (70%) and testing (30%) subsets. The training dataset is used to find the weights and build the model. The testing data is used to find errors and prevent overtraining during the training mode [151]. MLP neural networks are trained with a back-propagation learning algorithm, which uses gradient descent to update the weights towards minimizing the error function. The training dataset is used to find the weights and build the model [152]. Besides centralizing and automating administration tasks, LMSs rapidly assemble and deliver learning content, personalize content, and enable re-use of knowledge [153]. In previous studies, Multiple researchers have explored predicting performance accuracy [154]. One study examined 250 MBA students from a state university and compared ANN to traditional methods like OLS and logistic regression for academic prediction [155]. Another study focused on business school graduates using ANN and traditional techniques [156]. Some researchers used ANN to model and predict university students' performance[157]. Utilized a Multilayer Perception Neural Network to predict student performance. [158], achieving high accuracy in predicting semester one results using grade 12 scores as inputs and first-year college results as outputs [159]. These studies collectively demonstrate the effectiveness of ANN-based models in performance prediction.

8.3 The methodology of making ANN

8.3.1 Data

The Data from 2018 to 2022 was collected at a concrete batching plant and construction site in Misan, Iraq. This data includes temperature measurements for 48 ready mix concrete (RMC) mixes before and after cooling, weather conditions, evaporation rates before and after cooling, slump test results, density tests, admixtures percentage (1.5%), water/cement ratio (0.5), mixing and delivery times, and compressive strengths (96 samples). The data was categorized and stored in Moodle, a tracking system that records various activities, including parameter changes in compressive strength, in relational database tables as follows:

1. **Materials quality**

The descriptive statistics table offers an overview of the input variables, which contains six columns that include the values of [146]:

a) **N** represents the number of instances analyzed. This value should be consistent across variables when the listwise deletion of missing data is performed. When pairwise treatment of missing values is used, this value may not be constant. Since there are no missing values in this dataset, the value is just the number of instances.

b) **Minimum** is the numeric variable lowest value.

c) **Maximum** The value (higher) a numeric variable may attain.

The Minimum and Maximum columns generally display the (pre-binning) minimum and maximum values for each input variable in the dataset. In addition to providing a sense of the observed range of values for each variable, they may be used to identify values that fall outside the predicted range.

d) **Mean** refers to the sum of data collection, often to comprehend better a specific data set's overall value (magnitude and sign).

e) **Standard deviation** measures the dispersion of data around the Mean.

f) **A distribution's Skewness** is the asymmetry of its measure. The normal distribution skewness value is zero and is symmetric. A long right tail is indicative of a highly positive Skewness. A long-left tail shows significant negative Skewness. As the skewness guideline value is twice more than its error (standard), it indicates the departure from symmetry.

Table 8.1 Descriptive Statistics of the quality of materials for RMC data [Researcher].

Independent variable	*N*	*Minimum*	*Maximum*	*Mean*		*Std. Deviation*	*Skewness*	
	Statistic	*Statistic*	*Statistic*	*Statistic*	*Std. Error*	*Statistic*	*Statistic*	*Std. Error*
T.D.S (ppm)	*18*	*50.0*	*1022.0*	*306.66*	*99.4053*	*421.740*	*1.101*	*.536*
degree of acidity	*18*	*6.45*	*7.88*	*6.9317*	*.10814*	*.45880*	*1.309*	*.536*
alkali (Mg./l)	*18*	*30.0*	*190.0*	*71.056*	*14.8569*	*63.0326*	*1.149*	*.536*
Chloride (Mg./l)	*18*	*38.0*	*277.0*	*104.61*	*24.1182*	*102.324*	*1.094*	*.536*
Fineness (%)	*33*	*.02*	*.03*	*.0242*	*.00087*	*.00502*	*.321*	*.409*
IST (Min)	*33*	*93.0*	*180.0*	*128.12*	*4.4327*	*25.4641*	*.478*	*.409*
FST (hr)	*33*	*4.11*	*6.34*	*5.0215*	*.08698*	*.49967*	*.103*	*.409*
fc 3days	*33*	*9.9*	*16.2*	*13.206*	*.2979*	*1.7113*	*-.286*	*.409*
fc 7days	*33*	*16.7*	*25.6*	*21.239*	*.4028*	*2.3139*	*.130*	*.409*
Sio2	*32*	*7*	*19*	*11.92*	*.557*	*3.154*	*.337*	*.414*
Al2O3	*32*	*2*	*6*	*4.53*	*.177*	*1.003*	*.070*	*.414*
Fe2O3	*32*	*2*	*5*	*3.98*	*.123*	*.698*	*-.774*	*.414*
CaO	*32*	*2*	*5*	*3.49*	*.154*	*.872*	*-.112*	*.414*
SO3	*32*	*1*	*3*	*2.33*	*.079*	*.448*	*-1.496*	*.414*
BL.	*32*	*1*	*4*	*2.89*	*.107*	*.604*	*-.929*	*.414*
C3a	*32*	*3*	*5*	*4.01*	*.092*	*.520*	*-.087*	*.414*
LS F	*32*	*0*	*9*	*.84*	*.268*	*1.513*	*5.529*	*.414*
Sieve 10	*30*	*100.0*	*100.0*	*100.00*	*.0000*	*.0000*	*.*	*.*
Sieve 4.75	*30*	*93.0*	*100.0*	*97.167*	*.2541*	*1.3917*	*-.647*	*.427*
Sieve 2.36	*30*	*75.0*	*100.0*	*86.633*	*.8756*	*4.7957*	*.138*	*.427*
Sieve 1.18	*30*	*50.0*	*94.0*	*74.167*	*1.8017*	*9.8684*	*-.215*	*.427*
Sieve 0.6	*30*	*37.0*	*63.0*	*46.867*	*1.0708*	*5.8648*	*.656*	*.427*
Sieve 0.3	*30*	*14.0*	*29.0*	*19.477*	*.9065*	*4.9650*	*.876*	*.427*
Sieve 0.15	*30*	*2.0*	*9.0*	*5.890*	*.3502*	*1.9184*	*-.302*	*.427*
SO3 %	*30*	*.0220*	*.0891*	*.03573*	*.002508*	*.013737*	*2.199*	*.427*
Sieve 37.5	*30*	*100.0*	*100.0*	*100.00*	*.0000*	*.0000*	*.*	*.*
Sieve 20	*30*	*95.0*	*99.0*	*97.167*	*.1667*	*.9129*	*.232*	*.427*
Sieve 10	*30*	*33.0*	*58.0*	*43.033*	*1.3021*	*7.1317*	*.460*	*.427*
Sieve 5	*30*	*.0*	*8.3*	*3.413*	*.3950*	*2.1633*	*.395*	*.427*
SO3 %	*30*	*.08*	*.10*	*.0987*	*.00079*	*.00434*	*-3.495*	*.427*
Valid N (listwise)	*17*							

The descriptive data table demonstrates a change in the Mean, standard deviations, and Skewness for the quality of the materials, where the size of the sample, standard deviation, Mean, and the error(standard) for each of the thirty topics of 93 test samples.

2. RMC delivery time cases

The descriptive table of delivery cases monitoring time for seven independent variables and one dependent variable displaying the minimum, maximum, mean, standard deviation, variance, and Skewness for the data of real-time monitoring for 81 delivery cases from the stationary concrete batching plant (SCBP) to the construction site.

Table 8.2 Descriptive Statistics of the RMC delivery cases data [Researcher].

Independent variable	*N*	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*	*Variance*	*Skewness*	
	Statistic	*Statistic*	*Statistic*	*Statistic*	*Statistic*	*Statistic*	*Statistic*	*Std. Error*
Time load	*81*	*8.0*	*30.0*	*13.136*	*3.3157*	*10.994*	*2.603*	*.267*
Delivery Time	*81*	*20.0*	*41.0*	*25.667*	*3.7182*	*13.825*	*1.191*	*.267*
Unloading time	*81*	*8.0*	*16.0*	*10.148*	*1.7826*	*3.178*	*1.237*	*.267*
Washing time	*81*	*3.0*	*7.0*	*4.556*	*.9487*	*.900*	*.017*	*.267*
Return Journey Time	*81*	*20.0*	*31.0*	*22.926*	*2.0963*	*4.394*	*.868*	*.267*
Waiting/construction site for loading	*81*	*2.0*	*26.0*	*8.395*	*5.1640*	*26.667*	*.911*	*.267*
RMC Pouring Time	*81*	*18.0*	*28.0*	*19.543*	*1.6959*	*2.876*	*2.375*	*.267*
Downtime at the construction site	*81*	*2.0*	*6.0*	*2.531*	*.8673*	*.752*	*2.143*	*.267*
Total Discharge Time	*81*	*0*	*1*	*.88*	*.331*	*.110*	*-2.333*	*.267*
Valid N (listwise)	*81*							

The descriptives table shows the size of the sample, standard deviation, Mean, variance, and Skewness for each of the seven variables with 81 samples. Skewness was 0.267, which shows the distribution asymmetry where the distribution with positive Skewness.

3. The RMC parameters prediction

The descriptive table represents the information of the maximum, minimum, standard deviation, Mean, variance, and the Skewness of data will mention for each season for 48 samples for measurements of weather conditions (weather temperature, relative humidity percent, wind speed, air temperature at SCBP, and air temperature at worksite), 48 measurements of the rate of evaporation before cooling, and other 80 samples for the rate of evaporation after cooling, 96 samples for slump test (48 before and 48 after cooling), 48 samples for RMC density test, admixtures percent(1.5%), water/cement ratio 0.5, 48 cases of monitoring mixing time (Min), 48 delivery time (Min) to the construction site, 48 total discharge time (Min), and 96 compressive strengths(48 samples first phase and 48-second phase), 96 sample air content percent, 96 porosity percent(48 samples before and 48 samples after cooling). The data were randomly assigned to training (70%) and testing (30%) subsets.

The training dataset is used to find the weights and build the model. The testing data is used to find errors and prevent overtraining during the training mode [151].

8.3.2 Type of variables to build ANN

The type variables used in building an Artificial Neural Network (ANN) are two types, independent variables and dependent variables, used in our case study for cases as follows:

1) Material quality

The variable representing material quality is derived from an extensive dataset consisting of 93 sample tests conducted on the properties of the materials as part of the real-time monitoring process. The following variables characterize this dataset:

i. Independent variables

The independent variables are taken based on the topics of each test of the material properties for the materials of ready-mix concrete ingredients in clouding the mixing water, as follows:

a) The water of the RMC mixture

It includes the samples of water for characters:

1. Total dissolved solids (T.D.S)
2. The degree of acidity (PH.)
3. Alkali
4. Chloride

b) Cement

It includes the samples of cement for the characters:

1) fineness percentage
2) Initial setting time
3) Final setting time
4) Compressive strength at 3 days
5) Compressive strength at 7 days
6) Sio_2
7) Al_2O_3
8) Fe_2O_3
9) Cao
10) SO_3
11) Burning limit
12) C_3a
13) Limestone saturation

c) Fine aggregate

It includes the samples of fine aggregate passing through:

1. Sieve 10
2. Sieve 4.75
3. Sieve 2.36
4. Sieve 1.18
5. Sieve 0.6
6. Sieve 0.3
7. Sieve 0.15
8. So_3 percent

d) Coarse aggregate

It includes the samples of coarse aggregate passing through:

1) Sieve 3.75
2) Sieve 20
3) Sieve 10
4) Sieve 5
5) So_3 percent

ii. Dependent variable

Materials quality outcome results of testing the quality of the materials used may take on just two values, either 0 or 1. Failure to fulfill required material quality is represented by a value of 0, while 1 represents materials quality that meets the quality of the materials. Materials quality outcome variable results directly from the test of each of 93 laboratory test samples of the properties of the raw materials provided, In addition to 18 tests for water quality (water properties test) for RMC mixing. If the test results meet his limitations, In the event of success (high quality), the Materials quality primary outcome will have the value 1, and in the event of failure (low quality), the value 0.

2) RMC Delivery cases time monitoring

The variable of the RMC delivery cases time monitoring taken according to the data of 81 samples for each variable of the time taken in the real-time monitoring process, where the variable is as follows:

i. Independent variables

1) loading time in the mixer of the SCBP (Mixing time)
2) Delivery time to the construction site
3) Unloading time
4) Waiting at the construction site before unloading RMC
5) RMC pouring time.
6) Truck mixers washing time.
7) Time to the stationary concrete batching plant (SCBP) or back journey.

ii. Dependent variable

In the RMC delivery cases, the monitoring outcome can only take on one of two values, either 0 or 1. The value 0 indicates the failure of the total discharge time to meet the ASTM limitation (less than or equal to 90 Min), while the value 1 shows that the total discharge time meets the ASTM limitation required. The RMC delivery time outcome variable results directly from the testing the data of each case from 80 RMC delivery cases time monitoring, where if the test results meet with his limitations, the total discharge time outcome variable takes the value 1 (success (less than or equal 90 Min)), otherwise the value 0 (failure more than 90 Min).

3) RMC Compressive strength

The variable of the RMC was taken according to the data of the parameters of the RMC for samples for each season taken in real-time monitoring, where the variable is as follows:

A. Independent variables

The independent variables of the RMC compressive strength taken based on the tests have been done for the RMC parameters as mentioned above to control and improve the quality of RMC, to be ready for use to build ANN and predict the values of the compressive strength, where the variable was as follows:

1. Weather temperature
2. Ready mix concrete (RMC) temperature.
3. Consistency
4. Air content percent of the RMC.
5. Porosity percent of the RMC.
6. Density
7. RMC compressive strength.

B. Dependent variable

To predict the parameters outcome, which is the dichotomous variable values of each independent variable of the RMC, will build ANN for each variable by making it the dependent variable and the rest independent variables, for example, for RMC compressive strength as the dependent variable the variables of weather temperature, RMC temperature, consistency, air content, porosity, and density will be independent. The RMC quality outcome variables result based on the test of the data of 48 RMC mix temperatures (after reducing the temperature of a mix by ice), 48 weather conditions (weather temperature, relative humidity percent, wind speed, air temperature at SCBP, and worksite), 48 measurements of the rate of evaporation before cooling, and other 80 rates of evaporation after cooling, 96 samples for slump test, 48 density test, admixtures percent (1.5%), water/cement ratio 0.5, 48 cases of monitoring mixing time, 48 delivery time to the construction site, 48 total discharge time, and 96 compressive strengths, 96 sample air content percent, 96 porosity percent. RMC quality outcome variable takes the values of the compressive strength predicted.

8.3.3 The design of ANN and setup

The neural network model was constructed and validated using IBM SPSS Statistics 22's Multilayer Perceptron (MLP) feature. Backpropagation is a kind of gradient descent used to update weights during training and to train MLP neural networks to reduce an error function.

Seventy percent of the information was set aside for training and thirty percent for testing. Finding the weights and constructing the model need access to the training dataset; mistakes may be discovered, and overtraining is avoided using testing data. The covariates were normalized to the values of return (1 and 0), and the set's data training is only used for training based on equation (x-min)/(max- min), where the yield values are between 0 and 1 [146].

Hyperbolic tangent (or tanh) was used for the hidden layer as an activation function. The activation of the (j) output neuron is.

$$O_j = \tanh\left(S_j\right) = \frac{e^{S_j} - e^{-S_j}}{e^{S_j} + e^{-S_j}} \quad (55)$$

It takes real numbers as arguments, and the values returns are between 1 and -1. The softMax function is used as an activation for the output layer, where the neuron of output is:

$$O_j = \sigma\left(S_j\right) = \frac{e^{S_j}}{\sum_{k=1}^{m} e^{S_k}} \quad (56)$$

SoftMax function accepts actual numbers as parameters and converts them to actual values ranging from 0 to 1 with a total of 1. However, since the sum of the output activation functions is 1, the Softmax can be considered a probability distribution, and the Oj value can be understood as the estimated likelihood that the network will classify input x.

Two optimization implementations by gradient descent technique may obtain the optimal solution: batch mode and ongoing (or incremental) mode. A batch algorithm utilizes all training dataset records to update synaptic weights [151]. It was adopted for the training stage since it conforms to a similar minimum as the online learning algorithm and is significantly more effective in numerous calculations. The most popular iterative approach for calculating linear equations, backpropagation gradient, was employed to train an ANN in batches. If this approach is employed to train the multilayer perceptron networks, it solves optimization issues more statistically efficiently than in the gradient-descent and conjugated gradients methods [160]. Each cycle begins with a complete transfer of the training dataset and a refresh of the synaptic weights. Errors are minimized at each iteration, leading the algorithm towards the minimization problem upon that error function. The conjugate gradient scaled method constructs the model based on the values of four factors: the starting lambda, early sigma, the interval core, and the interval offset. The lambda parameter determined the probability that the matrix becomes negative definite [161] to estimate the first derivative products of an error function [150]. Forcing the stochastic optimization method to create random weights between ao a and ao + a and then updating them to minimize the error function is the parameters interval center ao and a [151]. It is started with lambda around 0.0000005 with sigma around 0.00005. It was decided that 0 would serve as the interval's core and -0.5 as its offset. The halting Laws are Error-free increment size limit set at 10. Only 15 minutes should be spent training. Epochs of optimum training: automatic, training error proportion shift 1.0e-3, mean minimum training error 1.0e-4. The network output is activated using the SoftMax function, and SPSS employs the cross-entropy error function instead of the squared error measure often employed by other activation algorithms. For a single example of training, the equation yields the function of error cross-entropy :

$$E = -\sum_{j=1}^{m} t_j \ln O_j \tag{57}$$

Where the (*m*) symbol refers to the output number of the nodes, while the (*tj*) symbol refers to the value of the output targeted (*j*), and (*Oj*) refers to the actual value of the output (*j* node). The algorithm of backpropagation, in every repetition, accounts for the training error gradient:

$$\frac{\partial E}{\partial w_{hj}} = (O_j - t_j) x_h \tag{58}$$

In the case of the linking nodes, weights positioned in the hidden (nodes) layer and the output (nodes)layer of the ANN network,

$$\frac{\partial E}{\partial w_{hj}} = \sum_{j=1}^{m} (O_j - t_j) x_h w_{hj} (1 - x_h) x_i \tag{59}$$

While for the links weights of the input layer and hidden layer(nodes). For each training example, every weight *Wih* is updated as in the equation.

$$\Delta w_{ih} = -\gamma \frac{\partial E}{\partial w_{ih}} \tag{60}$$

Where γ refers to a constant that defines the pace of acquisition, generally, a more significant learning rate results in a quicker convergent, although at some point, the searching pathway may get stuck near the ideal solution, making further convergence impossible, neural network algorithm can automatically forecast the outputs for a new dataset values are unknown [146].

8.4 Results Of Multilayer Perceptron Neural Network

The results after running the ANN in our case study for the cases mentioned were that the accuracy of the MLP model was measured to gauge its ability to predict outcomes, as follows:

8.4.1 Materials Quality

This part examines whether a Mullite Layer Perception of an ANN might assist in predicting materials quality outcomes correctly (1 success or 0 failure) through data gain analysis based on 93 materials tests for the water, cement, fine aggregate, and coarse aggregate. Table 8.3 provides dataset information used to make a model of ANN.

Table 8.3 Case Process Summary for the quality of materials [Researcher].

		N	*Percent*
Sample	*Training*	*13*	*76.5%*
	Testing	*4*	*23.5%*
Valid		*17*	*100.0%*
Excluded		*16*	
Total		*33*	

Table 8.4 shows the case process summary for materials quality, where the training (as the partition set up before 70 training and 30 testings) for the case study date was training was 76.5 % and training 23.5 % for training, 13 samples, testing 4 samples, and excluded 16 samples. Moreover, the network information displays the number of factors, covariates, hidden layer, units in the input layer, hidden layer and output layer, activation function, and error function applied. The number of units in the input layer is 28, which consists of a total number of factor levels plus several covariates. It means to say that there are 28-factor levels and 28 covariates. The number of units in the output layer is 2, representing two categories of the dependent variable of quality of materials outcome. The rescaling method for covariates is standardized. Automatic architecture has included one hidden layer with 8 units, a Hyperbolic tangent activation function for the hidden layer, a Softmax activation function for the output layer, and a Cross-entropy error function for computing error in training and testing samples. The information presented in the table above summarizes the neural network model. It shows Cross entropy error during training and testing, the percent of incorrect predictions in training, and the testing sample. Cross entropy error is shown due to the Softmax activation function in the output layer. Furthermore, the artificial neural network for the case study consists of three elements: input data, 28 independent variables, and one dependent variable, 1 hidden layer with 8 nodes, and output 2 nodes. The network diagram shown in Figure 8.2 shows that to predict whether the materials meet requirements, the outcome (failure (0) and (1) success) from 28 independent variables represents the parameters' effect on materials quality based on previously processed data. Figure 8.2 represents 28 input nodes; 8 nodes are hidden, and 2 output nodes display the materials' quality of the RMC where failure 0 and success1 (meet with limitations) categories.

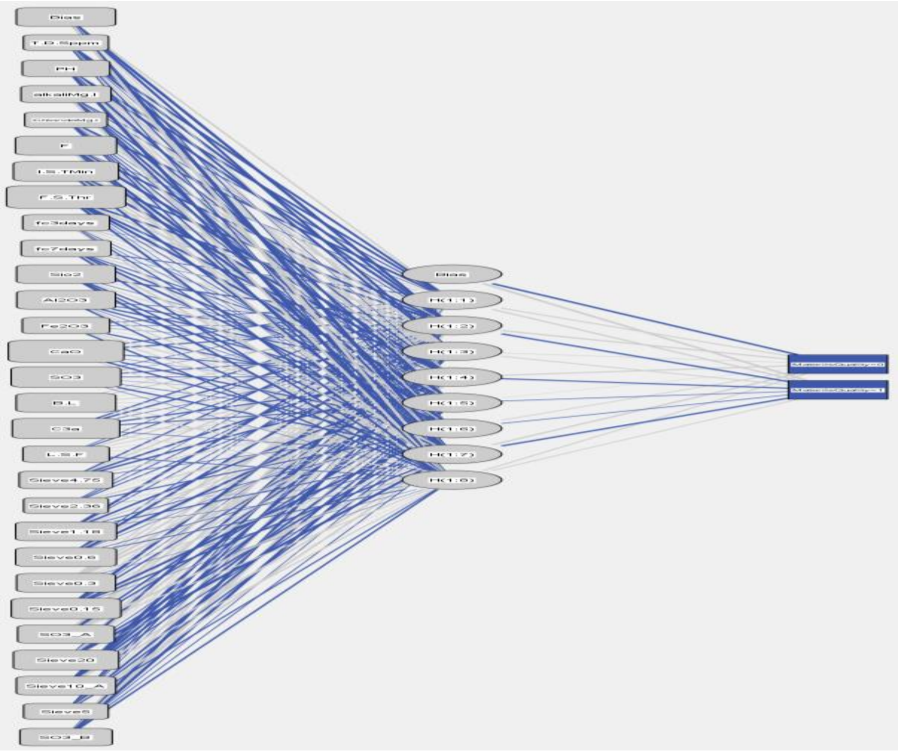


Figure 8.2 The Network Diagram for the quality of materials [Researcher].

The overview of a model described in the table 8.4 gives information on the outcomes of the training phase and testing phases. The cross-entropy error is provided with the training and the testing data because the network minimizes the error function throughout the training stage.

Table 8.4 The model summary for the quality of materials [Researcher].

Training	*Cross Entropy Error*	*.344*
	Percent Incorrect Predictions	*0.0%*
	Stopping Rule Used	*1 consecutive step(s) with no decrease in error*
	Training Time	*0:00:00.01*
Testing	*Cross Entropy Error*	*.003*
	Percent Incorrect Predictions	*0.0%*

This error's modest value (0.344) reflects the model's ability to anticipate if the material's quality fits the constraint. Cross-entropy error is less for the training dataset than for the testing data set, indicating that the network model has not been a feature of the training data and has learned to generalize the trend. The outcome validates the testing sample's function in avoiding overtraining. According to the table 8.4, the proportion of wrong predictions according to the training and the testing samples is 0% for both, indicating that the forecasts of a material quality required to fulfill a restriction are accurate to a degree of one hundred percent. A learning technique was carried out for a total of 28 iterations till an error function of the testing sample did not decrease. The next step is the parameter estimate, which is used to predict each parameter for the hidden layer of the ANN for 8 nodes related to 28 nodes from input layers and then predict parameter values for the output Layer 2 nodes; the classification model for the quality of materials presents a model summary of the network. One stopping rule has been used with no decrease in error rate. The percent correct given in the classification is 100 %. The present neural network dataset achieved a 100% accuracy rate for incorrect training and testing.

