



# **ADDIS COLLEGE**

**School of Post Graduate Study**

**Department of Construction Technology and  
Management**

**M.sc Thesis on:**

**Investigation on Ready-mixed Concrete Quality Control Practice In  
The Case of Gentium Concrete Industries.**

**BY**

**Demoze Zerihun Mezigebu**

**Advisor: Dr. Belachew Asteray**

**A Thesis Submitted to the School of Graduate Studies in Partial  
Fulfillment of the Requirements for the Degree of Master of Science in  
Construction Technology and Managemet**

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**Addis Ababa, Ethiopia**



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**School of Post Graduate Study Department of  
Construction Technology and Management  
THESIS APPROVAL SHEET**

**M.sc Thesis on:**

**Investigation on Ready-mixed Concrete Quality Control  
Practice In The Case of Gentium Concrete Industries.**

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## DECLARATION

I confirm that this research paper entitled “*Investigation on Ready-mixed Concrete Quality Control Practice in the case of Gentium Concrete Industries*” is submitted to the Partial Fulfillment of the Requirements for the Degree of Master of Science in Construction Technology and Management. It is my original work, and this work has not been previously formed as the basis for the award of any academic Degree or Diploma Program in this or any other institution. Any materials borrowed from other sources, whether published or unpublished have been properly cited and acknowledged by appropriate academic conventions.

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This is to certify that this research work on the topic entitled “*Investigation on Ready-mixed Concrete Quality Control Practice in the case of Gentium Concrete Industries*” has been carried out by **Demoze Zerihun** for the Partial Fulfillment of the Requirements for the Degree of Master of Science in Construction Technology and Management at the Addis Collage School of Graduate, is an ordinal work and not submitted earlier for any degree either at this college or any other university.

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## **ABSTRACT**

*Ready-Mixed Concrete (RMC) consists of concrete that is prepared by weighing and batching the components at a plant before it is transported to the construction site consequently, the quality of concrete is crucial for the integrity of structures, as it directly impacts their strength and durability. Currently, over half of the concrete produced in Addis Ababa does not meet Ethiopian and ACI Standards. As a result, Gentium Concrete Industry stands out as one of the largest commercial suppliers of RMC in the area. This research focused on assessing the quality control practices in the Gentium concrete industry. These research used descriptive survey research design and applied both quantitative and qualitative research approach. The data collection methodology included a thorough review of existing studies, a desk analysis of three projects, and the collection of concrete test data from laboratories. It also featured group interviews with experts and staff from a ready-mixed concrete producer, along with detailed observations at batching plants and concrete casting sites. The findings revealed that raw material handling, periodic calibration of equipment, road traffic conditions to the casting site, crew experience, and curing temperature were significant factors affecting quality control in ready-mixed concrete. Statistical analysis showed that, according to Ethiopian standards, 24% of the tested lots were defective, while 76% were non-defective based on the calculated standard deviation. When evaluated using ACI 318, the percentage of defective lots rose to 32%, with non-defective lots decreasing to 68%. Shewhart charts demonstrated that the concrete production process requires better control, indicating inconsistencies and susceptibility to variability. Therefore, regarding with previous research, there are some good changes in the results. The research concluded that the quality control practices for RMC at Gentium are inadequately managed, resulting in a failure to achieve the required concrete strength.*

**Keywords: Concrete, Ready-Mix Concrete, Quality, ACI, Ethiopian standard**

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## **Abbreviations and Symbols**

$\mu$	Population mean
$\sigma$	Population standard deviation
$\sigma_1$	Population within-batch standard deviation
$\sigma_2$	Population batch-to-batch standard deviation
$f_{cr}'$	Required average compressive strength of concrete
<b>ACI</b>	American Concrete Institute
<b>ASTM</b>	American Standard of Testing Materials
<b>EBCS</b>	Ethiopian Building Code of Standards
<b>ES</b>	Ethiopian Standards
<b>ESA</b>	Ethiopian Standards Agency
$F_{cr}'$	Required average compressive strength of concrete
<b>ISO</b>	International Standardization Organization
<b>OPC</b>	Ordinary Portland Cement
<b>OPC</b>	Portland Pozzolana Cement
<b>RMC</b>	Ready-mixed Concrete
<b>SD</b>	Standard Deviation
<b>SQC</b>	Statistical Quality Control
<b>SPSS</b>	Statistical Package for the Social Sciences
<b>TQM</b>	Total Quality Management
<b>V</b>	Coefficient of variation

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# **1 CHAPTER ONE: INTRODUCTION.**

## **1.1 Background**

The contribution of construction industry for the development of economy in developing country is paramount compared to other industries. This is mainly because developing countries are substantially dependent on the growth and development of their physical infrastructures and the linkage of the construction industry to both economic and social sectors is very important. Ethiopia's construction sector is one of the most robust in Africa. The updating and building of new infrastructure links, residential developments and so on is of considerable interest to the Ethiopian Government. A wide range of buildings and construction facilities are required by the society, including residential and commercial property, manufacturing facilities, schools, hospitals, complex transport infrastructure, and so on. Thus, the construction industry is a major sector of the economy of the country (Habenom, 2017).

It is forecasted that about 20 percent of the total population of Ethiopia is living in urban areas, which has rendered it as one of the least urbanized countries in Sub-Saharan countries. Even with this low level of urbanization, however, the country has one of the highest rates of urbanization even by the standards of developing countries, which is estimated at 4.1 percent. This is also much higher than the average growth rate of the total national population, which is estimated at 3 per cent per annum. The level of urbanization has been only 6 percent in the 1960, which has increased to 11 percent in 1984 and 14 per cent in 1994, which is estimated to have already reached 17.2 percent by 2013 and projected to account for 30 percent of the total population in the year 2025 ((MOWUD), 2019.). Addis Ababa, it should be noted, is home to the headquarters of the African Union and the United Nations Economic Commission for Africa. As such, affluent international visitors could be found here. A demand for luxury developments is likely to be in part, driven by their presence. In addition, the rapid growth of population in Addis Ababa presents extraordinary pressure on the existing housing policy and on the entire infrastructures like- water, electrical power supply, drainage and road. At the same condition, urbanization, rapid growth of population and proper usage of land leads the government to increase the public construction projects to satisfy society needs. In addition, contribution of private sector for the industry is significant.

The quality of concrete has also a very direct effect on the strength & durability of the structure as a whole. Concrete structures are designed and constructed so that, they maintain their required serviceability, durability and performance for a sufficiently long period of time, which is expected to be in excess of 50 years. Concrete structures fail when it can no longer offer the required strength to support its designed load. The failure of concrete can sometimes be mild with visible cracks and deflections or severe, leading to partial or total collapse of the structure during the construction or post-construction stage. To obtain quality concrete products, proper care and control has to be done during ingredient selection by checking compliance with the standards, and during production processes and workmanship. Repairing poor quality concrete structure is costly, undesirable, time consuming, and in many cases not possible. Therefore, every effort should be made to avoid the production of a poor quality concrete structures and it should be reminded that all professionals and firms involved in the construction industry have to give special emphasis to quality control of concrete. (Mihiretab, 2021).

Concrete quality produced in Ethiopia did not meet the requirements due to many reasons. Unsatisfactory quality of ingredients, poor supervision and poor way of concrete production are some of them. Researches agreed that there is gap in concrete produced and the standard requirements. The quality of concrete produced on the projects varies from good to bad and the variability in the quality of concrete production on those projects is due to lack of testing, selecting and handling of concrete making materials (Habtamu, 2017).

In Ethiopia, concrete production is not extensively automated. Based on concrete production methods concrete is classified as cast in situ or site mix concrete and ready mixed concrete. Ready-mixed Concrete is a type of concrete that is produced in batching plant, according to a set procedure, and then transported to a worksite, by truck mounted transit mixers. This results in accurate mixture, letting specialty concrete mixtures to be developed and implemented on construction sites. RMC is commonly referring to a concrete that is specifically manufactured for delivery to the customer's construction site in a freshly mixed and plastic or unhardened state. While the majority of construction projects rely on cast-in-situ concrete for their structures, there is a notable rise in the availability of ready-mixed concrete and its suppliers in urban areas. The cast-in-situ concrete production process is

generally carried out manually on-site by unskilled laborers, and many construction companies lack proper equipment and organization (Andnet, 2020).

Currently More than 15 RMC suppliers in Addis Ababa. Majority of suppliers produced RMC for their own construction project but not for commercial purpose. Only Gentium concrete industry and few suppliers produced and delivery RMC for commercial purpose in the city. Consequently, the quality of concrete and the overall standard of construction can fluctuate significantly between different projects. This paper seeks to examine quality control practices among ready-mix concrete suppliers, with a specific focus on Gentium Concrete Industries Plc.

## **1.2 Statement of the problem**

Different studies revealed that the RMC quality in Ethiopia frequently falls short of required standards due to several contributing factors. Among these are the use of substandard materials, lack of adequate oversight, and incorrect production techniques (Andnet, 2020). Studies have revealed a gap between the actual quality of concrete produced and the established standards. In construction projects, concrete quality ranges from acceptable to subpar, with variations attributed to inadequate testing, poor selection, and mishandling of materials used in concrete production. Moreover, factors such as ineffective quality control of raw materials, improper batching and mixing processes, along with insufficient training and management for construction teams can further compromise the quality of concrete. Additionally, while a considerable number of construction projects in Ethiopia utilize cast-in-situ concrete, the trend of companies offering ready-mix concrete (RMC) is increasingly evident in urban centers (Habenom, 2017).

In Addis Ababa, more than half of the concrete produced fails to comply with Ethiopian standards. Statistical quality control analyses, based on compressive strength tests conducted across selected projects, indicated that 60% of the lots did not meet Ethiopian standards (EBCS-2, 1995), with only 40% achieving compliance. Evaluations conducted using (ACI 318R) standards revealed that 47.6% of the lots were substandard, while 52.4% met the criteria (Mihiretab, 2021). This indicates that a considerable portion of concrete produced by ready-mixed concrete suppliers does not meet the necessary standards, highlighting inadequate quality control within the ready-mix market.

Gentium Concrete Industries Plc, a prominent producer of high-quality concrete in Ethiopia, was founded as a joint venture with a foreign enterprise in Addis Ababa. The company boasts a modern ready-mix concrete plant that produces concrete daily for various applications. The production processes are governed by stringent quality standards, which encompass material selection and storage, ongoing quality monitoring, plant maintenance, equipment calibration, concrete sampling and testing, stock management, and the identification and rectification of any issues.

Based on the researcher's analysis and reviews of various project documents, certain quality control challenges and deficiencies were identified at Gentium Concrete Industries Plc. These include improper handling of raw materials, issues with material delivery from truck mixers, delays in delivering materials to construction sites, and bulging formworks during the pumping of concrete into molds. It is a common issue for ready-mix concrete suppliers to provide concrete of inferior quality compared to expectations. This problem necessitates robust quality assurance and control measures. Consequently, this study focuses on quality control practices at Gentium Concrete Industries Plc, aiming to pinpoint gaps and improve ready-mixed concrete quality control techniques to enhance the overall quality of the produced concrete.

### **1.3 Research Questions**

- What are the primary factors that affect the quality control of ready-mixed concrete at Gentium Concrete Industries Plc?
- How is the quality control of ready-mixed concrete practiced at Gentium Concrete Industries Plc?
- How often and when are compliance criteria utilized to double-check the quality assurance of ready-mixed concrete?
- What are the recommended solutions to track factors contributing to variability between batches of RMC for decision makers' consideration?

## **1.4 Objectives of the Study**

### **1.4.1 General Objective**

The study's main objective is to investigate the practice of quality control in ready-mixed concrete in the case of Gentium Concrete Industries Plc.

### **1.4.2 Specific Objectives**

The specific objectives of this study are:

- To Identify the factors influencing RMC operations and the quality of ready-mixed concrete at Gentium Concrete Industries Plc.
- To Identify any gap between the RMC process practiced in Gentium Concrete Industries Plc. and Ethiopian standards.
- To Assess the level of quality control by employing statistical quality control based on Ethiopia and ACI standards.
- To Propose solutions to track factors contributing to variability between batches of RMC.

## **1.5 Significance of the Study**

Effectively managing and executing qualified projects is essential for enhancing human safety, increasing productivity, and promoting sustainability. In Ethiopia, project management and quality management as professions are still in the early stages of development. This research aims to contribute to the existing body of knowledge and findings from similar projects, with the objective of improving the quality of project implementation and management. Consequently, this research effort will help advance the field of project management by providing new insights and experiences from the organization.

The findings of this study will also serve as valuable input for Gentium Concrete Industries Plc in assessing the current strengths and weaknesses of their quality control practices for ready-mix concrete and in applying them to ongoing projects. Similarly, other ready-mix concrete suppliers can leverage the results of this research to address quality-related issues. Additionally, the insights gained may be beneficial to development policymakers, program/project designers, donors, and non-governmental organizations. Furthermore, this research might serve as a foundation for future studies in this area at both regional and national levels.

## **1.6 Scope and Limitations of the Study**

The scope of this study was limited to focusing on the quality control practices of ready-mixed concrete in Gentium Concrete Industries Plc.

Methodologically, the study was conducted using a quantitative and qualitative research method. The study was used a descriptive research design to investigate the practice of quality control in ready-mixed concrete at Gentium Concrete Industries Plc. It did not include all the test results of materials. Instead, it focused on selected test results related to concrete-producing materials and cube tests. Additionally, the study only assessed batching plant managers, clients, and testing agencies.

Geographically, the study only considered the quality control production methods employed by Gentium Concrete Industries. The study only assessed Supplier, not addressed on clients, and consultants due to limitations in personal and financial capacity, as well as time constraints.

## **1.7 Structure of the Thesis**

The thesis is organized in to five chapters. Chapter one presents the introduction that explains the problem, objective of the study, significance of the study, scope of the study, limitations of the study, organization of the study and procedures of the investigation in general.

Chapter Two deals the literature review. Here, the concepts and related theories have discussed.

Chapter Three presents the methodology and it discusses the methods and techniques employed for the investigation. Under this chapter, data collection techniques, sampling & sample size determination methods, data quality assurance techniques, data analysis & interpretation methods are explained.

Chapter Four provides the data analysis and discussion portion. In this portion, all the collected raw data is presented, analyzed and interpreted in the detailed manner.

The last chapter (Chapter Five) presents conclusions and recommendations. In the final section of this last chapter the study forwards some recommendations.

## 2 CHAPTER TWO: LITERATURE REVIEW

### 2.1 Introduction

This chapter focuses on various literature reviews about quality control practices for ready-mixed concrete. The information is sourced from various journals, articles, thesis papers, and books. The chapter primarily delves into the physical and chemical quality of ready-mixed concrete, as well as the factors that significantly impact its quality.

### 2.2 Theoretical Literature Review of RMC

#### 2.2.1 Definition

**Concrete** consists of a coarse granular component known as the aggregate or filler, enveloped by a rigid matrix of cement or binder that occupies the gaps between the aggregate particles and unites them. This material is highly adaptable and extensively utilized in civil engineering projects. Depending on the production technique, concrete can be categorized as either Site Mixed Concrete or Ready-mixed Concrete.

RMC is concrete where cement, aggregate, and other ingredients are weighed and batched at a plant before delivery to the construction site (Kumar, 2018). It is delivered to a work site, often in truck mixers capable of mixing the concrete ingredients en route or just before delivering the batch (Shah, A., Pitroda, P. J., & Bhavsar, P. J, 2014).

#### 2.2.2 History of RMC

(Biswas, A., & Sen, S. K., 2016) Biswas, reported that ready mix (RMC) was first patented in Germany in 1903. It is said that the first commercial shipment of RMC took place in Baltimore, United States, in 1913 and was the first composite drum. It was built in 1926. Currently, most RMCs are designed through a computer-controlled operation and transported and placed to the project site using advanced equipment and methods (Shah, A., Pitroda, P. J., & Bhavsar, P. J, 2014) Ethiopia, where most of the concrete is produced on-site On the contrary, in most developed and developing countries, RMC manufacturing facilities are responsible for producing the majority of their countries' total output. Denamo A found that in the German construction industry, RMC accounts for approximately 87% of all concrete products (excluding precast concrete) and accounts for approximately 47% of all cement Progressive Growth of RMC in Some Countries:

### 2.2.3 Types of RMC.

RMC has two categories: **mixed media and public transport or mixed vehicles**. In central mixing, mixing is done in central facilities and the concrete is then transported using truck mixers. In mixed transport or mixed vehicles, materials are distributed at the central facility but mixed in trucks (Jemal, 2017) .

However, according to the quality control of the concrete mixer truck, the quality of the concrete mixer is not as good as the concrete made from fixed materials (Mascolo, 2013). During the process or before pouring concrete, the mixing is done in the mixer. In some cases, it is a part of the mixing plant in the middle so that the concrete can be mixed with a mixer, and the mixing process is done on the road. This type of concrete is called shrinkage concrete but is rarely used. The capacity of the mixer is usually 6 cubic meters or 7.5 cubic meters (Alam M. A., 2016).

### 2.2.4 Advantages of RMC over Traditionally Mixed Concrete

Kumar stated that the major projects require speed as well as quality of construction, compatible with International standards. This is the cause of the growing of RMC use to maintain the standard of construction (Kumar, 2018).

Li, (2011) puts the advantages of RMC as follows: (1) it provides concrete with better quality due to specialized operation; (2) mass production; (3) elimination of storage space for basic materials at the site; (4) basic materials can be fully utilized; (5) it reduces the labor requirement; (6) it reduces noise and dust pollution on the construction site; and (7) it reduces the production cost of concrete (Li, 2011).

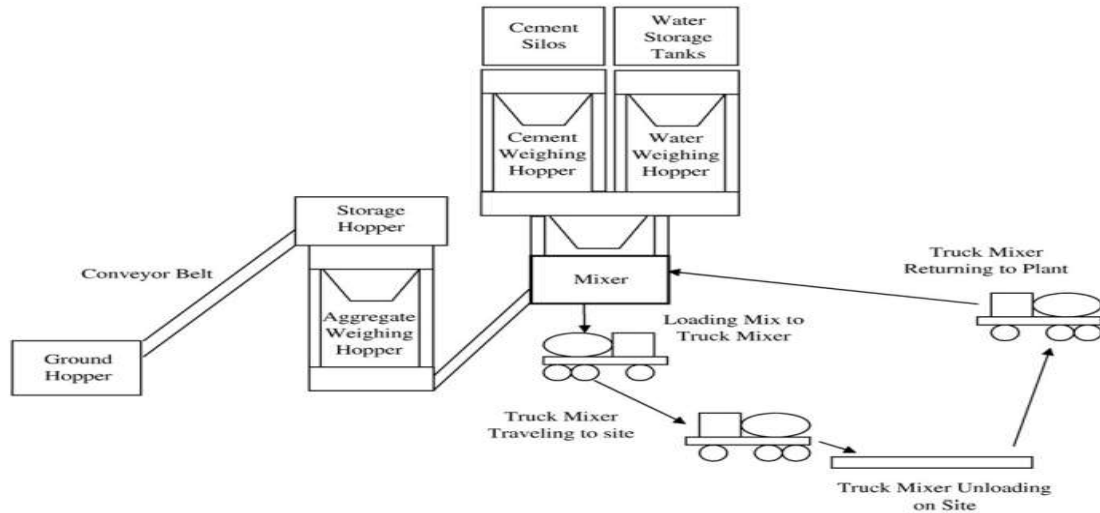
Shah, A., Pitroda, P. J., & Bhavsar, P. J,( 2014)add to this stating that it's time-saving and cheaper and that it is also eco-friendly as it reduces noise and air pollution because mixing is done in a closed chamber as compared to site mix concrete (Shah, 2014).

The advantages of RMC as stated by Jemal (2017). According to him, this type of concrete is extensively used abroad due to its numerous advantages compared to other manufacturing methods. The listed advantages include close quality control of batching, suitability for use on congested sites, use of agitator trucks to ensure careful transportation, and convenience in cases where small quantities of concrete or intermittent placing are required (Jemal, 2017).

### 2.2.5 Components of RMC Batching Operation

Park et al. details the various elements involved in the operation of a ready-mixed concrete (RMC) batching plant. A standard RMC plant typically comprises a batching plant, cement

silos, water storage tanks, ground hoppers, storage facilities, weighing hoppers, and trucks. Figure 2.1 below illustrates the conceptual framework of the batching plant operation, accompanied by a concise description of each section.



**Figure 2.1 Batching plant operation. Source from internet**

#### 2.2.5.1 Ground Hopper

The hopper is situated on the ground and linked to the storage hopper via a conveyor belt. An operator is required to operate the vehicle to load sand and aggregates into the ground hopper. Subsequently, the conveyor belt moves these materials to the storage hopper.

#### 2.2.5.2 Storage Hopper

The hopper is equipped to store sand and aggregates such as sand, 10 mm aggregate and 20 mm aggregate. Once released, the product is discharged into the aggregate gravity hopper located just below the storage hopper.

#### 2.2.5.3 Cement Silo and Water Storage Tank

The cement silo and water storage tank are located at the top of the mixer. Cement is placed in the cement weighing bunker and its weight is measured. The cement is then discharged into the mixer by gravity. Similarly, water is discharged into the mixer through the heavy funnel

#### 2.2.5.4 Weighing Hopper

There are three types of bucket weights. Cement and water weight bunkers are located below the cement silo and water tank and above the mixer. This arrangement allows cement and water to be pumped by gravity directly into the mixer after weighing. Alternatively,

sand and aggregates are weighed in the aggregate weighing hopper and sent to the mixer via a conveyor belt.

### 2.2.5.5 Mixer water-weight

The concrete mixer brings together all the elements to produce ready-mixed concrete. With continuous rotation, the mixer ensures that the ingredients are mixed evenly and thoroughly, resulting in the proper consistency for workability. The operator monitors the mixture using an amp-meter to check if it is overly dry or wet and makes the required adjustments before transferring it to the truck mixers.

## 2.2.6 Statistical Quality Control of Concrete

According to ACI 214, the primary purpose of statistically evaluating concrete data is to identify sources of variability. This knowledge can be used to determine appropriate steps for maintaining quality control.

### 2.2.6.1 Normal Distribution

The normal probability distributions are characterized by a symmetric bell shape but can have any real mean, labeled  $\mu$ , and any positive real standard deviation, labeled  $\sigma$  (Wesolowski, 2018). According to ACI 214, the standard deviation is the most widely recognized measure of dispersion of the individual test data from their average. The table below summarizes standard deviations for different control standards.

Table 2. 1. Standard deviation for different control standards, ACI 214

Class of operation	The standard deviation for different control standards				
	Excellent	Excellent	Excellent	Excellent	Excellent
General construction testing	Lower than 2.8	2.8-3.4	3.4-4.1	4.1-4.8	Greater than 4.8
Laboratory trial batch	Lower 1.4	1.4-1.7	1.7-2.1	2.1-2.4	Greater than 2.4

(ACI 214R)

states that data showing skewness or kurtosis are not normally distributed, and all analyzes assume that a normal distribution is more likely to confuse the data sheet. Available information shows that the distribution is always suitable in most cases where the rock strength does not exceed 70 MPa. The most popular methods include the Shapiro-Wilk test, Kolmogorov-Smirnov test, skewness, kurtosis, histogram, box plot, P-P plot, Q-Q plot, and SD mean (Prabhaker Mishra, 2019)

According to (Prabhaker Mishra, 2019), To determine if continuous data is normally distributed, certain criteria need to be met. First, for small sample sizes ( $n < 50$ ), **the z-values** for skewness and kurtosis should fall between -1.96 and +1.96, and for medium-sized samples ( $50 \leq n < 300$ ), they should be within -3.29 to +3.29. For sample sizes greater than 300, normality can be assessed using histograms and the absolute values of skewness and kurtosis. An absolute skewness value of  $\leq 2$  or an absolute kurtosis (excess) value of  $\leq 4$  can indicate substantial normality. Second, **the p-value of the Shapiro-Wilk or Kolmogorov–Smirnov** test should be greater than 0.05. The Shapiro-Wilk test is more suitable for small sample sizes (<50 samples) but can also be used for larger sample sizes, while the Kolmogorov–Smirnov test is suitable for  $n \geq 50$ .

**Thirdly, histograms, normal Q-Q plots, and box plots** should visually indicate that the data are approximately normally distributed. If the graph is approximately bell-shaped and symmetric about the mean, we can assume the data is normally distributed. (Prabhaker Mishra, 2019).

Normality tests can be conducted in the statistical software “SPSS” (Prabhaker Mishra, 2019). Once it’s known that the distribution is normal, parametric tests such as t-tests can be conducted (ACI 214). One sample t-test compares the mean of a sample to a predefined value (Gerald, 2018).

#### 2.2.6.2 Statistical Process Control (SPC) Tools

SPC is an analytical tool for decision making which allows us to see whether a process is working correctly or not (Aichouni, 2012). (E.Poovaragavan, & Sekar, K, 2016). put that the SPC tools are very useful in identifying the defects in the process and developing the solutions for eliminating them to improve the quality of the products (E.Poovaragavan, & Sekar, K, 2016). Specifically, SPC tools which constitute a major part of the basic quality tools can be used efficiently by the construction industry to continuously improve their processes by reducing variability eliminating errors, and reworking their projects (Aichouni, 2012).

There are seven quality tools that can be used to improve processes (Mulat, 2018). The first is **the Pareto Chart**, which is used to display problem categories graphically to prioritize them effectively. The second is **the Cause-and-Effect Sheet**, which organizes and displays relationships between different causes for the effect being examined and helps in organizing the brainstorming process. **The third is the Scatter Diagram**, used to uncover possible cause-and-effect relationships. **The fourth is a Flow Chart**, a diagram that represents an algorithm,

workflow, or process, displaying the steps as boxes and connecting them with arrows to show their order.

**The fifth is a Histogram**, a snapshot of the variation of a product or the results of a process. The sixth is Check Sheets, which are charts for gathering data. When designed clearly and cleanly, they assist in gathering accurate and pertinent data and allow the data to be easily read and used. Lastly, the seventh tool is the Control Charts, which are graphical devices that aid in process control and make it easy to identify trends, points and processes that are out of control, without using complicated statistical tests.

As (Aichouni, 2012) discussed, a cause and effect diagram (also called **Ishikawa or fishbone chart**) identifies many possible causes for an effect or problem and sorts ideas into useful categories (Aichouni, 2012).

### **2.2.7 Variability of properties of RMC.**

It is important to consider properties such as durability, permeability and volumetric stability in the construction of reinforced concrete buildings, but strength is the most important factor (Hasan, 2012). In a construction project, the compressive strength of concrete is the most important factor measuring the acceptance of concrete by a particular facility (Okasha, 2015). (Hasan, 2012)

stated that waiting 28 days for the energy assessment is a critical time for construction. This period also includes integration, release, commit, fix, etc. It also represents the quality control process. and the difference in the compressive strength of the facility's concrete is inevitable (Santamaria, 2017).

According to (M. Orozco, 2018) factors affecting RMC quality can be divided into **material, operation, method, system and environment**. Subcomponent to understand changes in the properties of this component. ACI 214R explains the batch-to batch variation in concrete strength based on the properties and characteristics of the components, etc. ties.

