EFFECT OF LOCAL SAND SOURCE AND COARSE AGGREGATE PRODUCTION ON CONCRETE PROPERTIES: A CASE OF HAWASSA CITY

MSc THESIS

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A THESIS SUBMITTED TO DEPARTMENT OF CONSTRUCTION TECHNOLOGY AND MANAGEMENT, HAWASSA INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES
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HAWASSA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADVISORS' APPROVAL

This is to certify that the thesis entitled "Effect of local sand source and coarse aggregate production on concrete properties: a case of Hawassa city" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Construction Technology and Management, the Graduate Program of the Department of Construction Technology and Management, and has been carried out by Mintesinot Kassahun Zafu Id.No PGCoTM/033/11, under my supervision. Therefore, I recommend that student has fulfilled the requirements and hence here by can submit the thesis to the department.

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EXAMINERS' APPROVAL

We, the undersigned, members of the Board of Examiners of the final open defense by Mintesinot Kassahun Zafu have read and evaluated his thesis entitled "Effect of local sand source and coarse aggregate production on concrete properties: a case of Hawassa city ", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the masters' degree.

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DECLARATION

I declare that this MSc thesis entitled ‘‘Effect of local sand source and coarse aggregate production on concrete properties: a case of Hawassa city’’ is original work of my own, has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name of candidate: Mintesinot Kassahun Zafu

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Date: February, 2021

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DEDICATION

I dedicate this work for my family.

ABBREVIATIONS

AAV	Aggregate Abrasion Values
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society of Testing Materials
BGS	British Geological Survey
BS	British Standards
Cc	Coefficient of curvature
Cu	Coefficient of uniformity
EI	Elongation Index
FI	Flakiness Index
FM	Fineness Modulus
HRWR	High Range Water Reducer
HSC	High Strength Concrete
ITZ	Interfacial Transition Zone
NSC	Normal Strength Concrete
OPC	Ordinary Portland Cement
POC	Palm Oil Clinker
USCS	Unified Soil Classification System
w/c	water to cement ratio
WRA	Water Reducing Agent

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ABSTRACT

Concrete structures are integral parts of modern civil infrastructures constituting a large portion of the national wealth of any country. Concrete consists of *60–75% volume* with aggregates. *Therefore be expected to have most suitable aggregate properties utilization in concrete are reducing volume change, improving the concrete properties against applied load and environment on concrete. Currently, it is normal practice to see the traditional method of fine aggregate production and both traditional and modern means of coarse aggregate production in Hawassa city to produce concrete. In this study, an investigation has been performed on properties of sand sources from Bilate, Dimtu, and Halaba while coarse aggregate production from Waye Bonge Quarry, Daete Quarry, and Derago Quarry and their effect on fresh and hardened concrete properties. This experimental investigation has been performed on nine concrete batches for each C-30 and C-50 concrete grades with different selected quarries that supply aggregate to Hawassa city. The fresh concrete property was done through concrete workability in terms of slump cone and compaction factor tests. Hardened concrete properties were done through concrete hardened density, compressive strength, splitting tensile strength, water absorption, sulfate attack resistance, and chloride attack resistance tests. For hardened density, compressive strength, and durability tests 150mm concrete cube specimens and for splitting tensile strength test cylinder specimens (150mm diameter and 300mm length) were used. Detailed experimental test results of different aggregates and concrete properties were presented, analyzed and discussion was done based on standards and previous related literature to investigate aggregates properties and their effect on concrete properties. The results show that all sand sources classified under poorly graded sand with high silt content; coarse aggregate production with poorly graded and high percentage of flaky and elongated aggregate in concrete negatively affects the workability, strength, and durability of concrete. It is recommended that aggregate producers should give proper attention to producing consistent and quality products in terms of relevant parameters, which are compatible with the standard requirements.*

Keywords: Aggregates, Compressive strength, Durability, Hardened density, Splitting tensile strength, and Workability

CHAPTER ONE
INTRODUCTION

1.1 Background

The construction industry is one of the largest industries in the world in terms of the base of the world economy. Nowadays, the pace of development of this industry is increasing enormously all over the world especially in developing countries due to the rapid economic and industrial development of infrastructures and standard of living (Gebru, 2017). With the rapid growth in infrastructure, the construction industry is booming and thus the demand for constructing materials has increased in many different forms. Concrete is the most widely used construction material due to its versatility, economy, strength, availability of raw materials, and durability (Kalra and Mehmood, 2018 and Ede *et al.*, 2017). Concrete has found major applications in the construction industry. They are essential for constructing and maintaining the physical framework of the buildings and infrastructure on which our societies depend. The high-quality of concrete produced in any process is typically reflected through fresh and hardened concrete properties (Eme and Nwaobakata, 2019).

Concrete has a multiphase material consisting of fine aggregate, coarse aggregate, cement paste, and interfacial transition zone (ITZ) between aggregates and cement paste. Thus, concrete properties are strongly linked to the properties of aggregate, cement paste, and the interfacial region as well. Since approximately aggregates occupy 60–75% volume of concrete, it is assumed that the aggregate properties greatly have an effect on the workability, strength, and durability performance of concrete. Therefore be expected to have the most high-quality aggregate properties utilization in concrete are reducing volume change in the concrete, improving concrete properties against applied load and environment on concrete. Aggregates play an essential role in the mechanical and durability properties of concrete against aggressive environmental media during service life (Jayswal and Mungule, 2019 and Okonkwo and Emmanuel, 2018). Thus, aggregate selection in concrete production can significantly have an effect on concrete performance.

The most widely used coarse aggregate in Ethiopia is generally crushed rock which typically sourced from parent rocks. On the other hand, fine aggregates are typically sourced from riverbed for concrete production (Addissie, 2005). Currently, it is normal practice to see the traditional method of fine aggregate production and both traditional and modern means of coarse aggregate production in Hawassa city to produce concrete. Concrete properties are considerably guided by taking into account various factors consisting of the source from where aggregates are collected, estimation of aggregate properties, and material source description. Knowing these factors will prevent making the wrong choice of selecting unsuitable aggregate materials that may lead to concrete failure as well as a collapse in buildings (Olanitori, 2011; Olagunju *et al.*, 2013; Bamigboye *et al.*, 2019 and Qureshi *et al*., 2015). Therefore, this study evaluates aggregate properties against the applicable standards used for concrete production. Furthermore, the investigation into effect of aggregates on concrete workability, strength, and durability that is used in concrete production in Hawassa city is undertaken.

1.2 Problem statement

Aggregates normally constitute 60-75% by volume of the concrete. Therefore be expected to have most high-quality properties of aggregate utilization in concrete are reducing volume change, improving the concrete properties against applied load and environment on concrete (Jayswal and Mungule, 2019 and Okonkwo and Emmanuel, 2018). When fine aggregate from different sources show variety in their properties used in concrete production, it leads to different effects on concrete properties (Hasdemir *et al*., 2016). However, without further attempt to wash, dry, and classify based on properties fine aggregates with high silt content are used for concrete production in Hawassa city (Yusuf, 2014 and Tadele, 2019). Poorly graded related to gradation with high silt content fine aggregate sources have an effect on both fresh and hardened concrete properties.

Coarse aggregate is generally produced in Ethiopia by crushing parent rocks using both mechanical crushers and traditional methods. The majority more than 60% quality problems both for fine and coarse aggregates attribute to the production process of aggregates in general

(Addissie, 2005 and Hailu, 2019). Nevertheless, such coarse aggregates are used for concrete production in Hawassa city where aggregates produced without considering their properties.

Hence, using poor-quality construction materials especially aggregates in concrete production have been identified as one of the construction project failure causes. Construction project failures result in life loss and property damages (Olanitori, 2011; Olagunju *et al.*, 2013; Bamigboye *et al.*, 2019 and Qureshi *et al*., 2016). This implies that the inappropriate aggregates selection for concrete production causes premature concrete failure. Selecting the right aggregate is essential to overcome the frequent concrete failure. Its properties should therefore be tested in the view of the concrete design before used in concrete production. However, this study evaluates properties of different local sand sources and coarse aggregate from different production centers against the applicable standards, and their effect on concrete properties are investigated.

1.3 Research questions

- Do the properties of different local sand sources and coarse aggregate production used in Hawassa city satisfy the requirement of the applicable standards?
- What is the effect of different local sand source and coarse aggregate production on fresh concrete property?
- What is the effect of different local sand source and coarse aggregate production on hardened concrete properties?

1.4 Objectives of the study

1.4.1 General objective

The general objective of this study is to investigate effect of local sand source and coarse aggregate production on concrete properties in Hawassa city.

1.4.2 Specific objective

- To evaluate properties of different local sand source and coarse aggregate from different production centres against the applicable standards
- To investigate the effect of local sand sources and coarse aggregate production on fresh concrete property
- To investigate the effect of local sand sources and coarse aggregate production on hardened concrete properties

1.5 Significance of the study

This study can be used as a prospecting tool for selecting suitable aggregates to produce required quality concrete. It provides important information on aggregate properties against the applicable standards in Hawassa city. This will help to a concerted effort for improving the performance of the relevant aggregate producers aggregate production in terms of relevant parameters with the view of producing a satisfactory product. The study outcome will provide necessary information for clients, contractors, and consultants to produce a required quality concrete regarding the application of aggregates in Hawassa city. This will prevent them from making the wrong choice of selecting unsuitable aggregate that may lead to concrete failure as well as a collapse in buildings. Furthermore, the results and findings of this study can be used as a benchmark for further research and inquiry for those who wish to widen the scope.

1.6 Scope and limitations of the study

1.6.1 Scope of the study

The scope of this study focuses on effects of local sand sources from Bilate, Dimtu, and Halaba; and coarse aggregate production from Waye Bonge Quarry, Daete Quarry, and Derago Quarry based on concrete properties like concrete workability, hardened density, compressive strength, splitting tensile strength, and durability. In addition, evaluate aggregate properties against the applicable standards. The concrete mix design is performed based on the DOE mix design method and nine concrete batches were prepared for each concrete grade was performed by mass. The concrete specimens were prepared by hand mixing of cement, fine aggregate, coarse aggregate, and water for C-30 concrete grade and in addition to chemical admixture for C-50 concrete grade. To study the workability of fresh concrete slump cone and compaction factor tests were done. In the study of hardened concrete properties hardened density, compressive strength, water absorption, sulfate attack resistance, chloride attack resistance tests were performed on 150mm cubes concrete specimens. In the study of the hardened concrete property of splitting tensile strength test were performed on diameter 150mm and height 300mm cylinder concrete specimens. The experimental investigation was conducted at Hawassa University, Civil Engineering Department, and Construction materials laboratory.

1.6.2 Limitations of the study

During the investigation, the study is limited to fresh concrete properties like slump cone and compaction factor tests and hardened concrete properties like hardened density, compressive strength, splitting tensile strength, water absorption, sulfate attack resistance, and chloride attack resistance tests. Other concrete properties like flexural strength, air content, and other tests were not conducted due to time, budget, and laboratory constraints.

1.7 Organization of the study

This study is divided into five chapters. Chapter one is an introductory containing background, objectives, and scope, and limitation of the study. Chapter two provides a review of various literatures on properties of aggregates and their effect on fresh and hardened concrete properties investigations done by different researchers. Chapter three details the materials used in the current study, aggregate properties, and the methods adopted to prepare and test specimens. Chapter four focuses on results, analysis, and discussion on experimental investigation including the laboratory tests. Chapter five gives summery, conclusion and recommendation that are forwarded in accordance with study objectives.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of past studies that is relevant to the current study, with the aim of providing sufficient background information to facilitate understanding and evaluation of this investigation. This chapter also deals with previous studies regarding effect of aggregates on fresh and hardened concrete properties.

2.2 Aggregates

Aggregate is a granular material, such as sand, gravel, crushed stone, or iron blast furnace slag, used with a cementing medium to form hydraulic cement concrete or mortar (ASTM C 125:2004). Aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence fresh and hardened concrete properties. Aggregates used in concrete must conform to certain standards to produce the required quality concrete. Aggregates must be clean, hard, strong, and durable particles that are largely free of absorbed chemicals, coatings of clay, and other fine materials in amounts that could affect hydration and bond of the cement paste (Kosmatka and Wilson, 2011). Based on particle size aggregates are classified as fine aggregate and coarse aggregate. Fine aggregate that portion of an aggregate passing the 4.75mm (No. 4) sieve and retained on the 75µm (No. 200) sieve. Coarse aggregate that portion of an aggregate retained on the 4.75mm (No. 4) sieve (ASTM C 125:2004). Aggregates play an essential role in reducing the volume change in concrete; cheaper filler for cementing material and improving concrete properties that resist the actions of applied loads and environment (Jayswal and Mungule, 2019 and Okonkwo and Emmanuel, 2018).

Aggregate production involves various stages which include the development of the quarry by taken the coordinate of the site, stripping, drilling, stemming, blasting, mucking and loading, haulage, and crushing (Thomas *et al*., 2018). The production of fine aggregate in Ethiopia is mainly by the process of extracting from river beds the use of the traditional method. The method of quarrying sand is generally very old, and the producers do not attempt to clean and grade the sand right from the source. Coarse aggregates for the Ethiopian construction sector are produced both, traditional and modern means. Coarse aggregates produced using such a method are usually flaky and do not satisfy the grading requirements set by standards (Dinku, 2005 and Addissie, 2005).

Aggregates have physical, mechanical, thermal, and chemical properties. These properties are attributed to the parent rock and to the mode of production. It is very important to give consideration to the source and production of aggregates (Addissie, 2005). Therefore, the properties of aggregates have an important influence on fresh and hardened concrete properties (Eme and Nwaobakata, 2019).

2.2.1 Classification of aggregates

Aggregates are classified into several categories based on criteria such as particle size, mode of formation, weight, particle size, and source mentioned in Table 2.1.

Table 2.1 General classification of aggregates (Neville and Brook, 2010)

Based on mode of formation	Based on particle shapes and texture	Based on weight	Based on particle size	Based on sources
Igneous	Round	Light weight	Fine aggregates	Natural aggregate
Sedimentary	Irregular			
	Flaky	Normal weight	Coarse aggregates	Manufactured aggregate
Metamorphic	Elongation	Heavy weight		Recycled aggregate

2.2.1.1 Based on sources

Aggregates may also be classified in terms of natural aggregate from mineral sources with only physical processing, often referred to as primary aggregate. Manufactured aggregate derived from industrial processes as a by-product, often referred to as secondary aggregate. Recycled aggregate recovered from material previously used in construction (BGS, 2013).

2.2.1.2 Based on bulk density

Lightweight aggregate such as pumice and scoria which are used to make lightweight concrete with their bulk density is range from 560 $\mathrm{Kg/m^3}$-1120$\mathrm{Kg/m^3}$. Normal weight aggregate with their bulk density is between 1200 $\mathrm{Kg/m^3}$ –1750$\mathrm{Kg/m^3}$. Heavyweight aggregate with their bulk density is over 2100$\mathrm{Kg/m^3}$ (BS 882: 2003).

2.2.1.3 Based on mode of formation

The physical and mechanical properties of aggregates are inherited from parent materials, while the properties of the parent material depend on its geological formation. Geologically rocks are classified into three major divisions based on their origin, namely igneous rocks, sedimentary rocks, and metamorphic rocks (Dinku, 2005).

Igneous rocks are primarily crystalline and are formed by the cooling of molten rock material beneath the earth's crust magma. The most widespread of all igneous rocks are basalts. Basalts are dark-colored, fine-grained extrusive rocks (Adeyi *et al*., 2019). Sedimentary rocks are formed from the physical, mechanical, and chemical breakdown of other pre-existing rocks; and depend their properties largely on the nature of binding or cementing phases. Their layered structure sometimes can result in poorly shaped and flaky particles in the case of aggregates crushed from such rocks (Alexander and Mindess, 2010).

Metamorphic rocks are comprised of pre-existing igneous or sedimentary rocks, altered under conditions of high temperature and pressure usually at great depth. Consequently, they are even more variable in composition and structure than the other rock types (Alexander and Mindess, 2010).

2.2.1.4 Based on particle size

Aggregates classified into fine aggregates and coarse aggregates depending on particle size. Fine aggregate that portion of an aggregate passing the 4.75-mm (No. 4) sieve and retained on the 75µm (No. 200) sieve. Coarse aggregate that portion of an aggregate retained on the 4.75mm (No. 4) sieve (ASTM C 125:2004).

2.2.1.5 Based on particle shape and texture

Aggregates are classified as rounded, irregular, flaky, angular and elongated based on particle shape illustrated in Table 2.2.

Table 2.2 Shape classification of particles (BS 812 Part 1)

Classification	Description	Examples
Rounded	Fully water-worn or completed shaped by attrition	River or seashore gravel; desert, seashore and wind-blown sand
Irregular	Naturally irregular, or partly shaped by attrition and heaving rounded edges	Other gravel; land or dug flint
Flaky	Material of which the thickness is small relative to the other two dimensions	Laminated rocks
Angular	Possessing well defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types
Elongated	Material, usually angular in which the length is considerably larger than the other two dimensions	
Flaky and elongated	Material having the length considerably larger than the width and the width considerably larger than the thickness	

The classification of the surface texture is based on the degree to which the particle surfaces are polished or dull, smooth or rough. Surface texture depends on the hardness, grain size, and pore characteristics of the parent material illustrated in Table 2.3.

Table 2.3 Surface texture of aggregates (BS 812 Part 1)

Surface	Texture characteristics	Examples
Glassy	Irregular break with curved face	Black flint (chalk), vitreous slag
Smooth	Water-worn, or smooth due to fracture of laminated or fine-grained rock	Gravels, marble, slate
Granular	Fracture showing more or less uniform rounded grains	Sandstone
Rough	Rough fracture of fine or medium grained rock containing no easily visible crystalline constituents	Limestone
Crystalline	Crystalline constituents. Containing easily visible crystalline	Granite
Honeycombed	Constituents with visible pores and cavities	Brick, slag

2.2.2 Function of aggregates

The role of aggregates is crucial to ensure the satisfactory performance of concrete since they govern the volumetric stability of concrete. Aggregates have three principal functions cheaper filler for cementing material; a mass of particles that resist the actions of applied loads and environment and reduce volume changes resulting from the setting and hardening process and from moisture changes in cement paste. The coarse aggregate gives strength to the concrete while fine aggregate fills the space between particles (Okonkwo and Emmanuel, 2018; Jayswal and Mungule, 2019 and Ghasemi, 2017).

2.3 Aggregates production

Aggregate production involves various stages which include the development of the quarry by taken the coordinate of the site, stripping, drilling, stemming, blasting, mucking and loading, haulage, and crushing (Thomas *et al.*, 2018). Different geological locations result in diverse types of aggregates. All rocks do not necessarily provide aggregates with similar qualities. Good quality aggregates are hard, tough, and do not easily break down into pieces. Selection of a quarry should be based on the suitability of the parent material, proximity to settlement areas, transport costs, the existing and planned land use of the quarry location, and its impact on the environment. The selection of quarry sites for aggregates production should be decided after core samples are taken and tested for the suitability of aggregates (Addissie, 2005).

2.3.1 Fine aggregate production

2.3.1.1 Practice Globally

Sand is the second most widely used commodity on earth after water. Almost 80% of the construction industry is made up of sand. The booming construction industry, real estate, buildings all are constructed with the help of sand (Aksarabhyudaya, 2013). The largest producer of sand and gravel in the world is the United States, which produced 26.5 million metric tonnes of the materials. Italy ranks second with an annual production of over 14 million metric tonnes. The third place is occupied by Germany, producing 6.5 million metric tonnes (Sverdrup *et al*., 2017).

A mining project begins once know how on the extent and value of the mineral ore deposit has been accomplished. Information on the location and value of the mineral ore deposit is obtained during the exploration phase. This phase includes surveys, field studies, drilling test boreholes, and other exploratory excavations (EIAs, 2016). Mining is the actual removal of the material from the source. Before any actual mining is done at a site, overburden which is mainly composed of silt, loam, clay, or combinations of the three is removed from the top of the sand formation with the help of scrapers or tracked excavators and off-road haul trucks (Schaff, 2012).

Sand must be of consistent size and shape. To achieve this consistency, the sand is run through a processing plant. The processing of sand and gravel involves the use of different combinations of washers, driers, screens, and classifiers to segregate particle sizes; crushers to reduce oversized material; storage and loading facilities (EPA, 2005). The purpose of washing sand is to free it from fine particles, clay, and organic impurities. Washing is done by spraying the sand with water as it is carried over a vibrating screen. Prior to sand being sized and stored as a final product, it typically goes through a drying process to reduce the moisture content. Once the sand is dried, it is cooled and may be further sorted by screening. The dried sand is then fed by conveyors to storage bins or directly to a screen house via conveyors (Schaff, 2012).

In modern processing plants, different grain sizes can be selected. The graded sand is then conveyed to storage silos or on to a bagging shed. The whole operation is controlled from a central diagnostic desk, controlling flow and storage. The sand is tested several times at various stages of the process to ensure that it conforms to the specifications of that particular grade of sand. Once washed, dried, graded, and tested; the sand is stored in piles or bagged ready for transportation. In the case of the bagged sands, the correct weight of sand is deposited into each polythene sack, which is sealed and sprayed with a batch number, date, and grade and moved to the waiting trucks (Museum, 2010). Transportation is a key element of the supply process and a large part of the delivered price. Within the mine, the sand may be transported by front-end loaders, large open-topped off-road trucks, or dump trucks (Schaff, 2012).

2.3.1.2 Practice in Ethiopia

The production of fine aggregate in Ethiopia is mainly by the process of extracting from river beds. Crushed aggregates are also being used in some parts of the country to serve as sand when there is a scarcity or unavailability of natural sand. Due to the overflow of rivers and inaccessibility to the site, natural sand obtained from river sands are difficult to produce during the wet (Addissie, 2005).

The sand production sites found in Ethiopia are not mechanized but rather make use of the traditional method where the local people of the area are the producers and transportation is done by donkeys that have a maximum carrying capacity of 70kg or 0.05 m^3 per trip. The donkeys transport it to a place where vehicles have access. Sand is then loaded to vehicles manually and transported to the actual site or to construction material suppliers which are then directly used for the intended purpose (Addissie, 2005).

The construction industry utilizes sand mainly from stream beds, sandy marine sediments, and alluvial deposits. Currently, the major sand supply for the construction works in Hawassa city is Bilate, Dimtu, and Halaba; rarely used other types sourced from in and around Hawassa city. The method of quarrying sand is generally very old and the producers do not attempt to clean and grade the sand right from the source. Sand with high silt content is usually purchased from those quarry sites. The typical method of sand quarrying operations and transporting to the nearby loading station using animal transport (Yusuf, 2014 and Tadele, 2019).

It has been learned that the fine aggregate production process in Ethiopia is so old fashioned that it is prone to non-uniformity in gradation, susceptible to contamination by deleterious substances; there is no room for quality check, there is no standardization, there is no consistent sand (Addissie, 2005).

2.3.2 Coarse aggregate production

2.3.2.1 Practice Globally

Crushed rock aggregate is produced from hard and strong rock formations including igneous rocks, sedimentary rocks, and metamorphic rocks (BGS, 2013). The properties of aggregates depend on exploitation location and production method. Desired particle size, shape, and surface texture are possible to achieve dependably on applied processing methods during their production and can directly influence other features (Adeyi *et al*., 2019).

Aggregate production basically turns big rocks into little rocks and carefully sorts them by size. Excavating crushed stone is dependent on the geologic characteristics and the extent and thickness of the deposit. Open-pit mining and quarrying methods are commonly used, although some stone is mined underground. Quarrying and mining stone generally require drilling and controlled blasting before the rock is extracted with power shovels, bulldozers, and draglines (William *et. al*, 2005).

Once the aggregates are extracted from the quarry site, the next step that takes place is processing. Processing includes crushing, sorting, washing, sizing, and transporting. Crushing reduces the size of the aggregate depending on the requirements for the final product (William *et. al*, 2005). Crushing can be done in three or four stages primary secondary, tertiary, and in some quarries, a quaternary. Crushed rock, or product, is transported along the process line on conveyor belts or down chutes (Adeyi *et al*., 2019 and XSM, 2017).

The primary crusher is fed via a chute and vibrating feeder. The base of the feeder is made of steel grizzly bars and it is here that the first screening operation is actually done. Fine material and dust produced by the blast, along with any remaining subsoil or weathered rock from the top of the quarry face, drops through the bars onto a separate conveyor belt and onto a stockpile. This screened material is called scalping and is used as rock fill. The scalped product is crushed once to transform the block into a broken stone. The process is repeated as many times as necessary to obtain the desired fragment size (Adeyi *et al*., 2019 and Northstone, 2018).

The output from the primary crusher is conveyed onto the primary stockpile from which the secondary crusher is fed. The resulting material is then screened by a screen house just after the secondary crusher to obtain aggregates of the desired grade. The larger pieces that are rejected are returned to the crusher and subsequently re-screened, with the process continued until the desired size is obtained. Historically, cone and roll crushers were the most common choice crushers, but in recent years impact crushers that tend to produce a more particle shape, are more widely used (Adeyi *et al*., 2019 and Northstone, 2018).

Secondary, tertiary, and quaternary crushers are generally gyratory or cone crushers. These operate on the principle of steel mounted on an eccentric bearing and vertical shaft assembly. Rotation of the eccentric assembly makes the mantle gyrate within a static outer concave. There is a gap between the mantle and the concave. The shape of the gap is tapered towards the base. As the mantle gyrates inside the concave, the gap between it and the concave at any one point opens and closes on each gyration, this produces the required crushing action. Stone is fed in at the top and crushed product falls out from the bottom of the cone. The mantle can be raised or lowered within the concave, allowing the gap, and therefore the size of the crushed product, to be varied to a limited degree. If the crusher is jammed by a stray bit of steel e.g., a digger bucket tooth, the mantle automatically moves down to clear the obstruction (Adeyi *et al*., 2019; Northstone, 2018 and Gunlake, 2020).

Each stage of crushing produces progressively smaller sized stones. In order to produce a usable end-product, the crushed rock has to be screened into various size categories. Screening is carried out at various stages in the crushing process. Screens that are made to vibrate by a rotating transverse shaft are usually multi-deck i.e. two or more screen meshes are stacked vertically within the screen frame. The whole screen is coupled to its support frame by springs or resilient rubber mountings. Screen decks are mounted at an angle so that the aggregate moves them down. Aggregate is fed onto the high end of the top deck and the vibration causes the aggregate to jiggle down the screen until it either drops through a mesh aperture or falls off the end of a deck. The aggregate is then sorted or screened according to the mesh sizes fitted, from large aperture mesh at the top to small aperture mesh at the bottom. Screen mesh sizes are chosen with regard to the nature of aggregate being crushed (e.g. shape – cubical, flaky, elongate, or any combination), and the characteristics of the screen (e.g. screen efficiency, throughput, and whether the screen is over, under, or correctly loaded) (Adeyi *et al*., 2019; Northstone, 2018 and Gunlake, 2020).

Final screens are typically mounted in a screen house over large bins or hoppers into which the different sizes or grades of aggregate are fed. The hoppers are roused on legs so that trucks can drive under them to be loaded. Material is continually drawn from the storage bins for immediate use or for transfer, either by dump truck or conveyor, to storage stockpiles in the quarry to different grading categories (Adeyi *et al*., 2019 and Northstone, 2018).

2.3.2.2 Practice in Ethiopia

Coarse aggregate is produced in Ethiopia using aggregate crushers and by crushing manually using human labor and small hand tools. Especially, in rural areas and in construction sites where the coarse aggregate demand is low manual crushing is normally experienced. In addition, the crusher plants vary in size and production quality (Addissie, 2005).

Coarse aggregates for the Ethiopian construction sector are produced by both, traditional and modern means. Traditionally coarse aggregate is produced by heating a boulder at a higher temperature and crushing it with a hammer using manual labor to the required approximate sizes. Aggregates produced using such a method are usually flaky and do not satisfy grading requirements set by standards. Nevertheless, such aggregates are used for construction in areas where aggregates crushing plant is not available and quality control is not a criterion in the execution of the work (Dinku, 2005). Coarse aggregate for concrete production in Hawassa city majorly from Waye Bonge Quarry, Daete Quarry, and Derago Quarry with large scale crushing plants and some other small scale quarries at Monopol which is located in Hawassa city near the parent rock material.

2.4 Properties of aggregates

Aggregates have physical, mechanical, thermal, and chemical properties. These properties are attributed to the parent rock and to the mode of production. Therefore, very important to give due consideration to the source and production of aggregates (Addissie, 2005). Since up to 80% of the total concrete volume comprises aggregates, therefore, aggregates properties have an important influence on fresh and hardened concrete properties (Eme and Nwaobakata, 2019). Therefore aggregate properties should be well tested and conform to certain standards to produce required quality concrete.

2.4.1 Physical properties

The physical properties of aggregates refer to the physical structure of particles that make up the aggregate (Afeni, 2016). Since at least three-quarters volume of concrete is occupied by aggregate, the physical properties of the aggregate greatly affect the workability, strength, and durability of concrete (Anonymous, 2012).

2.4.1.1 Gradation

Grading refers to the particle size distribution of the aggregates. Well shaped and well-graded aggregates produce more workable concrete. Grading, particularly fine aggregate, is an essential factor in concrete production as it influences concrete properties in a fresh state. Grading also affects void content, water demand, and the available specific surface area of particles (Neville, 2011).