Table 8.5 Classification of the quality of materials [Researcher].

Sample	***Observed***	***Predicted***		
		poor quality	***good quality***	***Percent Correct***
Training	*poor quality*	*4*	*0*	*100.0%*
	good quality	*0*	*9*	*100.0%*
	Overall Percent	*30.8%*	*69.2%*	*100.0%*
Testing	*poor quality*	*0*	*0*	*0.0%*
	good quality	*0*	*4*	*100.0%*
	Overall Percent	*0.0%*	*100.0%*	*100.0%*

Table 8.5 displays a categorical dependent variable classification for the material quality outcome through the partition and overall of every case, where the MLP network correctly classified 4 poor quality out of 13 in the training samples and 0 poor quality out of 4 in testing samples. Overall, 100 % of the training was correctly classified.

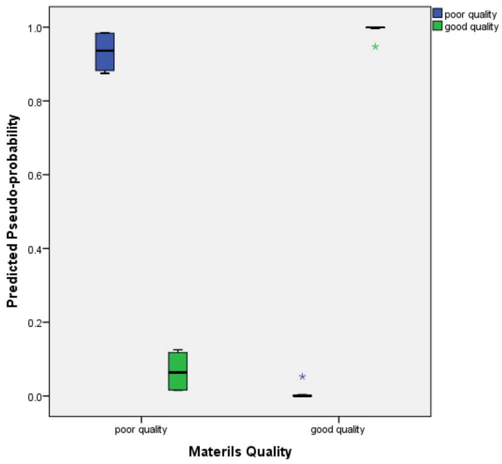


Figure 8.3 Predicted-by-observed chart for the quality of materials [Researcher].

Box plots of anticipated pseudo-probabilities predicted according to the dataset are shown in the image as shown in Figure 8.3 [15] for materials quality outcome predictor variables. For every plot, the numbers above represent accurate forecasts. The first boxplot, beginning on the left, depicts the estimated chance that observed low-quality materials would fall into the failure group. The second boxplot depicts the likelihood that high-quality items will be classed as successful. The third boxplot displays the outcomes witnessed category success and the distribution of those outcomes. The boxplot on the right depicts the chance of anticipated high-quality items being classed as successful. Figure 8.4 compares the cumulative benefits of accurate classifications acquired by the ANN model against the probability of obtaining the correct classifications. For instance, the second point on a category of failure curve is located between (10% and 50%), which indicates that the network scores a dataset of the case scenarios by the failure pseudo-probability predicted; the top 10% will probably contain around 50% of all cases that fall under the failure category. The 100% selection of the dataset yields every instance of failure. The Gain chart measures the efficacy of a classification model computed as the ratio of the proportion of accurate predictions achieved with the model to the proportion of accurate predictions gained without the model. The bigger the gain, the farther a curve is above the baseline. A more significant total gain represents a performance improvement.

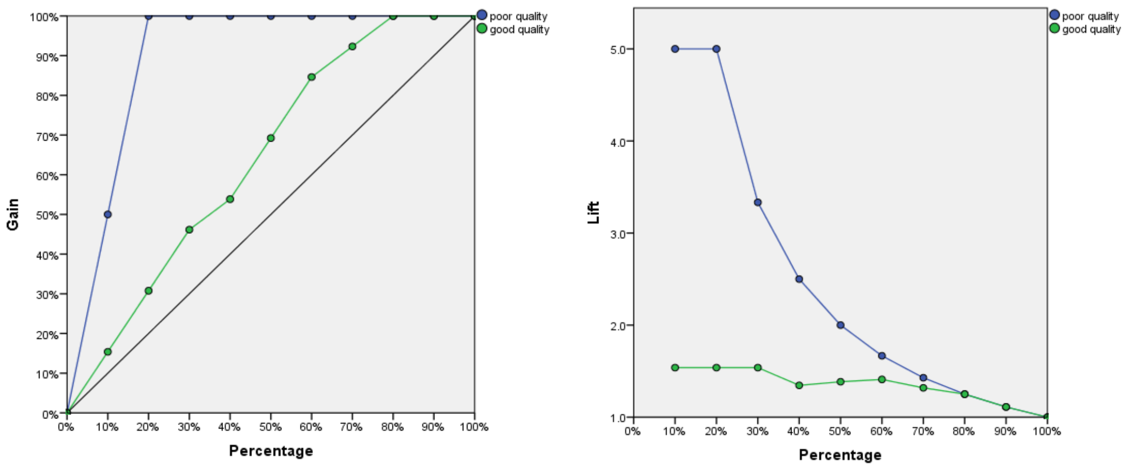


Figure 8.4 The cumulative Gains and the Lift Charts of quality of materials [Researcher].

Figure 8.4 illustrates the cumulative gains and the lift Chart for the quality of RMC materials, where the Lift charts and gain are visual assistances for the performance evaluation of the models' classification. However, the gain chart (lift chart) evaluates the model's performance from the perspective of the quality of RMC materials. The lift chart utilizes some information to illustrate the advantage of employing a model vs. not using one. The data of the gains chart are used later to determine the factor of the lift chart (the benefit): the category failure lift at 50% is 50%/10% = 5. Furthermore, there is an impact for each independent variable on the ANN model known as the term of relative and normalized importance. Moreover, the relative and normalized importance of the independent variables, where the highest value was assigned to the final setting time of the cement with a value of 0.081 of 100 percent, which has the most significant impact on the ANN model, and the second most significant impact normalized value is 0.071 with 90.6 percent. C3a of the cement is the primary contributor to cured Concrete's early phase strength. Multilayer perceptron of ANN has been trained through a backpropagation technique to predict the quality of materials. The classification performance rate is very high (100%) accuracy in putting pupils into success and failure groups.

Table 8.6 Independent Normalized Variables Importance [Researcher].

Variable indebendents	*Importance*	*Normalized Importance*
TDS (ppm)	*.012*	*14.3%*
Degree of acidity	*.016*	*20.2%*
alkali (Mg./l)	*.022*	*27.0%*
Chloride (Mg./l)	*.006*	*7.6%*
Fineness (%)	*.044*	*54.5%*
IST (Min)	*.052*	*65.1%*
FST (hr)	*.081*	*100.0%*
fc 3days	*.015*	*18.3%*
fc 7days	*.021*	*26.1%*
Sio2	*.039*	*48.9%*
Al2O3	*.039*	*48.5%*
Fe2O3	*.016*	*20.0%*
CaO	*.073*	*90.6%*
SO3	*.061*	*75.9%*
B.L	*.041*	*50.5%*
C_3a	*.057*	*70.2%*
LS F	*.014*	*17.6%*
Sieve 4.75	*.029*	*35.6%*
Sieve 2.36	*.011*	*13.3%*
Sieve 1.18	*.043*	*54.0%*
Sieve 0.6	*.043*	*53.6%*
Sieve 0.3	*.040*	*49.4%*
Sieve 0.15	*.061*	*75.6%*
SO3 %	*.035*	*43.7%*
Sieve 20	*.053*	*65.2%*
Sieve 10	*.041*	*50.4%*
Sieve 5	*.011*	*13.1%*
SO3 %	*.026*	*32.3%*

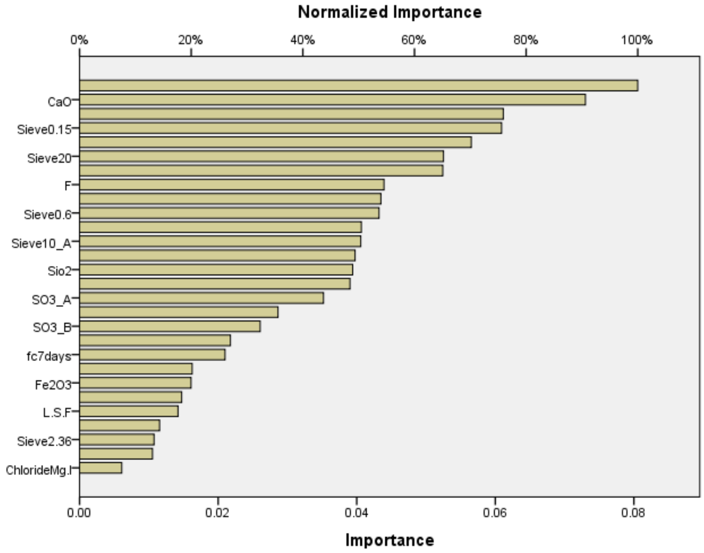


Figure 8.5 Independent variable importance normalized importance for materails quality [Researcher].

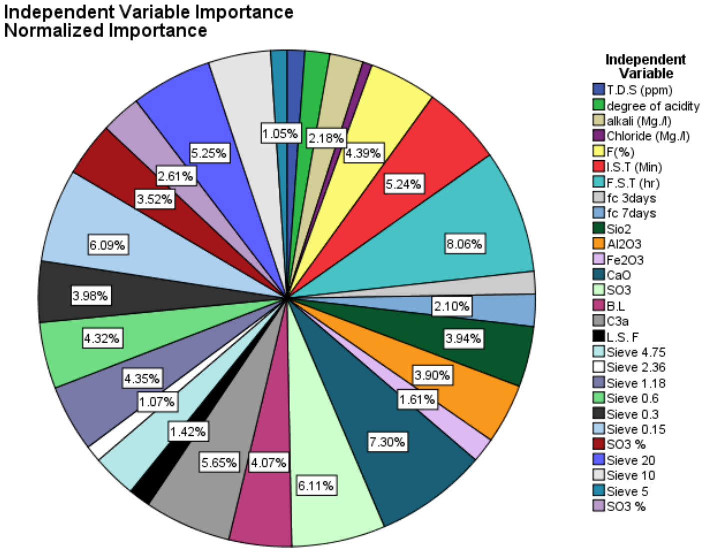


Figure 8.6 Independent variable importance percent importance for the quality of materials [Researcher].

Moreover, to determine the effectiveness of artificial neural networks in predicting the quality of RMC materials, the figures and the table above show the impact of every independent variable on the model of ANN, the values of each variable based on the percent of normalized importance, based on data collected from 93 tests samples of the quality of ready mix concrete (RMC) materials.

8.4.2 RMC Delivery time

This section analyzes data from 81 RMC delivery events to see if an MLP using Artificial Neural Networks could assist in forecasting the delivery time again for total time discharge result (success or failure) (RMC) to the ability store building delivery (independent variables), the time of loading (mixing time), time of delivery to the construction site, the time waiting at the construction site before RMC pouring, the time of RMC placing (pouring time), truck mixers washing time, return journey time to the stationary concrete batching plant, and the downtime at the construction time before start journey back to SCBP. The table below provides a clear view of the information (datasets) used to make (build) a model of ANN.

Table 8.7 Case of processing Summary of Ready-Mix Concrete (RMC) delivery time [Researcher].

		N	*Percent*
Sample	*Training*	*49*	*60.5%*
	Testing	*32*	*39.5%*
Valid		*81*	*100.0%*
Excluded		*0*	
Total		*81*	

Table 8.7 shows the case process summary RMC delivery time, where the training (as the partition set up before 70 training and 30 testings) for data of the case study was training was 60.5 %, and 39.5 % for testing, 49 samples for training, for 32 samples for testing, and 0 samples excluded. Moreover, the table below provides more information about the network. The ANNs are powerful machine learning techniques that model complex relationships between inputs and outputs. In the context of RMC delivery time and total discharge time, ANNs can be used to analyze and forecast the delivery time based on various factors such as loading time, delivery time to the construction site, waiting time at the construction site, pouring time, washing time, return journey time, and downtime at the construction site. It can provide a robust solution for modeling the complex relationships between these factors and RMC delivery time, providing valuable insights and predictions for optimizing the delivery process. This information can help ensure timely and efficient deliveries, improving customer satisfaction and reducing costs.

Table 8.8 displays information about the network, such as the number of factors, covariates, hidden layer, number of units in the input layer, hidden layer and output layer, activation function, and error function applied. The number of units in the input layer is 8, which consists of the total number of factor levels plus the number of covariates. It means to say that there are 8-factor levels and 8 covariates. The number of units in the output layer is 2, representing two categories of ready-mix concrete dependent variable, the total time discharge outcome. The rescaling method for covariates is standardized.

Table 8.8 Network Information of RMC delivery time/total discharge time [Researcher].

Input Layer	*Covariates*	*1*	*Loading Time*
		2	*Delivery Time*
		3	*Unloading time*
		4	*Waiting at worksite*
		5	*RMC Pouring Time*
		6	*Truck's washing time.*
		7	*Return Journey Time*
		8	*Downtime at worksite*
	Number of Units		*8*
	Rescaling Method for Covariates		*Standardized*
Hidden Layer(s)	*Number of Hidden Layers*		*1*
	Number of Units in Hidden Layer 1[a]		*4*
	Activation Function		*Hyperbolic tangent*
Output Layer	*Dependent Variables*	*1*	*total discharge time*
	Number of Units		*2*
	Activation Function		*Softmax*
	Error Function		*Cross-entropy*

Automatic architecture has included one hidden layer with 4 units, a hyperbolic tangent activation function for the hidden layer, a Softmax activation function for the output layer, and a Cross-entropy error function for computing error in training and testing samples. The information presented in the table above summarizes the neural network model. It shows Cross entropy error during training and testing percent of incorrect predictions in training and testing. Cross entropy error is shown due to the Softmax activation function in the output layer. The training stopped using one consecutive step with no decrease in error. Furthermore, the artificial neural network for the case study consists of three elements: input data 8 independent variables, and one dependent variable, 1 hidden layer with 4 nodes, and output 2 nodes, as follows:

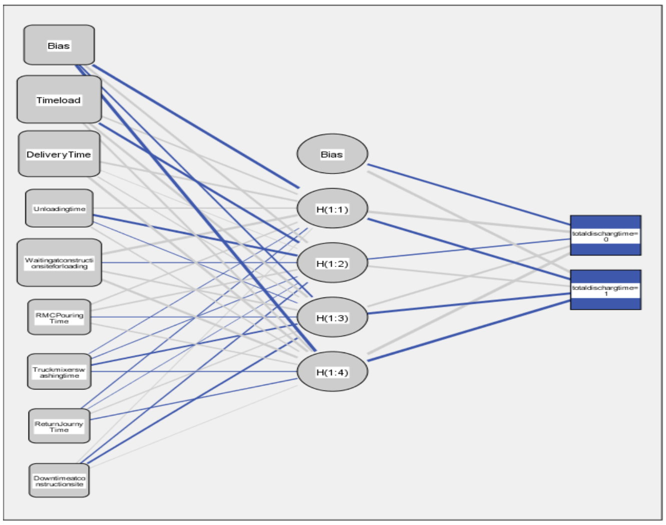


Figure 8.7 Network Diagram of RMC delivery /total discharge time [Researcher].

The network diagram shown in the figure above shows that SPSS used to predict the RMC delivery time for total discharge time outcome, where the failure (0) if the total discharge time is less than or equal to 90 Min (ASTM), success (1) which is mean more than total discharge time is more than 90 Min from 8 independent variables represent parameters effect based on data measured previously. It represents a network with eight input nodes, four hidden nodes, and two output nodes of the ready mix concrete (RMC) delivery time for the total discharge time failure (0) if the total discharge time is less than or equal to 90 Min (ASTM) categories, success (1) which is mean more than RMC total discharge time is more than 90 Min categories.

Table 8.9 Model Summary of the ready-mix concrete (RMC) delivery time [Researcher].

Training	*Cross Entropy Error*	*1.011*
	Percent Incorrect Predictions	*0.0%*
	Stopping Rule Used	*1 consecutive step(s) with no decrease in error* [a]
	Training Time	*0:00:00.01*
Testing	*Cross Entropy Error*	*4.755*
	Percent Incorrect Predictions	*3.1%*

Table 8.9 provides an overview of the model and includes data from the training and testing phases. Since cross-entropy error is the error function that the network reduces during training, it is provided in both the testing and the training samples. That this error is so minimal (1.011) demonstrates the robustness of the model for predicting RMC results. The network model has not been overfitting to the training data since the cross-entropy error is less for the training sample than the testing data set. The table shows that the proportion of erroneous predictions made from the sample set used for training is 0 % for both, which means that the RMC predictions for total discharge time are 100% correct. For the testing, the percentage of incorrect predictions based on testing samples is 3.1 % for both, which means that the RMC predictions for total discharge time are 96.9 % correct. The technique was repeated until the testing sample reached eight consecutive steps with no drop in error function. The next step is the time estimates, which it used to predict each parameter value for the hidden layer of the ANN for 4 nodes related to 8 nodes from input layers and then predict parameter values for the output Layer 2 nodes. Table 8.10 displays the synaptic weights using data from the training phase [15]. Moreover, the values calculated for each predictor in the hidden layer and in the output layer for each RMC delivery time, the total discharge time predicted, and, as mentioned above, the percent of incorrect predictions is 0% for the data of the training dataset, and the 3.1% for the data of the testing dataset, where based on the weights as shown in the table above the values of the delivery time for the total discharge time outcomes predicted.

Table 8.10 Parameter Estimates for RMC delivery time for total discharge time [Researcher].

Predictor		***Predicted***					
		Hidden Layer 1				***Output Layer***	
		H(1:1)	*H (1:2)*	*H (1:3)*	*H (1:4)*	*total discharge time =0*	*total discharge time =1*
Input Layer	*(Bias)*	*-.969*	*.594*	*-.385*	*-1.151*		
	Timelord	*.431*	*-.691*	*.638*	*.536*		
	delivery time	*.591*	*.028*	*.245*	*.661*		
	Unloading time	*.336*	*-.751*	*-.159*	*.262*		
	Waiting at worksite	*.836*	*-.208*	*.535*	*.666*		
	RMC Pouring Time	*.293*	*.444*	*-.163*	*.284*		
	Trucks washing time	*-.141*	*-.159*	*-.450*	*-.242*		
	Return Time	*-.234*	*-.020*	*.259*	*-.254*		
	Downtime at constr. site	*.030*	*-.262*	*-.524*	*.004*		
Hidden Layer 1	*(Bias)*					*-.634*	*.931*
	H(1:1)					*1.069*	*-.815*
	H(1:2)					*-.270*	*.586*
	H(1:3)					*.591*	*-.799*
	H(1:4)					*1.091*	*-1.014*

The classification table displays the actual outcomes of utilizing the model for each scenario; the projected answer is the classification with the most significant framework probability. Samples were weighted according to the final sample weight where success is 1, the delivery time for the total discharge time less than or equal to 90 Min, and the failure is 0, which is means the concrete delivery time for the total discharge time more than 90 Min this means that the predicted model performance may be found in the categorization table in the delivery time.

Table 8.11 Classification for ready mix concrete delivery time for total discharge time [Researcher].

Sample	***Observed***	***Predicted***		
		more than 90	***less than 90***	***Percent Correct***
Training	*more than 90*	*8*	*0*	*100.0%*
	less than 90	*0*	*41*	*100.0%*
	Overall Percent	*16.3%*	*83.7%*	*100.0%*
Testing	*more than 90*	*2*	*0*	*100.0%*
	less than 90	*1*	*29*	*96.7%*
	Overall Percent	*9.4%*	*90.6%*	*96.9%*

Table 8.11 displays a classification for categorical dependent variable material quality outcome by partition and overall, for each case, where the MLP network correctly classified 8 samples more than 90 Min out of 49, and 41 out of 49 samples less than 90 Min in the training samples, where overall 100 % of the training cases were correctly classified. The testing 2

samples were more than 90 Min out of 32, and 29 samples out of 32 samples were less than 90 Min in testing samples, where overall 96.9 % of testing samples were classified correctly.

The box plots of predicted pseudo-probabilities for the dependent variable of the delivery time for the total discharge time outcome the chart display box plots that classify the predicted pseudo-probabilities based on the whole dataset [15]. For each box plot, the values show correct predictions. The first, from the left, boxplot shows the predicted probability of the observed RMC delivery time for a total discharge time of more than 90 Min to be in a failure category. The secondary boxplot depicts the likelihood that the delivery time of RMC would be considered successful for the total discharge duration of less or equal to 90 Min.

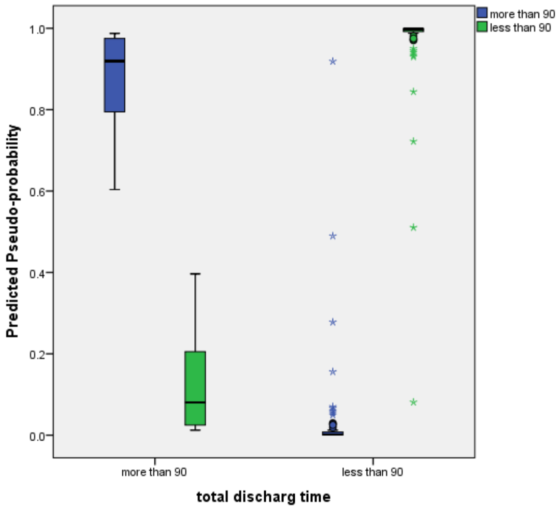


Figure 8.8 Predicted-by-observed chart for RMC total discharge time [Researcher].

Figure 8.8 shows the results that have achieved category success; the third boxplot (sub-boxplot) demonstrates that if the total discharge time is shorter than 90 Min, then the delivery time of RMC is anticipated to fall into the success category, as shown in the boxplot on the right.

The cumulative gains, or the frequency of accurate classifications produced by the ANN model relative to the frequency of correct classifications that may happen by chance, are shown in the chart below. If the network assigns a score to a dataset and then ranks all the instances by anticipated pseudo-probability of failure, then the top 10% should include around 80% of cases that take the category failure, as shown by the second point on the curve for the failure category, which is at (10%, 80%) to retrieve all of the observed failure instances in the dataset, one must choose 100% of the scored dataset. The calculating difference between the proportion of accurate predictions made with and without a model yields a classification model's "gain" (baseline). As a curve rises above the baseline, the benefit grows. In general, a more significant gain signifies superior performance.

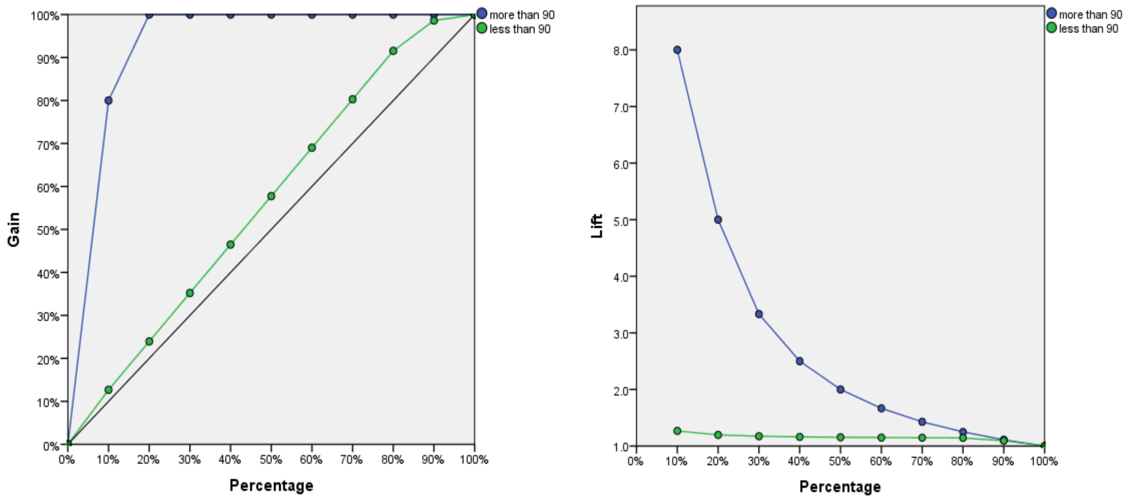


Figure 8.9 Cumulative Gains RMC delivery and Lift Charts is for total discharge time [Researcher].

