JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR

ASSESSMENT OF CONCRETE PRODUCTION QUALITY CONTROL IN BUILDING CONSTRUCTION SITES: A CASE OF ADAMA CITY

A thesis submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillments of the Requirements for the Degree Master of Science in Construction Engineering and Management

By

Henock Birhanu Anshiso

March 2022

Jimma, Ethiopia

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Approved by board of examiners

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DECLARATION

I declare that this thesis entitled "Assessment of concrete production quality control in building construction sites: A case of Adama city '' is my own original work and has not been presented for a degree in any other university, and all sources of materials used for this thesis proposal have been duly acknowledge.

Henock Birhanu Anshiso ____________________ ________________

NAME SIGNATURE DATE

As a research advisor, I here by certified that I have read and evaluated this thesis paper under my guidance, By Henock Birhanu Anshiso entitled "ASSESSMENT OF CONCRETE PRODUCTION QUALITY CONTROL IN BUILDING CONSTRUCTION SITES: A CASE OF ADAMA CITY '' recommend and would be accepted as a fulfilling requirement for the Degree Master of Science in Construction Engineering and Management.

Advisor Name: Dr. Lucy Feleke ________________ ________________

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ABSTRACT

Concrete is a major component of most of our infrastructural facilities today in the 21st century because of its versatility in use. Concrete is generally produced in batches at the site with the locally available materials of variable characteristics. Moreover, concrete undergoes a number of operations, such as transportation, placing, compacting and curing. During these operations considerable variations occur partly due to quality of plant available and partly due to differences in the efficiency of techniques used. Thus there are no unique attributes to define the quality of concrete entirely. Under such a situation concrete is generally referred to as being of good, fair or poor quality.

The aim of this paper is to assess concrete production quality control in the building construction project sites of Adama city by identifying the factors affecting the quality of concrete production, by identifying the impacts caused by factors affecting the quality of concrete production, by assessing the current practices implemented on the quality of concrete production.

Concrete quality control related literature was reviewed. A survey questionnaire supported by site observation was used to explore the local practice in concrete quality control and compressive strength tests results of concrete was also collected from consultant's data files and analyzed with compliance of different scientific code and standards. A questionnaire was distributed to consultants and contractors sides' professionals who are assigned to perform building construction sites of grade one general contractors.

The researcher collected 20 lots of 7th, 14th and 28th days concrete compressive test results in which the 7th and 14th days results are used by the researcher to assess the progress by evaluating the percentage values at those ages with respect to attainable scientific grounds. In fact, quality control is done for both OPC and PPC cements concrete at 28 days commonly. Additionally, each of the lots contains 3 pieces and a total of 60 pieces for each ages from 16 ongoing building projects in Adama city are collected from consultants whereas 8 lots with C-30 and 12 lots with C-25 compressive strength. To sum up, all lots are collected and assessed from ongoing concrete structural work of columns, beams, slabs and shear walls on the period of the researcher site observation while concrete casting. Each lot is examined according to Ethiopian building code and standard (EBCS-2:1995), and American concrete institute (ACI 318).

Based on standard deviation 5% and based on coefficient of variation 15% of projects have poor concrete quality control. Though the research expelled that, variations and non-conformity to standards is available within the investigated project. This implies that the test results among the investigated projects have shown large variability indicating the quality control is unsatisfactory on those projects.

Key words: - batching, cement, compacting, compressive strength test, concrete, curing, mixing, placing, quality control, transporting.

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ACRONYMS

AAR	Alkali aggregate reaction
ACI	American concrete institute
ACR	Alkali carbonates reaction
ACV	Aggregate crushing value
AIV	Aggregate impact value
ASTM	American society for testing of materials
BS	British standard
CV	Coefficient of variation
DBB	Design bid build
DOE	Department of environments
EBCS	Ethiopian building codes and standards
ES	Ethiopian standard
GC	General Contractor
IS	Indian standards
JIT	Jimma institutes of technology
OPC	Ordinary Portland cement
PH	Power of hydrogen
PPC	Portland pozzolans cement
RII	Relative importance index
SD	Standard deviation
SQC	Statistical quality control

CHAPTER ONE

INTRODUCTION

1.1 Background

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in hard matrix of material (the cement of binder) that fills the space between the aggregate particles and glue them together [1]. The binder or matrix is a combination of cement and water; it is commonly called the cement paste. Aggregates are essentially filler materials that can be separated into fine and coarse aggregates. In addition to aggregates and binders, there is another material called additive which may be used in concrete to improve certain of its properties [2].

Concrete is used more than any other man-made material in the world. Concrete is a major component of most of our infrastructural facilities today in the 21st century because of its versatility in use. It has been a very significant construction material since its discovery in the entire world. Concrete has been a choice for all forms of construction; residential, industrial, agricultural, etc., in the world because of its versatility and ease of construction.

Many buildings structures made of concrete elements such as; beams, columns, slab, foundation, etc. had been constructed in Ethiopia and their performance in service after several years of construction are still found to be satisfactory. However, the actual application of concrete in construction in the recent times in most in Ethiopia has become to its lower level.

Concrete is generally produced in batches at the site with the locally available materials of variable characteristics mostly in Adama town. It is, therefore, likely to be variable from one batch to another. The magnitude of this variation depends upon several factors, such as (a) variation in the quality of constituent materials; (b) variation in mix proportions due to batching process; (c) variation in the quality of batching and mixing equipment available; (d) the quality of overall workmanship and (e) supervision at the site. Moreover, concrete undergoes a number of operations, such as transportation, placing, compacting and curing. During these operations considerable variations occur partly due to quality of plant available and partly due to differences in the efficiency of techniques used. Thus there are no unique attributes to define the quality of concrete entirely. Under such a situation concrete is generally referred to as being of good, fair or poor quality. Due to the large number of variables influencing the performance of concrete, quality control is needed to assess.

1.2 Statement of the problem

In the world, concrete is a major construction material commonly and regularly used on buildings. To produce concrete as economically as possible with appropriate workability, strength and durability care has to be taken during concrete production because poor quality of concrete even from well-designed mix can be happen due to lack of control in production [1]. In Ethiopia, concrete is usually non-factory product or cast in situ product where it is mostly produced on site manually, it is very important and proper to study its production quality control, and buildings are usually made of concrete structures which cost a significant amount out of the total cost of the project; the concrete should only become a quality material for the construction [3]. Though there is no a research done on the quality control of concrete used on construction building sites of specifically Adama city that has been done till now. Different stakeholders believe that the concrete they use is low quality due to uncontrolled concrete production process. This creates fears to the quality of this project among stakeholders. The researcher also participated on the construction of these building projects and observed many factors in concrete production that hinder the quality of concrete. Hence, this research was conducted to assess quality control of concrete production in Adama city selected building projects.

1.3 Research questions

1. What are the factors affecting the quality of concrete production in selected building construction sites of Adama city?
2. What are the impacts caused by factors affecting the quality of concrete production in selected building construction sites of Adama city?
3. What are the current practices implemented in Adama city on the quality of concrete production?

1.4 The Objective of the Study

1.4.1 General Objective

This study's general objective is assessing concrete production quality control in building construction sites: A Case of Adama city.

1.4.2 Specific Objectives

The specific objectives of this study will be:

- To identify the factors affecting the quality of concrete production in selected building construction sites of Adama city.
- To identify the impacts caused by factors affecting the quality of concrete production in selected building construction sites of Adama city.
- To assess the current practices implemented in Adama city on the quality of concrete production.

1.5 Scope and limitation of the study

This research was limited and focused on assessing quality control of concrete production in building project sites of Adama city. The reason behind choosing concrete is its greatest significance to be used in a building construction. This study addressed the stated objectives of the research and assessed the quality control for concrete production in building projects of Adama city based on the existing theories and principles. This research was conducted by collecting data from selected building construction sites in Adama city.

1.6 Significance of the study

In Adama, most of the buildings are constructed using concrete due to strength and protection concrete provide against aggressive conditions. In order to satisfy the owners and the users need, the quality of the buildings must satisfy the stated codes and standards. Despite of the advantages of concrete, still concrete constructed buildings in Adama are facing quality control problems which are mainly caused by negligence of national building codes and standards, design deficiencies such as lack of design details and accuracy, unsatisfactory quality of concrete ingredients, inappropriate construction technology, lack of quality control measures and inadequate supervision on construction sites. On the other hand different stakeholders also believe that the concrete they use is low quality due to uncontrolled concrete production process. This creates lack of assurance to the quality of those projects among stakeholders. Generally this study will be significant to those all construction stakeholders as well as the construction industry.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on different literature reviews available on quality for concrete materials selection, handling, batching, transporting, placing, compacting, curing and testing that was taken from different journals, articles, thesis papers and books. Therefore, this chapter mainly focuses on the quality of those concrete materials in relation to physical and chemical as well as workmanship that intensively affect the quality of concrete. Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in hard matrix of material (the cement of binder) that fills the space between the aggregate particles and glue them together [1].The production of concrete involves two distinct but equally important activities. One is related to material required for concrete production such as selection and proportioning of ingredients and the other is the process involved in its production such as batching, mixing, transporting, placement, compaction and curing [1].To produce concrete as economically as possible with appropriate workability, strength and durability care has to be taken during concrete production because poor quality of concrete even from well-designed mix can be happen due to lack of attention in production [1]. A good and a bad concrete may be made from exactly the same ingredients if there is a difference on the quality control during production. The importance of quality of concrete is being increasingly realized to derive the optimum benefit from the materials employed.

Quality concrete is that which is capable of meeting the requirements of the job in terms of strength, durability and appearance. Strength is often the major feature in defining the quality because strength is both easy to define and to measure. Therefore in many cases, strength is the unique measurement of concrete quality [4].

From production point of view Inspection of materials on site shall be made at delivery to check compliance with the specifications and the requirements of EBCS-2:1995 (Chapter

8). It is an established fact that the compressive strength of concrete is influenced by the quality and proportion; of fine and coarse aggregate, the cement paste and the paste-aggregate bond characteristics. Other qualities of concrete such as durability and abrasion resistance are also highly dependent on the aggregate, which in turn depends on strength of parent rock, purity, surface texture, gradation and so on. In order to get quality concrete the most important thing is obtained by skilled supervisors and well trained workers who understand the science of concrete. Hence, the workmanship of concreting operations is therefore important in maintaining the required concrete quality. The specifications should also contain sufficient information on the workmanship requirements as well as on materials to maintain satisfactory supervision. A good level of supervision helps to improve the standard of workmanship on the site [5].

2.2 Ingredients of concrete

2.2.1 Portland Cement

2.2.1.1 Portland cement and its production process

Portland cement is by far the most important member of the family of hydraulic cements - that is, cements that harden through chemical interaction with water. The first patent for “Portland” cement was taken out in England in 1824 by Joseph Aspdin, though it was probably not a true Portland cement; the first true Portland cements were produced about 20 years later. Since then, many improvements have been made to cement production, leading to the sophisticated, though common, cements that are now so widely available. Cement in general can be described as a material with adhesive and cohesive prosperities which make it capable of bonding mineral fragments into a hard continuous compact mass [6]. Though there are various types of cements used for concrete production, Portland cement is the one which is commonly used in Ethiopia for concrete production. Portland cement is one of the Hydraulic cements which are capable of setting and hardening under water.

The principal raw materials used in the manufacture of cement are:-

1. Argillaceous or silicates of alumina in the form of clays and shale.

2. Calcareous, or calcium carbonate, in the form of limestone, chalk and marl which is a mixture of clay and calcium carbonate [7].

The manufacture of Portland cement is, in principle, a simple process that relies on the use of inexpensive and abundant raw materials. Two processes of manufacture are employed, the dry process and the wet process. In the dry process the materials are crushed, dried, and then ground in ball mills to a powder, which is burnt in its dry condition. In wet process the materials are first crushed and then ground to form slurry in wash mills. After passing through the wash mills and the slurry silos, the slurry passes to the slurry tanks. The slurry is next pumped to a kiln and made to clinker at clinkering temperature of about 1400 to 1500°c. The cement clinker then passes through clinker coolers. Having cooled sufficiently, the clinker is ground to the required degree of fineness. During grinding, gypsum, which acts as "a retarder" is, incorporated [8].

2.2.1.2 Chemical composition of Portland cement

The major constituents of raw materials used in Portland cement production; mainly, lime, silica, alumina and iron oxide compounds interact with one another in the kiln to form a series of more complex products, and those usually regarded as the major constituents of cement. These are the tricalcium silicate (C3S), Dicalcium silicate (C2S), tricalcium aluminate (C3A) and tetra calcium alumino ferite or iron compound (C4AF). Table 2.1 gives approximate oxide composition limits of Portland cement [9]. The chemical composition of Portland cement is customarily reported in terms of the oxides of the various elements that are present.

Table 2.1 Approximate oxide composition limits of Portland cement [9]

Oxide	**Content in percent**
CaO	60-67
SiO2	17-25
Al2O3	3-8
Fe2O3	0.5-6
MgO	0.1-4
A1kalis	0.2-1.3

SO_3	1-3

2.2.1.3 Hydration of cement

Hydration is the reaction in which cement becomes a bonding agent takes place in a water cement paste or the process in which in the presence of water, the silicates and aluminate compounds of cement form products of hydration, which in time produce a firm and hard mass [9]. The hydration reactions that take place between finely ground Portland cement and water is highly complex, because the individual cement grains vary in size and composition. As a consequence, the resulting hydration products are also not uniform; their chemical composition and micro structural characteristics vary not only with time but also with their location within the concrete.

Hydration is fast during the first few minutes of mixing and decreases continuously with time. Because of reduction in rate of hydration even after a long time there remains an appreciated amount of un hydrated cement. Hence there is hydration at any time after hardening of concrete though it is at a very lower rate [9].

The various compounds of cements mentioned previously has different rate of hydration, the rate of hydrations of C_4AF is higher than the three major compounds of cement. C_3A has higher rate than C_3S and C_2S; and C_3S has higher rate of hydration than C_2S [9].

The hydration products of the major cement compounds, C_3S and C_2S, gives calcium silicate hydrates which is commonly designated as C-S-H. This hydrate product determines the basic physical properties of concrete such as setting and strength gain [9].

The hydration of C_3A cement is fast and violent in comparison to the other cement compounds and it leads to immediate stiffening of the paste, known as flash set. To prevent this from happening gypsum is used which reacts with C_3A and forms insoluble calcium sulphoaluminate by protecting the direct reaction of water and C_3A [9].

The presence of C_3A in cement is undesirable, it contributes little or nothing to the strength of cement at early ages, and when hardened cement paste is attacked by sulphates, expansion due to the formation of calcium sulphoaluminates from C_3A may result in a disruption of the hardened paste.

However, C_3A & C_4AF acts as a flux and thus reduces the temperature of burning of clinker and facilitates the combination of lime & silica, hence they are useful in the production of cement [9].

According to Ethiopian standard, ESC.D5.201, the percentage by mass of SO_3 in Portland cement is limited to 3% if the C_3A content is limited to 8% or less and to 3.5% when C_3A exceeds 8%. However; its content in Portland Pozzolans cement is 3% which is independent of the C_3A content.

2.2.1.4 Heat of hydration of cement

The hydration of cement compound is exothermic, and hence there is significant amount of heat energy evolved during hydration, which may reach up to 500 joules per gram (120 cal/ gram). Since the conductivity of concrete is comparatively low, it acts as insulator, and in the interior of a large concrete mass, hydration can result in a large rise in temperature. At the same time the exterior of the concrete mass loses some heat so that a steep temperature gradient may be established, and during subsequent cooling of the interior serious cracking may result. It is clear, then, that it is advisable to know the heat producing properties of different cements in order to choose the most suitable cement for a given purpose or environment [9].