Gradation plays an important role in the workability, segregation, and pump ability of the concrete. Grading changes are more prevalent than particle shape and surface texture in the case of coarse aggregates. For example, well graded aggregates require less paste which will also decrease bleeding, creep, and shrinkage while producing better workability, more durable concrete, and higher packing (Group, 2009).

The process of dividing a sample of aggregate into fractions of the same particle size is known as sieve analysis, and its purpose is to determine the grading or particle size distribution of the aggregate. Particle size distribution is determined in accordance with BS 812-103.1: 2004. A sample of air-dried aggregate is graded by shaking or vibrating a nest of stacked sieves with the largest sieve at the top, for a specified time so that the material retained on each sieve represents the fraction coarser than the sieve under but finer than the sieve above.

There are several reasons for specifying grading limits and nominal maximum aggregate size, they affect relative aggregate proportions as well as cement and water requirements, workability, pump ability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from batch to batch. Very fine sands are often uneconomical and very coarse sands can produce harsh, unworkable mixtures. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results (Kosmatka and Wilson, 2011). Fine and coarse aggregate grading limits according to BS 882: 2003 are described in Table 2.4 and Table 2.5 respectively.

Table 2.4 Grading requirement for fine aggregate (BS 882: 2003)

Sieve size	Percentage by weight passing sieves			
	BS 882: 2003			
BS	Grading Zone 1	Grading Zone 2	Grading Zone 3	Grading Zone 4
10.00 mm	100	100	100	100
5.00 mm	90 – 100	90 – 100	90 – 100	95– 100
2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100
600 µm	15 – 34	35 – 59	60 – 79	80 – 100
300 µm	5 – 20	8 – 30	12 – 40	15 – 50
150 µm	0 – 10	0 – 10	0 – 10	0 – 15

Table 2.5 Grading requirement for coarse aggregate (BS 882: 2003)

Sieve Size (mm)	Percentage by mass passing BS sieves for nominal sizes							
	Graded aggregates			Single sized aggregate				
	40mm to 5mm	20mm to 5mm	14mm to 5mm	40mm	20mm	14mm	10mm	5mm
50	100	-	-	100	-	-	-	-
37.5	90-100	100	-	85-100	100	-	-	-
20	35-70	90-100	100	0-25	85-100	100	-	-
14	25-55	40-80	90-100	-	0-70	85-100	100	-
10	10-40	30-60	50-85	0-5	0-25	0-50	85-100	100
5	0-5	0-10	0-10	-	0-5	0-10	0-25	45-100
2.36	-	-	-	-	-	-	0-5	0-30

The weight retained on each sieve is recorded and the percentage computed. The summation of the cumulative percentage of the material retained on sieves divided by 100 is called the fineness modulus (FM) as shown in the following Equation (1):

$$\text{Fineness modulus (FM)} = \frac{\sum(\text{Cumulative percentage retained})}{100} \quad (1)$$

The specified sieves are 50.0mm, 37.5mm, 20.0mm, and 14.0 mm, 10mm and 5.0 mm, 2.36 mm, 1.18 mm, 600µm, 300 µm, and 150 µm. Note that the lower limit of the specified series of sieves is the 150 µm sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The fineness modulus is used as an index to the fineness or coarseness of aggregate supply, but it is not an indication of grading since there could be an infinite number of grading that will produce a given fineness modulus (Kosmatka and Wilson, 2011). The following limits presented in Table 2.6 taken as a guide for the determination of fineness of fine aggregates.

Table 2.6 Categorization of fine aggregates based on fineness modulus (BS 12620: 2002)

FM	Fineness
<1	Very fine
1.0-2.0	Fine
2.0-2.9	Medium
2.9-3.5	Coarse
>3.5	Very coarse

Fineness modulus outside the specified range of 2.3 - 3.1 will pose workability problems and supplementing them with mineral admixture in areas of their deficiency to make them workable may therefore be necessary (Neville, 2011).

The grading of fine aggregates has a much greater effect on the workability of concrete than does the grading of coarse aggregate. Experience has shown that usually very coarse sand or very fine sand is unsatisfactory for concrete making. The coarse sand results in harshness, bleeding, and segregation and the fine sand requires a comparatively greater amount of water to produce the necessary fluidity (Ajagbe *et al.*, 2018).

Maximum size of aggregate is defined as the smallest sieve opening through which the entire amount of aggregate is required to pass. Nominal maximum size of aggregate is defined as the smallest sieve opening through which the entire amount of aggregate is permitted to pass (ASTM C 125:2004). The maximum size of coarse aggregate influences the paste requirements of concrete, and the optimum grading of the coarse aggregate depends on the maximum aggregate size. In practice, it is considered that if only a small amount of aggregate is retained on a sieve, it will not significantly affect concrete properties. Thus, it is usual to use a nominal maximum size, which is the smallest sieve opening through which the entire sample is permitted to pass. A percentage usually 5 - 10% of the sample weight may be retained on this sieve.

BS 882: 2003 grading requirements are based on nominal maximum size. In general, it is an advantage to have as large a maximum aggregate size in a concrete mix as possible, since this reduces the total surface area per unit volume of aggregate which the paste has to cover. Using the largest possible maximum aggregate size will result in a reduction of the cement content and reduction in water requirement (Li, 2011 and Alexander and Mindess, 2010).

The grading of aggregates is represented in the form of a curve or an S curve. The curve showing the cumulative percentages of material passing the sieves represented on the ordinate with the sieve openings to the logarithmic scale represented on the abscissa is termed as grading curve. The grading curve for a particular sample indicates whether the grading of a given sample conforms to that specified, or it is too coarse or too fine, or deficient in a particular size (Pawar *et al.*, 2016).

Uniform graded aggregate: a gradation that contains most of the particles in a very narrow size range. In essence, all the particles are the same size. The curve is steep and only occupies the narrow size range specified. It is noted in a narrow range of sizes, grain-to-grain contact, high void content, high permeability, and low stability, and difficult to compact.

Well graded: means the size within the entire range is in approximately equal amount. It is characterized by friction at many points, excellent interlocking, and very few voids.

Open-graded aggregate: a gradation that contains only a small percentage of aggregate particles in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. The curve is near vertical in the mid-size range and flat and near-zero in the small-size range.

Gap graded aggregate: It refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. Gap graded are missing middle sizes, no grain-to-grain contact, moderate void content, moderate permeability, low stability, and easy to compact.

Dense graded aggregate: a gradation that is approximately equal amounts of various sizes of aggregate. By having a dense gradation, most of the air voids between the materials are filled with particles. A dense gradation will result in an even curve on the gradation graph. It is a wide range of sizes, grain-to-grain contact, low void content, low permeability, high stability, and difficult to compact. Types of gradation are shown in Figure 2.1 (Pawar *et al*., 2016; Pavement, 2019 and Engineering, 2019).

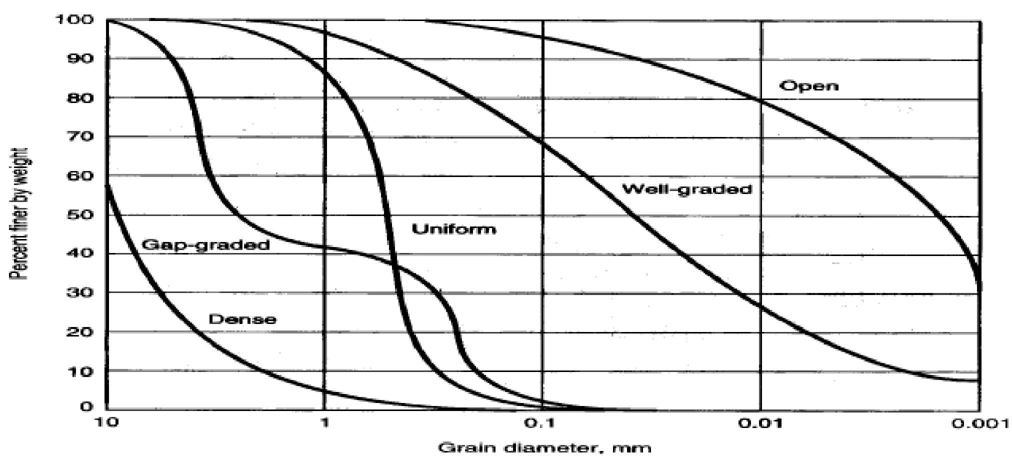


Figure 2.1 Types of gradation (Pawar *et al*., 2016)

The unified soil classification system (USCS) that has been adopted by American Society of Testing Materials (ASTM) based on particle size distribution divide aggregates into groups. The system is the most popular for use in all types of engineering problems involving soils.

Table 2.7 Unified Soil Classification chart (ASTM D 2487: 2000)

Material	Criteria using laboratory tests		Group symbol	Group name
Fine aggregates	5% -12% fines	Cu ≥ 6 and 1 ≤ Cc ≤ 3	SW-SM	Well-graded sand with silt
			SW-SC	Well-graded sand with silty clay
		Cu < 6 and 1 > Cc >3	SP-SM	Poorly graded sand with silt
			SP-SC	Poorly graded sand with silty clay

2.4.1.2 Particle size, shape and surface texture

The study of Aginam *et al.* (2013) shows that workability, strength, and durability of concrete are grossly affected by particle size, shape, and surface texture of aggregates.

2.4.1.2.1 Particle size

There is a growing research interest to understand the effect of maximum aggregate size on the characteristics of normal strength concrete (NSC) and high strength concrete (HSC) due to the uncertainty of interfacial bond stress transition between the aggregates and matrix which are regarded as the weakest link in concrete (Nagaraj and Jeyakumar, 2018). The findings from previous studies regarding the effect of coarse aggregate sizes on concrete properties had a large difference. Some researchers concluded that the compressive strength of concrete increased with reducing the coarse aggregate sizes (Grabiec et al., 2015). While the others reported that the compressive strength of concrete increased with increasing the coarse aggregate sizes in NSC (Meddah *et al*., 2010).

Furthermore, Kumar and Krishna (2012) indicated that concrete reached the highest compressive strength with the use of optimal coarse aggregate sizes. This finding was found based on the investigation of HSC concrete made with coarse aggregate sizes of 8mm, 12.5mm, 16mm, and 20mm. The optimal coarse aggregate size found in the study was 12.5mm. Salau and Busari (2015) investigated the effect of coarse aggregate sizes on NSC. They studied 19.5mm, 12.5mm, 9.5mm, 5.0mm, and 2.36mm coarse aggregates obtained from Ojodu-Berger in Lagos State while the sharp river sand was used as a fine aggregate. Their results showed that workability, density, and compressive strength at constant water-cement ratio increase with the increase in the coarse aggregate particle size and also with curing age.

The study by Woode and Ballow (2015) stated that among the various factors that influence the specified characteristic strength of concrete is the size of coarse aggregates. The function of coarse aggregate in concrete is vital to the overall strength of the concrete. Aggregate sizes have been reported to have significant effects on both the fresh and hardened concrete properties. Thus implying that poor judgment in maximum coarse aggregate sizes selection could have an adverse effect on the quality of concrete, hence the construction of poor quality structures. That is the concrete may not be able to achieve the desire specified characteristic strength. Studies by Olanitori (2011) and Olagunju *et al.*, (2013) asserted that the root causes of building failures and collapsed in most parts of Nigeria can be attributed to low-quality building materials and construction in terms of concrete production and placement. This established the importance of ensuring that the right aggregate size is used in concrete production. Therefore, it is recommended that careful attention must be paid to the sizes of aggregates used in concrete production for structural purposes.

2.4.1.2.2 Particle shape

Natural sand, which consists primarily of uncrushed rounded particles, is often used in concrete mixes because it is generally less expensive, readily available, can be blended easily with other materials, and more workable. However, natural sand has a smooth, rounded surface texture that greatly reduces the interlocking properties of the concrete, reducing its strength properties (Neville and Brook, 2010).

From the standpoint of the economy in cement requirement for a given w/c ratio, rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregate is offset to some extent by the higher strengths and sometimes by greater durability as a result of the interlocking texture of the hardened concrete and higher bond characteristic between aggregate and cement paste. Flat particles in concrete aggregates will have a particularly objectionable influence on the workability, cement requirement, strength, and durability. In general, excessively flaky aggregate makes very poor concrete (Neville, 2011).

The aggregate shape affects the workability of concrete due to the differences in a surface which are caused by different shapes. Sufficient paste is required to coat the aggregate to provide lubrication. Not only had the characteristic of the parent rock but also the type of crusher used influence the shape of aggregates. Generally, the most common shapes of aggregates can be irregular, angular, rounded, flaky, elongated, etc. (Li, 2011).

Flaky aggregates have a thickness of less than 0.6 of their mean sieve size. Elongated aggregates have a length of more than 1.8 of their mean sieve size. The flakiness index (FI) and elongation index (EI) of an aggregate sample is found by separating the flaky and elongated particles and expressing their mass as a percentage of the mass of the sample tested in accordance with BS 812-105.1: 2004 and BS 812-105.2: 2004 respectively. The flakiness index (FI) and elongation index (EI) maximum 40% specified in BS 882: 2003. Generally, high values of flakiness and elongation index indicate that the aggregate sample is poorly shaped and consists of a high proportion of flaky, elongated, and irregular shaped particles. Lower values of flakiness and elongation index better-shaped particle. Changes in aggregates flaky and elongation value are related to the crusher type.

2.4.1.2.3 Particle surface texture

Surface texture is the pattern and relative roughness or smoothness of aggregate particles. Surface texture plays a big role in developing the bond between an aggregate particle and a cementing material. A rough surface texture gives the cementing material something to grip, producing a stronger bond, and thus creating a stronger concrete. The reasonable effect on compressive strength is realized when the slump is widely varied. Surface texture also affects the workability and water requirements of concrete. Rough texture particles are known to require more water to achieve similar workability compared with smooth particles. Generally, it has a significant influence on fresh concrete and bond between aggregate and cement paste of hardened concrete (Arumugam, 2014 and Ngugi *et al.*, 2014).

2.4.1.3 Porosity and absorption

Porosity is a ratio of the volume of pores to the total volume of the particle. Permeability refers to the particles ability to allow liquids to pass through. If the rock pores are not connected, a rock may have high porosity and low permeability. The internal pore characteristics are very important properties of aggregates. The size, number, and continuity of pores through an aggregate particle may affect the strength of aggregate, abrasion resistance, surface texture, specific gravity, bonding capabilities, and resistance to freezing and thawing action (David, 2015).

Absorption refers to the process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body; also, the increase in the mass of a porous solid body resulting from the penetration of a liquid into its permeable pores (ASTM C 125:2004). Aggregates that are porous can absorb water. Absorption is thus governed by porosity. For the pores of an aggregate particle to fill with water, the pores must be interconnected and open to the surface so that water from the exterior can penetrate the solid (Alexander and Mindess , 2010). In concrete mix proportioning, for a given water-cement ratio (w/c), the aggregates with considerable absorption will require additional water and cement to meet the w/c requirement and make the fresh concrete workable (Neville, 2011).

Absorption tests were carried out according to BS 812-Part 2 :2004. Aggregate samples were immersed in water for approximately 24 hours to essentially fill the pores. It is then weighed in both the saturated surface dry condition, submerged in water, and oven-dried conditions. The ratio of the increase in mass to the mass of the dry sample, expressed as a percentage, is termed absorption. BS 882: 2003 states that the water absorption of the fine and coarse aggregates is in the range of 0.2% to 2.0% and 0.2% to 4.0% respectively.

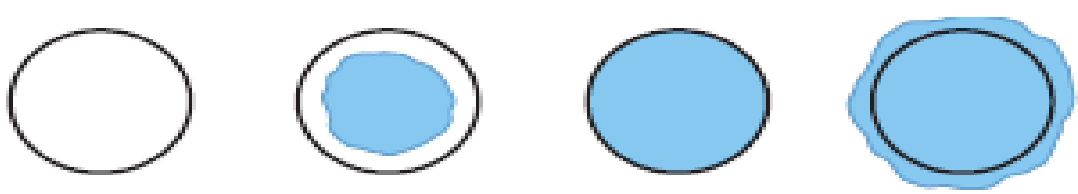
There are aggregate particle voids, and there are voids between aggregate particles. As solid as aggregate may be to the naked eye, most aggregate particles have voids, which are natural pores that are filled with air or water. These voids or pores influence the specific gravity and absorption of aggregate. The void within an aggregate particle is not the same as the void system which makes up the space between particles in an aggregate mass. The voids between the particles influence concrete (Afeni, 2016). The pores at the surface of the particle affect the bond between aggregate and cement paste, and may thus exert some influence on concrete strength (Neville, 2011).

Aggregate porosity may affect durability as freezing of water in pores in aggregate particles can cause surface pop-outs. Absorption can be used as an initial indicator of soundness. Furthermore, aggregates with low absorption tend to reduce shrinkage and creep. Solid rocks with low porosity, low absorption, and high strength are used as raw materials for the production of coarse crushed aggregates suitable for structural concretes (Aslam *et al*., 2015).

2.4.1.4 Moisture content

Aggregate particles can assume different moisture conditions depending on the water amount held in the pores or on the surface of the particles. Oven dry, in which evaporable water is driven off at $100 - 110^{o}c$; air dry, when aggregates dry to equilibrium with the surrounding air and some moisture is retained by the aggregates; and saturated surface dry (SSD), which is the condition when the aggregate particles themselves are saturated, but there is no free or excess moisture on the surface. The condition of saturated particles with free surface moisture damp or wet can also occur. Figure 2.2 illustrates these different moisture states.

State	Oven dry	Air dry	Saturated surface dry	Damp or wet



Total Moisture	None	Less than potential absorption	Equal to potential absorption	Greater than absorption

Figure 2.2 Moisture condition of aggregates

The aggregates in concrete are assumed to be inert materials. But most of the aggregates do not meet this assumption by either dry aggregate absorbing water or wet aggregate by releasing it into the mix. As a result of this property of aggregates the design water to cement ratio of the mix changes (Ararsa *et al.*, 2018). Therefore, it is important to determine the moisture content of the aggregate in order to determine the net water-cement ratio for the concrete batch.

The moisture content of aggregates was determined according to BS 812-109: 2004. Aggregate samples were dried in an oven at a temperature of 110°C for 24 hours and dividing the weight difference by the oven-dry weight. So that the total water content of concrete can be controlled and correct batch weights determined. BS 882: 2003 states that the moisture content of the fine and coarse aggregates is in the range of 0.2 to 2.0% and 0.2 to 4.0% respectively.

Moisture content has been cited by many researchers as one of the variables that affect aggregate properties. The variation of moisture affects properties like bulk density, permeability, compressive strength, and other concrete properties. Therefore, there is no doubt that continuous measurement of moisture and automatic adjustment of the amount of water added into the mixer greatly reduce the variability of concrete produced when the aggregate moisture content is variable (Neville, 2011).

2.4.1.5 Specific gravity

Specific gravity is an expression of the density of an aggregate. It is the ratio between the weight of the substance and that of the same volume of water. Aggregates contain pores in their structure. Therefore, the specific gravity depends on whether the pores included in the measurement or not. The apparent specific gravity of an aggregate refers to the solid materials excluding the pores, and bulk specific gravity refers to total volume, i.e., including pores of the aggregate (ASTM C 125:2004).

The moisture state will influence aggregate specific gravity and therefore specific gravity is measured at a specified moisture state. The most useful moisture state is SSD since the aggregate will not take up water from the mix thereby adversely affecting workability, nor contribute excess water to the mix thus reducing the strength (Alexander and Mindess, 2010).

BS 812-Part 2:2004 was used in the determination of the specific gravity of aggregates. Aggregate samples were immersed in water for 24 ± 4 hours to essentially fill the pores; it is then removed from the water; the water dried from the surface of the particles, and the mass determined. Subsequently, the aggregate sample volume is determined by the displacement of the water method; and finally, samples oven-dried and the mass determined. BS 882: 2003 specifies that the apparent specific gravity of a normal concrete aggregate lies between the range of 2.4 and 3.0.

Aggregate specific gravity in relation to concrete performance is important in several ways. First, most mix designs are based on a measure of aggregate bulk specific gravity (SSD). Aggregate with a higher specific gravity the lower its void content, and consequently the less volume of paste required to fill the voids. This usually translates not only into a better economy for the mix but also results in improved concrete properties if adequate workability is maintained. The aggregate specific gravity also has an important influence on concrete density, since aggregates occupy up to 80 % of the volume of concrete (Alexander and Mindess, 2010).

The specific gravity of aggregates generally is indicative of their quality because aggregates greatly influence the strength and absorption of concrete. A low specific gravity may indicate high porosity and therefore poor durability and low strength because concrete density will greatly depend on specific gravity (Alexander and Mindess, 2010).

2.4.1.6 Bulk density

The bulk density of an aggregate is the mass or weight of aggregate required to fill a container of a specified unit volume. The volume referred to here is that occupied by both aggregates and the voids between aggregate particles (ASTM C 125:2004). The bulk density depends on how densely the aggregates are packed and, consequently, on the particle size distribution and shape of the particles. Thus, the degree of compaction has to be specified BS 812 -2:2004 recognize two degrees: loose and compacted. The loose bulk density is simply determined using BS 812: 102 by filling a container of known volume and weighing it. The compacted bulk density is determined by filling the measure one-third full and level the surface with the fingers; rod the layer of aggregate with 25 strokes of the tamping rod evenly distributed over the surface; fill the measure two-thirds full and again level and rod as above. Finally, fill the measure to overflowing and again rod as above; weighed and its contents and record the net aggregate weighed; divide this weight by the volume of the measure. The result is the compact bulk density of aggregate. The BS 882: 2003 suggests 1200 to 1750 Kg/m^3 as an acceptable bulk density for aggregates to be part of concrete.

Bulk density depends upon their packing, the shape, and size of the particles, grading, and moisture content. For coarse aggregate, increasing moisture content increases the bulk density; for fine aggregate, however, increasing moisture content beyond the saturated surface dry condition can decrease the bulk density. This is because thin films of water on the sand particles cause them to stick together so that they are not as easily compacted. The resulting increase in volume decreases the bulk density. Other properties that affect the bulk density of an aggregate include grading, specific gravity, surface texture, shape, and angularity of particles. Angularity increases void content while larger sizes of well-graded aggregate and improved grading decrease void content (Li, 2011).

2.4.1.7 Deleterious substances

Sand fines are materials that pass through the 75µm sieve. These fines are considered as an impurity in building sand in ASTM C117:2003. The presence of sand fines in concrete is likely to affect the workability, strength, and durability of concrete (Neville, 2011). To this effect, the percentage limit of sand silt content is recommended by various building standards in other to check their effects on concrete properties. Therefore it is necessary that one make a test on silt content and checks against permissible limits.

Silt content tests were carried out according to BS 812-103.1: 2004. Sand samples from splitter were taken; take a jar having a capacity of 500 ml and pour 125 ml (1/4 of the jar) of sand; fill ¾ of the jar with water and shack vigorously for about a minute; leave the cylinder for 24 hours, and allow the silt to settle on the layer of the sand. Finally, measure the layers forming. BS 882: 2003 which recommends 4% of fines in building sand to produce concrete.

When the fines content in the sand is excessive, there is the need to add more water to the concrete mix in other to improve the workability. That is fine particles such as clay and cement interact with water in a physiochemical state which leads to more absorption of water than that of fine and coarse aggregates. Studies have shown that a higher amount of sand fines in concrete results in poor workability. This eventually leads to the addition of water to the concrete mix before or even during the unloading process to improve workability (Heerden and Booyens, 2017).

Studies revealed that an increase in the percentage in sand fines content has also been found to decrease the compressive and tensile strengths of hardened concrete. Sand fines and w/c ratio have been reported to be one of the causes of weakness in concrete strength. The results show that the workability of concrete decreased as fines content increases. The study again revealed that up to 4% fines content, the compressive strength increased as the fines content increases. The same trend was found for the splitting tensile strength results Cho (2013) and Yalley and Sam (2018) have studied.

According to Neville (2011) clay lump and friable particles exist as surface adherent coatings or lumps in aggregate and when present in an undesirable amount they may interfere and seriously affect bond development between aggregate particles and cement paste and subsequently affecting workability, strength, and durability of concrete. Thus, assessing the quality of construction materials is very important to build strong, durable, and cost-effective structures for sustainable infrastructure development (Savitha, 2012).

2.4.2 Mechanical properties

2.4.2.1 Bond of the aggregates

The resistance developed to shear particles from the hardened cement paste is called the bond strength of aggregate. Bond is partly due to the interlocking of the aggregates and the paste owing to the roughness of the aggregate particle surface. A rougher texture as that of crushed stone results in a greater adhesion or bond between the particles and the cement matrix. The determination of the quality of bond of aggregate is difficult and no accepted tests exist. Generally, when the bond is good, a crushed concrete specimen should contain some aggregate particles broken right through, in addition to the more numerous ones separated from the paste matrix. However, an excess of fractured particles suggests that the aggregate is too weak. Bond strength is found to increase with the age of the concrete. The strength of concrete is therefore dependent on the bond strength (Ezeokonkwo *et al.*, 2015).

2.4.2.2 Strength of the aggregates

Strength is a measure of the ability of an aggregate particle to stand up to pulling or crushing forces. High strength is desirable in aggregate to producing good concrete. (Afeni, 2016). In general, the strength of aggregate depends on its composition, texture, and structure.

Aggregate Impact Value (AIV) is the percentage of fines produced from an aggregate sample after subjecting it to a standard amount of impact. Resistance to the impact of aggregate samples was measured in accordance with BS 812-112: 2004 by subjecting 14mm sieve passing and 10mm sieve retained materials in a 102mm diameter hardened steel mold to 15 blows from a 14kg hammer falling from a height of 380mm. The percentage mass of fines materials passing through 2.36mm sieve, formed in the test is known as the Aggregate Impact Value (AIV). BS 882: 2003 specifies that aggregate impact value shall not exceed 45 percent by weight for aggregate used for concrete other than wearing surface and 25 percent by weight, for concrete for wearing surfaces, such as runways, roads, and pavements.

The Aggregate Crushing Value (ACV) is a value that indicates the ability of an aggregate to resist crushing under a gradually applied compressive load over a period of 10 minutes, after passing through sieve 14.0mm and retained on 10.0mm sieve. The retained materials were poured into a mold in three layers and tamped 25 times in each layer. After compression, the fine materials passing through 2.36mm sieve produced, expressed as a percentage of the original mass is the aggregate crushing value (ACV). BS 882: 2003 specifies that aggregate crushing value should not be more than 30% for wearing surfaces and not more than 50% for concrete other than wearing surface (BS 812-110, 2004).

Aggregate Abrasion Values (AAV) is a measure of the resistance of an aggregate to surface wear by abrasion. The most widely used abrasion test is the Los Angeles abrasion test. 500g of the sample retained on the 1.70mm sieve was poured in a large rotating drum-the Los Angeles Machine with 12 balls and allowed to rotate for 500 revolutions at speeds of 30-33 revolution per minute. The materials were then extracted and separated into materials passing the 1.70mm sieve and those retained on the 1.70mm. The retained materials were then weighed and compared to the original sample weight. The difference in weight is reported as a percent of the original weight and called the percent loss. Rock materials with Aggregate Abrasion Values below 30% are regarded as strong, while those above 35% would normally be regarded as too weak for use on the road surface.

2.4.3 Chemical and durability properties

2.4.3.1 Soundness

Soundness refers to the ability of an aggregate to resist excessive changes in volume as a result of changes in physical conditions. These physical conditions that affect the soundness of aggregate are freezing, thawing, and variation in temperature, alternate wetting and drying under normal conditions, and wetting and drying in saltwater. Aggregates that are porous, weak, and containing any undesirable extraneous matters undergo excessive volume change when subjected to the above conditions. Aggregates that undergo more than the specified amount of volume change are said to be unsound aggregates. If concrete is liable to be exposed to the action of frost, the coarse and fine aggregate which are going to be used should be subjected to a soundness test (Neville, 2011).

The physical causes of large or permanent volume changes of aggregate are freezing and thawing, thermal changes at temperatures above freezing, and alternating wetting and drying. If the aggregate is unsound, such changes in physical conditions result in a deterioration of the concrete in the form of local scaling, pop-outs, and even extensive surface cracking. Unsoundness is exhibited by porous flints and cherts, especially lightweight ones with a fine-textured pore structure, by some shales, and by other particles containing clay minerals (Li, 2011).

2.4.3.2 Freeze–thaw resistance

The frost resistance of an aggregate is related to its porosity, absorption, permeability, and pore structure. An aggregate particle with high absorption may not accommodate the expansion that occurs during the freezing of water if that particle becomes critically saturated. If enough offending particles are present, the result can be expansion and cracking of the aggregate and possible disintegration of the concrete. If a single problem particle is near the surface of the concrete, it can cause a popout. Popouts generally appear as conical fragments that break out of the concrete surface. The offending aggregate particle or a part of it is usually found at the bottom of the resulting void. Generally, it is coarse rather than fine aggregate particles with higher porosity values and medium-sized pores (0.1 to 5μm) that are easily saturated and that cause concrete deterioration and popouts. Larger pores do not usually become saturated or cause concrete distress, and water in very fine pores may not freeze readily (Kosmatka and Wilson, 2011 and Alexander and Mindess, 2010).