Figure 8.9 represents the evaluation of the performance of a classification model for delivery time. The lift chart and gain chart visually represent the model's performance, comparing them to the performance without the model. The lift factor is calculated by dividing the model's gains by the gains without the model. The table provides information on each independent variable's relative and normalized relevance in the ANN model. Moreover, it illustrates the cumulative gains and the lift chart for RMC delivery time, where the Lift charts and gain charts are visual aids for evaluating the performance of classification models. However, the gain or lift chart evaluates model performance in a portion of the RMC total discharge time. The advantage of using a model vs. not using a model may be seen with a lift chart, which only utilizes a subset of the dataset. The lift factor is calculated using the numbers in the gains diagram; for example, the lift at 50% for the category failure is 2.5 (5 /2= 2.5). Table 8.12 illustrates the independent variable's relative and normalized relevance in the ANN model.

Table 8.12 Independent Variable Importance of RMC delivery time [Researcher].

	Importance	***Normalized Importance***
Time load	*.247*	*99.3%*
Delivery Time	*.221*	*88.7%*
Unloading time	*.096*	*38.4%*
Waiting at the construction site for loading	*.249*	*100.0%*
RMC Pouring Time	*.055*	*22.1%*
Truck mixers' washing time	*.061*	*24.3%*
Return Journey Time	*.041*	*16.6%*
Downtime at the construction site	*.031*	*12.3%*

Table 8.12 demonstrates the relevance of the variables and how sensitive the model is to a change in each input variable in the ANN model, as well as their relative and normalized

importance, where the figure below represents the percent of normalized importance for each independent variable. The independent variable importance normalized importance chart of the RMC delivery found that waiting at the construction site for RMC unloading is the most normalized importance independent variable, mixing time is the second, and delivery time is the third normalized importance. The rest are unloading time, washing time, pouring time, return journey time, and downtime at a construction site, respectively, where Figure 8.12 illustrates the importance of normalized values for independent variables in an ANN model. Among these variables, waiting at the worksite had the highest normalized value of 0.249, accounting for 24.89% of overall samples and representing 100% normalized importance. This variable had the most significant impact on the ANN model's predictions.

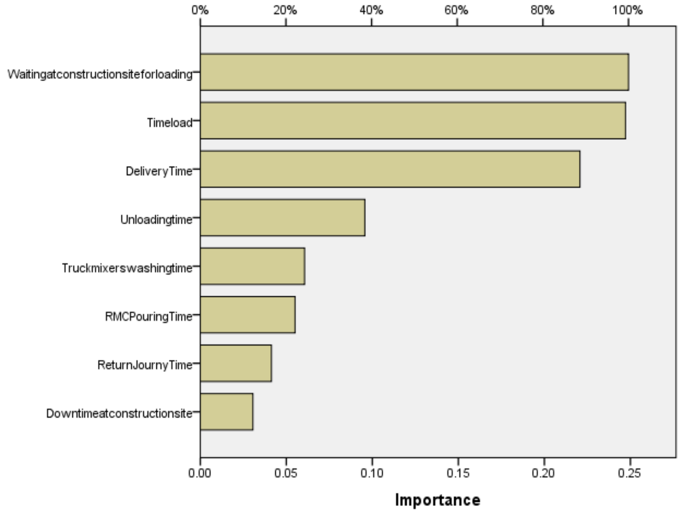


Figure 8.10 Independent variable normalized importance chart for RMC delivery time [Researcher].

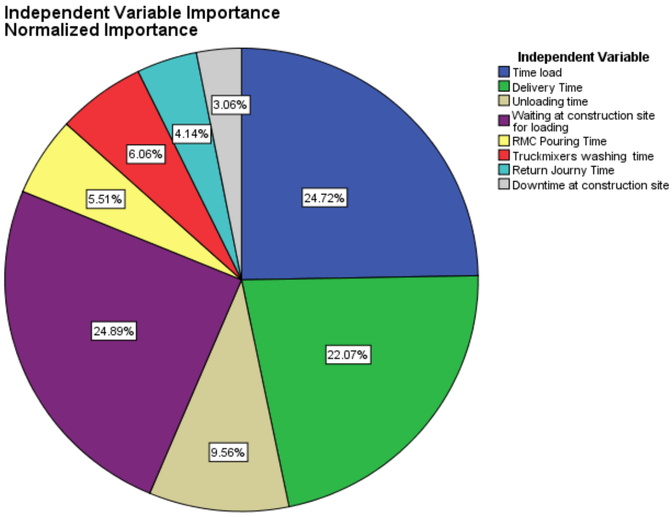


Figure 8.11 The independent variable normalized importance for RMC delivery time [Researcher].

The second most important variable was loading time (mixing time at SCBP), with a normalized value of 0.247, contributing to 24.72% of overall samples and demonstrating 99.3% normalized importance. Following closely, a delivery time has held the third position in importance, with a normalized value of 0.221, impacting 22.07% of overall samples and representing 88.7% normalized importance. The model exhibited an impressive success rate of 100% in predicting whether the concrete delivery time for the entire discharge period would be successful. These results suggest that the proposed model is highly reliable for estimating RMC delivery times and can play a crucial role in developing timely interventions to ensure the production of high-quality RMC and increase the likelihood of success in construction projects.

8.4.3 Prediction RMC parameters Temperature, Consistency, Air content, Porosity, Density, and Compressive strength

The primary objective of this case study is to explore the effectiveness of a multilayer perceptron artificial neural network (ANN) in predicting various parameters, namely RMC temperature, consistency, air content, porosity, density, and compressive strength, in both plant SCBP and construction site settings across different seasons. This prediction is based on experimental data gathered in previous chapters, which include information on RMC mix temperature post-cooling at the SCBP and construction site, weather temperature, slump test results (before and after cooling), density tests, delivery time, air content, porosity, and compressive strengths. The dataset consists of nine values for each parameter, totaling 63 cases at SCBP and 63 cases at the construction site for each season, resulting in 126 cases.

1) Spring season

This section provides a detailed description of the ANN model for the spring season, as follows:

a) Data

This dissertation encompasses data collected from 2018 to 2022, focusing on ready-mix concrete at a stationary concrete batching plant and a construction site in Misan, Iraq, specifically at the Misan governmental building. The data comprises:

- 48 measurements of RMC mix temperature (post-cooling with ice) at the stationary concrete batching plant (SCBP) and the construction site
- 48 weather temperature measurements
- 32 samples for slump tests (measurements before and after cooling).
- 48 cases of monitoring mixing time with 0.5 Water/cement ratio.
- 48 delivery times to the construction site, and total discharge times.
- 48 compressive strength values and density tests
- 48 samples for air content percentage and porosity percentage.

These data points were collected and categorized for predicting new compressive strength values. The information was gathered from the SCBP and the construction site and stored in Moodle, a platform for tracking various activities and maintaining records. The Moodle platform continuously logs changes in parameters related to compressive strength, storing the data in relational database tables. To achieve predictions for each parameter in our case study, 12 ANN models were developed for the spring season. There are two models for each parameter, one for the SCBP and another for the construction site. This approach facilitates a comprehensive analysis of the data, as follows:

Table 8.13 The experimental values of the variables in the spring season [Researcher].

No	Weather Temperature (°C)	RMC Temperature (°C)	Consistency (%)	Air content (%)	Porosity (%)	Density (Kg/mm^3)	Compressive strength (MPa)
Stationary Concrete Batching Plant (SCBP) Experimental values							
1.	25.0	30.1	6.2	3.4	20.07	2364.0	38.8
2.	29.0	29.0	6.2	3.8	20.91	2340.0	35.6
3.	30.0	30.0	6.2	3.7	20.63	2352.0	37.2
4.	25.0	28.3	6.7	3.6	20.49	2235.0	37.1
5.	25.0	30.1	6.7	3.4	20.07	2411.0	39.2
6.	29.0	30.4	6.7	3.6	20.49	2291.0	36.9
7.	28.0	30.0	6.8	3.7	20.63	2301.0	37.1
8.	29.0	30.1	6.8	3.5	20.32	2375.0	38.9
9.	29.0	28.0	6.8	3.2	19.79	2415.0	39.5
Construction Site Experimental values							
10.	27.0	30.1	7.3	2.8	19.22	2346.0	43.7
11.	32.0	31.3	7.3	3.0	19.51	2375.0	40.9
12.	34.0	31.2	7.3	3.4	20.07	2255.0	37.4
13.	28.0	31.8	6.5	3.5	20.32	2361.0	38.6
14.	27.0	29.0	6.5	3.9	20.91	2275.0	34.3
15.	32.0	30.2	6.5	3.7	20.63	2202.0	36.4
16.	27.0	30.0	7.0	4.3	21.72	2119.0	33.8
17.	29.0	28.4	7.0	3.1	19.73	2314.0	39.6
18.	32.0	30.0	7.0	3.4	20.07	2428.0	41.1

Table 8.13 represents the experimental values of RMC parameters measured for the stationary concrete batching plant and at the construction site. These are used to make ANN models (12 ANN models for each season). The feed-forward architecture of the MLP model is used to identify RMC compressive strength. The interconnections between neurons in a feed-forward architecture run from the input layer to the hidden layer and finally to the output layer. Moreover, creating a model is required to make the parameter that would like to predict its value by ANN the dependent variable, and the other variables will be the predictors (constants). The descriptive statistics give summary statistics based on ANN models, showing the minimum, maximum, mean, and standard deviation for each case at SCBP and a construction site. Table 8.14 shows vital descriptive statistics for the data used to elaborate the ANN models

to predict each variable; for example, were: the weather temperature the 25 is the minimum value from the nine values of the weather temperature and the same situations apply to the rest of the values 30 Maximum, 27.667 Mean, and 2.0616 Standard Deviation.

Table 8.14 Descriptive statistics of experimental values at SCBP and construction site [Researcher].

	N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Stationary Concrete Batching Plant (SCBP)					
Weather Temperature (℃)	*9*	*25.0*	*30.0*	*27.667*	*2.0616*
RMC Temperature (℃)	*9*	*28.0*	*30.4*	*29.556*	*.8876*
Consistency (mm)	*9*	*6.2*	*6.8*	*6.567*	*.2784*
Air content (%)	*9*	*3.2*	*3.8*	*3.544*	*.1878*
Porosity (%)	*9*	*19.79*	*20.91*	*20.377*	*.34892*
Density (Kg/mm^3)	*9*	*2235.0*	*2415.0*	*2342.6*	*58.6238*
Compressive strength(MPa)	*9*	*35.6*	*39.5*	*37.811*	*1.3252*
Valid N (listwise)	*9*				
Construction Site					
Weather Temperature (℃)	*9*	*27.0*	*34.0*	*29.778*	*2.7285*
RMC Temperature (℃)	*9*	*28.4*	*31.8*	*30.222*	*1.0918*
Consistency (mm)	*9*	*6.5*	*7.3*	*6.933*	*.3500*
Air content (%)	*9*	*2.8*	*4.3*	*3.456*	*.4667*
Porosity (%)	*9*	*19.22*	*21.72*	*20.242*	*.76558*
Density (Kg/mm^3)	*9*	*2119.0*	*2428.0*	*2297.2*	*95.5167*
Compressive strength (MPa)	*9*	*33.8*	*43.7*	*38.422*	*3.2802*
Valid N (listwise)	*9*				

Table 8.14 illustrates essential statistics for various parameters derived from a dataset used to construct an artificial neural network (ANN) model. The dataset consists of nine values for each parameter. The key findings are summarized below:

a. RMC Temperature: The Minimum is 28, 30.4 Maximum, 29.556 Mean, and 2.0.8876 Standard Deviation.

b. Consistency: The Minimum is 6.2, 6.8 Maximum, 6.567 Mean, and 0.2784 Standard Deviation.

c. Air Content: The Minimum is 3.2, 3.8 Maximum, 3.544 Mean, and 0.1878 Standard Deviation.

d. Porosity: The Minimum is 19.79, 20.91 Maximum, 20.3778 Mean, and 0.349Standard Deviation.

e. Density: The Minimum is 2235, 2415 Maximum, 2342.667 Mean, and 58.62 Standard Deviation.

f. Compressive Strength: The Minimum is 35.6 MPa, 39.5 MPa Maximum, 37.81 MPa Mean, and 1.235 Standard Deviation.

These statistics serve as a valuable reference for the dataset used in making the ANN model.

Table 8.15 Case Process Summery [Researcher].

		N	*Percent*
Sample	*Training*	*5*	*55.6%*
	Testing	*4*	*44.4%*
Valid		*9*	*100.0%*
Excluded		*0*	
Total		*9*	

Table 8.15 shows the case process of summery ready mix concrete compressive strength, where the training (as the partition set up before 70 training and 30 testings) for the date of the case study was training was 55.6%, and training 44.4 % for training, 5 samples, testing 4 samples, and excluded 0 samples. Moreover, the table below provides more information about the network. The ANN for the network information of RMC compressive strength consists of three elements: the first element is the input data with independent variables, one dependent variable is the second element for only one hidden layer, and the output layer which is the third element, for each season there are 12 ANN models as shown in the figure below for 6 models for RMC properties network diagrams of parameters RMC Temperature, Consistency, Air content, Porosity, Density, and Compressive strength at a plant in the autumn season, where it shows the input layers with the number of neuron nodes, the number of the hidden layer, and the outcome.

The network diagrams shown in the figure 8.12 show that SPSS used to predict the ready mix concrete (RMC) parameters RMC temperature, consistency, air content, porosity, density, and compressive strength at plant outcome at the plant, where each model has it is own structure and the correlation coefficient (R), R square, and Root Mean Square Error (RMSE), in addition, there are 6 ANN other models at the construction site for the same variables of RMC with it own descriptive statistics based on the experimental data at the construction site.

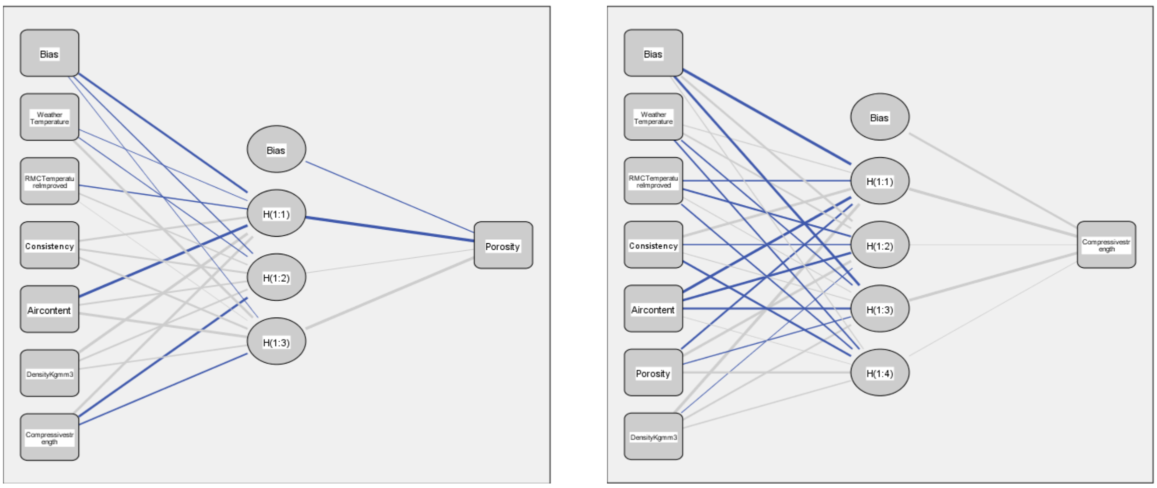


Figure 8.12 Network Diagram of RMC Porosity and Compressive Strength at SCBP [Researcher].

Furthermore, the next step is the examine the primary predictions for the variables mentioned previously by checking the liner relationship by a scatter plot, the correlation, and the regression line equation to determine the x value (see equation no. 62), which will multiply by predicted value of the ready mix concrete (RMC) parameters to find a new value with high accuracy prediction based on the regression line equation for each model.

b) Correlation and Regression

A correlation is a relationship between two or more variables. The data can be represented by the ordered pairs (x, y) where x is the independent variable, and y is the dependent variable.

- The independent variable can be described as the cause.
- The dependent variable can be described as the effect (Its value is calculated based on variations in the independent variable).
- A scatter plot may be used to see whether the variables have a linear relationship.

The degree and direction of a linear connection between the variables may be measured using the correlation coefficient (R) statistic. R. denotes correlation coefficients where the equation for R is as follows:

$$R = \frac{\sum_i^n YX}{\sqrt{n(\sum_I Y)^2 - (\sum_I Y^2)}\sqrt{n(\sum_i X)^2 - (\sum_i X)^2}} \tag{61}$$

The range of the correlation coefficient is -1 to 1. After confirming the significance of the linear correlation between the variables, the next step is to determine the line's equation that can be used to predict the value of y given a value of x. Each data point represents the deviation from the expected y-value at a certain x-value. Residuals are shorthand for these variations. A regression line, known as a best-fit line, is the line where the sum of the squares of the residuals is the smallest. Generally, when two variables, x and y, are being analyzed, the regression line's equation looks like this:

$$\hat{Y} = mx + b \tag{62}$$

Where $\hat{\boldsymbol{Y}}$ Is the predicted y-value for a given x-value. The slope $\boldsymbol{m}$ and y-intercept $\boldsymbol{b}$ are given by

$$m = \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2} \tag{63}$$

Therefore, The regression line equation for more than two variables is as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_kX_k + e \tag{64}$$

Each regressor in a linear model is assigned a numerical weight—the ***b*** next to each ***X*** in the equation, also known as its regression coefficient, slope, and regression weight, which dictates the extent to which values on that variable are used to estimate ***Y***.

The predicted compressive strength of concrete is recorded as the output of the ANN network. The simulation results were recorded by varying hidden layers from 2 to 5 to identify the best architecture using the correlation coefficient (R) and Root Mean Square Error (RMSE) as stopping criteria for the epochs value of 1000, the learning rate of 0.3, and momentum of 0.2. the R and RMSE values are calculated using equations (61) and (62). The experimental datasets train the ANN network to identify the best architecture.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (Y - X)^2}, \qquad (65)$$

X is the predicted value, Y is the experimental value, and "n" is the total number of datasets. From the Table below, the maximum R-value was obtained as 0.999 for 4 hidden layers at the construction site, and the minimum RMSE value was 0.01173 for 3 hidden layers at the plant. Therefore, the predicted value becomes as shown in Table 8.16:

Table 8.16 The RMC predicted values of the variables in the spring season [Researcher].

No	*Weather Temperature (°C)*	*RMC Temperature (°C)*	*Consistency (mm)*	*Air content (%)*	*Porosity (%)*	*Density (Kg/m³)*	*Com. Strength (MPa)*
			Stationary Concrete Batching Plant (SCBP)				
1.	*25.0*	*29.65377*	*7.07812*	*4.05138*	*20.06378*	*2386.29565*	*38.73193*
2.	*29.0*	*28.97990*	*6.77526*	*4.45118*	*20.89003*	*2307.54296*	*35.77407*
3.	*30.0*	*30.55947*	*6.94718*	*4.32670*	*20.65600*	*2362.07214*	*37.02754*
4.	*25.0*	*28.85643*	*7.26934*	*4.21337*	*20.48521*	*2269.35338*	*36.87542*
5.	*25.0*	*30.04509*	*7.01452*	*4.05229*	*20.08056*	*2360.74775*	*39.41564*
6.	*29.0*	*29.33965*	*7.16004*	*4.23565*	*20.48541*	*2307.43439*	*37.30772*
7.	*28.0*	*30.33833*	*7.06208*	*4.31287*	*20.65784*	*2285.48500*	*37.23556*
8.	*29.0*	*29.64985*	*7.42792*	*4.16951*	*20.27983*	*2399.90622*	*38.27079*
9.	*29.0*	*28.57752*	*7.30604*	*3.85677*	*19.80135*	*2405.16251*	*39.66132*
			Construction site				
10.	*27.0*	*29.41624*	*9.80420*	*2.77274*	*19.04510*	*2406.37629*	*8.90686*
11.	*32.0*	*29.41592*	*9.80506*	*3.02843*	*19.23530*	*2326.07598*	*7.91433*
12.	*34.0*	*29.08364*	*10.04306*	*3.37746*	*19.92800*	*2280.12288*	*5.54401*
13.	*28.0*	*29.74454*	*9.82252*	*3.51187*	*19.99640*	*2336.83904*	*5.00036*
14.	*27.0*	*28.87762*	*9.82650*	*3.87637*	*20.68130*	*2264.22100*	*2.52663*
15.	*32.0*	*29.17166*	*10.23070*	*3.69895*	*20.39080*	*2258.88506*	*3.80489*
16.	*27.0*	*29.49034*	*10.44980*	*4.31289*	*21.53420*	*2117.06183*	*3.10396*
17.	*29.0*	*28.83726*	*9.79994*	*3.13248*	*19.44420*	*2283.53134*	*7.22279*
18.	*32.0*	*29.62064*	*9.95646*	*3.38881*	*19.79570*	*2401.88659*	*5.06071*

Table 8.16 represents the RMC predicted values of the variables in the spring season for the 12 ANN model, where it is shown that the variables have changed based on the algorithm of

each model, but according to the correlation coefficient (R), has been determined in this step, R squared, and Root Mean Square Error that will use in regression after checking the significant of residuals.

Table 8.17 The correlation coefficients (R) and Root Mean Square Errors (RMSE) [Researcher].

Number of hidden layers	*R*	R^2	*RMSE*
Stationary Concrete Batching Plant (SCBP)			
2	*0.766*	*0.587*	*0.789410985*
2	*0.718*	*0.515*	*0.182699242*
3	*0.998*	*0.996*	*0.01172795*
3	*0.998*	*0.996*	*0.020899137*
5	*0.872*	*0.760*	*27.05005353*
4	*0.972*	*0.945*	*0.366197177*
Construction site			
3	*0.990*	*0.980*	*0.926538856*
2	*0.717*	*0.514*	*0.230115879*
4	*0.999*	*0.998*	*0.023466431*
4	*0.999*	*0.998*	*0.03483171*
2	*0.912*	*0.833*	*36.84784006*
4	*0.959*	*0.919*	*0.879612786*

Table 8.17 represents the values of the coefficients (R and RMSE) after generating the new predicted values to examine these predicted values during the spring season, where the maximum correlation coefficient (R) is 0.999, the maximum R square 0.998 and minimum the root mean square error (RMSE) is 0.01172795. Moreover, the next step is to use the values of the coefficients to find $\hat{Y}$ is the predicted y-value for a given x-value, The slope m, and y-intercept b to compute variables to generate new values based on the regression line equation to predict new values for parameters RMC Temperature, Consistency, Air content, Porosity, Density, and Compressive strength at SCBP and at a construction site. Therefore, 12 regression line equations are generated to predict the accurate values of the parameters based on the coefficients for each parameter that has been determined, correlation coefficient (R), and minimum RMSE.

Fig.8.13 shows that the graphs of regression lines at the SCBP can be used to predict accurate values of parameters based on predictor variables. The coefficients of the equations for each parameter are determined, along with the correlation coefficient and minimum root mean square error, which indicate the accuracy and reliability of the regression line equation. A high correlation coefficient and low RMSE are essential for ensuring the accuracy of the predicted values. Therefore, a high correlation coefficient indicates that the regression line equation is a good predictor of a predicted parameter. The minimum root mean square error (RMSE) measures the accuracy of the regression line equation.