**Material:** Alem et al. If ingredients from different sources are used, the raw material, energy and other properties of the products may change and therefore they should be used only after evaluation and (Alam M. A., 2016)

It is said that since the cost of cementitious materials can be measured fairly, constant w/cm control of all water used should be strictly controlled. Additionally, as Li (2011) stated, unlike other raw materials, the quality of raw water varies. and well-trained staff at all levels (Alam MA, 2016).

**Personnel/Labor:**RMC deployment is also affected by the skills of the crew, especially the driver. For the successful delivery of concrete, people involved in all stages of production, planning and transportation need to be coordinated (Afzal, S., & Khan, Z. R., 2018). Blending, mixing and vibration equipment must have sufficient capacity. According to them, weighing and dosing machines should be checked more frequently and the accuracy of the equipment should be evaluated. Settlement, delayed placement, inadequate care, inadequate early prevention. Stated that the properties of concrete such as workability, compressive strength and other properties depend on the properties of the components, the mixing process of new concrete, compression method, repair etc.

**Equipment:** (Alam M. A., 2016) states that the equipment used for batching, mixing, and vibration shall be of the right capacity. According to them, weigh-batchers shall be frequently checked and plants calibrated for their accuracy.

He said he was affiliated. Alam M. A. (2016) added that batching error is partly responsible for variations in stone quality.

**Methodology:**

identified various factors that cause changes in property, including material weight, vibration, and compaction quality. Batch-to-batch variation refers to differences in durability between products; this may be attributed to differences in ingredients, mixing, and sampling. Make a difference in your work. Vaghela (2018) confirmed that weather conditions are an important factor in crop losses.

**Environment:**In addition, RMC distribution involves many problems such as accurate estimation of temperature as well as travel time and transportation between the mass facility and the office (Werku Koshe& Jha, 2016).

### 2.2.8 Composition of RMC

Concrete is a composite material comprising aggregates and a binding paste. This paste forms a rocklike mass as a result of the chemical reaction between cement and water. To obtain specific properties in the paste, various mineral and chemical admixtures are introduced. The overall quality of concrete is influenced by the quality of both the paste and the aggregates, along with the bond that adheres them together. In well-prepared concrete, each particle of aggregate is thoroughly coated with paste, and the voids between aggregates are filled with paste, which constitutes approximately 25% to 40% of the total volume. Concrete is primarily made up of aggregates and paste, with cement typically accounting for 7% to 15% of the total volume and water making up 14% to 21%. Air-entrained concrete generally includes about 4% to 8% air content. Aggregates represent around 60% to 75% of the total concrete volume, and additional admixtures may be added

to achieve desired properties. The quality of concrete relies heavily on the meticulous selection of its individual components (Shetty M.S, 2009).

After concrete is mixed, it must meet several criteria in its fresh state; it needs to be workable and cohesive. Good workability is essential for the proper placement and compaction of fresh concrete, while cohesiveness is necessary to prevent segregation during transportation, placement, and compaction. Once the concrete has hardened, it should possess strength and durability, with minimal voids. Additionally, it must provide adequate strength and resistance to abrasion, as well as impermeability to withstand weathering, chemical attacks, and corrosion (H.Kosmatka, 2003).

#### **2.2.8.1 Cement**

Cement is the main active component on which the compressive strength of concrete and other important properties such as durability and volume change depend (Ibrahim, 2018).

As soon as cement is mixed with water, the hydration reaction starts to set off (Peter, 2013). According to (Lee, 2011) the properties of fresh concrete, such as setting and hardening, and also of hardened concrete are influenced by the process of hydration. The initial set indicates the beginning of gel formation. The final set occurs 5–10 h after mixing, which indicates that sufficient hydration products are formed and the cement paste is ready to carry some external load (Li, 2011).

##### **2.2.8.1.1 Type and Composition of Portland Cement**

According to the ASTM standard, there are five basic types of Portland cement. These are Type I regular cement, general use; Type II moderate sulfate resistance, moderate heat of hydration; Type III increase C3S, high early strength; Type IV low heat; the last one is Type V high sulfate resistance cement.

The Ethiopian Building Codes and Standards (EBCS-2, 1995)(state that the cement used for concrete shall be Portland or Portland-Pozzolana cement complying with the requirements of the latest Ethiopian Standards' on such cement. It also states that where cements other than those complying with these standards are used, accounts shall be taken of their properties and any particular conditions of use. (Neville A., 2011.)

##### **2.2.8.1.2 Cement Production in Ethiopia**

The primary component of concrete is cement, so it's crucial to have high-quality cement and a consistent supply for making good concrete. The development of the Ready-Mix Concrete (RMC) industry in any country is closely tied to the growth of its cement

industry and the demand for cement by the construction sector. Additionally, investors were hesitant to adopt RMC technology because they were concerned that RMC plants would suffer from a lack of available cement. (Jain A, 2013).

#### **2.2.8.1.3 Tests on Cement**

The cement shall be tested initially once from each source of supply and, subsequently, at every two months interval (Alam M. A., 2016)

The basic tests for checking the quality of Portland cement are Fineness (= surface area/weight), Normal consistency test, Time of setting, Soundness, Strength, and Heat of hydration test

#### **2.2.8.1.4 Handling of Cement**

To reduce the likelihood of cement damage, careful handling is essential from the time it exits the factory until it is incorporated into the concrete mix at the construction site. This entails implementing effective measures for transportation, unloading, storage, and limiting the duration of storage (Duggal S, 2000)

#### **2.2.8.2 Aggregates**

In any concrete, aggregates (fine sand and Coarse) usually occupy about 70-75% and between 60 – 80% of the total volume of the concrete mass (Alam M. A., 2016). A constituent occupying such a large percentage of the mass should inevitably contribute important properties to both the fresh and hardened product. (Lee, 2011).

##### **2.2.8.2.1 Effects of aggregates on concrete properties**

Behaviors of new concrete such as fluidity, cohesion and rheological behavior are generally affected by the amount, type, surface finish and size of the aggregates (Lee, 2011).

Aggregate provides better strength, stability and durability for structures made of cement concrete compared to cement mortar alone (Alam M. A., 2016).

Evaluation results revealed that the product made from water gravel works well as the most effective stone, Then crushed quartzite and crushed granite aggregates. Additionally, stones composed of quartzite aggregates have the highest strength among all ages, followed by water pebbles and finally granite aggregates (Afzal, S., & Khan, Z. R., 2018). Alam et al. (2016) stated that aggregates are incomplete and their physical, thermal and chemical properties can affect the performance of rocks (Lee, 2011).

**Grading and size distribution:** Grading determines the paste requirement for workable concrete, as the number of voids among aggregate particles necessitates the same amount of cement paste to fill the concrete mixture (Lee, 2011).

**Aggregate shape:** Shape is another important property that significantly influences the properties of concrete. It is broadly described as angular, rounded, flaky, and elongated (Kiran Kumar Poloju, 2017). The shape of aggregates affects the workability of concrete due to differences in surface area caused by different shapes (Lee, 2011).

**Texture of aggregates:** The surface texture of aggregates can be classified into six groups: glassy, smooth, granular, rough, crystalline, and honeycombed. The surface texture of aggregates has a significant influence on the fluidity of fresh concrete and the bond between aggregate and cement paste of hardened concrete (Lee, 2011).

#### 2.2.8.2.2 Handling of Aggregates

When stockpiling aggregates on-site, appropriate handling methods must be employed. According to Alam M. A. (2016), aggregates should be stockpiled in single sizes. Additionally, the Ethiopian Building Codes and Standards (EBCS-2, 1995) specify that aggregates must generally adhere to the latest Ethiopian Standards for aggregates.

#### 2.2.8.3 Admixtures

Admixtures are substances or chemicals added to concrete to enhance or provide specific characteristics. The primary objective of using these admixtures is to improve properties that would be costly to achieve through simple adjustments in the ratios of cement and concrete, without negatively impacting any existing properties of the concrete mix. It is crucial to understand that admixtures should not replace sound concreting practices. Prior to employing an admixture, it is vital to assess its impact on the concrete being produced. Often, it is necessary to test representative samples of the materials under conditions that simulate actual job site situations to gather trustworthy data on the properties of concrete that includes admixtures (Lee, 2011).

The various types of admixtures are as follows:

- a) **Accelerating admixtures:** These substances hasten the setting process of concrete, making them ideal for use during cold weather conditions.
- b) **Retarding admixtures:** These materials prolong the setting time of concrete, which is beneficial for applications in hot weather.
- c) **Water-reducing admixtures:** These admixtures decrease the water needed in the concrete mix without compromising its workability.
- d) **Air-entraining admixtures:** These are utilized in concrete that will be subjected to freeze-thaw cycles.
- e) **Super plasticizing admixtures:** This category of admixture significantly lowers the water content in concrete while preserving its workability and enhancing strength.

Typically, these admixtures are used in quantities ranging from 0.5% to 1.2% of the total weight of cementitious materials, which includes cement, fly ash, and GGBS.

The effectiveness of these admixtures is influenced by various factors, such as the type and brand of the admixture, the quantity of cementing agents, water content, the shape and grading of aggregates, mixing duration, slump, and the concrete temperature[ (BS EN 206, 2013)]

#### **2.2.8.4 Water**

Water is an important ingredient of concrete (Nikhil.T, 2014). However, the water added to the mix is usually much higher than what the chemical reaction needs due to the fluidity requirement of concrete for placing ((Lee, 2011).

##### **2.2.8.4.1 Water for Mixing Concrete**

The water used for mixing concrete shall be free from silt, organic matter, alkali, and suspended impurities (Alam, 2016). Interpreting in another way, Li (2011) states that if water does not have any particular taste, odor, or color, and does not fizz or foam when shaken, then there is no reason to assume that such water will hurt the concrete when used properly as mixing water (Li, 2011). EBCS 2 simply states that mixing water shall be clean and free from harmful matter. 2.4.4.2.

##### **2.2.8.4.2 Water for Curing**

Proper curing of concrete is crucial to obtain design strength and maximum durability, especially for concrete exposed to extreme environmental conditions at an early age. (James, 2011). According to Li (2011), the requirements for curing water are less stringent than for mixing concrete, mainly because curing water is in contact with the concrete for only a relatively short time. He, however, asserted that the permissible amounts of the impurities are still restricted (Li, 2011).

#### **2.2.8.5 Mix Design of Concrete**

According to the Ethiopian Building Codes and Standards (EBCS 2- 1995), the required concrete may be specified in designed, prescribed, or standard (or nominal) mix methods. The mix proportions of concrete of grades C5 to C30 are specified in the code as standard.

### **2.2.9 Process Involved in the Production of RMC**

#### **2.2.9.1 Batching of Concrete**

Alam M. A., (2016) defines batching as the correct measurement of the various materials used in the concrete mix. They state that concrete can be batched either by volume batching

or by mass (weight) batching (Alam M. A., 2016). (EBCS-2, 1995) requires the regular checking of the accuracy of the mix proportions.

### 2.2.9.2 Mixing Concrete

There are two analysis stages in the mixing process. In the first stage, cement paste is formed when the aggregate absorbs water. In the second stage, cement mortar covers the mixture. The mixing process should be continued until the concrete is mixed properly and thoroughly. At the end of this stage, the stones appear to have a uniform color and tone. Consistency must be maintained when releasing the concrete from the mixer

(Alam M. A., 2016)

There are two main categories of integrated planning. But in general, the mixing and delivery of concrete can be done in one or more of three categories: base mix, shrinkage concrete and concrete mix (Alam MA., 2016), and to create a mass consisting of all products. This stone should not be affected by the mixing (Jemal, 2017)

#### 2.2.9.2.1 Uniformity of Mixing

In order to create a homogeneous rock in each mixture, the necessary material change must occur in different parts of the room (Jemal, 2017). EBCS 2 requires the consistency of new concrete to be checked regularly through slump testing.

#### 2.2.9.2.2 Mixing Time

The stone must be mixed for the specified time. Combinations and combinations should be avoided (Alam MA., 2016). According to Neville A. (2011), good mixing time depends on the type and size of the mixer, rotation speed, and good mixing of the ingredients while charging the mixer (Neville A., 2011). In general, mixing times between one minute and one minute and fifteen seconds (1 minute 15 seconds) will result in an uneven mix and reduced strength. Mixing longer than two minutes (2 minutes) will not improve this product.

Table 2-2: the type and size of mixer and mixing: source ACI

Capacity of mixer (yd <sup>3</sup> )	Mixing time (Minutes)
2	1.25
3	1.5
4	1.75
5	2
6	2.25
10	3.25

Jemal (2017) argues that prolonged mixing of concrete causes water to evaporate from the mix, resulting in reduced workability and increased strength. He also points out that

excessive mixing can grind the aggregate, especially if it's soft, leading to finer grading and lower workability (Jemal, 2017).

#### **2.2.9.2.3 Transportation of Concrete**

After mixing, concrete should be transported and placed at the site as quickly as possible to prevent segregation and drying (Alam M. A., 2016). Fresh concrete is typically delivered to construction sites by agitators, such as truck mixers or truck agitators (Li, 2011). If concrete needs to be transported over rough ground, the distance should be kept as short as possible to avoid segregation caused by vibrations (Alam M. A., 2016). Delays due to traffic conditions, long distances, and other factors can result in the loss of concrete (Afzal, 2018). Therefore, once the truck is loaded, it should be dispatched to the site immediately.

According to (Vaghela, 2018), when water is added to dry concrete materials, it takes only 2 hours to achieve the final setting (hardened state) unless a specific chemical retarder is added. Large orders require a continuous supply of concrete to avoid dangerous construction joints (Vaghela, 2018). Typically, retarding admixtures are used to keep concrete workable for 5 to 6 hours with an initial setting time of 7 to 8 hours (Li, 2011).

#### **2.2.9.2.4 Placing Concrete.**

Although concrete can be mixed and proportioned correctly, its quality can be significantly compromised by improper or careless methods of transportation and placement. The transportation method should efficiently deliver the concrete to its final destination without major alterations to its characteristics.

Concrete must be transported and placed in the intended location as swiftly as possible to avoid problems such as segregation, drying, and other complications. Once the concrete is discharged from the mixer, internal and external forces can cause the various components to separate. When heavy concrete is contained within restrictive forms, the larger and denser particles tend to settle while the lighter, finer materials rise to the top. When moving concrete over uneven terrain, it is crucial to keep the distance traveled as short as possible to minimize vibrations that could lead to material segregation.

Concrete is typically moved using a variety of equipment designed for placement. Common transportation tools include wheelbarrows, buckets, agitating trucks, non-agitating trucks, chutes, belt conveyors, dumpers, concrete pumps, and hoists. To ensure

the production of high-quality concrete, proper transportation and handling techniques must be utilized. Factors that can impact concrete quality during transportation and placement include slump loss, ingredient loss, segregation, and the formation of cold joints [ (M.Orozco, 2018)].

#### **2.2.9.2.5 Curing of Concrete**

Concrete curing involves the process of ensuring adequate moisture levels and optimal temperatures shortly after the material has been placed. This practice facilitates ongoing cement hydration, which is essential for achieving the desired characteristics needed for performance standards (Alam, 2016). Different curing methods are available, and selecting the appropriate one depends on the surrounding conditions and the specific requirements of the project (Harris, 2004)

Moist curing can be achieved through water spraying, ponding, or covering the concrete surface with wet sand, plastic sheets, burlap, or mats. Additionally, curing compounds, which can be sprayed onto the concrete surface to form a thin continuous sheet, are commonly used, especially for vertical surfaces such as walls and columns (Li, 2011)

#### **2.2.9.3 Fresh concrete properties**

Fresh concrete properties are short-term requirements that should allow for easy mixing and transportation, uniformity within and between batches, maintenance of fluidity during transportation, filling of forms, full compaction without segregation, reasonable setting time, and proper finishing ability (Li, 2011)

#### **2.2.10 Quality of Concrete**

Quality is an indicator of excellence that embodies a philosophy rather than merely a characteristic. It serves as a benchmark for distinguishing between two items and establishes standards for assessing their acceptability. In sectors like manufacturing and processing, the concept of quality control has been longstanding and widely adopted. In contemporary times, quality control has become not only prevalent but also essential in the construction sector. It is crucial to adopt and implement available quality control techniques and tools in a cohesive manner. Effective quality control in construction activities guarantees the accurate execution of structural designs, adherence to specifications, appropriate material usage, and the quality of workmanship provided by contractors or subcontractors (Chin-Keng, 2011).

Quality concrete should meet the job's needs regarding strength, durability, and appearance. Strength is a key indicator of quality, as it is straightforward to define and quantify, making it

a primary measure of concrete quality (Gupta, 2004). Quality concrete must be fit for its intended purpose and should fulfill or surpass customer expectations. Achieving this necessitates enhancements in concrete production, encompassing improvements in products, processes, and personnel. Process improvement pertains to actions geared towards the production of quality concrete, while personnel development is focused on equipping workers with the requisite skills, knowledge, and experience to enhance in-situ concrete quality (PMI 2004 (Anosike N. M., 2011)).

Concrete is an inherently variable material, and to satisfy quality standards, meticulous control over its production, handling, compaction, finishing, curing processes, and constituent materials is essential. Skilled supervisors and trained workers who comprehend the principles of concrete are vital for achieving quality in concrete. Thus, the quality of workmanship in concreting operations plays a pivotal role in sustaining the desired concrete quality.

Achieving quality design in concrete construction necessitates adherence to relevant standards, regulations, codes, and statutes outlined in the specifications. Quality construction is characterized by compliance with contract agreements, clauses, and specifications that delineate the quality expectations for construction by defining material standards, acceptance criteria, and the testing and inspection requirements for concrete construction (MERL, 2015).

#### 2.2.10.1 Quality Control of RMC

Quality control, which is often referred to as process control, includes the necessary actions and considerations to evaluate production and construction processes and to uphold the quality of the final product. This process involves sampling and testing to keep track of the production, although it typically does not include acceptance sampling and testing (William C, 2008). The combined efforts of the producer and/or contractor guarantee that a product meets the specifications outlined in the contract. In the context of ready-mixed concrete construction, this encompasses the handling of ingredients, construction methods, equipment calibration and maintenance, production process management, as well as the relevant sampling, testing, and inspection carried out for these purposes. Organizations implement these actions to establish oversight and documentation of activities and outcomes, ensuring adherence to recognized standards of good practice and compliance with contract requirements (William C, 2008).

Quality control of ready-mixed concrete (RMC) can be categorized into three areas: forward control, immediate control, and retrospective control. Forward control involves

quality control procedures to be followed before the production process (H.Kosmatka, 2003) This involves:

- ✓ Materials storage
- ✓ Monitoring the quality of materials
- ✓ Modifying mix design
- ✓ Plant maintenance
- ✓ Equipment calibration
- ✓ Plant and transit mixer condition

### 2.2.10.2 Factors Affecting Ready-mixed Concrete Operation and Quality

The study examined the various factors that impact ready-mixed operations and the quality of concrete produced (William C, 2008). These factors include:

- Plant location
- Number of transit mixers involved in the supply process
- Efficiency of the batching plant
- Delivery time (e.g., early morning, late night, evening)
- Traffic on the delivery route
- Coordination among personnel involved in concrete production and supply
- Age of transit mixer
- Weather conditions
- Challenges in concrete pouring (e.g., location, height)
- Inspection intervals
- Maintenance

### 2.2.11 Statistical Quality Control of Concrete

To implement statistical quality control (SQC) in concrete production or any other sector, it is essential to thoroughly comprehend the factors that lead to variation in the product being monitored. In the concrete industry, quality control often relies on compressive strength tests conducted at 28 days. The strength of concrete naturally fluctuates due to variations in its properties and the methods used for testing. (Hasan, 2012)

Table 2.5 **Variations due to the properties of concrete : source** (Hasan, 2012)

Variations due to the properties of concrete ❖ Changes in w/c ratio caused by ➤ Poor control of water ➤ Excessive variation of moisture in	Variations due to testing methods  Improper sampling procedures ❖ Variation due to fabrication techniques
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<p>aggregates or variable aggregate moisture measurement</p> <ul style="list-style-type: none"> <li>❖ Variations in water requirements caused by: <ul style="list-style-type: none"> <li>➤ Changes in aggregate grading, absorption, particle shape</li> <li>➤ Changes in cementitious and admixtures properties</li> <li>➤ Changes in air content</li> <li>➤ Improper sampling procedures</li> <li>➤ Variations due to fabricated mold: poor quality, damaged or distorted molds</li> <li>➤ Changes in curing: <ul style="list-style-type: none"> <li>➤ Temperature variation</li> <li>➤ Variable moisture control</li> <li>➤ Delays in bringing cylinders to the laboratory</li> <li>➤ Delays in bringing standard curing</li> <li>➤ Delivery time and temperature changes</li> </ul> </li> <li>❖ Variations in characteristics and production process: <ul style="list-style-type: none"> <li>➤ Variation in batching, mixing, transporting, placing, compacting and finishing.</li> <li>➤ Variation in temperature and curing</li> </ul> </li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>➤ Handling, curing, and storing newly made cubes</li> <li>➤ Poor quality, damaged or distorted molds</li> <li>❖ Changes in curing: <ul style="list-style-type: none"> <li>➤ Temperature variation</li> <li>➤ Variable moisture control</li> <li>➤ Delays in bringing cylinders to the laboratory</li> <li>➤ Delays in bringing standard curing</li> </ul> </li> <li>❖ Poor testing procedures: <ul style="list-style-type: none"> <li>➤ Specimen preparation</li> <li>➤ Test procedure</li> <li>➤ Uncalibrated testing equipment</li> </ul> </li> </ul>
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### 2.2.12 Statistical Function

It is important that adequate testing is carried out to facilitate the use of appropriate statistical methods to evaluate the difference in concrete performance and determine test results. Statistical techniques provide a reliable way to determine the capacity and strength of concrete and obtain the best results in practice. The strength measurement result is the average strength of all samples of the same age made from samples taken from a group of rocks. It is important to note that the available power rating should not be based solely on a single cylinder; A typical power measurement is often seen as a distribution pattern similar to the daily power distribution curve shown in Figure 2.5.

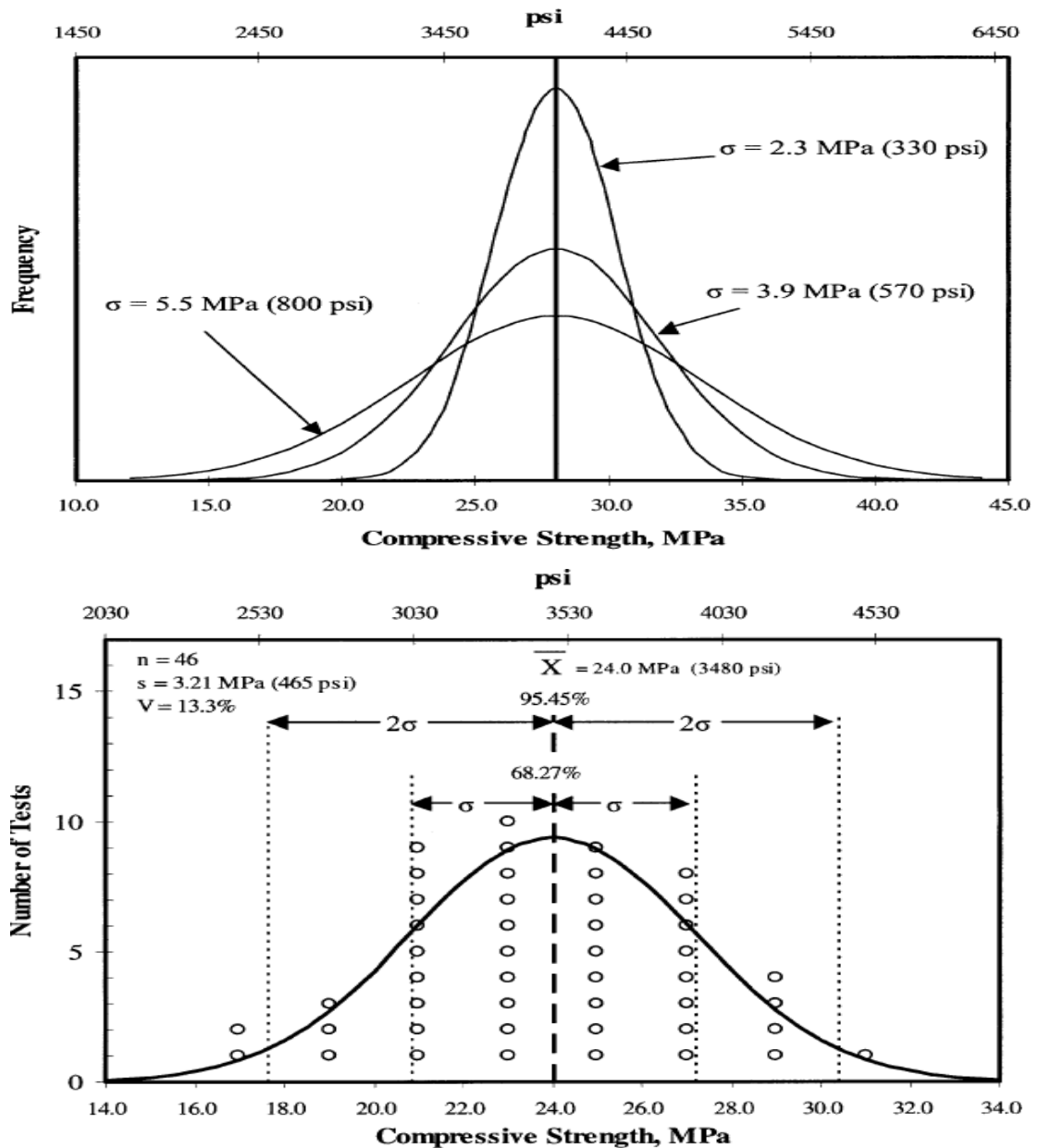


Figure 2.5 illustrates the normal distribution: source EBCS 2 1995

which can be represented by three distinct frequency curves. All curves share the same mean but exhibit different levels of variability. This distribution is characterized by two key statistical parameters: the mean and the standard deviation. The calculations of these parameters are outlined in [Equation. 2.1]:

- **The mean ( $\bar{X}$ ) represents the average strength test result, computed using the following formula:**

$$\bar{X} = \frac{\sum_{i=1}^n X_i}{n} = \frac{1}{n} \sum X_i = \frac{1}{n} (X_1 + X_2 + X_3 + \dots + X_n) \quad \text{----- [Equation. 2.1]}$$

- In this equation,  $X_i$  denotes the  $i$ -th strength test result, derived from the average of at least two cylinder strength tests.  $X_2$  refers to the second strength test result recorded.

$\sum X_i$  represents the total of all strength test results, while 'n' indicates the number of tests included in the record.

- The standard deviation is a widely acknowledged measure of how individual test data points disperse from their average value, as illustrated in [Eq. 2.2].

$$s = \sqrt{\frac{n \sum_{i=1}^n X_i^2 - \left(\sum_{i=1}^n X_i\right)^2}{n(n-1)}} = \sqrt{\frac{\sum_{i=1}^n X_i^2 - n\bar{X}^2}{n-1}} \quad \text{[Equation q. 2.2]}$$

- Here, 's' stands for the sample standard deviation, 'n' is the number of strength test results on record,  $\bar{X}$  is the mean or average strength test result, and  $\sum X$  is the cumulative sum of the strength test results.
- The coefficient of variation (V) is determined by expressing the sample standard deviation as a percentage of the average strength, detailed in [Equation. 2.3].

$$V = \frac{s}{\bar{X}} \times 100 \quad \text{----- [Equation. 2.3]}$$

In this equation, V denotes the coefficient of variation, 's' is the sample standard deviation, and  $\bar{X}$  is the mean strength test result.