2.4.3.3 Alkali–aggregate reactivity

The resistance of an aggregate to an aggressive external chemical substance will depend on the nature of the aggregate itself and the type of aggressive agent. The types of rocks contain alkali-silica and alkali carbonate reactive constituents. The reaction starts with an attack on the reactive siliceous minerals are associated with alkali-silica reaction (ASR) in the aggregate by the alkaline hydroxide derived from the alkalies in cement. As a result, the alkali silicate gels of unlimited swelling type are formed (Alexander and Mindess, 2010).

Reactions observed with certain dolomitic rocks are associated with alkali-carbonate reaction (ACR). Reactive rocks usually contain large crystals of dolomite scattered in and surrounded by a fine-grained matrix of calcite and clay. Calcite is one of the mineral forms of calcium carbonate; dolomite is the common name for calcium magnesium carbonate. Reactive type of aggregate, high alkali content in cement, availability of moisture, and optimum temperature conditions are the main factors that contribute to the alkali-aggregate reaction (Kosmatka and Wilson, 2011).

2.4.4 Thermal properties

Aggregate possesses three thermal properties which are significant in establishing the quality of aggregate for concrete production. These are coefficient of expansion, specific heat, thermal conductivity. Out of these, specific heat and conductivity are found to be important only in mass concrete or where insulation is required, but not in ordinary structural work. The coefficient of thermal expansion of aggregate influences the value of such a coefficient of concrete containing the given aggregate. The higher the coefficient of the aggregate the higher the coefficient of the concrete, but depends also on the aggregate content in the mix and on the mix proportions in general (Neville, 2011 and Shetty, 2019).

It has been suggested that if a particular concrete is subjected to normal variation of atmospheric temperature, the thermal incompatibility between the aggregates and paste or between the aggregate and matrix may not introduce serious differential movement and break the bond at the interface of aggregate and paste or aggregate and matrix. But if the concrete is subjected to a high range of temperature difference the adverse effect will become acute (Neville, 2011 and Shetty, 2019).

2.5 Effect of aggregates on concrete property

The quality of constituent materials used in concrete production plays a principal role in determining concrete properties. Aggregates account for about 60 -75% of the total volume of concrete and 70-85% of the weight. Thus, the choice of aggregate in concrete production can significantly affect the workability, strength, and durability of concrete (Ngugi *et al*., 2014; Sulymon *et al.*, 2017 and Sabih *et al.*, 2016).

2.5.1 Fresh concrete

Fresh concrete or plastic concrete is a freshly mixed material that can be molded into any shape. The relative quantities of cement, aggregates, and water mixed together, control concrete properties in the wet state as well as in the hardened state. Since up to 80% of the total concrete volume comprises aggregates. Therefore, aggregates properties such as silt content, particle shape, and surface texture, grading influence workability, finish ability, bleeding and segregation of fresh concrete have an important influence on concrete properties (Shetty, 2019).

2.5.1.1 Workability

The ease of placing, consolidating, and finishing freshly mixed concrete and the degree to which it resists segregation is called workability. ASTM C 125:2004 defines workability as property determining the effort required to manipulate a freshly mixed quality of concrete with minimum loss of homogeneity. In general, there are two basic concrete properties that clearly describe the meaning of workability. Those two points are consistency and cohesiveness of concrete.

Consistency is considered a close indication of workability. Slump is used as a measure of the consistency or wetness of concrete. A low slump concrete has a stiff consistency. If the consistency is too dry and harsh, concrete will be difficult to place and compact and larger aggregate particles may separate from the mix. However, it should not be assumed that a wetter, more fluid mix is necessarily more workable. If the mix is too wet, segregation and honeycombing can occur. The consistency should be the driest practicable for placement using the available consolidation equipment (Kosmatka and Wilson, 2011).

Cohesiveness is a tendency to bleed and segregate. Bleeding is the development of a layer of water at the top or surface of freshly placed concrete. It is caused by the settlement of cement and aggregate and the simultaneous upward migration of water. Bleeding is normal and it should not diminish the quality of properly placed, finished, and cured concrete. Some bleeding is helpful to control plastic shrinkage cracking (Shetty, 2019).

Excessive bleeding increases w/c ratio near the top surface; a weak top layer with poor durability may result, particularly if finishing operations take place while bleed water is present. A water pocket or void can develop under a prematurely finished surface (Shetty, 2019). Specifically, the coarser materials having little or no fines will likely produce fresh concrete bleeding excessively, proving difficult to be pumped not easily compacted and hardened concrete having honeycomb and voids that would otherwise have been filled up with fines (Obla, 2011).

Segregation can be defined as the separation of constituents of the heterogeneous mixture so that their distribution is no longer uniform. There are two forms of segregation. In the first, coarser particles tend to separate out since they tend to travel further along a slope to settle more than the finer particles. The second form of segregation, occurring particularly in wet mixes, is manifested by the separation of cement plus water from the mix. With some grading when a lean mix is used, the first type of segregation may occur if the mix is too dry; the addition of water would improve the cohesion of the mix, but when the mix becomes too wet the second type of segregation would take place (Neville, 2011). Furthermore, this class of materials will tend to produce concrete that is segregated and that is resistant to surface finish attempts leading to hardened concrete that is porous, less dense, and having a rough surface (Kosmatka and Wilson, 2011).

Slump and compacting factor tests are commonly employed to measure the parameters very close to workability and provide useful information. The slump test is the most commonly used method of measuring the consistency of concrete which can be employed either in a laboratory or at the site of work. It is not a suitable method for very wet or very dry concrete. While the compacting factor test is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability (Shetty, 2019).

Table 2.8 Workability, slump and compaction factor of concrete (BS 206-1, 2000)

Degree of workability	Slump (mm)	Compaction factor
Very low	< 25	< 0.78
Low	25 - 50	0.78 – 0.85
Medium	50 - 100	0.85 – 0.92
High	100 - 150	0.92 – 0.95
Very high	> 150	> 0.95

Factors that influence the workability of concrete are water content, silt content, fine aggregates fineness modulus, mix proportions, particle size, shape, surface texture, grading of aggregate, and admixtures (Kosmatka and Wilson, 2011).

Grading of aggregates is important for creating workable and cohesive concrete. Fine aggregate grading has a much greater effect on concrete workability than does coarse aggregate grading. Fine aggregates have a higher specific surface leads to lesser workability as more water would be needed to wet the surface of the particles. As the particle size decreases, its specific surface increases leading to a loss in workability. A sample of the well-graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. The minimum paste will mean less quantity of cement and less quantity of water, which will further mean increased economy, higher strength, and greater durability. Fine aggregates have a high water requirement due to their high specific surface area and an inadequate amount of fine aggregate causes mixtures to become stiff and segregate (Pawar *et al.*, 2016 and Sabih *et al.*, 2016).

The decrease in concrete workability as a result of an increase in fines percentage in the sand can be attributed to the fact that finer particles have a larger surface area which absorbs more water in a concrete mix. This result is again similar to the reports Olusola et al. (2012); Iyappan and Manu (2015); Heerden and Booyens (2017) and Yalley and Sam, (2018).

Effect of aggregate particle shape of angular, elongated, smooth rounded, and flaky aggregate on concrete workability have been studied using experiments. It was concluded that smooth rounded aggregates have better workability while flaky and elongated aggregates beyond certain limit decrease workability hence concrete workability depends on the shape of aggregates (Khan and Dhobale, 2018).

Okonkwo and Emmanuel (2018) have been studied on effect of fine aggregate to the coarse aggregate ratio on concrete workability based on different aggregate proportions of concrete batches. The result indicated that a reduction in the workability of concrete when the aggregate proportion was varied slightly above and below 0.4 and 0.6 aggregate proportion.

The workability of concrete can increase with the addition of water-reducing admixtures without increasing water content. However, typically no more than 2% by weight of cement of water-reducing admixtures are added to concrete to increase consistency while reducing water content by 15 % (Kumar *et al.*, 2014 and Hora, 2014). In the present study, 1% by weight of cement High Range Water Reducer (HRWR) super plasticizing admixture was added to C-50 concrete grade to increase consistency while reducing water content by 15 %.

2.5.2 Hardened concrete

The properties of hardened concrete depend on the selected raw materials: properties of aggregate, as well as on the ratio of other components. The study of the quality of good concrete shows that particle size distribution, silt content, particle shape, and surface texture, specific gravity, the strength of aggregates, and bulk density were properties that determine hardened concrete properties. The aggregate properties affect harden density, strength, and durability of hardened concrete properties (Neville and Brook, 2010).

2.5.2.1 Hardened density

Lightweight concrete is hardened concrete having an oven-dried density not greater than 2000 kg/m^3. Normal weight concrete is hardened concrete having an oven-dried density greater than 2000 kg/m^3 but not exceeding 2600 kg/m^3. Heavyweight concrete hardened concrete having an oven-dried density greater than 2600 Kg/m^3 (BS 5328-1, 2003).

Concrete must have to ensure satisfactory hardened density, compressive strength, and durability. The mechanical properties of concrete are highly influenced by its hardened density. A denser concrete generally provides higher strength and fewer amount of voids and porosity. The smaller the voids in concrete, it becomes less permeable to water and soluble elements. So water absorption will also be less and better durability is expected from this type of concrete. In an experimental program conducting on hardened density, compressive strength, absorption capacity, and percent voids of hardened concrete are described. The variation of these properties with the maturity of concrete was the main focus of this experiment. It was observed from the experiment that, hardened density and compressive strength increases with the maturity of concrete, and percent void and absorption capacity decreases with time (Iffat, 2015).

The laboratory test results in hardened density indicated that the increase in bulk density and the specific gravity of aggregates enhance hardened density. This is due to the fact that the smaller the voids in aggregates more hardened density, strength, durable and less water absorbing. The study also reported that the low bulk density reduced the hardened density (Ramteja, 2016; Abutaha, 2018 and Quayson and Mustapha, 2019).

2.5.2.2 Compressive strength

The compressive strength of concrete is the axial loading concrete can withstand per its cross-sectional area before it collapses. It is usually determined by crushing 150mm cubes in a compression machine. It is generally expressed in N/mm^2 at the age of 28 days. Other test ages are also used. However, it is important to realize the relationship between the 28 days strength and other test ages (Neville and Brook, 2010).

The factors influencing concrete strength are the amount and type of cement, w/c ratio, aggregate type and grading, particle shape and surface texture, the strength of aggregate, the maximum size of aggregate used, workability of fresh concrete, mineral admixtures used, chemical additives, age and conditions of curing (Olusunle *et al.*, 2015).

Concrete strength is determined depending upon the curing conditions either through the bond between cement paste and aggregate and by interlocking characteristics of aggregates. Angular aggregates are considered as the finest solution to achieve an optimal bond between aggregates and cement and provide high values of strength (Nagaraj and Jeyakumar, 2018).

The compressive strength of NSC increases as the maximum size of aggregate increases. On the contrary, the compressive strength of HSC increases as the maximum size aggregate decreases. However, this could indicate that the maximum size of aggregate is not the only predominant factor regarding the compressive strength of concrete but also the particle size distribution of the granular system has a great impact on the compressive strength development. Results have revealed that the mixtures without chemical admixture made with a ternary combination of granular fraction and having a maximum size of 25 mm, that assures a continuous granular size distribution, have shown the highest compressive strength. However, decreasing the w/c by the inclusion of WRA or HRWRA requires a decrease of the maximum size of coarse aggregate and some adjustment in the granular size distribution system. The binary granular system has led to the highest compressive strength when dealing with low w/c (Seddik *et al.*, 2010; Hamid and Abas, 2015 and Ogunbayo and Aigbavboa, 2019).

In normal strength concrete (NSC) failure in compression almost exclusively involves segregation of the cement paste from the aggregate particles. This type of concrete mixtures typically corresponds to a w/c ratio in the range of 0.5–0.7. Within this range, the weakest components in concrete are hardened cement paste and the transition zone between cement paste and coarse aggregate, rather than the coarse aggregate itself. The reason is that concrete with higher fines content in sand absorbs more water thereby living an inadequate amount of water for the hydration of cement leading to decreased strength.

Moreover, a higher percentage of fines in the sand will require a higher amount of water to make the concrete workable which intend result in lower strength of concrete (Yalley and Sam, 2018 and Ngugi *et al.*, 2014).

Effect of aggregate particle shape of angular, elongated, smooth rounded, and flaky aggregate on concrete strength have been studied using experiments. It was concluded that angular aggregates have a better strength while flaky and elongated aggregates beyond a certain limit decrease strength hence concrete strength depends on the shape of aggregates (Khan and Dhobale, 2018).

High strength concrete(HSC) there is concrete prepared with a low w/c ratio and a high cement content, the compressive strength is dependent on the quality of coarse aggregate. In a rich concrete mix, the possibility of failure within the paste matrix alone is very rare, since this phase is very strong. Therefore, the failure plan has to pass through the paste–aggregate interface or through the aggregate. In both modes of failure, the quality of aggregate significantly influences the mode of failure of concrete under compression. The influence of coarse aggregate properties on the concrete strength becomes paramount as the quality of the paste is improved such as in the case of HSC (Neville, 2011 and Seddik *et al.*, 2010).

Effects of fine aggregate to coarse aggregate ratio on concrete strength have been studied based on different aggregate proportions of concrete batches. The compressive strength result shows that when the aggregate proportion was varied beyond 0.4 and 0.6 there was a reduction in the strength of the concrete (Okonkwo and Emmanuel, 2018; Al-thairy, 2019 and Seddik *et al*., 2010).

The inclusion of WRA and HRWRA has led to some changes in the optimum content of the coarse aggregate. The results have shown that when adding 2% of the HRWRA, the effect of coarse aggregate content on the compressive strength becomes more important and the optimum content of the coarse aggregate is approximately 45% (Seddik *et al.*, 2010).

From the above research findings, aggregate added to the mix will significantly affect concrete compressive strength. Therefore, during the selection of construction material, especially aggregate due care should be taken.

2.5.2.3 Splitting tensile strength

The determination of the splitting tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The tensile strength of concrete depends on strength of cement paste, particle size of aggregate, maximum size, aggregate types and interfacial bond strength between cement paste and aggregates. The tensile strength of HSC increases as the maximum size aggregate decreases. While the splitting tensile strength values of concrete samples produced increased linearly with increasing cement dosage in high strength concrete (Iqbal *et al*., 2018; Kalra and Mehmood, 2018 and Tunc, 2018).

Experimental investigation of the relationship between splitting tensile strength with the compressive strength of concrete has been studied. Based on the investigation, a directly proportional relationship for the prediction of splitting tensile was derived from the compressive strength of concrete (Juki *et al.*, 2013; Piasta *et al*., 2018; Tunc, 2018 and Sharma *et al*., 2016).

Wei and Faguang (2011) indicated that properties of aggregate have varying degrees of influences on splitting tensile strength of concrete. The study confirmed that the possibility of cracking of concrete prepared by aggregate with low specific gravity is much bigger than concrete prepared by aggregate with high specific gravity.

The effect of river sand on the tensile strength of various grades of concrete when it is utilized as a fine aggregate has been investigated. The results showed that there was a reduction in the tensile strength of river sand concrete because of the improper material bonding due to the larger amount of silt content present in river sand (Lakhiar *et al*., 2018 and Yalley and Sam, 2018).

Experimental investigation on the usage of POC as a partial and full replacement of the natural aggregates and filler material was carried out on normal and high strength concrete. The good bond between the POC coarse and the matrix has a significant role in the tensile strength of concrete. The results revealed that incorporating high contents of POC coarse the lower splitting tensile value. The failure of the specimen was mainly due to the breaking of POC particles, while the bonding between the hardened cement paste and POC remained good (Abutaha, 2018).

Concretes with dolomite aggregate, and then basalt and quartzite had the highest tensile strength, which is primarily related to aggregate-paste bond strength and crushing strength. Which implied that the existence of tough and cohesive bonds between the aggregates (Piasta *et al*., 2018 and Ramteja, 2016).

With the increase in flaky aggregate percentage, the concrete members cracked for the smaller load. The splitting tensile strength of concrete has decreased with an increase in the percentage of flaky aggregate content (Khan and Dhobale, 2018).

2.5.2.4 Durability

The durability of concrete is the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties for the expected service life of the structure. To ensure the durability of concrete, care in materials selection, design, and construction is most important (Shetty, 2019).

The durability of concrete is naturally related to the nature of the pore system within the hardened concrete. Aggregate can also contain pores, but these are usually discontinuous. Moreover, aggregate particles are enveloped by the cement paste, which is the only continuous phase in concrete so that the pores in aggregate do not contribute to the durability of concrete. The hardened cement paste has the greatest effect on the durability of concrete. Generally, the greater the resistance of the concrete to the movement of water, the lower its permeability and the greater its resistance to deterioration (Hamid and Abas, 2015).

Concrete is resistant to most natural environments; however, concrete is sometimes exposed to various substances that can cause deterioration. Most concrete durability failure mechanisms are controlled by the availability of moisture. Deterioration processes typically involve two stages. Initially, aggressive fluids water or solutions with dissolved solids penetrate or are transported through the capillary pore structure of the concrete to reaction sites such as chlorides penetrating to steel reinforcement. The chloride attack leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. Sulfates penetrating to hydration of cement where they trigger chemical or physical deterioration mechanisms. The sulfate attack leads to extensive cracking and loss of bond between the paste and aggregates. Therefore, the resistance of concrete to the ingress of fluids that is, low permeability is fundamental to durability (Kosmatka and Wilson, 2011 and Kabashi *et al.*, 2017).

Developing the sulfate attack is divided into two different sources. The internal source is rarer but, originates from such concrete making materials as hydraulic cement, fly ash, aggregate, and admixtures. The external sources are more common and usually are as a result of high sulfate soils and ground waters, or can be the result of atmospheric or industrial water pollution (Kabashi *et al.*, 2017).

Chloride attack is one of the most important aspects for consideration when we deal with the durability of concrete. Chloride attack is particularly important because it primarily causes corrosion of reinforcement. Statistics have indicated that over 40% of failure of structures is due to corrosion of reinforcement. Due to the high alkalinity of concrete, a protective oxide film is present on the surface of steel reinforcement. This protective layer can be lost due to the presence of chloride in the presence of water and oxygen (Kabashi *et al.*, 2017).

Zhang and Zong (2014) have been investigated an experimental study of the influence of water absorption on the durability of concrete. After the age of 28 days of curing, compressive strength, permeability, sulfate attack, and chloride ion diffusion of concrete specimens were investigated. Results obtained also showed that only surface water absorption related to the performance of concrete including permeability, sulfate attack, and chloride ion diffusion. Furthermore, higher water absorption decreased compressive strength, resistance to sulfate attack, and chloride ion diffusion of concrete, and the relationship between surface water absorption and resistance to sulfate attack and chloride ion diffusion was approximately linear.

Mass change prediction model for sulfate attack of concrete containing mineral admixtures through an immersion test in sulfate solutions. The concrete specimens were immersed in 10% sodium sulfate solution and mass change of the specimens was measured at 28, 56, 91, 182, and 365 days. The experimental results indicated that the resistance of concrete containing mineral admixture against sodium sulfate attack was far greater than that of 100% OPC concrete. In the case of immersion in 10% sodium sulfate solution, almost no mass change was observed in all of the concrete specimens regardless of the use of mineral admixture when w/c was 0.32. This is because the low w/c increased the density of concrete microstructure and therefore slowed down degradation by sodium sulfate attack. When w/c was 0.43, the rate of mass decrease in 100% OPC concrete and PPC concrete specimens was found to be higher as the age of immersion increased (Lee *et al.*, 2015).

The validation of neural network to predict mortar and concrete properties due to sulfate attack have been investigated. These properties were expansion, weight loss, and compressive strength loss. Assessment of concrete compressive strength up to 200 years due to sulfate attack was considered in phase two. The neural network model showed high validity in predicting compressive strength, expansion, and weight loss due to sulfate attack. Design charts emphasize the importance of using a low w/ c ratio to increase the sulfate resistance of concrete. In addition, the use of concrete with high cement content enhances the resistance of concrete due to sulfate attack (Diab *et al.*, 2014).

Concrete pore volume is never constant; it changes with time either due to continuing paste hydration or due to its deterioration and it also can be considerably modified by an applied load to the concrete. Therefore it is expected that migration of deleterious ions into concrete by means of convection and diffusion may be modified by the type and magnitude of the external load applied to it. Chloride migration through convection and diffusion is diminished when a minor compressive load is applied to concrete but the opposite effect is noticed when the applied load overcomes a certain limit, usually 30 or 50 % of the concrete maximum compressive capacity. At this instant, some micro-cracks are formed generating fresh pathways that increase the chloride intrusion. Under direct tensile load the rate of chloride penetration increases progressively as the load is increased (Fuxiang *et al*., 2012 and Donghun *et al*., 2010). The chloride distributions of architectural concrete in the marine atmosphere zone and tidal zone are similar. The total and free chloride content generally decreases with depth; chloride content increases significantly with exposure time, forming a maximum chloride peak near the surface of the concrete. Concrete of higher strength grade has better chloride binding capacity due to a larger quantity of hydration products and a more densities microstructure, both of which are beneficial for the chloride penetration resistance of concrete (Chang *et al.*, 2020).

The effect of chloride content on the probability of corrosion has been evaluated, and it has been observed that an increase in chloride content increases the probability of corrosion. The effect of compressive strength on the chloride content also has been investigated and it has been observed that they are having an inverse relationship with each other. Concrete structures with low compressive strength have a higher probability of corrosion. It has been observed that concrete cover and chloride content at rebar depth is having an inverse relationship. A minimum concrete cover of 40mm is required to keep the chloride content below the threshold limit. The results indicated a decrease in the probability of corrosion with the increase in concrete cover. Also, results indicated that the significance of age and compressive strength on the chloride content of the structure. Increasing concrete cover depth is the most appropriate technique for increasing chloride resistance and further improving the service life of structures (Verma et al., 2013).

2.6 Summary of literature review

Based upon the previous studies presented in this chapter, some conclusions are drawn in this summary. This chapter has presented a detailed review of the properties of aggregates and their effect on concrete workability, hardened density, compressive strength, splitting tensile strength, and durability of concrete. The following points have been identified as significant, which should be addressed or considered in this investigation.

Gradation, silt content, particle size, shape and surface texture, specific gravity, bulk density, and strength of aggregates have the major effect on fundamentally important properties of concrete workability, hardened density, compressive strength, splitting tensile strength, and durability of concrete. Water absorption, sulfate attack, and chloride attack are the major form of deterioration mechanisms that affect the durability of concrete.

In general, it is expected to have satisfactory aggregate properties to ensure a required quality concrete workability, hardened density, compressive strength, splitting tensile strength, and durability. A major effect was noted for the properties of aggregates used on fresh and hardened concrete properties. It would therefore be interesting to select the proper aggregates to meet the intended purpose of using concrete.

2.7 Research gap identification

Several studies have been investigated on handling, environmental impact, and properties of aggregates by varying the replacement levels, mix proportions, and other factors. Tekle (2015) has been investigated the practices and challenges of handling of aggregates in Ethiopian construction industry. In addition, Yusuf (2014) and Mulatu (2013) have been assessed environmental impact of fine aggregate and coarse aggregate production in some selected quarry sites respectively. Tadele (2019) has been examined effect of sand silt content on compressive strength of concrete by investigating sand samples collected from different sources. Furthermore, Tamiru (2019) has been studied coarse aggregate source, production and quality in and around Hawassa city. However, studies focusing on varying local sand sources and coarse aggregate production and their effect on concrete workability, hardened density, compressive strength, splitting tensile strength, and durability of concrete found in and around Hawassa city are still limited and their effect is not yet well established. A comprehensive study is necessary to fill the existing knowledge gaps. Taking all of these into account, this study summarized the variation of different experimental studies on aggregate properties and their effect on fresh and hardened concrete properties of C-30 and C-50 concrete grades using different combinations of local sand sources and coarse aggregate production in Hawassa city.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

This chapter describes the materials and methods used in achieving the objectives of this study. Details of the materials used, the methods adopted in preparing the test specimens, and the different test procedures are discussed. The methods employed in preparing the test specimens including concrete mix proportioning, batching, mixing, filling molds, casting, curing, and finally the experimental work on both fresh and hardened concrete properties are also described.

3.2 Study area

The study area Hawassa city is located 273 km south of Addis Ababa, which is the capital city of Ethiopia, in the Great Rift Valley. The city is situated in the latitude of 7°3'N and longitude of 38°28'E with an average altitude of 1708m above mean sea level. Quarries, where fine aggregate samples were collected for this study, were from Bilate, Dimtu, and Halaba which are located around Hawassa city. Quarries, where coarse aggregate samples were collected for this study, were from Monopol which is located in Hawassa city near the parent rock material on the road from Hawassa to Dilla. The coarse aggregate samples selected from three different quarries named Waye Bonge Quarry, Daete Quarry, and Derago Quarry. The details of selected quarries were identified and presented in Table 3.1 and Table 3.2. Figure 3.1 shows the locations of the quarries from where the aggregates were collected.

Table 3.1 Description of selected fine aggregate quarries

No.	Quarry	Location		Distance from Hawassa
		Region	Zone	
1	Bilate	Sidama	Sidama	90km
2	Dimtu	SNNPRS	Wolita	93km
3	Halaba	SNNPRS	Halaba Special Woreda	85km

Table 3.2 Description of selected coarse aggregate quarries

No.	Name of Company	Location
1	Waye Bonge Quarry	Hawassa city
2	Daete Quarry	Hawassa city
3	Derago Quarry	Hawassa city

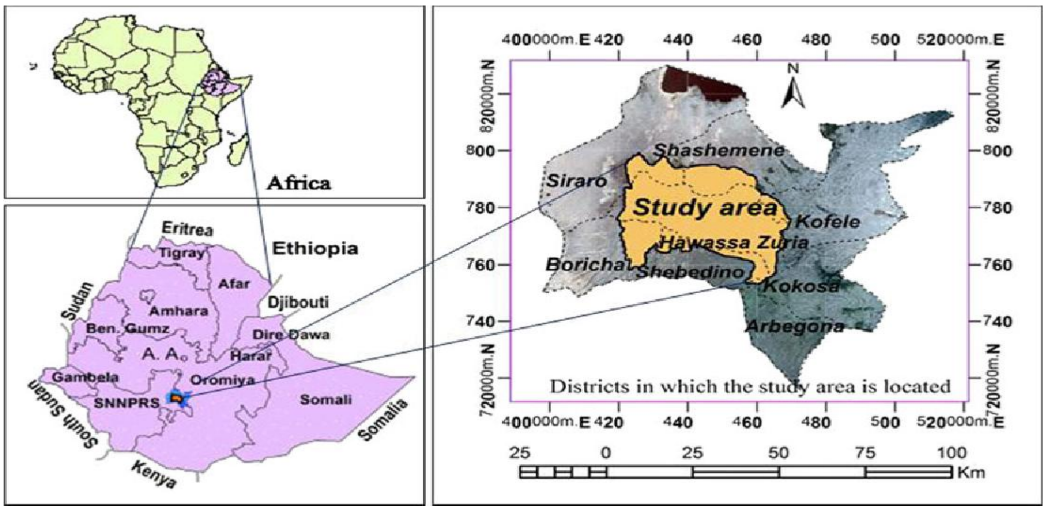


Figure 3.1 Locations of the sites from where the aggregates were collected (Reta, 2016)

3.3 Materials

3.3.1 Aggregate

3.3.1.1 Fine aggregate

3.3.1.1.1 Sample size and sampling procedure of fine aggregate

In this study, three fine aggregate quarries around Hawassa city were selected which are Bilate, Dimtu, and Halaba based on the results of the questionnaire administered, and the fine aggregate market share was investigated. For field sample collection, procedures are given in BS 812-101: 2004 were adopted as a guiding principle in the sampling procedure. BS 812-102: 2004 informed and guided the sampling procedure employed in reducing the field sample to obtain the required test portion for each of the tests performed. Fine aggregate samples from each source were subjected to series of laboratory experiments in accordance with BS standards. The samples were classified using the Unified Soil Classification System described in ASTM D 2487: 2000. The test results were used to evaluate fine aggregate samples from different quarries against the applicable standards in addition to investigate their effect on fresh and hardened concrete properties for selecting suitable fine aggregate for concrete production.

Three fine aggregate samples were collected from each fine aggregate quarry. Those samples were labeled and identified with name given by combining general quarry name and a unique numeric identity. Three fine aggregate samples from Bilate area are labeled BL 1, BL 2 and BL 3 which indicates BL 1 was the first quarry in Bilate area that fine aggregate samples taken. Whereas samples from Dimtu area were labeled as DM 1, DM 2 and DM 3 and samples from Halaba area were labeled as HL 1, HL 2 and HL 3 in the same manner. Using this labeling technique nine fine aggregate samples were taken from those three fine aggregate quarries and labeled accordingly.

3.3.1.1.2 Tests on fine aggregate samples

Laboratory tests were conducted on fine aggregate samples to determine physical properties in accordance with BS standards are presented in Table 3.3.