2.2.1.5 Tests on physical and chemical properties of cement

Cement tests are conducted to ensure the quality of cement and to determine the chemical and physical properties of cement. Testing of cement can be brought under two categories namely field testing and laboratory testing. According to scientific grounds if the cement satisfies the different field tests it may be concluded that the cement is not bad, however this test does not give any quantitative result.

On the other hand, Ethiopian Standard ESC.D6.201 sets quality requirements of Portland cement by chemical and physical tests on cement. Chemical tests are normally conducted by the manufacturer on regular basis in order to check the quality of the product. They may also be conducted in research laboratories in order to determine the compound composition of the cement used in a research. Chemical tests are of little importance to the ordinary consumer. In addition to the chemical composition, it is required to that Portland cement conforms to the relevant physical requirements for fineness, consistency, setting time, soundness and strength [7].

2.2.1.6 Ordinary Portland and Portland Pozzolana cement

There are various types of Portland cements. The two, namely, Ordinary and pozzolanic Portland cements, are cements which are mostly produced by the cement factories in Ethiopia and used for concrete production [2]. Hence the properties of these two cements are discussed in detail here.

Ordinary Portland cement is admirably suitable for use in general concrete construction when there is no exposure to Sulphates in the soil or in ground water. However; in urban and near urban areas, underground water has higher tendency of getting spoiled with chemicals due to the possibility of percolation of wastes discharged from factories and various chemicals which has been used for domestic purposes. Therefore, the placing of sub structural reinforced concrete elements like footing, mats or piles generally concrete foundations are subject to these chemicals.

Portland Pozzolana cement is produced by partially replacing a certain percentage of the Portland cement by Pozzolanic material obtained from volcanic ash [10]. The Pozzolana added varies commonly between 10 and 30%. Pozzolanas aren't reactive by themselves but becomes reactive when it gets in contact with Portland cement. It reacts with the calcium hydroxide liberated from Portland cement at ordinary temperatures to form compounds possessing cementitious properties. Portland Pozzolana cements gain strength slowly and require, therefore, curing over comparatively long period, but their ultimate strength is approximately the same as that of ordinary Portland cement alone [9].

Low heat Portland cement such as Portland pozzolana cement has approximately half the strength of ordinary Portland cement at 7days, two thirds at 28 days and is approximately equal in strength at 3 months [11]. Pozzolanas are cheaper than Portland cement. Its slow hydration and the resulting slow rate of heat development make it important in mass concrete construction. It also shows good resistance to sulphate attack and to some other destructive agents. This is so because the Pozzolanic reaction leaves less lime to be leached out and also reduces the permeability of concrete [9].

2.2.1.7 Storage of cement

The storage of cement is entirely a matter of keeping it dry, and it is necessary to stack the bags in a shed or under whatever cover is available. On small projects where storage without a shed is required for a few days, the cement should be placed on a raised platform and covered with transpaulins, polyethylene film (0.2mm thick) or water proof building paper [8,12].

Even when stored under good conditions bagged cement may lose 20 percent of its strength after 2 months of storage, and 40 percent after 6 months of storage [9]. Cement can be stored in air tight bins indefinitely without deteriorating in any way, but this is not practicable for site use. Cement which is 4 months old should be classified as "aged" and be retested for use [12].

Air set cement results from storage in a damp atmosphere. This is due to the moisture present in the air being absorbed by the cement and causing a partial set. Preventing the movement of air in to the store as far as practicable reduces the absorption of moisture from a damp atmosphere. As a rough guide, lumpy cement, which cannot be easily crumbled in the fingers, is unsatisfactory for general use [8,12]. Cement should be stacked in such a way that the cement first delivered can be used first. In the quality control of concrete, the packing slip or bin card of cement explaining its date of packing is required when delivering cements to construction sites as per din 1084 [13]. The production date of cements produced in Ethiopia is not specified and written on the packing paper; hence the age of cement used for concrete production on construction sites is not exactly known so it makes difficult to vary the long aged cement packs from the new one [2].

2.2.2 Water

2.2.2.1 Introduction

Water is the most important and least expensive ingredient of concrete. A part of mixing water is used in the hydration of cement to form the binding matrix. The remaining serves as a lubricant between fine and coarse aggregate and makes concrete workable [2]. Cement requires around 30% of its weight of water for hydration. But concrete containing water in this proportion will be very harsh and difficult to place.

Hence additional water is required for workability. However; if this additional water is present in excess, will pose a problem. Therefore it must be kept to the minimum. The problems associated with too much water in the mix are, reduction in strength, formation of laitance on surfaces of concrete through bleeding. The excess water may also leak through the joints of the formwork and make the concrete honeycombed [6].

2.2.2.2 Quality of mixing water

The water used for mixing and curing of concrete should be free of materials that significantly affect concrete quality like rate of hardening, strength and durability of concrete, or which promote efflorescence or the rusting of steel reinforcement. Potable water is generally considered satisfactory for mixing concrete. In the case of doubt about the suitability of water particularly in remote areas, where water is derived from sources of normally utilized for domestic purpose, water should be tested [6]. The old rule of thumb for water quality is “If you can drink it, you can use it in concrete,” although good-quality concrete can be made with water that is not really potable [14]. Indeed, more bad concrete is made by using too much drinkable water than by using the right amount of undrinkable water. The criterion of potable of water is not absolute; drinking water may be unsuitable as mixing water when the water has a high concentration of sodium or potassium and there is a danger of alkali aggregate reaction [9].

Some specifications require that if the water is not obtained from source that has proved satisfactory, the strength of concrete or mortar made with questionable water should be compared with similar concrete or mortar made with pure water. Some specification also accept water for making concrete if the pH value of water lies between 6 and 8 and the water is free from organic matter. Instead of depending upon pH value and other chemical composition, the best course to find out whether a particular source of water is suitable for concrete making or not, is to make concrete with this water and compare its 7 days' and 28 days' strength with companion cubes made with distilled water. If the compressive strength is up to 90 per cent, the source of water may be accepted [15].

2.2.2.3 Impurities in water which affect concrete Properties

The effects of impurities present in mixing water are mainly expressed in terms of the difference of the setting times and strength of cement mixes containing impure mixing water as compared to clean fresh water or distilled water. Tests show that water containing excessive amounts of dissolved salts reduces compressive strength by 10 to 30 percent of that obtained using fresh water [6].

Deleterious substances which affect both the fresh and hardened quality of concrete that could possibly be found in impure water like silt, clay, acids, alkalis, algae, inorganic salts and sugars should be within the permissible limits so that concrete quality shouldn't be adversely affected.

Generally, the PH value of water which is suitable for concrete construction has to be in the range of 6 to 8. The water which is fit for drinking purposes is fit for concrete production. Table 2.2 shows the limits set for impurities in mixing water [6].

Table 2.2 Limits of permissible impurities in water [6]

<table>
<tr><th colspan="2">Type of impurities</th><th>Permissible percentage of solids by weight of water</th></tr>
<tr><td colspan="2">Organic</td><td>0.02</td></tr>
<tr><td colspan="2">Inorganic</td><td>0.3</td></tr>
<tr><td colspan="2">Sulphates</td><td>0.05</td></tr>
<tr><td rowspan="2">Alkali chlorides</td><td>a. For plain concrete</td><td>0.2</td></tr>
<tr><td>b. For reinforced concrete</td><td>0.1</td></tr>
</table>

2.2.3 Aggregates

2.2.3.1 General

Aggregate represent the major proportion of concrete by volume. Hence it has significant importance on the quality of concrete, especially on strength. This is because good aggregate are known to have better crushing strength and better resistance to impact. Not only that aggregates affect the strength of concrete, but the proper ties of aggregates such as its size and shape affect the durability and structural performance of concrete [9,6].

Aggregate is cheaper than cement. It is, therefore, economical to put in to the mix in as much proportion as possible. Aggregate may be defined as relatively inert mineral filler used in the construction of concrete. This aggregate consists of uncrushed or crushed gravel, crushed stone or rock, sand, or artificially produced inorganic materials [9].

As a matter of convenience, aggregates are generally divided into two size ranges: coarse aggregate, which is the fraction of material retained on a No. 4 (4.75-mm) sieve, and fine aggregate, which is the fraction passing the No. 4 sieve but retained on a No. 100 (0.15-mm) sieve [14].

2.2.3.2 Physical properties of Aggregates

The physical properties of aggregates such as size shape, texture, porosity, absorption, moisture content, bulking of fine materials, presence of deleterious substances etc. affects significantly the resulting concrete quality produced as briefly explained under.

A. Aggregate size, shape and texture

In accordance with the Ethiopian standard aggregates are classified as coarse and fine depending on their size [16]. The Ethiopian standard has adopted the requirement set on the parts of the American standard (ASTM C-33) [17]. In the size classification of aggregates by the British Standard (BS 882), there is an additional size group called all-in aggregate that contains mixed coarse and fine aggregate [18]. But all- in aggregate is recommended for the production of low grade concrete [7].

Shape of aggregates has an effect on the degree of packing particles and on the surface area to volume ratio of particles. Well-packed aggregates have less void content. This is important in concretes as it reduces the void content of concrete resulting in better strength concrete. Particles with high ratio of surface area to volume lower the workability of the mix; however, it has an advantage of providing larger bond surface area. Flaky and elongated particles affect the durability of concrete in that, as they tend to be oriented in one plan, with water and air voids forming underneath. As a result, the presence of elongated or flaky particles in excess of 10 to 15% of the weight of course aggregate is undesirable [9,6].

The rounded aggregate requires lesser amount of water and cement paste for a given workability. The amount of mixing water could be reduced by 5 to 10 percent and the sand content by 3 to 5 percent by the use of rounded aggregate. On the other hand, the use of crushed aggregate may result in 10 to 20 percent higher compressive strength due to the development of stronger aggregate-mortar bond. This increase in strength may be up to 38 percent for a concrete having a water-cement ratio below 0.4. The elongated and flaky particles, having a higher ratio of surface area to volume reduce the workability appreciably. These particles tend to be oriented in one plane with water and air voids underneath. An aggregate with a rough and porous texture is preferred to one with a smooth surface as the former can increase the aggregate-cement bond by 75 percent, which may increase the compressive and flexural strength up to 20 percent [6].

B. Porosity and Absorption of Aggregate

Due to the presence of air bubbles, which are entrapped in a rock during its formation or on account of the decomposition of certain constituent minerals by atmospheric action, minute holes or cavities are formed in it that is commonly known as pores [9,6].

As mentioned at the beginning of this chapter, since aggregate constitutes about 75% by volume of concrete, the porosity of aggregate contributes to the overall porosity of concrete. The porosity and absorption affect the bond between aggregate and the cement paste, the resistance of concrete to freezing and thawing, chemical stability, resistance to abrasion, and the specific gravity of the aggregate [9,6].

The water absorption of aggregate is determined by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. The ratio of the increase in weight to the weight of the dry sample expressed as percentage is known as absorption of aggregate. The aggregate absorbs water in concrete and thus affects the workability and final volume of concrete. The rate and amount of absorption within a time interval equal to the final set of the cement will only be a significant factor rather than the 24 hours absorption of the aggregate [9,6].

In proportioning the materials for concrete, it is always taken for granted that the aggregates are saturated and surface dry. In mix design calculation the relative weight of the aggregates are based on the condition that the aggregates are saturated and surface dry. But in practice, aggregates in such ideal condition are rarely met with. Aggregates are either dry or absorptive to various degrees or they have surface moisture [9,6].

C. Moisture content of Aggregates

Aggregate exposed to rain collects a considerable amount of moisture on the surface of the particles, and, except at the surface of the stockpile, keeps this moisture over long periods. This is particularly true of fine aggregate, and hence the surface or free moisture (in excess of that held by aggregate in a saturated and surface dry condition) must be allowed for in the calculation of batch quantities. The surface moisture is expressed as a percentage of the weight of the saturated and surface dry aggregate, and is termed the moisture content [9,6].

Since absorption represents the water contained in aggregates in a saturated and surface-dry condition, and the moisture content is the water in excess of that state, the total water content of a moist aggregate is equal to the sum of absorption and moisture content [9,6].

The determination of moisture content of an aggregate is necessary in order to determine the net water-cement ratio for a batch of concrete [9,6]. Otherwise; if the moisture content and absorption of aggregates is not properly determined, the water added during preparing the mix becomes variable. This results in either high or low water to cement ratio. Higher water to cement ratio may affect the properties of concrete like workability in which concretes with lower water content becomes less workable as a result it makes difficult to attain full compaction and leave excessive void in the concrete mass.

D. Bulking of fine Aggregate

The presence of free moisture on the surface of sand results in a phenomenon known as bulking. This is the increase in the volume of a given mass of fine aggregate caused by the films of water pushing sand particles apart [9,6]. The extent of bulking depends on the percentage of moisture present on the sand and on its fineness. The increase in volume relative to that occupied by saturated and surface dry sand increases with an increase in the moisture content of the sand up to a value of some 5 to 8 percent, when bulking of 20 to 30 percent occurs. Upon further addition of water, the films merge and the water moves in to the voids between the particles so that the total volume of the sand decreases until, when fully saturated or flooded, its volume is approximately the same as the volume of dry sand for the same method of filling the container. Finer sand bulks considerably more and the maximum bulking is obtained at higher water content than the coarse sand. In the case of coarse aggregate, the increase in volume is negligible due to the presence of free water as the thickness of the moisture film is very small compared with particle size [9,6].

Bulking doesn't affect the proportion of materials by weight. In the case of volume batching, bulking results in a smaller weight of sand occupying the fixed volume of the measuring. These results in mix deficient sand hence the concrete is prone to segregation and honeycombing. Therefore allowance for bulking of sand has to be considered during proportioning of sand [9,6].

E. Deleterious substances in Aggregates

Materials in aggregates, which may affect adversely the strength or durability of concrete, or reinforcement in concrete are termed deleterious materials. There are three broad categories of deleterious substances, these are: -

I. Impurities interfering with the process of hydration of cement.
II. Coatings preventing the development of good bond between aggregate and the cement paste, and
III. Unsound particles which are weak or bring about chemical reaction

The impurities in the form of organic matter interfere with the chemical reactions of hydration. These impurities are generally consisting of decayed vegetable matter (mainly tannic acid and its derivatives) and appearing in the form of humus or organic loam are more likely to be present in fine aggregate than coarse aggregate, which is easily washed [6].

Clay and other fine materials in aggregate may affect the quality of concrete if present in excess amount. Clay may be present in the form of surface coatings which interfere with the bond between aggregate and the cement paste. Since good bond is essential to ensure a satisfactory strength and durability of concrete, the problem of clay coating is an important one. The other two fine materials which can be present in aggregate are silt and crusher dust. Silt is a material between 2μm and 60 μm reduced to this size by natural process of weathering; silt may thus be found in aggregate obtained from natural deposits. On the other hand, crusher dust is a fine material formed during the process of crushing rock into crushed coarse and fine aggregate. The soft or loosely adherent coatings can be removed by washing. The well-bonded chemically stable coatings have no harmful effect except that the shrinkage may be increased. However, aggregates with chemically reactive coatings, even if physically stable, can lead to serious trouble. Silt and fine dust, if present in excessive amount, increases the surface area of the aggregate and hence the amount of water required to wet all particles in the mix, thereby reducing the strength and durability of concrete [6]. Hence it is necessary to control the clay, silt and fine dust contents of aggregate as per the limitations set by the standards specified in the technical specification of the contract document.