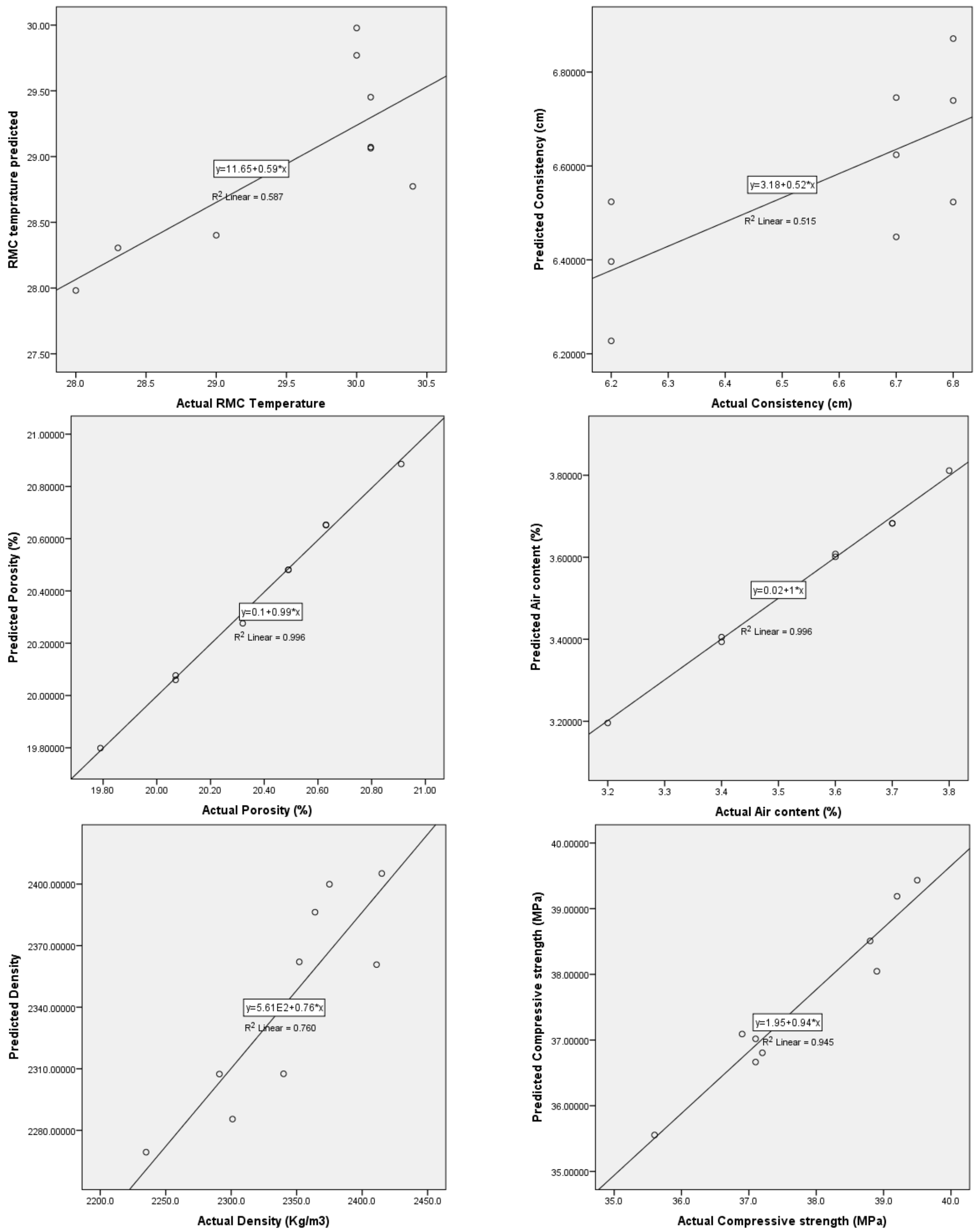


Figure 8.13 RMC properties predicted (a) RMC temperature, (b) consistency, (c) air content, (d) porosity, (e) density, and (f) compressive strength.at plant [Researcher].

Fig.8.14 presents the graphs of regression line equations, which are powerful tools for visualizing and analyzing data, and regression lines are commonly used to predict accurate values of parameters based on a set of predictor variables. The regression line equations for RMC temperature, consistency air content, porosity, density, and compressive strength at the plant and the construction site have been generated in this case.

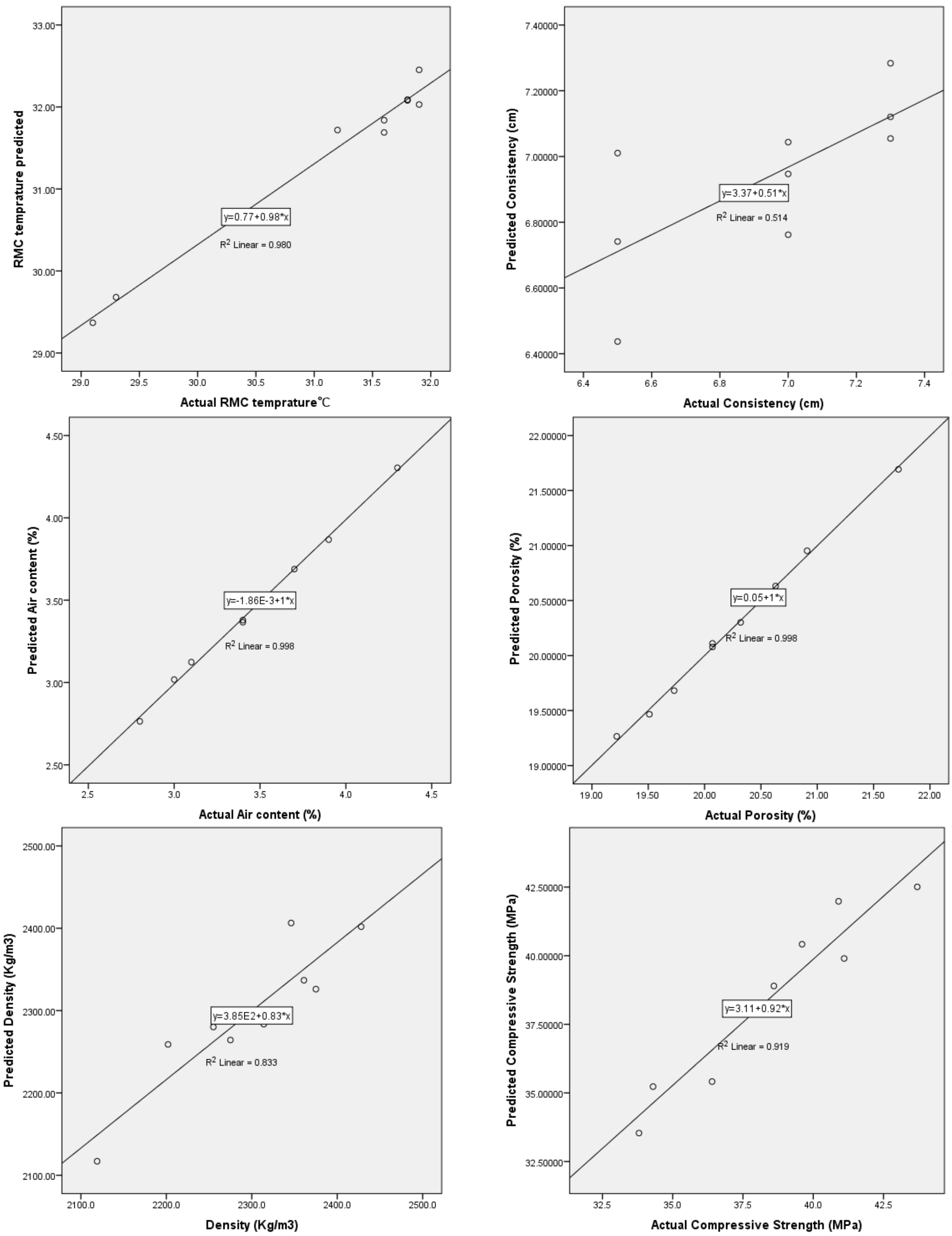


Figure 8.14 RMC properties predicted (a) RMC temperature; (b) consistency; (c) air content; (d) porosity; (e) density; (f) compressive strength at construction site [Researcher].

Moreover, The coefficients of the equations for each parameter have been determined, along with the correlation coefficient (R) and the minimum root mean square error (RMSE). These values are essential indicators of the accuracy and reliability of the regression line equations. The correlation coefficient (R) measures the strength and direction of the linear relationship between the predictor variables and the parameter being predicted. A value of R close to 1 indicates a strong positive correlation, while a value close to -1 indicates a strong negative correlation. A value of R close to 0 indicates little or no linear relationship between the variables. It represents the difference between the actual values of the parameter and the predicted values based on the equation. It is essential to ensure that the correlation coefficient is high in our case of study, 0.999, and the RMSE is low (0.01172795 in our case of study) to ensure the accuracy and reliability of the regression line equations. Therefore, Instead of the RMC temperature, consistency, air content, porosity, and density are used to validate and predict the ready-mix concrete's compressive strength. From Figure 8.14 it is evident that the RMC temperature is within the acceptable value of R 0.766 at plant of ANN1and 0.99 at construction site of ANN7, the consistency (standard) validated value of the RMC is within the acceptable value of R of 0.718 at plant of ANN2 and 0.717 at construction site of ANN8, the Air content validated value of the RMC is within the acceptable value of R of 0.998 at plant of ANN3 and 0.999 at construction site of ANN9, porosity validated value of the RMC is within the acceptable value of R of 0.998 at plant of ANN4 and 0.999 at construction site of ANN10, and the Density validated value of the RMC is within the acceptable value of R of 0.872 at plant of ANN5 and 0.912 at construction site of ANN11, respectively. It is proved that the experimental values are validated with the predicted values generated.

Therefore, the predicted variables with high accuracy prediction will be as follows:

Table 8.18 The RMC predicted values of the variables in the spring season [Researcher].

No	*Weather Temperature (°C)*	*RMC Temperature (°C)*	*Consistency (mm)*	*Air content (%)*	*Porosity (%)*	*Density (Kg/m3)*	*Compressive Strength (MPa)*
			Stationary Concrete Batching Plant (SCBP)				
1.	*25.0*	*29.07219*	*6.52375*	*3.40531*	*20.05988*	*2386.30026*	*38.50918*
2.	*29.0*	*28.40167*	*6.22745*	*3.81132*	*20.88576*	*2307.54828*	*35.55364*
3.	*30.0*	*29.97811*	*6.39644*	*3.68292*	*20.65187*	*2362.07814*	*36.80562*
4.	*25.0*	*28.30573*	*6.74560*	*3.60112*	*20.48139*	*2269.35752*	*36.66516*
5.	*25.0*	*29.45199*	*6.44895*	*3.39363*	*20.07657*	*2360.75226*	*39.18868*
6.	*29.0*	*28.77333*	*6.62376*	*3.60798*	*20.48079*	*2307.43982*	*37.09146*
7.	*28.0*	*29.77011*	*6.52326*	*3.68267*	*20.65333*	*2285.49004*	*37.01862*
8.	*29.0*	*29.06344*	*6.87133*	*3.51916*	*20.27595*	*2399.91206*	*38.04688*
9.	*29.0*	*27.98143*	*6.73947*	*3.19589*	*19.79871*	*2405.16882*	*39.43416*
			Construction site				
10.	*27.0*	*29.88790*	*7.28369*	*2.76417*	*19.26526*	*2406.37832*	*42.50790*
11.	*32.0*	*30.58379*	*7.12052*	*3.01776*	*19.46659*	*2326.07826*	*41.98239*
12.	*34.0*	*30.57641*	*7.05467*	*3.36601*	*20.11065*	*2280.12512*	*37.91272*
13.	*28.0*	*30.09499*	*6.74121*	*3.50208*	*20.30168*	*2336.84032*	*38.89693*
14.	*27.0*	*29.51308*	*6.43698*	*3.86755*	*20.95235*	*2264.22216*	*35.23103*
15.	*32.0*	*30.46079*	*7.01030*	*3.68876*	*20.63148*	*2258.88698*	*35.41385*
16.	*27.0*	*29.87770*	*6.76203*	*4.30372*	*21.69262*	*2117.06282*	*33.53760*
17.	*29.0*	*29.95983*	*7.04368*	*3.12379*	*19.68116*	*2283.53348*	*40.41836*
18.	*32.0*	*30.04552*	*6.94693*	*3.37907*	*20.07822*	*2401.88912*	*39.89922*

Thus, the correlation coefficient R-value of the RMC compressive strength (28 days) is obtained to be 0.972 of ANN6 at SCBP and 0.959 of ANN12 at the construction site. (as all the experimental results are validated using the high R values resulting in the predicted values of ANN6 at the plant and 0.912 at the construction site of ANN12.

Table 8.18 presents the RMC predicted values of the variables in spring, considering all the experimentation data gained and using ANN to estimate the RMC compressive strength, the RMC temperature, consistency, air content, porosity, and density. Using the ANNs in RMC mixes prediction is reaffirmed as the model resulted in a good R2 value. Using the correlation coefficient (R) and root mean square error (RMSE) as stopping criteria for the epochs value of 1000, the simulation results were recorded by altering the number of hidden layers from 2 to 5 to determine the optimum architecture, the highest R-value achieved was as 0.999 at the construction site, and the minimum RMSE value was found to be 0.01172795 at the plant.

2) Summer season

The data values of the variables of RMC gained in the summer season according to the experimental work done in previous chapters and analysis by SPSS software, as follows:

Table 8.19 The experimental values of the variables in the summer season [Researcher].

No	*Weather Temperature (°C)*	*RMC Temperature (°C)*	*Consistency (mm)*	*Air content (%)*	*Porosity (%)*	*Density (Kg/m3)*	*Compressive Strength (MPa)*
Stationary Concrete Batching Plant (SCBP)							
1.	*46.3*	*30.8*	*6.6*	*3*	*19.51*	*2479*	*41*
2.	*47.1*	*30.5*	*6.6*	*2.8*	*19.22*	*2384*	*42.5*
3.	*48.2*	*31*	*6.6*	*3.8*	*20.91*	*2345*	*35.4*
4.	*47.2*	*32*	*5.9*	*3.6*	*20.49*	*2267*	*37.7*
5.	*49.2*	*31.4*	*5.9*	*3.3*	*19.99*	*2272*	*38.7*
6.	*34*	*30*	*5.9*	*3.3*	*19.99*	*2379*	*38.1*
7.	*47.1*	*31*	*7.8*	*4.3*	*21.72*	*2193*	*32.9*
8.	*49.3*	*31.9*	*7.8*	*4.2*	*21.45*	*2189*	*33.4*
9.	*38.5*	*29.2*	*7.8*	*4.9*	*22.52*	*2113*	*32*
Construction site							
10.	*48.9*	*28.6*	*8.3*	*3.1*	*19.73*	*2416*	*41.6*
11.	*49.7*	*29.8*	*8.3*	*2.7*	*18.93*	*2492*	*53*
12.	*50.5*	*27.6*	*8.3*	*4.4*	*21.8*	*2215*	*32.6*
13.	*49.8*	*25.9*	*7.2*	*3.7*	*20.63*	*2204*	*35.2*
14.	*51.8*	*28.9*	*7.2*	*3.6*	*20.49*	*2320*	*38*
15.	*37.3*	*29.1*	*7.2*	*4.1*	*21.8*	*2175*	*34.2*
16.	*49.7*	*27.2*	*8.5*	*4*	*21.18*	*2211*	*36.5*
17.	*51.5*	*26.8*	*8.5*	*4.3*	*21.72*	*2130*	*33.3*
18.	*40.8*	*25.3*	*8.5*	*3.7*	*20.63*	*2305*	*36.1*

Table 8.19 represents the experimental values of RMC parameters measured for the Stationary Concrete Batching Plant and at the Construction Site, which is used to make ANN models (12 ANN models). In the current work, the feed-forward architecture of the MLP model is used to identify

the compressive strength of RMC using data. The interconnections between neurons in a feed-forward architecture run from the input layer to the hidden layer and finally to the output layer.

Moreover, creating a model requires the parameter that would like to predict its value by ANN as the dependent variable, and the other variables will be the predictors (constant). The descriptive statistics give summary statistics that will be base for ANN models, which shows the minimum, maximum, mean, and Standard Deviation for each case at the plant and the construction site, as shown in Table 8.20, where it shows an essential descriptive statistics for the data at the SCBP and at the construction site will be used to elaborate the ANN models to predict each variable where for more clarification the values at the plant, were the weather temperature the 34 is the minimum value from the values of the temperature and the same situations for the rest values 49.3 maximum, 45.211 mean, and 5.2982 standard deviations.

Table 8.20 Descriptive statistics for the variables at the SCBP and the construction site [Researcher].

	N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Stationary Concrete Batching Plant (SCBP)					
Weather Temperature (°C)	*9*	*34.0*	*49.3*	*45.21*	*5.2982*
RMC Temperature (°C)	*9*	*26.2*	*29.0*	*27.867*	*.8902*
Consistency (mm)	*9*	*5.9*	*7.8*	*6.767*	*.8322*
Air content (%)	*9*	*2.8*	*4.9*	*3.689*	*.6791*
Porosity (%)	*9*	*19.22*	*22.52*	*20.644*	*1.09490*
Density (Kg/mm^3)	*9*	*2113.0*	*2479.0*	*2291.2*	*115.8024*
Compressive strength(MPa)	*9*	*32.0*	*42.5*	*36.856*	*3.6739*
Valid N (listwise)	*9*				
Construction Site					
Weather Temperature (°C)	*9*	*37.3*	*51.8*	*47.778*	*5.1070*
RMC Temperature (°C)	*9*	*25.3*	*29.8*	*27.689*	*1.5284*
Consistency (mm)	*9*	*7.2*	*8.5*	*8.000*	*.6062*
Air content (%)	*9*	*2.7*	*4.4*	*3.733*	*.5545*
Porosity (%)	*9*	*18.93*	*21.80*	*20.767*	*.98597*
Density (Kg/mm^3)	*9*	*2130.0*	*2492.0*	*2274.2*	*119.1908*
Compressive strength (MPa)	*9*	*32.6*	*53.0*	*37.833*	*6.2958*
Valid N (listwise)	*9*				

The RMC temperature values were 29.2 as a minimum value from the 9 values of the RMC temperature (Improved), and the same situation for the rest values 32 maximum, 30.867 mean, and 0.8876 standard deviations. The consistency the 5.9 is the minimum value from the 9 consistency values, and the same situation for the rest values: 7.8 maximum, 6.767 mean, and 0.8322 standard deviation. The air content the 2.8 is the minimum value from the 9 values of the air content, and the same situation for the rest values: 4.9 maximum, 3.689 mean, and 0.6791 standard deviation. The porosity the 19.22 is the minimum value from the 9 values of the air content, and the same situation for the rest values: 22.52 maximum, 20.644 mean, and 1.0949 Standard Deviation. The density 2113 is the minimum value from the 9 values of the air content, and the same situation for the rest of the values: 2479 maximum, 2291.2 mean, and 115.8024 standard deviation, and finally, for the Compressive strength the 32 MPa is the minimum value from the 9 values and the same situations for the rest values 42.5 MPa maximum, 36.856 mean, and 3.6739 standard deviation, and the same situation at the construction site.

Table 8.21 Case process summery [Researcher].

		N	***Percent***
Sample	*Training*	*5*	*55.6%*
	Testing	*4*	*44.4%*
Valid		*9*	*100.0%*
Excluded		*0*	
Total		*9*	

Table 8.21 provides information about the used datasets to make a model of ANN and shows the case process of summary RMC compressive strength, where the training (as the partition set up before 70 training and 30 testings) for the date of the case study was training was 55.6%, and training 44.4 % for training, 5 samples, testing 4 samples, and excluded 0 samples. Moreover, the table below provides more information about the network. The ANN for the network information of RMC compressive strength consists of three elements: the first element is the input data with independent variables, one dependent variable is the second element for only one hidden layer, and the output layer which is the third element, for each season there are 12 ANN models as shown in the figure below for 6 models for RMC properties network diagrams of parameters RMC Temperature, Consistency, Air content, Porosity, Density, and Compressive strength at the plant in the summer season, where it shows the input layers with the number of neuron nodes, the number of hidden layer, and the outcome for each dependent variable by using SPSS software, for RMC compressive strength as an example from 12 ANN models.

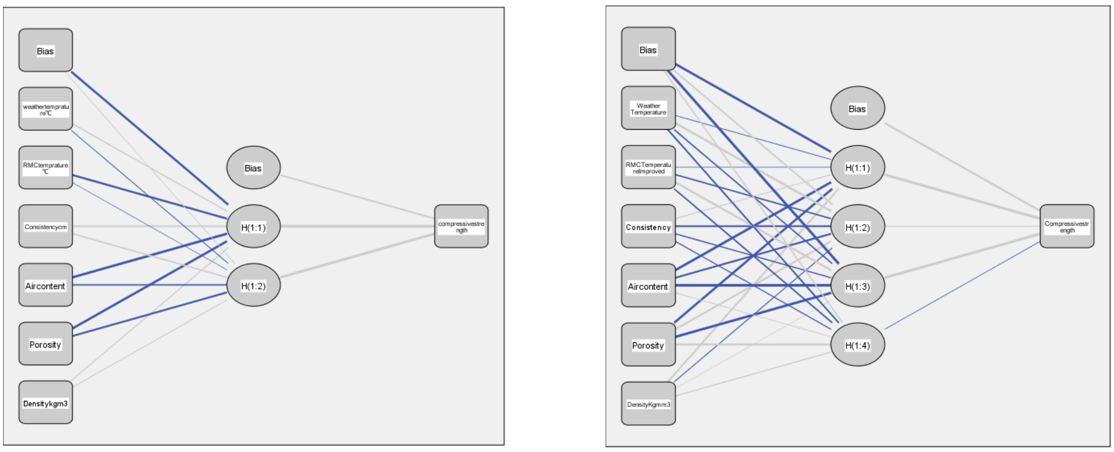


Figure 8.15 Network diagram of Compressive strength at SCBP and construction site[Researcher].

The network diagrams in Figure 8.15 predict the RMC Compressive strength at SCBP with 2 hidden layer ANN model and at the construction site with 5 hidden layer ANN model outcom.

a) Correlation and Regression

The independent variables, which can be characterized as the cause, and the dependent variable, which can be described as the effect, may be used to show a correlation connection between the variables for the data. Changes in the independent variable determine its value. A scatter plot might determine if the variables have a linear connection, as follows:

Table 8.22 The RMC predicted values of the variables in the Summer season [Researcher].

No	Weather Temperature (°C)	RMC Temperature (°C)	Consistency (cm)	Air content (%)	Porosity (%)	Density (Kg/m3)	Compressive strength (MPa)
Stationary Concrete Batching Plant (SCBP)							
1.	*46.3*	*27.61981*	*5.47003*	*2.97613*	*19.53610*	*2393.53835*	*40.86162*
2.	*47.1*	*28.68032*	*5.31236*	*2.82224*	*19.19131*	*2437.49106*	*42.12756*
3.	*48.2*	*27.99451*	*6.34573*	*3.80790*	*20.89892*	*2293.84778*	*35.66716*
4.	*47.2*	*28.67954*	*5.38327*	*3.61543*	*20.45475*	*2261.85011*	*36.77001*
5.	*49.2*	*28.68478*	*5.66407*	*3.27642*	*20.03249*	*2318.66822*	*39.42928*
6.	*34*	*27.30830*	*4.98187*	*3.30419*	*19.99139*	*2389.98029*	*38.45460*
7.	*47.1*	*27.95724*	*6.61416*	*4.33832*	*21.67043*	*2227.75794*	*32.76571*
8.	*49.3*	*28.94715*	*6.37545*	*4.17459*	*21.49030*	*2188.87976*	*33.83789*
9.	*38.5*	*27.60937*	*7.19016*	*4.88478*	*22.53431*	*2108.98649*	*31.78617*
Construction site							
10.	*48.9*	*28.65536*	*8.09646*	*3.12693*	*20.49147*	*2432.30101*	*44.86298*
11.	*49.7*	*29.83135*	*8.10825*	*2.96420*	*20.13351*	*2488.29660*	*51.39483*
12.	*50.5*	*26.91657*	*8.03738*	*4.32941*	*21.84040*	*2164.34659*	*32.78721*
13.	*49.8*	*27.18754*	*8.06927*	*3.68900*	*20.59790*	*2219.29617*	*35.25352*
14.	*51.8*	*28.03421*	*8.01833*	*3.37525*	*20.37891*	*2285.71016*	*36.63520*
15.	*37.3*	*27.87101*	*8.04078*	*4.00669*	*21.10906*	*2218.42420*	*34.37751*
16.	*49.7*	*27.22056*	*8.04778*	*3.99745*	*21.12608*	*2251.45163*	*35.38145*
17.	*51.5*	*27.20874*	*8.07273*	*4.33713*	*21.71813*	*2179.47792*	*33.85261*
18.	*40.8*	*26.95049*	*8.10814*	*3.70643*	*20.68963*	*2283.33316*	*35.73118*

Table 8.22 represents the RMC predicted values of the variables in the summer season for the 12 ANN model, where it is shown that the variables have changed based on the algorithm of each model, but according to the correlation coefficient (R), has been determined in this step, R square, and Root Mean Square Error (RMSE) that will use in regression after checking the significant of residuals. The degree and direction of a linear connection between the variables may be measured using the correlation coefficient (R) statistic. Correlation coefficients in samples are denoted by R (see equation no. 61).