Table 3.3 Tests on fine aggregate samples

<table>
<tr><th>No.</th><th colspan="2">Types of test</th><th>Samples per test</th><th>Test Methods</th></tr>
<tr><td>1</td><td colspan="2">Silt content</td><td>3</td><td>BS 812-103.1: 2004</td></tr>
<tr><td>2</td><td colspan="2">Sieve analysis</td><td>3</td><td>BS 812-103.1: 2004</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Bulk density</td><td>Compacted bulk density</td><td rowspan="2">3</td><td rowspan="2">BS 812: 102</td></tr>
<tr><td>Loose bulk density</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Specific gravity</td><td>Bulk specific gravity</td><td rowspan="3">3</td><td rowspan="3">BS 812-Part 2 :2004</td></tr>
<tr><td>Bulk specific gravity(SSD)</td></tr>
<tr><td>Apparent specific gravity</td></tr>
<tr><td>5</td><td colspan="2">Water absorption</td><td>3</td><td>BS 812-Part 2 :2004</td></tr>
<tr><td>6</td><td colspan="2">Moisture content</td><td>3</td><td>BS 812-109: 2004</td></tr>
</table>

3.3.1.2 Coarse aggregate

3.3.1.2.1 Sample size and sampling procedure of coarse aggregate

For the purpose of this study, samples of crushed coarse aggregate from three selected quarries from Monopol which is located in Hawassa city was investigated which were Waye Bonge Quarry, Daete Quarry, and Derago Quarry. The selection made based on the results of the questionnaire administered and the rate of production of aggregates from the quarries as compared to others within the city. The sampling of aggregates for tests were done at the selected quarries following the appropriate sampling procedure in BS 812-101: 2004 as described. The samples were investigated in a laboratory to determine the physical and mechanical properties of aggregates in accordance with BS standards. Performing laboratory test on physical and mechanical properties were used to evaluate coarse aggregate from different quarries against the applicable standards in addition to investigate their effect on fresh and hardened concrete properties for selecting suitable coarse aggregate for concrete production.

Coarse aggregate of two nominal maximum sizes was collected from each quarry. The nominal maximum size of coarse aggregate selected for this study was 25mm and 10mm for C-30 and C-50 concrete grades respectively. The objective of taking samples from each quarry of two different nominal maximum sizes is to investigate effect of coarse aggregate on different concrete grades with respect to their size. Those samples were labeled and identified with the name given by combining a general quarry name and a unique numeric letter identity based on the sequence of sampling at a specific quarry. Coarse aggregate of two nominal maximum sizes 10mm and 25 mm with three samples was selected from each quarry were labeled as A and B respectively. Waye Bonge Quarry is labeled WB A and WB B which indicates that 10mm and 25mm nominal maximum size from Waye Bonge Quarry aggregate samples taken. Whereas samples from Daete Quarry were labeled as DT A and DT B and samples from Derago Quarry were labeled as DG A and DG B in the same manner. Using this labeling technique eighteen aggregate samples were taken from those three coarse aggregate quarries and labeled accordingly.

3.3.1.2.2 Tests on coarse aggregate samples

Laboratory tests were conducted on coarse aggregate samples to determine the physical and mechanical properties in accordance with BS standards are presented in Table 3.4.

Table 3.4 Tests on coarse aggregates samples

No.	Types of test		Samples per test	Test methods
1	Sieve analysis		3	BS 812-103.1: 2004
	Bulk density	Compacted bulk density	3	BS 812: 102
		Loose bulk density		
2	Specific gravity	Bulk specific gravity	3	BS 812-Part 2 :2004
		Bulk specific gravity(SSD)		
		Apparent specific gravity		
3	Water absorption		3	BS 812-Part 2 :2004
4	Moisture content		3	BS 812-109: 2004
5	Flakiness Index (FI)		3	BS 812-105.1: 2004
6	Elongation Index (EI)		3	BS 812-105.2: 2004
7	Aggregate Impact Value (AIV)		3	BS 812-112: 2004

3.3.2 Cement

In this study, the Ordinary Portland Cement type was used, Dangote Ordinary Portland Cement which has a grade of 42.5R was chosen because it is widely available and extensive use in concrete production in Hawassa city. The properties of portland cement according to conforming code ES: 1177- 1CEM 1/42.5 R and the type of cement used for the experiment are shown in Table 3.5.

Table 3.5 Properties of Portland cement(ES 1177-1: 2005)

Property	Average value of OPC used in present investigation	Standard value for OPC
Specific Gravity	3.15	-
Consistency (%)	31.5	-
Initial setting time(min)	30	>30
Soundness (mm)	2.8	< 10

3.3.3 Water

Potable water or tap water is suitable for mixing concrete, therefore water available in Civil Engineering Laboratory, Hawassa University conforming to BS 3148, 2003 for concreting and curing.

3.3.4 Chemical admixture

High Range Water Reducer (HRWR) super plasticizing admixture SASplast SP 60 which is sulfonated naphthalene polymers from SAS Construction Chemicals Ltd., Addis Ababa, Ethiopia which confirms with BS 5075-3: 2004 and ASTM C 494: 2004 was used only for C-50 concrete grade in this study. The properties of superplasticizers are summarized in Table 3.6

Table 3.6 Properties of super plasticizer

S. No.	Properties of SP60	Observations
	Color	Dark brown liquid
	Specific gravity (kg/lit.)	1.22 ± 0.03 at 25°c
	Chemical base	Naphthalene sulphonate
	Air entrainment	1-2 % depending on dosage
	Chloride content	Nil

3.4 Experimental details

3.4.1 Mix design

The mix proportions were selected according to the requirement of different types of aggregates. The DOE mix design approach was used to design both C-30 and C-50 concrete grades. This method considers the influence of cement, type of aggregate as crushed and uncrushed, and different consistency classes are specified which covers the workability of concrete (Chandrakar and Mishra, 2012). The concrete batching is divided into eighteen different batches, nine batches from each type of concrete grade. The two concrete grades both C-30 and C-50 with nominal maximum aggregate size 25mm and 10mm respectively were selected to divide concrete specimens. The mix design adopted as per the specification laid down by method using material properties test conducted above as a design input parameter for this study. Different aggregate samples were used to investigate their effect on the workability of fresh concrete, hardened density, compressive strength development, splitting tensile strength, and durability of C-30 and C-50 concrete grades. Cubic and cylindrical concrete specimens were prepared to investigate hardened concrete properties. The test specimens for concrete were prepared by mixing cement, fine aggregate, coarse aggregate, and water for C-30 concrete grade and in addition chemical admixture for C-50 concrete grade. In this investigation, mixtures were prepared with three different fine aggregate and three coarse aggregate quarries.

3.4.2 Specimen preparation

A total of 378 concrete specimens were cast for experimental work. Out of this, 162 were made of 150mm cube specimens for compressive strength testing at 3 days, 7days, and 28 days curing, 162 were made of 150mm cube specimens for durability whereas 54 were made of cylinder specimen of size 300mm height and 150mm diameter for splitting tensile strength testing. Nine concrete batches were prepared for each C-30 and C-50 concrete grades with different selected quarries. Test methods, concrete specimen type, curing period, and total samples of the concrete test are illustrated in Table 3.7.

Table 3.7 Concrete specimens and test matrix

Fresh concrete property	Test Methods	Specimen type	Age (days)	Samples per test	Total samples
Slump	BS 1881-102: 2003	Φ 100mm× Φ200mm ×300mm cone	Immediately after mixing	2	36
Compaction factor	BS 1881-103: 2003		Immediately after mixing	2	36
Hardened concrete property					
Hardened density	BS 1881-114: 2003	150mm cubes	28	3	54
Compressive strength	BS 1881-116: 2003	150mm cubes	3, 7 and 28	3	162
Splitting tensile strength	BS 1881-116: 2003	Φ150mm× 300mm cylinder	28	3	54
Water absorption	BS 1881-122: 2003	150mm cubes	28	3	54
Sulfate attack resistance	BS 1881-116: 2003	150mm cubes	56	3	54
Chloride attack resistance	BS 1881-116: 2003	150mm cubes	56	3	54

3.4.2.1 Batching

The effect of two methods of batching by mass and volume on fresh and hardened concrete properties has been investigated. Studies have revealed that for a given mix proportion, batching by mass will give an improvement in fresh and hardened concrete properties (Olusola *et al.*, 2012). Therefore, in this study mass batching was preferred for a higher degree of accuracy in experimental work. Batching of materials was done by mass using an electronic balance in accordance with the mix designed.

3.4.2.2 Mixing

Concrete mixtures were blended with hand mixing on the clean metal sheet. Hand mixing was used for the mixing concrete mixture. The materials were added to the metal sheet in accordance with the sequence indicated as follows: coarse and fine aggregates were subsequently weighed and added to the metal sheet; cement was weighed and blend the mixtures properly and mixing water with weighted admixture added steadily to the mixture to facilitate complete mixing of constituents for C-50 concrete grade and without admixture for C-30 concrete grade. Before casting the specimen, the workability of each batch of the concrete mix was determined using the slump cone test and compaction factor test.

3.4.2.3 Filling of molds

After slump cone test and compaction factor test were conducted on fresh concrete, adjustable steel molds with internal dimensions of 150mm×150mm×150mm were used for casting the concrete cubes used for hardened density, compressive strength, and durability tests. Adjustable cylindrical steel molds with internal dimensions of 300 mm height and 150mm diameter were used for casting the concrete cylinders used for splitting tensile strength test. Internal faces of the molds were lightly coated with oil before each use to aid the release of molds easily 24 hours after casting. Concrete specimens were compacted using a tamping rod manually in three layers each layer was tamped 25 times then vibrated for sufficient time to close the voids created by the tamping rod. The top surface was leveled with a trowel and finished properly. An average result of hardened concrete properties was obtained after performing a test on three specimens.

3.4.2.4 Curing

The concrete specimens were removed from the adjusted steel molds after 24 hours of casting. The specimens were immediately transferred into metal tanks containing water at room temperature for the curing to start. Curing then continued with the specimens fully submerged underwater at room temperature for 3 days, 7 days, and 28 days. The test specimens were removed from the curing metal tank 24 hours before testing. The cubes were kept submerged underwater throughout the curing period to ensure there was no reduction in the strength of the specimens.

3.4.3 Laboratory tests

Laboratory tests were done on fresh and hardened concrete to obtain the properties of the concrete designed. Slump test and compaction factor test were carried out to determine the workability of fresh concrete. After the concrete is hardened and cured for 3days, 7days, and 28 days hardened density, compressive strength, splitting tensile strength, and durability tests were done to determine hardened concrete properties.

3.4.3.1 Workability

The workability of concrete in the fresh state was assessed using both slump test and compaction factor test in accordance with BS 1881-102: 2003 and BS 1881-103: 2003 respectively. The procedures used for the slump test were as follows: slump tests were measured using a mold in the shape of a frustum of a cone with a base diameter of 200mm, a top diameter of 100mm, and a height of 300mm. The mold and base plate were dampened and the mold was placed on the horizontal base plate. The mold was filled in three layers, each approximately one-third of the height of the mold when compacted. Each layer was compacted with 25 strokes of the tamping rod. After the top layer has been compacted, the concrete surface was stroked off by means of the rolling motion of the compacting rod. The mold was removed from the concrete by raising it carefully in a vertical direction. Immediately after removal of the mold, the slump was measured and recorded by determining the difference between the height of the mold and that of the highest point of the slumped test specimen.

Compaction factor tests were measured using a compaction factor test apparatus. Weigh the empty cylinder using an electronic balance and record its mass. The internal surfaces of the hoppers and cylinder were damped and the axes of the hoppers and the cylinder all were laid on the same vertical line. The two trap doors were closed then place the sample of concrete gently in the upper hopper using the scoop; open the upper trap door so that the concrete falls into the lower hopper; open the trap door of the lower hopper and allow the concrete to fall into the cylinder; cut off the excess concrete remaining above the top level of the cylinder by holding afloat in each hand then wipe clean the outside of the cylinder and weight the cylinder and its contents. By subtracting the mass of the empty cylinder, calculate and record the mass of partially compacted concrete. Empty the partially compacted concrete from the cylinder and refill it with concrete from the same sample and produce full compaction of the concrete by means of place the concrete in the cylinder in six layers approximately equal in depth and compact each layer by using a tamping rod; smooth it level with the top of the cylinder then wipe clean the outside of the cylinder and weigh the cylinder and its contents. By subtracting the mass of the empty cylinder, calculate and record the mass of fully compacted concrete. The compaction factor was calculated using Equation (2) and the average value of two samples is reported as the compaction factor of concrete.

$$\text{Compaction factor} = \frac{W_2 - W_1}{W_3 - W_1} \quad (2)$$

Where, W_1 = Weight of empty cylinder(Kg)

W_2 = Weight of partialy compacted concrete (Kg)

W_3 = Weight of fully compacted concrete (Kg)

3.4.3.2 Hardened density

Hardened density tests were carried out according to BS 1881-114: 2003. At 28 days, 150mm concrete cubes were measured for their mass and dimension. The dimensions of the specimens were measured to calculate their volume. The hardened density was calculated using Equation (3) and the average value of three concrete specimens is reported as the hardened density of concrete.

$$\rho = \frac{m}{V} \quad (3)$$

Where, ρ = Hardened density of concrete(Kg/m^3)

m = Mass of cube specimens (Kg)

V = Cube specimens volume (m^3)

3.4.3.3 Compressive strength

The compressive strength test was determined based on BS 1881-116: 2003. A 150mm concrete cube was tested using a universal compression testing machine at the rate of 0.010 KN/sec with a maximum capacity of 1500KN. The test procedure was as follows: one day prior to the test cubes were removed from the curing tank; the cubes were then brushed clean, turned on their sides with respect to the position in the mold, and placed centrally in the testing machine; the plates of the testing machine were brought into contact with the cast faces of the cube; loading of the cube then continued at the specified rate of loading until the cube crushed. Each value was taken as the average of three samples test results of the prepared specimen with a curing period of 3days, 7 days, and 28 days. The compressive strength is determined using Equation (4) by dividing the maximum applied load at the failure by the surface area of the specimen as shown in the following:

$$\text{Compressive strength} = \frac{P}{A} \tag{4}$$

Where, P = Maximum load applied (N)

A = Cross sectional area of specimen (mm^2)

3.4.3.4 Splitting tensile strength

The splitting tensile strength test was carried out in accordance with BS 1881-116: 2003 on a cylinder specimen size 150mm diameter and 300mm height at the age of 28 days. The test procedure was as follows: The cylindrical specimens were removed from the curing tank 24 hours before testing; then center one of the plywood strips was used to prevent local failure along the center of the lower plates of the testing machine. Place the specimen on the plywood strip and align so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip; place a second plywood strip length on the cylinder centered on the lines marked on the ends of the cylinder. The load is applied continuously at the rate of 0.010 KN/sec until failure occurs. Each value was taken as the average of three samples test results of the prepared specimens at the age of 28 days. Then the maximum load at the point of failure is noted and the splitting tensile strength is determined by using the following Equation (5):

$$\sigma = \frac{2P}{\pi l d} \tag{5}$$

Where, $\sigma = \text{Splitting tensile strength (N/mm}^2\text{)}$

$P = \text{Maximum applied load (N)}$

$l = \text{Length (mm)}$

$d = \text{Diameter (mm)}$

3.4.3.5 Durability

The rate of absorption of the dry concrete surface can be used to predict the concrete durability. Water is the most common liquid, which the concrete comes in contact. Therefore, the absorption of water is widely used to show the absorption capacity of concrete. It can be determined based on the increase in the mass of a concrete sample resulting from the ingress of water into its pores. The water absorption in this study was carried out according to BS 1881-122: 2003. At the ages of 28 days of water curing, a 150mm cube specimen was placed in an oven at a temperature of 100±5˚C for 48 hours. The specimen is taken out and leftover to cool to room temperature. Then the water absorption is calculated after 72 hours of submerging the specimen in water by using the following Equation (6):

$$\text{Water absorption (\%)} = \frac{W_1 - W_0}{W_0} \times 100 \qquad (6)$$

Where, $W_0 = \text{Mass of oven} - \text{dried cube specimens(Kg)}$

$W_1 = \text{Mass of surface} - \text{dry cube specimens after immersion(Kg)}$

Chemical resistance of concrete cube specimens in sodium sulfate and sodium chloride solution test was determined based on JSTMC 7401: 2000. 150mm concrete cubes were cured for 28 days in a metal tank containing water at room temperature before exposure to the sulfate and chloride environment. Concrete cubes from each batch were transferred to the exposure condition after measuring their initial mass using an electronic balance. Before measuring the initial mass, all concrete cubes were air-dried in laboratory conditions. According to Aye and Oguchi (2011), the most commonly found salt on concrete surfaces exposed to environments conducive to physical sulfate attack is sodium sulfate. Therefore, in order to approach the laboratory work with in situ conditions, all concrete cube specimens were immersed in 5% sodium sulfate and sodium chloride solutions.

In order to evaluate chemical attacks on concrete, a number of different methods have been developed, each of them evaluating a different parameter that may, or may not, indicate the severity of a chemical attack. Currently, the most used ones are expansion measurements, mass loss, strength loss, and elastic modulus variation (El-Hachem *et al*., 2012).

Mass loss and strength loss methods were selected to evaluate sulfate and chloride attack on concrete specimens in this study. Concrete cube specimens were evaluated after 28 days immersion in a solution, whereby the specimens were removed, air-dried for one day in a laboratory environment, and weighed. The weight loss and compressive strength loss were determined using Equation (7) and Equation (8):

$$\text{Weight loss }(\%) = \frac{W_i - W_t}{W_i} \times 100 \qquad (7)$$

Where, Wi = Initial mass of cube specimens (Kg)

Wt = Mass weight cube specimens after a prescribed exposure period (Kg)

$$\text{Compressive strength loss }(\%) = \frac{f_{cr} - f_{cs}}{f_{cr}} \times 100 \qquad (8)$$

Where,

f_{cr} = Reference compressive strength of cube specimens before immerssion(MPa)

f_{cs} = The average compressive strength of cube specimens after immerssion(MPa)

3.5 Data collection

Secondary data: secondary data were used to extract relevant data and information from texts, local and foreign journals, dissertations, thesis, technical papers, local and foreign documents on standards, specifications, and the internet.

Primary data: primary data were involved field sampling and laboratory specimen tests of concrete making materials and concrete properties. It has been noted that the choice of data collection is determined by the outputs required in this study.

3.6 Data analysis

Data analysis is an essential task for ensuring that the researchers have all the relevant data for making contemplated comparison and analysis. Quantitative data analysis involves two considerations. The first is that standard and literature, by advancing relationships between variables via research questions. The second is to ensure that, especially if using a computer, the data have been input correctly. Usually, data have to be processed. Processing implies editing, coding, classification, and tabulation of collected data so that they are suitable for analysis whereas the term analysis refers to the computation of certain measures along with searching for patterns of relationships that exist among data groups (Fellows and Liu, 2015). Since analysis in a general way involves a number of closely related operations which are performed with the purpose of summarizing data that answered the research questions.

3.6.1 Aggregate samples test result data

Aggregate samples test results on physical and mechanical properties were compared against the applicable standard. Results were processed and analyzed using MS Excel. Simple computation, tabulation, plotting charts, and comparison against standards were carried out to facilitate discussion, interpretation, and evaluation of aggregate samples being studied.

3.6.2 Workability test result data

Slump test and compaction factor test results of all concrete batches that composed of different aggregate samples were compared against target slump value where the range is from 30mm to 60mm and degree of workability specified on DOE mix design and BS 206-1, 2000 respectively to evaluate the effect of aggregates on concrete workability.

3.6.3 Hardened density test result data

Hardened density test results of all concrete batches composed of different aggregate samples were compared against the classification of concrete based on weight specified in in BS 5328-1, 2003 to evaluate the effect of aggregates on hardened density.

3.6.4 Compressive strength test result data

Compressive strength test results of concrete batches that compose all aggregate samples were compared against the target mean strength value. This analysis was carried out first calculating the expected target mean strength value according to DOE mix design for each grade of concrete and then comparing the attained compressive strength values of each batch. The percentage of expected target mean strength was calculated by the following Equation (9):

$$(f'c)_t = \frac{t}{4 + 0.85t}(f'c)_{28} \qquad (9)$$

Where,

$(f'c)_t$ = Concrete compressive strength at the age of t days

$(f'c)_{28}$ = Concrete compressive strength the age of 28 days

The experimental compressive strength values of concrete cube specimens at the age of 3, 7, and 28 days were compared and contrasted to evaluate effect of aggregates on the compressive strength of concrete. MS Excel was used for coding, compiling, computing, and comparing stages in the analysis of the data.

3.6.5 Splitting tensile strength test result data

Splitting tensile strength test results of all concrete batches from different aggregate samples were compared against recommended values 10 to 15% of its concrete compressive strength given in BS 206-1, 2000 to evaluate effect of aggregates on split tensile strength.

3.6.6 Durability test result data

Water absorption, sulfate attack resistance, chloride attack resistance test results of all concrete batches from different aggregate samples analysis were done based on standards and previous related literature to evaluate effect of aggregates on concrete durability.

3.7 Summary of materials and methods

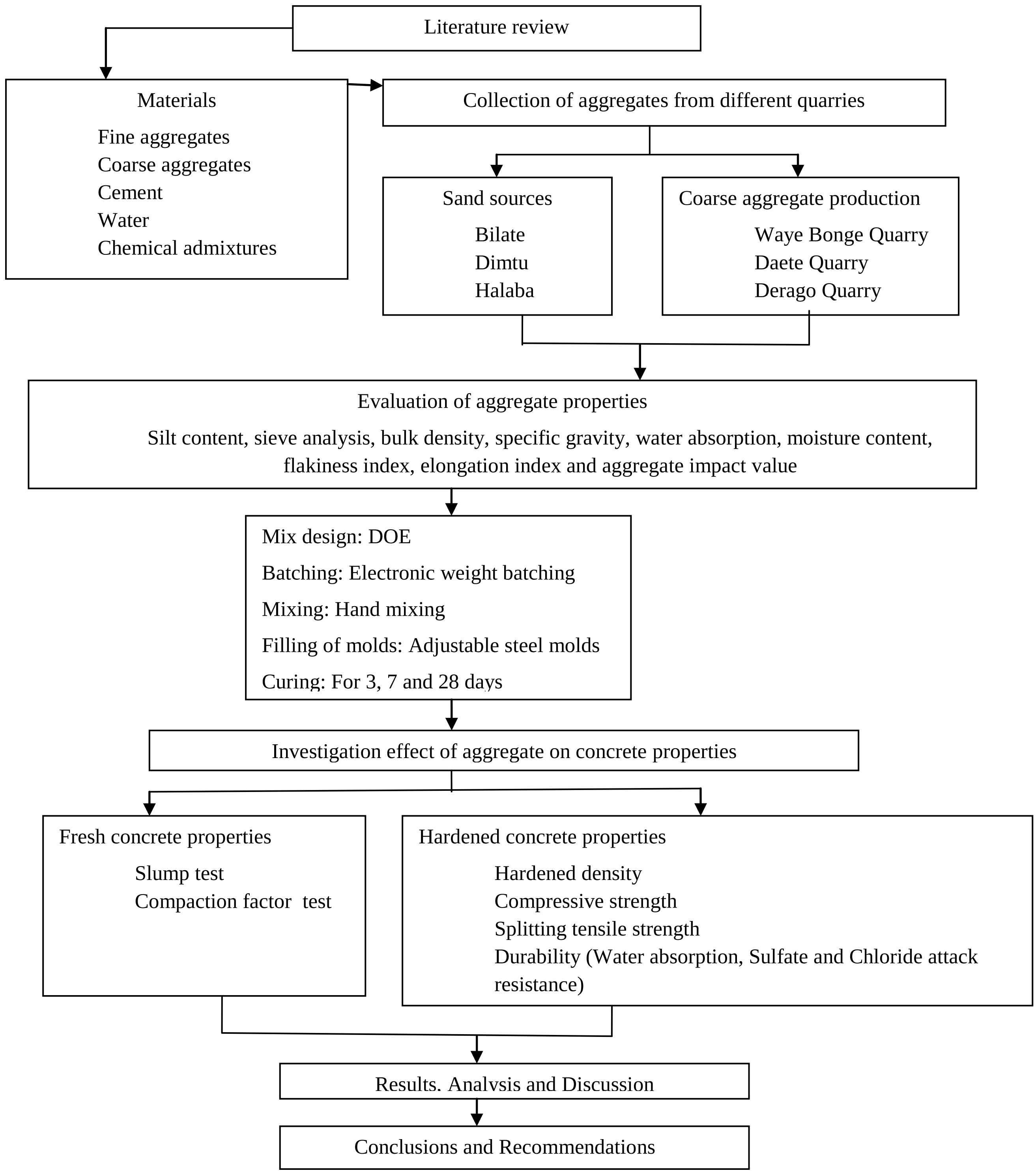


Figure 3.2 Flow diagram of concrete preparation and evaluation

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Results obtained from different aggregates and concrete specimens are addressed in this chapter. First of all, the results of laboratory tests on the physical and mechanical properties of aggregates are presented, analyzed, and discussed against applicable standards. Then, analysis and discussion of the results with much emphasis on the effect of aggregates on concrete workability, hardened density, compressive strength, splitting tensile strength, and durability of concrete.

4.1 Fine aggregate

4.1.1 Sieve analysis

Sieve tests were carried out for fine aggregate samples collected from three quarries with respect to BS 812-103.1:2004 in order to determine particle size distribution and to evaluate fine aggregate samples based on the grading requirement. The particle size distribution of all aggregate samples observed results are summarized in Table 4.1.

Table 4.1 Summary of particle size distribution analysis results for fine aggregate samples

Sieve size (mm)	10	5	2.36	1.18	0.6	0.3	0.15	Remark
Limiting values	Allowable cumulative % passing (Grading requirement for fine aggregate as per BS 882: 2003 (Grading Zone 1)							
Lower limit	100	90	60	30	15	5	0	
Upper limit	100	100	95	70	34	20	10	
Bilate	100	96.93	89	66.07	26.87	6.07	1.6	Complying
Limiting values	Allowable cumulative % passing (Grading requirement for fine aggregate as per BS 882: 2003 (Grading Zone 2)							
Lower limit	100	90	75	55	35	8	0	
Upper limit	100	100	100	90	59	30	10	
Dimtu	100	97.93	94.87	82.13	43.27	12.87	3.4	Complying
Halaba	100.0	97	91.67	78	40	9.67	1.33	Complying

Particle size distribution

The particle size distribution curve obtained is presented in Figure 4.1 which is the graphical presentation of results contained in Table 4.1 it shows that all fine aggregates fell within the upper and lower limits specified by BS 882: 2003. This result indicates that all fine aggregate samples show acceptable limits in all the size ranges. Nevertheless, according to the Unified Soil Classification System (USCS) the samples were classified in ASTM D 2487: 2000 presented in Table 4.2, all fine aggregates can be classified as poorly graded sand with silt.

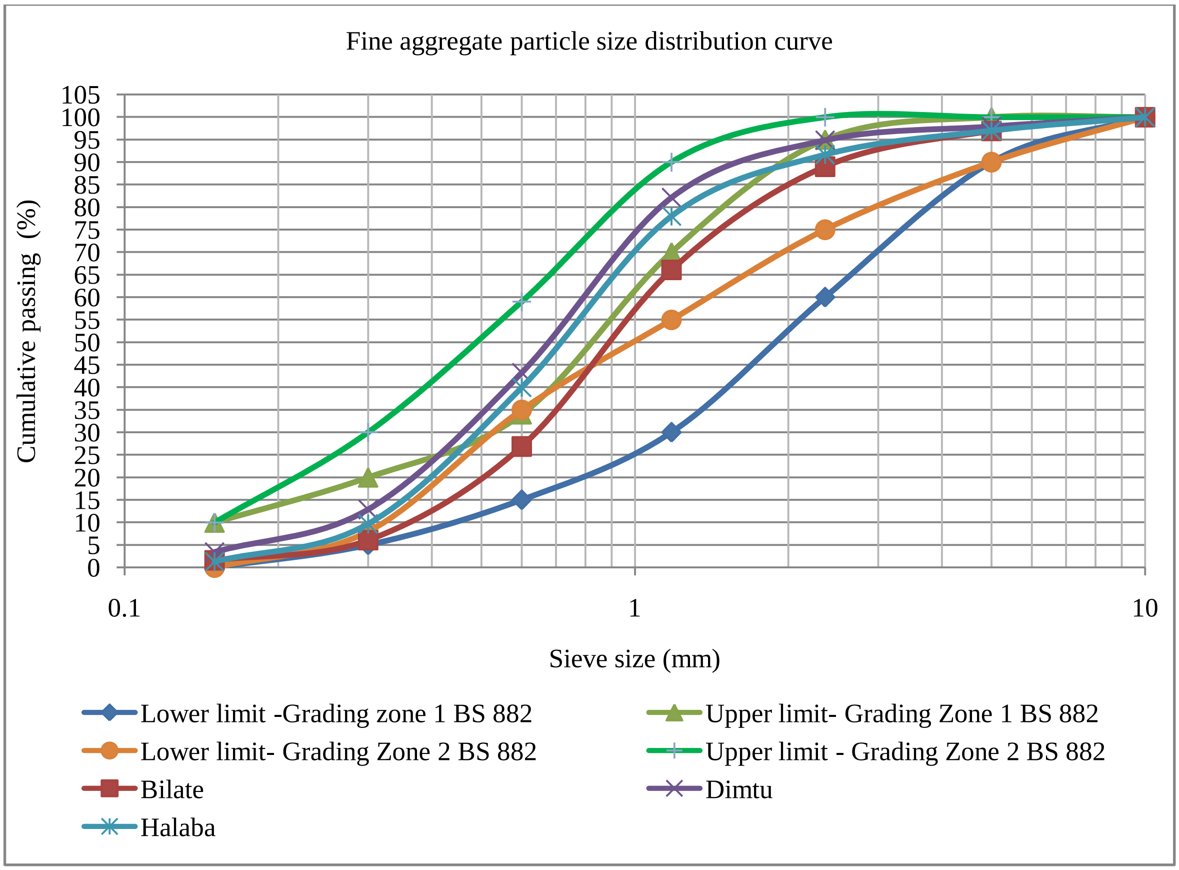


Figure 4.1 Fine aggregate particle size distribution curve

Table 4.2 shows the coefficient of uniformity (Cu) and coefficient of curvature (Cc) computed from the results of particle size distribution analysis. The result from Table 4.2 was used for sample classification according to the Unified Soil Classification System described in ASTM D 2487: 2000.