The other deleterious material is salt. The sand obtained from seashore or a river estuary may sometimes contain salt, which may be significant in amount. The salt can be removed from the sand by washing it with fresh water before use. If salt is not removed, it absorbs moisture from air and may cause efflorescence; and corrosion of reinforcement may also occur if soluble chloride salts are present [6].

F. Soundness of aggregates

Soundness is the resistance of aggregates changes in volume as a result of changes in physical or environmental conditions such as freezing and thawing, thermal changes at temperatures above freezing, and alternating wetting and drying. The aggregate is said to be unsound when volume changes result in deterioration of the concrete. This may range from local scaling and so-called pop-outs to extensive surface cracking and to disintegration over a considerable depth, and can thus vary from no more than impaired appearance to structurally dangerous situation [6]. Aggregates used for concrete production are tested for its soundness and it should comply with the requirement set in the specification.

G. Reactions between active aggregates and alkalis that affect concrete quality

One of these reactions is the deleterious chemical reaction which takes place between the active silica of aggregate and the alkalis in cement that is called the alkali-aggregate reaction (AAR). The reactive forms of silica occur in opaline chalcedonic cherts, siliceous limestone, rhyolites and rhyolitic tuffs, andesite and andesite tuffs, phyllites, etc. The reaction between the siliceous mineral of the aggregate and the alkaline hydroxide of the cement results in an alkali silicate gel. The gel is confined by the surrounding cement paste and an internal pressure is developed leading to expansion resulting in cracks and disruption of cement paste [6].

There is another reaction that takes place between alkalis of the cement and carbonate of aggregates known as alkali carbonate reaction (ACR). This results in expansive material that deteriorates concrete. Humid condition is required for the reaction to take place [9]. Hence the amount and type of the mineralogical content of aggregates used in concrete production is essential for determining the resulting quality of concrete.

H. Grading of Aggregates

The particle size distribution of an aggregate as determined by sieve analysis is termed grading of the aggregate. If an aggregate is composed of all uniform size, the compacted mass will contain more voids, whereas an aggregate comprising particle of various sizes will give a mass containing lesser voids. Proper grading of an aggregate produces dense concrete, and needs less quantity of fine aggregate and cement paste. Hence it is essential that the coarse and fine aggregate be well graded to produce quality concrete. [6]

The grading of aggregates affects the workability which, in turn, controls the water and cement requirements, segregation, and influence the placing and finishing of concrete. These factors represent the placing and finishing of concrete. These factors represent the important characteristics of fresh concrete and affect properties in the hardened state [6]. Therefore aggregate has to conform to the grading requirement of standards specified on the technical specification.

I. Strength of aggregate

Aggregates contribute the significant proportion of strength possessed by concrete due to its higher modulus of elasticity as compared to the cement paste. To have a strong concrete, the aggregate should have high load bearing capacity and resistant to wearing and abrasion effects. To assess the strength of aggregates, a number of strength tests are undertaken in laboratories. Some of these are; aggregate crushing value, aggregate impact value, losangeles abrasion test, ten percent fines values etc. ACV is used to evaluate the resistance of aggregates against a gradually applied load. AIV is used to evaluate the resistance of aggregates against sudden impact loading and abrasion test is used to resist the abrasion effect. Therefore, aggregates in use for concrete production have to be strong that satisfy standards requirement [11,8].

J. Handling and storing of Aggregates

All kind of sand and aggregates need to be stored on hard and flat ground, preferably as level as possible. The ground of the storage space should be clean and dry, should store properly. If dry and flat ground is not available, platform should be constructed instead and stored the aggregates on top. Unless care is taken in handling and storing of aggregates, there is a marked tendency for segregation of the fine and coarse particles to occur that affects the gradation. In addition to segregation, contamination of stockpiles could also occur due to poor handling and storage [2].

When dry sand is dropped from the end of an elevating conveyor, a chute or chimney (with exit opening) should be installed so as to prevent segregation of sizes by wind action. The segregation of aggregate moving down a sloping surface can be prevented by a retaining baffle. The bottom 0.5m of wet sand in a stockpile is best allowed to serve as a drainage layer for the upper part.

Bulk storage should be on hard ground or a thin slab of weak concrete that is graded for drainage. A space or dwarf walls should be placed between different materials [9]. Placing of various material sizes separately is useful in avoiding segregation. For instance, aggregate sizes that range from 5 to 10mm, 10 to 20 mm, and 20 to 40 mm could be stock piled separately on sites.

2.2.4 Admixtures

These are substances or chemicals used in concrete for the purpose of improving particular properties. The use of admixture should offer an improvement not economically attainable by adjusting the proportions of cement and concrete, and should not adversely affect any property of the concrete. Admixtures are not substitute for good concreting practice. An admixture should be employed only after an appropriate evaluation of its effects on the concrete that is intended to be used is made. It is often necessary to conduct tests on the representative samples of the materials for a particular job under simulated job conditions in order to obtain reliable information on the properties of concrete containing admixtures [9,6].

It will be slightly difficult to predict the effect and the results of using admixtures because, many a time, the change in the brand of cement, aggregate grading, mix proportions and richness of mix alter the properties of concrete. Sometimes many admixtures affect more than one property of concrete. At times, they affect the desirable properties adversely. Sometimes, more than one admixture is used in the same mix. The effect of more than one admixture is difficult to predict. Therefore, one must be cautious in the selection of admixtures and in predicting the effect of the same in concrete [9,6].

The properties of concrete commonly modified are workability, rate of hydration or setting time i.e. either accelerating or retarding the setting time, and air entertainment.

Admixture is generally added in a relatively small quantity. A degree of control must be exercised to ensure proper quantity of admixture, as an excess quantity may be detrimental to the properties of concrete. In using any admixture, careful attention should be given to the instructions provided by the manufacturer of the product [9,6].

2.3 Specification of concrete

In concrete production the proportioning of ingredient materials has to be in such a way that the resulting concrete shows good performance both in the fresh and hardened state. To attain this goal, various national standards have set mix design procedures. The American (ACI) and the British method of mix design, commonly called DOE method, are the two most common [9].

Concrete can be specified in one of the three common ways. These are Designed Mix, Prescribed Mix and Standard Mix.

Designed Mix: This mix is specified by the grade which is corresponding to the required characteristic compressive strength at 28 days. In addition to stating the strength grades the purchaser must also specify any particular requirements for cement and aggregate content and maximum free water/cement ratio.

Prescribed Mix: This is a recipe of constituents with their properties and quantities used to manufacture the concrete. The concrete designer must state: the type of cement, type of aggregates and their maximum size, mix proportions by weight, the degree of workability (slump and or water cement ratio) and the application. Prescribed mixes are based on established data indicating conformity to strength, durability and other characteristics.

Standard Mix: Mix composition and details are specified by: cement to aggregate by weight, type of cement, aggregate type and maximum size, workability and use or omission of reinforcement. These mixes are most suited to site production, where the scale of operations is relatively small. They may be used where mix design procedures would be too time consuming, inappropriate or uneconomic.

2.4 Production of concrete

2.4.1 Introduction

Only a good concrete mix design is not sufficient in getting the intended concrete quality product, rather the concrete placed in a structure must be of uniform quality, free of voids and discontinuities, and adequately cured [11]. Hence, the proper execution of the operations in the production process, namely, batching, mixing, transportation, placing, compaction, finishing and curing are important in attaining the desired quality.

Concrete production is a scientific process that is based on some established principles and governs the properties of concrete mixes in fresh as well as in hardened state [9]. The various phases of the production processes stated above will be discussed in detail in the succeeding section with the consequent impact on concrete quality.

2.4.2 Batching

The measurement of materials for making concrete is known as batching. Batching involves measuring the quantities of the concrete making materials (cement, water, sand, and coarse aggregate, and sometimes admixtures). The correct amount of each material must be batched if the quality of the concrete is to be maintained in both individual and successive batches. Mistake in measuring the ingredients reduces the accuracy of the batching. Poor accuracy in the batching cause's variation in the properties and the quality of the concrete produced. There are two methods of batching; Volume batching and Weight batching [1].

For solid granular materials, such as aggregates and cements, batching is best done by weight. Only water and liquid admixtures can be measured accurately by volume. Batching by weight also follows rapid and convenient adjustments aggregates and water contents when changes in aggregates moisture contents occur [1]. In volume batching, solid ingredients are measured by loose volume using measuring boxes, wheel barrows, etc. In batching by volume allowances has to be made for the moisture present in sand which results in its bulking and adjustments to the amount of water depending on the absorption capacity and the free moisture content of the sand and the coarse aggregate [1]. In volume batching, it is generally advisable to set the volumes in terms of whole bags of cement. Fractional bags lead to variable proportions, resulting in concretes of non-uniform strength in successive batches. Before the batching operations are started; the engineer-in-charge should check the batch box volumes. When filling the boxes, the material should be thrown loosely in to the box and struck off, and no compaction is to be allowed [1].

According to EBCS 2 of 1995, the quantity of cement, the quantity of fine aggregate and the quantities of the various sizes of coarse aggregates shall be measured by weight except that aggregates may be measured by volume for Class II Concrete or for standard mix.

2.4.3 Mixing

The main objective of mixing is that the materials be uniformly distributed throughout the mixture and that all aggregate surfaces be well coated with the cement-water paste. Equipments called mixers normally do concrete mixing, but sometimes the mixing of concrete is done by hand. Machine mixing is more efficient, economical and results in better quality concrete compared to hand mixing [9,6,1].

When mixers are used for mixing purposes, the mixer must be clean and in good condition, properly designed, particularly as to type and numbers of blades, not overloaded or under loaded, charged correctly, and operated at the optimum speed as recommended by the manufacturers. The valves controlling the mixing water should not allow leakage in to the mixer [9].

In the occasions when concrete has to be mixed by hand, it has to be done thoroughly. A clean surface should be selected for mixing. If this is not available, a wooden platform with close joints to prevent loss of mortar should be obtained. It is usually specified that the concrete shall be mixed three times dry and three times wet, turning over from one spot to another [8]. Hand mixing usually results in poor concretes of lower strength. Hence to compensate for the lower strength, it is advisable to allow an extra 10 percent of cement above that normally required [8].

There are two observed stages in the mixing process. In the first stage, the cement paste is formed with simultaneous absorption of water by aggregates. In the second stage the cement paste coats the aggregate particles. The mixing process should be continued till a thoroughly and properly mixed concrete is obtained. At the end of this stage the concrete appears to be of uniform color and grading. The uniformity must be maintained while discharging the concrete from the mixer [9,6].

2.4.3.1 Mixing time and its impact on concrete quality

On a site, there is often a tendency to mix concrete as rapidly as possible, and it is, therefore, important to know what the minimum mixing time necessary to produce a concrete uniform in composition and of satisfactory strength. The mixing time varies with the type of mixer and also on its size. On some researches made previously, it appears that it is not the mixing time but the number of revolutions of the mixer that is the criterion of adequate mixing. Generally, about 20 revolutions are sufficient. Since, however, there is optimum speed of rotation recommended by the manufacturer of the mixer; the numbers of revolutions and the time of mixing are interdependent [6,8].

The average strength of concrete increases with an increasing of mixing time up to five minutes. The rate of increase in strength falls rapidly beyond about one minute and is not significant beyond two minutes. Within the first minute, however, the influence of mixing time on strength is of considerable importance. The minimum mixing time in relation to capacity of mixer is indicated in table 2.3. A mixing time of not less than one minute after all the materials have been added in the mixer drum is generally recognized as a satisfactory period for mixers up to capacity of 750 liters [6].

And also the maximum permitted time of two hours between mixing and discharging concretes if the concrete is transported in a truck mixer or agitator in the temperature range of 5^oC to 32^oC [6].

Table 2.3 Recommended minimum mixing times [9]

Capacity of mixer (m^3)	**Mixing times, min American concrete institute and ASTM standard C94-78a**
0.8	1
1.5	$1^{1/4}$

2.3	$1^{1/2}$
3.1	$1^{3/4}$
3.8	2
4.6	$2^{1/4}$
7.6	$3^{1/4}$

The mixing time is counted from the time when all the solid materials have been put in the mixer, and it is usual to specify that all the water has to be added not later than after one quarter of the mixing time. The figure quoted above refers to the usual mixers but there are many modern large mixers, which, perform satisfactorily with a mixing of 1 to 1 and 1/2 min. In high speed pan mixers, the mixing time is as short as 35 seconds. On the other hand, when light weight aggregate is used, the mixing time should not be less than five minutes, sometimes divided in to two minutes of mixing the aggregate with water, followed by 3 minutes with cement added. For mixers of larger capacity than shown in the table above, the mixing time should be increased at the rate of 20 seconds more for each cubic meter or fraction thereof; however, this is not applicable to light weight aggregate concrete [9,6].

If mixing is done over a long period, evaporation of water from the mix takes place, with a consequent decrease in workability. A secondary effect is that of grinding of the aggregate, particularly if soft, the grading of the aggregate thus becomes finer, and the workability lower. The friction effect also produces an increase in the temperature of the mix. No general rules on the order of feeding the ingredients into the mixer can be given as they depend on the properties of the mix and of the mixer. Generally, a small amount of water should be fed first, followed by all the solid materials, preferably fed uniformly and simultaneously in to the mixer. If possible, the greater part of the water should also be fed during the same time, the remainder of water being added after the solids [6].

The choice of mixer depends on the size, extent, and the nature of work. The choice between central and site mixing will be governed by factors such as accessibility, water supply, transport routes, availability of working space, etc. [6].

Engineers at site, many a time, reject the concrete partially set and unduly stiffened due to the time elapsed between mixing and placing [15]. Mixed concrete is a costly material and it cannot be wasted without any regard to cost. It is required to see whether such a stiffened concrete could be used on work without Modern ready mixed concrete plant. The process of remixing of concrete with addition of just the required quantity of water is known as "Retempering of Concrete". Sometimes, a small quantity of extra cement is also added while retempering. Many specifications do not permit retempering. IS. 457 – 1957 did not permit retempering of partially hardened concrete or mortar requiring renewed mixing, with or without addition of cement, aggregate or water [15]. However, many research workers are of the view that retempering with the addition of a small quantity of water may be permitted to obtain the desired slump provided the designed water/ cement ratio is not exceeded. They caution that the production of concrete of excessive slump or adding water in excess of designed water cement ratio to compensate for slump loss resulting from delays in delivery or placing should be prohibited [15].

2.4.4 Transport of Concrete

The concrete has to be placed before setting has commenced. When concrete has been transported to a job site, it is conveyed by a variety of methods, including mortar pan, belt conveyors, buckets, chutes, cranes, pumps, wheelbarrows, and other equipment. Concrete should be conveyed in such a manner that it is not allowed drying out; it should not be delayed, and it should not be allowed to segregate before it is placed [14].

Mortar pan is labor intensive. In this case, concrete is carried in small quantities. While this method nullifies the segregation to some extent, particularly in thick members, it suffers from the disadvantage that this method exposes greater surface area of concrete for drying conditions. This results in greater loss of water under conditions of low humidity. It is to be noted that the mortar pans must be wetted to start with and it must be kept clean during the entire operation of concreting. Mortar pan method of conveyance of concrete can be adopted for concreting at the ground level, below or above the ground level without much difficulty [14].

Wheel barrows are normally used for transporting concrete to be placed at ground level. This method is employed for hauling concrete for comparatively longer distance. If concrete is conveyed by wheel barrow over a long distance, on rough ground, it is likely that the concrete gets segregated due to vibration. The coarse aggregates settle down to the bottom and matrix moves to the top surface. To avoid this situation, sometimes, wheel barrows are provided with pneumatic wheel to reduce vibration [14].