Table 8.23 represents the values of the correlation coefficient (R) and the root mean square error (RMSE) after generating the new prediction values to examine these predicted values during the summer season, where the maximum correlation coefficient (R) is one at the plant, the maximum R^2 0.999 and minimum RMSE is 0.28641649 at the construction site, as follows:

Moreover, this phase describes using the values of the coefficients to find the predicted y-value for a given x-value; the slope *m* and y-intercept *b* to compute variables to generate new values based on the regression line equation to predict new values for parameters RMC Temperature, Consistency Air content, Porosity, Density, and Compressive strength at the plant and at the construction site. Therefore, 12 regression line equations are generated to predict the RMC parameters' accurate values based on the equations' coefficients for each variable that have been determined R^2 and minimum RMSE.

Table 8.23 The correlation coefficients (R) and Root Mean Square Errors (RMSE) [Researcher].

ANN	*Number of hidden layers*	*R*	*R^2*	*RMSE*
Stationary Concrete Batching Plant (SCBP)				
1	*2*	*0.919*	*0.845*	*2.78954195*
2	*4*	*0.843*	*0.711*	*0.422136177*
3	*4*	*0.999*	*0.999*	*0.442062019*
4	*1*	*1.000*	*0.999*	*0.416911573*
5	*2*	*0.921*	*0.848*	*42.59686895*
6	*4*	*0.991*	*0.981*	*0.483119703*
Construction site				
7	*4*	*0.999*	*.0998*	*0.28641649*
8	*2*	*0.986*	*0.971*	*0.447622009*
9	*2*	*1.000*	*0.999*	*1.090151777*
10	*4*	*1.000*	*1.000*	*0.32390749*
11	*4*	*0.999*	*0.999*	*40.124352484*
12	*2*	*0.999*	*0.997*	*0.797152575*

Fig.8.16 shows that the graphs of regression lines at the SCBP can be used to predict accurate values of parameters based on predictor variables. The coefficients of the equations for each parameter are determined, along with the correlation coefficient and minimum root mean square error, which indicate the accuracy and reliability of the regression line equation. A high R^2 and low RMSE are essential for ensuring the accuracy of the predicted values. The R^2 and the regression line equation are shown for each variable graph to examine the accuracy of predictions or used to predict accurate values of parameters based on a set of predictor variables.

Fig.8.17 presents the graphs of regression lines equations at the construction site and the correlation coefficient squared (R^2). The regression line equations for RMC temperature, consistency air content, porosity, density, and compressive strength at the plant and the construction site have been generated in this case. It is essential to ensure that the correlation coefficient is high, which is one at the construction site, and the RMSE is low (0.28641649) to ensure the accuracy and reliability of the regression line equations. Therefore, instead of the RMC temperature, consistency, air content, porosity, and density are used to validate and predict the ready-mix concrete's compressive strength where, in Figure 8.16, it is evident that the RMC temperature is within the acceptable value of R 0.919 at the plant of ANN1and 0.999

at the construction site of ANN7, the consistency validated value of the RMC is within the acceptable value of R of 0.843 at plant of ANN2 and 0.986 at construction site of ANN8.

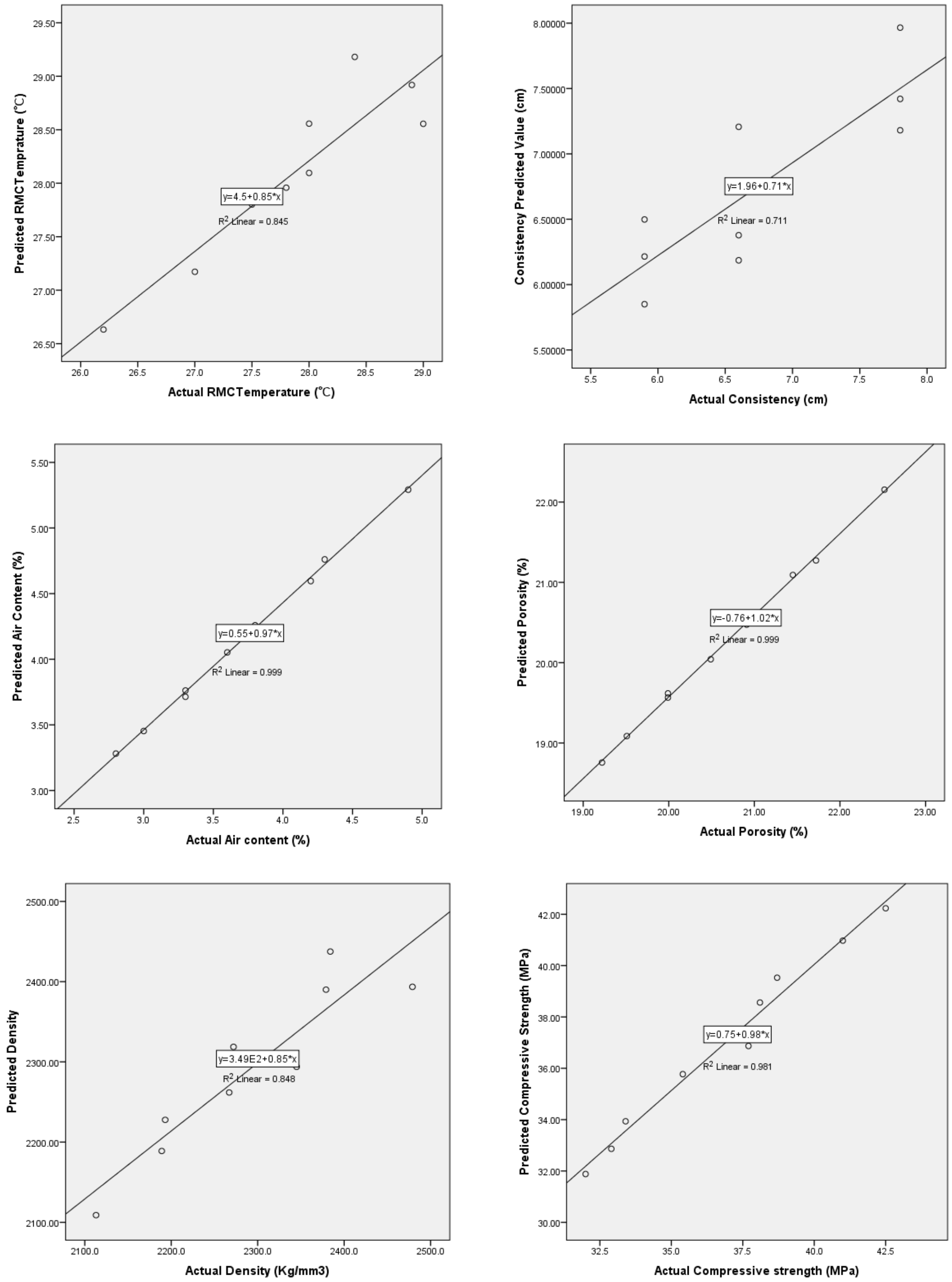


Figure 8.16 RMC properties predicted (a) RMC temperature, (b) consistency, (c) air content, (d) porosity, (e) density, and (f) compressive strength.at the SCBP [Researcher].

Moreover, figures 8.16 and 8.17 the Air content validated value of the RMC is within the acceptable value of R of 0.999 at SCBP of ANN3 and 1.000 at construction site of ANN9, porosity validated value of the RMC is within the acceptable value of R of 1.000 at SCBP of ANN4 and 1.000 at construction site of ANN10, and the density validated value is within the acceptable value of R of 0.921 at plant of ANN5 and 0.999 at construction site of ANN11, respectively.

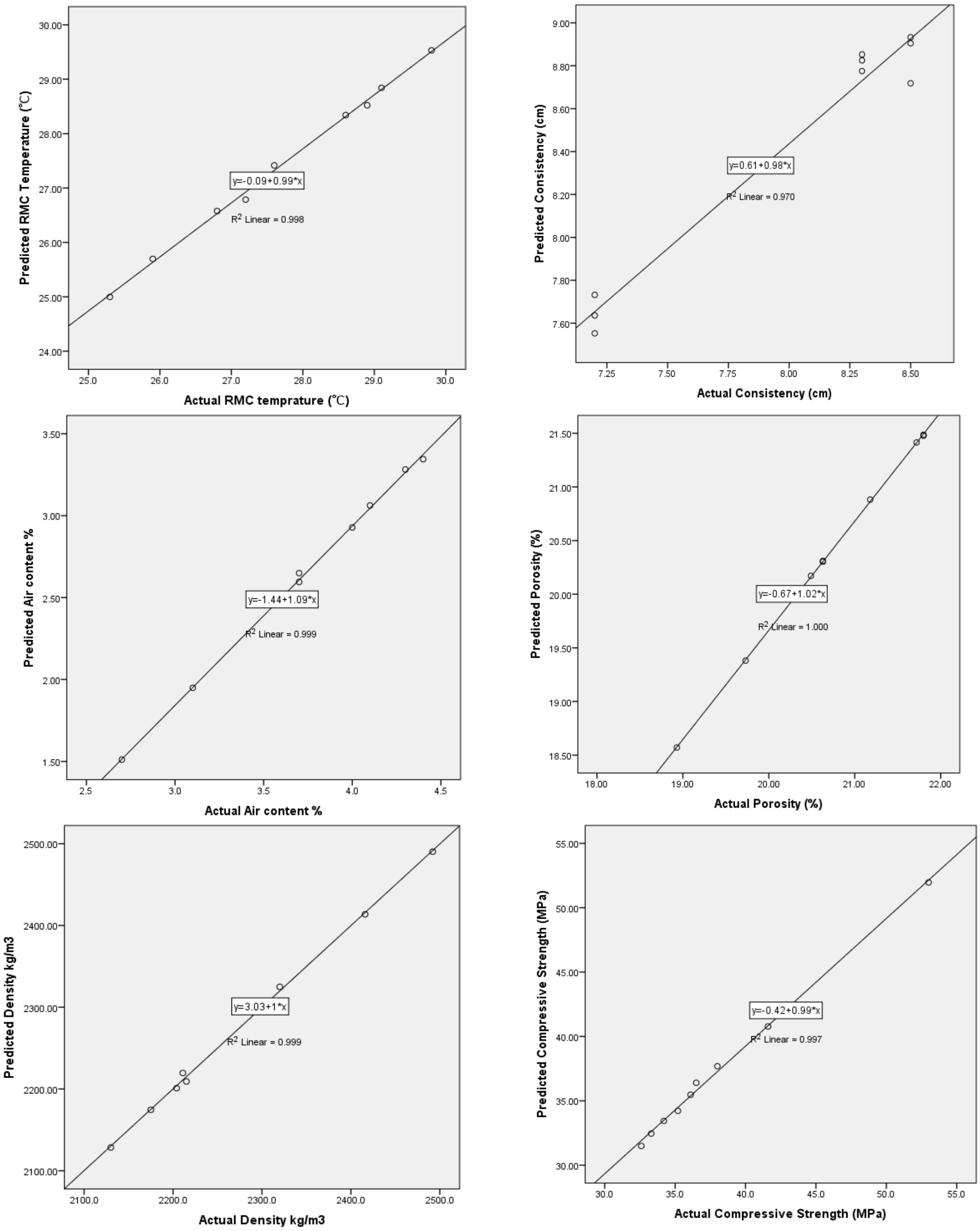


Figure 8.17 RMC properties predicted (a) RMC temperature, (b) consistency, (c) air content, (d) porosity, (e) density, and (f) compressive strength at the construction site [Researcher].

Figure 8.17 presents the precise values of the correlation coefficient, denoted as R^2, alongside the variables of the regression equation applied to the parameters of Ready-Mix Concrete (RMC). The findings therein reveal notably high R^2 values, signifying robust positive linear relationships for each parameter, specifically within the context of the summer season. Consequently, the forecasted variables exhibit a commendable level of accuracy, as follows:

Table 8.24 The RMC predicted values of the variables in the summer season [Researcher].

No	*Weather Temperature (°C)*	*RMC Temperature (°C)*	*Consistency (cm)*	*Air content (%)*	*Porosity (%)*	*Density (Kg/m3)*	*Compressive strength (MPa)*
			Stationary Concrete Batching Plant (SCBP)				
1.	*46.3*	*27.95803*	*6.37776*	*3.45283*	*19.08630*	*2393.55*	*40.97181*
2.	*47.1*	*27.80096*	*6.18562*	*3.28106*	*18.75670*	*2437.50*	*42.23322*
3.	*48.2*	*28.55663*	*7.20688*	*4.25903*	*20.47360*	*2293.86*	*35.77111*
4.	*47.2*	*28.55547*	*6.21489*	*4.05207*	*20.04270*	*2261.86*	*36.86999*
5.	*49.2*	*29.18057*	*6.49801*	*3.71397*	*19.61790*	*2318.68*	*39.52929*
6.	*34*	*27.17217*	*5.84998*	*3.76197*	*19.56550*	*2389.99*	*38.56129*
7.	*47.1*	*28.09606*	*7.42052*	*4.76046*	*21.27300*	*2227.77*	*32.86322*
8.	*49.3*	*28.91885*	*7.18061*	*4.59595*	*21.09260*	*2188.89*	*33.93485*
9.	*38.5*	*26.63196*	*7.96572*	*5.29196*	*22.15470*	*2109.00*	*31.88122*
			Construction site				
10.	*48.9*	*28.33976*	*8.77532*	*1.94890*	*19.38100*	*2413.6984*	*40.78029*
11.	*49.7*	*29.53036*	*8.82512*	*1.51110*	*18.57100*	*2490.3332*	*51.96589*
12.	*50.5*	*27.41580*	*8.85280*	*3.34450*	*21.47750*	*2209.2190*	*31.49260*
13.	*49.8*	*25.69696*	*7.73192*	*2.64900*	*20.31130*	*2200.9861*	*34.21939*
14.	*51.8*	*28.52118*	*7.55286*	*2.48020*	*20.17160*	*2324.9817*	*37.69037*
15.	*37.3*	*28.84140*	*7.63630*	*3.06180*	*21.48690*	*2174.5344*	*33.43880*
16.	*49.7*	*26.78726*	*8.71822*	*2.92800*	*20.88210*	*2219.5935*	*36.40174*
17.	*51.5*	*26.57604*	*8.93248*	*3.28140*	*21.41520*	*2128.4951*	*32.45576*
18.	*40.8*	*24.99696*	*8.90442*	*2.59540*	*20.30300*	*2306.1689*	*35.47379*

Thus, the correlation coefficient R-value of the RMC compressive strength (28 days) is obtained to be 0.991 of ANN6 at the plant and 0.999 of ANN12 at the construction site. All the experimental results are validated using the high R values, resulting in the predicted values of ANN6 at the plant and 0.912 at the construction site of ANN12.

3) Winter season

The data of the variables associated with RMC obtained during the winter season stem from the experimental work conducted in earlier chapters, subject to analysis via SPSS software. The specific details are in Table 8.25, which showcases the experimental values for the RMC parameters. These measurements were obtained at the stationary concrete batching plant and on-site during construction, which was the foundation for creating 12 Artificial Neural Network (ANN) models. In this current study, the feed-forward architecture of the Multilayer Perceptron (MLP) model has been employed to ascertain the compressive strength of RMC through data analysis. To meet the unique requirements of our case study, 12 ANN models were created for the winter season. Each parameter necessitated the development of two models: one for the plant data and another for data collected at the construction site.

Table 8.25 The experimental values of the variables in the winter season [Researcher].

No	*Weather Temperature (°C)*	*RMC Temperature (°C)*	*Consistency (mm)*	*Air content (%)*	*Porosity (%)*	*Density (Kg/m3)*	*Compressive strength (MPa)*
Stationary Concrete Batching Plant (SCBP)							
1.	*16.0*	*21.0*	*6.3*	*3.3*	*19.99*	*2434.0*	*40.0*
2.	*21.0*	*23.4*	*6.3*	*3.3*	*19.99*	*2420.0*	*39.2*
3.	*19.0*	*21.0*	*7.2*	*3.4*	*20.07*	*2435.0*	*39.2*
4.	*19.0*	*21.7*	*7.2*	*3.0*	*19.51*	*2458.0*	*40.4*
5.	*21.0*	*24.3*	*7.2*	*2.8*	*19.22*	*2387.0*	*43.3*
6.	*25.0*	*30.5*	*6.3*	*3.6*	*20.49*	*2374.0*	*38.3*
7.	*27.0*	*30.1*	*7.2*	*3.6*	*20.49*	*2480.0*	*44.9*
8.	*20.0*	*24.0*	*6.3*	*3.0*	*19.51*	*2462.0*	*41.6*
9.	*17.0*	*21.7*	*6.3*	*2.8*	*19.22*	*2387.0*	*43.3*
Construction site							
10.	*19.0*	*23.7*	*6.9*	*3.2*	*19.79*	*2388.0*	*40.2*
11.	*19.0*	*26.6*	*6.9*	*3.6*	*20.49*	*2374.0*	*38.3*
12.	*25.0*	*26.4*	*6.9*	*3.6*	*20.49*	*2480.0*	*44.9*
13.	*19.0*	*23.4*	*7.5*	*3.9*	*20.91*	*2207.0*	*34.5*
14.	*21.0*	*26.4*	*7.5*	*3.6*	*20.49*	*2263.0*	*37.4*
15.	*24.0*	*28.0*	*7.5*	*3.2*	*19.79*	*2381.0*	*38.9*
16.	*27.0*	*28.8*	*6.9*	*3.6*	*20.49*	*2294.0*	*37.5*
17.	*24.0*	*26.4*	*7.5*	*3.2*	*19.79*	*2445.0*	*40.2*
18.	*28.0*	*31.8*	*7.5*	*3.9*	*20.91*	*2361.0*	*37.4*

Furthermore, when constructing a model for predicting a specific parameter's value using an Artificial Neural Network (ANN), it is essential to designate the variable of interest as the dependent variable while the remaining variables serve as predictors (constants). The foundation for the ANN models is derived from the descriptive statistics, encapsulating key summary statistics, as illustrated in the table below. This table presents essential statistical measures, encompassing minimum, maximum, mean, and standard deviation, for each case, observed both at the plant and on-site. The details are outlined in Table 8.26, providing essential descriptive statistics of the data collected at the stationary concrete batching plant (SCBP) and the construction site. These statistics serve as a crucial foundation for the subsequent elaboration of Artificial Neural Network (ANN) models, enabling the prediction of each variable. For clarity, consider the data at the plant, where, for instance, the weather temperature exhibited a minimum value of 16, derived from a set of 9 temperature values. Similarly, the maximum value was 27, the mean temperature was 20.556, and the standard deviation was 3.5395. In the case of RMC temperature (Improved), the minimum value was 21, calculated from 9 data points, with the maximum value at 30.5, a mean of 24.189, and a standard deviation of 3.6771.

Table 8.26 Descriptive statistics for RMC variables at the stationary concrete batching plant and construction site [Researcher].

	N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Stationary Concrete Batching Plant (SCBP)					
Weather Temperature (℃)	*9*	*16.0*	*27.0*	*20.556*	*3.5395*
RMC Temperature (℃)	*9*	*21.0*	*30.5*	*24.189*	*3.6771*
Consistency (mm)	*9*	*6.3*	*7.2*	*6.700*	*.4743*
Air content (%)	*9*	*2.8*	*3.6*	*3.200*	*.3122*
Porosity (%)	*9*	*19.22*	*20.49*	*19.832*	*.49104*
Density (Kg/mm^3)	*9*	*2374.0*	*2480.0*	*2426.3*	*37.3530*
Compressive strength(MPa)	*9*	*38.3*	*44.9*	*41.133*	*2.2672*
Valid N (listwise)	*9*				
Construction Site					
Weather Temperature (℃)	*9*	*19.0*	*28.0*	*22.889*	*3.5158*
RMC Temperature (℃)	*9*	*23.4*	*31.8*	*26.833*	*2.5524*
Consistency (mm)	*9*	*6.9*	*7.5*	*7.233*	*.3162*
Air content (%)	*9*	*3.2*	*3.9*	*3.533*	*.2784*
Porosity (%)	*9*	*19.79*	*20.91*	*20.350*	*.45365*
Density (Kg/mm^3)	*9*	*2207.0*	*2480.0*	*2354.7*	*86.5849*
Compressive strength (MPa)	*9*	*34.5*	*44.9*	*38.811*	*2.8611*
Valid N (listwise)	*9*				

In the dataset, several vital parameters exhibit noteworthy characteristics. For instance, when considering consistency, the minimum value among the nine recorded data points is 6.3, with a corresponding maximum value of 7.2, a mean of 6.7, and a standard deviation of 0.4743. Similarly, the minimum value for air content stands at 2.8, with a maximum of 3.6, a mean of 3.2, and a standard deviation of 0.3122. Regarding porosity, the minimum value is 19.22, with a maximum of 20.49, a mean of 19.832, and a standard deviation of 0.49104. The minimum recorded value for density is 2374, with a maximum of 2480, a mean of 2426.3, and a standard deviation of 37.353. Finally, when examining compressive strength, the dataset reveals a minimum value of 38.3 MPa, a maximum of 44.9 MPa, a mean of 41.133, and a standard deviation of 2.2672. It is important to note that these statistics are consistent at the stationary concrete batching plant and the construction site. The table below presents an overview of the datasets used to construct ANN models.

Table 8.27 Case process summery [Researcher].

		N	*Percent*
Sample	*Training*	*5*	*55.6%*
	Testing	*4*	*44.4%*
Valid		*9*	*100.0%*
Excluded		*0*	
Total		*9*	

Table 8.27 illustrates the process of summarizing the RMC compressive strength. The data has been partitioned into training and testing sets, with 70% allocated for training and 30% for testing. In this specific case study, 55.6% of the data was designated for training, and 44.4% was allocated for testing. The results in 5 samples for training and 4 samples for testing, with 0 samples excluded. Furthermore, detailed network information is presented in the table below. The Artificial Neural Network (ANN) for analyzing the compressive strength of RMC comprises three fundamental components. The first element encompasses input data, consisting of independent variables and one dependent variable. The second element comprises a single hidden layer, while the third is the output layer. In each season, a total of 12 ANN models have been developed. These models pertain to the properties of RMC, including parameters such as RMC Temperature, Consistency, Air content, Porosity, Density, and Compressive strength at the plant during the summer season. Figure 8.19 provides a visual representation of the network architecture, showcasing the number of neuron nodes in the input layer, the configuration of the hidden layer, and the outcomes for each dependent variable. These models were created using SPSS software, and a similar approach was applied to RMC compressive strength as one example among the 12 ANN models.

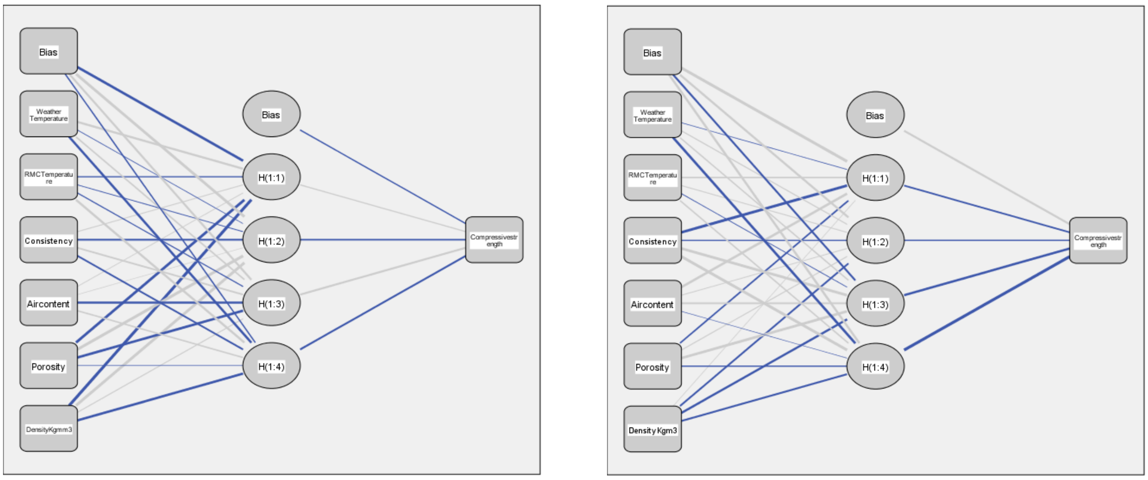


Figure 8.18 Network diagram of compressive strength at the plant and construction site[Researcher].