### 2.2.13 Approaches to the variability of concrete strength in Ethiopian (EBCS), American (ACI), and their acceptance criteria.

Given the natural variability in concrete strength and the assumption of a normal distribution, it is important to specify a strength that exceeds the required strength. Various codes have distinct methods and criteria for determining the necessary strength to ensure that the likelihood of the compressive strength being less than the design strength remains low. This paper examines the approaches and acceptance criteria for test results as specified in the EBCS, ACI, and BS codes. After conducting concrete tests, it is crucial to verify whether the specified strength,  $f_c'$ , has been met or if the probability of the compressive strength falling below  $f_c'$  is sufficiently low. To address this, ACI 318 provides two acceptance criteria.

$$f_{cr}' \geq f_{ck} + 1.48 \sigma \quad \text{----- Equation (2.4)}$$

The initial criterion for laboratory-cured job concrete specimens stipulates that the arithmetic average of any three consecutive strength tests must meet or exceed  $f_c'$ .

The subsequent criterion indicates that no single test, which is the average of two cylinders, should fall below  $f_c'$  by more than 3.5 MPa for values of  $f_c'$  at or below 35 MPa, or by more than 0.1 times  $f_c'$  when  $f_c'$  exceeds 35 MPa. Should either of these acceptance criteria not be met, adjustments in mix proportions and construction methods must be made to enhance concrete strength. Furthermore, if the second criterion is not satisfied, an investigation into the strength of the concrete within the structure is mandated (Neville, 1985).

The Ethiopian standard also mandates the requirement for characteristic compressive strength or specified strength. Characteristic compressive strength is defined as the level below which 5% of all strength measurements are anticipated to fall.

The acceptance criteria established in EBCS-2, 1995, are outlined as follows:

Two acceptance criteria are presented. Criterion 1: This criterion is applicable in all situations, although it is less appropriate for large-scale sampling, where each lot is represented by three samples, denoted as  $x_1 < x_2 < x_3$ .

The lot is considered accepted if the following conditions are simultaneously fulfilled:

$$M_3 = f_{ck} + k_1 \dots\dots\dots \text{(Equation 2.5)}$$

$$X_1 \geq f_{ck} - k_2 \dots\dots\dots \text{(Equation 2.6)}$$

Where:  $M_3$  - represents the mean value  $f$

$f_{ck}$  - denotes the specified characteristic strength

$k_1$  &  $k_2$  - are the strength margins provided in Table 2.6 below

$X_1$  is the average strength of the minimum strengths across various lots.

Table 2.6 presents the strength margins in MPa.

Margin of strength	First two lots	Third and fourth lot	Fifth lot and above
K1	5	4	3
K2	1	2	3

**Criterion 2:-** this is suitable for large lots.

Each lot is represented by a lot less than 15 test specimens (No) the lot is accepted if the following conditions are satisfied simultaneously.

$$M_n - \lambda S_n > f_{ck} \dots\dots\dots \text{(Equation 2.7)}$$

$$X_l \geq f_{ck} - k_2 \dots\dots\dots \text{(Equation 2.8)}$$

$$f_{cr} = f_c' + z_s \dots\dots\dots \text{(Equation 2.9)}$$

Where

- $M_n$  is the mean value
- $S_n$  is the standard deviation of the set of sample results.
- $f_{ck}$  is the characteristic cylindrical strength.
- $\alpha_1$  is the coefficient (may be taken as 1.4)
- $k_2$  is the margin of strength (may be taken as 4MPa)
- $n$  is the member of specimens

A lot can be described as the quantity of concrete produced under similar essential conditions and evaluated individually. There are minimum requirements regarding the lot size and sampling frequency (EBCS-2, 1995), which are outlined as follows:

- a) No single sample can represent more than 100 mixes or 100m<sup>3</sup>, on average.
- b) A minimum of one sample must be collected for each concrete grade every week.
- c) At least two lots must be produced for each concrete grade.

If the test results fall short of meeting the specified acceptance criteria, several recommended actions should be taken. These actions may include verifying strength through non-destructive testing, reassessing structural integrity by recalculating or redesigning based on the compressive strength that did not comply, and other related measures (EBCS-2, 1995).

Non-destructive tests such as ultrasonic and Schmidt hammer tests can be employed to evaluate the quality of hardened in-situ concrete. However, these tests have limitations, and therefore, accurate results cannot always be guaranteed. The Schmidt hammer test is commonly used, but it only provides reliable information for the surface layer of concrete up to a depth of 30mm (Neville A., 2011.).

$$f_{cr}' \geq f_{ck} + 1,48 \sigma \text{ ----- (Equation 2.10)}$$

### **2.3 Empirical Review of Literature**

The empirical literature provides empirical evidences of quality management practices in ready mix concrete suppliers. Additionally, at the end of this section the conceptual framework of this study is presented.

Quality Management has increasingly been adopted by ready mix concrete supplier companies as an initiative to solve quality problems and to meet the needs of the final customer. Accordingly, this section is concerned with other studies conducted on other area in similar discipline. The first study selected for the empirical review is “Study of Quality Management to continuous improvements in process of Ready-Mix Concrete production” in India. This research explores preliminarily the practices of quality management, management commitment in quality management, and quality management implementation problems in construction projects in the context of indian construction industry. The other study conducted by (William C, 2008) in their study on factors involved in equipment quality and management in ready mix concrete in India, identified four major factors that most important determinants in general ready-mix concrete; Experience and qualification of personnel, quality of materials and equipment, conformance to specification and quality assurance training and meetings (Karthik, 2018). In addition, as Joy stated in his study on factors influencing quality of construction projects, the major factors that affect quality; material, labor, financial issues, conformance to codes and standards, top management support, management factors, selection of contractor, selection of designer design, co - operation of parties, contract documents and lack of communication (Joy, 2014).

Factors like increasing urbanization, growing population and rising focus of government oninfrastructural development are driving India ready-mixed concrete market. The government of India launched smart cities program to create cities equipped with good infrastructure offering high quality of life through smart solutions, which is likely to foster the demand for RMC. Further, establishment of manufacturing facilities and power plants to keep up with the growing demand for energy is further anticipated to stimulate the demand for RMC during the forecast period.

## 2.4 Conceptual Framework

Ready-mix concrete provides a prototypical example of a just-in-time construction process. The following figure shows the details of the conceptual framework:

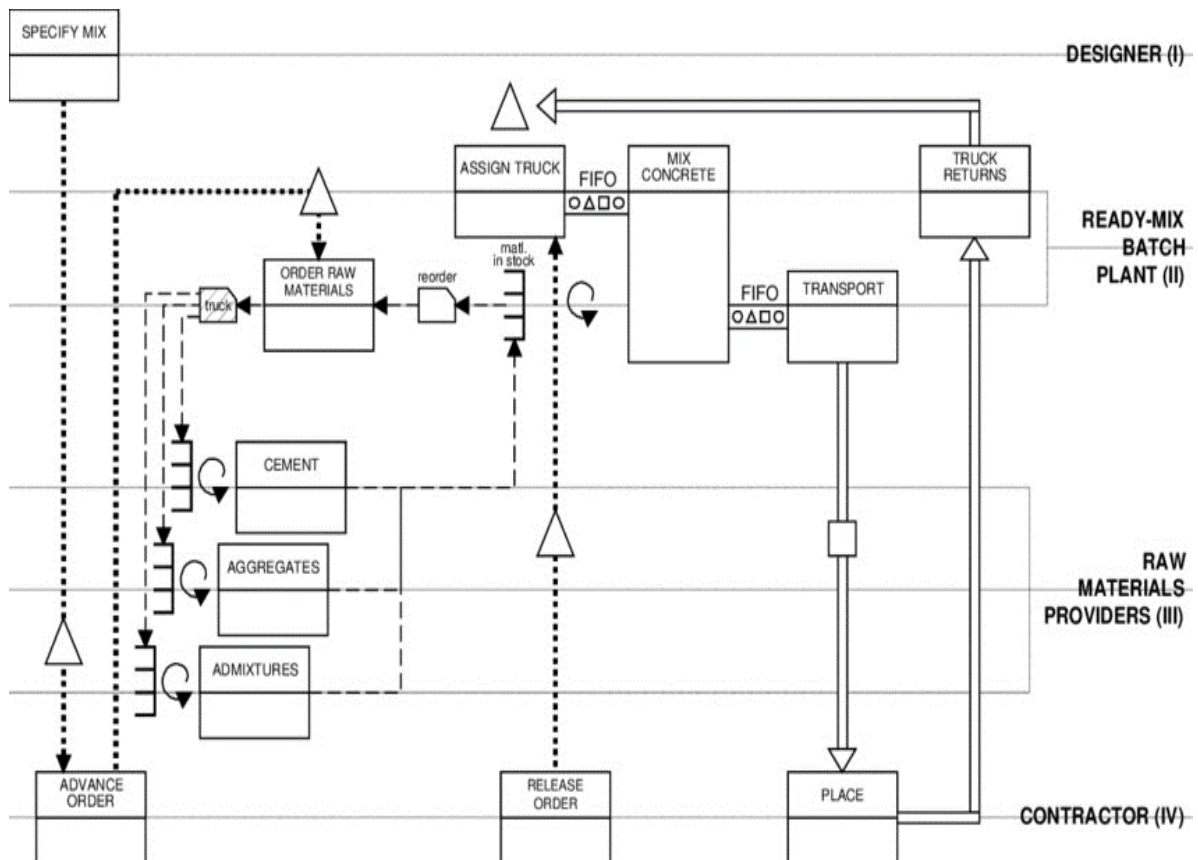


Figure 2.3 Conceptual Framework SOURCE: Andinet kassaye

## 2.5 Best international and local practices

### 2.5.1 Global

RMC, or Ready-Mix Concrete, was first invented in Germany in 1903. However, due to transportation constraints, commercial delivery was initially not possible. It wasn't until 1913 that the first commercial delivery was made in Baltimore, Maryland, United States. In 1926, the first revolving drum transit mixer was invented. A RMC factory was established in 1931 for the development of Heathrow Airport in London. By the mid-1990s, the UK had over 1100 RMC factories, consuming about 45 percent of the cement produced there. In 1997, 5850 firms in Europe produced a total of 305 million cubic meters of RMC. RMC factories consumed roughly 72 percent (more than 2/3) of cement produced in the United States by 1990. The first RMC factory in Japan was established in 1949. By 1992, Japan had become the world's largest producer of RMC, with 18196 million tons produced. The RMC business is well developed in many other nations throughout the world, including some developing countries like Taiwan and Malaysia.

### **2.5.2 United Kingdom**

There is a high demand for planned mixed housing in the UK, with approximately 16 million cubic meters per year being used to meet their needs. To meet their needs, they use very good composite materials, especially for the construction and construction of buildings. Demand is expected to be approximately 25 million cubic meters by 2025 (BRMCA, 2016). The stone manufacturer's quality management system is BS EN ISO 9001 approved. Validity of the manufacturer's declaration of conformity.

### **2.5.3 South Africa**

The demand for ready-mixed concrete in the South African construction industry has increased significantly in recent years. This is due to extensive investment from both the government and private sectors in new construction projects, including the 2010 FIFA World Cup stadiums and other infrastructure developments such as the Gautrain Rapid Rail Link and airports. The production of concrete is expected to continue consuming large amounts of energy and resources in order to meet the needs of the growing population (Rachel M., 2013)

### **2.5.4 Concrete Production practice in Ethiopia**

In developing countries, concrete production is often labor-intensive and highly susceptible to waste, resulting in poor quality. Quality control in concrete production begins at the early stage with material selection. The constituents of concrete, primarily naturally occurring materials, exhibit a wide range of variability. Water, the first constituent, is relatively consistent and readily available. Cement, the second constituent, is a factory product and its production process and quality can be easily controlled. However, the third constituents of concrete, which are coarse and fine aggregates, are naturally occurring and subject to significant variability (Denamo A, 2005.).

It is crucial to focus on the entire production system of concrete to achieve the intended quality. Research conducted on quality control in the Ethiopian construction industry indicates a significant gap between the produced concrete and the required standard. This suggests that substantial improvements are necessary to enhance concrete quality in the construction industry. An analysis of test results reveals that 51.23% of projects do not meet the quality control requirements, with 19.51% falling in the "fair" classification range and 31.72% in the "poor" range based on the computed standard deviation. Additionally, the coefficient of variation shows that 53.67% of projects do not meet the quality control standards, with 39.02% falling in the "fair" range and 14.65% in the "poor" range. This

indicates unsatisfactory quality control in a significant portion of the investigated projects. Furthermore, more than half (52.17%) of the projects have defective lots that fail to meet the compliance requirements set by the Ethiopian building codes and standards (Abebe E, 2005)

Examples collected by Cube Testing according to Ethiopian Standards (EBCS - 2, 1995) It shows that 60% of the products are defective and 40% are defective. When measured against other parameters, the number of defective materials dropped to 47.6%, meaning that most mixed concrete produces concrete that does not comply with established standards. The quality of the concrete mix is not properly controlled (Mihiretab, 2021)

Additionally, research using consistent criteria to assess the quality of concrete in Ethiopia indicates minimal improvement over the span of more than ten years. This stagnation is troubling, underscoring the urgent need to address not only the unsatisfactory results but also the ongoing lack of progress. Statistical quality control, based on compressive strength tests from selected projects, reveals that 40.4% of the results were deemed defective according to EBCS-2:1995 compliance standards. Furthermore, another assessment shows that 35.4% of the results indicate inadequate quality control when evaluated by standard deviation, while 71.25% reflect poor quality control practices based on their coefficient of variation (Habtamu, 2017)

Several factors contribute to these issues, which are widespread in the Ethiopian construction sector. These include the use of poorly graded aggregates, excessive silt, clay, and dust content in sand, contaminated water, insufficient understanding of the bulking effect of sand, variations in moisture content of aggregates, and the uncertainty regarding the dates of cement, which may lead to the use of expired products. Quality problems are also significantly exacerbated by batching errors such as under batching and over batching. Furthermore, inadequate supervision of each stage of production, a lack of commitment from management, and poor workmanship in the production of quality concrete further complicate these challenges (Habtamu, 2017).

Site-mix concrete production has been the dominant method in Ethiopian concrete production. However, there are efforts to promote the use of ready-mixed concrete in the Ethiopian construction industry. Challenges with site mix production include a shortage

of skilled laborers, inadequate space for raw material storage and handling, excessive raw material wastage on construction sites, improper mixing of ingredients, lack of proper maintenance of the water-to-cement ratio, and low productivity.

## **2.6 Summary of Literature Review**

To ensure the production of high-quality concrete, it is essential to adhere to the appropriate procedures beginning from the initial planning phase and continuing throughout the entire lifecycle of the concrete structures. All individuals involved in the concrete manufacturing process must recognize that every step affects the quality of the concrete produced. It is vital that the materials used in concrete production are tested and found to be free from defects. Furthermore, the machinery and equipment utilized for concrete production should receive regular maintenance and calibration.

The quality of concrete is assessed based on its ability to satisfy specific job requirements regarding strength, durability, and aesthetics. Strength is a crucial criterion for evaluating concrete quality, as it is straightforward to define and measure during production. To guarantee the intended quality of ready-mixed concrete, meticulous management of all elements—including the quality of materials, conditions at batching plants, maintenance of equipment, proper mixing techniques, timely delivery of the mixed concrete, and other relevant factors—is essential.

International practices in ready-mixed concrete have demonstrated that developed countries possess the capability and expertise needed to produce high-quality ready-mixed concrete. Currently, these countries use over 70% of their cement for ready-mixed concrete. In contrast, developing nations need to shift from traditional methods to mechanized concrete production and prioritize the quality of concrete they manufacture.

At this time, the ready-mixed concrete (RMC) sector is well-established in Europe and the USA. In the USA, 75% of cement is used through RMC, representing the highest achievement in mechanization within concrete construction globally. In Europe, approximately 47% of cement is consumed in RMC plants.

Concrete is a composite material made from two primary components: aggregates and paste. The paste, created through the chemical reaction between cement and water, binds the aggregates into a solid mass. To obtain the desired characteristics in the paste, mineral

and chemical admixtures are incorporated. Typically, cement constitutes around 7% to 15% of the total volume of concrete, while water makes up 14% to 21%. In air-entrained concrete, air content ranges from 4% to 8% of the total volume. Aggregates represent about 60% to 75% of the overall concrete volume, with admixtures added as necessary. Properly mixed concrete ensures that each aggregate particle is fully coated with paste, filling all the gaps between aggregates, which compose roughly 25% to 40% of the total volume. The quality of the concrete largely depends on the quality of both the paste and aggregates, as well as the bond between them; thus, the selection of materials significantly influences the desired concrete quality.

For the effective production of ready-mixed concrete, it is imperative to store concrete-making materials in appropriate locations to prevent contamination. Cement should be stored in silos to keep it away from moisture, which could cause premature hardening and compromise the concrete's strength. Aggregates should be kept in covered bins, sorted by size, to protect them from rain and direct sunlight. Water is generally stored in tanks situated near the plant, which should be kept clean and well-maintained. Admixtures are typically stored in drums, but can also be placed in dedicated storage tanks.

Moreover, the process of ready-mixed concrete production plays a significant role in determining the quality of the final product. Each stage—including batching the ingredients, mixing the concrete, transporting it from the batching plant to casting sites, and transferring the concrete—must be executed correctly according to established requirements.

The construction industry in Ethiopia predominantly utilizes conventional on-site concrete production methods. However, concrete structures often fail to meet requirements due to various factors, such as infrequent availability of concrete-making materials, usage of materials that do not meet requirements, inadequate documentation of test results and production processes, lack of proper supervision, improper decision-making based on non-compliant concrete test results, and failure to apply statistical quality controls.

## 2.7 Research Gaps

In the review part of this paper, an attempt was made to see few years ago RMC is practices in our county. research's done on our country from the review part of this paper many of the papers worked on quality management practice of RMC Suppliers in Addis Ababa. most of the researchers analyzed or done on commercial delivery RMC company and contractors small RMC batching plants at the same times. Separately RMC commercial suppliers company was not investigated.

Similarly, from the review part of this paper few researchers were worked on quality control practice of RMC Suppliers in Addis Ababa by

**Population gap:** - This research differs from the other by firstly, investigated on Separately commercial RMC suppliers company or industry.

**Methodological gap:** - Secondly, unlike the other researches this research's conducting the research in relation to the study's objectives by data though observation, interviews of experts, comprehensive cube tests and case studies this is methodological gap. The previous researchers collect the data through simply distributing questionnaire.

## 3 CHAPTER THREE: RESEARCH METHEDODOLOGY

### 3.1 Introduction

This section focuses on detailing the methodological approach employed, outlining the procedures followed in conducting the research in relation to the study's objectives. Initially, it describes the data collection methods, which included observation, interviews of experts, comprehensive cube tests and case studies. The gathered data is subsequently analyzed and discussed, leading to the formation of conclusions and recommendations.

### 3.2 Description of Study Area

Leading Ethiopian producer of concrete GENTIUM Concrete Industries Plc was established as a joint venture with a foreign business. GENTIUM concrete industries plc is a leading concrete manufacturer in Ethiopia that was founded through a joint venture with a foreign subsidiary.

Gentium industries was founded in 2019 by a group of like-minded individuals with extensive knowledge in the construction material industry, as well as experts in the managerial, technical, and operational aspects of the concrete industry in Addis Ababa, around Bole, Bulebula. They place the utmost emphasis on exceeding clients' expectations. they have earned clients' trust and are proud to associate they names with the majority of iconic projects throughout the GCC countries thanks to decades of successful experience combined with the most recent technological advancements in the design and provision of various types of ready-mix concrete.

The goal of Gentium Industries PLC is to supply the Ethiopian construction industry with high-quality concrete products that are delivered on time and with perfect service while adhering to the highest standards in terms of people technology, and equipment.

#### 3.2.1 Product and Services.

**Ready Mix Concert:** - A single batch of ready-mixed concrete that is delivered to the customer on-site and is specifically made for their construction projects. Sand, gravel, or crushed stone are combined with cements, water, and aggregates.

**Supply of Chemicals (ADD MIXTURES):**-By combining cutting-edge chemical admixtures with the correct ratios of the various concrete ingredients, Gentium concrete businesses are able to alter the properties of concrete. We can build concrete that is more

fluid, stronger, develops strength faster, and also maintains workability longer, depending on the type of application and jobsite requirements.

**Research & Development:-**They carry out a variety of research projects aimed at maximizing the use of ready-mixed concrete. to find the best techniques and components for our consumers around the nation.

### 3.2.2 Project done by Gentium Concrete Industries plc

Table 3. 1. Project done by Gentium: **source company profile of gentium**

ITEM NO	Project name	Project type	Total supplied concrete	location	Status of project
1	GIFT Real Estate	G+9, 2B+G+14 2B+G+12.	35,000 m3	Hayat	<b>finished</b>
2	GTS Construction	3B+G+19, 3B+G+12, and 2B+G+16.	supplied more Than 6,000m3. For three different sites in 3 days	Bole	<b>finished</b>
3	Oromia Insurance company OIC HQ	5B+G+44	Casted 6300m3 within 6 days	Mexico Square Wabishebele Hotel.	<b>Ongoing project</b>
4	Oromia International Bank OIB HQ	3B+G+30	4,514m3 within three days	Senga tera	<b>Ongoing project</b>
5	Mehal OLOMPIA	3b+g+22	MORE THAN 21,000 M3 OF CONCRETE This project	Bole, next to dembel city center	<b>Ongoing project</b>
6	ASEPH Engineering		11,000m3	kasanchis and around bulgaria.	
7	GIFT Real Estate	3B+G+20, 4B+G+20 8,BLOCK	>35,000.00m3 of concrete	HAYAY	<b>Ongoing project</b>

### **3.3 Research Design and Approach.**

The research design serves as a comprehensive strategy for addressing the questions posed and managing the challenges experienced throughout the research process. This study utilized a descriptive survey research design and incorporated both quantitative and qualitative methodologies. The primary objective of the research was to examine quality control practices for ready-mixed concrete at Gentium Concrete Industries.

To gather data for this investigation, various methods were employed, including desk studies, interviews, and site observations. Interviews were specifically tailored to gather in-depth insights regarding the inventory and sourcing of materials. Additionally, observations were conducted to gain firsthand knowledge about the storage and handling of materials. The desk study aimed to assess the compliance of compressive strength with standards set by ACI and EBCS-2. Moreover, it also included a comparative analysis of aggregate test results in relation to the codes used in various countries.

### **3.4 Target Population and Sample Size**

The targeted population of the study was staff and projects found under Gentium Concrete Industries. In Gentium, there are 8 ongoing projects and batching plant sites in Addis Ababa and 53 staff with experience related to batching plant and RMC work on the ongoing project. This study aims to investigate Ready-mixed Concrete Quality Control Practices.

### **3.5 Sampling Techniques and sample size**

Sampling size was pre-determined experts that from 53 staffs 43 key professionals were taken for sample.

To choose the interview experts, a purposive (Expert) sampling method was utilized. This technique was selected because it enables the researcher to concentrate on a specific group of informants drawn from various departmental employees in order to gather the necessary information for the study and gain optimal insights. Discussions with key experts were held, including those in positions such as ready-mixed concrete plant managers, quality managers, project managers, lab technicians, material engineers, sales engineers, and site engineers. In this research, the batching plant served as the unit of analysis. The experts were chosen based on their expertise, knowledge, and the relevance of their work

concerning the implementation of project quality management and the management challenges faced in Gentium Concrete Industries.

### **3.6 Data Collection Methods and Approaches**

To gather the information required, both primary and secondary or structured and unstructured method of data collection methods were used. The primary data approaches were collected by using conducting observations at the construction and batching plant sites, group interviewing experts at RMC suppliers, and conducting concrete tests. Secondary data were obtained from concrete compressive strength cube test results of 3 projects and on batching plants that were using the material, and from literature.

The research commenced with an evaluation of various literature connected to the research goals. It included references to established concrete standards like the Ethiopian Building Code of Standards (EBCS) and the American Concrete Institute (ACI) codes, among others. Additionally, concrete test results from 15x15x15 cm cubes were gathered for three projects, as well as from batching plants using Ready-Mix Concrete (RMC) situated in different areas of the city for analysis. These projects were selected based on their accessibility, allowing for a comprehensive review of test results and the opportunity to explore the diverse range of concrete grades achieved..

#### **3.6.1 Methods of Data Collection**

This study considered a mix of both quantitative and qualitative data. Data were gathered through a review of documents, direct observations at construction sites, group interviews, and discussions, as well as from documents containing shear and compression strength test results. The expert interviews focused on the responsibilities and construction work experience of the experts.

The research commenced with an assessment of existing literature relevant to the study area, which yielded various insights from journals, prior research on similar topics, and relevant books. It also included an examination of standard codes for concrete quality control, such as the Ethiopian Building Code of Standards (EBCS), American Concrete Institute (ACI) codes, and ASTM C94.

To evaluate the quality of concrete materials and implement statistical analysis, a panel study was conducted on selected projects. Data were obtained from the Addis Ababa University Testing Center laboratories, specifically from test results conducted in 2023-2024, and were analyzed in comparison to the Ethiopian Building Code of Standards (EBCS 1995) and ACI guidelines. This desk study aimed to fulfill one of the objectives, which was to evaluate the level of statistical quality control applications in relation to both Ethiopian and ACI standards.

Additionally, to address the remaining specific objectives, the study required discussions with key experts or focus groups, including ready-mixed concrete plant managers, quality managers, project managers, lab technicians, material engineers, sales engineers, and site engineers. Based on the literature review, observations, and the desk study, the researchers utilized a Likert scale to assess the attitudes of experts through a structured portion of the interviews, which were categorized as follows: 1 = Strongly No Influence; 2 = No Influence; 3 = Influence; 4 = Moderate Influence; 5 = Strong Influence.

### **3.6.2 Observation and Interview**

From the 7 ongoing projects, 3 ongoing projects and batching plants were addressed through observation and interview, and Gentium Concrete Industries batching plant sites were visited. Enabling an observation of about 50 Trucks of RMC delivery, 5 concrete pumps, placing, finishing, and curing activities.

#### **3.6.2.1 Observation and focus group discussion at the Concrete Batching Plant Sites**

Data about the inventory of Gentium Concrete Industries, and their sources of raw materials have been collected through Key expert discussion or focus group discussion for ready-mixed concrete plant managers, quality managers, project managers, lab technicians, material engineers, sales engineers, and site engineers. Besides, the way raw materials were handled, the adequacy of the facilities furnished, the practices that might affect the properties of the concrete delivered, and the practice thereof in general in producing concrete were observed in both structured and unstructured ways.