Table 4.2 Soil classification according to USCS for fine aggregates (ASTM D 2487: 2000)

Sample	Cu	Cc	Group symbol	Group name
Bilate	3.06	1.07	SP-SM	Poorly Graded Sand With Silt
Dimtu	3.34	1.02	SP-SM	Poorly Graded Sand With Silt
Halaba	2.99	0.91	SP-SM	Poorly Graded Sand With Silt

Bilate sand particle size distribution: Figure 4.2 which is the graphical presentation of results contained in Table 4.1 indicates that fine aggregate from Bilate is within acceptable limits in all the size ranges. The classification results obtained in Table 4.2 shows that the coefficient of uniformity (Cu) is 3.06 and its coefficient of curvature (Cc) is 1.07 for Bilate sand samples. This implies that Bilate sand is classified under poorly graded sand with silt since Cu is less than 6 and its Cc is close to 1 with a silt content of 12 % greater than the maximum 5% allowed for pure sand classification.

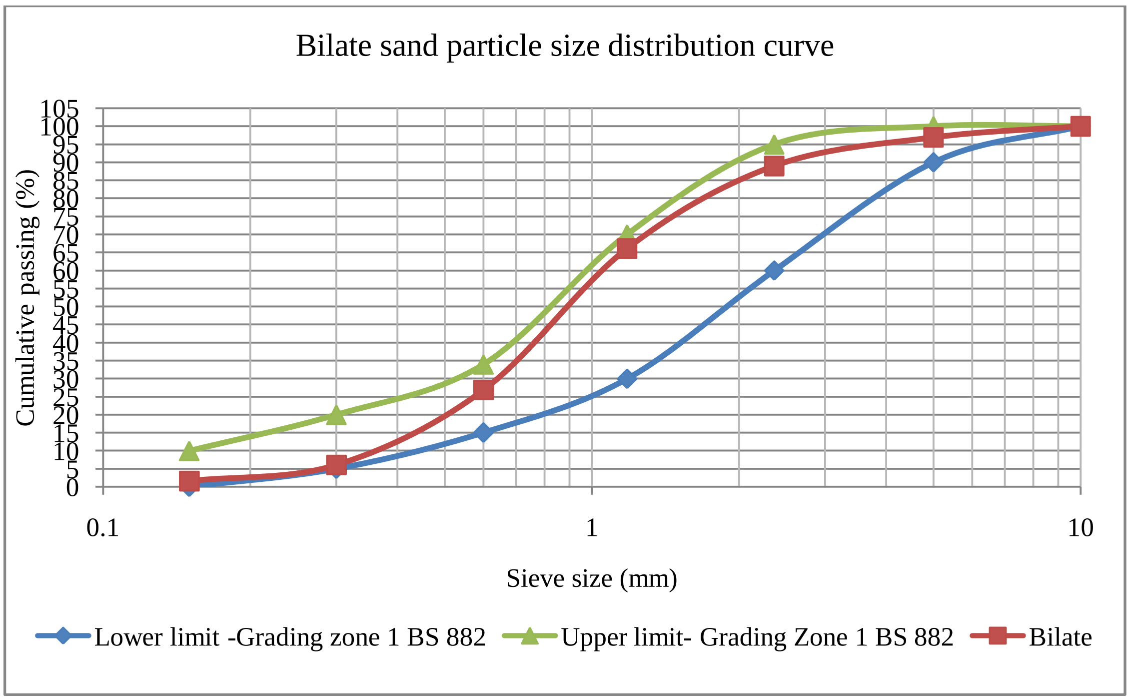


Figure 4.2 Bilate sand particle size distribution curve

Dimtu sand particle size distribution**:** Figure 4.3 which is the graphical presentation of results contained in Table 4.1 indicates that fine aggregate from Dimtu is within acceptable limits in all the size ranges. The classification results obtained in Table 4.2 shows that the coefficient of uniformity (Cu) is 3.34 and its coefficient of curvature (Cc) is 1.02 for Dimtu sand samples. This implies that Dimtu sand is classified under poorly graded sand with silt since Cu is less than 6 and its Cc is close to 1 with a silt content of 7.5 % greater than the maximum 5% allowed for pure sand classification.

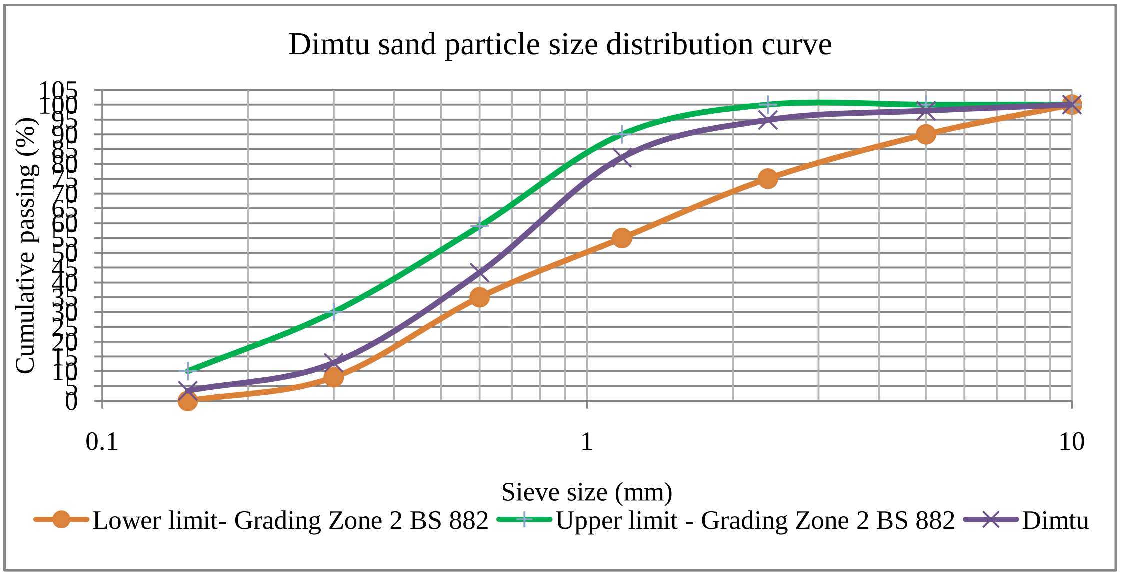


Figure 4.3 Dimtu sand particle size distribution curve

Halaba sand particle size distribution**:** Figure 4.4 which is the graphical presentation of results contained in Table 4.1 indicates that fine aggregate from Halaba is within acceptable limits in all the size ranges. The classification results obtained in Table 4.2 shows that the coefficient of uniformity (Cu) is 2.99 and its coefficient of curvature (Cc) is 0.91 for Halaba sand samples respectively. This implies that Halaba sand is classified under poorly graded sand with silt since Cu is less than 6 and its Cc is close to 1 with a silt content of 9.6 % greater than the maximum 5% allowed for pure sand classification.

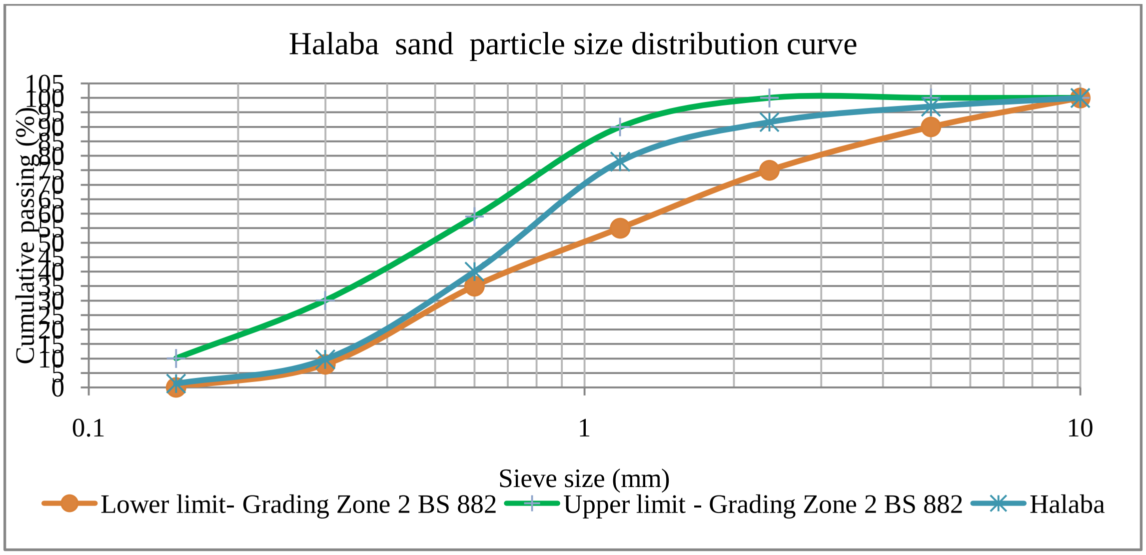


Figure 4.4 Halaba sand particle size distribution curve

The classification results show that all sand samples were poorly graded sand with silt according to USCS (ASTM D 2487: 2000). Furthermore, all of the samples have silt components due to the presence of a considerable amount of silt content greater than the maximum 5% allowed for pure sand classification. This implies that unwashed sand is not fairly graded. The implication of this poor grading and silt content being on the high side is that concrete made from these materials might pose concrete workability, strength, and durability problems and necessary measures such as the introduction of mineral admixture adjustment, reduction of silt content, and suitable blends of sand within fine, medium and coarse ranges to avoid this problem should be considered (Neville, 2011; Yalley and Sam, 2018 and Sabih *et al.*, 2016).

Fineness modulus (FM)

Results of fineness modulus (FM) computed from results of particle size distribution analysis are presented in Table 4.1. It can be observed from Table 4.3 that the fineness modules result of fine aggregates is 2.66 for Dimtu, 2.82 for Halaba, and 3.13 for Bilate within the range of 2.3-3.1 given in BS 12620: 2002. This implies that fine aggregate source from Bilate is classified under coarse fineness since its FM within ranges 2.9-3.5.

While fine aggregates sources from Dimtu and Halaba are classified under medium fineness since its FM within ranges 2.0-2.9.

Table 4.3 Fine aggregates classification based on fineness modulus (FM)

Sample code	FM	Fineness
Bilate	3.13	Coarse
Dimtu	2.66	Medium
Halaba	2.82	Medium

On the basis of the fineness modulus (FM) classification results shows that fine aggregate source from Bilate has coarse fineness while from Dimtu and Halaba have medium fineness. This result implies that Bilate sand will tend to produce concrete that is harsh, bleed, and segregated. Dimtu and Halaba sand require a comparatively greater amount of water to produce the necessary fluidity. Obla (2011) reported that usually very coarse sand or very fine sand is unsatisfactory for concrete making. Remedies that have to be taken like blending of sand within the fine, medium, and coarse ranges should be considered (Sabih *et al.*, 2016).

Grading zone as per cumulative percentage passing 0.6mm sieve

The grading zone of all fine aggregates obtained from the results of particle size distribution analysis is presented in Table 4.4. The results presented in Table 4.4 shows that the value of cumulative percentage passing 0.6mm 26.87% for Bilate, 43.27% for Dimtu, and 40% for Halaba given in BS 882: 2003. This implies that fine aggregate source from Bilate is classified under grading zone 1 since its cumulative percentage passing 0.6mm within ranges 15-34%. While fine aggregates sources from Dimtu and Halaba are classified under grading zone 2 since its cumulative percentage passing 0.6mm within ranges 35-59%.

Table 4.4 Classification of fine aggregates based on value of cumulative passing 0.6mm

Sample code	Cumulative % passing 0.6mm	Grading zone
Sand sample having 15-34 % of cumulative % passing 0.6mm		
Bilate	26.87	Grading zone 1
Sand sample having 35-59 % of cumulative % passing 0.6mm		
Dimtu	43.27	Grading zone 2
Halaba	40	Grading zone 2

The classification of fine aggregates based on results of cumulative percentage passing 0.6mm obtained from particle size distribution analysis implies that fine aggregate source from Bilate grouped under grading zone 1 and fine aggregate source from Dimtu and Halaba grouped under grading zone 2 for the determination of fine aggregates proportion in the process of DOE mix design in the present study.

4.1.2 Silt content

Results of the silt content of fine aggregates are presented in Table 4.5. The result shows that the maximum average silt content was 12% for Bilate sand compared with the minimum 7.5% for Dimtu sand and 9.6% for Halaba sand were carried out according to BS 812-103.1:2004. BS 882: 2003 recommends that no more than a maximum of 4% silt content for fines aggregates be used in concrete production. This result of silt content shows that all fine aggregate samples have values greater than the maximum of 4% specified in BS 882: 2003.

Table 4.5 Silt content in fine aggregate

Sample	Silt content (%)	Remark
Bilate	12.0	Not complying
Dimtu	7.5	Not complying
Halaba	9.6	Not complying

The result shows that fine aggregate samples contained silt content that exceeded the allowable limits. This implies that all fine aggregates are unwashed. Studies have shown that a higher amount of sand fines in concrete results in poor workability. The study also reported that increased silt content in fine aggregate requires more water content to obtain the required workability (Heerden and Booyens, 2017). According to Cho (2013), Neville (2011), and Kosmatka and Wilson (2011) silt content of sand when present at an undesirable level will result in seriously affect bond development between aggregate particles and the cement paste and subsequently affecting strength and durability of concrete.

4.1.3 Specific gravity

Fine aggregate samples were subjected to specific gravity tests obtained in BS 812-Part 2 :2004. Results of the specific gravity of all the samples tested are illustrated in Table 4.6. The result shows that varies from a minimum of 2.38 (Bulk Sp. Gr.) for Halaba to a maximum of 2.61 (Apparent Sp. Gr.) for Dimtu fine aggregate samples. Specifically, the bulk specific gravity ranges from 2.38-2.40, the surface-saturated-dry specific gravity ranges from 2.44-2.48. As expected, the relation Bulk Sp. Gr. < SSD < Apparent, holds for the entire fine aggregate samples. BS 882: 2003 specifies specific gravity from 2.4-3.0 for normal-weight aggregates.

Table 4.6 Fine aggregate specific gravity

Samples	Bulk Sp. Gr	Bulk Sp gr (SSD)	Apparent Sp. gr. (SSD)	Remark
Bilate	2.40	2.44	2.50	Complying
Dimtu	2.40	2.48	2.61	Complying
Halaba	2.38	2.46	2.59	Complying

From the result, it is observed that fine aggregate samples compare well with the expected specific gravity values that were specified. This implies that fine aggregates from Bilate, Dimtu, and Halaba used in concrete production were within the normal range for building sand.

4.1.4 Water absorption

Water absorption for fine aggregate samples tests obtained in BS 812-Part 2:2004. Water absorption of fine aggregate samples tested is mentioned in Table 4.7. Based on fine aggregate samples tested, the maximum average water absorption was 3.46% for Halaba compared with the minimum 1.70% for Bilate and 3.45% for Dimtu slightly lower than Halaba. BS 882: 2003 recommends that no more than a maximum of 2% water absorption for fines aggregates be used to produce concrete.

Table 4.7 Fine aggregate water absorption

Samples	Water absorption	Remark
Bilate	1.70	Complying
Dimtu	3.45	Not complying
Halaba	3.46	Not complying

From the result, it is obtained that the rates of water absorption for Dimtu and Halaba sand samples tested have values of 3.45% and 3.46% respectively are above 2% specified in BS 882: 2003 except for Bilate sand with a value of 1.70% below 2%. In concrete mix proportioning, for a given water-cement ratio (w/c), the aggregates with considerable absorption will require additional water and cement to meet the w/c requirement and make the fresh concrete workable (Neville, 2011).

4.1.5 Bulk density

Bulk density tests were performed on the samples based on BS 812: 102. Both loose and compacted bulk density of fine aggregate samples is presented in Table 4.8. The results of loose bulk density range from 1298.42Kg/m^3 for Dimtu sand to 1309.11Kg/m^3 for Bilate sand and 13088.48Kg/m^3 for Halaba sand slightly lower than Bilate sand. While compacted bulk density ranges from 1410.40 Kg/m^3 for Bilate sand to 1414.80 Kg/m^3 for Dimtu sand and1412.28Kg/m^3 for Halaba sand within similar ranges with other fine aggregate samples. The BS 882: 2003 suggests 1200 to 1750Kg/m^3 as an acceptable bulk density for aggregates to be part of concrete.

Table 4.8 Fine aggregate bulk density

Samples	Loose bulk density(Kg/m^3)	Compacted bulk density(Kg/m^3)
Bilate	1309.11	1410.40
Dimtu	1298.42	1414.80
Halaba	1308.48	1412.28

These results shows that samples satisfactorily fit normal weight aggregates can be used as fine aggregate for normal weight concrete.

4.2 Coarse aggregate

4.2.1 Sieve analysis

Sieve analysis was carried out for coarse aggregate samples collected from three crushing quarry sites were performed according to BS 812-103.1: 2004 in order to determine particle size distribution and evaluate the samples based on grading requirements for the coarse aggregate. The percentage of coarse aggregate tested sample results are summarized and presented in Table 4.9.

Table 4.9 Summary of particle size distribution analysis results for coarse aggregate samples

Sieve size (mm)	37.5	25	20	14	10	5	Remark
Limiting values	Allowable cumulative % passing (Grading requirement for CA as per BS 882: 2003						
Lower limit	100	95	85	0	0	0	
Upper limit	100	100	100	70	25	5	
Cumulative % passing for nominal sizes 25 mm coarse aggregate samples							
WB B	100	78.37	53.27	20.27	0.7	0.23	Not complying
DT B	100	78.53	46.57	20.97	2.63	0.37	Not complying
DG B	100	66.03	30.47	6.5	0.2	0.17	Not complying
Limiting values	Allowable cumulative % passing (Grading requirement for CA as per BS 882: 2003						
Lower limit				100	85	0	
Upper limit				100	100	25	
Cumulative % passing for nominal sizes 10 mm coarse aggregate samples							
WB A				100	64.33	0.17	Not complying
DT A				100	99.75	0.08	Complying
DG A				100	85.1	1.75	Complying

Particle size distribution

The particle size distribution curve obtained is presented in Figure 4.5 which is the graphical presentation of results contained in Table 4.9 it shows that all coarse aggregates except DT A and DG A did not fell within the upper and lower limits specified by BS 882: 2003. This result indicates that coarse aggregates samples from Daete and Derago quarries with 10mm nominal maximum size showed acceptable limits in all the size ranges. While coarse aggregates samples from all quarries with 25mm nominal maximum size and Waye Bonge quarry with 10mm nominal maximum size shows that not complying acceptable limits specified under BS 882: 2003.

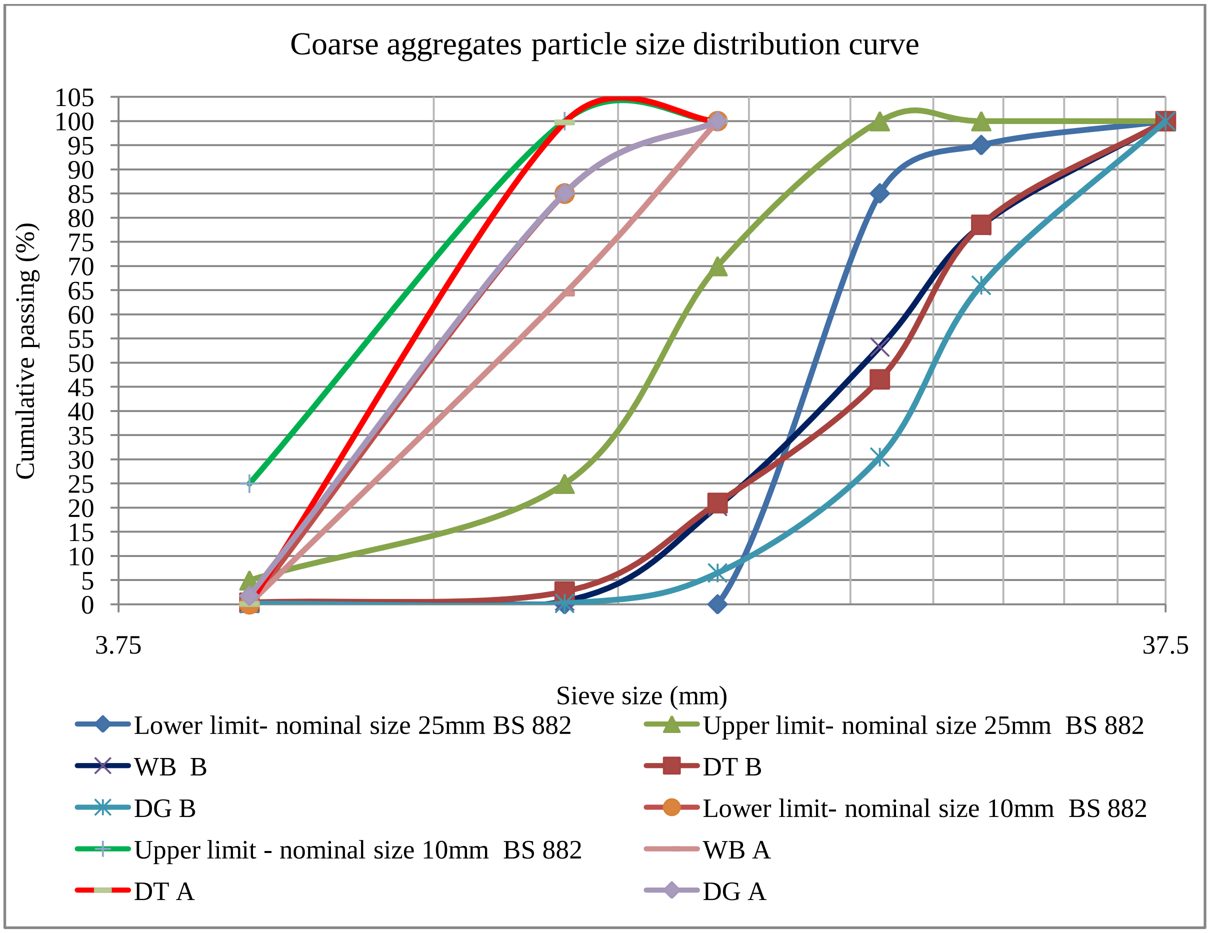


Figure 4.5 Coarse aggregate particle size distribution curve

Particle size distribution results in tabular and graphical depicted above, revealed that all coarse aggregate quarries are unsatisfactory in the production of 25 mm nominal maximum size. While Daete and Derago quarries are satisfactorily producing 10 mm nominal maximum size inversely Waye Bonge quarry is not complying. The particle size distribution of the sample is of utmost importance in the view that voids percentage, as well as interconnection, governed the engineering properties of particle aggregate matrix. Thus existed characters are enhanced by having a binder material called cement paste to yield concrete (Pawar *et al.*, 2016).

4.2.2 Specific gravity

Coarse aggregate samples were subjected to specific gravity tests obtained in BS 812-Part 2 :2004. Results of the specific gravity of coarse aggregate samples tested are presented in Table 4.10. The results show that for 10 mm nominal maximum size of aggregates varying from a minimum of 2.50 (Bulk Sp. Gr.) for Waye Bonge Quarry to a maximum of 2.65 (Apparent Sp. Gr.) for Daete Quarry. Specifically, the bulk specific gravity ranges from 2.50-2.55, the surface-saturated-dry specific gravity ranges from 2.54-2.59. In addition, the result shows that for 25 mm diameter nominal maximum size of aggregates varies from a minimum of 2.53 (Bulk Sp. Gr.) for Derago Quarry to a maximum of 2.66 (Apparent Sp. Gr.) for Waye Bonge Quarry. Specifically, the bulk specific gravity ranges from 2.53-2.56, the surface-saturated-dry specific gravity ranges from 2.57-2.60. As expected, the relation Bulk Sp. Gr. < SSD < Apparent, holds for the entire aggregate samples. BS 882: 2003 specifies specific gravity from 2.4-3.0 for normal-weight aggregates.

Table 4.10 Coarse aggregate specific gravity

Samples	Bulk Sp. Gr.	Bulk Sp Gr. (SSD)	Apparent Sp. Gr. (SSD)	Remark
WB B	2.56	2.60	2.66	Complying
DT B	2.54	2.58	2.65	Complying
DG B	2.53	2.57	2.63	Complying
WB A	2.50	2.54	2.61	Complying
DT A	2.55	2.59	2.65	Complying
DG A	2.52	2.57	2.64	Complying

From the result, it is observed that coarse aggregate compares well with the expected values of specific gravity that was specified. This implies that coarse aggregates from Waye Bonge Quarry, Daete Quarry, and Derago Quarry used in concrete production were within the normal range for building aggregates.

4.2.3 Water absorption

Water absorption for coarse aggregate samples tests in accordance with BS 812-Part 2 :2004. The rates of water absorption of coarse aggregate samples tested are presented in Table 4.11. Based on coarse aggregate samples tested, the maximum average water absorption was 1.80% for both Waye Bonge Quarry and Derago Quarry compared with the minimum 1.52% for Daete Quarry for 10 mm nominal maximum size of aggregates. In addition, the maximum average water absorption values were 1.69% for Daete Quarry compared with the minimum 1.39% for Waye Bonge Quarry and 1.52% for Derago Quarry slightly higher than Waye Bonge Quarry for 25 mm nominal maximum size of aggregates. BS 882: 2003 recommends that no more than a maximum of 4% water absorption for coarse aggregates be used in concrete production.

Table 4.11 Fine aggregate water absorption

Samples	Water absorption	Remark
WB B	1.39	Complying
DT B	1.69	Complying
DG B	1.52	Complying
WB A	1.80	Complying
DT A	1.52	Complying
DG A	1.80	Complying

From the results, it was obtained that the rates of water absorption for all coarse aggregate samples tested have values that are within the acceptable limits of less than 4% specified in BS 882: 2003. The samples of aggregate are all below 2% indicates that low effective porosity. This relatively low value of water absorption suggests the suitability of these aggregates in concrete production. All the samples have a water absorption of less than 2%, which implies that they are strong aggregates for most construction work.

4.2.4 Bulk density

Bulk density tests were performed on coarse aggregate samples based on BS 812: 102. Both loose and compacted bulk density of coarse aggregate samples is presented in Table 4.12. The result showed that for 10 mm nominal maximum size of aggregates loose bulk density ranges from 1261.30Kg/m^3 for Derago Quarry to 1288.35Kg/m^3 for Daete Quarry and 1262.56Kg/m^3 for Waye Bonge Quarry slightly higher than Derago Quarry. In addition, an average loose bulk density values for 25 mm nominal maximum size of aggregates were 1289.61Kg/m^3 for Daete Quarry to 1327.36Kg/m^3 for Waye Bonge Quarry and 1292.13Kg/m^3 for Derago Quarry slightly higher than Daete Quarry. While compacted bulk density for 10 mm nominal maximum size of aggregates result showed that ranges from 1378.94Kg/m^3 for Waye Bonge Quarry to 1402.22Kg/m^3 for Daete Quarry and 1384.60 Kg/m^3 for Derago Quarry slightly higher than Waye Bonge Quarry. In addition, the average compacted bulk density values for 25 mm nominal maximum size of aggregates was 1414.17Kg/m^3 for Waye Bonge to 1436.19Kg/m^3 for Daete Quarry Quarry and 1433.04Kg/m^3 for Derago Quarry slightly lower than Daete Quarry. The BS 882: 2003 suggests 1200 to 1750Kg/m^3 as acceptable bulk density weight for aggregates to be part of concrete.

Table 4.12 Coarse aggregate bulk density

Samples	Loose bulk density (Kg/m^3)	Compacted bulk density (Kg/m^3)	Remarks
WB B	1327.36	1414.17	Complying
DT B	1289.61	1436.19	Complying
DG B	1292.13	1433.04	Complying
WB A	1262.56	1378.94	Complying
DT A	1288.35	1402.22	Complying
DG A	1261.30	1384.60	Complying

These results shows that samples satisfactorily fit normal weight aggregates can be used as coarse aggregate for normal weight concrete.

4.2.5 Flakiness Index

Flakiness index for coarse aggregate samples tests obtained in BS 812-105.1: 2004. The flakiness index of coarse aggregate samples tested is illustrated in Table 4.13. Based on coarse aggregate samples tested, the maximum average flakiness index was 24.79% for Waye Bonge Quarry compared with the minimum 11.90% for Daete Quarry and 18.87% for Derago Quarry. According to BS 882: 2003 flakiness index must be less than 40% for coarse aggregates to be used to produce concrete.

Table 4.13 Coarse aggregate flakiness index

Samples	Flakiness index (%)	Remarks
WB B	24.79	Complying
DT B	11.90	Complying
DG B	18.87	Complying

From the results, it was obtained that the flakiness index for all coarse aggregate samples tested has values within the acceptable limits below 40% specified in BS 882: 2003. Waye Bonge Quarry with maximum values of 24.79 % flakiness index indicates that the aggregate sample is poorly shaped and consists of a high proportion of flaky shaped particles when compared to others. While Daete Quarry with lower values of 11.90 % flakiness index indicates that the aggregate sample is a better-shaped particle.