The network diagrams in Figure 8.18 illustrate the predictive models for ready-mix concrete (RMC) compressive strength. These models utilize a 4-hidden-layer Artificial Neural Network (ANN) structure and have been designed for both the plant and construction site scenarios. The outcomes of these models were generated using SPSS software.

a) Correlation and Regression

The independent variables, which can be characterized as the cause, and the dependent variable, which can be described as the effect, may be used to show a correlation connection between the variables for the data. Changes in the independent variable determine its value. A scatter plot might determine if the variables have a linear connection. The critical prediction for the RMC variables is as follows:

Table 8.28 The RMC predicted values of the variables in the winter season [Researcher].

No	Weather Temperature (°C)	RMC Temperature (°C)	Consistency (cm)	Air content (%)	Porosity (%)	Density (Kg/m3)	Compressive strength (MPa)
Stationary Concrete Batching Plant (SCBP)							
1.	16.0	20.75620	6.13726	3.30810	19.97645	2424.05149	39.94228
2.	21.0	24.98905	6.75416	3.31074	19.97327	2435.32354	39.51863
3.	19.0	20.90358	7.15274	3.38301	20.09518	2456.31717	38.40563
4.	19.0	21.60784	6.74758	3.01244	19.49206	2419.76850	42.85860
5.	21.0	24.33687	6.94151	2.80227	19.21719	2413.46901	43.22319
6.	25.0	29.78044	6.19933	3.59800	20.49326	2385.23167	39.63625
7.	27.0	30.25170	7.17286	3.60227	20.48557	2470.44531	43.31258
8.	20.0	23.28971	6.67689	2.98613	19.53278	2416.13450	41.87691
9.	17.0	21.78459	6.51767	2.79703	19.22424	2416.25880	41.42592
Construction site							
10.	19.0	23.02769	7.89945	3.18188	18.78020	2411.24585	39.51557
11.	19.0	26.45912	7.62095	3.61093	19.43890	2346.66133	39.05339
12.	25.0	26.62465	7.52255	3.59997	19.41310	2484.16201	44.33651
13.	19.0	24.29702	8.04965	3.89681	19.95340	2201.96455	34.79206
14.	21.0	25.72769	7.79005	3.60745	19.49570	2286.24585	36.71557
15.	24.0	27.24277	8.06125	3.19443	18.76630	2397.31240	38.44240
16.	27.0	29.38854	7.80395	3.60722	19.48510	2293.93081	37.99453
17.	24.0	27.82954	7.88355	3.21410	18.70490	2405.44175	41.34203
18.	28.0	30.90298	8.18415	3.88721	19.90680	2366.03545	37.10794

Table 8.28 represents the RMC predicted values of the variables in the summer season for the 12 ANN model, where it is shown that the variables have changed based on the algorithm of each model, but according to the correlation coefficient (R) has been determined in this step, R squared, and Root Mean Square Error (RMSE) that will use in regression after checking the significant of residuals. The degree and direction of a linear connection between the variables may be measured using the correlation coefficient (R) statistic. Correlation coefficients in samples are denoted by R (see equation no. 61). Table 8.29 represents the values of the correlation coefficient (R) and the root mean square error (RMSE) after generating the new prediction values where to examine these predicted values during the summer season, where the maximum correlation coefficient (R) is 0.999 at the plant and construction site, the maximum R square 0.999 and minimum the root mean square error (RMSE) is 0.010027111 at the SCBP.

Table 8.29 The correlation coefficients (R) and Root Mean Square Errors (RMSE) [Researcher].

ANN	*Number of hidden layers*	*R*	*R^2*	*RMSE*
Stationary Concrete Batching Plant (SCBP)				
1	*3*	*0.983*	*0.966*	*0.655396475*
2	*5*	*0.779*	*0.607*	*0.283096234*
3	*3*	*0.999*	*0.999*	*0.010027111*
4	*2*	*0.999*	*0.999*	*0.01531779*
5	*5*	*0.672*	*0.451*	*26.09306441*
6	*4*	*0.802*	*0.604*	*1.534009775*
Construction site				
7	*2*	*0.945*	*0.894*	*0.786196355*
8	*1*	*0.702*	*0.493*	*0.212361963*
9	*4*	*0.999*	*0.998*	*0.020387677*
10	*3*	*0.999*	*0.999*	*0.016564229*
11	*4*	*0.968*	*0.938*	*20.35007707*
12	*4*	*0.971*	*0.943*	*1.094708745*

Subsequently, the next phase involves utilizing the coefficients to determine the predicted y-values for a given x-value to employ the slope (m) and y-intercept (b) to calculate variables, thereby generating fresh values by the regression line equation. These new values predict the parameters of Ready Mix Concrete (RMC), including RMC Temperature, Consistency, Air content, Porosity, Density, and Compressive strength, both at the plant and on-site.

Consequently, 12 regression line equations have been established to forecast RMC parameter values accurately. These equations are founded on the coefficients specific to each variable, alongside the correlation coefficient (R) and the minimum root mean square error (RMSE) that have been ascertained.

As illustrated in Figure 8.19, the graphical representations of regression lines at the SCBP serve as valuable tools for precisely predicting parameter values based on predictor variables. In this context, coefficients for each parameter are meticulously derived, and corresponding correlation coefficients and minimum root mean square errors are computed. These statistical indicators collectively offer insights into the accuracy and reliability of the regression line equations. It is worth noting that a high correlation coefficient and a low RMSE are pivotal factors in guaranteeing the precision of the projected values. Furthermore, the squared correlation coefficient (R^2) is presented within each variable graph alongside the regression line equation. These analytical components serve the dual purpose of assessing the accuracy of predictions and facilitating the prediction of parameter values based on a given set of predictor variables.

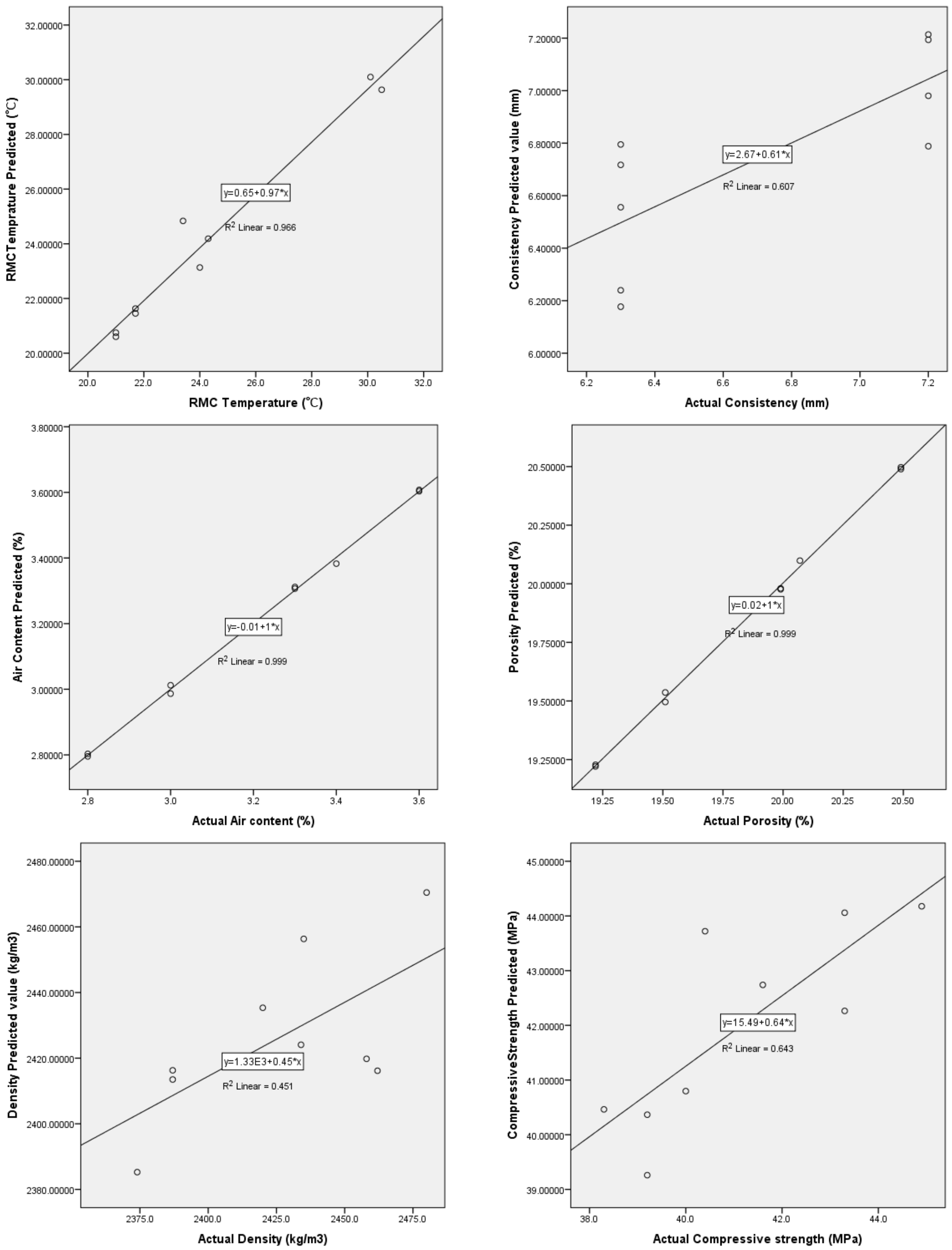


Figure 8.19 RMC properties predicted (a) RMC temperature, (b) Consistency, (c) Air content, (d) Porosity, (e) Density, and (f) Compressive Strength. At plant [Researcher].

Fig.8.19 presents the graphs of regression lines equations at the SCBP and the correlation coefficient squared (R^2). The regression line equations for RMC temperature, consistency air content, porosity, density, and compressive strength at the SCBP site have been generated in this case.

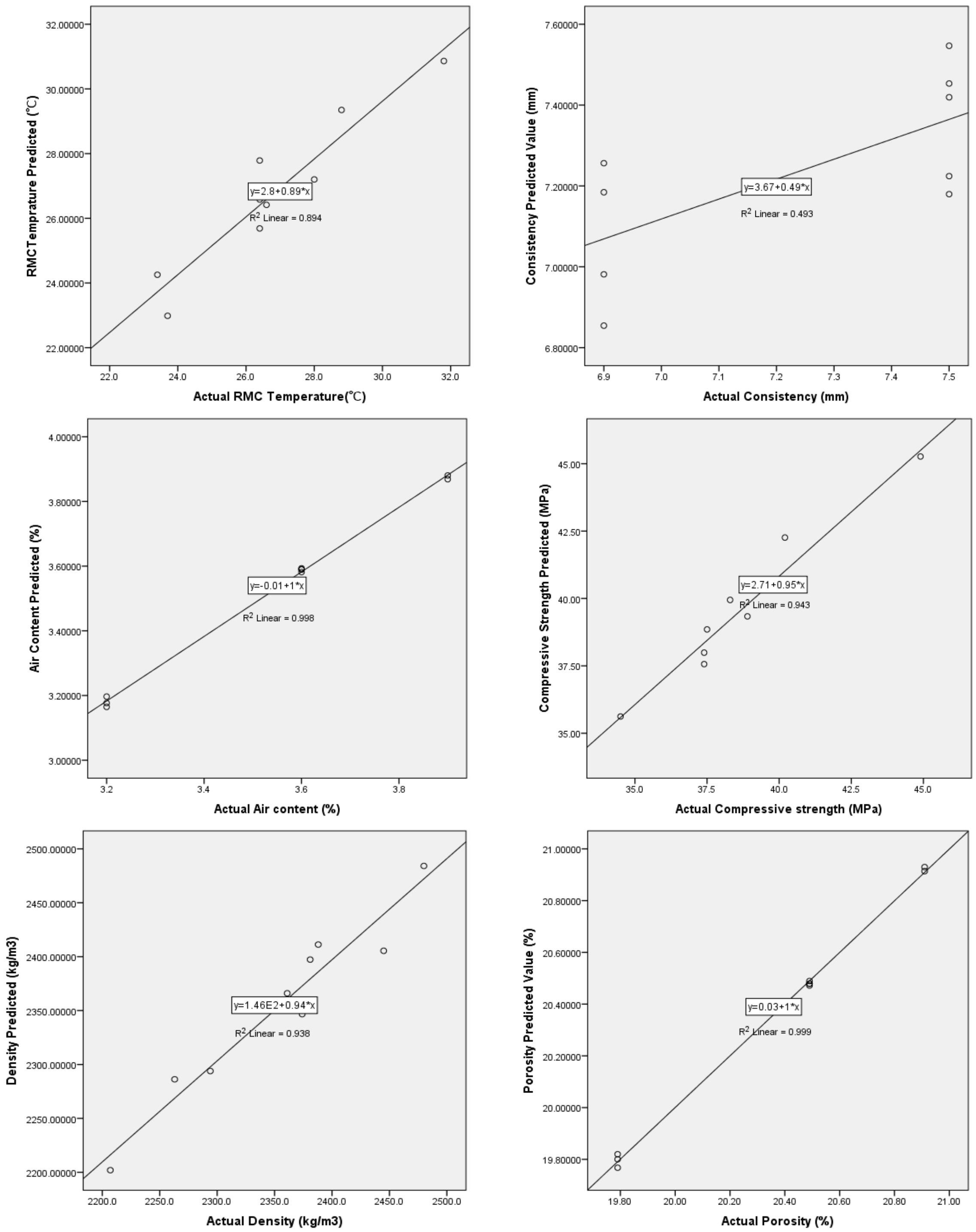


Figure 8.20 RMC properties predicted (a) RMC temperature, (b) Consistency, (c) Air content, (d) Porosity, (e) Density, and (f) Compressive Strength at the construction site [Researcher].

Fig.8.20 illustrates the regression line equations and the squared correlation coefficient (R^2) for the parameters associated with Ready Mix Concrete (RMC), including RMC temperature, consistency, air content, porosity, density, and compressive strength at the construction site. It is crucial to emphasize that a high correlation coefficient is a prerequisite for reliability, and in our case, it approaches unity at the plant. Additionally, a low Root Mean Square Error (RMSE) of 0.0375 indicates the accuracy of the regression line equations. In light of these considerations, we employ parameters such as RMC temperature, consistency, air content, porosity, and density to validate and predict the compressive strength of ready-mix concrete. The figures presented in Figure 8.17 demonstrate the RMC temperature's acceptability with a coefficient (R) of 0.919 at the plant (ANN1) and 0.99 at the construction site (ANN7).

Similarly, the consistency of RMC is within acceptable limits with R values of 0.843 at the plant (ANN2) and 0.708 at the construction site (ANN8). Air content exhibits high validation with R values of 0.999 at the plant (ANN3) and 0.997 at the construction site (ANN9). Porosity validates well with an R-value of one at the plant (ANN4) and 0.996 at the construction site (ANN10). Lastly, the density of RMC falls within acceptable limits with R values of 0.921 at the plant (ANN5) and 0.953 at the construction site (ANN11). As a result, the correlation coefficient R-value for RMC compressive strength (28 days) reaches 0.991 for ANN6 at the plant and 0.942 for ANN12 at the construction site. These experimental results validate the predictions with high R values, leading to predicted values of 0.912 for ANN6 at the plant and 0.912 at the construction site for ANN12, are as follows:

Table 8.30 The RMC predicted values of the variables in the winter season [Researcher].

No	***Weather Temperature (°C)***	***RMC Temperature (°C)***	***Consistency (cm)***	***Air content (%)***	***Porosity (%)***	***Density (Kg/m3)***	***Compressive strength (MPa)***
Stationary Concrete Batching Plant (SCBP)							
1.	*16.0*	*20.60092*	*6.17705*	*3.30671*	*19.98042*	*2424.07683*	*40.79741*
2.	*21.0*	*24.83712*	*6.79505*	*3.31188*	*19.97644*	*2435.34963*	*40.36641*
3.	*19.0*	*20.74986*	*7.19375*	*3.38288*	*20.09869*	*2456.34209*	*39.26003*
4.	*19.0*	*21.45238*	*6.78845*	*3.01221*	*19.49559*	*2419.79417*	*43.72089*
5.	*21.0*	*24.18686*	*6.98040*	*2.80321*	*19.22074*	*2413.49694*	*44.05828*
6.	*25.0*	*29.63362*	*6.23955*	*3.60347*	*20.49713*	*2385.26043*	*40.46321*
7.	*27.0*	*30.09852*	*7.21395*	*3.60763*	*20.48913*	*2470.47643*	*44.17691*
8.	*20.0*	*23.13428*	*6.71735*	*2.98674*	*19.53627*	*2416.16177*	*42.73969*
9.	*17.0*	*21.63256*	*6.55580*	*2.79551*	*19.22794*	*2416.28574*	*42.26358*
Construction site							
10.	*19.0*	*22.98373*	*7.25625*	*3.16477*	*19.81984*	*2411.23970*	*40.41468*
11.	*19.0*	*26.41463*	*6.98140*	*3.59320*	*20.47196*	*2346.65670*	*39.94588*
12.	*25.0*	*26.58183*	*6.85443*	*3.58160*	*20.48903*	*2484.15350*	*45.26748*
13.	*19.0*	*24.25547*	*7.45333*	*3.88046*	*20.91396*	*2201.95980*	*35.62122*
14.	*21.0*	*25.68663*	*7.17978*	*3.59002*	*20.47868*	*2286.24090*	*37.56468*
15.	*24.0*	*27.20093*	*7.41942*	*3.17673*	*19.80025*	*2397.30670*	*39.33548*
16.	*27.0*	*29.34903*	*7.18439*	*3.58968*	*20.47918*	*2293.92430*	*38.85228*
17.	*24.0*	*27.78653*	*7.22433*	*3.19661*	*19.76755*	*2405.43510*	*42.26028*
18.	*28.0*	*30.86227*	*7.54667*	*3.86879*	*20.92956*	*2366.03000*	*37.99002*

Table 8.30 comprises the predicted values of RMC variables for the winter season, following a comprehensive procedure that involved linearity checks, the development of ANN models, and the determination of correlation coefficients (R) and root mean square errors (RMSE).

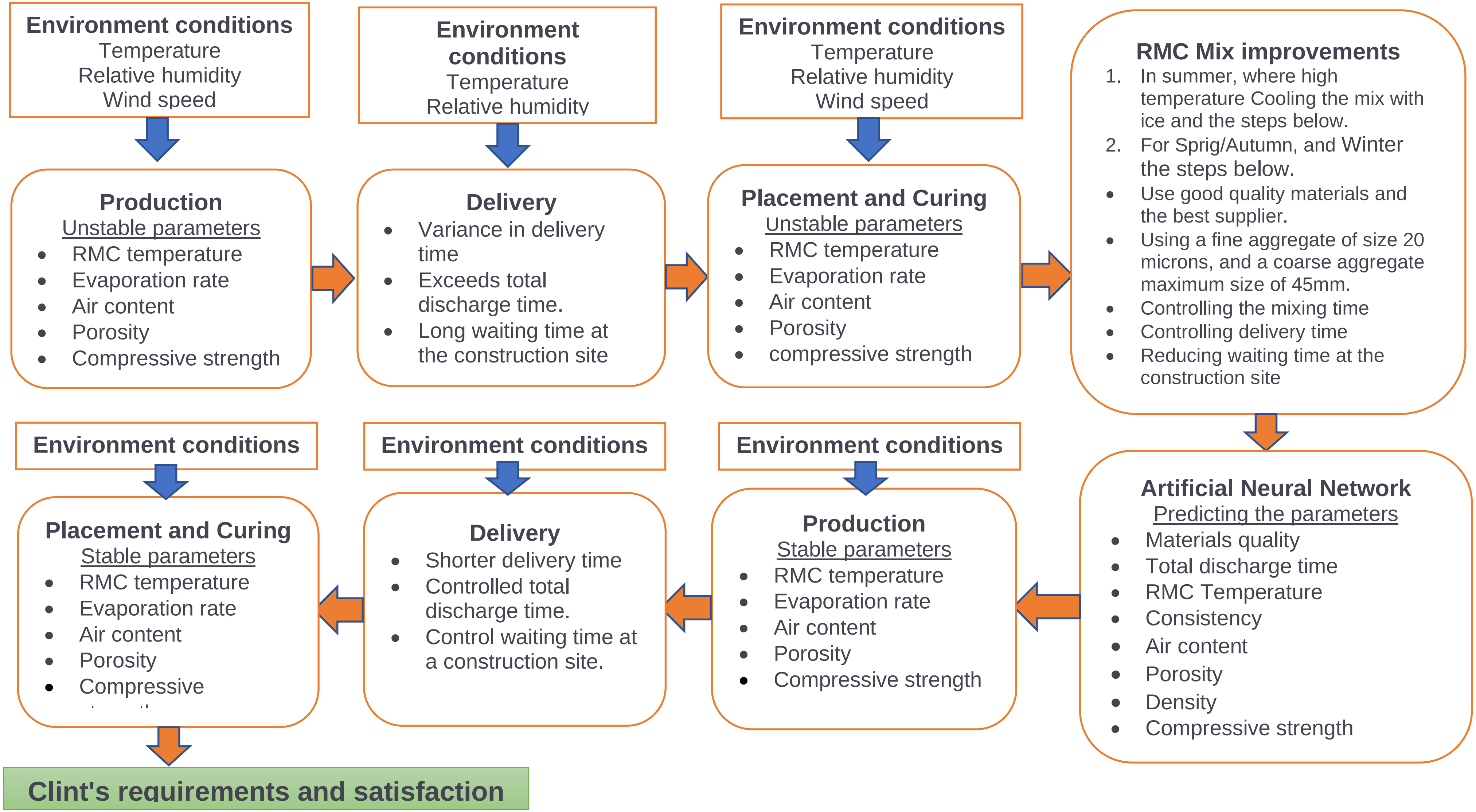


Figure 8.21 The flexible procedure for ready mix concrete production, delivery, and placement for different environmental conditions [Researcher].

Figure 8.21 illustrates a comprehensive and dynamic approach for producing, delivering, and placing ready mix concrete (RMC) in various environmental conditions across different seasons before any improvements are made at the production phase. It portrays a scenario characterized by unstable parameters, including high RMC temperature, a high evaporation rate, elevated air content, increased porosity, and inadequate compressive strength. These challenges are compounded by irregularities in the RMC delivery phase, such as variances in delivery time, exceeding total discharge time, and prolonged waiting times at the construction site. Moreover, the placement phase is also affected by unstable parameters, resulting in high RMC temperature, a significant evaporation rate, elevated air content, and increased porosity, all leading to suboptimal compressive strength. These conditions are influenced by varying environmental factors: temperature, relative humidity, and wind speed, where a series of improvements are introduced for the RMC mix. These improvements encompass measures such as cooling the RMC temperature by adding ice as a percentage of the water-cement (w/c) ratio, employing high-quality materials and selecting the best suppliers, using fine aggregate with a particle size of 20 microns and coarse aggregate with a maximum size of 45mm, controlling mixing and delivery times, and reducing waiting times at the construction site.

Additionally, the figure highlights the importance of limiting volatility by incorporating better raw materials and stable parameters while selecting the most suitable suppliers based on material quality, cost, quantity, and delivery time. This strategic approach aims to stabilize RMC parameters and minimize variations in parameter values between the plant and construction site. The expected outcomes include shorter delivery times, controlled total discharge times, reduced waiting times at construction sites, and alignment of mix/RMC production parameters with the planned targets. Ultimately, this comprehensive strategy strives to ensure that mix/RMC parameters meet client requirements at the construction site, enhancing the competitive position of the SCBP company. Furthermore, it aims to reduce costs associated with quality deficiencies and customer complaints, ultimately meeting clients' requirements.

As a culmination of the steps mentioned above, we have acquired remarkably accurate data regarding RMC mix properties, encompassing practical measurements for various weather conditions during the winter. These findings are significant for potential applications in future projects conducted under similar weather conditions.