Fig 3. 1. Batching plant, source: from company profile of Gentium

### 3.6.2.2 Observation at Construction Sites

The observation included an assessment of the practice in assuring continuous delivery of the material. Besides, it was also observed, in both structured and unstructured ways, how the produced concrete had been handled at the construction sites, including the practice of placing, finishing, curing, and removal of forms.

### 3.6.3 Compressive Strength Tests

In this study, samples of concrete were taken from concrete that was continuously produced for 3 days for use at construction sites located in the city. The specified grade of concrete was c30, C-40, and c-60. A total of 110 cubes of concrete were tested from samples taken 3 times from 3 projects total of 330 cubes; i.e., 3 cubes were cast each time a sample was taken. They were cured for 28 days in clean tap water at the batching plant where they were cast with the curing water getting changed every 7 days to assure the cleanliness of the water. After curing for 28 days, the 28 days' compressive strength tests were conducted for each at one of the laboratories in the city to evaluate their average compressive strength.



Fig 3. 2. Testing strength at a laboratory, **source: prepared by researcher**

### **3.6.4 Case Studies**

three different projects which were located in different areas of the city, and which had been utilizing RMC supplied by Gentium Concrete Industries were considered for evaluating their level of quality control by using statistical tools. Records of the 28-day strength test results of each of the projects were collected for analysis. The details of the projects and the durations within which the tests were conducted are discussed herein below. The projects are named Project 1, Project 2, Project 3, and on batching plant by the researcher.

#### **3.6.4.1 Project 01 Oromia Insurance headquarters project.**

The 44-story structure, which has five basements, is built on 3,004 square meters of land that were leased from the city government and is situated between the offices of the Federal Small & Medium Manufacturing Industry Development Agency and the Ethiopian Coffee, Tea Marketing and Development Authority near Mexico Square and the Wabishebele Hotel.

Records of 28 days compressive strength conducted from 9-jan-23 to Feb Jan-24, A total of concrete cubes of 90 were collected. under construction, at the time the data was collected. The desired compressive strength c-40mpa and c-60mpa were collected.



Fig 3. 3. **Oromia Insurance headquarters project. source: prepared by researcher**

#### 3.6.4.2 Project 02 Oromia International Bank headquarter project.

The 28-story structure, which has four basements, is built on 1,192 square meters of land that was leased from the city government and located at Mixico Senga Tera. Records of 28 days of compressive strength were conducted from 17-Feb-24 to 23-Mar-24, A total of concrete cubes of 90 were collected. under construction, at the time the data was collected. The desired compressive strength c-40 and c-60mpa



Fig 3. 4. **Oromia International Bank headquarter project, source: prepared by researcher**

### 3.6.4.3 Project 03 Mehal OLOMPIA project.

The 22-story structure, which has three basements, was built on 2200 square meters of land that was located near Bole, next to the Dembel city center building in front of the roundabout. Records of 28 days' compressive strength conducted from 1-feb-23 to 12-march-24, i.e., for about 1 year, a total of 60 concrete cubes were collected. The desired compressive strength c-30mpa and c-40mpa



Fig 3. 5. Mehal Olympia project , **source: from company profile of Gentium.**

## 3.7 Method of Data Analysis Applied

This research used a combination of qualitative and quantitative data analysis methods. Information gathered from primary sources, including contractors on-site and Gentium employees, was analyzed and interpreted utilizing the Statistical Package for the Social Sciences (SPSS) version 27. Once the data was entered into SPSS, descriptive statistics such as frequency, percentage, mean, and standard deviation were computed and analyzed.

### 3.7.1 Ishikawa Diagrams/Fishbone Diagrams

That shows the potential causes of a specific event. Factors that are identified and collected through literature review and surveys are analyzed using a cause and effect diagram. An Excel template already prepared for such purpose is used in developing the diagram in this study.

### 3.7.2 Statistical Analysis

The 28 days' compressive strength test results are analyzed using SPSS 27 statistical analysis software based on an output of which statistical values were discussed; and, the numeric and visual outputs for skewness and kurtosis z-values, the Shapiro-Wilk test and the Kolmogorov-Smirnov p-value, standard deviations, and histograms were investigated to tell whether or not the strength results are normally distributed. In addition, one sample t-test was conducted on the test results, and the outputs are then discussed.

### 3.7.3 Mean Score (MS)

The results of this part of the study provide the mean score (MS) and the rank of the factors causing variation of properties of RMC between batches of products. Strength is considered among the properties of concrete for the assessment as this property can be indicative of other properties also. It was assumed that an expert interview can assist in studying the attitude of professionals in the field towards the impact of the factors causing variability of properties of RMC. The from expert intrerview 46 factors collected through literature review, and these factors were categorized under 5 groups, namely: material factors, machine factors, methodology factors, human factors, and environmental factors. The mean score (MS) for each potential factor of variation is calculated using the following formula:

$$MS = \sum (fxS)/N..... [3.3]$$

Where:

MS = Mean score

f = frequency of responses for each score

S = score given to each factor (1 to 5)

N = Total number of responses for each factor

The ranking of the factors was determined using SPSS 27.

## 3.8 Validity and Reliability Test

**Validity** refers to the extent to which a researcher accurately measures what they intend to measure (Smith 1991: 106). In this study, the researcher aimed to enhance both the validity and reliability of the data collection and findings by utilizing a combination of observation, interviews, and desk studies, thereby triangulating the results acquired from these varied methods.

**Cronbach's alpha** is commonly employed to assess the internal consistency of surveys that incorporate multiple Likert-type scales and items. The findings reveal that Cronbach's Alpha values vary between 0.822 and 0.929 across different categories, indicating that the expert interviews exhibit strong reliability. A score below 0.7 for Cronbach's Alpha suggests that the experts interview may need to be disregarded (Anosike N. M., 2011). According to this standard, the scores are as follows: material-related factors received a score of 0.929, batching plant machine-related factors garnered 0.903, people-related factors achieved 0.894, methodology-related factors received a score of 0.827, and environment-related factors obtained a score of 0.822 for Cronbach's Alpha. Consequently, it can be concluded that the findings from the expert interviews and observations are both reliable and valid.

### **3.9 Ethical Consideration**

Prior to initiating the study, informed consent was obtained from all individuals participating in the interviews and discussion. Participants were given a detailed explanation of the study's purpose, as well as information about the procedures and methods employed for data collection. To protect participants' anonymity, they were not obligated to provide their names or the names of their companies, and explicit instructions were given to emphasize this point. Consequently, all information gathered from the survey was treated with the highest level of care to ensure strict confidentiality.

## 4 CHAPTER FOUR: RESULTS, ANALYSIS AND DISCUSSION

### 4.1 Introduction

In this chapter, the researcher analyzes and discuss the results derived from observations, expert interviews, and analyses of case study materials related to the cubes studied. Additionally, the researcher incorporate concrete laboratory test outcomes and observations gathered from RMC batching plant locations.

The interviews revealed that key participants held positions such as plant manager, quality manager, project manager, lab technician, materials engineer, sales engineer, and site engineer. Additionally, concrete cube test results and the material mix design tests used for preparing the concrete cubes were sourced from the Material Testing Centers at Addis Ababa University AAiT.

### 4.2 Analysis and Discussion of Expert interviews

The collected raw data through expert interview were analyzed using SPSS 27 Statistical Analysis Software. The results of the software are then discussed. The analysis and discussion are presented in the same sequence of the parts as presented in the interview and observation.

#### 4.2.1 Part One: General Information

##### 4.2.1.1 Educational Background of the Experts

As presented in the Fig 4.1 above, the majority of the experts (40%) hold First Degree whereas only 37% hold Advanced Diploma, and the remaining are post graduates. It can be seen that the professionals engaged varied in their level of education with the maximum percent being with first degree or greater. This makes the responses more reliable.

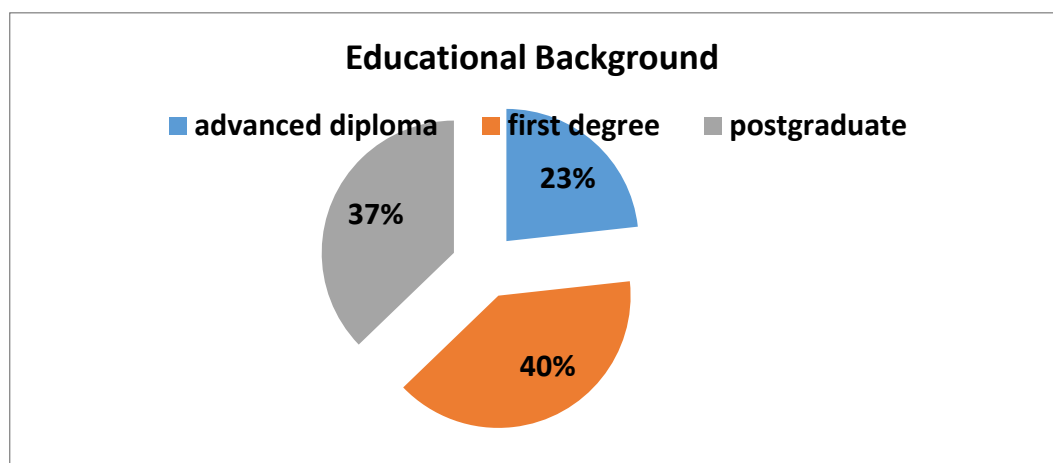


Fig 4:1 Educational background of the experts, source: prepared by researcher

#### 4.2.1.2 Position in the Company

Of the total experts, 3% are plant managers, and 2% are quality managers by Job title as presented in the fig. below. Others take 9% project manager. 28% are lab technicians, 30% are sales engineers, and 28% are site coordinator engineers. All of them had direct involvement in the use of RMC in their projects. It was reasonably assumed that all these professionals were required to monitor the processes involved from production until placement and curing of the material.

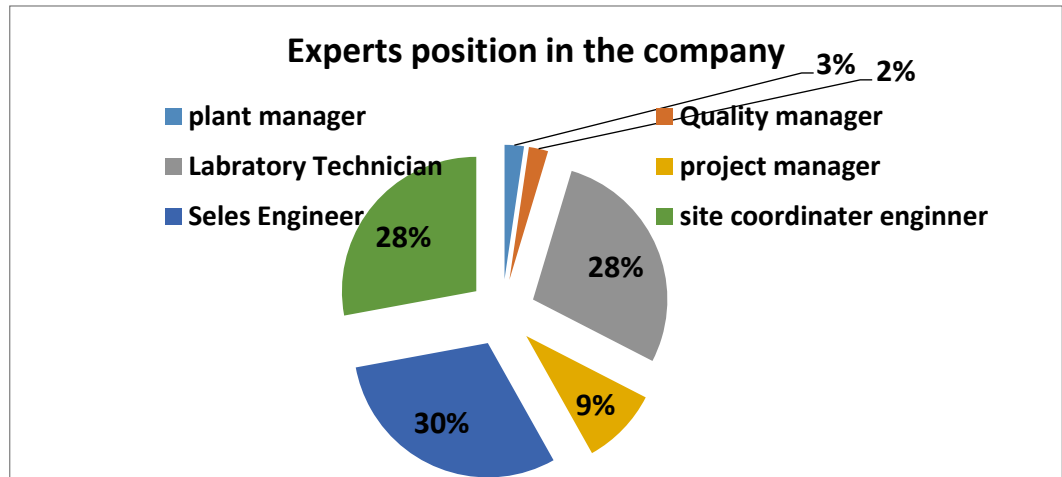


Fig 4:2 Position in the company ,source: prepared by researcher

#### 4.2.1.3 Years of experience

Fig 4.3 above depicts that more than half of the experts (51%) have experience in the construction industry between 5 and 10 years, the experts (26%) greater than 10 years. The remaining 23% have experiences in the industry between zero and five. The experts were varied with their experience in the industry, the majority being senior in level. This gives more weight to the response of the personnel.

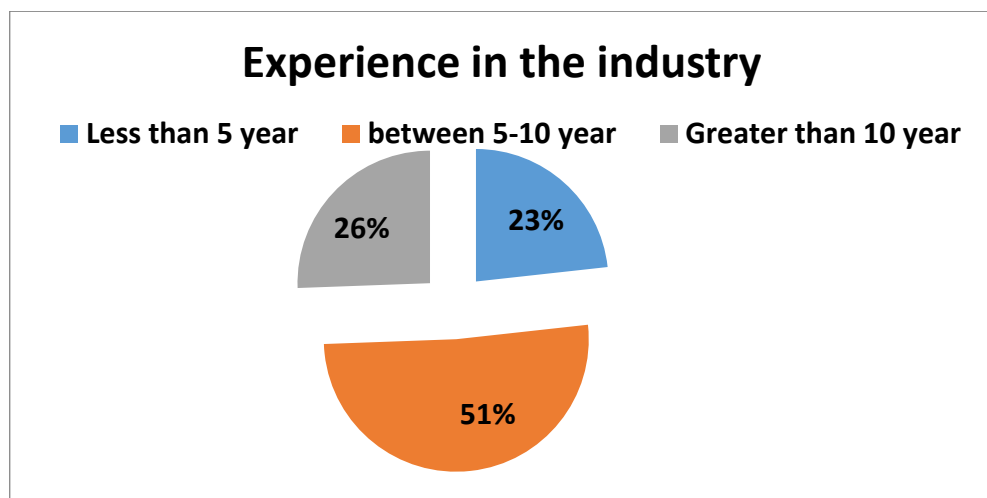


Fig 4-3: Experience of the experts, source: prepared by researcher

#### 4.2.2 Part Two: Factors that influence RMC operations and the quality of ready-mixed concrete.

Depending on respondent experience, the factors were ranked from strongly no influence to strongly influence concerning their company. These factors were grouped into material factors, machine factors, methodology factors, human factors, and environmental factors. The Mean values of the factors included in the interview are presented in Appendix A of this research. The results of all the factors can be leveled as ‘strongly important’ because the Mean values of all the factors are greater than 3.63. However, the factors vary in their ranks, with ‘Periodical calibration of plants and machines taking the first rank.

##### 4.2.2.1 Top Significant Factors

From the total of 46 factors that were identified as causing variability between batches of RMC, the top significant factors as perceived by the experts are presented in the Table 4.1 below.

Table 4. 1. The Top Significant Factors with Their Ranks, **source: prepared by researcher**

<b>Descriptive Statistics</b>				
Groups/Factors	N	Mean	Std. Deviation	RANK
Periodical calibration of plants and machines	43	4.95	0.213	1
The traffic situation on the road to the casting site	43	4.88	0.324	2
Raw material handling	43	4.86	0.351	3
Crew experience	43	4.86	0.351	4
Curing temperature	43	4.84	0.374	5
Travel duration	43	4.84	0.374	7

The top significant factors that cause variation in the properties of RMC batches as perceived by the professionals in the field are; Periodical calibration of plants and machines, The traffic situation on the road to the casting site , Raw material handling, Crew experience, Curing temperature. However, whereas the factor ‘Periodical calibration of plants and machines’ is rated as the most significant factor, the control of the personnel at construction sites over this factor is almost none.

Mihiretab (2021) state that it was found that improper storage of the concrete making materials and its method of transfer and feed systems are the key contributing factors which affect the quality of ready-mixed concrete. In addition, material source, mix design, curing method and lack of periodic calibration of batching plants have also a significant impact on

the quality of RMC. (Mihiretab, 2021). Therefore almost similar factor that influence RMC operations and the quality of ready-mixed concrete.

#### 4.2.2.2 Category Factors

The factors causing variability between batches of RMC are categorized under five groups, namely Material Factors, Machine Factors, People Factors, Methodology Factors, Environmental Factors. The prime factors at each group, together with their mean values are presented in the Table 4.2 below.

Table 4. 2. Prime Factor at Each Category: **source: prepared by researcher**

Descriptive Statistics		
Groups	Factor	Mean
1) machine factors	Periodical calibration of plants and machines	4.95
2) Methodology Factors	The traffic situation on the road to the casting site	4.88
3) Material Factors	Raw material handling	4.86
4) People Factors	Crew experience	4.86
5) Environmental Factors	Curing temperature	4.84

### 4.3 Analysis and Discussion of Observation

#### 4.3.1 Part III Gaps between the process of RMC practiced in Gentium Concrete Industries Plc. and Ethiopian standards

The gaps between the actual practices and the recommended scientific approaches and codes of standards were investigated by undertaking observation at the batching plants and at different construction sites that utilized RMC supplied by Gentium Concrete Industries Plc.

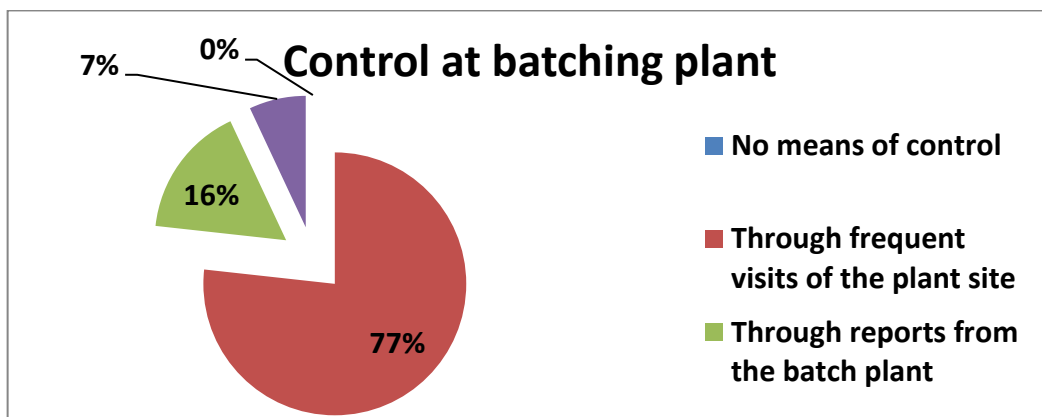


Fig 4-4: Control at batching plant, **source: prepared by researcher**

The largest portion of experts (77%) indicated that they ensure the quality of raw materials at the batching plant through regular site visits. However, when asked about the frequency of these visits, some did not provide an answer. Those who did respond mentioned visiting once a month, every two months, whenever concrete is needed for their project, twice a week, or based on every five trucks at the batching plant and every 100m<sup>3</sup> at the construction sites. The second largest group (16%) reported that they depend on reports from the batching plants to monitor the raw materials. Others either employed a different method (7%), as outlined in the experts' interview, or claimed to have no control over the raw materials (0%). The methods mentioned included conducting cube tests, visiting the aggregate crusher, and verifying the cleanliness of sand and the grade of aggregate and cement to ensure compliance with the mix design. However, during observations at the batching plants and construction sites, no personnel from the construction teams were seen visiting the batching plant sites. In fact, many appeared to rely entirely on the suppliers for the control of raw materials.

#### **4.3.1.1 Gaps in Quality of Ingredients**

##### **4.3.1.1.1 General**

Ready-mix production materials must meet the safety, performance, durability and needs of the finished structure, and also take into account the environment in which it lives. The selection and use of information must comply with standards and regulations. The equipment must meet appropriate standards. Where information does not fall within the scope of standard procedures, satisfactory information regarding its suitability and quality control should be available. Information and details of elements of such information will be preserved. Details of quality control of prepared plant materials are discussed below

##### **4.3.1.1.2 Types of cement**

Two primary types of cement are widely utilized in concrete production. In the case of ready-mixed concrete, 90% of their output comprises OPC (Ordinary Portland Cement), while the remaining 10% consists of PPC (Portland Pozzolana Cement). Consequently, the concrete produced by ready-mixed facilities employs either OPC or PPC, as illustrated in Figure 4.8 below. OPC is well-suited for general concrete construction, particularly when there is no risk of sulfate exposure from contact with soil or groundwater. However, in urban and suburban areas, underground water is more likely to be contaminated with chemicals due to the potential percolation of waste from factories and various household chemicals. As a result, special cement is required when installing sub-structural reinforced concrete elements such as footings, mats, or piles (ACI 116R).

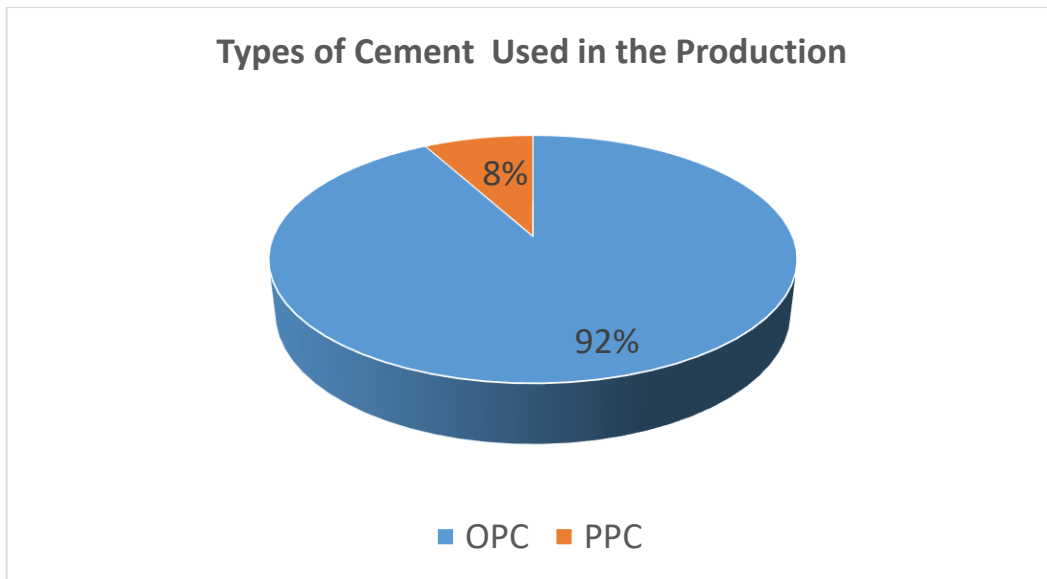


FIG 4.5 cement types used in concrete production, **source: prepared by researcher**

The transport and storage of cement have a significant impact on the quality of concrete. Therefore, it is essential to handle cement with care; otherwise, there is an increased risk of moisture contact, which can result in a considerable loss of strength. In Ethiopia, cement is often transported long distances using trucks and trailers, making it prone to moisture exposure if not properly managed. Another major issue relates to cement storage. After being transported from factories, cement is frequently kept in inadequately constructed stores or shops (as noted in ACI 116R).

In the case of Gentium Concrete Industries, nearly 100% of its cement is sourced in bulk, either through direct delivery from manufacturers or via trucks owned by ready-mixed concrete producers. Using bulk cement offers advantages, such as minimizing waste and improving tracking of the cement's age before use. However, as it stands, Ethiopian cement industries do not provide manufacturing dates on their bags, and trucks and trailers should be utilized more effectively to lessen cement waste. Batching plants typically have silo systems for cement storage, which ready-mixed concrete producer must prioritize during transportation and handling. **Gentium Concrete Industries has a cement storage capacity that includes four large silos, each holding 200 tons, for a total of 800 tons, along with one smaller silo that can store 80 tons, allowing for an overall storage capacity of 880 tons on the batching plant site.**

Before usage, cement needs to be tested for compliance with various standards and codes. At Gentium, there is currently no on-site test laboratory. As a result, ready-mixed concrete

producers rely on external testing companies, such as TCD in Addis Ababa, 5 Kilo University, and Hints College, conducting assessments of the cement at least once a month



FIG 4.6 cement storage source: prepared by researcher

#### 4.3.1.1.3 Water

Water utilized in the production of ready-mixed concrete, which primarily facilitates chemical reactions with cement, must be free from impurities. The Indian standards pose several questions that must be addressed before using water for concrete production: What is the water source? Is there sufficient quality and quantity available? Are there test reports accessible? What measures have been implemented to protect the water storage facility from contamination by harmful substances?

An investigation into Gentium Concrete Industries revealed that 100% of their water source for producing ready-mixed concrete **comes from groundwater extracted from drilled wells**. The research indicated that the water quality was satisfactory and adheres to the Ethiopian Standard Requirements outlined in the literature review. Additionally, Gentium Concrete Industries conducts tests on the water prior to its use. It is recommended that water be tested in Addis Ababa, given the potential for higher contamination risks.

#### 4.3.1.1.4 Admixtures

The use of admixtures should not provide commercially successful improvements by adjusting the cement and concrete proportions and should not affect the properties of the concrete. Additives are not a substitute for good practice. Admixtures should only be used after careful consideration of their effects on the concrete in which they will be used. Evaluation of representative data samples for a given job under simulated operating

conditions is often necessary to obtain reliable information on the performance of concrete containing admixtures [(Alam M. A., 2016)

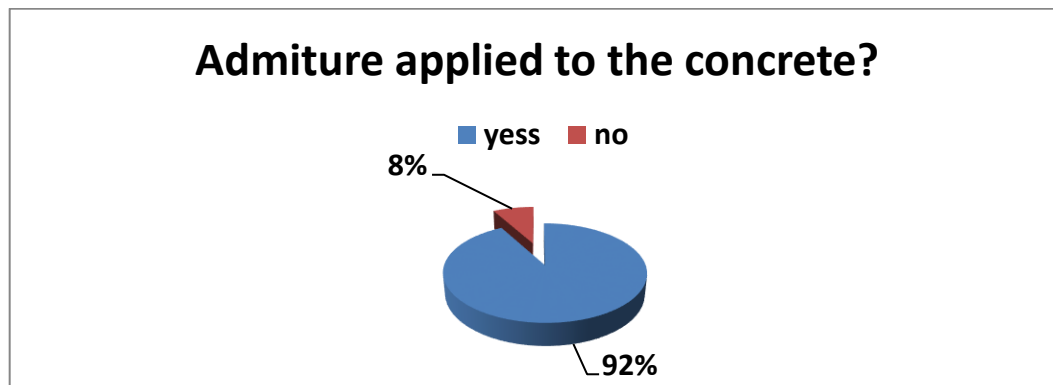


FIG 4.7 Admixture applied to the concrete **source: prepared by researcher**

The majority of the experts (92%) stated admixtures had been applied to the concrete at their batching plant. The remaining (8%) stated that they had not been using such material for concrete delivered to their sites. Those experts who stated that admixture had been applied to concrete delivered to the site stated that it's added at the batching plant every time the material is delivered, at the requirement of modification of workability, when fresh concrete was cast over older concrete already cast, or when rapid curing of structural element is required.

The stated admixtures were RP 30B with a dosage of 1% of cement content, SAS plastic RP 60 with a dosage of 1% of the cement used, and plasticizers (DAYNAMON MR2100 own produced on-site its dosage is 2%-3.5%) of cement content. water-tight chemicals used for waterproof work and its dosage is 0.8%-1%. The addition of admixtures at the sites was left to untrained daily laborers as observed when the material was applied. The dosage should not have been under the manufacturer's instruction, and by trained personnel though.

#### 4.3.1.1.5 Aggregates

Aggregates are essential components of concrete-making materials, significantly contributing to the strength of concrete due to their higher modulus of elasticity. As such, the quality of aggregates has a considerable impact on overall concrete quality, even more so than cement and water.

According to survey results, 89% of experts indicate that ready-mixed concrete production utilizes both natural and crushed aggregate sources. The remaining 11% reported that only natural sand is used for concrete production.