According to EBCS 2 of 1995 it is illustrated that concrete shall be transported from the mixer to the formwork as rapidly as practicable by methods which will prevent the segregation or loss of any of the ingredients, and maintain the required workability. It shall be deposited as nearly as practicable in its final position to avoid re handle.

A maximum of two hours between mixing and discharge of concrete is permitted, if the concrete is transported in a truck mixer or agitator. In the absence of agitator, the time is reduced to one hour only. This maximum permitted time lapse between mixing and discharging holds if the concrete temperature is between 5°c and 32°c [9]. Delayed concrete transportation may result in the formation of pour planes, cold joints or construction joints between the interfaces of previously placed and newly placed concrete. Such joints are susceptible to water leakage and leave weak structural parts [19]. In case when the mixing and placing locations are far apart or transportation of concrete takes longer time, the use of retarding admixture could help in increasing the setting time by two to four hours and reducing water requirement by 5 to 10 percent [6]. The prevention of segregation is the most important consideration in handling and transporting concrete. The segregation should be prevented and corrected before its occurrence. The concrete being a non-homogenous composite material of widely differing particle sizes and specific gravities is subjected to internal and external forces during transportation and placing tending to separate the dissimilar constituents [6]. The other point that needs to be considered in handling and transporting of concrete is that the method should protect concrete from the effects of the weather like heat or cold that has an impact on the performance of concrete.

2.4.5 Placement of Concrete

The methods used in placing concrete in its final position have an important effect on its homogeneity, density and behavior in service. The same care which has been used to secure homogeneity in mixing and the avoidance of segregation in transporting must be exercised to preserve homogeneity in placing. The concrete should be placed in its final position rapidly so that it is not too stiff to work. Water should not be added after the concrete has left the mixer. The concrete must be placed and as close as possible to its final position. It should never be moved by vibrating it and allowing it to flow, as this may result in segregation which will show on the surface of the finished work. When placing the concrete, care should be taken to drop the concrete vertically and from not too great height [6]. As per the Ethiopian building code, the free fall height of concrete mass is restricted to a maximum of three meters [19].

2.4.5.1 Effect of delay in placing concrete

The effect of delay in placement of concrete varies with the richness of the mix and the initial slump [6]. When concrete in a lift hardens before the next lift can be placed, a weak layer called cold joint or construction joint is formed. This is one of the serious problems of extreme delay of concrete placement. In case when such a joint is formed either because of delay in concrete placement or for another reasons, the following measures are recommended to be taken during construction time.

The surface of the last lift should be left in a roughened state to provide a good mechanical bond. Before placement of the next lift, the surface should be scarified to remove any laitance. Air-water jets, wire brooming, or even sand blasting are useful techniques. The concrete should be dampened and a layer of mortar worked well into the surface [1]. The Ethiopian building code of standard recommends construction joints to be at right angle to the general direction of the member and shall take due account of shear and other stresses [19].

2.4.6 Compaction of Concrete

This is one of the most important concrete production phases that determines both the strength and durability of concretes. For good quality concrete, after placement, the concrete should be worked to eliminate voids and entrapped air and to consolidate the concrete into the corners of the forms and around the reinforcing steel. Most concrete is compacted by vibration. Proper vibration allows stiffer mixes to be used and generally leads to better consolidation and a superior finish [1]. However; over vibration brings excess paste to the surface, enhances bleeding, and causes loss of entrained air [1]. The presence of 5 percent of voids in improperly or insufficiently compacted concrete reduces the strength by as much as 30 percent [9]. Therefore, it is imperative that 100 per cent compaction of concrete is one of the most important aim to be kept in mind in good concrete-making practices.

The two methods of compacting concrete are using mechanical vibration and hand Rodding. Hand Roding; however, better than no compaction, cannot assure thoroughly dense and compacted concretes free of air pockets [6]. Mechanical vibrators are the most commonly used for compaction of concrete [6]. There are various types of mechanical vibrators. The two widely used of these are the external and internal vibrators. Internal vibrators have a steel tube called poker connected to a motor or diesel engine through a flexible tube.

It is this steel poker which is immersed in the concrete to compact. The poker is applied in the concrete mass at center to center interval of 0.5 m to 1 m for 5 seconds to 30 seconds, depending on the consistence of the mix, but with some mixes up to 2 min is required [6]. But it is limited on some literatures that the poker immersion location shouldn’t be more than 600 mm or 8 to 10 times the diameter of the poker. The concrete should be placed in layers not more than 600 mm high [6].

According to EBCS 2 of 1995 the following points about placing and compacting of concrete is stated; those are, all placing and compacting shall be carried out under the direct supervision of a competent member of the contractor's (or manufacturer's) staff, class I concrete of grades C20 and above shall be compacted by using vibrators. Concrete shall be placed soon after mixing and thoroughly compacted during the operation of placing, it shall be thoroughly worked around the reinforcement, tendons or duct formers, around embedded fixtures and into corners of formwork to form a solid mass free from voids. Care shall be taken to avoid the displacement of reinforcement or movement of formwork and damage to faces of formwork, the depth of lift to be concreted shall be determined by the contractor or the manufacturer in consultation with the engineer. In order to avoid segregation, the free fall of concrete mass shall be restricted to a maximum of three meters unless the system of placing concrete is approved by the designer. When vibrators are used to compact the concrete, vibration shall be applied continuously during the placing of each batch of concrete until the expulsion of air has practically ceased and in a manner which does not promote segregation of the ingredients, and the mix shall be such that there will not be excess water on the top surface on completion of compaction.

2.4.7 Curing of concrete

Theoretically; there is enough water in concrete to ensure complete hydration without additional water being supplied only with the water added during mixing [1]. However, in practice a significant loss of water due to evaporation or by absorption of water by aggregates, form work or sub grade [6]. Hence, in order to obtain good concrete the placing of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening.

Evaporation of water from concrete after placing depends on the temperature, relative humidity of the surrounding air and the velocity of wind which affects change of air over the surface of the concrete.

There are various methods adopted for curing. These are direct provision of water or moisture, preventing evaporation by providing impervious cover or by spraying chemical compounds forming membrane and the method which accelerates strength gain by providing heat and moisture. The last technique of curing, i.e. curing with heat and moisture is mainly used with the production of prefabricated element and sometimes for testing concretes on production sites. Since the 28 day strength could be obtained in hours or few days.

To develop design strength, the concrete has to be cured for up to 28 days with the normal curing techniques that is with direct supply of water. As the rate of hydration, and hence the rate of development of strength, reduces with time, it is not worthwhile to cure for the full period of 28 days [6].

Exposed surfaces of concrete containing ordinary or standard Portland cement be kept continually moist cured for at least 7 days. Concretes containing high early strength cements require less time, about half the time required for OPC. For pozzolans or blast furnace slag cements [slow hardening cements] it is two up to three times more than OPC [6].

2.5 Statistical quality control of concrete

2.5.1 Introduction

The basis for statistical quality control (SQC) in concrete production or any other industry depends upon a thorough knowledge of the sources of variation affecting the product being subjected to control [20]. In concrete production, quality control is usually done based on 28 days of compressive strength tests. The strength of concrete has an inherent variability as it depends on the variations in properties of concrete and variations due to testing methods [21].

Because of the different elements associated with concrete production, like materials, proportioning and production process, the concrete got at the end has shown changeability from batch to batch [6,1]. Hence, this variability in properties should be considered when preparing concrete specifications. Elements that add to variability of concretes might be gathered into the accompanying three general categories [1].

1. Materials: - these include inconsistency in the cement; in the grading, moisture content, mineral composition, physical properties, and particle shape of the aggregates; and in the admixture used.

2. Production: - this involves the type of batching plant and equipment, the technique for moving concrete to the site, and the methodology and workmanship used to produce and place the concrete.

3. Testing: - this includes the sampling procedures, the making and curing of test specimens, and the test system utilized.

The variability in concrete properties due to the factors mentioned above makes significant the importance of quality control. Quality control is defined as an action and decisions taken to ensure the compliance of works with the specification. It contains two parts, namely, production control and compliance control. Production control is a measure taken during production to obtain a reasonable assurance that the specifications will be satisfied. And compliance control is a check made to ensure the compliance of the product with the specification [19].

The variation saw in concrete which demonstrate the level of quality control practiced during concrete production could be quantitatively computed from compressive strength test results with variability measuring statistical parameters like standard deviations and coefficient of variation as displayed beneath [2].

2.5.2 Variability Measurement

It has been tracked down that distribution of concrete strengths can best be approximated by the normal or Gaussian distribution. Such a distribution is characterized by two parameters; the mean $\bar{x}$ and the standard deviation, S [22].

The mean is given by Equation (2.1) below

$$\bar{x} = \frac{\sum x}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

And the standard deviation or the root-mean-square deviation, which is the measure of dispersion or variability of the values, is given by:

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

Where $\mathbf{x_i}$ = is the values of strength of a given sample

n = is the number of samples tested

$\overline{X}$= Arithmetic mean strength of all the samples

The variation of results about the mean can also be expressed by the coefficient of variations which is a non-dimensional measure of variation and is given by:-

$$V = \frac{s}{\overline{X}} \times 100 \quad \ldots\ldots (2.3)$$

2.5.3 Concrete and Variability Measurement

The above statistical boundaries; in particular, standard deviation and coefficient of variation are valuable in the design and quality control of concrete expecting that variations in concrete properties is to be portrayed by normal distribution.

Depending on the quality of control measures taken in construction sites or in laboratories, there are values of standard deviation and coefficient of variation assigned to each class of activities (ACI 214) as shown in table 2.4 and 2.5.

Table 2.4 ACI standard of concrete quality control using standard deviation [23]

Class of Operation, Over all variations	Standard deviation for different control standards, MPa (lb/in2)				
	Excellent	Very good	Good	Fair	Poor
General construction testing	Below 2.8 (400)	2.8-3.5 (400-500)	3.5-4.2 (500-600)	4.2-4.9 (600-700)	Above4.9 (700)
Laboratory trial batches	Below 1.4 (220)	1.4-1.8 (220-250)	1.8-2.1 (200-300)	2.1-2.5 (300-350)	Above 2.5 (350)

Table 2.5 ACI standard of concrete quality control using coefficient of variation [23]

Class of Operation Over all variations	Coefficient of variation for different control standards (%)			
	Excellent	**Good**	**Fair**	**Poor**
Field control testing	Below 10	10-15	15-20	Above 20
Laboratory trial batches	Below 5	5-7	7-10	Above 10

Different codes have their own methodologies or criteria set for the required strength in such a way that to guarantee low probability of the compressive strength obtained below the design strength [2]. In this paper the EBCS and ACI codes approaches and acceptance criteria of test results are examined.

As EBCS-2 : 1995 Compliance with specified properties of concrete shall be judged by tests made on proper specimens at an age of 28 days unless there is evidence, satisfactory to the authority having jurisdiction, that a particular testing regime is capable of predicting the strength at 28 days of concrete tested at an earlier age, in which case compliance may be based on the results of such tests alone.

After testing concrete, the strength has to be checked whether the specified strength, f_c`, is obtained or the probability of compressive strength falling below $f_c$` is small enough. For this ACI 318 provides two acceptance criteria. For laboratory cured specimens of job concrete:

1. Every arithmetic average of any three consecutive strength tests must equal or exceed f_c`; and

2. No individual tests (average of two cylinders) may fall below f_c` by more than 3.5 Mpa when $f_c$` is less than or equal to 35 Mpa or by more than o.1 f_c` if $f_c$` is greater than 35 Mpa.

Failure to satisfy either of the acceptance criteria requires changes in the mix proportions and construction procedures to increase concrete strength. Failure to meet the second criterion requires an investigation of the strength of the concrete in the structure [1].

The Ethiopian standard has also set the requirement for characteristic compressive strength or specified strength. Acceptance criteria are also stated as follows.

Two acceptance criteria are envisaged [19].

Criterion 1: this criterion may be applied in all cases but is less suited to large scale sampling each lot is represented by three samples, the strength of which are $x_1 < x_2 < x_3$.

The lot is accepted if the following conditions are satisfied simultaneously.

$$\bar{m}_3 \geq f_{ck} + k_1 \quad \text{.......} \quad (2.4)$$

$$\bar{x}_1 \geq f_{ck} - k_2 \quad \text{.......} \quad (2.5)$$

Where, $\bar{\mathbf{m}}_{\mathbf{3}}$ is the mean value

$\mathbf{f_{ck}}$ is the specified characteristic strength

$\mathbf{K_1}$ & $\mathbf{K_2}$ are the margins of strength given in the table 2.6 below

$\bar{\mathbf{x}}_{\mathbf{1}}$ is the average strength of the minimum strengths for the several lots

Table 2.6 Margins of strengths in MPa [19]

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.

$$\bar{m}_n - \lambda s_n \geq f_{ck} \quad \text{.......} \quad (2.6)$$

$$\bar{x}_1 \geq f_{ck} - k_2 \quad \text{...} \quad (2.7)$$

Where, $\bar{\mathbf{m}}_{\mathbf{n}}$ is the mean value.

$\mathbf{S_n}$ is the standard deviation of the set of sample results.

$\mathbf{f_{ck}}$ is the characteristics cylindrical strength.

$\boldsymbol{\lambda}$ is the coefficient (may be taken as 1.4).

$\mathbf{K_2}$ is the margin of strength (may be taken as 4MPa).

N is the member of specimens.

The lot could be defined as the quantity of concrete produced in the same essential conditions and subjected to individual assessment. There is a minimum requirement set on the size of lot and frequency of sampling (EBCS-2, 1995) as given hereunder.

(a) No individual sampling can represent, on the average, more than 100 mixes or 100 m^3.

(b) For each grade of concrete, at least one sample shall be taken every week.

(c) For each grade of concrete, at least two lots shall be made.

If the test results do not satisfy the requirements of the above acceptance criteria, there are recommended measures to be taken according to EBCS-2:1995. The measures include;

i. The position of concrete which does not fulfill the compliance criterion shall be identified.
ii. The structural safety shall be checked by appropriate calculations on the basis of the actual test results which did not comply. If safety is assured, the concrete can be accepted.
iii. If such structural safety or durability are not assured, then the strength of the concrete shall be examined by taking drilled cores or by non-destructive methods.

iv. If this new information shows that structural safety is assured, the concrete may be accepted after it has been decided whether repairs are necessary to ensure durability.

v. If the results of check tests by non-destructive methods show that the quality of concrete is inadequate or show other defects, the engineer may require a loading test to be made.

vi. If structural safety and durability are not assured, then the possibility of strengthening the structure must be investigated. If strengthening is not feasible, then the concrete shall be rejected, and the structure or member demolished or given a reduced structural grading by limiting its service rating, as appropriate.

Furthermore, compressive strength test of concrete can be done for different ages and also concrete shall gains 16%, 40%, 65%, 90%, 94% and 99% of its desired compressive strength in 1, 3, 7, 14, 21, 28 days respectively [25].

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study area

Adama is the location of this study. Adama (Oromo: Adaamaa or Hadaamaa), officially known as Adaamaa and formerly Nazareth, is a city in central Oromia Region, Ethiopia. It is located at 8.54°N 39.27°E at an elevation of 1712 meters, 99km southeast of Oromias Addis Ababa. The city sits between the base of an escarpment to the west, and the Great Rift Valley to the east. This research is carried out on building construction projects takes charge by general grade one contractors. It is believed that proper data and significant reliable information is obtained from them.

Figure 3.1 Map of the study area

3.2 Study Period

This thesis work is takes a period of from March 2021 up to March 2022 in Adama city. The activities in each month are found in proposed work plan of this thesis proposal.

3.3 Research design

The research design adopted for this study is be a descriptive analysis. It is rely on qualitative and quantitative research approaches to understand concrete production quality control in building construction project in Adama city.