4.2.6 Elongation Index

Elongation index for coarse aggregate samples tests obtained in BS 812-105.2: 2004. The elongation index of coarse aggregate samples tested is illustrated in Table 4.14. Based on coarse aggregate samples tested, the maximum average elongation index was 38.02% for Derago Quarry compared with the minimum 33.65% for Daete Quarry and 36.27% for Waye Bonge Quarry. BS 882: 2003 specified that a maximum 40% elongation index is desirable for coarse aggregates to be used to produce concrete.

Table 4.14 Coarse aggregate elongation index

Samples	Flakiness index (%)	Remarks
WB B	36.27	Complying
DT B	33.65	Complying
DG B	38.02	Complying

From the results, it was obtained that the elongation index for all coarse aggregate samples tested has values within the acceptable limits below 40% specified in BS 882: 2003. The three coarse aggregate quarries have values of slightly varying among their elongation index indicates that the aggregate sample is poorly shaped and consists of a high proportion of elongated shaped particles.

4.2.7 Aggregate Impact Value

Aggregate Impact Value for coarse aggregate samples tests obtained in BS 812-112: 2004. AIV of coarse aggregate samples tested are presented in Table 4.15. Based on coarse aggregate samples tested, the maximum average AIV was 18.70% for Waye Bonge Quarry compared with the minimum 15.41% for Daete Quarry and 15.63% for Derago Quarry slightly lower than Daete Quarry for 10 mm nominal maximum size of aggregates. In addition, the maximum average AIV was 12.27% for Waye Bonge Quarry compared with the minimum 10.35% for Daete Quarry and 11.88% for Derago Quarry for 25 mm nominal maximum size of aggregates. BS 882: 2003 specified that a maximum of 25% AIV is desirable for coarse aggregates to be used to produce concrete.

Table 4.15 Aggregate Impact Value (AIV) of coarse aggregate

Sample code	Aggregate Impact Value (AIV) (%)
WB B	12.27
DT B	10.35
DG B	11.88
WB A	18.70
DT A	15.41
DG A	15.63

The Aggregate Impact Value obtained for all the samples is below the maximum value of 25% specified in BS 882: 2003. It indicates that the aggregate is strong enough and has good properties and is, therefore, suitable for concrete production.

4.3 Effect of aggregates on concrete workability

4.3.1 Compaction factor test

4.3.1.1 Compaction factor test of C-30 concrete grade

The results of the workability test in terms of compaction factor values for the various mixing batches are explained in Figure 4.6. The degree of workability of concrete batches prepared from aggregates collected from different quarries had different compaction factor values ranging from a minimum of low 0.834 for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of medium 0.917 for DMDT where the concrete prepared from DM sand and DT Quarry. All concrete batches prepared from different aggregates had a medium degree of workability compaction factor values ranging from 0.854 to 0.917 except the BLWB concrete batch had a low degree of workability compaction factor value of 0.834.

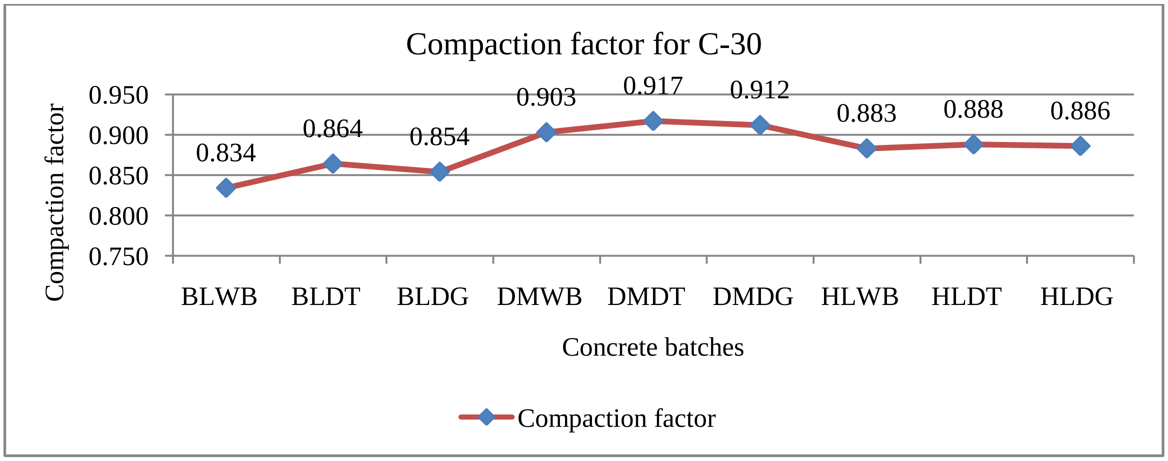


Figure 4.6 Compaction factor results of C-30 concrete grade

The compaction factor of concrete batches prepared with different aggregates is shown in Figure 4.6. Results show that the compaction factor values of concrete prepared with different sands whose gradation according to the Unified Soil Classification System (USCS) classified as poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have a medium degree of workability except BLWB concrete batch had a low degree of workability compaction factor. Compaction factor will have a low degree of workability with poorly graded aggregates because of high void content. This implies that concrete prepared from poorly graded aggregates will have a low degree of workability. Thus remedies that have to be taken as a reduction of silt content and blending of sand within a fine, medium, and coarse ranges should be considered. It is noted that this result is again similar to the reports by Pawar *et al*. (2016) and Sabih *et al.* (2016).

The results show that in Figure 4.6 a reduction in concrete workability compaction factor values of 0.834 for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and maximum compaction factor values of 0.917 for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. The decrease in compaction factor value as a result of an increase in fines percentage in the sand can be attributed to the fact that finer particles have a larger surface area which absorbs more water in the concrete mix. This implies that compaction factor values decreased as the percentage of the fines in sand increased agreeing with earlier reports Olusola et al. (2012), Iyappan and Manu (2015), Heerden and Booyens (2017), and Yalley and Sam, (2018).

The results show that in Figure 4.6 a reduction in concrete workability minimum compaction factor values of 0.834 for BLWB concrete batch prepared from WB quarry with highest flakiness index of 24.79%; and maximum compaction factor values of 0.917 for DMDT concrete batch prepared from Daete quarry with lowest flakiness index of 11.90%. This implies that compaction factor values of concrete are influenced by the flaky aggregate content compaction factor values decrease with increasing the flaky aggregate content and its use should therefore be limited to avoid the unexpected mixture properties that might be occurred during construction (Khan and Dhobale, 2018).

Figure 4.6 shows that a reduction in concrete workability minimum compaction factor values of 0.834 for BLWB concrete batch prepared from BL sand to WB quarry ratio of 0.82;

and maximum compaction factor values of 0.917 for DMDT concrete batch prepared from DM sand to DT quarry ration of 0.61. It is also observed that compaction factor values decreases as the quantity of fine aggregate is increased and this is likely due to the increase in the surface area of the aggregate proportion and the dryness of the concrete mix. This result indicates that adequate paste content and aggregate surface area is required to achieve a certain degree of workability (Okonkwo and Emmanuel, 2018).

4.3.1.2 Compaction factor test of C-50 concrete grade

The result of the workability test in terms of compaction factor values for the various mixing batches is explained in Figure 4.7. The degree of workability of concrete batches prepared from aggregates collected from different quarries had different compaction factor values ranging from a minimum of low 0.802 for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of medium 0.895 for DMDT where the concrete prepared from DM sand and DT Quarry. All concrete batches prepared from different aggregates had a medium degree of workability compaction factor values ranging from 0.863 to 0.895 except concrete batch prepared from BL sand with coarse aggregate quarries had a low degree of workability.

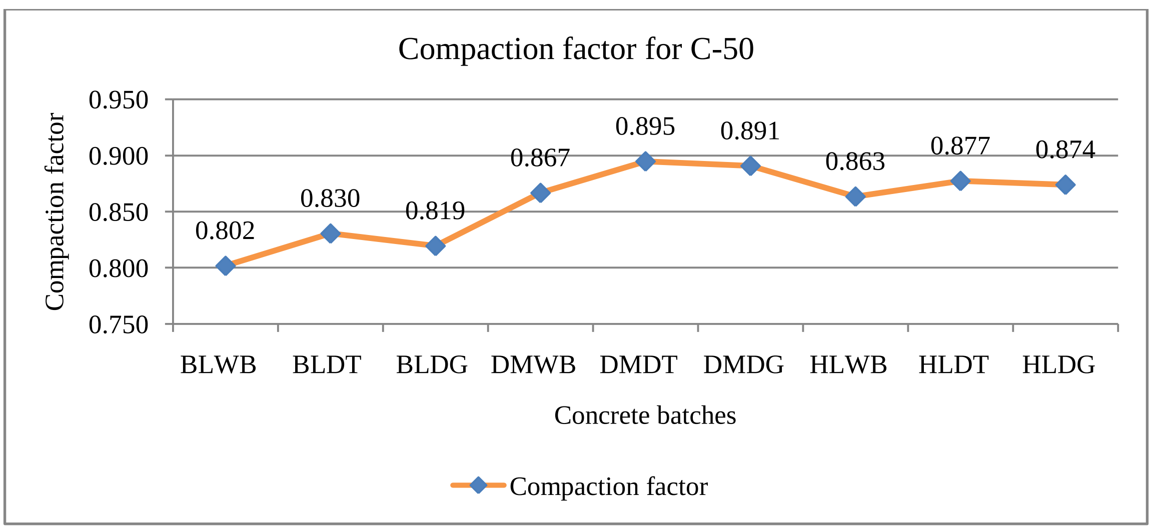


Figure 4.7 Compaction factor results of C-50 concrete grade

The compaction factor of concretes prepared with different aggregates is shown in Figure 4.7. Results show that compaction factor values of concrete prepared with BL sands whose gradation according to the Unified Soil Classification System (USCS) classified as poorly graded sand with the highest silt content of 12% and different coarse aggregate quarries have a low degree of workability. However, compaction factor values of concrete prepared with DM sand and HL sand with silt content of 7.5% and 9.6% respectively and coarse aggregate from DT quarry and DG quarry whose gradation is complying and WB quarry not complying with a specification in BS 882: 2003 and have a medium degree of workability. Compaction factor will have a low degree of workability with poorly graded aggregates because of high void content. This implies that concrete prepared from poorly graded aggregates will have a low degree of workability. Thus remedies that have to be taken as a reduction of silt content and blending of sand within a fine, medium, and coarse ranges should be considered. It is noted that this result is again similar to the reports by Pawar *et al*. (2016 and Sabih *et al.* (2016).

The results show that in Figure 4.7 a reduction in concrete workability compaction factor values of 0.802 for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and maximum compaction factor values of 0.895 for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. The decrease in compaction factor value as a result of an increase in fines percentage in the sand can be attributed to the fact that finer particles have a larger surface area which absorbs more water in a concrete mix. This implies that compaction factor values decreased as the percentage of the fines in sand increased agreeing with earlier reports Olusola et al. (2012), Iyappan and Manu (2015), Heerden and Booyens (2017), and Yalley and Sam, (2018).

Figure 4.7 shows that a reduction in concrete workability minimum compaction factor values of 0.802 for BLWB concrete batch prepared from BL sand to WB quarry ratio of 1.22; and maximum compaction factor values of 0.895 for DMDT concrete batch prepared from DM sand to DT quarry ration of 0.85. It is also observed that compaction factor values decrease as the quantity of fine aggregate is increased and this is likely due to the increase in the surface area of the aggregate proportion and the dryness of the concrete mix. This result indicates that adequate paste content and aggregate surface area is required to achieve a certain degree of workability (Okonkwo and Emmanuel, 2018).

The compaction factor of concrete can increase with the addition of water-reducing admixtures without increasing water content. In the present study 1% by weight of cement High Range Water Reducer (HRWR) super plasticizing admixture which conforms with BS 5075-3: 2004 and ASTM C 494: 2004 were added to C-50 concrete grade to increase consistency while reducing water content by 15 % (Mehta and Monteiro, 2014 and Hora, 2014).

4.3.2 Slump cone test

4.3.2.1 Slump cone test of C-30 concrete grade

The results of the workability test given the slump values for the various mixing batches are explained in Figure 4.8. The degree of workability of concrete batches prepared from aggregates collected from different quarries had different slump values ranging from a minimum of low 27 mm for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of low 46 mm for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had an intermediate low degree of workability sump values ranging from 30mm to 40mm. Therefore, target slump has been achieved, where the range is from 30mm to 60mm except BLWB concrete batch slump values of 27mm.

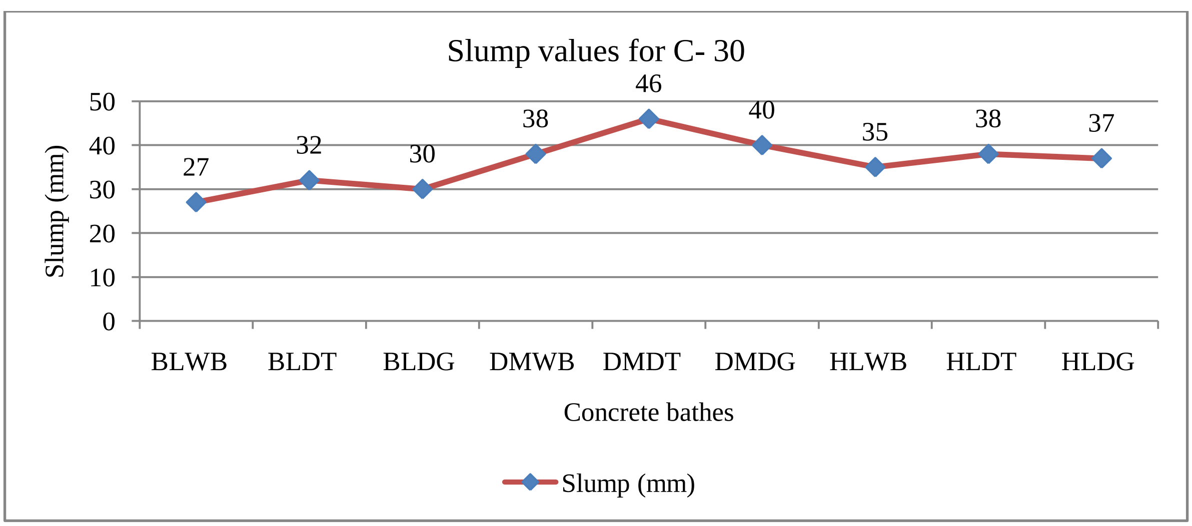


Figure 4.8 Slump values for C-30 concrete grade

The slump of concrete prepared with different aggregates is shown in Figure 4.8. Results show that the slump values of concrete prepared with different sands whose gradation according to the Unified Soil Classification System (USCS) classified as poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have a low degree of workability. The slump will have a low degree of workability with poorly graded aggregates because of high void content. This implies that concrete prepared from poorly graded aggregates will have a low degree of workability. Thus remedies that have to be taken as a reduction of silt content and blending of sand within a fine, medium, and coarse ranges should be considered. It is noted that this result is again similar to the reports by Pawar *et al*. (2016) and Sabih *et al.*, (2016).

The results show that in Figure 4.8 suggest a reduction in concrete workability slump values of 27mm for BLWB concrete batch prepared from Bilate sand with the highest silt content of 12%; and maximum slump values of 46mm for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. The decrease in slump value as a result of an increase in fines percentage in the sand can be attributed to the fact that finer particles have a larger surface area which absorbs more water in a concrete mix. This implies that slump values decreased as the percentage of the fines in sand increased agreeing with earlier reports Olusola et al. (2012), Iyappan and Manu (2015), Heerden and Booyens (2017), and Yalley and Sam, (2018).

The results show that in Figure 4.8 suggest a reduction in concrete workability minimum slump values of 27mm for BLWB concrete batch prepared from WB quarry with highest flakiness index of 24.79%; and maximum slump values of 46mm for DMDT concrete batch prepared from Daete quarry with lowest flakiness index of 11.90%. This implies that slump values of concrete are influenced by the flaky aggregate content slump values decrease with increasing the flaky aggregate content and its use should therefore be limited to avoid unexpected mixture properties that might be occurred during construction (Khan and Dhobale, 2018).

Figure 4.8 shows that a reduction in concrete workability minimum slump values of 27mm for BLWB concrete batch prepared from BL sand to WB quarry ratio of 0.82; and maximum slump values of 46mm for DMDT concrete batch prepared from DM sand to DT quarry ration of 0.61. It is also observed that slump values decreases as the quantity of fine aggregate is increased and this is likely due to the increase in the surface area of the aggregate proportion and the dryness of the concrete mix. This result indicates that adequate paste content and aggregate surface area is required to achieve a certain degree of workability (Okonkwo and Emmanuel, 2018).

4.3.2.2 Slump cone test of C-50 concrete grade

The results of the workability test given the slump values for the various mixing batches are illustrated in Figure 4.9. The degree of workability of concrete batches prepared from aggregates collected from different quarries had different slump values ranging from a minimum of low 23 mm for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of medium 55 mm for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had an intermediate low degree of workability sump values ranging from 28mm to 52mm. Therefore, target slump has been achieved, where the range is from 30mm to 60mm except BLWB and BLDG concrete batch slump values of 23mm and 28mm respectively.

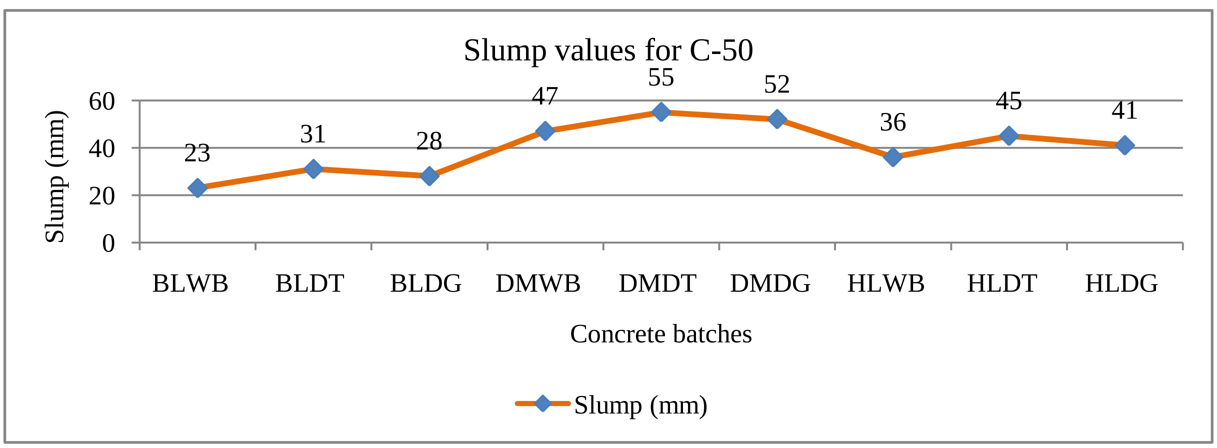


Figure 4.9 Slump values for C-50 concrete grade

The slump of concretes prepared with different aggregates is shown in Figure 4.9. Results show that the slump values of concrete prepared with different sands whose gradation according to the Unified Soil Classification System (USCS) classified as poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have a low degree of workability. However, slump values of concrete prepared with DM sand with the lowest silt content of 7.5% and coarse aggregate from DT quarry and DG quarry whose gradation is complying with a specification in BS 882: 2003 have a medium degree of workability. The slump will have a low degree of workability with poorly graded aggregates because of high void content as well as interconnection governed the engineering properties of particle aggregate matrix. This implies that concrete prepared from poorly graded aggregates will have a low degree of workability. Thus remedies that have to be taken as a reduction of silt content and blending of sand within a fine, medium, and coarse ranges should be considered. It is noted that this result is again similar to the reports by Pawar *et al*. (2016) and Sabih *et al.* (2016).

The results show that in Figure 4.9 a reduction in concrete workability slump values of 23mm for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and maximum slump values of 55mm for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. The decrease in slump value as a result of an increase in fines percentage in the sand can be attributed to the fact that finer particles have a larger surface area which absorbs more water in a concrete mix. This implies that slump values decreased as the percentage of the fines in sand increased agreeing with earlier reports Olusola et al. (2012), Iyappan and Manu (2015), Heerden and Booyens (2017), and Yalley and Sam (2018).

Figure 4.9 shows that a reduction in concrete workability minimum slump values of 23mm for BLWB concrete batch prepared from BL sand to WB quarry ratio of 1.22; and maximum slump values of 55mm for DMDT concrete batch prepared from DM sand to DT quarry ration of 0.85. It is also observed that slump values decreases as the quantity of fine aggregate is increased and this is likely due to the increase in the surface area of the aggregate proportion and the dryness of the concrete mix. This result indicates that adequate paste content and aggregate surface area is required to achieve a certain degree of workability (Okonkwo and Emmanuel, 2018).

The slump of concrete can increase with the addition of water-reducing admixtures without increasing water content. In the present study 1% by weight of cement High Range Water Reducer (HRWR) super plasticizing admixture which conforms with BS 5075-3: 2004 and ASTM C 494: 2004 were added to C-50 concrete grade to increase consistency while reducing water content by 15 % (Mehta and Monteiro, 2014 and Hora, 2014).

4.4 Effect of aggregates on hardened density

4.4.1 Hardened density of C-30 concrete grade

The result of hardened density values for the various mixing batches is presented in Figure 4.10. The hardened density of concrete batches prepared from aggregates collected from different quarries slightly varying ranging from a minimum of 2518.52Kg/m^3 for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of 2594.57Kg/m^3 for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had slightly varying intermediate hardened density values ranging from 2536.30Kg/m^3 to 2592.59Kg/m^3. Therefore, all concrete batches having hardened density greater than 2000 kg/m^3 but not exceeding 2600Kg/m^3 are normal weight concrete against the classification of concrete based on weight specified in BS 5328-1, 2003.

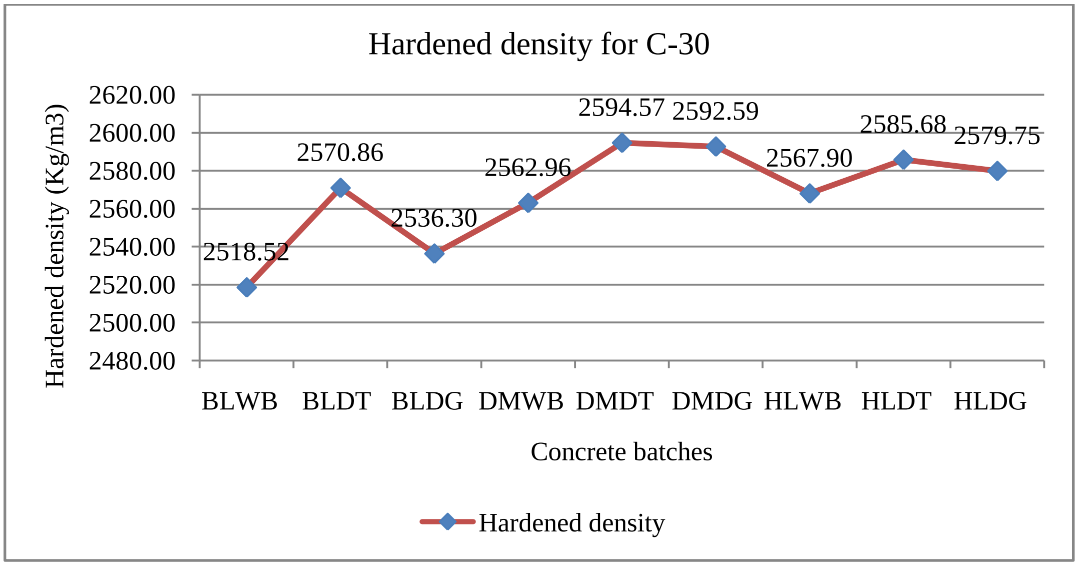


Figure 4.10 Hardened density of C-30 concrete grade

Results show that in Figure 4.10 slightly varying in hardened density values due to aggregates having closer values of specific gravity and bulk density (Shah, 2016). Results show a slight reduction in hardened density values of 2518.52Kg/m^3 for BLWB concrete batch prepared from Bilate sand and WB quarry with slightly lower compacted bulk density of 1410.40Kg/m3 and 1414.17Kg/m^3 respectively; and maximum hardened density values of 2594.57Kg/m^3 for DMDT concrete batch prepared from Dimtu sand and DT quarry with slightly higher compacted bulk density of 1414.80Kg/m^3 and 1436.19Kg/m^3 respectively. The slight increase in hardened density value is due to the fact that the smaller the voids in aggregates more hardened density. This implies that hardened density values increase as bulk density in aggregates increased agreeing with earlier reports Ramteja (2016), Abutaha (2018), and Quayson and Mustapha (2019).

4.4.2 Hardened density of C-50 concrete grade

The result of hardened density values for the various mixing batches is explained in Figure 4.11. The hardened density of concrete batches prepared from aggregates collected from different quarries slightly varying ranging from a minimum of 2514.57Kg/m^3 for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of 2596.54Kg/m^3 for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had slightly varying intermediate hardened density values ranging from 2534.32Kg/m^3 to 2586.67Kg/m^3. Therefore, all concrete batches having hardened density greater than 2000 Kg/m^3 but not exceeding 2600Kg/m^3 are normal weight concrete against the classification of concrete based on weight specified in BS 5328-1, 2003.

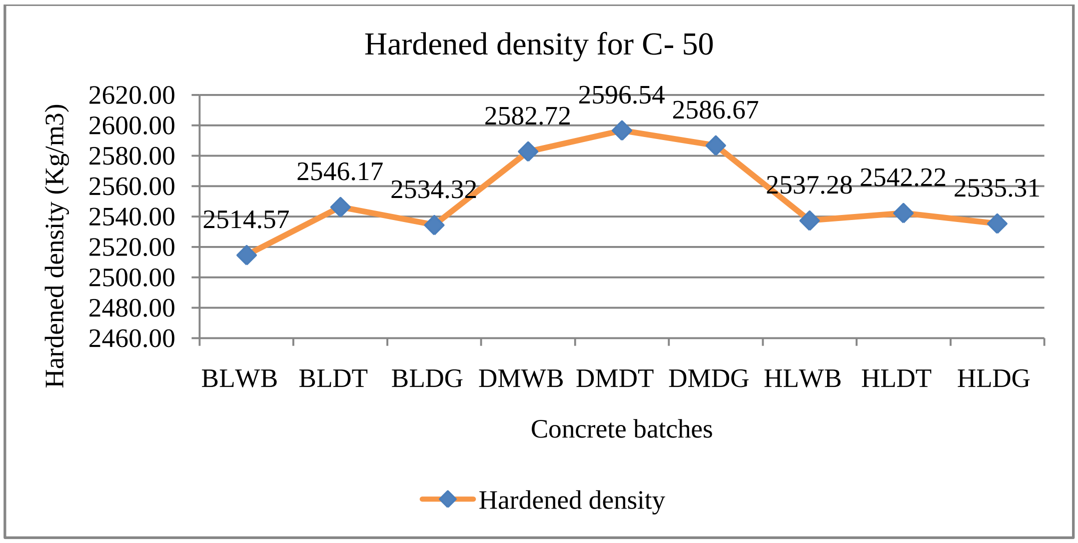


Figure 4.11 Hardened density of C-50 concrete grade

Results show that in Figure 4.11 slightly varying in hardened density values due to aggregates having closer values of the specific gravity and bulk density (Shah, 2016). Results show a slight reduction in hardened density values of 2514.57Kg/m^3 for BLWB concrete batch prepared from Bilate sand and WB quarry with slightly lower compacted bulk density of 1410.40Kg/m^3 and 1378.94Kg/m^3 respectively; maximum hardened density values of 2596.54Kg/m^3 for DMDT concrete batch prepared from Dimtu sand and DT quarry with slightly higher compacted bulk density of 1414.80Kg/m^3 and 1402.22Kg/m^3 respectively. The slight increase in hardened density value is due to the fact that the smaller the voids in aggregates more hardened density. This implies that hardened density values increase as bulk density in aggregates increased agreeing with earlier reports Ramteja (2016), Abutaha (2018), and Quayson and Mustapha (2019).

4.5 Effect of aggregates on concrete compressive strength

4.5.1 Compressive strength of C-30 concrete grade

The compressive strength of concrete cubes tested at the age of 3, 7, and 28 days curing for the various mixing batches is shown in Figure 4.12. The results revealed that for all concrete mixtures, the compressive strength increases when extending the curing time. This increase in strength as the curing age increased is in agreement with the findings of Ibhadode *et al.* (2017). The most important compressive strength development has been reached during the first 7 days as the hydration reactions process progress quickly during this stage. Furthermore, it is important to mention that, slight differences were observed between the compressive strength values of each of the three concrete cube specimens at all the curing ages. From results only BLWB where concrete batches with BL sand and WB Quarry compressive strength of 19.10MPa slightly failed to meet the minimum compressive strength of 19.75MPa expected at 3 days, all concrete batches failed to meet the compressive strength of 30.34MPa and 43.12MPa expected at 7 days and 28 days respectively.