Gentium sources natural sand from various locations to ensure different quality specifications for concrete production, maintaining a consistent supply. These sand sources include **Metehara, Dogo, Meki, Alage, and Elkaadi, situated in Addis Ababa and the Oromia or SNNP regions. Furthermore, artificial sand and crushed aggregate material from TDT and Aleletu are also used.**

Aggregates constitute 60% to 70% of concrete's composition, directly influencing its strength. Variations in aggregate characteristics can significantly affect concrete properties if not carefully managed during production. Unlike cement, aggregates are not manufactured in controlled environments; their physical and chemical attributes—including shape, size, texture, mineral content, and others—can vary widely, thereby impacting the final product's consistency. Consequently, it is crucial to conduct thorough testing and inspection of aggregates.

The tests performed on coarse aggregates include sieve analysis, unit weight measurement, water absorption, soundness, dust content, specific gravity, evaluation of clay lumps and friable particles, flakiness index, aggregate crushing value, Los Angeles abrasion test, as well as tests for alkali-silica reaction (ASR) and aggregate corrosion (ACR). All these tests are routinely carried out at ready-mixed concrete batching sites, which is a commendable practice that should be sustained.

The analysis of the experts interview responses revealed that unit weight, specific gravity, and chloride tests are conducted regularly, whereas water absorption and soundness tests are performed infrequently.

**Surface Moisture, Porosity and Absorption.**

Table 4.3 Specific gravity and water absorption of the tested course and fine aggregate samples. **source: prepared by researcher**

Materials designation used for mix	Date	Coarse Aggregate		Fine Aggregate	
		Specific Gravity	Water Absorption (%)	Specific Gravity	Water Absorption (%)
D1	2/7/2024	2.36	0.8	2.4	1.05
D2	2/7/2024	2.68	0.99	2.8	0.88
D3	2/7/2024	2.7	1.5	2.6	1.15
D4	2/7/2024	2.8	1.2	2.7	1.22
D5	2/8/2024	2.5	1.11	2.45	1.3
<b>Requirement</b>		<b>2.4-3.0</b>	<b>0.2-4.0</b>	<b>2.4-3.0</b>	<b>0.2-4.0</b>

Table 4.3 presents results from five mix design tests for coarse and fine aggregates used in the production of concrete cubes, as discussed in section 4.8 of this thesis. The results according to established requirements are outlined below. While the Ethiopian Standard does not specify any requirements for water absorption, ASTM standards stipulate that the water absorption content for concrete aggregates should fall within the 0.2 to 4% range (ASTM C127). All samples of coarse and fine aggregates tested exhibit water absorption and specific gravity values that conform to this range of 0.2-4%. Therefore, it can be concluded that nearly all aggregates utilized in ready-mixed concrete production comply with ASTM standards.

The specific gravity of aggregates serves as a key indicator of their quality, significantly affecting the strength and absorption characteristics of concrete. Aggregates with low specific gravity may suggest high porosity, which could lead to reduced durability and lower strength, given that the density of concrete heavily relies on specific gravity. Conversely, the bulk density of aggregate refers to the mass or weight required to occupy a predetermined volume, which includes both the aggregates and the spaces between them. This measurement is influenced by factors such as packing, particle shape and size, grading, and moisture content. In the case of coarse aggregate, a higher bulk density generally signifies fewer voids that need to be filled with sand and cement (ASTM C94).

Accurately determining the moisture content of aggregates is essential for establishing the correct water-cement ratio in a concrete batch. Inaccurate assessment of moisture and absorption levels in aggregates may lead to unpredictable water quantities being added during mixing, which can result in incorrect water-to-cement ratios. Thus, continuous monitoring of moisture content and automatic adjustments of water levels in the mixer are vital for minimizing variability in concrete production, especially when the moisture content of the aggregates is inconsistent (Mihiretab, 2021).

Table 4.4: Silt and clay contents of the fine aggregate **source: prepared by researcher**

Materials designation used for mix	Type of sand	Date	Silt and Clay Content (%)	Remark
D1	Natural sand	2/6/2024	4.2	passed
D2	Natural sand	2/6/2024	5.1	failed
D3	Natural sand	2/6/2024	4.8	passed
D4	Natural sand	2/6/2024	4.2	passed
D5	Natural sand	2/6/2024	4.5	passed
<b>Requirement</b>			<b>&lt;5%</b>	

The Ethiopian Standard does not specify any limitations regarding fine aggregate; however, ASTM (C40 – 79) sets the maximum allowable organic content for fine aggregates at plate number 3. If a sample evaluated according to ASTM (C40 – 79) exhibits a color darker than the standard or Organic Plate No. 3 (Gardner Color Standard No. 11), it indicates the potential presence of harmful organic impurities [(ASTM C94 C94M-20, 2020)].

In this study, the test results for the silt and clay content in fine aggregate revealed that the samples fell within plates number 2, with all samples demonstrating acceptable organic impurity levels. According to the Ethiopian Standard, the silt and clay content in any fine aggregate sample must not exceed 5% for all types of normal concrete (ES. C. D3. 201). The silt and clay content values for these fine aggregate samples are presented in Table 4.5 above. The findings show that 20% of the tests did not satisfy the requirements, while 80% met the minimum criteria.



**FIG 4.8 sand storage source: prepared by researcher**

The storage of sand is not well and it is not covered it is exposed to rain or moisture and sunlight or excess temperature also due to this the dust particles negative impact on the environment bs see fig4.8

#### **4.3.1.2 Gaps at Batching Plant Sites**

At batching plant sites, observation and interview were undertaken: collecting data of inventories Gentium Concrete Industries, getting a range of grades of concrete produced in their stories, identifying their sources of raw materials, figuring out the challenges of the Gentium Concrete Industries, and points of deviations of their practices in the processes

involved from material handling until delivery to the Construction site and its placement were assessed.

#### 4.3.1.2.1 Inventory of the Gentium Concrete Industries

Data on the inventory of the Gentium Concrete Industries have been collected through an interview with the staff. Table 4.6. below is the inventory of Gentium Concrete Industries addressed. It was noted that they own 2 batching plants, and all batching plants conduct wet mixing. On the other hand, all of these batching plants are fully automatic though the quality and capacity differ significantly between each other. The no. of trucks owned ranges from 50. However, it was also noted that the Gentium uses rented mixer trucks in addition to what they own. It was noted that cranes, stationary pumps, and truck-mounted pumps were in use to place the delivered concrete to the required location. The capacity of the Gentium is 2000m<sup>3</sup> /day. Table 4.5. below is the capacity of each RMC supplier in terms of their inventory.

table 4.5. Summary of Inventory of the local RMC Suppliers **source: prepared by researcher**

No.	Company name	Batching plants (No.)	Mixer trucks (No.)	Truck mounted pumps (No.)	Stationary pumps (No.)	Cranes (No.)	Capacity of mixer per batch (m <sup>3</sup> )
1	Gentium Concrete Industries	2.00	50	4	4	1	3

The analysis indicated the result that was collected from the experts interview laboratory should have been availed at RMC batching plants. This is very essential for the following reasons: checking raw material quality, checking attainment of mix designs, and conducting between and within the variability of properties of the RMC.

#### 4.3.1.2.2 Ready-mixed Concrete Production Process

##### 4.3.1.2.2.1 Batching

Batching is a process in which a computer is equipped to measure the components of a concrete mix and feed them into the mixer. Batch processing errors are partly responsible for variations in stone quality. Gentium’s batching plant uses gravimetric or mass batchi

ng technology. Weightbased technology has the potential to reduce errors that can occur during concrete construction.

#### *4.3.1.2.2.2 Mixing*

Ready-mixed concrete is prepared and transported to the designated location specified by the buyer or user using various methods.

a) **Central Mixed or Stationary Mixed Concrete:** Concrete is prepared in a stationary mixer at the plant, ensuring a complete mix before being transferred into either a truck agitator or a truck mixer that operates at agitating speed, or into non-agitating equipment as agreed upon by the purchaser. Central mix plants are also known as wet batch or pre-mix plants. When using a truck mixer or agitator for transporting concrete that has been fully mixed prior to leaving the plant, it must be agitated during transit. Additionally, it should be remixed at the site for a minimum of 2 minutes to achieve the desired consistency. According to survey results, 88% of experts in Gentium batching plants utilize central or stationary mixing methods, as illustrated in Fig 4.9.

b) **Shrink Mixed Concrete:** This method involves partially mixing the concrete in a stationary mixer before completing the mixing process in a truck mixer. The duration of the partial mixing should be just enough to combine the ingredients. Once transferred to the truck, the concrete must undergo additional mixing at the designated speed to ensure uniformity, typically for about two minutes in the truck drum. The remaining 12% of batching plants utilize shrink-mixed concrete, as depicted in Fig 4.9.

c) **Truck Mixed Concrete:** While truck-mixed concrete is a method of mixing ready-mixed concrete, it is not recognized as a viable option because it lacks facilities for automatic record-keeping, such as digital computer slips. Consequently, this method is not commonly employed. As shown in Fig 4.9, the results indicate that shrink mixing is not practical in real-world applications.

In Fig 4.9, the result witnessed shrink mix was not practicable in the real world.

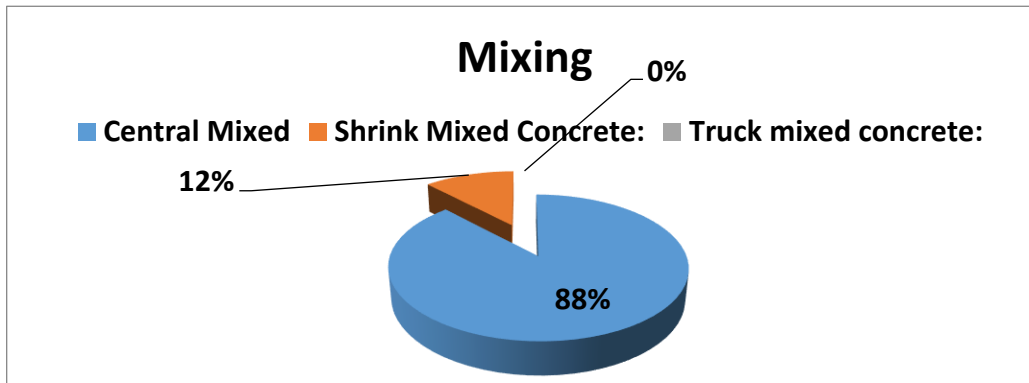


FIG 4.9 Mixing of concrete

#### 4.3.1.3 Gaps of Delivery, Transporting and Transference of Ready-mixed Concrete

Once the concrete is completed at the factory, the next step is shipping. For transportation, mixed concrete is collected in trucks. Transport and planning need to be arranged to deliver the concrete mix on time. Traffic, distance, time allocation, etc. Delays caused by reasons and transportation may cause concrete to fall out. Once loaded onto the truck, it must be sent to its place immediately. RMC deployment is also affected by the skills of the crew, especially the driver. For a successful delivery, special people must be involved in every stage of production, and planning and delivery must be done correctly. RMC customers' choices and decisions will affect delivery time. The distance between the factory and the destination determines the travel time for delivery. The increase in the number of trucks making deliveries between the factory and the construction site also affects the delivery time, causing some congestion between the factory and the construction site. [(Mihiretab, 2021)].

Participants acknowledged that the following factors significantly influence the transportation and delivery time of concrete at Gentium Concrete Industries:

- The distance between the production plant and the construction site
- The speed and traffic conditions
- The location of the site
- The type of casting operation
- The quantity of unloading equipment and the size of the crew at the job site
- The pumping speed
- The number of trucks involved

The researcher noted that the batching plants of Gentium Concrete Industries are situated near Bole Bulbula. During peak hours, it typically takes around 3 hours to transport

concrete from the batching plant to the casting site. Furthermore, the maximum distance that a dump truck has to travel is 130 km, which occurs when going from Addis Ababa to Debre Birhan. According to the responses gathered, the types of equipment commonly utilized for concrete placement include pumps, buckets, chutes, and cranes.

#### 4.3.1.4 Erroneous Practices Exercised at Batching Plant and Construction Sites

**Raw material handling:** In most of the batch plants' sites the only criteria for stockpiling aggregates is placing them by their sizes only. Most often, the newly delivered ones are stocked over the existing ones, and the last entered material was noted to be used first.

At batching plant sites, raw materials are not separated from one another by a wall or another separator so that materials are not intermixed. On the other hand, no treatment of aggregates was seen to be done, dusty aggregates were observed so often though. It seems that the criteria of assuring the quality of raw materials was at selecting better quarry sources for fine aggregates, and the gradation and shape of coarse aggregates. Though tests are done on the aggregates that were delivered, such results were used only to judge the extent of deviation from what was required and to prioritize uses for different classes of concrete produced.



Fig 4. 10. Material Handling at Batching Plants **source: prepared by researcher**



Fig 4.11 Good practice sample **source: prepared by researcher**

**FIG 4.11 indicates that The most serious Erroneous Practice is when the raw materials are not covered they are exposed to rain moisture sunlight or excess temperature and also due to this the dust particles negatively impact the environment.**

**Control over water:** From the time concrete is produced and loaded into the truck mixer to the time even after finishing, additional water was observed to be added to the fresh concrete, either deliberately or without knowledge of the effect of such an act. Most often, daily laborers must unload concrete from a truck mixer to a pump, where they adjust the amount of water in the delivered concrete to make it more workable. The decision of the amount of water to be added is left in their hands. Besides, it was observed that water was added to the concrete while cleaning the truck mixer after it got loaded with concrete at the batching plant. It was noted, through an interview, that additional water had been added to concrete in a truck mixer as a result of the failure to close the water line of the truck mixer. The other time the addition of extra water was observed was when the pump was choked.

- Delayed inter-arrival of delivery trucks: This was observed at some sites affecting the continuity of casted elements and causing idling of crew.
- Delayed unloading/placing of concrete: It was observed that concrete had been placed by using a crane in small amounts, or by hand tools taking large time to unload.

- Formwork failure: Especially at vertical elements, the formworks were noted buckling, failing, and causing bleeding of concrete. Avoiding vibration near the forms, and avoiding directly placing the concrete into the forms are practices some applied to avoid failure of forms at the time of concreting.
- Failing to rotate the truck mixer before pumping began resulted in the segregation of concrete.
- Overvibration of fresh concrete: This was especially a case at times when the continuity of placing was interrupted due to delayed inter-arrival of delivery trucks, pump breakage, etc.
- Placing and finishing without vibration: At a time when there was a lack of close follow-up, it was observed that the crew left the placed concrete without vibration.
- Method applied to correct slump of the concrete

### **Control temperature**

The heat of hydration is the heat generated when water reacts in contact with the cement powder. The amount of heat released depends on the cement composition, curing temperature, water-to-cement ratio, and cement fineness. High temperatures resulting from heat of hydration may cause thermal cracking of concrete and consequent reduction of mechanical properties.

The heat of hydration is an important factor in mass concrete (ACI 207.1R). Mass concrete is any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from the hydration of the cement and resulting volume change to minimize cracking.

Researchers observed the heat of hydration control practice of the gentium concrete industry. As seen in Fig 4. 12 fresh concrete is good under the requirement. The requirement is <30



Fig 4. 12. The way of thermal heat of hydration control on site **source: prepared by researcher.**

But in the case of casted mass of concrete above the requirement listed the value in the thermal modeling design. the values are 88 °c,90°c,92°cand 85 °c but the requirement listed the value in the thermal modeling design is 81°c This indicates not well-controlled heat of hydration

#### **4.4 Analysis and Discussion of Case Studies**

##### **4.4.1 Case Studies and Compressive Strength Tests Conducted**

Four different projects which were located in different areas of the city, and which had been utilizing RMC supplied by Gentium Concrete Industries were considered for evaluating their level of quality control by using statistical tools. Records of 28 days of strength test results of each of the projects were collected for analysis. The projects are named Project 1, Project 2, Project 3, and Project 4 by the researcher.

Here, the results of tests of normality, standard deviations, and histograms obtained from SPSS 27 are analyzed and discussed.

##### **4.4.1.1 Normal Distribution**

The results of the test of normality and histograms of compressive strength test values of the projects studied under a case study are presented below.

Table 4. 6. Tests of Normality source: prepared by researcher.

Tests of Normality								
project	Cubical strength		Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
			Statistic	df	Sig.	Statistic	df	Sig.
project 01	Compressive Strength(MPa )	fck=C 40Mpa	0.289	12.000	0.007	0.835	12.000	0.024
		fck=C 60 Mpa	0.082	78.000	.200*	0.975	78.000	0.131
Test Conducted at the Batch Plant	Compressive Strength(MPa )	fck=C 60 Mpa	0.089	36	.200*	0.968	36	0.368
			0.109	54	0.161	0.966	54	0.127
project 02	Compressive Strength(MPa )	fck=C 40Mpa	0	24	.200*	1	24	1
		fck=C 60 Mpa	0	36	.200*	1	36	0
project 03	Compressive Strength (MPa)	fck=C 60Mpa	0	24	.200*	1	24	1

**Tests of Normality**

	PROJECT	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Compressive Strength(MPa)	PROJECT 01	.279	90	.000	.686	90	.000
	Test Conducted at the Batch Plant	.110	90	.009	.962	90	.009
	PROJECT 02	.229	90	.000	.854	90	.000
	PROJECT 03	.096	60	.200*	.963	60	.066

\*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

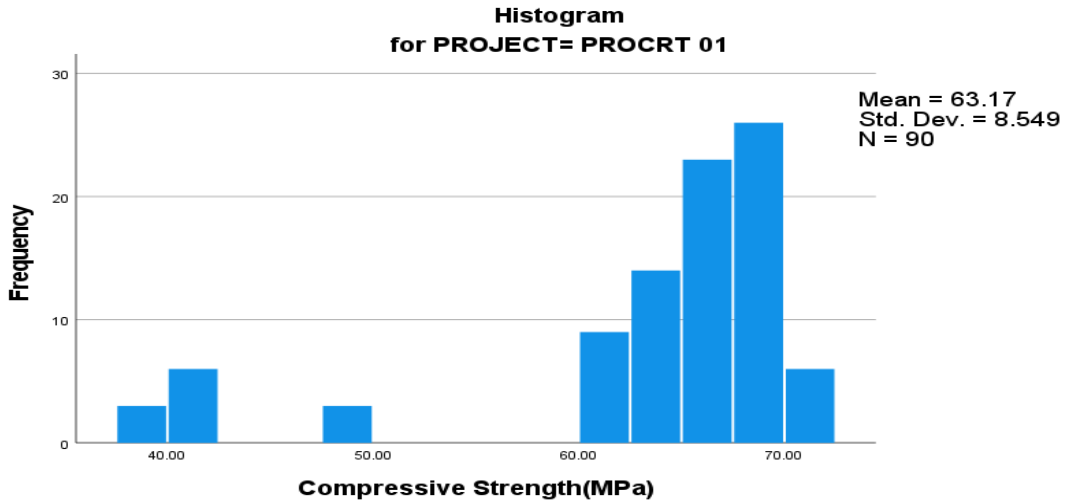


Fig 4. 13. Histogram (Project 1) source: prepared by researcher.

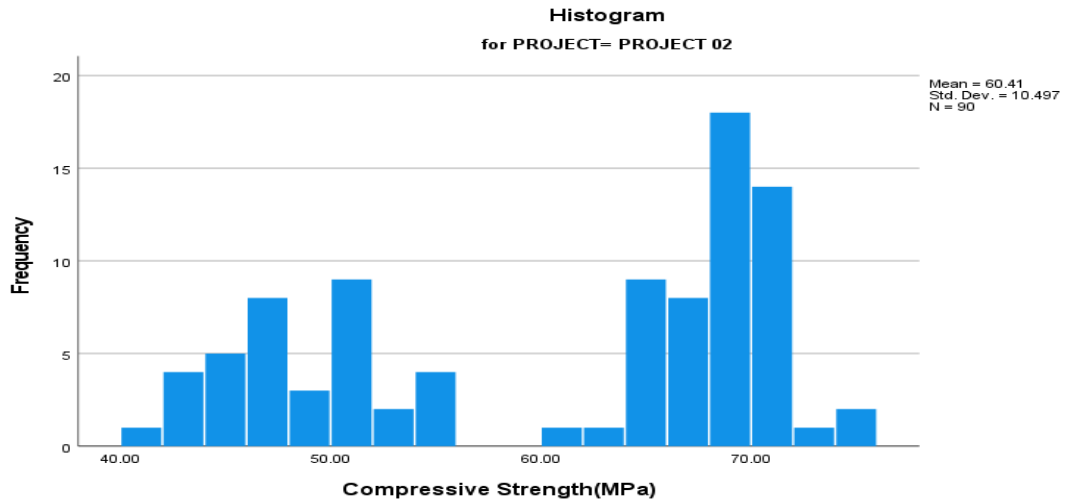


Fig 4. 14. Histogram (Project 2) source: prepared by researcher.

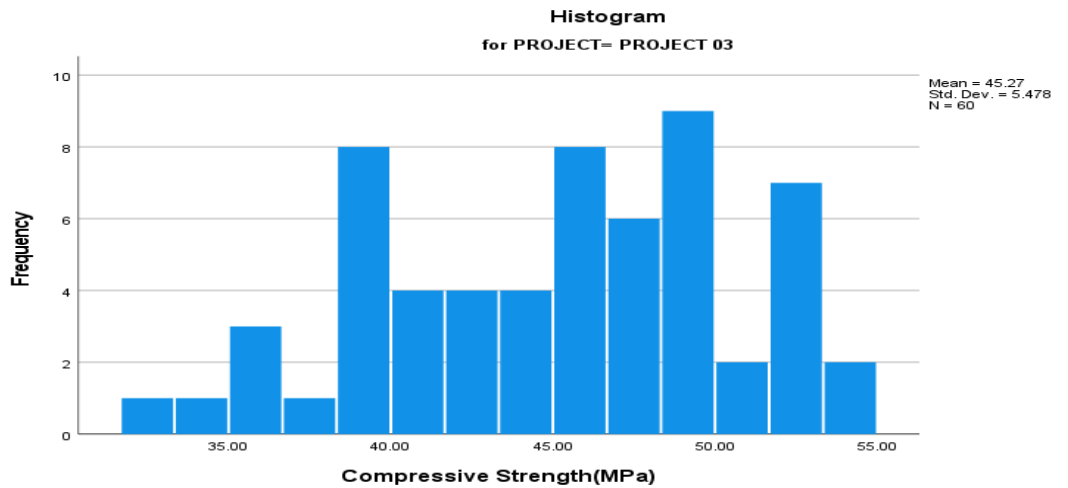


Fig 4. 15. Histogram (Project 3) **source: prepared by researcher.**

Histogram (Test Conducted at the Batch Plant)

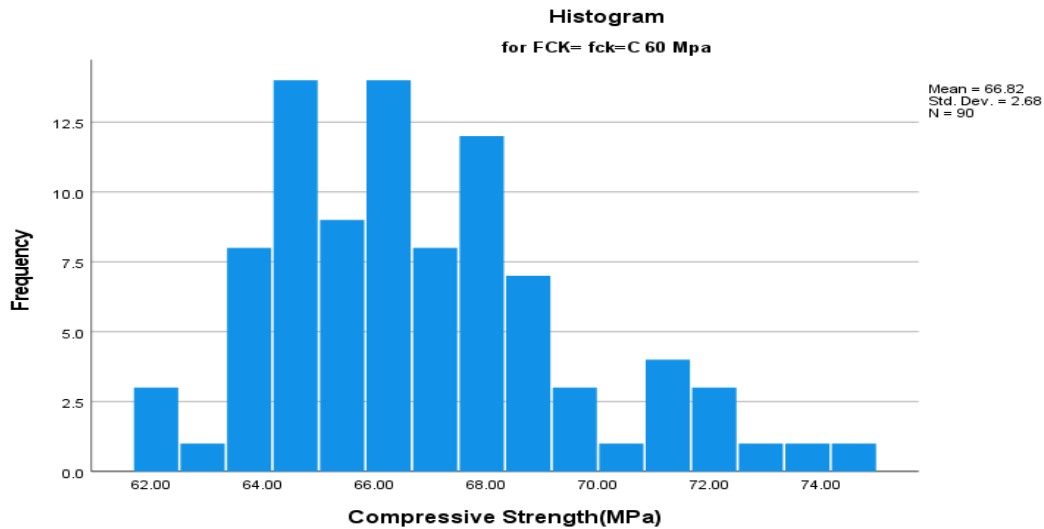


Fig 4. 16. Histogram Fig (Test at the Batch Plant) **source: prepared by researcher.**

As can be observed from the tables and histograms above presented, Shapiro-Wilk or Kolmogorov–Smirnov test ( $p > 0.05$ ) and the visual inspection of their histograms indicate that the test results of the concrete from all the projects except at batching plants are not normally distributed with a skewness together with standard error, kurtosis together with standard error, and the calculated z values tabulated above. The skewness z value is obtained by dividing manually the skewness measure by its standard error. Both the skewness measure and its standard error are obtained from the output of SPSS 24. And, the p value is directly obtained from the SPSS output labeled as “sig”.

The standard deviations of projects 1, 2, and 3, and the test conducted at the batch plant are 8.549, 10.497, 5.478, and 2.68 respectively in MPa as presented in table 4.8 below. These values are also obtained as an output of SPSS 27 Software. Except for the last one, all figures are above 3.51 indicating that the control over the concrete is poor for those projects according to ACI 214.

Table 4. 7. Standard Deviation **source: prepared by researcher.**

Name of the Project	Concrete class	standard deviation
project 1		8.55
	Fck 40 mpa	3.6
	Fck 60mpa	2.6
project 2		10.49
	Fck 40 mpa	3.91
	Fck 60mpa	2.88
project 3		4.478
	Fck 30 mpa	2
	Fck 40mpa	3.6
Test Conducted at the Batch Plant		2.68
	Fck 600 mpa	2.68

However, the standard deviation of the concrete strength test result of the samples taken at the batch plant is between 2.76 and 3.45MPa, indicating that the Control is very good as per ACI 214.

Table 4. 8. Range of strength results **source: prepared by researcher.**

Name of the Project	Concrete class	Range
project 1		
	Fck 40 mpa	9.9
	Fck 60mpa	10.7
project 2		
	Fck 40 mpa	14
	Fck 60mpa	16.6
project 3		
	Fck 30 mpa	8
	Fck 40mpa	13
Test Conducted at the Batch Plant		
	Fck 600 mpa	12.9

On the other hand, concrete mixtures are considered to be similar if their nominal strengths are within 6.9 MPa (1000 psi), represent similar materials, and are produced, delivered, and handled under similar conditions (ACI 214). However, as it can be observed from Table 4.8 below, all the test results are well above 6.9MPa, indicating that none of the concrete produced for the projects represent similar materials, and are not produced, delivered, and handled under similar conditions.

#### 4.4.1.2 Statistical Quality Control

The aim of this study is to evaluate the level of quality control applied after conducting statistical analyses on sample test results obtained from laboratories, specifically those not affiliated with contractors or concrete manufacturing materials. This evaluation will also include an assessment of compliance of compressive strength test results against Ethiopian and American standards. Furthermore, process control is utilized through Shewhart control charts.