3.4 Study variables

Dependent variables: The dependent variable is concrete production quality control.

Independent variables: The independent variables are cement, aggregates, water, admixtures, batching, mixing, transporting, placing, compacting and curing of concrete.

3.5 Population and sampling method

The targeted population in this study was both public and private building project. The respondents are construction stakeholders such as consultants and contractors involved in public, and private building construction works in Adama City.

A non-probability purposive sampling technique is adopted for selecting the sample population of the study because it allows a researcher to get information from a sample of the population that one thinks or knows most about the subject matter. Therefore, during the study period 16 ongoing building projects were selected purposively based on their contracting level, physical progress and complexity of the projects, financial capacity, and organized data recording and involving experienced professionals. As well, the respondent from the population were consultants and contractors. Therefore, 40 from contractor's side (project manager, architect, site engineer, office engineer, construction engineer, and quantity surveyor) and 20 from consultant's side (office engineer, architects, site engineer, and resident engineer) were selected for the questionnaire survey.

3.6 Source of data

The study was depends on both primary and secondary data. This study primary source of data was made up of first-hand data collected by the researcher through the use of questionnaires, site observation and collected compressive strength test result from the consultant office. The secondary sources of data were obtained using relevant books, journals, magazines and research papers.

3.7 Data collection procedure

In this study, structured questionnaire was distributed to consultant and contractor's side's professionals working on investigated projects. The questionnaire survey was helped to get feedback on opinions of respondents" about the objective of this research. In addition to collecting information with questionnaire, observation on site activities related with concrete production was takes place on active building projects. On top of that, Compressive strength test results of structural grade concrete used in building construction was collected from the consultant`s test data files.

3.8 Data presentation and analysis

The sample for this study was relatively small. As a result, the analysis was combined all groups of respondents (consultants, contractors) in order to obtain significant results. Data was analyzed based on information gathered through questionnaire, collected test results from consultant office and observations. Then after, subjective assessment was made on the current concrete production quality control practices with respect to the recommended scientific approaches of literatures and also to make a quantitative evaluation of the level of concrete quality control on building construction sites of the investigated projects. Data was analyzed by calculating percentage, frequencies and Relative Importance Index (RII) by MS excel 2010. Besides, data is presented by using table, graph and charts.

3.9 Ethical clearance

Initially support letter, which expresses the identity of researcher, is obtained from Jimma institute of Technology (JIT). Then, for test results and data collection procedures permissions was obtained from relevant project stakeholders. All the collected results of compressive strength tests are used only for research purpose.

CHAPTER FOUR

RESULT AND DISSCUSSION

Here this research briefly discussed the information gathered through questionnaire, site observations and compressive strength test results. The concrete production practices in the building construction industry of Adama city are evaluated against the recommended scientific practices. The quality of concrete making materials and the production processes could affect the quality of concrete, for this sake each concrete ingredient and every production processes are thoroughly seen.

Sixty-four questionnaires are distributed and relevant sixty questionnaires are returned and used from active projects which are among the total of sixteen projects investigated. 20 lots of the 7^{th}, 14^{th} and 28^{th} days compressive strength test results of concretes are collected from sixteen projects with grade of C-25 and C-30 located in various parts of the city. To sum up, all lots are collected and assessed from ongoing concrete structural work of columns, beams, slabs and shear walls on the period of the researcher site observation while concrete casting.

In fact, compressive strength of concrete affected by types of cements used and the weather condition occurred. And quality control is done for both OPC and PPC cements concrete at 28 days age commonly. Whereas the 7^{th} and 14^{th} days of concrete compressive strength test result is used by the researcher to assess the attained strength at that age by comparing to the acceptable percentage values.

Lastly, 28^{th} day concrete compressive test results are analyzed and the level of concrete quality control is assessed from the observed variability in the test results. The requirement of various codes and standards (EBCS-2:1995 & ACI 318) and the compliance of those collected test results within those codes and standards are also examined. The questionnaires and the collected test results are attached on the appendix part of this paper.

4.1 Analysis of the questionnaires

To accomplish this research work the researcher used questionnaires to obtain the primary data.

Table 4.1 Result of distributed, returned, unreturned, rejected and analyzed questionnaire

Respondent	**Distributed questionnaire**		**Returned questionnaire**		**Unreturned questionnaire**		**Rejected questionnaire**		**Analysed questionnaire**	
	Frequency	Percentage %	Frequency	Percentage %	Frequency	Percentage %	Frequency	Percentage %	Frequency	Percentage %
Contractor	42	65.63 %	42	67.74 %	0	0%	2	100%	40	66.67 %
Consultant	22	34.37 %	20	32.26 %	2	100%	0	0%	20	33.33 %
Total	64	100%	62	100%	2	100%	2	100%	60	100%

Table 4.1 show the result of distributed, returned, unreturned, rejected and analyzed questionnaires. Sixty four (64) questionnaires were distributed to building construction projects. For which 42 questionnaires for contractor and 22 questionnaires were distributed to consultant. The numbers of returned questionnaires from contractors were 42 and from consultant were 20. On the whole a total of 62 questionnaires returned and 2 questionnaires rejected from contractor. Totally 60 questionnaires which is 100% were analyzed.

4.2 Profiles of respondents

4.2.1 Respondents current organizational position

The following table 4.2 shows that, distribution of respondent's current organizational positions for two parties (contractor and consultant).

Table 4.2 Respondent current position

Respondent current positions	**Contractor**		**Consultant**	
	Frequency	Percentage %	Frequency	Percentage %
Project manager / resident engineer	4	10%	2	10%
Architect	6	15%	5	25%
Site engineer	8	20%	2	10%
Construction engineer	10	25%	4	20%
Office engineer	9	22.5%	5	25%
Others	3	7.5%	2	10%
Total	40	100%	20	100%

Construction engineer is a respondent's positions with highest percentage for contractor with 25%. Architect and Office engineer are a respondent profession with equal highest percentage (25%) for consultant. For contractor Office engineer is the second (22.5%), site engineer is the third (20%) and architect is the fourth (15%). For consultants construction engineer has the second highest percentage with 20%. For contractor side project manager is found at the fifth rank with 10%. Project manager for consultants and other professions for both parties take more than 7% and this indicates that the respondents have other profession like surveyor, electrical engineer, sanitary engineer and etc. This implies all respondents are relevant to the research questions.

4.2.2 Respondents experience

The following table 4.3 indicates experience of the respondent in building construction site found in Adama city.

Table 4.3 Respondent's year of experience

Experience of the respondents	**Contractor**		**Consultant**	
	Frequency	Percentage %	Frequency	Percentage %
0-5	14	35%	9	45%
6-10	16	40%	8	40%
11-15	8	20%	3	15%
More than 15	2	5%	0	0%
Total	40	100%	20	100%

The maximum percent of experience by contractor side is 6-10 years (40%) and by consultant side also 0-5 years (45%). The experience of the respondents from 0-5 years by contractor side is 35%. On behalf of consultant side 6-10 years of experience are 40 by percent. Besides, the contractor side year of experience to 11-15 (20%) and the consultant sides 16-15 years of experience are (15%). There is no respondent who has more than 15 years of experience by consultant side but 5% exist on contractor side. This indicates that the respondents have an appropriate year of experience to understand the research questions and give right answer by using their work experience.

4.2.3 Respondents educational background

The following table 4.4 verifies the level of respondent's educational background for contractor and consultant.

Table 4.4 Respondents highest educational qualification

Educational qualification	Contractor		Consultant	
	Frequency	Percentage %	Frequency	Percentage %
Certificate	4	10%	0	0%
Diploma	8	20%	2	10%
Degree	22	55%	14	70%
MSc	6	15%	4	20%
PhD	0	0%	0	0%
Total	40	100%	20	100%

BSC degree takes more than 50% (contractor 55% and consultant 70%). The remaining percentages from total for consultant are 10% for diploma and 20% for MSc. For contractor certificate take 10%, MSc 15% and diploma 20%. For both parties a respondent with PhD does not exist as well as certificate for consultants. The result indicate the respondents were qualified enough to answer the questions related with the objective.

4.3 Current practice implemented on the quality of concrete constituent

4.3.1 Cement

Cement is a dirty greenish heavy powder and finds its importance as a building material. It is investigated that there are two common types of cement used in construction projects of Adama city. These are called OPC and PPC.

Table 4.5 Sources of cements on building projects

Sources of cement	Percentage of projects using the source of cements
Factory	70%
Agent	20%
Both factory and agents	10%

As shown on table 4.5, the sources of those Portland cements are also different. From total of investigated building construction projects 70% of the project used the cement which is sourced directly from the factory, 20% of the projects used from agents and the remaining 10% are used both from factory and agents based on the conditions. It is believed by the stakeholders of the building projects, cements which are sourced directly from the factory has a better quality compared to sourced from agents with accordance to cement storing periods. To clarify they are believed about cement with hands of agents would have a long age which is leads to poor concrete quality production.

As the research discussed above there are two common types of Portland cement used, namely OPC and PPC and with different consumption on projects.

Table 4.6 Projects usage of types of cements

Types of cement usage	Percentage of types of cement usage
OPC	41.67%
PPC	33.33%
Either OPC or PPC	25%

When the research observed the usage of these two cements, which is shown on table 4.6, building projects which consume OPC`s is higher in which 41.67% of the projects have been using OPC cement for concrete production, 33.33% PPC and the remaining 25% of the projects used either OPC or PPC cement. All the projects are used the cements after making trial mixes and by setting the appropriate mix proportions which could provide the required concrete quality. According to the information obtained from the site engineers and other project active stakeholders most of the project sites are used OPC due to its faster early strength gain capacity than PPC and also believed that generally concrete produced with OPC is of better quality than PPC without considering its ultimate strength. In fact, thought like this doesn't have any ground of science. Therefore the researchers recommended to give emphasize of using PPC cements because the level of ground water is rises in Adama city which would chemically affect the sub structural part of building structures.

Besides it is known that cements can be tested chemically and physically.

Table 4.7 projects performed tests on cement

Tests on cement	**Percentage**
Yes	30%
No	70%

As shown on table 4.7 from total active ongoing building projects only 30% of projects are performed tests on cement. Whereas the rest 70% which is the majority is not performed any type of tests on cements. But according to the information the researcher gained from the resident engineers of projects which doesn't conducted any test of cements, they are believed that only field test of cements is enough.

On top of that, physical tests on cements which are conducted on 30% of projects are fineness of cement, consistency of cement, setting time of cement, soundness of cement and strength of cement.

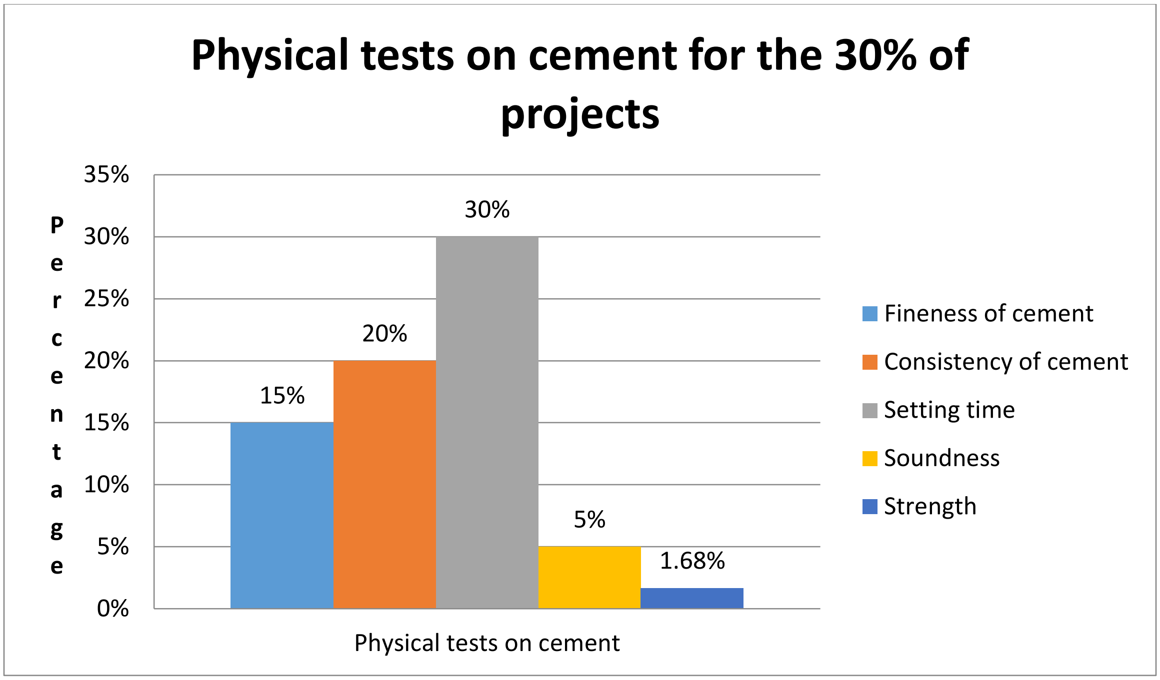

Figure 4.1 Physical tests on cement for the 30% of projects

As shown on figure 4.1 from out of 30% projects which are performed tests on cement, half or 15% of projects performed fineness of cement tests, which means the rest projects which are not performed this test could not know the rate of hydration, and hence the rate of gain of strength and also on the rate of evolution of heat which has a direct effect on the concrete quality. 20% of project performed consistency of cement tests which is the remaining against projects are not determined for any given cement the water content which will produce a paste of standard consistence and this puts an effect on the concrete quality. 5% of projects performed soundness of cement tests and the least 1.68% of projects performed strength of cement tests. The projects without soundness and strength tests are exposed to a large change in volume of concrete and unidentified compressive strength of cement respectively. Also it is investigated that from out of 30% projects which are undergoes tests on cement, all or 30% of projects are performed setting time test of cement which is used to describe the stiffening of cement paste or the change from fluid to a rigid state. It has a scientific ground to have those physical tests to obtain the desire concrete quality.

From the data the researcher obtained through questioner it is investigated that all building construction projects are used the cement which has age in between 3 up to 4 months since its production periods. It is also assessed tests on cements performed for long time storing is not takes place at any of the building projects.

Table 4.8 Tests of cements for each lot of cement

Tests of cement for each lot of cement	Percentage of projects
Yes	5%
No	95%

On top of that, as shown on table 4.8 only 5% of projects are performed tests on cement for each lot of cements and the rest are not doing. Therefore, this is considered as one of the problems that could seriously affect the quality of concrete. In the quality control of concrete, the packing slip of cement explaining its date of packing is shall require when delivering cements to construction sites.

At all stages up to the time of use, cement must be kept dry so as to prevent or minimize deterioration from the effects of moisture, atmospheric humidity and carbonation.

Table 4.9 Storing of cements

Storing of cements	Percentage of projects
Proper storing	86.67%
Improper storing	13.33%

As shown on the table 4.9 according to data the researcher obtained 86.67% of projects have proper storage of cement and the rest 13.33% of projects have not. This implies that the projects with improper cement storage could have a problem to get a desire concrete quality.

4.3.2 Aggregates

The researcher observed different aggregate sources for the investigated projects. Most of these projects have used materials which can be obtained nearer to the location of the projects. On the basis of the assessment there is an observation that the coarse aggregate used for concrete production is crushed aggregate whereas the fine aggregate is either crushed, natural sand, or both crushed and natural sand as the condition.