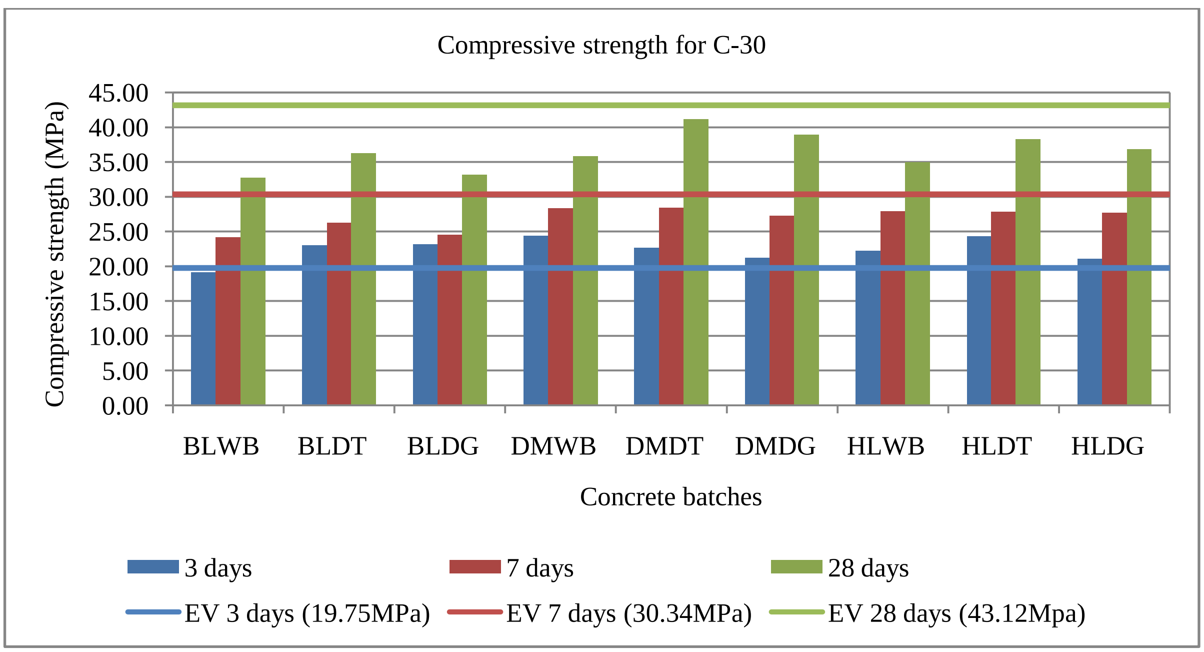


Figure 4.12 Compressive strength comparisons against TMS of C-30 concrete grade

The compressive strength of concrete cubes prepared with different aggregates are shown in Figure 4.12. Results show that the compressive strength of concrete cubes prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have failed to meet the minimum compressive strength expected at 7 days and 28 days. Compressive strength will reduce with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have low compressive strength. Thus remedies that have to be taken as a reduction of silt content and blending of sand within a fine, medium, and coarse ranges should be considered. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Figure 4.12 a reduction in compressive strength at 28 days of 32.73MPa for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and maximum compressive strength of 41.11MPa slightly difference from the expected value of 43.12MPa for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that the compressive strength of concrete decreased when silt content of fine aggregates increased. This failure and variation in strength development could be due to fine coatings of silt which are deterrents to the development of concrete strength. This further supports the opinion of Yalley and Sam, (2018) and Ngugi *et al.*, (2014) say that the cleaner the aggregates, the better the strong performance. Indeed cleanliness is an important factor in concrete strength development. The micro fines absorb the water that is made available for the initial hydration of cement and consequently, disrupts the aggregate-cement bond. The effect of this could be more pronounced at larger quantities of the fines.

The results show that in Figure 4.12 a reduction in compressive strength at 28 days of 32.73MPa for BLWB concrete batch prepared from WB quarry with highest flakiness index of 24.79%; and maximum compressive strength of 41.11MPa slightly difference from the expected value of 43.12MPa for DMDT concrete batch prepared from Daete quarry with lowest flakiness index of 11.90%. This implies that the compressive strength of concrete is reduced when flaky aggregates increased due to the reduction of interlocking characteristics of the bond between cement paste and flaky aggregates. The trend was found to be consistent with the report by Khan and Dhobale (2018).

Figure 4.12 shows that a reduction in compressive strength at 28 days of 32.73MPa for BLWB concrete batch prepared from BL sand to WB quarry ratio of 0.82; and maximum compressive strength of 41.16MPa slightly different from the expected value of 43.12MPa for DMDT concrete batch prepared from DM sand to DT quarry ratio of 0.61. It is noticed that compressive strength decreases as the quantity of fine aggregate is increased and this is likely because there was insufficient cement paste to completely fill all the voids in the concrete mix. This result indicates that adequate paste content and aggregate surface area are required to achieve a target compressive strength (Okonkwo and Emmanuel, 2018; Seddik *et al*., 2010 and Al-thairy, 2019).

4.5.2 Compressive strength of C-50 concrete grade

The compressive strength of concrete cubes tested at the age of 3, 7, and 28 days curing for the various mixing batches is shown in Figure 4.13. The results revealed that for all concrete mixtures, the compressive strength increases when extending the curing time. This increase in strength as the curing age increased is in agreement with the findings of (Ibhadode *et al.*, 2017). The most important compressive strength development has been reached during the first 7 days as the hydration reactions process progress quickly during this stage. Furthermore, it is important to mention that, slight differences were observed between the compressive strength values of each of the three concrete cube specimens at all the curing ages. From results all concrete batches compressive strength attain the minimum compressive strength expected at 3 days, all concrete batches failed to meet the compressive strength of 44.41MPa and 63.12MPa expected at 7 days and 28 days respectively.

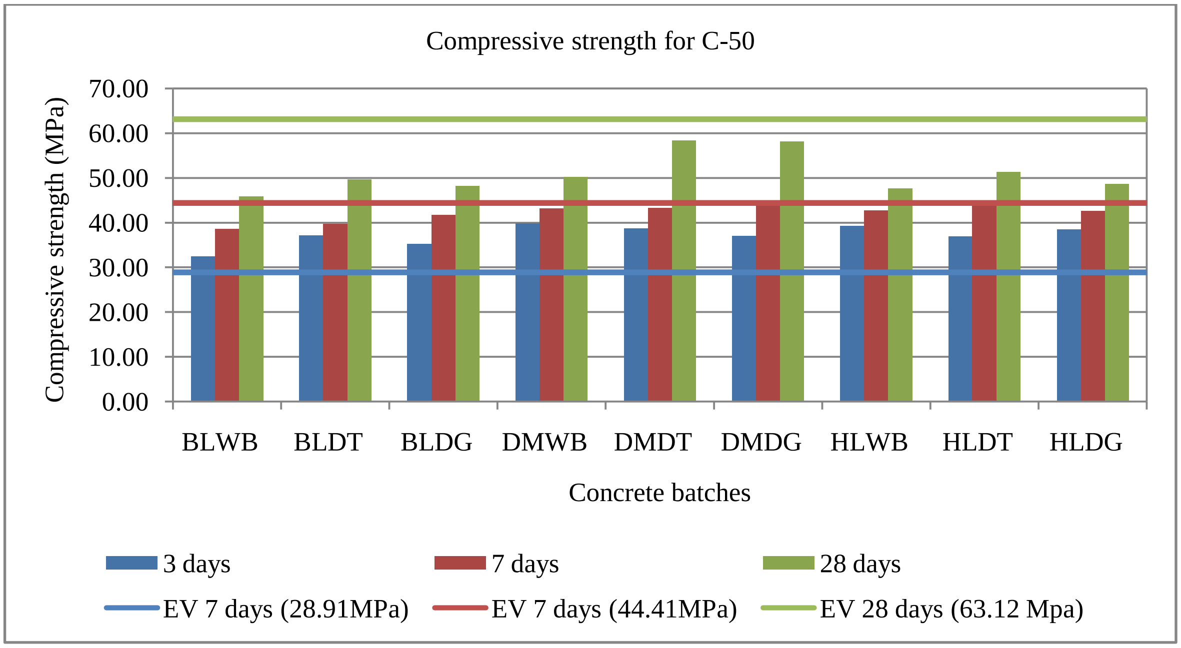


Figure 4.13 Compressive strength comparisons against TMS of C-50 concrete grade

The compressive strength of concretes prepared with different aggregates is shown in Figure 4.13. Results show that the compressive strength of concrete prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have failed to meet the minimum compressive strength expected at 7 days and 28 days. However, the compressive strength of DMDT and DMDG concrete batches 58.30MPa and 58.20MPa respectively prepared with DM sand with lowest silt content of 7.5% and coarse aggregate from DT quarry and DG quarry whose gradation is complying with a specification in BS 882: 2003 have a slight difference from 63.12Mpa expected at 28 days. Compressive strength will reduce with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have low compressive strength. Thus remedies that have to be taken as a reduction of silt content and blending of sand within a fine, medium, and coarse ranges should be considered. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Figure 4.13 a reduction in compressive strength at 28 days of 45.90MPa for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and maximum compressive strength of 58.30MPa slight difference from the expected value of 63.12MPa for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that the compressive strength of concrete decreased when silt content of fine aggregates increased. This failure and variation in strength development could be due to fine coatings of silt which are deterrents to the development of concrete strength. This further supports the opinion of Yalley and Sam, (2018) and Ngugi *et al.*, (2014) say that the cleaner the aggregates, the better the strong performance. Indeed cleanliness is an important factor in concrete strength development. The micro fines absorb the water that is made available for the initial hydration of cement and consequently, disrupts the aggregate-cement bond. The effect of this could be more pronounced at larger quantities of the fines.

The results show that in Figure 4.13 a reduction in compressive strength at 28 days of 45.90MPa for BLWB concrete batch prepared from WB quarry with highest Aggregate Impact Values (AIV) of 18.70%; and maximum compressive strength of 58.30MPa slight difference from the expected value of 63.12MPa for DMDT concrete batch prepared from WB quarry with lowest Aggregate Impact Values (AIV) of 15.40%. It can be noted that the compressive strength of concrete decreased when AIV coarse aggregates increased. This failure and variation in strength development could be due to the early failure of concrete prepared with a high value of AIV coarse aggregates. In high strength concrete, there is concrete prepared with a low w/c ratio and high cement content, the compressive strength is dependent on the quality of coarse aggregate. Therefore, the failure plain has to pass through the paste–aggregate interface or through the aggregate. The influence of coarse aggregate properties on the concrete strength becomes paramount as the quality of the paste is improved such as in the case of HSC (Neville, 2011 and Seddik *et al.*, 2010).

Figure 4.13 shows that a reduction in compressive strength at 28 days of 45.90MPa for BLWB concrete batch prepared from BL sand to WB quarry ratio of 0.82; and maximum compressive strength of 58.30MPa slightly different from the expected value of 63.12MPa for DMDT concrete batch prepared from DM sand to DT quarry ratio of 0.61. It is noticed that compressive strength decreases as the quantity of fine aggregate is increased and this is likely because there was insufficient cement paste to completely fill all the voids in the concrete mix. This result indicates that adequate paste content and aggregate surface area are required to achieve a target compressive strength (Okonkwo and Emmanuel, 2018; Seddik *et al.*, 2010 and Al-thairy, 2019).

4.6 Effect of aggregates on concrete splitting tensile strength

4.6.1 Splitting tensile strength of C-30 concrete grade

The splitting tensile strength of the concrete cylinder tested at the age of 28 days curing for the various mixing batches is shown in Figure 4.14. Splitting tensile strength of concrete batches prepared from aggregates collected from different quarries had different splitting tensile strength values ranging from a minimum of 2.57MPa for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of 3.24MPa for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had intermediate splitting tensile strength values ranging from 2.67MPa to 3.16Mpa. Therefore, all concrete batches having to splitting tensile strength smaller than against recommended values 10 to 15% of its concrete compressive strength given in BS 206-1, 2000.

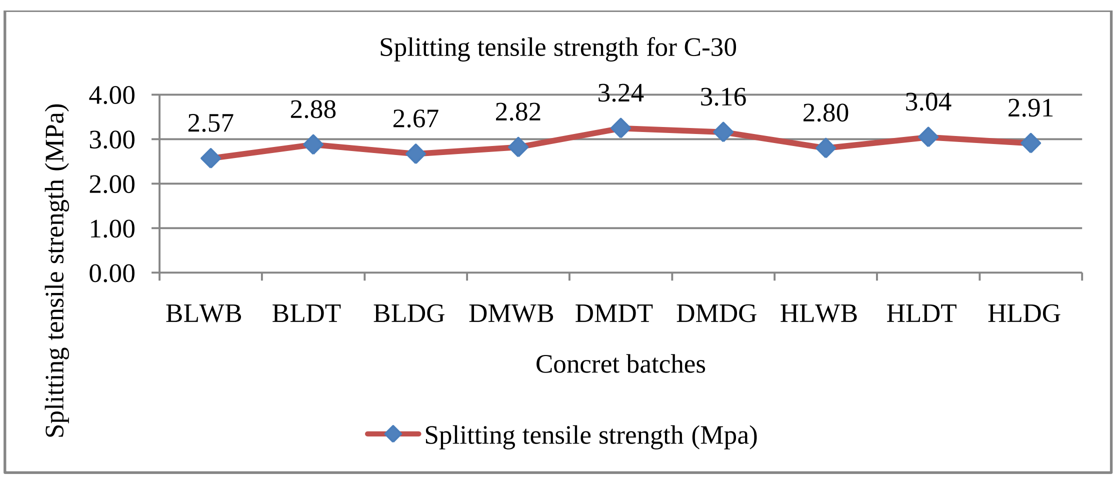


Figure 4.14 Splitting tensile strength of C-30 concrete grade

The splitting tensile strength of concretes prepared with different aggregates is shown in Figure 4.14. Results show that the splitting tensile strength of concrete prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have smaller than against recommended values 10 to 15% of its concrete compressive strength given in BS 206-1, 2000 at 28 days. Splitting tensile strength will reduce with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have low splitting tensile strength. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Figure 4.14 a reduction in splitting tensile strength at 28 days of 2.57MPa for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and maximum splitting tensile strength of 3.24MPa for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that the splitting tensile strength of concrete decreased when the silt content of fine aggregates increased. This failure against recommended in BS 206-1, 2000 could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018) and Yalley and Sam (2018).

The results show that in Figure 4.14 a reduction in splitting tensile strength at 28 days of 2.57MPa for BLWB concrete batch prepared from WB quarry with highest flakiness index of 24.79%; and maximum splitting tensile strength of 3.24MPa for DMDT concrete batch prepared from Daete quarry with lowest flakiness index of 11.90%. This implies that the splitting tensile strength of concrete is reduced when flaky aggregates increased due to the reduction of interlocking characteristics of the bond between cement paste and flaky aggregates. The trend was found to be consistent with the report by Khan and Dhobale (2018).

4.6.2 Splitting tensile strength of C-50 concrete grade

The splitting tensile strength of the concrete cylinder tested at the age of 28 days curing for the various mixing batches is shown in Figure 4.15. Splitting tensile strength of concrete batches prepared from aggregates collected from different quarries had different strength values ranging from a minimum of 3.37MPa for BLWB where concrete batches with BL sand and WB Quarry; to a maximum of 3.93MPa for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had intermediate splitting tensile strength values ranging from 3.47MPa to 3.85Mpa. Therefore, all concrete batches having to split tensile strength smaller than against recommended values 10 to 15% of its concrete compressive strength given in BS 206-1, 2000.

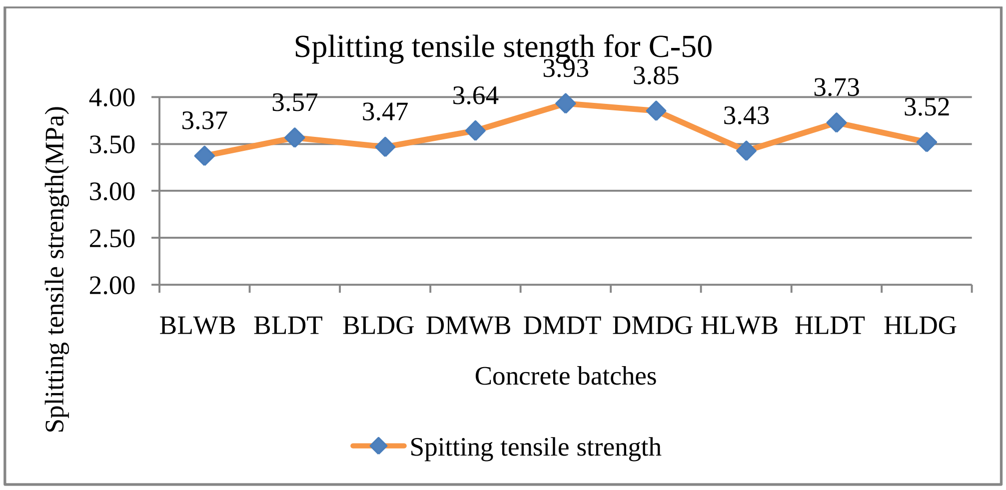


Figure 4.15 Splitting tensile strength of C-50 concrete grade

The splitting tensile strength of concretes prepared with different aggregates is shown in Figure 4.15. Results show that the splitting tensile strength of concrete prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have smaller than against recommended values 10 to 15% of its concrete compressive strength given in BS 206-1, 2000 at 28 days. However, splitting tensile strength of DMDT and DMDG concrete batches 3.93MPa and 3.85MPa respectively prepared with DM sand with lowest silt content of 7.5% and coarse aggregate from DT quarry and DG quarry whose gradation is complying with a specification in BS 882: 2003 have higher values compared to other concrete batches. Splitting tensile strength will reduce with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have low splitting tensile strength. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Figure 4.15 a reduction in splitting tensile strength at 28 days of 3.37MPa for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and maximum splitting tensile strength of 3.93MPa for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that the splitting tensile strength of concrete decreased when the silt content of fine aggregates increased. This failure against recommended in BS 206-1, 2000 could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018) and Yalley and Sam (2018).

The results show that in Figure 4.15 a reduction in splitting tensile strength at 28 days of 3.37MPa for BLWB concrete batch prepared from WB quarry with highest Aggregate Impact Values (AIV) of 18.70%; and maximum splitting tensile strength of 3.93MPa for DMDT concrete batch prepared from DT quarry with lowest Aggregate Impact Values (AIV) of 15.40%. It can be noted that the splitting tensile strength of concrete decreased when AIV coarse aggregates increased. This failure and variation in splitting tensile strength are primarily related to improper aggregate-paste bond strength and concrete prepared with a high value of AIV coarse aggregates (Piasta *et al*., 2018; Ramteja, 2016 and Seddik *et al*., 2010).

4.7 Effect of aggregates on concrete durability

4.7.1 Water absorption capacity

4.7.1.1 Water absorption capacity of C-30 concrete grade

The water absorption capacity of concrete cubes tested at the age of 28 days curing for the various mixing batches is shown in Figure 4.16. Water absorption of concrete batches prepared from aggregates collected from different quarries had different water absorption values ranging from a maximum of 8.29% for BLWB where concrete batches with BL sand and WB Quarry; to a minimum of 6.60% for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had intermediate water absorption values ranging from 7.01% to 8.12%.

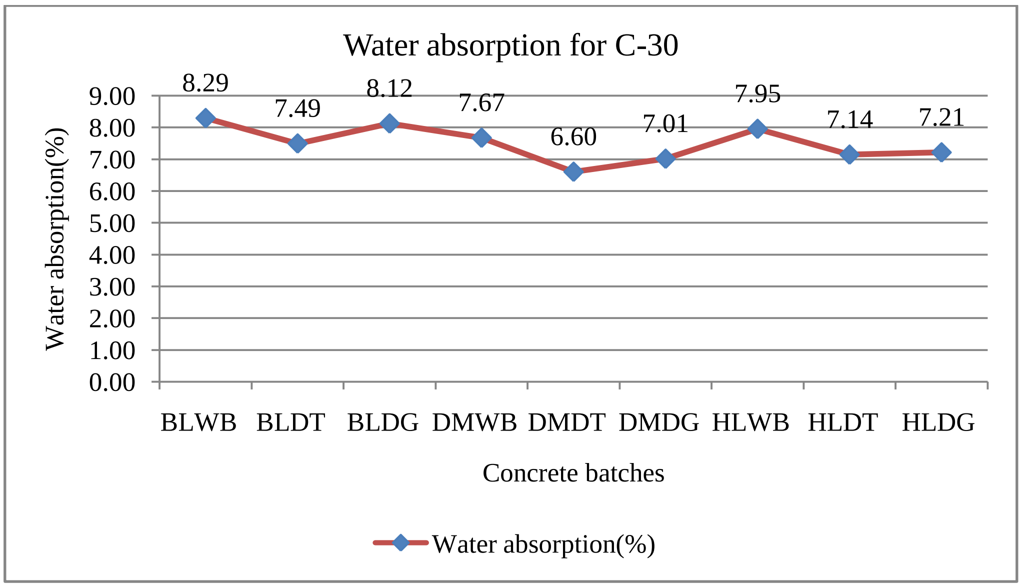


Figure 4.16 Water absorption capacity of C-30 concrete grade

The water absorption capacities of concrete cubes prepared with different aggregates are shown in Figure 4.16. Results show that the water absorption of concrete cubes prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have high water absorption capacity. Water absorption will reduce with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have high water absorption capacity. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Figure 4.16 an increment in water absorption capacity at 28 days of 8.29% for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and minimum water absorption of 6.60% for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that water absorption of concrete increased when the silt content of fine aggregates increased. This increment in water absorption capacity could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018) and Yalley and Sam (2018).

The results show that in Figure 4.16 an increment in water absorption capacity at 28 days of 8.29% for BLWB concrete batch prepared from WB quarry with highest flakiness index of 24.79%; and minimum water absorption of 6.60% for DMDT concrete batch prepared from Daete quarry with lowest flakiness index of 11.90%. This implies that water absorption of concrete is increased when flaky aggregates increased due to the reduction of interlocking characteristics of a bond between cement paste and flaky aggregates. The trend was found to be consistent with the report by Khan and Dhobale (2018).

4.7.1.2 Water absorption capacity of C-50 concrete grade

The water absorption capacity of concrete cubes tested at the age of 28 days curing for the various mixing batches is shown in Figure 4.17. Water absorption of concrete batches prepared from aggregates collected from different quarries had different water absorption values ranging from a maximum of 5.51% for BLWB where concrete batches with BL sand and WB Quarry; to a minimum of 4.62% for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from

HL sand and DG Quarry had intermediate water absorption values ranging from 4.84% to 5.43%.

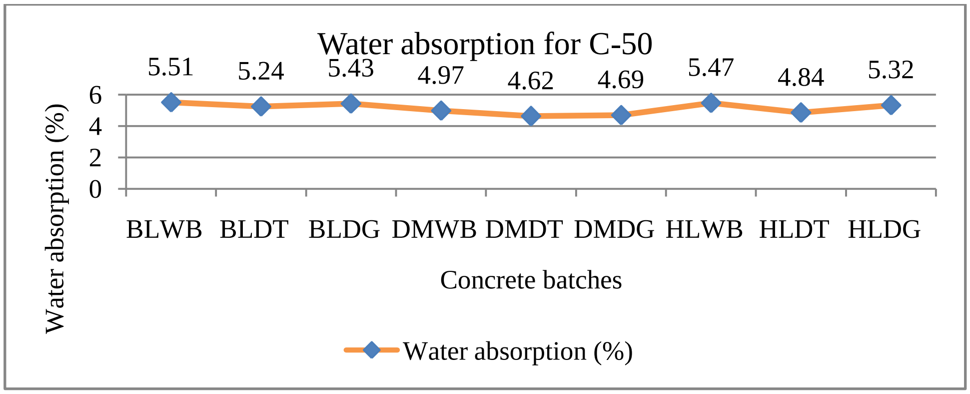


Figure 4.17 Water absorption capacity of C-50 concrete grade

The water absorption of concrete cubes prepared with different aggregates are shown in Figure 4.17. Results show that the water absorption of concrete cubes prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have higher values of water absorption capacity. However, water absorption of DMDT and DMDG concrete batches 4.62% and 4.69% respectively prepared with DM sand with lowest silt content of 7.5% and coarse aggregate from DT quarry and DG quarry whose gradation is complying with a specification in BS 882: 2003 have lower values compared to other concrete batches. Water absorption capacity will be increased with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have high water absorption. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Figure 4.17 an increment in water absorption capacity at 28 days of 5.51% for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and minimum water absorption of 4.62% for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that water absorption of concrete increased when the silt content of fine aggregates increased. This increment in water absorption capacity could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018) and Yalley and Sam (2018).

4.7.2 Sulfate attack resistance

4.7.2.1 Sulfate attack resistance of C-30 concrete grade

Mass loss of concrete cubes tested after 28 days immersion in 5% sodium sulfate solution for the various mixing batches is shown in Table 4.16 and Figure 4.18. Mass loss of concrete batches prepared from aggregates collected from different quarries displayed almost no mass change values ranging from 0.132% to 0.226%.

Table 4.16 Mass loss in sulfate attack resistance of C-30 concrete grade

Concrete batches	Weight before immersion(Kg)	Weight after immersion(Kg)	Mass loss (%)
BLWB	8.657	8.639	0.204
BLDT	8.370	8.357	0.152
BLDG	8.577	8.557	0.226
DMWB	8.573	8.558	0.179
DMDT	8.467	8.454	0.154
DMDG	8.580	8.569	0.132
HLWB	8.663	8.645	0.212
HLDT	8.570	8.557	0.156
HLDG	8.560	8.545	0.179

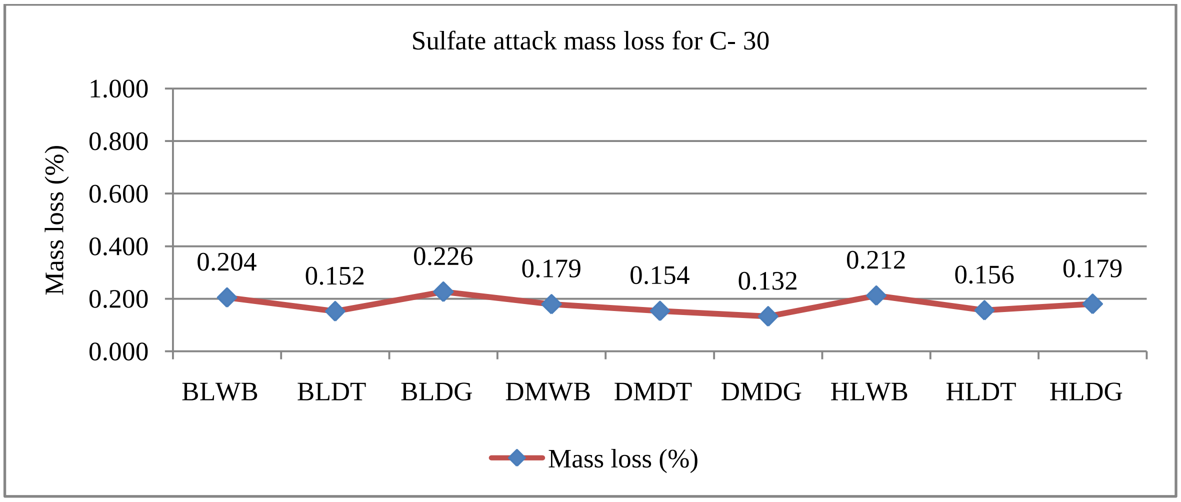


Figure 4.18 Mass loss in sulfate attack resistance of C-30 concrete grade

Mass loss of concrete cubes prepared with different aggregates is shown in Table 4.16 and Figure 4.18. Results show that mass loss of concrete cubes prepared with different aggregates all of the concrete specimens immersed in 5% sodium sulfate solution displayed almost no mass change. This implies that having the high hardened density of concrete and therefore slowed down the process of deterioration by sodium sulfate attack. This result indicated that the high hardened density of concrete was very effective in resisting sodium sulfate attack (Lee *et al.*, 2015).

Compressive strength loss of concrete cubes tested after 28 days immersion in 5% sodium sulfate solution for the various mixing batches is shown in Table 4.17 and Figure 4.19. Compressive strength loss of concrete batches prepared from aggregates collected from different quarries had different compressive strength loss values ranging from a maximum of 10.96% for BLWB where concrete batches with BL sand and WB Quarry; to a minimum of 6.38% for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had intermediate water absorption values ranging from 6.99% to 10.35%.