Compressive strength or cube test results were gathered from the Material Testing Centers of Addis Ababa University. These centers were selected frequently by clients because of their testing capabilities and convenient access. The data collected consists of compressive strength test results dated over a year, encompassing concrete grades fck30, fck40, and fck60. In total, one hundred ten (110) sets were obtained from the laboratories where Gentium Concrete Industries Plc. and other concrete users requested testing. Each set includes three cubes (15cm x 15cm x 15cm), resulting in a total of one hundred eighty-nine (330) cubes collected. The names of the projects are provided in this section as the thesis is intended for academic purposes. The corresponding results and evaluations based on the standards are summarized in Table 4.9 below.

To assess the quality of concrete produced by Gentium Concrete Industries Plc., the study applies the statistical quality control methodology and utilizes the compliance and conformity criteria outlined in the Ethiopian Building Code Standards (EBCS2:1995), ACI-214, and ACI-318.

According to ACI- 214

$$fcr' \geq f_{ck} + 1,48 \sigma \text{ ----- (4.1)}$$

As detailed in the literature review, EBCS-2:1995 establishes two compliance criteria. The Ethiopian building codes indicate that the values of K1 and K2 are variable, as illustrated in Table 2.10. For the purposes of this specific analysis of test results, both K1 and K2 are assumed to be 3 MPa, based on the assumption that all project lots are classified above the fifth lot. Among the two criteria, the first criterion, pertinent to small lots, is applied for this analysis, employing equations 2.1-2.6. To assess compliance, the American standard requires that cube strength results be converted to cylindrical strength using a conversion factor of 0.8 for cubic strength.

This can be mathematically expressed as:

$$f_{cyk} = 0.8f_{cck} \text{----- [Eq. 4.2]}$$

Where,  $f_{cyk}$ =Cylindrical strength and

$f_{cck}$ =Cubical strength

additional

$$f_{cr}' = f_{c}' + z_s \text{----- (4.3)}$$

Table 4-10: Summary of compliance and conformity source: prepared by researcher

project	Grade (fck)	Number of tests	Adherence to Ethiopian Standards EBCS-2:1995.				Adherence to ACI 318			
			Defective lots		Nondefective lots		Defective lots		Nondefective lots	
			Number	%	Number	%	Number	%	Number	%
project1	40	5	2	40%	3.00	60%	3	60%	2	40%
	60	25	3	12%	22.00	88%	7	28%	18	72%
project2	40	12	5	42%	7.00	58%	4	33%	8	67%
	60	18	5	28%	13.00	72%	5	28%	13	72%
project3	30	7	3	43%	4.00	57%	4	57%	3	43%
	40	13	5	38%	8.00	62%	5	38%	8	62%
Test Conducted at the Batch Plan	60	30	3	10%	27.00	90%	7	23%	23	77%
Total	Total	110	26	24%	84.00	76%	35	32%	75	68%

#### 4.4.2 Discussion on Compliance Criteria Based on EBCS-2:1995 and ACI

As illustrated in Table 4.12, a total of 110 sets of concrete samples, equating to 330 individual specimens, were gathered from four distinct project laboratories within the Material Testing centers of Addis Ababa University. This section analyzed concrete grades with compressive strengths of fck30, fck40, and fck60. Based on the compliance criteria set forth by Ethiopian standards (EBCS-2:1995), 24% of the lots were deemed defective, while 76% of the samples satisfied the specified requirements. When examining the concrete grades separately, it was observed that 43% of fck30 concrete grades were

classified as defective, leaving 57% as non-defective samples. Among the 30 lots of fck40 concrete grades, 40% were found to be defective, and 60% met the requirements. For the fck60 concrete grades, 15% were considered defective while 85% were categorized as non-defective according to Ethiopian Standard compliance criteria.

Additionally, the same cube samples were assessed using ACI 318, which revealed that the proportion of defective sets decreased to 32%, with non-defective sets increasing to 68%. The results for the aforementioned concrete grades were recorded consecutively: for fck30, 57% of the sets were deemed defective, while 43% were classified as non-defective based on evaluation standards. In the case of fck40, which had the largest number of sets, 43% were defective, whereas 57% were found to be non-defective. Finally, for fck60, 24% of the samples were defective, leaving 76% as non-defective.

According to (Mihiretab, 2021), research indicates that, based on Ethiopian standards (EBCS-2, 1995), 60% of the lots were identified as defective, and 40% as non-defective. When evaluated against ACI 318, the proportion of defective lots was reported at 47.6%, while non-defective lots accounted for 52.4%. This points to a concerning trend where a significant proportion of concrete produced by ready-mixed concrete suppliers fails to meet established standards, highlighting deficiencies in quality control in the production of ready-mixed concrete. In light of previous research, it is evident that there have been some improvements in results.

Concrete cube test samples collected represent various components of the concrete work, including slabs, beams, columns, footings, and shear walls, sourced from ready-mixed concrete produced at Gentium Concrete Industries Plc's project and batching plants. The structures from which samples were taken are currently in use, as test results were obtained during their construction. As noted in the problem statement, frequent failures in concrete structure tests, particularly cube tests, are characteristic of concrete production in Ethiopia. Currently, over half of the concrete produced in Addis Ababa does not comply with Ethiopian Standards. Statistical quality control assessments based on compressive strength tests from selected projects have revealed that 24% of the results were classified as defective according to EBCS-2:1995 compliance criteria.

This study aimed to evaluate the quality control measures for ready-mixed concrete. There is significant potential for improved quality in the production of ready-mixed concrete, attainable only through robust quality control practices implemented before, during, and after production. While advancements in concrete grades have been observed, additional efforts are necessary to achieve the desired quality levels in the construction industry of our country.

These findings indicate a disparity between concrete production practices and the level of oversight exercised by Gentium Concrete Industries. Consequently, it is recommended that nondestructive testing be conducted on the non-compliant concrete structures.

Inevitably, strength test results will exhibit variations. Fluctuations in measured strength may arise from several factors (ACI 214R-02):

- ✓ Variations in batch-to-batch proportions and characteristics of the constituent materials, as well as issues related to the production, delivery, handling processes, and climatic conditions;
- ✓ Within-test variations that stem from discrepancies in sampling, specimen preparation, curing, and testing methodologies;
- ✓ Overall variations, denoted as  $\sigma$  (for a population) or  $s$  (for a sample), encompass two components: within-test variation, represented as  $\sigma_1$  (population) or  $s_1$  (sample), and batch-to-batch variation, indicated as  $\sigma_2$  (population) or  $s_2$  (sample).

Table 4-10: Standard deviation for different control standards, MPa (ACI-214)

Class of Operation, Overall Variations	The standard deviation for different control standards, MP				
	Excellent	Very good	good	Fair	Poor
General construction testing	Below 2.8	2.8 to 3.4	3.4 to 4.1	4.1 to 4.8	Above 4.8
Laboratory trial batches	Below 1.4	1.4 to 1.7	1.7 to 2.1	2.1 to 2.4	Above 2.4

The quality control of concrete is assessed according to ACI-214. This standard defines and categorizes the level of control, ranging from excellent to poor, based on the coefficient of variation and standard deviation, as detailed in the literature review section of this thesis. Below, Tables 4.14 and 4.15 provide a summary of the control status for this

project, reflecting the standard deviation and coefficient of variation from the test results, respectively. Table 4-11: Level of control based on Standard Deviation (ACI-214

Grade(ck)	Level of control Based on (SD)									
	excellent (<2.8)		Very good (2.8-3.4)		Good (3.4-4.1)		Fair (4.1-4.8)		Poor (>4.8)	
	Number	%	Number	%	Number	%	Number	%	Number	%
30	6	85.7%	0	0%	1	14.3%	0	0%	0	0%
40	15	50%	4	13%	3	10%	5	16.6%	3	10%
60	56	76.7%	10	13.76%	4	5.48%	1	1.36%	2	2.7%
total	77	70.0%	14	12.7%	8	7.27%	6	5.45%	5	4.54%

As shown in Table 4.14 and Table 4.15 concrete level based on standard deviation showed 70% is categorized under Excellent, 12.7% very good, 7.27% good, 5.45% fair and 4.54% poor. Table 4-12: Level of control based on the coefficient of variation (ACI-214

Grade(ck)	Level of control Based on (coefficient of Variation									
	excellent (<7)		Very good (7-9)		Good (9-11)		Fair (11-14)		Poor (>14)	
	Number	%	Number	%	Number	%	Number	%	Number	%
30	6	85.7%	1	14.3%	0	0%	0	0%	0	0%
40	19	63.7%	6	20.0%	3	10%	2	6.6%	0	0%
60	64	87.6%	2	6.8%	4	5.47%	3	4.1%	0	0%
total	89	80.9%	9	8.18%	7	6.3%	5	4.5%	0	0%

Table 4.15 shows that 80% of the produced concrete was rated as excellent, 8.18% as very good, 6.3% as good, and 4.5% as fair according to the coefficient of variation analysis.

The findings in Tables 4.15 and 4.16 reveal that ready-mixed concrete exhibited less variability.

#### 4.4.2.1 Shewhart Control Charts

Although graphical plots can provide valuable insights into the patterns of a production process, the control chart becomes significantly more effective when statistical rules are utilized in analyzing the data. Shewhart control systems assess variables within production processes, such as the target mean strength. They rely on calculated control limits and establish warning thresholds based on the observed variability in the production process (Abdul-Rahman, 2011).

The Shewhart chart features a horizontal central line that indicates the expected mean value of test results derived from samples collected during production; for instance, in the context of concrete, this would be the Target Mean Strength used for monitoring compressive strength. Additional lines may be incorporated to represent the upper control limit (UCL), lower control limit (LCL), upper warning limit (UWL), and lower warning limit (LWL). Generally, if any result exceeds the control limits, action is required (Abdul-Rahman, 2011). The construction of a Shewhart control chart can be achieved using equations Eq. 4.4 to Eq. 4.7.

$$UCL = TMS + 3 \times \sigma \text{----- [Eq. 4.4]}$$

$$LCL = TMS - 3 \times \sigma \text{----- [Eq. 4.5]}$$

$$UWL = TMS + 2 \times \sigma \text{----- [Eq. 4.6]}$$

$$LWL = TMS - 2 \times \sigma \text{----- [Eq. 4.7]}$$

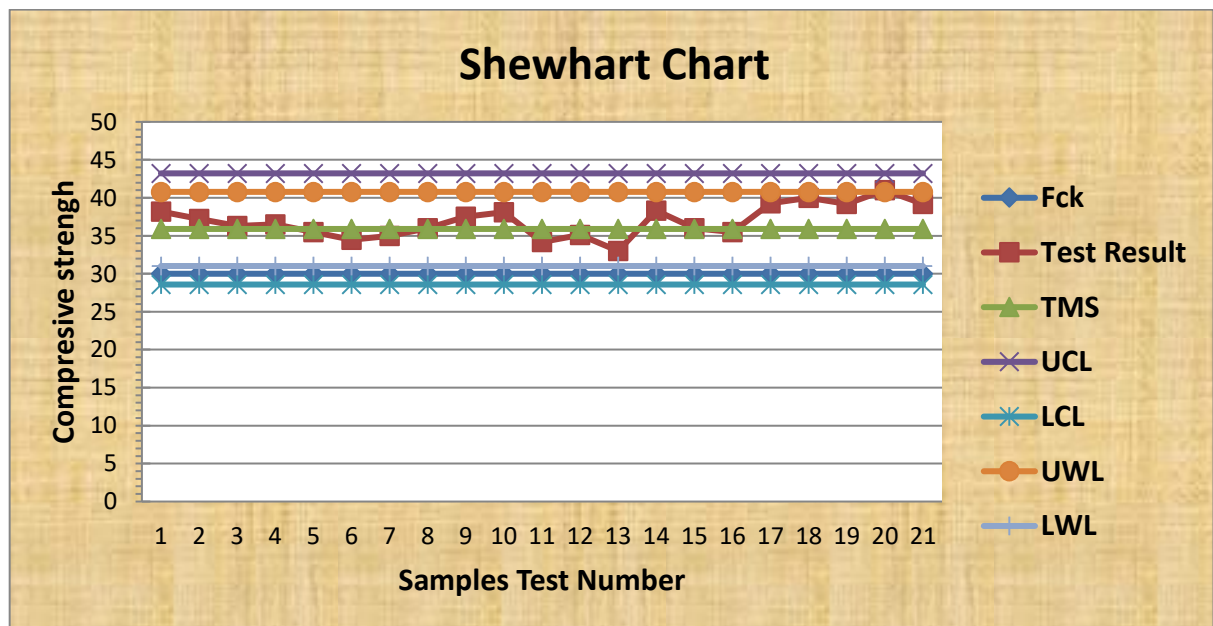
The figures below, namely Fig 4.17 for concrete grades fck30, Fig 4.18 for fck40, and Fig 4.19 for fck60, are created based on Shewhart quality control standards. In Fig 4.17, which corresponds to the fck30 concrete grade, there are no data points that exceed either the Upper or Lower Control Limits. This suggests that there is no likelihood of natural or special variations occurring during the production processes of these concrete grades.

To identify patterns within the warning limits, a few straightforward rules of thumb have been suggested for sequences of results that stay within these limits, as mentioned by (Abdul-Rahman, 2011). These criteria are applied to all charts (fck30, fck40, and fck60) analyzed in Figs 4.18 through 4.19 below:

- a) A sequence of seven or more consecutive results on one side of the target mean strength
- b) At least 10 out of 11 results on the same side of the target mean strength
- c) At least 12 out of 14 results on the same side of the target mean strength
- d) At least 14 out of 17 results on the same side of the target mean strength

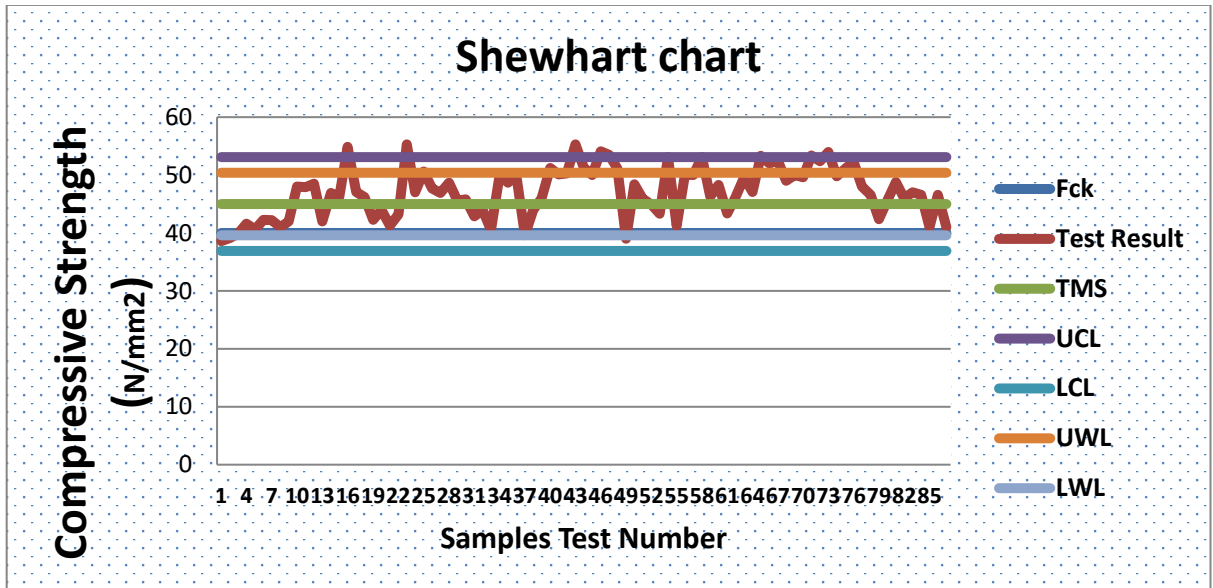
In Fig 4.18, Shewhart charts are utilized to display the results of 87 concrete cube tests for the fck40 concrete grade. It is necessary for points beyond both the upper and lower control limits to be less than 5%; however, 8 points exceeding these limits account for 9.1%. This indicates that the concrete production process is not operating within the required controls. Thus, effective supervision of the concrete production process is essential. Regarding the patterns within the warning limits shown in Fig 4.19, none of the criteria stated above are satisfied. Consequently, the production of ready-mixed concrete is inconsistent and highly susceptible to variations.

Fig 4.19 presents Shewhart charts for the fck60 concrete grades, utilizing results from 222 concrete cube tests. Of these results, 5.4% exceed the upper control limit. While the patterns within the warning limits meet the specified criteria, there are 7 consecutive results that fall within the target mean strength as well as the lower and upper warning limits. However, most results in the chart for this concrete grade lie near the lower warning limits. The Shewhart charts indicate that there is a need for better process control during concrete production.



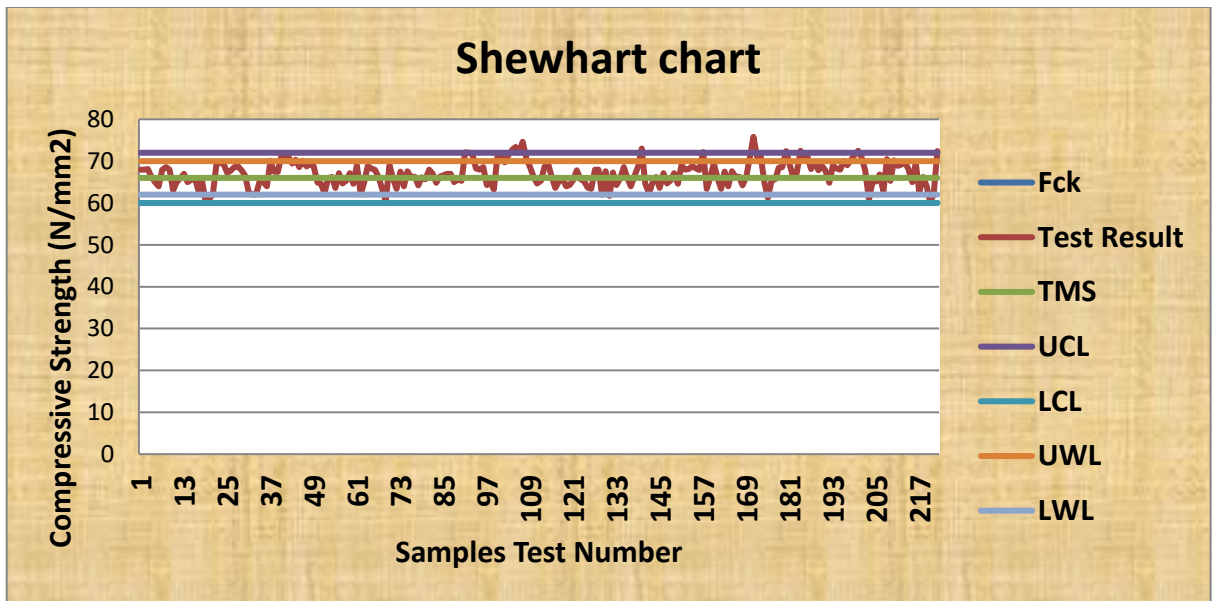
Samples Test Number

Figure 4-17: Shewhart control chart for fck 30 concrete grades source: prepared by researcher



Samples Test Number

Figure 4-18: Shewhart control chart for fck40 concrete grades source: prepared by researcher



Samples Test Number

Figure 4-19: Shewhart control chart for fck60 concrete grades source: prepared by researcher

Fig 4.19 presents Shewhart charts for the fck60 concrete grades, utilizing results from 222 concrete cube tests. Of these results, 5.4% exceed the upper control limit. While the patterns within the warning limits meet the specified criteria, there are 7 consecutive results that fall within the target mean strength as well as the lower and upper warning

limits. However, most results in the chart for this concrete grade lie near the lower warning limits. The Shewhart charts indicate that there is a need for better process control during concrete production.

#### **4.5 Cause and Effect Diagram**

The factors that cause batch variability of concrete that were identified and collected through literature review, observation, and interview are analyzed and presented herein under put using cause and effect diagram. The factors are first categorized under broad categories; namely, material factors, machine factors, methodology factors, human factors, and environmental factors followed by further categorization as presented in the diagram bellow figure 4.20.

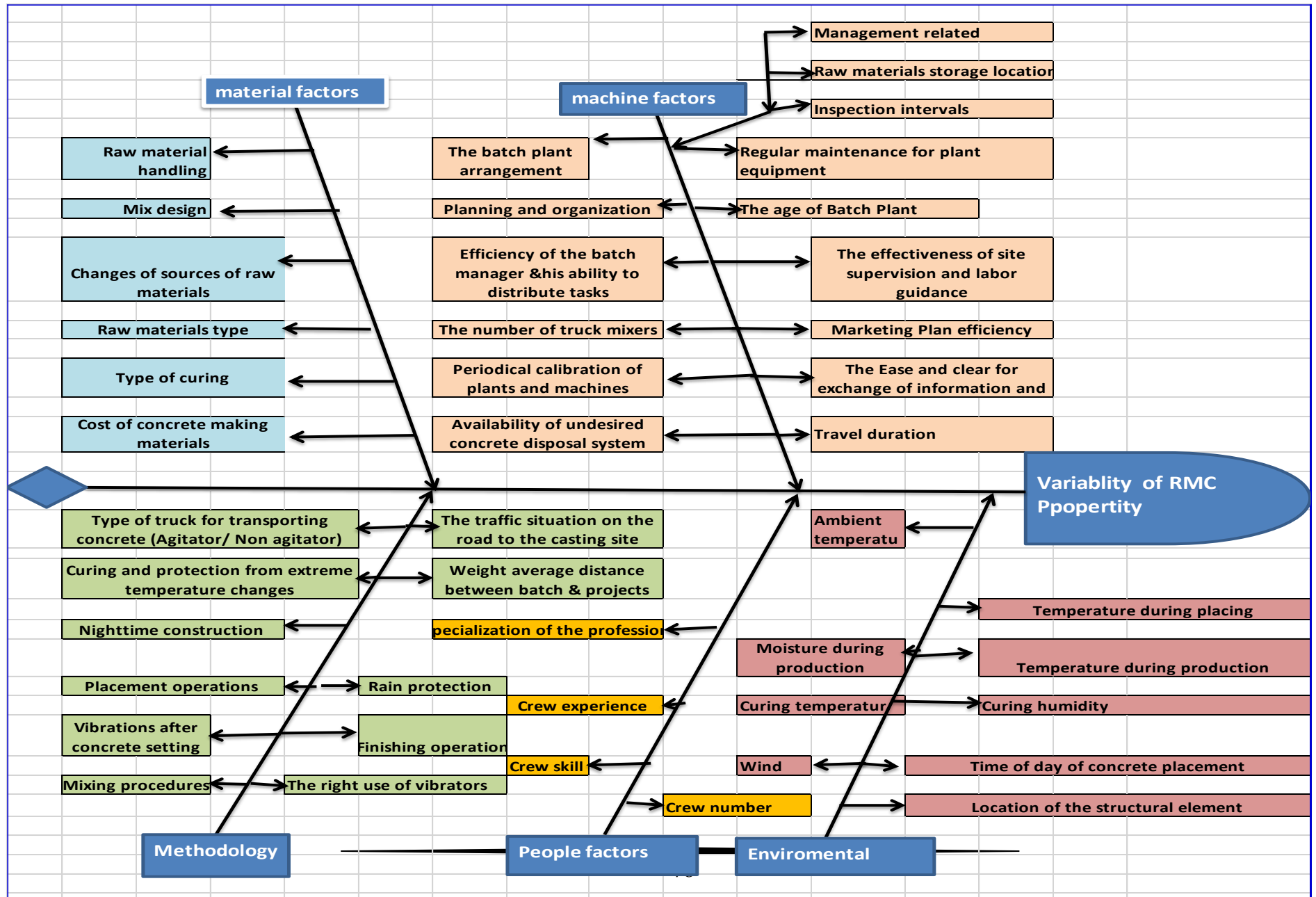


Fig 4. 20 Cause and effect diagram of factors causing variability of properties of RMC at batches of products on Quality  
 source: prepared by researcher

## 4.6 Summary of Major Findings

The company used Simma software across all departments, including production management, sales and marketing, and technical and quality management—at the batching plant and in the laboratory—to oversee the quality management system.

Managing quality in the construction sector is intricate due to the industry's dynamic nature. In construction, a product is deemed satisfactory when it fulfills its intended function, complies with design specifications, and upholds aesthetic standards. Consequently, it should be user-friendly, durable, safe, devoid of defects, and free from substantial variations. The viability of the construction industry is tied to the quality of concrete, with ready-mixed concrete being particularly crucial.

This research paper seeks to investigate the quality control practices of ready-mixed concrete at Gentium Concrete Industries, utilizing methodologies that effectively support its objectives. The study included observations to assess materials storage areas, site layouts, truck entry and exit points, and conditions at concrete casting sites. Interviews with senior staff and experts were conducted to gather data on material inventory and sourcing. Statistical quality control was applied to evaluate the compliance level of concrete grades, with samples taken from third-party concrete material testing centers.

Currently, the number of batching plants in Addis Ababa is on the rise. Notably, in the last two years, the count has doubled, although the total remains in the single digits. These batching plants can produce 1.8 million m<sup>3</sup> of concrete annually. In contrast, Gentium Concrete Industries has a capacity of 730,000 m<sup>3</sup> of ready-mixed concrete per year, representing 40% of the ready-mixed concrete produced in Addis Ababa, which is a substantial amount.

The factors influencing the quality of ready-mixed concrete were ranked based on expert feedback. These factors were categorized into five groups, with their influence assessed through mean values and standard deviations. Among the material-related factors, raw material handling, mix design, and changes in the sources of raw materials emerged as the most significant influences on the quality of ready-mixed concrete. In terms of batching plant machinery, periodic calibration, travel duration, and plant layout were found to be highly influential. Methodological factors such as traffic conditions, travel times, and batch plant logistics (general location) also scored high in terms of their impact on ready-mixed concrete quality. From the human perspective, crew experience, skills, and adequacy in numbers were identified as critical factors. Environmental influences included curing temperature, inspection frequency, and curing humidity, all of which significantly affected ready-mixed concrete quality.

Gentium batching plants primarily utilized bulk cement and performed tests on the cement quality. Groundwater from wells was generally used for concrete production. The research

indicated that the water quality met Ethiopian standards, as established in the literature, and was tested for suitability by the manufacturer prior to use.

Concrete-grade cube test results were gathered from AAIT testing centers in Addis Ababa. When compared to EBCS-2: 1995 and ACI 318 standards, the analysis revealed that 24% of samples were defective and 76% were satisfactory according to the former, while the latter showed 32% defective and 68% satisfactory samples.

Issues related to the delivery and transportation of ready-mixed concrete were identified as critical challenges, stemming from congested roads, distances between the plant and the site, traffic conditions, casting operations, and pumping speeds. In Addis Ababa, the transportation of ready-mixed concrete involved a distance of 25 km, taking up to 3 hours to arrive at the casting site. Significant erroneous practices noted included raw materials being left uncovered, exposing them to rain, moisture, sunlight, or excessive heat, which negatively affects the environment. Moreover, it was observed that additional water was often added to the freshly mixed concrete, either intentionally or unknowingly, throughout the process from production to loading onto the truck mixer.

Shewhart charts highlighted the need for stringent control over the concrete production process, indicating inconsistencies and significant variations in ready-mixed concrete production.