CHAPTER 9 KEY FINDINGS AND CONCLUSIONS

9.1 General Conclusion

Through the dissertation work, there are groups of general conclusions that can be summarized by the following:

1) The primary objective has been accomplished by stabilizing and improving RMC parameters at the plant (SCBP) and at the construction site to meet customers' expectations by reducing RMC temperature, decreasing the rate of evaporation, improving workability, decreasing air content, decreasing porosity, increasing density, and increase the compressive strength, (compressive strength has improved by more than 50 %), and predicting these parameters by ANN, by the following achievements:

A. Volatility limitation through better raw materials, stable parameters, choosing the best suppliers based on materials quality, cost, quantity, and delivery time.

B. Reduce quality variation of materials, determine the quantity of ice as apart from W/C ratio for each weather temperature.

C. Mix/RMC production parameters as planned.

D. Mix/RMC parameters responding to client requirements at the construction site.

E. The compressive strength has improved more than 50 %, (maximum $\boldsymbol{fc}$ was 53 MPa).

F. Prediction RMC compressive strength through its parameter's prediction by ANN

G. Better competitive position, reduce the costs of lack of quality and customer complaints.

H. Revealed the significant role of mix cooling on air entrapped, rate of evaporation, forming cracks, and changing properties, where the specific goals as following:

2) Goal no 1. was achieved by combining the PMBOK guide with Quality Management tools in one process which helps to express the level of quality system in SCBP.

3) Goal no.2 was achieved by monitoring, Six Sigma, and Monte Carlo simulation by SPSS and FMEA analysis for materials and suppliers in different conditions.

4) Goal no.3 was achieved by improving RMC mix properties and stabilized parameters, temperature, humidity, delivery time, rate of evaporation, air content, porosity, and compressive strength.

5) Goal no.4 achieved by Artificial Neural Network to predict the quality of the materials, RMC compressive strength, and RMC delivery time.

9.2 Detailed conclusion

The following conclusions can be withdrawn because of the work carried out in this research:

1. The maximum Problem Priority Number by FMEA analysis is Management (Defect in Quality system), which has the most negative influence on the process, then procedure defects and problems due to quality materials and suppliers.
2. The Analytic Hierarchy Process (AHP) results showed that the main effective criteria to improve the process of RMC production is the cost because updating the process for other products will cost additional money.
3. The pairwise comparison matrices generated by Expert Choice software indicate that enhancing Ready Mix Concrete holds greater significance in terms of cost when compared to Precast Members, Concrete Piles, and Pre-Stressed Concrete.
4. The Reverse Osmosis Water is the most essential to the RMC mix from the three types of water used based on a comparison result of the water properties test for the degree of acidity (PH), total dissolved solids (T.D.S), Alkali, and Chloride and the comparison with standard limitations for 18 samples taken at the SCBP.
5. The most efficient for the process of RMC production from a materials quality perspective is Majra Al Khairat company for RMC (Supplier no.2) based on the comparison of the results for 93 tests for cement, Fine, and Coarse aggregate.
6. Combining the real-time monitoring process, the Six Sigma method by DMAIC methodology helps to accurately improve the suppling activity from the materials quality perspective for the best supplier (supplier no.2) to the six-sigma level.
7. Monte Carlo simulations show that the probability of providing the total quantity (419 tons of cement, 580 cubic meters of fine aggregate, and 835 cubic meters of coarse aggregate for SCBP required to produce 1100 cubic meters) for supplier no.2 (Majra Al Khairat company for RMC) is 100% at 21 days, while supplier no.1 probability is more 85% at 37 days duration. Supplier no.3 probability is more than 87% at 27 days; therefore, supplier no.2 is the best process based on suppliers' offers.
8. The comparison between the results of the simulations of Monte Carlo for the companies supply materials to the SCBP shows that the revenues for supplier no. 2 (Majra Al Khairat company) are 61197$ with a probability of 90%, while supplier no.1 is 57812$ with a probability of 83%, and supplier no.3 is 60493$ with a probability of 82%; therefore, supplier no.2 is the most efficient for RMC production.
9. The workability, air content, porosity, and compressive strength test results at the SCBP are higher than their values at the construction site based on test results due to

uncontrol parameters (temperature, humidity, and delivery time), ambit conditions, which reduce the compressive strength at the construction site.

10. The maximum total discharge time of RMC was Monday, 04th October 2021, for truck mixer no.5 (TM5) was (103 Min), which exceeded standard limitations with average weather temperature (32.7℃) and 15 % relative humidity averaged.
11. Maximum journey time to the construction site was 41 minutes on 25th November 2021, with average weather temperature (20.3 ℃) and 41 % relative humidity.
12. The maximum waiting time before unloading at the construction site was 26 min on Mon 20th September 2021, with temperature (36.7 ℃) and 19 % relative humidity.
13. Based on the slump test results, there is a variance between the workability of RMC at the SCBP and the construction site, especially in the summer season in July 2021.
14. The air content percent at the construction site is more than the air content at the SCBP due to the water added to the truck mixer at the construction site, the long distance (11km), alkali percent in water used in RMC mix more than 0.8 mg/l and high temperature which increased rate of evaporation and increased entrapped air.
15. The porosity of RMC at the construction site is more than the porosity percent at the SCBP, where the maximum porosity was 28.15% at the construction site in the summer season on 20 July 2020.
16. The RMC compressive strength test results before improvements at SCBP were higher than results at a construction site where the maximum porosity was 28.15 %, and maximum air content of 8.5%, and minimum compressive strength of 23.8 MPa.
17. After controlling the parameters and cooling the RMC mix with ice, the compressive strength improved by more than 50 %, where the maximum *fc* was 53 MPa at the construction site on 1st July 2021, and the workability, air content percent, porosity, and compressive strength test results at the SCBP and construction site are balanced.
18. RMC temperature reduction helps to keep mix properties and rate of evaporation under control, where in the spring season, the average temperature at SCBP and work site is 37.6℃, (ΔT) 5 ℃ (to be in limitation), water required 152 Liters, so the m_{ice}= 37.59 kg/m^3 which required 1.6 blocks of ice to reduce temperature of one cubic meter of RMC mixture temperature 5℃, and 7.8 kg to reduce mix temperature 1℃.
19. The results of this study predicted the RMC compressive strength by its parameters at the SCBP and construction site for different environmental conditions in different seasons of the year where according to the correlation coefficient (R) and the root

mean square error (RMSE), RMC compressive strength can be well predicted in terms of RMC temperature, consistency, air content, porosity, and density.

20. Among the used approaches and based on the training data set, the twelve models for each season made based on the ANN and linear regression models seem to be the most reliable models to predict the RMC compressive strength with a high value of R^2 and low values of RMSE based on the comparison with experimental data.
21. This numerical and experimental study aims to find an optimal model for the compressive strength of RMC gains the client's requirements and satisfaction. Thus, the results obtained after training of several models showed that the architecture of the optimum with two hidden layers models is with a Pearson's correlation R= 95.9%, 99.9%, and 97.1% for spring, summer, and winter seasons, respectively, at the construction site, and 97.2%, 99.1%, and 80.2% at the SCBP.
22. The coefficient (R^2) of the RMC compressive strength at the construction site were 91.9 %, 99.7%, and 94.3% for spring, summer, and winter seasons, respectively, at the construction site, and 94.5%, 98.1%, and 60.4% at SCBP.
23. Root Means Square Error (RMSE) of the RMC compressive strength at the construction site were 0.8796, 0.7972, and 1.0947 for spring, summer, and winter seasons, respectively, at the construction site, and 0.3662, 0.4831, and 1.534 at SCBP.
24. The coefficient of determination (R^2) of the RMC temperature at the construction site were 98.1%, 99.8%, and 89.4% for spring, summer, and winter seasons, respectively at the construction site, and 58.7%, 84.5%, and 96.6% at the plant.
25. The coefficient of determination (R^2) of the consistency at the construction site was 51.4 %, 97.1%, and 49.3% for spring, summer, and winter seasons, respectively at the construction site, and 51.5%, 71.1%, and 60.7% at SCBP.
26. The coefficient of determination (R^2) of the air content at the construction site were 99.8 %, 99.9%, and 99.8% for spring, summer, and winter seasons, respectively at the construction site, and 99.6%, 99.9%, and 99.9% at SCBP.
27. The coefficient of determination (R^2) of the porosity at the construction site were 99.8 %, 100%, and 99.9% for spring, summer, and winter seasons, respectively at the construction site, and 99.6%, 99.9%, and 99.9% at SCBP.
28. The coefficient of determination (R^2) of the density at the construction site was 83.3 %, 99.9%, and 93.8% for spring, summer, and winter seasons, respectively, at the construction site, and 76%, 84.8%, and 45.1% at SCBP.

9.3 Recommendations

1) Selecting concrete materials and proportions with satisfactory records in hot weather conditions,
2) Best cement type suitable to the ambit conditions, good quality of raw materials through Selecting the best supplier and minizine the variability of parameters,
3) Managing Ready Mix Concrete temperature under control during production, delivery, placement, and curing.
4) Controlling and reducing the temperature of freshly mixed concrete starting temperature of RMC at the stationary concrete batching plant, including cooling.
5) In hot weather conditions in the summer, when the ambient temperature reaches maximum rate can work(pouring concrete) at night or stop working.
6) Using a Ready Mix Concrete consistency that allows fast placement and efficient consolidation.
7) Stable delivery time or Minimizing the time to transport, placement, and consolidate.
8) Scheduling placement operations during good weather conditions throughout the daytime or nighttime are favorable.
9) Preventing concrete from losing moisture during placement and curing phases.
10) Scheduling or making plans for a replacement time to go through the specifics of concrete placing in hot weather.

9.4 Further research

- Robotics in Ready Mix Concrete production.
- Building Information Modeling System (BIM) in the elaborate procedure for ready mix concrete production, delivery, placement, and curing.
- Made in China 2025 for Ready Mix Concrete process of production.

References

[1] Nanda V, “Quality Management System Handbook for Product Development Companies,” CRC Press P 352, 2005.

[2] Joint Technical Committee, Timber Structures, “Australian / New Zealand Standard Timber -Strength- Graded In Strength And Stiffness Evaluation,” Australian / New Zealand, AS/NZS4063,1992, ISBN 0726277509.

[3] F. Rashid and C. A. Taibb, “ Total Quality Management (TQM) Adoption In Bangladesh Ready-Made Garments (Rmg) Industry: A Conceptual Model,” Am. J. Ind. Bus. Manag., vol. 06, no. 11, pp. 1085–1101, 2016, doi: 10.4236/ajibm.2016.611102.

[4] R. Sanchez-Marquez, J. M. Albarracín Guillem, E. Vicens-Salort, and J. Jabaloyes Vivas, “ Diagnosis Of Quality Management Systems Using Data Analytics – A Case Study In The Manufacturing Sector,” Comput. Ind., vol. 115, p. 103183, Feb. 2020, doi: 10.1016/J.COMPIND.2019.103183.

[5] T. T. Yamada, C. F. Poltronieri, L. do N. Gambi, and M. C. Gerolamo, “ Why Does the Implementation of Quality Management Practices Fail? A Qualitative Study of Barriers in Brazilian Companies,” Procedia - Soc. Behav. Sci., vol. 81, pp. 366–370, 2013, doi: 10.1016/j.sbspro.2013.06.444.

[6] J. Abbas, “ Impact Of Total Quality Management On Corporate Sustainability Through The Mediating Effect Of Knowledge Management,” J. Clean. Prod., vol. 244, p. 118806, Jan. 2020, doi: 10.1016/J.JCLEPRO.2019.118806.

[7] A. Goyal, R. Agrawal, and C. R. Saha, “ Quality Management For Sustainable Manufacturing: Moving From Number To Impact Of Defects, ” J. Clean. Prod., vol. 241, p. 118348, Dec. 2019, doi: 10.1016/J.JCLEPRO.2019.118348.

[8] Ahluwalia, R.S., “ TQM Curriculum Needs An Engineering School Survey Report,” Industrial Engineering Department, West Virginia University, Morgantown, July 1990.

[9] P. Cicconi and R. Raffaeli, “An Industry 4.0 Framework for the Quality Inspection in Gearboxes Production,” pp. 97–100, 2019, doi: 10.14733/cadconfp.2019.97-100.

[10] M. S. Reis, “A Systematic Framework for Assessing the Quality of Information in Data-Driven Applications for the Industry 4.0,” IFAC-PapersOnLine, vol. 51, no. 18, pp. 43–48, 2018, doi: 10.1016/j.ifacol.2018.09.244.

[11] A. V. Carvalho, D. V. Enrique, A. Chouchene, and F. Charrua-Santos, “ Quality 4.0: An overview,” Procedia Comput. Sci., vol. 181, no. 2019, pp. 341–346, 2021, doi: 10.1016/j.procs.2021.01.176.

[12] K. Bowers and G. Walter, “ 8 Tips For Success With Safety 4.0 Big Data Tools Zoom In On Unseen Safety Risks,” Prof. Saf., vol. 64, no. 1, pp. 47–49, 2019,

[13] G. Erboz, “ How to Define Industry 4.0: The Main Pillars of Industry 4.0,” Manag. Trends Dev. Enterp. Glob. Era, no. November 2017, pp. 761–767, 2017.

[14] J. L. García-alcaraz, “ Lean Manufacturing in the Developing World Methodology, Case Studies and Trends from Latin America,” Book, Switzerland: Springer Cham Heidelberg New York Dordrecht London, 2014. doi: 10.1007/978-3-319-04951-9.

[15] M. Y. Santos, “A Big Data System Supporting Bosch Braga Industry 4.0 Strategy, ” Int. J. Inf. Manage., vol. 37, no. 6, pp. 750–760, Dec. 2017, doi: 10.1016/J.IJINFOMGT.2017.07.012.

[16] A. Ambroziak and P. Ziolkowski, “ Concrete Compressive Strength Under Changing Environmental Conditions During Placement Processes, ” Materials (Basel)., vol. 13, no. 20, pp. 1–14, 2020, doi: 10.3390/ma13204577.

[17] Adam. M. Neville and J.J. Brooks, “ Concrete Technology” book, Libr. Congr. Cat. Publ. Data, vol. 2nd edition, no. ISBN 978-0-273-73219-8 (pbk.), pp. 90–112, 2011.

[18] R. Sharma, W. Ren, S. McDonald, and Z. Yang, " Micro-Mechanisms Of Concrete Failure Under Cyclic Compression: X-Ray Tomographic In-Situ Observations, " 9th Int. Conf. Fract. Mech. Concr. Concr. Struct. Fram. V. Saouma, J. Bolander E. Landis, no. August, 2016, doi: 10.21012/fc9.205.
[19] "httpswww.worlddata.infoasiairaqclimate.php.pdf."
[20] S. Lagundžija and M. Thiam, " Temperature Reduction During Concrete Hydration In Massive Structures, " Sandra Lagundžija & Marie Thiam, SE-100 44 Stockholm, SWEDEN, pp. 1–118, 2017, ISSN 1103-4297.
[21] F. Furkan, Fehim, " Civil engineering materials," Herit. Sustain. Dev., vol. 3, no. 2, pp. 154–172, 2021, doi: 10.37868/hsd.v3i2.74.
[22] M. Wood, " What is concrete?" London Rev. Books, vol. 37, no. 5, pp. 19–21, 2015.
[23] J. M. Ng, S.T., Wong, Y.M., Wong, " Factors Influencing The Success Of PPP At Feasibility Stage – A Tripartite Comparison Study In Hong Kong." Habitat International, pp. 36 (4), 423–432., 2012. doi: https://doi.org/10.1016/j.habitatint.2012.02.002
[24] M. C. Sario and Y. T. Prasetyo, " Classification Scheme Of Work-Related Accidents In A Ready-Mixed Concrete Company, " 2021 IEEE 8th Int. Conf. Ind. Eng. Appl. ICIEA 2021, no. May, pp. 50–54, 2021, doi: 10.1109/ICIEA52957.2021.9436720.
[25] F. Sanchez, S. Steria, E. Bonjour, J. P. Micaelli, and D. Monticolo, "An Approach Based on Bayesian Network for Improving Project Management Maturity: An Application to Reduce Cost Overrun Risks in Engineering Projects, " Comput. Ind., vol. 119, p. 103227, 2020, doi: 10.1016/j.compind.2020.103227.
[26] X. Wu, W. Zhao, and T. Ma, " Improving the impact of green construction management on the quality of highway engineering projects, " Sustain., vol. 11, no. 7, 2019, doi: 10.3390/su11071895.
[27] M. S. Khattak and U. Mustafa, "Management competencies, complexities and performance in engineering infrastructure projects of Pakistan," Eng. Constr. Archit. Manag., vol. 26, no. 7, pp. 1321–1347, 2019, doi: 10.1108/ECAM-05-2017-0079.
[28] N. Yousefi, " Using a Duration-Based Schedule Performance Index to Monitor the Performance of Projects Including Estimating the Final Cost, " WVU, master of science thesis published, West Virginia University, Morgantown, West Virginia, 2016.
[29] A. M. Alhozaimy and A. I. Al-Negheimish, " Introducing and Managing Quality Scheme for RMC Industry in Saudi Arabia," J. Constr. Eng. Manag., vol. 125, no. 4, pp. 249–255, 1999, doi: 10.1061/(ASCE)0733-9364(1999)125:4(249).
[30] H. P. Naiknavare and S. S. Kulkarni, " Experimental Approach to Study Performance of RMC Plants in Western Maharashtra : Case Study, " Int. J. Sci. Eng. Res., vol. 4, no. 8, pp. 1608–1616, 2013, doi: 10.13140/2.1.2492.2242.
[31] E. Aydemir, G. Yılmaz, and K. O. Oruc, " A grey production planning model on a ready-mixed concrete plant," Eng. Optim., vol. 52, no. 5, pp. 817–831, 2020, doi: 10.1080/0305215X.2019.1698034.
[32] H. P. Naiknavare, S. D. Deshpande, and R. D. Padhye, " Model Chart of Quality Control Process for Ready Mixed Concrete Plants, " Journal of Mechanical and Civil Engineering (IOSR-JMCE), pp. 50–54, 2009, ISSN: 2278-1684, PP: 50-54.
[33] L. V. Kokh, V. S. Prosalova, E. N. Smolyaninova, A. V. Loksha, and A. A. Nikolaeva, " Neural Network Theory Evolution As An Innovative Factor Of Successful And Dynamic Development Of Economic Systems," Espacios, vol. 39, no. 21, 2018, ISSN 0798 1015.
[34] A. Mohammed, S. Rafiq, P. Sihag, R. Kurda, and W. Mahmood, " Soft Computing Techniques: Systematic Multiscale Models To Predict The Compressive Strength Of Hvfa Concrete Based On Mix Proportions And Curing Times, " J. Build. Eng., vol. 33, p.101851, 2021, doi: 10.1016/j.jobe.2020.101851.

[35] A. A. Yousef el Asri, Mouhcine Benaicha, Mounir Zaher, “ Prediction Of The Compressive Strength Of Self-Compacting Concrete Using Artificial Neural Networks Based On Rheological Parameters. ” John Wiley & Sons Ltd, Marseille, France, p. 13, 2022, doi: 10.1002/suco.202100796.
[36] J. Hoła and K. Schabowicz, “ Application Of Artificial Neural Networks To Determine Concrete Compressive Strength Based On Non - Destructive Tests, ” Journal of Civil Engineering and Management, p. 23-32, July 2017, 2005, doi: 10.1080/13923730.2005.9636329.
[37] N. Hong-Guang and W. Ji-zong, “ Prediction of compressive strength of concrete by neural networks,” Elsevier Science Ltd., vol. 30, no. June, pp. 1245–1250, People's Republic of China, 2000.
[38] K. T. Raja, N. Jayanthi, J. L. Tesfaye, N. Nagaprasad, R. Krishnaraj, and V. S. Kaushik, “ Using an Artificial Neural Network to Validate and Predict the Physical Properties of Self-Compacting Concrete,” Hindawi, Advances in Materials Science and Engineering, p. 10, 2022, https://doi.org/10.1155/2022/1206512.
[39] E. B. Ron S. Kenett, “ Process Improvement And CMMI For Systems And Software, book,1st Edition, ” Auerbach Publications, New York, USA, 2010, ISBN 9780367452360.
[40] I. Kulikovskaya and A. Andrienko, “ Pedagogical Education in Russia: Challenges, Prospects, and Quality Assurance, ” CBU Int. Conf. Proc., vol. 3, pp. 335–340, 2015, doi: 10.12955/cbup.v3.621.
[41] J. Sweeney and C. Heaton, “ Interpretations And Variations of ISO 9000 In Acute Health Care,” Int. J. Qual. Heal. Care, vol. 12, no. 3, pp. 203–209, 2000, doi: 10.1093/intqhc/12.3.203.
[42] G. L. D. John E. Bauer and Russell T. Westcott, “ The Quality Improvement Handbook, Second Edition,” Milwaukee, Wisconsin, USA: American Society for Quality, Quality Press, Milwaukee 53203, 2006. doi: 10.4324/9781482238761.
[43] S. Davis and D. L. Goetsch, “ Quality Management for Organizational Excellence Pearson New International Edition : Introduction to Total Quality, ” 2013.
[44] PMI, “A Guide to the Project Management Body of Knowledge,7th edition, ” Project Management Institute, Global Headquarters, 14 Compuse Boulevard, Newtown Square, P 19073, USA, vol. 44, no. 3. 2021. ISBN: 978-1-935589-67-9.
[45] D. G. Daniel and C. L. Lobo, “ User’s guide to ASTM specification C 94 on ready-mixed concrete, Book, ” ASTM Manual Series, West Conshohocken, PA 19428-2959, USA, 2005, ISBN 0-8031-3363-4.
[46] ASTM Standard C94/C94M − 18, “ Standard Specification for Ready-Mixed Concrete1, ” ASTM Int. West Conshohocken, PA 19428-2959, USA, pp. 1–15, 2019.
[47] ASTM Standard C 172 – 08, “ Standard Practice for Sampling Freshly Mixed Concrete, ” ASTM Int. West Conshohocken, PA 19428-2959, vol. 14, pp. 1–3, USA, 2009.
[48] Zongjin Li, “ Advanced Concrete Technology, ” John Wiley & Sons, Inc., Hoboken, New Jersey, USA, vol. 13, no. 1. 2011, ISBN 978-0-470-43743-8.
[49] C. a. Reeves and D. a. Bednar, “ Defining Quality: Alternatives and Implications, ” Acad. Manag. Rev., vol. 19, no. 3, pp. 419–445, 1994, doi: 10.5465/AMR.1994.9412271805.
[50] Abdul Razzak Rumane, “ Quality Management in Construction, Second Edition” Taylor & Francis Group, LLC, p. 6-578, New York, USA,2011, ISBN 9781498781688.
[51] T. Aized, “ Total Quality Management And Six Sigma, ” InTech Janeza Trdine 9, 51000 Rijeka, Croatia, P.69-304, 2012, ISBN 978-953-51-0688-3.
[52] S. B. Vardeman and J. M. Jobe, “ Statistical Methods for Quality Assurance Basics, Measurement, Control, Capability, and Improvement, Second Edition, ” Springer-Verlag, New York, vol. 32, no. 3, p. 12-447, 2016. doi: 10.2307/1269111.