Table 4.10 Sources of fine aggregates

Sources of fine aggregate	Percentage of projects
Natural Sand Only	86.67%
Crushed Aggregate Only	0%
Both natural sand and crushed aggregate	13.33%

As shown on the table 4.10 the projects that use natural sand as fine aggregate have a higher value of 86.67% and the remaining 13.33% of are belong to projects which use both natural sand and crushed aggregate as fine aggregate based on the condition they are faced. It is confirmed that most of the projects used natural sand as fine aggregate because it is nearly available in the Awash River (from Wonji or Metehara) which makes it very economical. On top of that the researcher was questioned the site engineers to know the reason of those projects which include crushed fine aggregate as a part of their mix ingredient and the answer is to improve the compressive strength of their concrete, in fact it is also stated on the literature part of aggregate shape, size and surface textures. The researcher also believed a good quality of aggregate is found from good sources and recommend usage of crushed fine aggregate as part of concrete mix because it improve the compressive strength of concrete and its workability.

Based on the assessment, all of the ongoing building projects of Adama city are performed tests of fine aggregates but the percentage for single particular test is obtained with different value. The tests conducted for fine aggregate are sieve analysis, water absorption, organic impurity, loose and compacted unit weight, silt and clay content, specific gravity, chloride content, clay lump, sand equivalent and soundness.

Table 4.11 Tests of fine aggregates

Tests of fine aggregates	Percentage of projects conducted tests
Sieve Analysis	86.67%
Water Absorption	51.67%
Organic Impurity	63.33%
Loose and compacted unit weight	78.33%
Silt and Clay contents	96.67%
Specific Gravity	46.67%
Chloride Contents	6.67%
Sand equivalent	1.67%
Clay lump	1.67%
Soundness	6.67%

As shown on the table 4.11 from total projects 86.67% of projects are conducted sieve analysis test for fine aggregate. It is also investigated 51.67% of projects only conducted water absorption tests for fine aggregate. Organic impurity tests for fine aggregate is takes place in 63.33% of projects and When organic impurities are available in significant amount in concrete aggregates, it interferes with the chemical hydration reaction process and it affect the strength gain of concretes.

Here also 78.33% and 46.67% of projects are conducted loose and compacted unit weight tests and specific gravity tests for fine aggregate respectively and expressed on how densely the aggregate is packed and, consequently, on the size distribution and shape of the particles, which has an effect of concrete quality. Besides, 96.67% of projects are conducted silt and clay content test for fine aggregate which is satisfactorily than other tests. On the other hand, only 6.67% of projects are conducted chloride content and soundness tests for fine aggregate which will lead to have a poor quality of concrete. To sum up, only 1.67% of projects are conducted sand equivalent and clay lump tests for fine aggregate respectively in which the first is used to qualify fine aggregates for applications where sand is desirable but fines and dusts are not and the second is used to determine the acceptability of aggregate with respect to the requirements of specification. But both are not conducted at most of projects.

Based on the assessment, all of the ongoing building projects of Adama city are also performed tests of coarse aggregates but the percentage for single particular test is obtained with different value. The tests conducted for coarse aggregate are sieve analysis, water absorption, organic impurity, loose and compacted unit weight, clay lump and friable particles, specific gravity, flakiness index, aggregate crushing value (ACV), aggregate impact value (AIV), elongation index, abrasion test and soundness test.

Table 4.12 Tests of Coarse aggregate

Tests of coarse aggregate	**Percentage of projects performed tests**
Sieve analysis	100%
Flakiness index	15%
Loose and compacted unit weight	56.67%
Clay lump and friable particles	3.33%
Specific gravity	36.67%
Soundness	1.67%
Organic impurity	20%
ACV	23.33%
AIV	38.33%
Elongation index	1.67%
Water absorption	61.67%
Abrasion test	76.67%

As shown on the table 4.12 all or 100% of projects, 15% of projects, 56.67% projects and 3.33% of projects conducted sieve analysis, flakiness index, loose and compacted unit weight, and clay lump and friable particles tests for coarse aggregate respectively. And also, 36.67% of projects, 1.67% of projects and 20% of projects are conducted specific gravity, soundness and organic impurity tests of coarse aggregate tests respectively. As well as fine aggregate tests for soundness here also coarse aggregate tests for soundness is at very minimal percentage which makes it difficult to know the volume changes occurred on the aggregates due the action of freezing and thawing.

Based on the assessment, 23.33% of projects conducted aggregate crushing value test (ACV), 38.33% of projects conducted aggregate impact value test (AIV) and 76.67% of projects conducted abrasion test of coarse aggregate. The above three tests are related to aggregate strength but actually those tests are not conducted satisfactorily and it is well to put the quality of concrete produced at those projects under questions. Finally, 61.67% of projects are conducted water absorption test and only 1.67% of projects conducted elongation index test for coarse aggregate. Elongation index test is not conducted at most of projects, implies an elongated aggregate would have taken place and puts the concrete quality under question again.

The tests for aggregates which are discussed in the previous parts are carried out either once or more than once for a source depending on the condition.

Table 4.13 Frequency of aggregate tests

Frequency of aggregate tests	Percentage of projects
Once for one source	6.67%
Depending on conditions	93.33%

As shown on the table 4.13 the percentages of those projects which take samples of aggregates to be tested once for one source are 6.67%. On the other hand 93.33 % of projects conduct tests more than once for one source depending on conditions. According to the resident engineers of those projects, depending on conditions means when new concrete mix design is prepared and if the aggregates seems poor quality by visualization.

Care has to be taken when storing of aggregates to prevent the tendency of segregation and contamination of stockpiles.

Table 4.14 Storage of aggregates

Storage of aggregates	Percentage of projects
Proper storage	71.67%
Not proper storage	28.33%

As shown on the table 4.14 it was observed on 28.33% of projects aggregates isn't stored properly till the time of usage. The stock places are exposed to different impurities such as dust due to construction equipment movement and cart away soils. This improper handling of aggregates affects or degrades the quality of aggregate as well as the quality of concrete. On the other hand, the rest 71.67% of projects have a proper aggregate storage.

It is also investigated about the failure of aggregate test results and the remedial measures taken by the respondents. And, 25% of respondents said if test result failed, they will send the sample to other laboratory and if it fails again they will reject the stock of aggregates, but if it passes they will use it. On the other hand, 15% of respondent answered if the aggregates fails they will take a measure to wash it. And the remaining 60% of respondent said if once stock of aggregate failed, they will blend it by other approved stock of aggregate found on the site till the aggregate satisfied the requirements. Here the researcher believed blending of aggregates will be a measure to only gradation failures.

Figure 4.2 Site storage of coarse aggregate

Figure 4.3 Site storage of fine aggregate

Figure 4.4 Poor quality stockpile of fine aggregate

4.3.3 Water for concrete

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement.

Table 4.15 Sources of water

Sources of water	Percentage of projects
Drinking water	60%
Awash River water	33.33%
Ground water	6.67%

As shown on the table 4.15 there has been three different type of water that the projects are used during the investigation periods, namely; drinking water, Awash River water and Ground water. The consumption of drinking water is 60%, Awash River water is 33.33% and ground water is 6.67%. Besides, based on the investigation there is only a visual inspection of water from Awash River before usage, but for the rest type of sources any type of inspections and tests are not performed. Therefore it is recommended by the researcher to have tests of water for total dissolved solid, alkalinity, electrical conductivity, carbonate, bicarbonate, sulfate and chloride.

4.3.4 Admixtures

An admixture is defined as a material, other than cement, water and aggregates, which is used as an ingredient of concrete and is added to the batch immediately before or during mixing.

According to the investigation only 8.33% of projects are used admixture type of water reducing agents or plasticizers for the sake of obtain a right required workability of concrete without excess of water by enhancing the strength too.

4.4 Current practice implemented on the quality of concrete production process

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. It is interesting to note that the ingredients of good concrete and bad concrete are the same. If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality. With the same material if intense care is taken to exercise control at every stage, it will result in good concrete. Therefore, it is necessary for us to know the good rules to be followed in each stage of manufacture of concrete for producing good quality concrete.

4.4.1 Batching

The measurement of materials for making concrete is known as batching. According to the investigation done C-30 and C-25 is the frequent concrete grade used for all types of buildings in Adama city whereas C-20 also used rarely. A box internal size of 50*40*16cm, 50*40*18cm and 50*40*20cm (length, width and depth respectively) is used to measure the proportion of sand and coarse aggregates used, as shown only changing the depth of the box is implemented to get different grade of concrete. Means cement is always measured by weight. The volume of one bag of cement is taken as thirty five (35) liters or $0.035m^3$. The mix ratio used to produce a C-20, C-25 and C-30 concrete in all projects is 1:2:3 which represents one bag cement (50kg), two boxes of sand and three boxes of coarse aggregates respectively with different box depth. Water is measured either in kilogram or liters as may be convenient. In this case, the two units are same, as the density of water is one kg/liter. The quantity of water required is a product of water/cement ratio and the weight of cement.

Figure 4.5 Measuring box for aggregate

During the assessment periods there is a negligence observed on adjusting the quantities of ingredients on construction sites, especially on aggregates. It is confirmed that from the respondent that among projects adopting volume batching techniques, 66.67% of building construction sites don't make any adjustment, 25 % adjust only the moisture content in aggregates and the remaining 8.33% have been making adjustments to both bulking of sand and the moisture content in aggregates. As the percentage indicated the batching process is not satisfactorily and generally improper batching affects the stability, mobility, and compactness of concretes, which finally affects the quality of concrete production.

4.4.2 Mixing

Through mixing of the materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in color and consistency. The purpose of concrete mixing is to provide a uniformity blended product of cement, water, and aggregates.

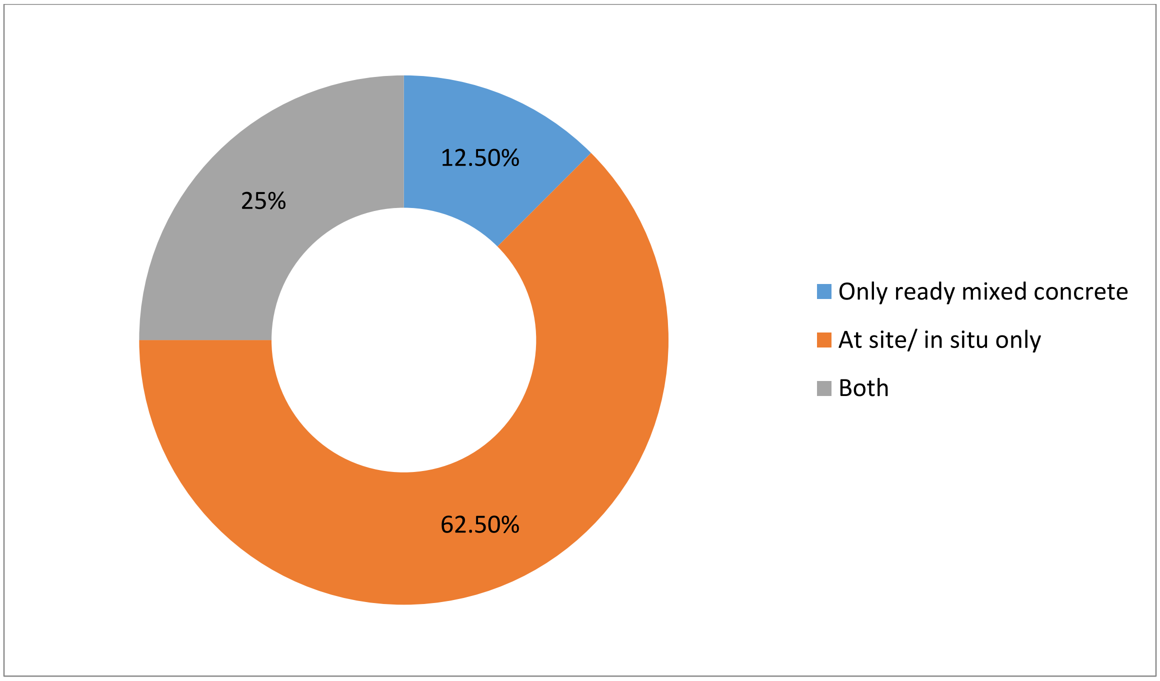

Figure 4.6 Types of concrete production

As shown on the figure 4.6 from total projects 62.5% used in situ type of concrete production method, 25% of projects used both ready mixed concrete production and in situ concrete production methods depending on the conditions, and the rest 12.5% projects used ready mixed concrete type. As we know ready mixed concrete production method has its different types such us; central mixing, transit mixing and shrink mixing. All of the projects which are used ready mixed production method are belong to transit mixing type which is mixed completely in a truck mixer and transported to the site.

Concrete can be mixed using hand tools or machine equipment of various sizes. Regardless of the type of process used, however, the principles are the same. As the investigation projects which are used machine for mixing purpose are 16.67% and 83.33% are used both manual and machine regarding to conditions.

Table 4.16 Capacity of mixer used

Capacity of mixer	Percentage of project used the mixer
$0.36m^3$	41.33%
$0.72m^3$	30.33%
$4m^3$	9.59%
$7.5m^3$	18.75%

As shown on the table 4.16 various mixer types are also observed on building construction projects within their size small to medium in capacity. Here the researcher stated the most frequently used mixer type in most of projects by percent. 41.33% projects used $0.36m^3$, 30.33% projects used $0.72m^3$, 18.75% projects used $7.5m^3$ and the rest 9.59% projects used $4m^3$ capacity mixer. 7.5m3 mixer type is mostly used for ready mixed concrete type. Though respondents from all stakeholders replied that, the mixing time for in situ concrete production ranges between 5-10 minute and 15-20 minute. This is a longer duration that could affect concrete quality. One minute of mixing is a satisfactory period for mixers up to capacity of $0.75m^3$.

And, if the concrete is mixed of the site (ready mixed concrete) the respondents said it would take 30-45 minute to be placed on the forms. This is in agreement with the maximum permitted time of two hours between mixing and discharging concretes if the concrete is transported in a truck mixer or agitator in the temperature range of 5^oC to 32^oC.

Most of the respondents agreed that attention to mixing shall be given in mixing of concrete especially related to mixing time. Therefore the researcher concluded that in most of project sites time taking for mixing is not according to standards stated based on capacity of mixers.

Figure 4.7 Mechanical mixer of 0.36m3 capacity

Figure 4.8 Machine mixing of concrete on site

Loss of workability and undue stiffening of concrete may take place at the time of placing on actual work site. The researcher has been raised the questions for the respondents as there corrective measures if the required slump is not attained and almost quarter of the projects are used a measures of rechecking the ingredients proportion and the rest half plus quarters are used a measures of adding more cement to the mix or adding $1m^3$ of new mix to the previous mix.

4.4.3 Transportation, placing and compacting of concrete

Once the mixing of concrete constituents is completed, it should be transported and placed at its desired position or place as soon as possible to avoid segregation, drying, etc.

As the researcher observed on the investigated projects site, it is shows that concrete is transported vertically for superstructures using winches and cylindrical barrels and using chutes made of corrugated iron sheets for the concrete mixed by mixer for substructure works. Besides, mortar pan constructed with iron sheet named on site "barella" and wheel barrows are used to transport and place in position. Use of mortar pan “barilla” and wheel barrows for transportation of concrete is one of the common methods adopted in Adama city. But as the researcher observed a satisfactory care for transporting of concrete by mortar pan is not undertake such us unclean and dry mortar pan is used. And also the researcher observed concrete is transported over very rough road which is exposed to segregation as well as affect the concrete quality when using wheel barrows.

This research on building projects has proved that there is a good understanding on 57% of projects to minimize the formation of honey comb, bug holes, cold joints and placement lines. In order to minimize the above consequences of improper placement and improper vibration the site active stakeholders are taken a measure such as chiseling, using fresh cement paste, making the surface free from unnecessary things before pouring concrete on it, and by stopping the concrete casting at one-third dimensions from the support. Opposing this, in most of observed sites concrete is dropped from height of more than 2.5m while they cast columns which are the major critical part of the building in which most of literatures recommended a height of 1.5m but EBCS 2 of 1995 stated a maximum height of 3m which means it is acceptable.