Gentium utilized a variety of concrete ordering techniques, including prescription-based, mixed, and prescribed methods. Notably, 100% of experts affirmed that the ready-mixed concrete produced by batching plants was generated through centralized or mixed concrete production systems.

## 5 CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

This chapter gives the major findings of the studies end and recommendation. The conclusions are drawn based totally on the research findings and the advice component is supplied based totally on the conclusions.

### 5.1 Conclusions

- The top significant factors that cause variation in the properties of RMC batches as perceived by the professionals in the field are; Raw material handling, Periodic calibration of plants, The traffic situation on the road to the casting site, Crew experience, and Curing temperature. However, whereas the factor ‘Periodical calibration of plants’ is rated as the most significant factor, the Raw materials storage location of this factor is almost none. This task is merely left to the supplier. On the other hand, the standard deviations and the mean values of strength test results indicate that the control over the production process is poor and inefficient.
- The most serious Erroneous Practice is that RMC raw materials, especially aggregates and sand materials are not covered they are exposed to rain or moisture and sunlight or excess temperature. Due to this, the dust particles harmed the environment and variable moisture content. The heat of hydration is not well controlled.
- From the survey results Gentium concrete industry has no owned cement testing laboratory centers. The cement strength is variable due to different reasons the concrete producer have not frequently check their cement quality and this will affect the quality control process.
- Based on the analyzed samples from cube tests, it was found that 24% of the lots were defective according to the compliance criteria of Ethiopian standards (EBCS-2:1995), while 76% were classified as non-defective. When these lots were assessed against ACI 318 standards, the percentage of defective lots decreased to 32%, and the non-defective lots increased to 68%. This suggests that a significant portion of the concrete produced by Gentium Concrete Industry is failing to meet the established standard criteria, indicating inadequate control over the quality of the ready-mixed concrete.
- The Shewhart charts revealed that the concrete production process requires better monitoring and control. They showed that the production of ready-mixed concrete lacks consistency and is highly susceptible to variations.
- Due to Political unrest in our country, the supply chain has been severely affected, including transporting cement from factories to end users, transporting quality sand and aggregate to the batching plant.
- As part of a solution to the inefficiency noted in the practice of production, delivery, and construction with RMC in Gentium Concrete Industries and to tell the root causes of batch variability of concrete, several factors were identified, categorized under material, machine, manpower, methodology, and environment factors, and then presented using cause and effect diagram, fig. 4.19 for decision makers’ consideration

## 5.2 Recommendation

- ❖ RMC raw materials, especially aggregates and sand materials should be stored in the warehouse at reasonable distances from the mixing plant and materials availability like Economic Material Ordering models usage.
- ❖ Considering the consistency, quality, strength, durability, and environmental benefits of Manufactured sand, replace or automatically remove river sand and replace it with Manufactured sand.
- ❖ Owners of batching plants should adopt a comprehensive management approach to oversee all production processes, such as implementing Total Quality Management practices. This includes selecting the right personnel, sourcing appropriate materials, conducting necessary material tests before use, effectively managing the batching plant site, calibrating machines and equipment, and utilizing the latest technology to enhance the overall quality of ready-mixed concrete.
- ❖ To improve the quality of the concrete produced, the system in the RMC production needs to be standardized. Norms and guidelines on the production and use of RMC need to be set, and close monitoring should be done using these as a tool.
- ❖ Because many steps are involved in the process of RMC production and usage, training of the individuals engaged at each step in the process should be done.
- ❖ In the pre-construction phase, the company should engage in communication with Addis Ababa City Road and Traffic Management to gain insights into the characteristics of ready-mixed concrete and to secure designated bus lanes for trucks during peak traffic hours.

## 5.3 Recommendation for Future Study

Suggestion for future study:-

- 1) Quality management practices in ready-mix concrete suppliers in Addis Ababa,
- 2) Optimization of ready-mixed concrete delivery route and schedule for Addis Ababa cases.
- 3) Need for relevant ready-mixed concrete standards, codes, and regulations in Ethiopia to upgrade the level of concrete quality.

## 6 Bibliography

- (MOWUD), M. o. (2019.). "National Report on Housing and Sustainable Urban Development," Addis Ababa, 2014. Addis Ababa,
- Abadir H, Y. (2011). Project management maturity in the construction industry of developing countries (the case of Ethiopian contractors).
- Abdalla, M. O. (2000). Causes of construction delay: Traditional Contracts, *International Journal of Project Management*.
- Abdul-Rahman, T. C.-K. (2011). Study of Quality Management in Construction Projects.
- Abebe E. (2005). Concrete Production And Quality Control In Building Construction Industry Of Ethiopia." Addis Ababa: MSc. Thesis, Addis Ababa University,
- ACI 116R. (n.d.). Cement and Concrete Terminology. Reported by ACI Committee.
- ACI 214R. (n.d.). Evaluation of Strength Test Results of Concrete. Reported by ACI Committee.
- ACI 318R. (n.d.). Building Code Requirements for Structural Concrete, ACI Standard. ACI.
- Afzal, S., & Khan, Z. R. (2018). A Review Paper on Factors Affecting Ready-Mix. *International Journal of Construction Engineering and Management*. *International Journal of Construction Engineering and Management*.
- Aibinu, A. &. (2006). Construction Delays And Their Causative Factors In Nigeria. *Journal of Construction Engineering and Management*,
- Aichouni, M. (2012). On the Use of the Basic Quality Tools for the Improvement of the Construction Industry: A Case Study of a Ready Mixed Concrete Production Process. *International Journal of Civil & Environmental Engineering IJCEE-IJENS*.
- Aichouni, M. (2012). On the Use of the Basic Quality Tools for the Improvement of the Construction Industry: A Case Study of a Ready Mixed Concrete Production Process. *International Journal of Civil & Environmental Engineering IJCEE-IJENS*.
- Alam, M. A. (2016). A Study on the Quality Control of Concrete Production. Dhaka City.: *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*.
- Alam, M. A. (2016). A Study on the Quality Control of Concrete Production in Dhaka City. Dhaka city: *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*.
- Alavifar, A. H. (2014). Identification, evaluation, and classification of time delay risks of construction projects in Iran, Bali, Indonesia.
- Andnet, K. e. (2020). Construction Practices with ready-mix concrete in Addis Ababa. Addis Ababa: Addis Ababa Science and Technology University.
- Anosike, N. M. (2011). Parameters for good site concrete production management practice. in Nigeria.
- Anosike, N. M. (2011). Parameters for good site concrete production management practice. Nigeria.

- Asaf, S. A.-H. (2006). Causes of delay in large construction project, *International journal of project management*.
- ASTM C125. (n.d.). *Standard Terminology Relating to Concrete and Concrete Aggregates*, ASTM Standard.
- ASTM C94. (n.d.). *Standard Specification for Ready-Mixed Concrete Standard*. , ASTM.
- ASTM C94 C94M-20. (2020). , "Standard Specification for Ready- Mixed Concrete,". ASTM International, West Conshohocken.
- Azhar, N. R. (2008). *Overrun Factors in the Construction Industry in Pakistan*. Proceeding of First International Conference on Construction in Developing Countries (ICCIDE-1), Karachi, Pakistan, 4-5. Pakistan.
- Biswas, A., & Sen, S. K. (2016). Study on Ready Mix Concrete. *International Journal of Scientific & Engineering Research*.
- BRMCA. (2016). *British Ready-mixed Concrete Association, "Ready-mixed Concrete: Essential, Local and Sustainable,"*. london: Mineral Products Association.
- BS EN 206. (2013). *BRITISH STANDARDS INSTITUTION, BS EN 206. Concrete Specification, performance, production and conformity*, BSI. london.
- C.R.KOTHARI. (1990). *RESEARCH METHODOLOGY, methods, and techniques*. new age international publishers.
- Chin-Keng, T. (2011). *Study of quality management in construction projects*.
- Denamo A. (2005.). *Handling of Concrete Making Materials in the Ethiopian Construction Industry*, Addis Ababa: MSc.Thesis, university,
- Duggal S. (2000). *Building Materials (3rd Edition)*,. New Age International Publishers.
- E.Poovaragavan, & Sekar, K. (2016). *Continuous Process Improvement in Ready Mix Concrete Plants*. *International Journal of Scientific & Engineering Research*.
- EBCS-2. (1995). "Ethiopian Building Codes and Standards, Structural Use of Concrete Part Seven. Ethiopian Construction Industry Development Policy, (. (2014). Ethiopian Construction Industry Development Policy.
- FDRMI. (2015.). *Ethiopian Cement Industry Development Strategy 2015 2025.*". Addis Ababa, Ethiopia.
- FS., N. (2016). *Nonparametric statistical tests for the continuous data: the basic concept and the practical use*. korean.
- Gerald, B. (2018). *A Brief Review of Independent, Dependent and One Sample t-test*. *International Journal of Applied Mathematics and Theoretical Physics*.
- Gupta, B. A. (2004). *Concrete Technology*.
- H.Kosmatka, B. K. (2003). , *Design and Control of Concrete Mixtures (14th edition)*, Skokie, Illinois. USA: Portland Cement Association, 2003.

- Habenom, G. (2017). Review of Past Studies and Future Need Assessment," in Research in Ethiopian Construction industry. Addis Ababa: Addis Ababa University School of Graduate Studies,
- Habtamu, s. (2017). Study on Quality of Site Concrete Production and its Management Practice in Addis Ababa Housing Projects (Case study on Koye Feche Housing Projects), MSc thesis, School of Civil and Environmental Engineering, AAU, Addis Ababa.
- Halloum, M. A. (2012). Cost and time overrun revisited: A study on the infrastructure construction projects in Abu Dhabi, Thailand, Bangkok.
- Harris, F. M. (2004). Modern Construction Management,
- Hasan, M. &. (2012). Early Age Tests to Predict 28 Days Compressive Strength of Concrete. Caspian Journal of Applied Sciences Research.
- Huemann, M. (2004). Improving Quality in Projects and Programs.
- Jackson, B. (2009). Construction Management.
- Jain A. (2013). "Ready-mixed Concrete Present Status and Future Growth Prospects .". UltraTech Cement Ltd, vol. 1.
- Jemal, H. (2017). aboutcivil.org. Retrieved from <https://www.aboutcivil.org>: <https://www.18>. Retrieved Jemal, H. (2017, March 18). aboutcivil.org. Retrieved from <https://www.aboutcivil.org>: <https://www.18>, 2017, from aboutcivil.org. Retrieved from <https://www.aboutcivil.org>: <https://www.18>.
- Kalkidane, M. (2021). Assessments of quality management practices in ready mix concrete supplier: The Case of Dugda Construction plc Addis Ababa, July,2021 Kalkidan Melesse ፣, Assessments of quality management practices in ready mix concrete supplier: T. Addis Ababa.
- Kamaruzzaman, A. A. (2010). Cost performance for building construction projects in Klang Valley. Journal of building performance.
- Kasimu, M. A. (2012). Significant factors that cause cost overruns in building construction projects in Nigeria, Nigeria: Interdisciplinary Journal of Contemporary Research in Business.
- Kumar, R. &. (2018). Critical Analysis of Properties of Ready Mix Concrete with Site Mix. International Research Journal of Engineering and Technology IRJE.
- Kumarswamy A., and Savitha S., (2014). A Study On Customer Preferences And Perceptions On Quality And Services Of Ready-mixed Concrete.,. International Journal of Research in Engineering and Technology.
- Lancaster., G. (2005). Research methods in management.
- Larry, R. M. (2002). Project Management: Step by Step. AMACOM, a division of the American Management Association, USA.

- Lee CW, K. M. (2017). Effects of pre-anesthetic dexmedetomidine on hemodynamic responses to endotracheal intubation in elderly patients undergoing treatment for hypertension: a randomized, double-blinded trial. *korean*.
- Lee, P. M. (2011). Supply Chain Management Model for Ready-mixed Concrete. *Automation in Construction*, vol. 20, no. 1, pp. 44-55.
- Li, Z. (2011). *Advanced Concrete*. Hoboken, New Jersey: John Wiley & Sons, Inc.
- Liu, A. M. (2003). The quest for quality in public housing projects: a behavior-to-outcome paradigm.
- Li-Yin Shen, A. P. (2006). Role of public-private partnerships to manage risks in public sector projects. in Hong Kong.
- M. Orozco, Y. A. (2018). Factors influencing concrete quality: a survey to the principal.
- M.Orozco, Y. A. (2018). Factors influencing concrete quality: a survey to the principal.
- Mahamid, I. (2011). The risk matrix for factors affecting time delay in road construction projects: Owners' perspective, *Engineering Construction, and architectural management*.
- Mascolo, R. M. (2013). Ready-mixed concrete: variability analysis of the compressive strength and physical properties.
- MERL, -2.-0. (2015). Technical Memorandum No., Quality Management Plan Guidance for Concrete Used for Construction of Significant Features, Denver. Colorado:: U.S. Department of the Interior Bureau of Reclamation.
- Mihiretab, A. (2021). Study on Ready-mixed Concrete Quality Control Practice. Addis Ababa.
- Ministry of Works and Urban Development, M. (2006). Plan for Accelerated and Sustained Development to End Poverty (PASDEP). Addis Ababa. Addis Ababa.
- Mulat, A. A. (2018). Implementation of Statistical Process Control (SPC) In the Sewing Section Of the Garment Industry For Quality Improvement. *AUTEX Research Journal*, Vol. 18, No 2.
- Nabil, I. M. (2013). Risks Leading to Cost Overrun in Building Construction from Consultants' Perspective. *Organization, technology, and management in construction · an International journal*.
- Nega, F. (2008). Causes and effects of cost overrun on public building construction projects in Ethiopia. Master thesis, Addis Ababa University, Addis Ababa, Ethiopia.
- Negash B. (n.d.). The Importance of Standardization of Aggregate in Ethiopian Construction Industry. Addis Ababa 2014: MSc Thesis, Addis Ababa University, AAiT.
- Neville, A. (1985). *Properties of Concrete*. Longman Scientific and Technical.
- Neville A. (2011.). *Properties of Concrete*, Fifth Edition, Longman. England.
- Nikhil.T, R. S. (2014). Impact of Water Quality on Strength Properties of Concrete. *Indian Journal of Applied Research*.

- Obla, K. (2013). Variation in Concrete Performance Due to Batching. In J. Andreu, Concrete in Focus.
- Ogunlana, S. O. (2006). Construction delays in a fast-growing economy: comparing Thailand with other economies. *International Journal of Project Management*,
- Okasha, N. M. (2015). Proposed Structural Reliability-Based Approach.
- Papadopoulou, T. C. (2012). Causes of cost overruns in transport infrastructure projects in Asia: Their significance and relationship with project size. *Built Environment Project and Asset Management*.
- PMI. (2004). A Guide to the Project Management Body of Knowledge.
- PMI. (2008). A Guide to the Project Management Body of Knowledge.
- Prabhaker Mishra, C. M. (2019). Descriptive Statistics and Normality Tests for Statistical Data. US National Library of Medicine.
- Rachel M. (2013). "Cradle-to-gate Environmental Impacts of Concrete Industry in South Africa. *Journal of the South African Institution of Civil Engineering*, Vol. 55 No 2, Paper 798, pp.2–7.
- Research, G. V. (2020], December 12). [Online]. Available: [www.grandviewresearch.com](http://www.grandviewresearch.com). Retrieved 2020
- Robel N. (2019). "Ready-mixed Concrete., "Masters of Art in Project Management, Ethiopia, Gambella.
- Rumane, A. R. (2011). *Quality Management in Construction Projects*.
- Sambasivan, M. &. (2006). Causes and effects of delays in the Malaysian construction industry. (Vol. *International Journal of Project Management*).
- Santamaria, J. L. (2017). Quantifying the effect of construction site factors on concrete quality, costs, and production rates. Mexico: University of New Mexico.
- Sara Kaffashi, M. N. (2015). Choice Experiment Attributes Selection: Problems and Approaches in a Modal Shift Study in Klang Valley. Malaysia: Asian Social Science.
- Seboru, M. A. (2015). An Investigation into Factors Causing Delays in Road Construction Projects in Kenya. *American Journal of Civil Engineering*.
- Shah, A., Pitroda, P. J., & Bhavsar, P. J. (2014). Ready Mix Concrete: Economic And Qualitative Growth for Construction Industry. Trends and Challenges of Civil Engineering in Today's Transforming World (p. 8). Gujarat:: Civil Engineering Department S.N.P.
- Shetty M.S. (2009). *Concrete Technology, Theory and Practice*, S. Chand, New Delhi, 2009. New Delhi.
- Shrestha, P. P. (2013). The magnitude of construction cost and schedule Overruns in Public Work Projects. *Journal of Construction Engineering*.
- Sidney Mindess, J. Y. (2003). *Concrete*, prentice hall, 2nd edition. The USA.
- Sohn HM, R. J. (2016). Monitored anesthesia care in and outside the operating room. korean.

- Sweis, G. J. (2013). Factors affecting time overruns in public construction projects: the case of Jordan, Jordan: International Journal of Business and management.
- UNDP. (2014). Ethiopia: quarterly economic brief. ethiopia.
- Vaghela, A. &. (2018). Factors Affecting Ready Mix Concrete Operation.
- Werku Koshe& Jha, K. N. (2016). Investigating Causes of Construction Delay in Ethiopian Construction Industries, Journal of Civil, Construction and Environmental Engineering, 1(1), 18-29.
- Wesolowski, D. J. (2018). The SAGE Encyclopedia of Educational Research, Measurement, and Evaluation . Thousand Oaks: SAGE Publications, Inc. Thousand Oaks: SAGE Publications, Inc.
- William C, T. J. (2008). "Quality Management System for Ready-mixed Concrete Companies,". South Carolina: RMC Research & Education Foundation, Greenville,.
- Zegeye S., and Hilaw C. (2012). Building Ethiopia Sustainability and Innovation in Architecture and Design,. ddis Ababa,: Ethiopian Institute of Architecture and City Development, AAU.

# **7 APPENDIX**

## **Annex A Interview Questions**

## Part One: Respondent's Data

1. What is your level of education?

- Postgraduate  Advanced Diploma  
 First Degree  Other (Please specify: \_\_\_\_\_)

2. What is your job title/position in the company?

- Plant Managers  Others (Please specify: \_\_\_\_\_)  
 Quality Managers  Material Engineers, and  Company Mangers

3. How many years of experience do you have in the industry?

- 0-5 year's  16-20 years  
 6-10 years  Over 20 years  
 11-15 years

### Interview Questions

- 1) How do you monitor the quality of materials at the batch plant?
- 2) What are the Factors that influence RMC operations and the quality of ready-mixed concrete ?
- 3) Demand for ready-mixed concrete in your company for the past 5 years in m3.  
a. 2023\_\_\_\_\_, 2022\_\_\_\_\_, 2021\_\_\_\_\_, 2020\_\_\_\_\_ 2019\_\_\_\_\_.
- 4) Your company's capacity of supply for the past 5 years in m3  
a. 2023\_\_\_\_\_, 2022\_\_\_\_\_, 2021\_\_\_\_\_, 2020\_\_\_\_\_ 2019\_\_\_\_\_.
- 5) What is the average daily production capacity of your company currently in m3\_\_\_\_\_?
- 6) If concrete, doesn't comply with the specification what are the remedial actions you use to correct?
- 7) What do you recommend for the improvement of concrete production in your company?\_\_\_\_\_
- 8) How do you evaluate the current practice of the RMC quality control mechanism?\_\_\_\_\_
- 9) How do you evaluate the future of ready-mixed concrete production contribution to the industry?\_\_\_\_\_
- 10) What are the major challenges you may face during transportation of concrete to the site?
- 11) Which structural grade of concrete is being produced in your company?
- 12) 25MPa  30MPa 40MPa  50MPa, 60MPa  if any other please, mention them\_\_\_\_\_
- 13) What are the major challenges you may face during the transportation of concrete to the site
- 14) What type of admixture you are using for concrete?\_\_\_\_\_
- 15) Are there any tests done on cement you are using? Please specify if any
- 16) Do you have your own material testing laboratory?.
- 17) Which laboratory tests were conducted for coarse aggregate

## Annex B: Checklist for Observation

### A. Observation at Batching Plant

No.	Property under investigation	Observation and Description of the property	Remark/ determination
<b>I. Material Quality</b>			
1.00	Availability of laboratory at the plant site Yes/No		Yes/No
<b>I.1. Cement Quality</b>			
1.00	Type of cement (Ordinary Portland, Pozolanic, Sulphate Resistant...)		(OPC/PPC/ Other_____)
2.00	Source		Acceptable/ Not Acceptable
3.0	Means of transportation to the batch plant		
4.0	Storage Of Cement		
	Other Notes, if any		
<b>Aggregate Quality</b>			
1.	Source		Acceptable/ Not Acceptable
2.0	Storage		
	2.1 Protected from contamination		Yes/No
	2.1 Protected from contamination		Yes/No
	2.2 Provision of sufficient area for different sizes of aggregates to be piled separately		Yes/No
	2.3 Whether materials of different sources/ classes are separated		Yes/No
	2.4 Criteria for Compartments		Acceptable/ Not Acceptable
	2.5 Condition of the ground the bulk is placed		Acceptable/ Not Acceptable
	Other Notes, if any		
3.0	Properties		
	3.1 Gradation		
	3.1.1 Uniform		Yes/No
	3.1.2 Well graded		Yes/No
	3.1.3 Poorly graded		Yes/No
	3.1.4 Gap graded		Yes/No
	3.2. Maximum size of aggregate in the mix		
	3.2.1 The same size as specified		Yes/No

	3.2.2 Greater than specified		Yes/No
	3.3 Shape		
	3.3.1 Flaky		Yes/No
	3.3.2 Rounded		Yes/No
	3.3.3 Angular		Yes/No
	3.3.4 Elongated		Yes/No
	3.3.5 Irregular		Yes/No
	3.4 Texture		
	3.4.1 Rough		Yes/No
	3.4.2 Smooth		Yes/No
	3.5 Porosity		Acceptable/ Not Acceptable
	Other Notes, if any		
<b>I.3. Water for mixing (At the Batch Plant)</b>			
1.0	Source		Acceptable/ Not Acceptable
2.0	Availability of color		Yes/No
3.0	Availability of suspended matter		Yes/No
4.0	Availability of Odor		Yes/No
5.0	Storage		Yes/No
6.0	Records of test results logged		Yes/No
	Other Notes, if any		
<b>I.4. Admixture</b>			
1.0	Source (Manufacturer's		
2	Type		
3.0	Dosage applied vs manufacturer's instruction		
	3.1 According to the manufacturer's instruction		Yes/No
	3.2 Overdosed		Yes/No
	3.3 Lesser than instructed		Yes/No
4.00	Storage		
	4.1 Stored according to manufacturer's instruction		Yes/No
	4.2 Shelf life		Expired/ Unexpired
	4.3 Protected to prevent damage from contamination and separation (Admixtures prevented from degradation of the product)		Yes/No
	4.4 Protected from freezing		Yes/No
	Other Notes, if any		

## B. Observation at the Construction Site

## II. Methodology Assessment

No.	Property under investigation	Observation	Remark
<b>A detailed description of the plant</b>			
1.00	<b>1.1 General Operation (Truck Mixing, Central Mixing)</b>		Manual, Semi-Automated, Fully Automated
	1.2 Batching System (Manual, Semi-Automated, Fully Automated)		Manual, Semi-Automated, Fully Automated
<b>II.2. Transporting</b>			
No.	Property under investigation	Observation	Remark
	The truck mixer		
	1.1 Type		
	1.2 Size/ Capacity		
	1.3 Other		
<b>II .3 Material Quality</b>			
I.1. The produced concrete			
No.	Property under investigation	Observation	Remark
1.0	Uniformity of all completely truck-mixed concrete		Yes/No
2.	Jobsite slump adjustment		
	2.1 Materials used to adjust the slump		
	2.1.1 Water		
	2.1.2 water reducer		
	2.1.3 Other		
	2.2 Whether the concrete is remixed in the truck mixer after application of the admixture		Yes/No
3.	Tests		
	3.1 Whether tests are performed		
	3.1.1 Slump		Yes/No
	3.1.2 Temperature		Yes/No
	3.1.3 Density (unit weight)		Yes/No
	3.1.4 Air content		Yes/No
	3.1.5 Compressive strength		Yes/No
	3.1.6 Flexural strength		Yes/No
	3.1.7 Other		Yes/No
	3.2 Sampling frequency _____		
<b>I.2. Water for Curing (At the construction site)</b>			

No.	Property under investigation	Observation	Remark
<b>1.00</b>	<b>Source</b>		Yes/No
	1.1 Underground		Yes/No
	1.2 River		Yes/No
	1.3 Tap Water		Yes/No
	1.4 Other		
2.	<b>Availability of color</b>		Yes/No
3.	<b>Availability of suspended matter</b>		Yes/No
4.	<b>Availability of odor</b>		Yes/No
5.	<b>Availability of humic matter</b>		Yes/No

<b>Defects Observed in the fresh concrete after casting</b>			
No.	Property under investigation	Observation	Remark
<b>1.00</b>	<b>Defects observed on the finished element</b>		
	1.1 Bleeding		
	1.2 Micro cracking		
	1.3 Honey Comb		
<b>2.00</b>	<b>Applied Method to repair unacceptable defects</b>		
	2.1 For cracks		
	2.2 Honeycombing		
	2.3 Bleeding		
	<b>Other Notes, if any</b>		

## Annex C: the rank of factors influencing ready mixed concrete property

<b>Descriptive Statistics</b>				
<b>Groups/Factors</b>	<b>N</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>RANK</b>
Periodical calibration of plants and machines	43	4.95	0.213	1
The traffic situation on the road to the casting site	43	4.88	0.324	2
Raw material handling	43	4.86	0.351	3
Crew experience	43	4.86	0.351	4
Curing temperature	43	4.84	0.374	5
Travel duration	43	4.84	0.374	7
The batch plant arrangement (General location) and easily maneuverable vehicles.	43	4.77	0.427	8
Crew skill	43	4.77	0.427	9
Mix design	43	4.74	0.539	9
The batch plant arrangement (General location) and easily maneuverable vehicles.	43	4.72	0.454	12
Planning and organization (procurement plan cement, sand, etc.)	43	4.70	0.465	13
Inspection intervals	43	4.70	0.465	12
Crew number (adequacy)	43	4.67	0.474	13
The number of truck mixers in the plant	43	4.65	0.482	14
Planning and organization (procurement plan cement, sand, etc.)	43	4.58	0.499	15
Efficiency of the batch manager & his ability to distribute tasks	43	4.56	0.502	16
Changes in sources of raw materials	43	4.56	0.666	21
specialization of the profession	43	4.51	0.551	18
The Ease and clarity for the exchange of information and instructions	43	4.51	0.506	26
Curing humidity	43	4.49	0.506	20
The number of truck mixers in the plant	43	4.47	0.505	21
Raw materials type	43	4.42	0.663	22
The effectiveness of site supervision and labor guidance	43	4.37	0.489	23
Availability of undesired concrete disposal system	43	4.37	0.578	32
Availability of undesired concrete disposal system	43	4.37	0.489	23
Temperature during production	43	4.35	0.482	26
Type of curing	43	4.35	0.650	27
Temperature during placing	43	4.35	0.482	28
Moisture during production	43	4.33	0.474	29