[53] N. Z. S. Iso, "Australian / New Zealand Standard Quality management and quality assurance -Vocabulary," Standards Australia, Homebush NSW 2140 Australia, p. 3-13, 1994. ISBN 0 7262 9214 1.
[54] T. Pyzdek, P. a Keller, and M. Dekker, " Quality Engineering Handbook, Second Edition, " Boca Raton, p. 44-732, 2003. ISBN9780429179822.
[55] J. G. Suarez, " Three Experts on Quality Management: Philip B.Grosby, W.Edwards Deming, Joseph M. Juran, " TQLO No. 92-02, Arlington, p. 41, 1992.
[56] P. Van Ho, " Total Quality Management Approach to the Information Systems Development Process: An Empirical Study," Alexandria, Virginia, pp. 1–287, 2011, doi: 10.1504/IJBIR.2012.046628.
[57] J. M. Juran and A. B. Godfrey, " Juran's Quality Control Handbook, Fifth Edition, " McGraw-Hill Companies, Inc., p.2.1-1699, 1998. ISBN 0-07-034003-X.
[58] Dyadem Engineering Corporation, " Guidelines for Failure Mode and Effects Analysis for Automotive, Aerospace, and General Manufacturing Industries, " Dyadem Press, Richmond Hill, Ontario, Canada. 2003. ISBN 0849319080.
[59] Philip B. Crosby, " Quality Without Tears-The Art of Hassle-free Management-A Plume Book" McGraw Hill, 1995. ISBN 13: 9780070145115.
[60] E. J. Klesta and J. K. Bartz, " Quality assurance and quality control," Methods Soil Part 3 Chem. Methods, February, pp. 19–48, 2018, doi:10.2136/sssabookser5.3.c2.
[61] PMI, " Project Management: Experience and Knowledge Self-Assessment Manual," Project Management Institute, p.3-48, 2000. ISBN: 1880410249.
[62] A. Mitra, " Fundamentals Of Quality Control And Improvement, Book, Fourth Edition, " John Wiley& Sons, Inc, Hoboken, NewJersey USA, and Canada, p.13-819, 2016. doi: 10.1002/9781119692379.
[63] Ben A. Maguad, and Robert M. Krone, " Managing Quality in Higher Education Managing for Quality in Higher Education : A Systems Perspective An Instructional Text for Teaching the Quality," Ventus Publishing Aps, p.40-181, 2012. ISBN 9788740302059.
[64] H. Eriksson, and R. Garvare, " Organisational performance improvement through quality award process participation, " Chalmers Publication Library, International Journal of Quality & Reliability Management, p.3-19, 2006.
[65] A. Anvari and Y. Ismail, " A Study on Total Quality Management and Lean Manufacturing: Through Lean Thinking Approach Personnel Selection View project A method for calculating average run length using Markov chain View project," World Appl. Sci. J., vol. 12, no. 9, pp. 1585–1596, 2011.
[66] A. Anvari, Y. Ismail, S. Mohammad, and H. Hojjati, "A Study on Total Quality Management and Lean Manufacturing: Through Lean Thinking Approach," World Appl. Sci. J., vol. 12, no. 9, pp. 1585–1596, 2011.
[67] Jens J. Dahlgaard, K. Kristensen, and Gopal K. Kanji, "Fundamentals of Total Quality Management, " Taylor & Francis Group, vol. 13, no. 1, London and New York, p.70-357, 2007. ISBN 0748772936.
[68] C.Cartwright, and M.Yinger, " Project Manager Competency Development Framework, " Global Congress, Project Management Institute PMI, Budapest, Hungary, 2007.
[69] T. Hadj-Hamou, " Failure Mode and Effect Analysis at Ely Copper Mine Superfund Site, Book, " SLR Global Environmental Solutions, California, p.19-120, 2016.
[70] R. Ariana, " Failure Modes and Effects Analysis, FMEA Handbook(with Robustness Linkages), " Ford Design Institute, Version 4, p.2-290, 2004.
[71] A. R. Rumane, " Quality Management in Construction Projects Handbook, Second Edition, " CRC Press Taylor & Francis Group, vol. 13, Suite 300 Boca Raton, 2018.
[72] C. M. and R. C. Frank Voehl, H. James Harrington, " The Lean Six Sigma Black Belt

Handbook, Tools and Methods for Process Acceleration, ” CRC Press, Taylor & Francis Group, p.158, 2014.
[73] N. Andler, “ Tools for Project Management, Workshops and Consulting, 3rd Edition, ” Publicis, 2016. ISBN 9783895789182.
[74] B. G. D. Beecroft, “ Cost of Quality, Quality Planning and The Bottom Line, ” Quality, no. 905, pp. 1–6, 2008.
[75] E. Douglas C. Wood, “ Principles of Quality Costs, Financial Measures for Strategic Implementation of Quality Management, Book, Fourth Edition, ” ASQ Quality Press, Milwaukee, Wisconsin, USA, 2013. doi: 10.4135/9781446220382.n7.
[76] L. Holm, “ Cost Accounting and Financial Management for Construction Project Managers, ” Routledge, 711 Third Avenue, New York, 2019. doi: 10.1201/9781315147307.
[77] J. Berk and S. Berk, “ Quality Management for the Technology Sector, ” Elsevier group, Newne, United States of America, 2000.
[78] J. Paslawski, “ Hybrid Flexible Approach For Six Sigma Implementation In Constructional Sme Hybrid Flexible Approach For Six Sigma Implementation,” Journal of Civil Engineering and Management, vol. 3730, August, 2017, doi: 10.3846/13923730.2013.804433.
[79] Jacob D. Rendtorff, M. Bonnafous, “ Stakeholder Theory A Model for Strategic Management, ” Springer Science+Business Media, Cham, 2016. ISBN 978-3-319-44356-0.
[80] Russ J. Martinelli and Dragan Z. Milosevic, “ Project Management Toolbox, tools and techniques for practicing project management, Book, Second Edition, ” John Wiley & Sons, Inc, Hoboken, New Jersey, USA, p.423-480, 2016. ISBN 978-1-118-97321-9
[81] J. Żak, “ The Application of Multiple Criteria Decision Making / Aiding Methodology in the Evaluation and Redesign of Logistics Systems,” vol. 13, no. 1, pp. 53–71, 2019.
[82] P. Tae, W. Lee, and Z. Yang, “ Multi-Criteria Decision Making in Maritime Studies and Logistics, ” Springer International Publishing AG, vol. 260. p.31, 2018. ISBN 978-3-319-62338-2
[83] ACI 305R, “ Guide to Hot Weather Concreting,” American Concrete Institute, ACI Committee 305, p.23, 2010. ISBN 978-0-87031-396-7.
[84] B. S. C. John Newman, “ Advanced Concrete Technology Testing and Quality, book,” Butterworth-Heinemann An Impr. Elsevier Linacre House, Jordan Hill, Oxford OX2 8DP 200 Wheel. Road, Burlington. MA 01803, vol. 4 edition, pp. 106–313, 2016.
[85] W. Kurdowski, “ Cement and Concrete Chemistry, book,” Springer Science and Business Media B.V, Kraków, Poland, pp. 106–313, 2016. ISBN 978-94-007-7945-7.
[86] K. W. Day, J. Aldred, and B. Hudson, “ Concrete mix design, quality control, and specification, fourth edition, ” CRC Press, Taylor & Francis Group, Boca Raton, p.92-340, 2013. doi: 10.1201/b15624.
[87] A. M. Neville, “ Properties of concrete, Fifth Edition, ” Pearson Education Limited, Edinburgh Gate, Harlow, England, 2012. doi: 10.1093/nq/199.mar.131-c.
[88] ASTM C109/C109M, “ Standard Test Method for Compressive Strength of Hydraulic Cement Mortars, in: Annual Book of ASTM Standards,” ASTM Int. West Conshohocken, vol. i, p. 109, 2019, doi: 10.1520/C0109.
[89] BS EN 12390-3:2019, “ Testing hardened concrete - Part 3: Compressive strength of test specimens,” BSI Stand. Publ., vol. 38, no. 10, p. 18, 2019.
[90] H. Hardjasaputra, J. Tirtawijaya, G. P. Ng, and S. Ayuningtias, “ Ultimate Compressive Strength and Its Deformation of Normal and High Strength Concrete Cylinder Confined with External Lateral Pre-Stressing,” MATEC Web Conf., vol. 138, 2017, doi: 10.1051/matec conf/201713803003.

[91] David A.Fanella, “ Reinforced Concrete Structures Analysis And Design, ” The McGraw-Hill Companies, Inc. vol. 13, no. 1. 2011.
[92] M. Kumar, R. Vaishya, and Parag, “ Real-Time Monitoring System to Lean Manufacturing,” Procedia Manuf., vol. 20, pp. 135–140, 2018, doi: 10.1016/j.promfg.2018.02.019.
[93] Irving Kett, “ Engineered Concrete Mix Design and Test Methods,” Cataloging-in-Publication Data, Boca Raton, Washington D.C, Library of Congress, 2016.
[94] S. M. Pham, L.T. and Cramer, “ Comparison of Fresh Concrete Air Content Test Methods & Analysis of Hardened Air Content in Wisconsin Pavements,” Wisconsin. Dept. Transp., no. 0092, p. 5-14., 2019.
[95] ASTM Standard C 172, “ Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method,'” ASTM Int. West Conshohocken, PA 19428-2959. United States, www.astm.org, pp. 545-545–3, 2009, doi: 10.1520/mnl10913m.
[96] J. F. Lamond and J. H. Pielert, “ Significance of Tests and Properties of Concrete and Concrete-Making Materials,” ASTM Spec. Tech. Publ., vol. STP 169D, 2006, doi: 10.1520/stp169d-eb.
[97] A.K. Lahtoi, S.K. Jha, and Parmod Sharma, “ Handbook On Railways Construction, Northern Railways, Second Edition, ” office of CAO/C, Northern Railways Construction Organization, India, pp. 666–756, 2020.
[98] M. Kewalramani and A. Khartabil, “ Porosity evaluation of concrete containing supplementary cementitious materials for durability assessment through the volume of permeable voids and water immersion conditions,” Buildings, vol. 11, no. 9, 2021, doi: 10.3390/buildings11090378.
[99] Council Six Sigma, “ Six Sigma A Complete Step-by-Step Guide,” Council of Six Sigma Certification, pp. 8, 2018.
[100] D. P. Kroese, T. Taimre, and Z.I. Botev, “ Handbook of Monte Carlo Methods. Wiley Series in Probability and Statistics, ” John Wiley & Sons, New York, 2011.
[101] P. G. Asteris, and Vaseilios G. Mokos “ Concrete Compressive Strength Using Artificial Neural Networks,” Neural Computing and Applications, vol. 32, pp. 11807–11826, 2019.
[102] L. Vanneschi and M. Castelli, “ Multilayer perceptrons, ” Elsevier, vol. 612-620, pp. 1–3. 2019. doi: 10.1016/B978-0-12-809633-8.20339-7.
[103] Q. Han, C. Gui, J. Xu, and G. Lacidogna, “ Special Issue Inspection Techniques for Damage Detection in Civil Engineering Structures A generalized method to predict the compressive strength of high-performance concrete by improved random forest algorithm,” Constr. Build. Mater., vol. 226, pp. 734–742, 2019, doi: 10.1016/j.conbuildmat.2019.07.315.
[104] J. Nievergelt, “ R69-13 Perceptrons: An Introduction to Computational Geometry,” IEEE Transactions on Computers, vol. C–18, no. 6, p. 572, 1969, doi: 10.1109/T-C.1969.222718.
[105] H. Cartwright, “ Artificial Neural Networks,”vol. 1260. 2015. doi: 10.1007/978-1-4939-2239_0.
[106] R. M. Hristev, “ The ANN book, ” GNU Public Licence, p. 392, 1998.
[107] S. Australia, “Australian / New Zealand Standard Quality management systems Guidelines for quality plans,” 2006.
[108] P. Nowotarski and J. Paslawski, “ Barriers in running construction SME – a case study on introduction of agile methodology to electrical subcontractor,” Procedia Eng., vol. 122, no. Orsdce, pp. 47–56, 2015, doi: 10.1016/j.proeng.2015.10.006.
[109] A. Askar and H. Treptow, “ Quality assurance in tropical fruit processing, ” Springer-Verlag, Berlin, 1993. doi: 10.1007/978-3-642-77687-8.

[110] B. Ahmadi and W. Al-Khaja, “ Utilization of paper waste sludge in the building construction industry,” Resour. Conserv. Recycl., vol. 32, no. 2, pp. 105–113, Jun. 2001, doi: 10.1016/S0921-3449(01)00051-9.
[111] B. Sawicki, E. Brühwiler, and E. Denarié, “ Inverse Analysis of R-UHPFRC Beams to Determine the Flexural Response under Service Loading and at Ultimate Resistance,” ASCE J. Struct. Eng., vol. 148, no. 2, 2022, doi: 10.1061/(asce)st.1943-541x.0003239.
[112] R. W. Saaty, “ The analytic hierarchy process-what it is and how it is used,” Math. Model., vol. 9, no. 3–5, pp. 161–176, 1987, doi: 10.1016/0270-0255(87)90473-8.
[113] J. Øvretveit and N. Klazinga, “ Learning from large-scale quality improvement through comparisons,” Int. J. Qual. Heal. Care, vol. 24, no. 5, pp. 463–469, 2012, doi: 10.1093/intqhc/mzs046.
[114] J. M. Cramm and A. P. Nieboer, “ High-quality chronic care delivery improves experiences of chronically ill patients receiving care,” Int. J. Qual. Heal. Care, vol. 25, no. 6, pp. 689–695, 2013, doi: 10.1093/intqhc/mzt065.
[115] M. V. Alava, S. P. D. Figueroa, H. M. B. Alcivar, and M. L. Vázquez, “ Single Valued Neutrosophic Numbers and Analytic Hierarchy Process for Project Selection,” Neutrosophic Sets Syst., vol. 21, pp. 122–130, 2018, doi: 10.5281/zenodo.1408760.
[116] H. Bao, F. Yang, X. Wang, S. Su, D. Liu, R. Fu, H. Zhang, and M. Liu. “ Developing a set of quality indicators for breast cancer care in China” International Journal for Quality in Health Care, Baojian Road, Harbin City, PR China, 2015, doi: 10.1093/intact/mzv042
[117] D. Botje, Niek S Klazinga, Rosa Sunol, and Oliver Groene “ Is having quality as an item on the executive board agenda associated with implementing quality management systems in European hospitals: A quantitative analysis,” Int. J. Qual. Heal. Care, vol. 26, no. February, pp. 92–99, 2014, doi: 10.1093/intqhc/mzu017.
[118] C. Wagner, O. Groene, Caroline A Thompson, and M. Dersarkissian“ DUQuE quality management measures : associations between quality management at hospital and pathway levels,” vol. 26, no. March 2014, pp. 66–73, 2018.
[119] S. Kristensen, A. Hammer, P. Bartels, and R. Sunol, “ Quality management and perceptions of teamwork and safety climate in European hospitals,” Int. J. Qual. Heal. Care, vol. 27, no. 6, pp. 499–506, 2015, doi: 10.1093/intqhc/mzv079.
[120] F. H. Mohammad Khasasi, A. M. Abdul, and Z. Mohd Yusof, “ Development of an Automated Storage and Retrieval System in a dynamic industrial environment,” Int. Conf. BioSignal Anal. Process. Syst. (ICBAPS), pp. 57–60, 2015, doi: 10.1109/ICBAPS.2015.7292218.
[121] R. Alexander and M. S. Dobson, “ Real-World Time Management: Second Edition, ” American Management Association, 1601 Broadway, New York, United States of America, 2009.
[122] Z. Zhao, L. Shen, C. Yang, W. Wu, M. Zhang, and G. Q. Huang, “ IoT and digital twin enabled smart tracking for safety management,” Elsevier, Comput. Oper. Res., vol. 128, p. 105183, 2021, doi: 10.1016/j.cor.2020.105183.
[123] F. Sartipi, “ Influence of 5G and IoT in construction and demolition waste recycling – conceptual smart city design,” Journal of Construction Materials, Australia, vol. 1, no. 4, pp. 1–9, 2020. ISSN 2652 3752.
[124] T. Stanivuk, T. Gvozdenović, J. Ž. Mikuličić, and V. Lukovac, “Application of Six Sigma model on efficient use of vehicle fleet,” Symmetry (Basel)., vol. 12, no. 5, 2020, doi: 10.3390/SYM12050857.
[125] Shyam Bhandari, Vince Showers, “ Six Sigma (6σ) in Process Control versus Sigma (σ) in Financial Decisions Conflicting Semantics, ” Proceedings of the Academy of Finance, 2019.
[126] ASTM Standard C 1602/C1602M-18, “ Standard Test Method for Air Content of Freshly

Mixed Concrete by the Pressure Method,'" ASTM Int. West Conshohocken, United States, www.astm.org, pp. 545-545–3, 2004, doi: 10.1520/C1602-C1602M-18.
[127] John Newman, and B. S. Choo "Advanced Concrete Technology Constituent Materials, book, " Elsevier Linacre House, Jordan Hill, Oxford OX2 8DP 200 Wheel. Road, Burlington. MA 01803, vol. 13, no. 1, pp. 107–281, 2003. ISBN 0 7506 5103 2.
[128] BS: EN:1008:2002, " Mixing water for concrete. Specification for sampling, testing, and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete," BSI Stand. Publ., vol. 3, no. December, p. 22, 2002.
[129] ASTM Standard C150/C150M − 16, "Standard Specification for Ferromolybdenum," ASTM Int. West Conshohocken, PA 19428-2959. United States, www.astm.org, pp. 6–7, 2016, doi: 10.1520/C0150.
[130] ASTM Standard C 115 – 96a, "' Standard Test Method for Fineness of Portland Cement by the Turbidimeter1,'" ASTM Int. West Conshohocken, PA 19428-2959. United States, www.astm.org, vol. 5, no. 061, pp. 15–32, 2009, doi: 10.3989/mc.1955.v05.i061.2479.
[131] ACI Education Bulletin E1-99, " Aggregates For Concrete, " Prep. Under Dir. Superb. ACI Comm. E-701, Materials for Concrete Construction, 2016.
[132] ASTM Standard C 33 – 03, " Standard Specification for Concrete Aggregates, " ASTM Int. West Conshohocken, PA 19428-2959. United States, vol. 04, pp. 1–11, 2001.
[133] Peter W. Glynn, " Monte Carlo simulation of diffusions, " In S. J. Mason, R. R. Hill, L. M¨onch, O. Rose, T. Jefferson, and J. W. Fowler, editors, Proceedings of the 2008 Winter Simulation Conference, pages 556–559, Piscataway, N. J., 2008. IEEE Press.
[134] Thomas F. Coleman, Yuying Li, and Maria-Cristina Patron, " Total risk minimization using Monte Carlo simulations, " In J. R. Birge and V. Linetsky, editors, Financial Engineering, Handbooks in Operations Research and Management Science, pages 593–635. Elsevier, Amsterdam, 2008.
[135] P. Brandimarte, " Handbook in Monte Carlo Simulation Applications in Financial Engineering, Risk Management, and Economics, " John Wiley & Sons, Inc., vol. 21, no. 1. Torino, Italy, 2014.
[136] Chrysler LLC, Ford Motor Company, and General Motor Corporation, "Potential Failure Mode And Effect Analysis (FMEA), Fourth Edition, " Reference Manual, 2008.
[137] V. Anes, T. Morgado, A. Abreu, J. Calado, and L. Reis, " Updating the FMEA Approach with Mitigation Assessment Capabilities—A Case Study of Aircraft Maintenance Repairs," Appl. Sci., vol. 12, no. 22, p. 11407, 2022, doi 10.3390/app122211407.
[138] ASTM C143/C143M, " Standard Test Method for Slump of Hydraulic-Cement Concrete," Astm C143, no. 1, pp. 1–4, 2015, doi: 10.1520/C0143.
[139] Bimrew Sendekie Belay, " Behaviour of concrete when coarse aggregate is partially Replaced with aluminum caps and fine aggregate with quarry dust," Juni Khyat (UGC Care Gr. I List. Journal), no. 8.5.2017, pp. 2003–2005, 2022.
[140] ASTM C231-09a, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method," ASTM Int., vol. i, pp. 1–10, 2010.
[141] Adam. M. Neville, " Properties of concrete." Longman Scientific &Techenical Longman Group UK Limited, Third Edition, p.96, 1981
[142] ASTM C 94/C 94M – 04, " Standard Specification for Ready-Mixed Concrete1," vol. i, 2015, doi: 10.1520/C0094.
[143] ACI Committee E-701, "ACI Education Bulletin E3-01 'CEMENTITIOUS MATERIALS FOR CONCRETE,'" Am. Concr. Inst., pp. 1–25, 2001.
[144] ACI 305, "ACI 305R-99 Hot Weather Concreting Reported by ACI Committee 305," J. Am. Concr. Inst., pp. 1–20, 2000.
[145] N. Aniskin, T. Chuc Nguyen, and A. Kiet Bui, " The use of ice to cool the concrete mix

in the construction of massive structures," E3S Web Conf., vol. 264, no. June, 2021, doi: 10.1051/e3sconf/202126402047.
[146] N. Z. Zacharis, " Predicting Student Academic Performance in Blended Learning Using Artificial Neural Networks," Int. J. Artif. Intell. Appl., vol. 7, no. 5, pp. 17–29, Sep. 2016, doi: 10.5121/ijaia.2016.7502.
[147] N. Z. Zacharis, " A multivariate approach to predicting student outcomes in web-enabled blended learning courses," Internet High. Educ., vol. 27, pp. 44–53, 2015, doi: 10.1016/j.iheduc.2015.05.002.
[148] J. P. Rowe, S. W. McQuiggan, J. L. Robison, and J. C. Lester, " Off-task behavior in narrative-centered learning environments," Front. Artif. Intell. Appl., vol. 200, no. 1, pp. 99–106, 2009, doi: 10.3233/978-1-60750-028-5-99.
[149] Timothy T. Rogers, a James L. McClelland, " Parallel Distributed Processing at 25: Further Explorations in the Microstructure of Cognition," Cognitive Science Society, Inc., pp. 52–72, 2014, doi: 10.1016/B978-1-4832-1446-7.50010-8.
[150] G. E. Zuriff, "7. The Organization of Behavior," *Behav. a Concept. Reconstr.*, pp. 119–149, 2019, doi: 10.7312/zuri90466-007.
[151] I. Lykourentzou, I. Giannoukos, G. Mpardis, V. Nikolopoulos, and V. Loumos, " Early and dynamic student achievement prediction in E-learning courses using neural networks," J. Am. Soc. Inf. Sci. Technol., vol. 60, no. 2, pp. 372–380, 2009, doi: 10.1002/asi.20970.
[152] J. D. Joann, R. R. Kouser, and K. Suganya, " Forecasting Student Academic Performance by Decision Tree Learning Using Artificial Neural Networks," Int. Res. J. Eng. Technol., vol. 3, no. 12, pp. 955–961, 2016.
[153] V. M. Bradley, "Learning Management System (LMS) Use with Online Instruction," Int. J. Technol. Educ., vol. 4, no. 1, p. 68, 2020, doi: 10.46328/ijte.36.
[154] S. Walczak and T. Sincich, "Comparative analysis of regression and neural networks for university admissions," Inf. Sci. (Ny)., vol. 119, no. 1–2, pp. 1–20, 1999, doi 10.1016/S0020-0255(99)00057-2.
[155] O. Kwon, H. H. Xia, S. Zhang, and K.-H. Xia-Zhang, "A comparison of artificial neural networks and the statistical methods in predicting MBA student's academic performance," J. Int. Technol. Inf. Manag., vol. 30, no. 2, p. 2021, 2021.
[156] M. Paliwal and U. A. Kumar, "A study of academic performance of business school graduates using neural network and statistical techniques," Expert Syst. Appl., vol. 36, no. 4, pp. 7865–7872, 2009, doi: 10.1016/j.eswa.2008.11.003.
[157] O. C. Asogwa and A. V. Oladugba, " Of Students Academic Performance Rates Using Artificial Neural Networks (ANNs)," Am. J. Appl. Math. Stat., vol. 3, no. 4, pp. 151–155, 2015, doi: 10.12691/ajams-3-4-3.
[158] S. S. A.-N. Mohsen Afana, Jomana Ahmed, Bayan Harb, Bassem S. Abu-Nasser, "Artificial Neural Network for Forecasting Car Mileage per Gallon in the City," Int. J. Adv. Sci. Technol., vol. 124, pp. 51–59, 2018.
[159] P. N. Subbanarasimha, B. Arinze, and M. Anandarajan, " Predictive accuracy of artificial neural networks and multiple regression in the case of skewed data: Exploration of some issues," Expert Syst. Appl., vol. 19, no. 2, pp. 117–123, 2000, doi: 10.1016/S0957-4174(00)00026-9.
[160] T. Nm, " Finite-element-model Updating Using Nelder – Mead Simplex and BFGS Methods," Springer, 2017.
[161] P. Kordík, J. Koutník, J. Drchal, O. Kovářík, M. Čepek, and M. Šnorek, " Meta-learning approach to neural network optimization," Neural Networks, vol. 23, no. 4, pp. 568–582, 2010, doi: 10.1016/j.neunet.2010.02.003.

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