In order to assess the value given to the proper compaction, related questions have included in the questioner and the following results are obtained. As stated on EBCS 2 of 1995 all projects are used a mechanical compaction method of immersion or poker vibrator for the concrete grade of C-20 and above. And from total of projects 57% of projects have given a caution of duration of compaction, the spacing of immersion vibrator during periods of compaction and depth of compaction. It is answered that the duration, spacing and depth of compaction is determined according to mix slump, vibrator size and the thickness of the placing concrete respectively. Further, the remaining 43% have no caution about duration and spacing, therefore awareness and caution shall be given by both contractors and consultants' personnel for the compaction of concrete in order to obtained the desired strength and durability of concrete. Proper use of immersion vibrators in terms of insertion time, center to center spacing of vibrators poker immersion and depth of compaction are important for better result in concrete compaction. To illustrate, if there is no attention on these terms, poor quality concrete may be obtained from well designed and produced mix.

Figure 4.9 Mechanical compaction of concrete by immersion vibratory

4.4.4 Curing of concrete

Curing is the process which controls the loss of moisture from concrete either after it has been placed in position (or during the manufacture of concrete products), thereby providing time for the hydration of the cement to occur.

According to the data obtained from the questioner a sprinkling type of curing is observed to all projects and 95% of projects conducted a minimum of seven days of curing for OPC and the rest 5% of projects conducted two up to three days of curing. On the other hand for PPC 92 % of projects performed a minimum of fourteen days of curing and the remaining 8% performed nine up to twelve days. Therefore the applications of curing in most of projects are based on scientific ground and acceptable. To emphasized, for the sake of obtaining an acceptable concrete quality it is obligatory to use proper concrete ingredients and follow proper production process.

4.5 Causes of poor quality of concrete production

The aim of quality control is to produce uniform material providing the characteristics desirable for the job envisaged. Thus quality control is a corporate, dynamic program to assure that all aspects of materials, equipment and workmanship arc well looked after.

The researcher has been included a Likert Scale questions in the questioner about as major causes of poor quality of concrete production and the following data on table 4.19 has obtained. The RII values and ranks also stated as follows.

Table 4.17 Factors as major causes of poor quality of concrete production

Major causes of poor quality of concrete production	RII values	Rank
Personnel	0.760	3
Equipment	0.756	4
Workmanship	0.890	1
Concrete materials	0.883	2

As the above table 4.19 represents depending on the data obtained from the respondent workmanship with relative importance index values of 0.89 becomes the first factors as major causes of poor quality of concrete production, whereas materials, personnel and equipment follows second, third and fourth rank respectively. The activities involved in the workmanship in all stages of concreting, i.e. batching of materials, mixing, transportation, placing, compaction, and curing should be proper, unless otherwise it will be a major cause. Based on the data the third basic requirement for the success of any quality control plan is the availability of experienced, knowledgeable and trained personnel at all levels. On the fourth factor, the equipment used for batching, mixing and vibration shall be of the right capacity.

The researcher also raised open ended questions for the respondents about factors affecting the quality of concrete production and the following answers were obtained:

- Batching
- Ingredients used
- Production process
- Climate

4.6 Impacts of poor quality concrete production

Here also the researcher raised open ended question about the impact of the above factors to the concrete production and the following results are obtained:

- Honey combing
- Cold joints
- Cracks
- Structural collapse
- Efflorescence
- Volume change
- deterioration

4.7 Causes of concrete quality control problems

Here also the researcher used a Likert scale questions of RII and ranking method about factor as causes of concrete quality control problems and obtained the following relevant data from the respondents.

Table 4.18 Factor as causes of concrete quality control problems

Causes of concrete quality control problems	RII values	Rank
Negligence of national building codes and standards	0.727	4
Design deficiency	0.880	2
Unsatisfactory quality of concrete ingredients	0.883	1
Inappropriate supervisions	0.817	3

According to the study negligence of national building codes and standards has the highest RII value of 0.727 and rewarded as the major causes of concrete quality control problems, whereas design deficiency, unsatisfactory quality of concrete ingredients and inappropriate supervisions takes the second, third and fourth places respectively.

On top of that the researcher raised questions about the remedial measures taken by the respondents to control concrete production quality problems, and then the following points are stated by the respondents as measures.

- By controlling of workmanship
- By don't use of over aged cements
- By controlling of concrete mixing and placing of concrete in short time interval
- By checking the quality of mixing water
- By taking tests of ingredients regularly and make sure the woks are done according to specification and design
- By checking the efficiency of machinery used

4.8 Methods of specifying concrete

As stated on EBCS 2 of 1995 concrete may be specified in one of three ways, namely; designed mix, prescribed mixes and standard (or nominal) mixes.

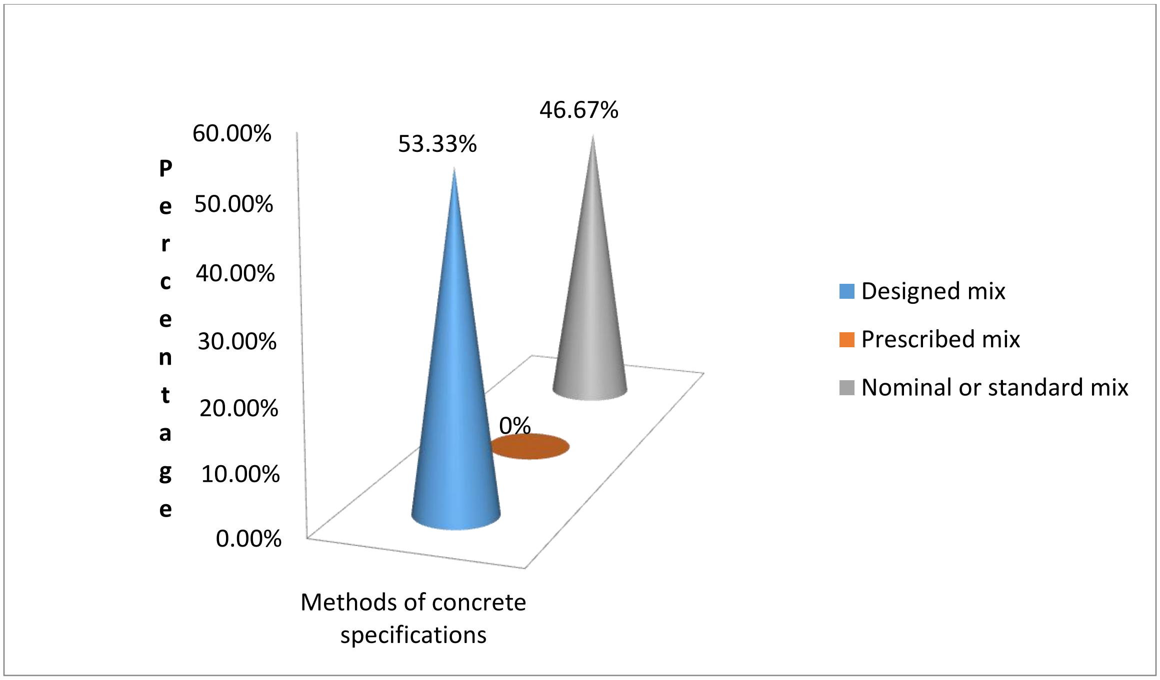

Figure 4.10 Types of concrete specification usage

As shown on the figure 4.9 based on the study conducted 53.33% of projects used a designed mix type of concrete specification and the rest 46.67% of projects used a nominal (standard) concrete specification type, whereas no project is conducted a prescribed specification type.

4.9 Statistical quality compliance control of concrete

To achieve the objective of the study and emphasizing the importance of testing to the quality control of concrete, sample specimens that are casted from ongoing concrete production sites of Adama city and tested for their 7th, 14th and 28th day compressive strength are collected from consultant office. For the sake of that statistical quality control method, compliance and conformity criteria's of EBCS-2:1995, ACI- 214 and ACI-318 have been used.

As it is known compressive strength test of concrete can be done for different ages and also concrete shall gains 16%, 40%, 65%, 90%, 94% and 99% of its desired compressive strength in 1, 3, 7, 14, 21, 28 days respectively. But the researcher bears in mind that compressive strength of concrete could affect by types of cements used and the weather conditions. In fact, both OPC and PPC cements cannot have the same early strength but almost very same ultimate strength in 28days. To illustrate, the researcher used 28days concrete compressive strength test results for quality control purpose as it is stated on the Ethiopian building codes and standards.

On top of this, the researcher also assessed the 7th and 14th days of compressive strength test results to examine the progress of concrete compressive strength by comparing to the acceptable percentage values in 7th and 14th days on the table below.

Generally, For the purpose of this research the researcher collected 20 lots of concrete in which each of the lots contains 3 pieces and a total of 60 pieces from 16 ongoing building projects in Adama city whereas 8 lots with C-30 and 12 lots with C-25 compressive strength.

Table 4.19 Collected 7th day compressive test results of concrete

Project code and concrete grade	**7th days Compressive strength**	**Mean**	**% to be attained**	**Actual % obtained**	**Result**
2B+G+15 C-30	28.24	25.81	65%	86.03%	Attained
	22.13				
	27.08				
2B+G+15 C-30	38.13	31.47	65%	104.9%	Attained
	30.16				
	26.14				
2B+G+15 C-30	23.04	22.84	65%	76.13%	Attained
	21.42				
	24.08				
2B+G+15 C-30	25.43	24.45	65%	81.5%	Attained
	23.27				
	24.66				
B+G+6 C-25	35.19	37.16	65%	148.64%	Attained
	37.28				
	39.01				

TMA C-25	37.16	40.27	65%	161.08%	Attained
	39.89				
	43.76				
AIP C-25	20.13	20.48	65%	81.92	Attained
	18.25				
	23.08				
MEP C-25	25.44	25.14	65%	100.56	Attained
	27.53				
	22.47				
AIP2 C-25	20.01	18.27	65%	73.08%	Attained
	16.38				
	18.42				
B+G+5 C-25	17.58	17.13	65%	68.52%	Attained
	19.54				
	14.29				
B+G+4 C-25	32.35	33.13	65%	132.52%	Attained
	33.01				
	34.05				
WMBP C-25	33.95	33.55	65%	134.2%	Attained
	34.16				
	32.54				
TMAP2 C-25	38.56	44.33	65%	177.32%	Attained
	49.42				
	45.02				
2B+G+7 K18 C-25	38.22	39.78	65%	159.12%	Attained
	40.18				
	40.95				
GHBP C-25	14.23	15.06	65%	60.24%	Not attained
	15.01				
	15.95				

B+G+5 PBP C-25	28.01	28.17	65%	112.68%	Attained
	29.55				
	26.96				
MUBP10 C-30	18.05	18.76	65%	62.53%	Not attained
	18.01				
	20.22				
MUBP09 C-30	22.26	21.59	65%	71.96%	Attained
	21.99				
	20.53				
MUBP15 C-30	26.16	25.19	65%	83.96%	Attained
	26.95				
	22.48				
MUBP OF K09 C-30	32.04	29.22	65%	97.4%	Attained
	28.09				
	27.54				

As it is shown on the above table 4.19, 90% of the lots are attained the acceptable percentage by obtaining a compressive strength of more than 65% at the age of 7day. On the other hand, 10% of lots are found under the acceptable percentage of 65% at the age of 7^{th} day.

Table 4.20 Collected 14th day compressive test results of concrete

Project code and concrete grade	**14th days Compressive strength**	**Mean**	**% to be attained**	**Actual % Obtaine**	**Result**
2B+G+15 C-30	30.32	28.61	90%	95.36%	Attained
	27.18				
	28.33				
2B+G+15 C-30	40.35	35.02	90%	116.73%	Attained
	33.47				
	31.26				
2B+G+15 C-30	28.23	27.84	90%	92.8%	Attained
	27.02				
	28.27				
2B+G+15 C-30	30.17	28.12	90%	93.73%	Attained
	27.01				
	27.18				
B+G+6 C-25	40.13	41.22	90%	164.88%	Attained
	40.99				
	42.56				
TMA C-25	41.65	50.20	90%	200.8%	Attained
	50.42				
	58.55				
AIP C-25	22.67	23.33	90%	93.32%	Attained
	19.96				
	27.36				
MEP C-25	29.45	30.41	90%	121.64%	Attained
	33.33				
	28.47				
AIP2 C-25	24.03	23.99	90%	95.96%	Attained
	22.43				

	25.52				
B+G+5 C-25	20.44	22.11	90%	88.44%	Not attained
	25.98				
	19.93				
B+G+4 C-25	36.11	36.06	90%	144.24%	Attained
	35.89				
	36.19				
WMBP C-25	36.05	36.24	90%	144.96%	Attained
	38.59				
	34.09				
TMAP2 C-25	41.16	47.65	90%	190.6%	Attained
	52.88				
	48.92				
2B+G+7 K18 C-25	40.95	42.87	90%	171.48%	Attained
	43.23				
	44.44				
GHBP C-25	20.13	20.95	90%	83.8%	Not attained
	20.17				
	22.56				
B+G+5 PBP C-25	30.44	31.22	90%	124.88%	Attained
	33.32				
	29.91				
MUBP10 C-30	22.03	22.81	90%	76.03%	Not attained
	22.01				
	24.41				
MUBP09 C-30	28.09	27.22	90%	90.73%	Attained
	28.01				
	25.58				
MUBP15 C-30	31.43	30.36	90%	101.2%	Attained
	31.50				

	28.17				
MUBP OF K09 C-30	38.09	33.23	90%	110.76%	Attained
	31.62				
	29.99				

As it is shown on the above table 4.20, 85% of the lots are attained the acceptable percentage by obtaining a compressive strength of more than 90% at the age of 14th day. On the other hand, 15% of lots are found under the acceptable percentage of 90% at the age of 14th day.

4.9.1 Compliance and conformity of 28th day concrete compressive strength with respect to EBCS -2 and ACI - 214

In case of American standard a test result is represented by two sample tests. However, the Ethiopian building code of standard requires one cube to represent one test result and a lot to have three samples or cubes. Hence, in the analysis, this average test result is used in the American standard by assuming that as an average of two sample tests.

As per EBCS-2:1995, it has been discussed in the literature review parts of this thesis, there are two compliance criteria's set. As it is introduced in the Ethiopian building code of standards, the values of K1 and K2 variable are shown in table 2.6 of margin of strength of concrete. For this particular analysis of test results, both the values of K1and K2 are taken to be 3MPa assuming that the lots considered in all the projects are above the fifth lot and this assumption entitles the least acceptance criterion which implies that the researcher is assessing the concrete compressive test results to the minimal requirement. Among the two criteria's set, criterion 1 which is applicable for small lots is used for this analysis.

To carry out the statistical analysis shown below, eq. (2.1), eq. (2.2) and eq. (2.3) are used for the determination of the mean, the standard deviation and the coefficient of variation respectively. The standard deviation is computed first with the cube test results then converted to the cylindrical strength with the conversion factor of 0.8 so that to label the level of quality control as per the ACI 214.