Ambient temperature (i.e., hot- and cold-weather concreting)	43	4.33	0.474	30
Cost of concrete making materials	43	4.30	0.638	31
Regular maintenance for plant equipment	43	4.28	0.504	32
The age of Batch Plant	43	4.23	0.527	33
Regular maintenance for plant equipment	43	4.23	0.527	33
The age of Batch Plant	43	4.16	0.531	35
Management related	43	4.12	0.498	36
Marketing Plan efficiency	43	4.09	0.526	37
Management related	43	4.07	0.593	38
Raw materials storage location	43	4.05	0.486	39
Efficiency of the batch manager & his ability to distribute tasks	43	3.98	0.462	40
Inspection intervals	43	3.74	0.658	41
The effectiveness of site supervision and labor guidance	43	3.72	0.591	42
The Ease and clear for exchange of information and instructions	43	3.63	0.578	43
Valid N (listwise)	43			

## Annex D: Test Results

Table D1 : project 01 Compressive Strength test results and analysis, according to EBCS-2 1995 and ACI-318

Item No.	fck	Compressive Strength(MPa)	Mean(m3)	SD(N/mm2) for Cubic Strength	SD (N/mm2) for Cylindrical Strength	Coefficient of Variation (%)	Decision According to EBCS-2: 1995 $\sigma=1.1$ for C40 $\sigma=2.63$ for C60 fcr =fck+1.48* $\sigma$ fcr= 41.6 for C60 fcr= 63.89 for C60	Decision According to ACI fcr $\zeta = f_c \zeta + z_s s=1.1$ for C40 $s=2.63$ for C60 $z=1.68$ fcr =fck+1.68*s fcr= 41.84 for C60 fcr= 64.82 for C60
1	40	38.6	39.20	0.65	0.52	1%	Not complied	Not complied
		39.1						
		39.9						
1	40	41.6	41.50	0.85	0.68	2%	Not complied	Not complied
		40.6						
		42.3						
3	40	42.2	41.73	0.9	0.72	2%	complied	Not complied
		41						
		42						
4	40	48	48.13	0.5	0.4	1%	complied	complied
		47.9						
		48.5						
5	40	68	68.03	0.054	0.0432	0%	complied	complied
		68						
		68.1						
6	60	66.3	65.07	1.15	0.92	1%	complied	complied
		64.9						
		64						
7	60	68	68.20	0.14	0.112	0%	complied	complied
		68.6						
		68						
8	60	63	64.67	1.523	1.2184	2%	complied	Not complied
		65						
		66						
9	60	67	65.83	1.04	0.832	1%	complied	complied
		65						
		65.5						
10	60	66	64.83	1.6	1.28	2%	complied	Not complied
		63						

		65.5						
11	60	60.5	61.17	0.76	0.608	1%	Not complied	Not complied
		61						
		62						
12	60	69.1	69.40	0.36	0.288	0%	complied	complied
		69.8						
		69.3						
13	60	67.2	67.83	0.7	0.56	1%	complied	complied
		67.7						
		68.6						
14	60	68.7	67.67	1.1	0.88	1%	complied	complied
		67.8						
		66.5						
15	60	62.3	62.13	0.14	0.112	0%	Not complied	Not complied
		62.1						
		62						
16	60	65.1	64.70	0.6	0.48	1%	complied	Not complied
		65						
		64						
17	60	70.1	68.33	0.78	0.624	1%	complied	complied
		67.5						
		67.4						
18	60	71.2	70.93	0.3	0.24	0%	complied	complied
		70.6						
		71						
19	60	69.4	69.43	0.85	0.68	1%	complied	complied
		70.3						
		68.6						
20	60	70.1	69.40	0.7	0.56	1%	complied	complied
		68.7						
		69.4						
21	60	68.80	66.10	2.34	1.872	3%	complied	complied
		64.90						
		64.60						
22	60	62.30	64.80	2.17	1.736	3%	complied	not complied
		65.90						
		66.20						
23	60	63.60	65.13	1.78	1.424	2%	complied	complied
		67.10						
		64.70						
24	60	65.40	65.70	1.27	1.016	2%	complied	complied
		67.10						
		64.60						

25	60	69.00	65.37	3.46	2.768	4%	complied	complied
		62.10						
		65.00						
26	60	68.80	68.33	0.44	0.352	1%	complied	complied
		68.30						
		67.90						
27	60	66.10	63.33	2.8	2.24	4%	Not complied	Not complied
		63.40						
		60.50						
28	60	69.00	66.10	2.8	2.24	3%	complied	complied
		65.90						
		63.40						
29	60	67.50	66.37	2	1.6	2%	complied	complied
		64.00						
		67.60						
30	60	66.20	65.57	1.18	0.944	1%	complied	complied
		66.30						
		64.20						

Table D2: project 02 Compressive Strength test results and analysis, according to EBCS-2 1995 and ACI-318

Item No.	fck	Compressive Strength(MPa)	Mean(m3)	SD(N/mm2) for Cubic Strength	SD (N/mm2) for Cylindrical Strength	Coefficient of Variation (%)	Decision According to EBCS-2: 1995 $\sigma=3.9$ for C40 $\sigma=2.73$ for C60 fcr =fck+1.48* $\sigma$ fcr= 45.77 for C60 fcr= 64.2 for C60	Decision According toACI fcr $\zeta = f_c\zeta + z_s$ s=3.9 for C40 s=2.77 for C60 z=1.68 fcr =fck+1.68*s fcr= 46.55 for C60 fcr= 64.6 for C60
1	40	42	45	0.7	0.56	1%	Not complied	Not complied
		46.9						
		46.2						
1	40	54.9	49	3.5	2.8	7%	complied	complied
		47.1						
		46.2						
3	40	42.3	43	0.76	0.608	1%	Not complied	Not complied
		44						
		41.3						
4	40	43.2	49	2.9	2.33	5%	complied	complied
		55.3						
		47						
5	40	50.6	48	0.85	0.68	1%	complied	complied
		47.7						
		46.9						
6	40	48.7	47	1.76	1.408	3%	complied	complied

		45.6						
		45.8						
7	40	42.9	42	1.51	1.208	3%	<b>Not complied</b>	<b>Not complied</b>
		44						
		40.5						
8	40	50	50	0.75	0.6	1%	<b>complied</b>	<b>complied</b>
		48.7						
		50						
9	40	39.6	43	3.14	2.712	7%	<b>Not complied</b>	<b>Not complied</b>
		44						
		46						
10	40	51.2	51	2.03	1.624	3%	<b>complied</b>	<b>complied</b>
		50.1						
		50.3						
11	40	55.3	52	3.76	3.208	7.1%	<b>complied</b>	<b>complied</b>
		51.3						
		50						
12	40	54.1	53	1.6	1.28	2%	<b>complied</b>	<b>complied</b>
		53.5						
		51.1						
13	60	66.4	71	2.8	2.24	3%	<b>complied</b>	<b>complied</b>
		71						
		75.8						
14	60	71.1	69	3.4	2.72	4%	<b>complied</b>	<b>complied</b>
		71						
		65						
15	60	61.2	64	3.2	2.56	7.2%	<b>Not complied</b>	<b>Not complied</b>
		65.5						
		65.7						
16	60	68.4	68	0.47	0.376	1%	<b>complied</b>	<b>complied</b>
		68.6						
		67.7						
17	60	69.2	68	1.5	1.2	2%	<b>complied</b>	<b>complied</b>
		66.3						
		67.1						
18	60	72.5	71	1	0.8	1%	<b>complied</b>	<b>complied</b>
		70.6						
		71						
19	60	68.1	69	1.1	0.88	1%	<b>complied</b>	<b>complied</b>
		69.8						
		67.8						
20	60	68.9	67	2.11	1.688	3%	<b>complied</b>	<b>complied</b>
		67.7						
		64.8						

21	60	68.9	68	0.46	0.368	1%	<b>complied</b>	<b>complied</b>
		68.3						
		68						
22	60	70	70	0.64	0.512	1%	<b>complied</b>	<b>complied</b>
		69						
		70.2						
23	60	71.5	71	0.64	0.512	1%	<b>complied</b>	<b>complied</b>
		70.6						
		70.9						
24	60	67.8	65	1.4	1.12	2%	<b>Not complied</b>	<b>Not complied</b>
		60.8						
		65.1						
25	60	65.1	65	2.13	1.704	3%	<b>Not complied</b>	<b>Not complied</b>
		66.8						
		62.8						
26	60	70.5	69	2.91	2.328	3%	<b>complied</b>	<b>complied</b>
		65.3						
		70.2						
27	60	68.9	69	0.64	0.512	1%	<b>complied</b>	<b>complied</b>
		69.2						
		69.8						
28	60	68.1	68	3.6	2.88	4%	<b>complied</b>	<b>complied</b>
		65						
		69.6						
29	60	62.6	64	0.6	6	9%	<b>Not complied</b>	<b>Not complied</b>
		66.2						
		64.1						
30	60	60.2	64	1.97	1.576	2%	<b>Not complied</b>	<b>Not complied</b>
		62						
		70.6						

Table D3: project 03 Compressive Strength test results and analysis, according to EBCS-2 1995 and ACI-318

Item No.	FCK	Compressive Strength(MPa)	Mean(m3)	SD(N/mm2) for Cubic Strength	SD (N/mm2) for Cylindrical Strength	Coefficient of Variation (%)	Decision According to EBCS-2: 1995 $\sigma=2.44$ , for C30 $\sigma=2.64$ for C40 $fcr=fck+1.48*\sigma$ $fcr= 35.9$ for C30 $fcr= 45$ for C40	Decision According to ACI for $\zeta = f_c\zeta + z_s s=2.44, fck+7$ for C430 $s=2.64$ for C60 $z=1.68$ $fcr =fck+1.68*s$ $fcr= 38$ for C30 $fcr= 46.6$ for C40
1	30	38.2	37.23	0.37	0.296	1%	complied	complied
		37.2						
		36.3						
2	30	36.5	35.50	0.47	0.376	1%	Not complied	Not complied
		35.5						
		34.5						
3	30	35	36.17	0.5	0.4	1%	complied	Not complied
		36						
		37.5						
4	30	38.1	35.80	1.08	0.864	2%	Not complied	Not complied
		34.2						
		35.1						
5	30	33	35.77	1.05	0.84	2%	Not complied	Not complied
		38.3						
		36						
6	30	35.5	38.27	3.5	2.2	7%	complied	complied
		39.3						
		40						
7	30	39.2	39.80	0.43	0.344	1%	complied	complied
		41						
		39.2						
8	40	39	44.43	5.1	4.08	9%	Not complied	Not complied
		48.4						
		45.9						
9	40	44.9	47.10	2.7	2.16	5%	complied	complied
		43.3						
		53.1						
10	40	41.2	47.10	6.3	5.04	11%	complied	complied
		50.1						
		50						
11	40	53.1	49.23	1.7	1.36	3%	complied	complied
		46.3						
		48.3						

12	40	43.4	46.40	3.46	22.968	6.4%	Not complied	Not complied
		46.2						
		49.6						
13	40	47.1	50.80	1.7	1.36	3%	complied	complied
		53.3						
		52						
14	40	52.5	50.50	0.63	0.504	1%	complied	complied
		49						
		50						
15	40	49.6	51.80	0.5	0.4	1%	complied	complied
		53.4						
		52.4						
16	40	54	51.63	0.8	0.64	1%	complied	complied
		49.8						
		51.1						
17	40	52.3	48.97	1.25	1	2%	complied	complied
		48						
		46.6						
18	40	42.4	45.60	4.89	3.312	9%	Not complied	Not complied
		45.6						
		48.8						
19	40	46	49.53	4.75	1.4	12%	Not complied	Not complied
		47						
		56.6						
20	40	41	42.87	3.32	2.656	6%	Not complied	Not complied
		46.6						
		41						

Table D4: Test Conducted at the Batch Plant Compressive Strength test results and analysis, according to EBCS-2 1995 and ACI-318

Item No.	fck	Compressive Strength(MPa)	Mean(m3)	SD(N/mm2) for Cubic Strength	SD (N/mm2) for Cylindrical Strength	Coefficient of Variation (%)	Decision According to EBCS-2: 1995 $\sigma=4.1$ for C60 fcr $=fck+1.48*\sigma$ fcr= 64.88 for C60	Decision According to ACI $s=3.3$ for C60 $z=1.68$ fcr $=fck+1.68*s$ fcr= 65.5 for C60
1	60	66.1	66.60	2.26	1.808	3%	complied	complied
		65.7						
		68						
1	60	67	66.03	1.3	1.04	2%	complied	complied
		64.8						
		66.3						
3	60	66.7	66.90	1.45	1.16	2%	complied	complied

		67						
		67						
4	60	65	65.33	2.6	2.08	3%	<b>complied</b>	<b>not complied</b>
		65.7						
		65.3						
5	60	72.1	71.90	2.6	2.08	3%	<b>complied</b>	<b>complied</b>
		72						
		71.6						
6	60	68.3	68.30	0.35	0.28	0%	<b>complied</b>	<b>complied</b>
		68						
		68.6						
7	60	64.3	64.17	5	0.72	7.1%	<b>Not complied</b>	<b>Not complied</b>
		58						
		63.2						
8	60	71.6	70.83	1	0.8	1%	<b>complied</b>	<b>complied</b>
		71.2						
		69.7						
9	60	71.3	72.47	0.8	0.64	1%	<b>complied</b>	<b>complied</b>
		72.7						
		73.4						
10	60	72	72.40	2.03	1.624	2%	<b>complied</b>	<b>complied</b>
		74.6						
		70.6						
11	60	68.6	66.53	9	7.2	11%	<b>complied</b>	<b>complied</b>
		66.3						
		64.7						
12	60	65.3	67.83	2.25	1.8	3%	<b>complied</b>	<b>complied</b>
		68.6						
		69.6						
13	60	66.1	65.93	0.76	0.608	1%	<b>complied</b>	<b>complied</b>
		63.6						
		65.1						
14	60	65.9	64.73	1	0.8	1%	<b>Not complied</b>	<b>Not complied</b>
		64						
		64.3						
15	60	65.5	66.33	1.27	1.016	2%	<b>complied</b>	<b>complied</b>
		67.8						
		65.7						
16	60	66.2	65.10	0.96	0.768	1%	<b>complied</b>	<b>complied</b>
		65.7						
		63.4						
17	60	68	66.00	1.55	1.24	2%	<b>complied</b>	<b>complied</b>
		68						
		62						

18	60	67.6	65.53	2.45	1.96	3%	complied	Not complied
		61.7						
		67.3						
19	60	64.3	66.27	2.17	1.736	3%	complied	complied
		65.9						
		68.6						
20	60	66	65.53	8.2	6.56	10%	complied	complied
		60						
		66.6						
21	60	68.8	66.10	2.34	1.872	3%	complied	complied
		64.9						
		64.6						
22	60	62.3	64.50	3.6	2.88	4%	Not complied	Not complied
		65						
		66.2						
23	60	63.6	65.13	1.78	1.424	2%	complied	Not complied
		67.1						
		64.7						
24	60	65.4	65.70	1.27	1.016	2%	complied	Not complied
		67.1						
		64.6						
25	60	69	68.37	3.16	2.528	4%	complied	complied
		68						
		68.1						
26	60	68.8	68.33	0.44	0.352	1%	complied	complied
		68.3						
		67.9						
27	60	64.1	65.50	2.8	2.24	3%	complied	complied
		63.4						
		66						
28	60	69.5	66.27	3.22	2.576	4%	complied	complied
		65.9						
		63.4						
29	60	67.5	66.37	2	1.6	2%	complied	complied
		64						
		67.6						
30	60	66.2	65.57	1.18	0.944	1%	complied	complied

## Annex E: Pictures of Results of Tests Conducted in a Laboratory (Cubes Casted at a Batching Plant Site)



**AAiT**

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አዲስ አበባ

**School of Civil &  
Environmental Engineering**  
የኢ.ቪ.አ. ኢንጅነሪንግና ሎጂስቲክስ  
ምህንድስና ትምህርት

Date:- June .30,2023

CONSTRUCTION MATERIALS TESTING LABORATORY

Client:- Oromia Insurance Company SC  
 Consultant:- Zeleke Belay Architects  
 Contractor:- CJIC  
 Project OIC Head Quarter Project  
 Location 2B- C-60 -D7  
 Test Required:- Compressive Strength of Concrete Cubes  
 \*Casting Date:- 27/5/2023  
 Date Tested :- 26/6/2023

SUMMARY OF TEST RESULTS

Specimen No.	Dimensions [cm]			Area [cm <sup>2</sup> ]	Failure Load [kN]	Compressive Strength [MPa]	Weight [gm]
	L	W	H				
1	15.0	15.0	15.0	225.00	1446.2	64.3	8577.0
2	15.0	15.0	15.0	225.00	1462.5	65.0	8634.0
3	15.0	15.0	15.0	225.00	1422.5	63.2	8686.0

\*Note: Casting date as reported by the Client  
 Loading rate=0.28 Mpa/S

Tested by:  
 Ato Fikru Bedada  
 Ato Demessew Melaku

\_\_\_\_\_



Verified by:  
 Dr. Ing. Adil Zekaria





# AAiT

Addis Ababa Institute of Technology  
አዲስ አበባ ቴክኖሎጂ ስራተኛ ቤት  
Addis Ababa University  
አዲስ አበባ ዩኒቨርሲቲ

School of Civil & Environmental  
Engineering  
የሲቪል እና አካባቢያዊ ማህንደሮች  
ምህንድስና ት/ክ/ፍ/ል

Date:-November .15,2023

### CONSTRUCTION MATERIALS TESTING LABORATORY

Client:- Oromia Insurance Company SC  
 Consultant:- Zeleke Belay Architects  
 Contractor:- CJIC  
 Project OIC Head Quarter Project  
 Location 1F-C-40- D1  
 Test Required:- Compressive Strength of Concrete Cubes  
 \*Casting Date:- 15/10/2023  
 Date Tested :- 13/11/2023

### SUMMARY OF TEST RESULTS

Specimen No.	Dimensions			Area [cm <sup>2</sup> ]	Failure Load [kN]	Compressive Strength [MPa]	Weight [gm]
	[cm]						
	L	W	H				
1	15.0	15.0	15.0	225.00	869.5	38.6	8468.0
2	15.0	15.0	15.0	225.00	880.6	39.1	8371.0
3	15.0	15.0	15.0	225.00	897.2	39.9	8306.0

\*Note: Casting date as reported by the Client  
 Loading rate=0.28 Mpa/S


**Tested by:**  
 Ato Fikru Bedada  
 Ato Demessew Melaku




**Verified by:**  
 Dr.Ing Adil Zekarias



Annex F: Picture of the material test result.

		<b>Gentium Concrete Industries PLC (GCI)</b> Addis Ababa - Ethiopia <b>Technical Department</b>		Cementing Your Concrete Needs			
<b>REPORT ON COMPRESSIVE STRENGTH FOR CONCRETE CUBES</b> BS1881 Part116:1983Amended1991							
Project	Client	M/s. Gentium Concrete Industries					
	Consultant	M/s. China JIANGXI Corporation For International Economic & Technical Cooperation Ethiopia Office					
	Project	OIC					
Internal	Source	Gentium Concrete Industries PLC	No of cubes	6			
	Sample Description	Concrete Cubes	Date of sampling	28/11/2022			
	Casting Date	28/11/2022	Cement type	Dangote opc 500kg/m3			
	Mix Grade	C60, PLANT TRIAL	Structural :-				
	Sample Prepared by	PLANT	Compaction method	Hand compaction			
	Unit Sampled from	Truck Mixer D.NO	Sampling method	BS1881Part108			
	Dimension	150X150X150mm					
Lab Test Report	Cube number	1	2	3	4	5	6
	Date tested	05-DEC-22	05-DEC-22	05-DEC-22			
	Actual test age	7	7	7			
	Required test age	7	7	7			
	Condition of cube	Normal	Normal	Normal			
	Average measurement dimension(B)mm	150	150	150			
	Average measurement dimension(H)mm	150	150	150			
	Oven Dry Density kg/m <sup>3</sup>						
	Weight (g)	8570	8519	8527			
	Max load at fail (KN)	1107.1	1064	1197.9			
	Compressive Strength(N/mm <sup>2</sup> )	49.2	47.3	53.2			
	Average Compressive Strength(N/mm <sup>2</sup> )	49.9					
	Type of Fracture	Satisfactory					
Specified strength(N/mm <sup>2</sup> )							

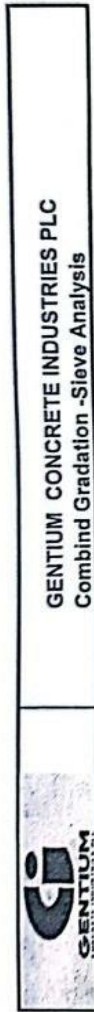
Remarks:

 **Beetshalew**  
(Tested by)



  
(Approved by)





Aggregate Size (mm)	20mm	Sampling Date	November 28, 2022
Source of Aggregate	Gentium Stock	Testing Date	November 29, 2022
Day Mass (g)	5242	Mass after Washing (g)	5333
Before Washe	5297		

BS Sieve Opening	Mass Retain (g)	Retaining (%)	Comulative passing (%)	BS Limits
37.5mm	804	15.2	84.8	100
20.0mm	4806	91.7	8.3	85-100
12.5mm	5212	99.4	0.6	0-70
9.5mm	5224	99.7	0.3	0-25
4.75mm	5225	99.7	0.3	0-5
2.36mm				
1.18mm				
600µm				
300µm				
150µm				
75µm				
Pan	5333			

Initial Weight of the Sample (W1)	5242	g
Final Weight of Sample After Washing through Sieve/75µm (W2)	5233	g
Dust Content (%) = (W1-W2)/W1-100	0.2	%



Tested by *[Signature]* Approved by *[Signature]*





**GENTIUM CONCRETE INDUSTRIES PLC**  
**Combine Gradation - Sieve Analysis**

Aggregate Size (mm)	River Sand	Sampling Date	November 28, 2022
Source of Aggregate	Sentium Stock	Testing Date	November 29, 2022
Day Mass(g)	1681	Mass after Washing (g)	1653
Before Wash	1879		

BS Sieve Opening	Mass Retain (g)	Retaining (%)	Comulative passing (%)	BS Limits
37.5mm				
20.0mm				
14.0mm	13			
9.5mm	47	2.8	97.2	100
4.75mm)	220	13.1	86.9	
2.36mm	469	27.9	72.1	60-100
1.18mm	814	48.4	51.6	30-90
600µm	1236	73.5	26.5	15-54
300µm	1527	90.8	9.2	5-40%
150µm	1623	96.5	3.5	
75µm	1623	96.5	3.5	
Pan	1651			

Initial Weight of the Sample (W1)	1681	g
Final Weight of Sample After Washing through Sieve 75µm (W2)	1653	g
Dust Content (%) = (W1-W2)/W1*100	1.7	%



Tested by [Signature] Approved by [Signature]



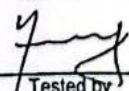


Sampling Date 07-Dec-22  
 Cylinder Weight = 4668  
 Cylinder volume = 5 Lt

River sand			
Loose		Compacted	
Weight	Density	Weight	Density
10892	1.245	11595	1.385
10842	1.235	11564	1.379
10834	1.233	11570	1.380
Average 1.238		Average 1.382	
Average(kg) 1310			
Moisture Content % 11.4			

00 aggregate(TDT & ZY)			
Loose		Compacted	
Weight	Density	Weight	Density
12008	1.468	12588	1.584
12049	1.476	12549	1.576
12038	1.474	12564	1.579
Average 1.473		Average 1.578	
Average(kg) 1525			
Moisture Content % 2.4			

01 aggregate (TDT & zy)			
Loose		Compacted	
Weight	Density	Weight	Density
10969	1.260	11693	1.405
10964	1.259	11658	1.398
10983	1.263	11170	1.300
Average 1.261		Average 1.368	
Average(kg) 1314			
Moisture Content % 1.2			

02 aggregate (TDT & ZY)			
Loose		Compacted	
Weight	Density	Weight	Density
11461	1.359	12194	1.505
11423	1.351	12198	1.506
11483	1.363	12186	1.504
Average 1.358		Average 1.505	
Average(kg) 1431			
Moisture Content % 0.7			

 Tested by  
 Approved By  


Annex G : picture of Hammer test result



**ENGINEERING PLC**  
Geotechnical Engineering Services  
Soil and Construction Material Laboratory

**SCHMIDT HAMMER TEST RAW DATA SHEET (FORM NO 15)**

Client: OIC  
 Project: OIC Head Quarter project  
 Consultant: Zeleke Belay  
 Location: Addis Ababa, Mexico Area  
 Date of Cast: \_\_\_\_\_  
 Test Conducted on: NOV. 03/2023  
 Direction of Impact: HORIZONTAL for Beam and Vertical for slab  
 Date of Test: (1) (2) (3)

SW-2		SW-10		C1/B5					
No.	R.No	No.	R.No	No.	R.No	No.	R.No	No.	R.No
1	54	1	50	1	52	1		1	
2	54	2	51	2	52	2		2	
3	53	3	53	3	52	3		3	
4	54	4	49	4	50	4		4	
5	54	5	49	5	55	5		5	
6	53	6	49	6	58	6		6	
7	53	7	51	7	52	7		7	
8	54	8	48	8	52	8		8	
9	52	9	48	9	52	9		9	
10	55	10	49	10	54	10		10	

Name: \_\_\_\_\_ Signature: \_\_\_\_\_  
 Client Side: Demozie Zorhan  
 Consultant side: Mekonen Dinsa  
 Contractor side: pelemaw Amare  
 Testing Company: Solomon T. Belen

## Annex H : Batching plant Dispatch sample



Plant 2  
Plant 2 M1 2032069 13.05.2024 14:57



11961 China civil engineering construction  
1437 2D+G+E AT DENDEL

TM 027 MESSAY Administrator 1142 VSA0 40 11363  
A27083

9,00 40Mpa OPC 20mm 420,00 590,00 30,00

FREE W/C: 0,37	SSD DESIGN	TARGET	REQ ACT	BATCHED	ERROR	ABS	ABS	MOIST	MOIST ACT	WATER
MATERIAL	KG/M3	KG	KG	KG	%	%	KG	%	KG	KG
05mm River Sand	580,0	5600,0	5610,0	0,2	10,0	4,40	220,4	12,00	601,1	380,
05mm Crushed Sa	280,0	2481,1	2505,0	1,0	23,9	3,60	88,4	2,00	49,1	-39,
10mm Crushed Ag	310,0	2798,2	2740,0	-2,1	-58,2	1,70	45,7	2,00	53,7	8,
20mm Crushed Ag	680,0	6120,0	6115,0	-0,1	-5,0	1,00	60,3	1,00	60,5	
Derba OPC	410,0	3690,0	3694,0	0,1	4,0					599,
Fresh Water	156,0	955,9	955,0	-0,1	-0,9					
30B			0,1	0,1	0,1					54,
Sika Viscoflow	9,6	87,2	88,0	0,9	0,8					

W/C ratio: 0,38

Max Agg Size: 20mm

Admix: 30B  
Sika Viscoflow 615 2,35 l