Table 4.21 Collected 28th day compressive test results of concrete

Project code and concrete grade	Compressive strength	Mean	SD (Mpa) for cuibic strength	SD (Mpa) for cylindrical strength	Coefficient of variation	Compliance to EBCS-2:1995	Compliance to ACI 318
2B+G+15 C-30	32.14	30.02	3.71	2.96	12.35	Failed	Complied
	26.64						
	31.28						
2B+G+15 C-30	43.21	38.60	4.12	3.29	10.67	Complied	Complied
	37.36						
	35.25						
2B+G+15 C-30	29.03	29.04	0.58	0.46	1.99	Failed	Failed
	28.46						
	29.63						
2B+G+15 C-30	31.27	29.50	1.62	1.29	5.49	Failed	Failed
	28.07						
	29.18						
B+G+6 C-25	41.06	42.48	1.57	1.25	3.69	Complied	Complied
	42.23						
	44.17						
TMA C-25	42.61	51.95	8.82	7.05	16.97	Complied	Complied
	53.10						
	60.14						
AIP C-25	24.25	24.08	4.08	3.26	16.94	Failed	Failed
	21.08						
	29.07						
MEP C-25	31.38	32.71	3.32	2.65	10.14	Complied	Complied
	36.49						
	30.26						
AIP2	27.26	26.6	3.03	2.42	11.39	Failed	Compl

C-25	24.18 28.37	0					ied
B+G+5 C-25	22.35 28.43 20.71	23.83	4.06	3.24	17.03	Failed	Failed
B+G+4 C-25	37.82 37.56 37.32	37.56	1.41	1.12	3.75	Complied	Complied
WMBP C-25	37.89 41.02 35.65	38.18	2.69	2.15	7.04	Complied	Complied
TMAP2 C-25	42.24 53.46 50.03	48.57	5.74	4.59	11.81	Complied	Complied
2B+G+7 K18 C-25	42.41 46.32 47.56	45.43	2.68	2.14	5.89	Complied	Complied
GHBP C-25	24.53 24.29 26.01	24.94	0.93	0.74	3.72	Failed	Failed
B+G+5 PBP C-25	34.12 37.28 31.03	34.14	3.12	2.49	9.13	Complied	Complied
MUBP10 C-30	23.93 23.12 29.13	25.39	3.26	2.60	12.83	Failed	Failed
MUBP09 C-30	30.49 30.07 27.58	29.38	1.57	1.25	5.34	Failed	Failed

MUBP15 C-30	33.24	32.37	1.65	1.32	5.09	Failed	Complied
	33.42						
	30.47						
MUBP OF K09 C-30	39.76	35.07	4.07	3.25	11.60	Complied	Complied
	33.03						
	32.42						

Table 4.22 Summary of compliance and conformity

Items	Compliance according to EBCS-2:1995		Compliance according to ACI 318	
	Number	Percentage	Number	Percentage
Defective lots	10	50%	7	35%
Non defective lots	10	50%	13	65%

As shown on the table 4.21 and 4.22 each lot is examined according to Ethiopian building code and standard (EBCS-2:1995), and American concrete institute (ACI 318). Based on EBCS-2:1995 half or 50% of the lots have been found defective and the rest half are non-defective. On the other hand, based on the criteria of ACI 318, 35% of the lots have been defective whereas the remaining 65% of the lots are non-defective and accepted. Here the researcher wants to notice that the same lots are used for both standards.

To sum up, all lots of concrete results are collected and assessed from ongoing concrete structures work of columns, beams, slabs and shear walls on the period of the researcher site observation while concrete casting, and as the consultants said all the lots are accepted. Though, the researcher recommended to take measures stated on section 9.4 of EBCS-2: 1995 in case of non-compliance.

Here in the below table 4.21 and 4.22 the researcher summarize the level of concrete quality control based on American concrete institute (ACI 214) of section 4.4 by using the values of standard deviation and coefficient of variation, and finally the result indicated the quality control within range of excellent to poor.

Table 4.23 Level of concrete quality control based on standard deviation of ACI 214 [23]

Level of control based on SD	Number of lot	Percentage (%)
Excellent (<2.8)	13	65%
Very good (2.8-3.4)	5	25%
Good (3.4-4)	0	0%
Fair (4.1-4.8)	1	5%
Poor (>4.8)	1	5%

Table 4.24 Level of concrete quality control based on coefficient of variations of ACI 214 [23]

Level of control based on CV	Number of lot	Percentage (%)
Excellent (<7)	8	40%
Very good (7-9)	1	5%
Good (9-11)	3	15%
Fair (11-14)	5	25%
Poor (>14)	3	15%

As it is shown on the tables 4.23 and 4.24 above, based on standard deviation 5% and based on coefficient of variation 15% of projects have poor concrete quality control. Though the research expelled that, variations and non-conformity to standards is available within the investigated project. Therefore, the level of supervision needs improvement for better concrete production on those projects. From observation the researcher bear to mind that, the capacity of consultant’s personnel assigned for each project is not enough to supervise and control the overall quality of the project. Therefore, concrete quality control level on investigated projects should be enhanced by taking different correction measures related to the concrete making materials, the production process and compliance control with reinforcement of personnel, equipment and workmanship.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Based on this study made on Adama building projects regarding to assessment on concrete production quality control, it has been seen that a number of problems related to concrete production have been found. Therefore, from the limited scope of this study the researcher reaches to the following conclusion and recommendations.

5.1 Conclusion

Concrete constitutes and concrete production quality practices are found unsatisfactorily in different projects. Workmanship becomes the first factors as major causes of poor quality of concrete production, whereas materials, personnel and equipment follow as second, third and fourth rank respectively.

Negligence of national building codes and standards is the major causes of concrete quality control problems, whereas design deficiency, unsatisfactory quality of concrete ingredients and inappropriate supervisions takes the second, third and fourth places respectively.

It is concluded that honey combing, cold joints, cracks, structural collapse, efflorescence, volume change, non-durability and deterioration as impacts of poor quality concrete production.

The remedial measures stated by the respondents to control concrete production quality control are by; controlling of workmanship, don't use of over aged cements, controlling of concrete mixing and placing of concrete in short time interval, checking the quality of mixing water, taking tests of ingredients regularly and make sure the woks are done according to specification and design, and checking the efficiency of machinery used

Based on EBCS-2:1995 half or 50% of the lots have been found defective and not attained the compliance standards, whereas the rest half are non-defective and attained the compliance standards. On the other hand, based on the criteria of ACI 318, 35% of the lots have been defective and not attained the compliance standards, whereas the remaining 65% of the lots are non-defective and attained the compliance standards.

Based on standard deviation 5% and based on coefficient of variation 15% of projects have poor concrete quality control. Though the research expelled that, variations and non-conformity to standards is available within the investigated project.

5.2 Recommendation

The design-bid-build method of building construction in Adama city needs to be properly monitored, and its effectiveness and relevance need to be evaluated.

Quality Control/Quality Assurance procedures are needed to be formulated and enforced in Adama city for good quality concrete production in building construction.

There is need for close collaboration between the professionals such as architects, engineers, surveyors, etc., involved in the building construction in Adama city in enlightening the clients on the dangers of not taking more risks of these factors during building construction.

The utilization of qualified and experienced personnel right at the top management level to the site manager, supervisors, machine operator, skilled and semi -skilled workers is necessary.

Construction companies should follow relevant standard rules and regulations for concrete works.

Government at all levels including private sector operators should urgently enforce the implementation of the provisions of the Ethiopian Building Code and Standards (EBCS).

Concrete Designers should specify the concrete materials i.e. water quality, aggregates (grading, shape, maximum size and absorption capacity). In addition important test of cement that is necessary for concrete works.

The researcher believed it is better to write the production date of cement on the cement bag to easily identified long aged cement bags.

Providing a continuous capacity building program for those stakeholders who participate in Adama building projects is advantageous to enhance the capacity of the consultants, contractors and their personnel.

The use of central automated batching plants for those projects greatly helps in the production of a quality concrete product that can be controlled at the central unit.

Precaution shall be taken to all concrete production process by implementing a well-organized quality control system that can be achieved with well-educated and experienced professionals who could understands the impact of each process towards to the desired concrete quality.

The researcher believed that it would be better if concrete work is awarded for well-trained subcontractor and produced.

Professional ethics shall be take part between stakeholders.

Training to the workers should be given in specific gap.

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APPENDICS

APPENDIX - A

Questionnaire Survey

For the title assessment of concrete production quality control in building construction sites: a case of Adama city

Questionnaire Survey

Dear respondents:

The purpose of this questionnaire and formats is to obtain information and data for the specified research conducted as partial fulfillment of the requirements for a master's degree in civil engineering (Construction Engineering and Management) at Jimma University.

Research Topic

Assessment of concrete production quality control in building construction sites: A case of Adama city

Objective

The purpose of this research is to **assess concrete production quality control in building construction sites: A case of Adama city**

Confidentiality

The data collected and the information to be answered in this questionnaire will be used for academic research purpose only. All specific companies and interviewee information will be kept confidential at all times. Only a generalized analysis of the information contained within this completed questionnaire will be utilized in the research process.

Instruction

Please answer, rate, and thick (✓) the questionnaire by choosing the appropriate choices. The questionnaire and data collection contain two parts. Part one contains the company and respondent's general information, part two deals with objective based questions. I realize that there are numerous demands on your time. However, your involvement is a vital requisite for this study. I appreciate your anticipated cooperation in answering this questionnaire, which may take less than 30 minutes of your valuable time.

Thank you for your earnest cooperation in advance.

Best Regards,

Sincerely yours

Henock Birhanu

Post graduate student in Construction Engineering & Management

Jimma University, JIT, Civil Engineering & Envi.. Department

Tel: 0910734555

E-mail: birhanuh567@gmail.com

Part 1: General Organization Information

Please add `✓` sign as appropriate:

1. Respondent Organization

☐ Contractor	☐ Consultant

2. Current position in your organization

☐ Project manager	☐ Construction Engineer
☐ Architect	☐ Office engineer
☐ Site Engineer	☐ Other (______________________)

3. Respondent working experience

☐ 0-5	☐ 6-10
☐ 11-15	☐ More than 15

4. Respondent highest educational qualification

☐ Certificate	☐ Diploma
☐ Degree	☐ MSc
☐ PhD	

Part 2: Objective Based Questions

Please answer the following question by putting an `✓` mark at your choice on the rectangles shown for the related questions having choices part or by writing your answers in the space provided.

1. Type of cement used on your sites
   - ☐ OPC
   - ☐ PPC
   - ☐ Either OPC or PPC
   - ☐ Others (____)
2. Source of cement collection
   - ☐ From factory
   - ☐ From agents
3. Test of cement
   - ☐ Yes
   - ☐ No
4. If your answer for question number 3 is yes, please specify the type of test you are using

   ____

   ____

   ____

5. Test of cement performed for each lot of cement
   - ☐ Yes
   - ☐ No
6. Test of cement performed for long time storing
   - ☐ Yes
   - ☐ No
7. How long is the cement stocked until casting date starting from its production?

   ____

   ____

8. Storing of cement at site
   - ☐ Properly stored
   - ☐ Not properly stored
9. Where is the source of your fine aggregate?

   ____

   ____

10. Type of fine aggregate you are using for concrete production
    - ☐ Natural sand
    - ☐ Crushed aggregate
11. Test of fine aggregate
    - ☐ Yes
    - ☐ No
12. If your answer for question number 11 is yes, please write down
    - Physical tests

      ____

      ____

      ____

      ____

      ____

    - Chemical tests

      ____

      ____

____

____

____

13. Tests performed for each lot of fine aggregate
    - ☐ Yes
    - ☐ No
14. When do you take test for fine aggregate?
    - ☐ Only once for one sources
    - ☐ Depending on the aggregate conditions
    - ☐ Other____

____

____

____

15. Where is the source of your coarse aggregate?

____

____

16. Test of coarse aggregate
    - ☐ Yes
    - ☐ No
17. If your answer for question number 16 is yes, please write down
    - Physical tests

____

____

____

____

____

    - Chemical tests

____

____

____

____

____

18. Storing of coarse aggregate
    - ☐ Properly stored
    - ☐ Not properly stored
19. When do you take test for coarse aggregate?
    - ☐ Only once for one sources
    - ☐ Depending on the aggregate conditions
    - ☐ Other____

      ____

      ____

      ____
20. What would you do if test result fails?

    ____

    ____

    ____

    ____
21. What do you do to maintain the quality of aggregate?

    ____

    ____

    ____

    ____
22. If the aggregate doesn't satisfy the requirement on the standard, what would you do in response?

    ____

    ____

    ____

    ____
23. Where is your source of water?

    ____
24. Is there any test conducted for water? If yes please mention it below

____

____

____

25. What is the structural grade of concrete (cubic strength in MPa) that is used for this project for different structure type (footing, column, beam, slab and etc…)? please mention the structure type and its grade of concrete used

____

____

____

____

26. Type of your concrete production
    - ☐ Ready mixed concrete
    - ☐ At site/ in situ
27. How do you mix your concrete if it is at site
    - ☐ Manually
    - ☐ By mixer
    - ☐ Both
28. For how long do you mix the ingredients?

____

29. If the concrete is mixed off the site, how long takes for the concrete to be placed on the forms? (The time between the start of mixing and placing)

____

____

30. If the required slump is not attained, what is the corrective measure you take?

____

____

____

31. If you are using a mixing plant, what is the capacity of your mixing plant?

____

32. If your answer for question number 26 is ready mixed concrete, would you do a test to check the performance of ready mixed concrete during site arrival? If yes mention it please

    ____

    ____

33. Do you use admixture in concrete production? If it is used, please specify the type and dosage of the admixture

    ____

    ____

34. Type of concrete specification and mixing procedure you follow
    - ☐ Prescribed mix
    - ☐ Designed mix
    - ☐ Nominal (standard) mix
35. Batching type
    - ☐ By weight
    - ☐ By volume
36. What are the adjustments that you made when you use weight batching?

    ____

    ____

    ____

    ____

37. What are the adjustments that you made when you use volume batching?

    ____

    ____

    ____

    ____

38. Water to cement ratio measure
    - ☐ By experience
    - ☐ By accurate measures

39. Type of compaction you are using
    - ☐ Hand compaction (Rodding)
    - ☐ Mechanical vibration
    - ☐ Others
40. If your answer is mechanical compaction (compaction by vibratory) :
    - For how long do you compact at an immersion place?

      ____

      ____
    - At what spacing do you use of vibrators tube on the fresh concrete surface being compacted?

      ____

      ____
    - In case of compacting thicker concrete sections, what is the maximum compaction depth that you use?

      ____

      ____
41. During concrete placing what are the measures that you take to prevent formation of cold joint?

    ____

    ____

    ____
42. After casting your concrete, how long is the curing period on your site if
    - OPC is used

      ____
    - PPC is used

      ____

43. What type of formwork is used in your construction?

    ____
44. Is there a proper erecting and removal of formwork?

____

45. From your experience, please express your opinion on the importance or give rank on the following determinant factors as major causes of poor quality of concrete production and cause of quality control problems in your construction site. Please indicate your response throughout the questionnaire by ticking the appropriate box where (5 = strongly agree, 4 = agree, 3 = fairly agree, 2 = never, 1 = Undecided)

Factors as major causes of poor quality of concrete production	**Please tick (√) on the box**				
	5	**4**	**3**	**2**	**1**
Personnel					
Equipment					
Workmanship					
Concrete materials					

Factor as cause of quality control problems	**Please tick (√) on the box**				
	5	**4**	**3**	**2**	**1**
Negligence of national building codes and standards					
Design deficiency					
Unsatisfactory quality of concrete ingredients					
Inappropriate supervision					

46. What are the factors affecting the quality of concrete production?

____

____

____

____

____

____

47. What are the impacts of poor quality of concrete production?

____
____
____
____
____
____
____

48. What are the remedial measures you take to control concrete production quality problems in your building construction site?

____
____
____
____
____
____
____

THANK YOU FOR YOUR COLLABORATION