Table 4.17 Compressive strength loss in sulfate attack resistance of C-30 concrete grade

Concrete batches	Compressive strength before immersion(MPa)	Compressive strength after immersion(MPa)	Compressive strength loss (%)
BLWB	32.73	29.14	10.96
BLDT	36.21	32.94	9.03
BLDG	33.14	29.71	10.35
DMWB	35.80	32.36	9.62
DMDT	41.11	38.49	6.38
DMDG	38.85	36.13	6.99
HLWB	34.94	31.51	9.79
HLDT	38.21	35.28	7.68
HLDG	36.85	33.68	8.58

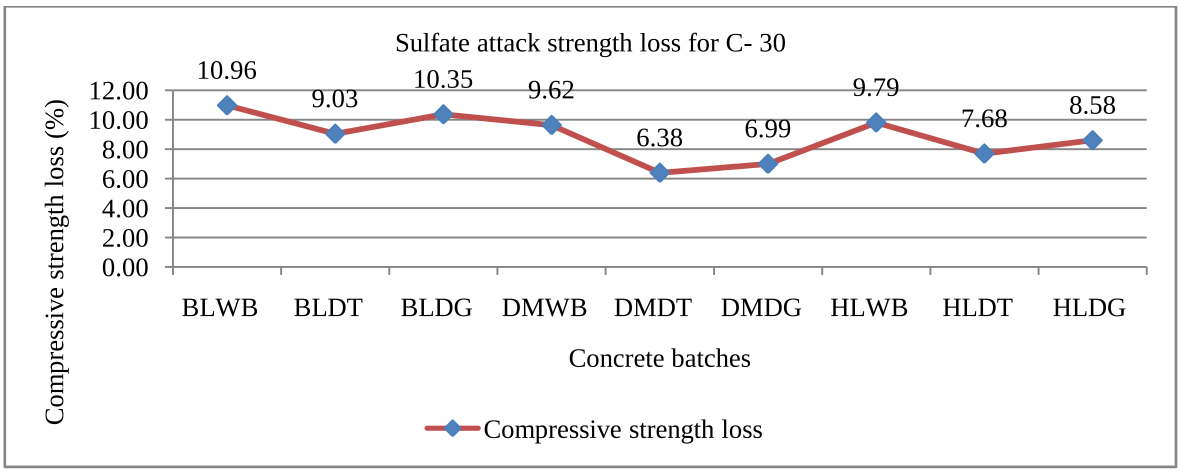


Figure 4.19 Compressive strength loss in sulfate attack resistance of C-30 concrete grade

Compressive strength losses of concrete cubes prepared with different aggregates are shown in Table 4.17 and Figure 4.19. Results show that compressive strength loss of concrete cubes prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have a high percentage of compressive strength loss. Compressive strength loss will increase with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have highly affected in a sodium sulfate solution. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al*. (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Table 4.17 and Figure 4.19 an increment in compressive strength loss after 28 days immersion in 5% sodium sulfate solution of 10.96% for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and minimum compressive strength loss of 6.38% for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that compressive strength loss of concrete increased when silt content of fine aggregates increased. This increment in compressive strength loss could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018) and Yalley and Sam (2018).

The results show that in Table 4.17 and Figure 4.19 an increment in compressive strength loss after 28 days immersion in 5% sodium sulfate solution of 10.96% for BLWB concrete batch prepared from WB quarry with highest flakiness index of 24.79%; minimum water absorption of 6.38% for DMDT concrete batch prepared from Daete quarry with lowest flakiness index of 11.90%. This implies that concrete compressive strength loss increased when flaky aggregates increased due to the reduction of interlocking characteristics of a bond between cement paste and flaky aggregates. The trend was found to be consistent with the report by Khan and Dhobale (2018).

4.7.2.2 Sulfate attack resistance of C-50 concrete grade

Mass loss of concrete cubes tested after 28 days immersion in 5% sodium sulfate solution for the various mixing batches is shown in Table 4.18 and Figure 4.20. Mass loss of concrete batches prepared from aggregates collected from different quarries displayed almost no mass change values ranging from 0.023% to 0.098%.

Table 4.18 Mass loss in sulfate attack resistance of C-50 concrete grade

Concrete batches	Weight before immersion(Kg)	Weight after immersion(Kg)	Mass loss(%)
BLWB	8.523	8.517	0.078
BLDT	8.573	8.567	0.078
BLDG	8.540	8.532	0.090
DMWB	8.620	8.617	0.039
DMDT	8.703	8.701	0.023
DMDG	8.627	8.624	0.027
HLWB	8.517	8.508	0.098
HLDT	8.523	8.517	0.074
HLDG	8.507	8.500	0.075

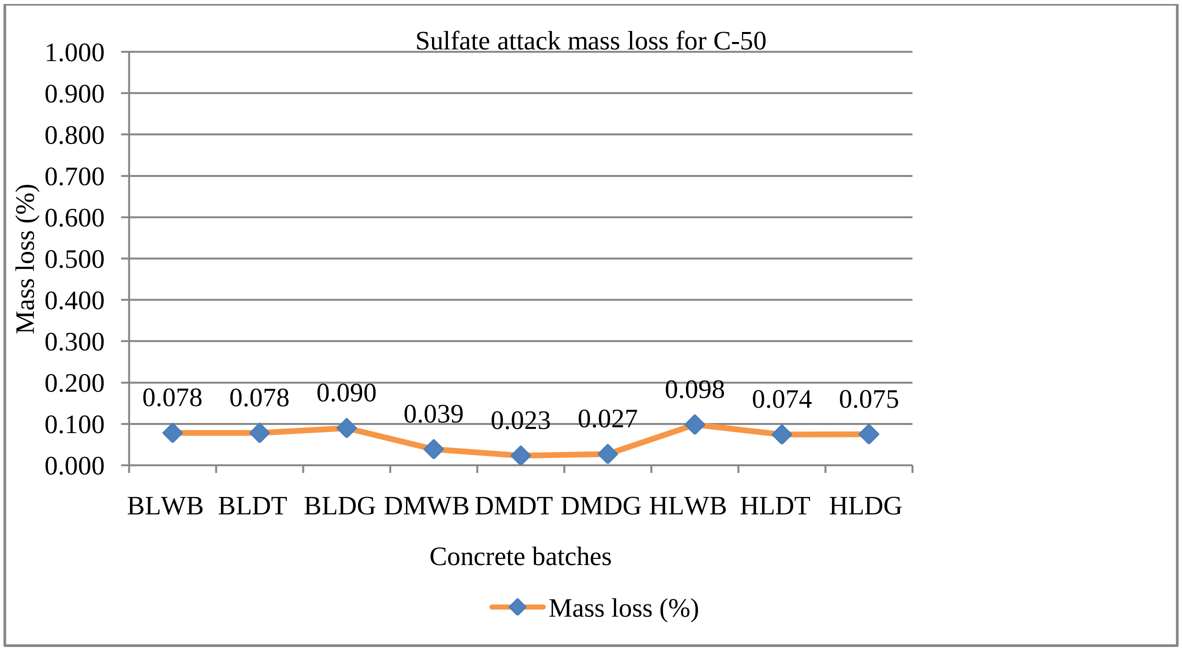


Figure 4.20 Mass loss in sulfate attack resistance of C-50 concrete grade

Mass loss of concrete cubes prepared with different aggregates is shown in Table 4.18 and Figure 4.20. Results show that mass loss of concrete cubes prepared with different aggregates all of the concrete specimens immersed in 5% sodium sulfate solution displayed almost no mass change. This implies that having low w/c and high hardened density of concrete and therefore slowed down the process of deterioration by sodium sulfate attack. This result indicated that the use of low w/c and high hardened density of concrete was very effective in resisting sodium sulfate attack (Lee *et al.*, 2015).

Compressive strength loss of concrete cubes tested after 28 days immersion in 5% sodium sulfate solution for the various mixing batches is shown in Table 4.19 and Figure 4.21. Compressive strength loss of concrete batches prepared from aggregates collected from different quarries had different compressive strength loss values ranging from a maximum of 8.32% for BLWB where concrete batches with BL sand and WB Quarry; to a minimum of 5.00% for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had intermediate water absorption values ranging from 5.16% to 7.62%.

Table 4.19 Compressive strength loss in sulfate attack resistance of C-50 concrete grade

Concrete batches	Compressive strength before immersion(MPa)	Compressive strength after immersion(MPa)	Compressive strength loss (%)
BLWB	45.90	42.08	8.32
BLDT	49.62	46.03	7.24
BLDG	48.27	44.59	7.62
DMWB	50.14	46.69	6.88
DMDT	58.30	55.39	5.00
DMDG	58.20	55.20	5.16
HLWB	47.58	43.76	8.02
HLDT	51.33	48.05	6.40
HLDG	48.67	45.04	7.47

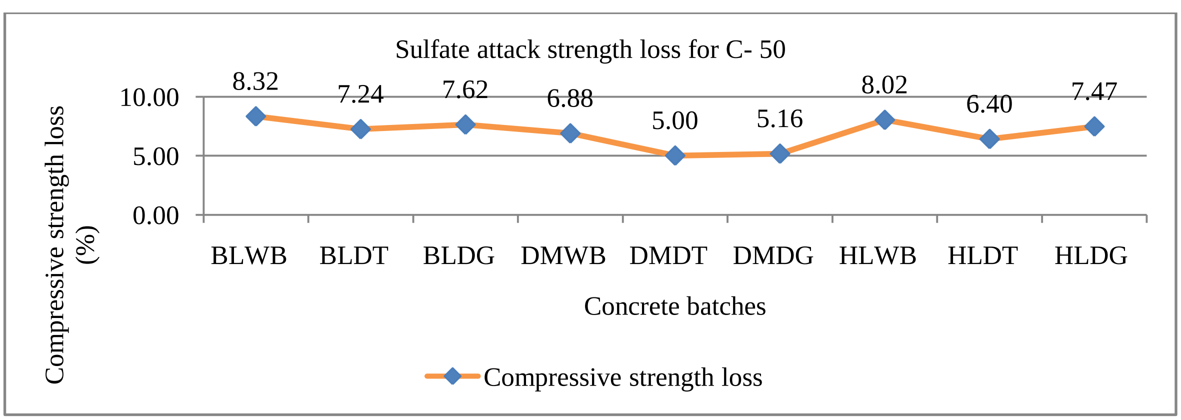


Figure 4.21 Compressive strength loss in sulfate attack resistance of C-50 concrete grade

Compressive strength loss of concretes cubes prepared with different aggregates is shown in Table 4.19 and Figure 4.21. Results show that the compressive strength loss of concrete prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have a high percentage of compressive strength loss. However, compressive strength loss of DMDT and DMDG concrete batches 5.00% and 5.16% respectively prepared with DM sand with lowest silt content of 7.5% and coarse aggregate from DT quarry and DG quarry whose gradation is complying with a specification in BS 882: 2003 have lower compressive strength loss compared to other concrete batches. Compressive strength loss will increase with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have highly affected by 5% in a sodium sulfate solution. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Table 4.19 and Figure 4.21 an increment in compressive strength loss after 28 days immersion in sodium sulfate solution of 8.32% for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and minimum compressive strength loss of 5.00% for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that compressive strength loss of concrete increased when the silt content of fine aggregates increased. This increment in compressive strength loss could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018) and Yalley and Sam (2018).

4.7.3 Chloride attack resistance

4.7.3.1 Chloride attack resistance of C-30 concrete grade

Mass loss of concrete cubes tested after 28 days immersion in 5% sodium chloride solution for the various mixing batches is shown in Table 4.20 and Figure 4.22. Mass loss of concrete batches prepared from aggregates collected from different quarries displayed almost no mass change values ranging from 0.109% to 0.215%.

Table 4.20 Mass loss in chloride attack resistance of C-30 concrete grade

Concrete batches	Weight before immersion(Kg)	Weight after immersion(Kg)	Mass loss (%)
BLWB	8.557	8.542	0.168
BLDT	8.537	8.522	0.168
BLDG	8.530	8.512	0.215
DMWB	8.633	8.621	0.143
DMDT	8.697	8.687	0.115
DMDG	8.587	8.577	0.109
HLWB	8.633	8.617	0.190
HLDT	8.600	8.587	0.155
HLDG	8.737	8.724	0.141

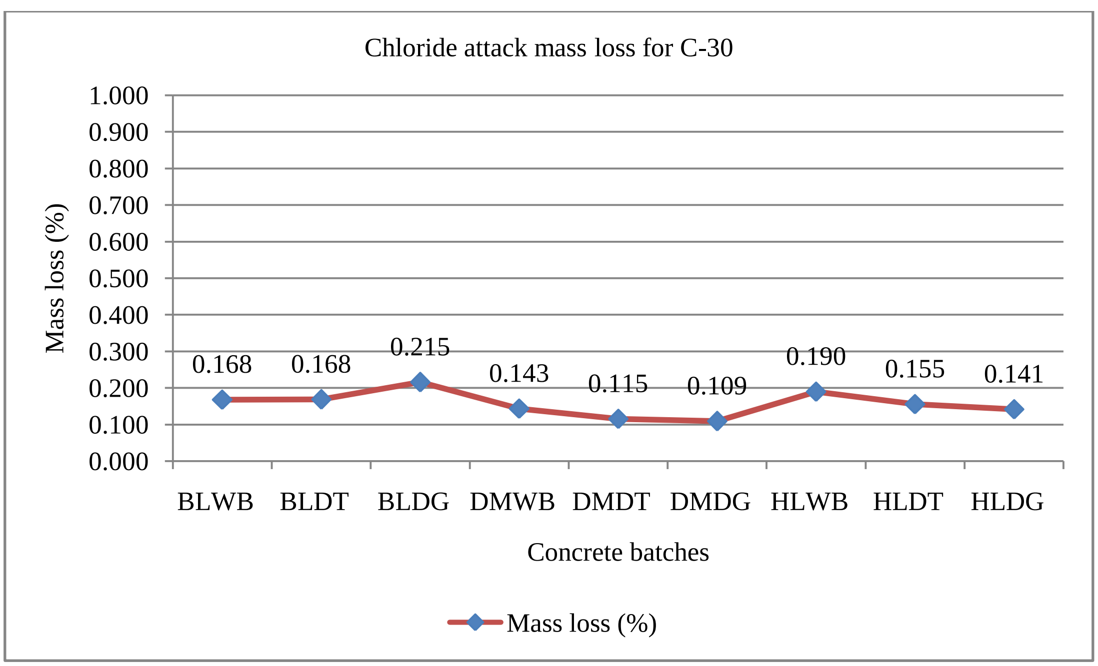


Figure 4.22 Mass loss in chloride attack resistance of C-30 concrete grade

Mass loss of concrete cubes prepared with different aggregates is shown in Table 4.20 and Figure 4.22. Results show that mass loss of concrete cubes prepared with different aggregates all of the concrete specimens immersed in 5% sodium chloride solution displayed almost no mass change. This implies that having the high hardened density of concrete and therefore slowed down the process of deterioration by sodium chloride attack. This result indicated that the high hardened density of concrete was very effective in resisting sodium chloride attack (Lee *et al.*, 2015).

Compressive strength loss of concrete cubes tested after 28 days immersion in 5% sodium chloride solution for the various mixing batches is shown in Table 4.21 and Figure 4.23. Compressive strength loss of concrete batches prepared from aggregates collected from different quarries had different compressive strength loss values ranging from a maximum of 9.77% for BLWB where concrete batches with BL sand and WB Quarry; to a minimum of 5.26% for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had intermediate water absorption values ranging from 5.95% to 8.99%.

Table 4.21 Compressive strength loss in chloride attack resistance of C-30 concrete grade

Concrete batches	Compressive strength before immersion(MPa)	Compressive strength after immersion(MPa)	Compressive strength loss (%)
BLWB	32.73	29.53	9.77
BLDT	36.21	33.36	7.87
BLDG	33.35	30.35	8.99
DMWB	35.80	32.82	8.32
DMDT	41.11	38.95	5.26
DMDG	38.85	36.54	5.95
HLWB	34.94	31.97	8.50
HLDT	38.21	35.73	6.49
HLDG	36.85	34.02	7.67

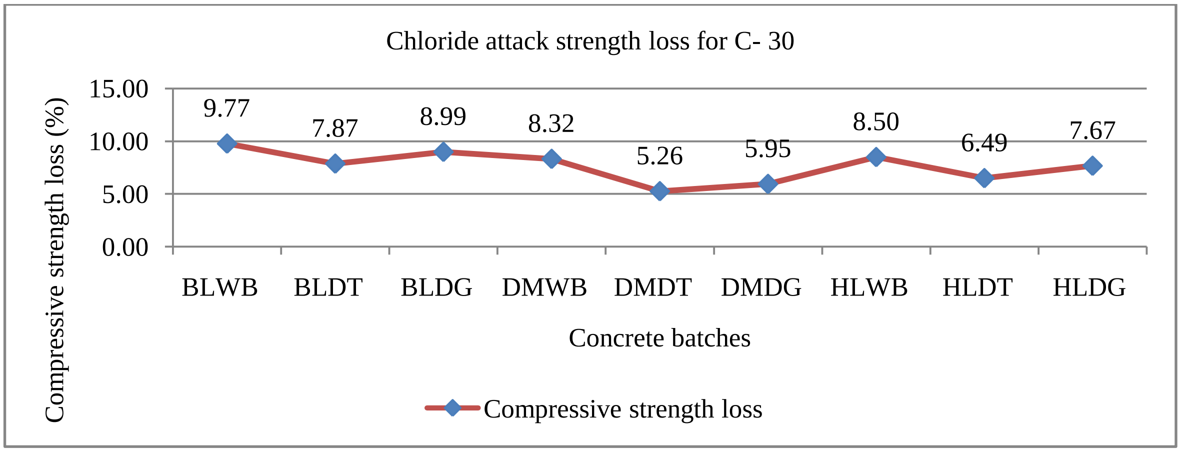


Figure 4.23 Compressive strength loss in chloride attack resistance of C-30 concrete grade

Compressive strength losses of concrete cubes prepared with different aggregates are shown in Table 4.21 and Figure 4.23. Results show that compressive strength loss of concrete cubes prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have a high percentage of compressive strength loss. Compressive strength loss will increase with poorly graded aggregates because of high void content, high permeability, and low stability. This implies that concrete prepared from poorly graded aggregates will have highly affected in 5% sodium chloride solution. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Table 4.21 and Figure 4.23 an increment in compressive strength loss after 28 days immersion in 5% sodium chloride solution of 9.77% for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and minimum compressive strength loss of 5.26% for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that compressive strength loss of concrete increased when silt content of fine aggregates increased. This increment in compressive strength loss could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018) and Yalley and Sam (2018).

The results show that in Table 4.21 and Figure 4.23 an increment in compressive strength loss after 28 days immersion in sodium chloride solution of 9.77% for BLWB concrete batch prepared from WB quarry with highest flakiness index of 24.79%; minimum water absorption of 5.26% for DMDT concrete batch prepared from Daete quarry with lowest flakiness index of 11.90%. This implies that compressive strength loss of concrete is increased when flaky aggregates increased due to the reduction of interlocking characteristics of a bond between cement paste and flaky aggregates. The trend was found to be consistent with the report by Khan and Dhobale (2018).

4.7.3.2 Chloride attack resistance of C-50 concrete grade

Mass loss of concrete cubes tested after 28 days immersion in 5% sodium chloride solution for the various mixing batches is shown in Table 4.22 and Figure 4.24. Mass loss of concrete batches prepared from aggregates collected from different quarries displayed almost no mass change values ranging from 0.015% to 0.079%.

Table 4.22 Mass loss in chloride attack resistance of C-50 concrete grade

Concrete batches	Weight before immersion(Kg)	Weight after immersion(Kg)	Mass loss(%)
BLWB	8.480	8.475	0.063
BLDT	8.633	8.630	0.042
BLDG	8.487	8.480	0.079
DMWB	8.713	8.709	0.050
DMDT	8.747	8.745	0.015
DMDG	8.660	8.658	0.019
HLWB	8.577	8.571	0.062
HLDT	8.650	8.647	0.039
HLDG	8.573	8.568	0.062

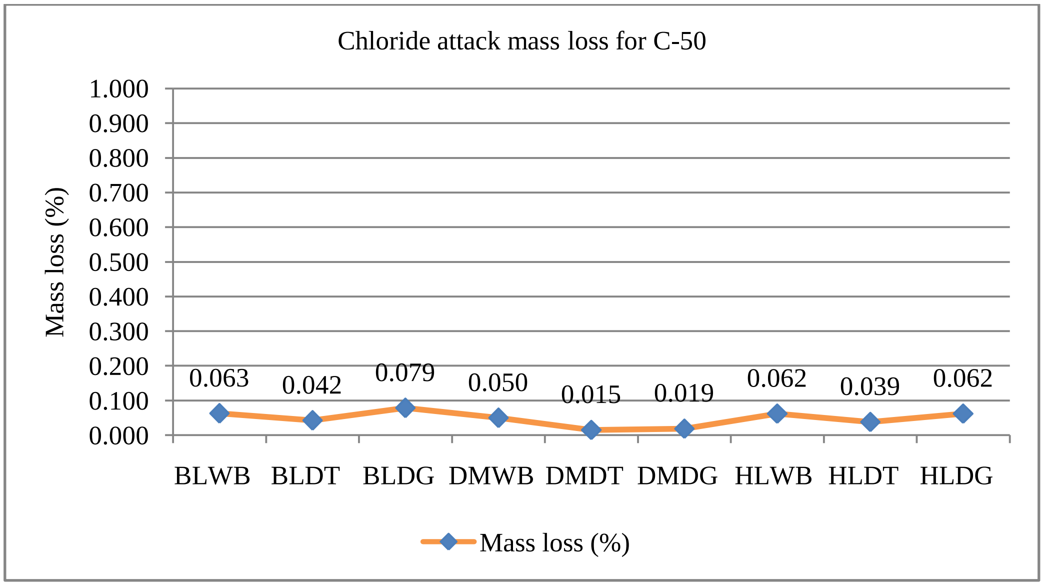


Figure 4.24 Mass loss in chloride attack resistance of C-50 concrete grade

Mass loss of concrete cubes prepared with different aggregates is shown in Table 4.22 and Figure 4.24. Results show that mass loss of concrete cubes prepared with different aggregates all of the concrete specimens immersed in 5% sodium chloride solution displayed almost no mass change. This is because having low w/c and high hardened density of concrete and therefore slowed down the process of deterioration by sodium chloride attack. This result indicated that the use of low w/c and high hardened density of concrete was very effective in resisting sodium chloride attack (Lee *et al.*, 2015).

Compressive strength loss of concrete cubes tested after 28 days immersion in 5% sodium chloride solution for the various mixing batches is shown in Table 4.23 and Figure 4.25. Compressive strength loss of concrete batches prepared from aggregates collected from different quarries had different compressive strength loss values ranging from a maximum of 7.34% for BLWB where concrete batches with BL sand and WB Quarry; to a minimum of 4.20% for DMDT where the concrete prepared from DM sand and DT Quarry. Concrete batches prepared from aggregates obtained from HL sand and DG Quarry had intermediate water absorption values ranging from 4.43% to 6.65%.

Table 4.23 Compressive strength loss in chloride attack resistance of C-50 concrete grade

Concrete batches	Compressive strength before immersion(MPa)	Compressive strength after immersion(MPa)	Compressive strength loss (%)
BLWB	45.90	42.53	7.34
BLDT	49.62	46.48	6.33
BLDG	48.27	45.06	6.65
DMWB	50.14	47.07	6.12
DMDT	58.30	55.86	4.20
DMDG	58.20	55.62	4.43
HLWB	47.58	44.38	6.72
HLDT	51.33	48.43	5.66
HLDG	48.67	45.47	6.59

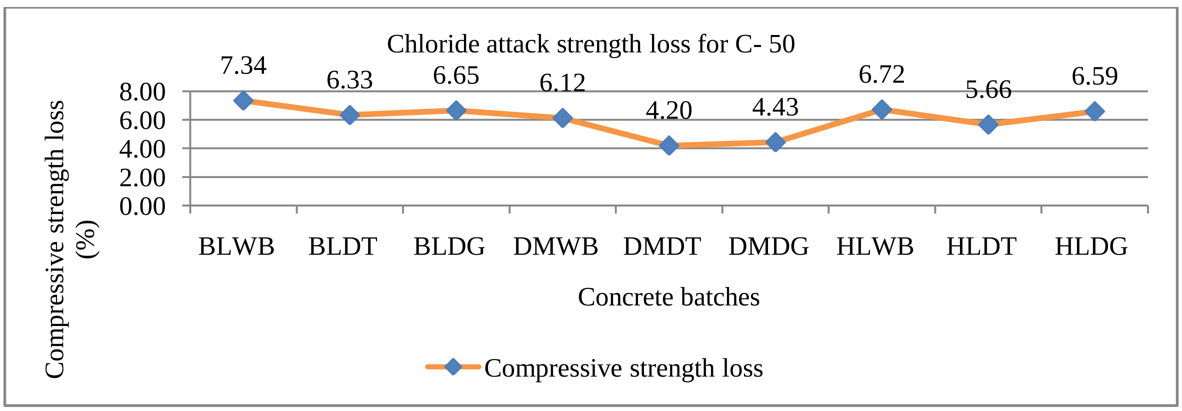


Figure 4.25 Compressive strength loss in chloride attack resistance of C-50 concrete grade

Compressive strength loss of concretes cubes prepared with different aggregates is shown in Table 4.23 and Figure 4.25. Results show that the compressive strength loss of concrete prepared with different sands whose gradation is poorly graded sand with silt and different coarse aggregate quarries whose gradation is not complying with a specification in BS 882: 2003 have a high percentage of compressive strength loss. However, compressive strength loss of DMDT and DMDG concrete batches 4.20% and 4.43% respectively prepared with DM sand with lowest silt content of 7.5% and coarse aggregate from DT quarry and DG quarry whose gradation is complying with a specification in BS 882: 2003 have lower compressive strength loss compared to other concrete batches. Compressive strength loss will increase with poorly graded aggregates because of high void content, high permeability and low stability. This implies that concrete prepared from poorly graded aggregates will have highly affected by 5% in sodium chloride solution. It is noted that this result is again similar to the reports by Pawar *et al*. (2016), Sabih *et al.* (2016), Ajagbe *et al.*(2018), Seddik *et al*. (2010), Hamid and Abas (2015), and Ogunbayo and Aigbavboa (2019).

The results show that in Table 4.23 and Figure 4.25 an increment in compressive strength loss after 28 days immersion in 5% sodium chloride solution of 7.34% for BLWB concrete batch prepared from Bilate sand with highest silt content of 12%; and minimum compressive strength loss of 4.20% for DMDT concrete batch prepared from Dimtu sand with lowest silt content of 7.5%. It can be noted that compressive strength loss of concrete increased when the silt content of fine aggregates increased. This increment in compressive strength loss could be due to the improper material bonding due to the larger amount of silt content in sand. This further supports the opinion of Lakhiar *et al*. (2018 and Yalley and Sam (2018).

CHAPTER FIVE
CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

The aggregate properties and their effect on fresh and hardened concrete properties were investigated. The following conclusions are drawn from this study.

The selection of different sand source and coarse aggregate production significantly affect concrete workability, strength, and durability. All local sand sources classified under poorly graded sand with high silt content; coarse aggregate production with poorly graded and the high percentage of flaky and elongated aggregate had a negative effect on the workability, strength, and durability of concrete.

Workability of fresh concrete assessed in terms of slump and compaction factor tests for C-30 and C-50 concrete grades significantly decreased with poorly gradation of sand and coarse aggregates, increase in high silt content, percentage of flaky and elongated aggregate and fine aggregate to coarse aggregate ratio.

Compressive strength, splitting tensile strength, water absorption resistance, sodium sulfate and sodium chloride attack resistance for C-30 and C-50 concrete grades decreased with poorly gradation of sand and coarse aggregates, increase in high silt content, percentage of flaky and elongated aggregate and fine aggregate to coarse aggregate ratio.

5.2 Recommendations

Based on the study the following recommendations are drawn.

- Contractors properly washed sand and suitable blending within a fine, medium, and coarse ranges should be considered before using.
- Coarse aggregate producers should be produce properly graded and reduce flaky and elongated particles content.
- Coarse aggregate producers should have to a close control of production process.
- Contractors should be utilizing of 10mm nominal aggregate size is strongly advisable in high strength concrete applications like in high rise buildings.
- Aggregate producers should give proper attention to producing consistent and quality products in terms of relevant parameters, which are compatible with the standard requirements.
- Consultants and contractors should be performing a test on aggregates before their use in concrete production. Also, priority must be placed on the selection of suitable aggregates for their accurate applications in the construction industry.
- Consultants and contractors should be conducting a test on concrete made from different sand sources and coarse aggregate production centers before being used in concrete production.
- Responsible statutory bodies should be check periodically without giving notice for satisfying standard requirements on sand and coarse aggregate production.

Various issues that need to be addressed by future researchers including long-term effect of aggregates on concrete in terms of strength properties and when subjected to aggressive environment. Moreover, the chemical and biological composition of fines is recommended to be investigated to determine their influence on concrete properties. Studies should be extended to other quarry sites not covered in this study with different cement type and concrete grades is an important field of study that will help to further clarify on concrete properties. Further studies should be investigated on how to improve the utilization of aggregates for higher strength applications. Comprehensive study incorporating manufactured sand would be another interesting aspect that can be explored.

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APPENDIX - A

QUESTIONNAIRE FOR COARSE AGGREGATE QUARRIES OWNERS AND WORKERS

Check lists for observations (by the researcher) on aggregate production quarries

1. When was the firm established?
2. Sources of raw materials Own ☐ Purchased ☐
3. Do you have parameters in the selection of raw materials? Yes ☐ No ☐
4. What is your parameter in the selection of raw materials?
5. What type of raw material used?

☐ Crushed rock ☐ B. Blasted rock ☐ C. Natural gravel

6. Preparation of raw material

☐ A. Dry process ☐ B. Dry Process

7. What type of crusher used?

☐ A. Jaw crusher ☐ B. Primary gyratory ☐ C. Impact crusher

☐ D. Con crusher ☐ E. Gyrator crusher ☐ . Bar mill ☐ G. Ball mill

H. Autogenous mill ☐

8. What is your parameter in the selection of Crusher type?

☐ A. Setting ☐ B. Strock ☐ C. Speed ☐ D. Reduction ration

☐ E Cavity ☐ F. Crushing force ☐ G. Other

9. Crushing Stages

☐ A. Primary ☐ B. Secondary ☐ C. Tertiary ☐ D. Quaternary

10. How often process equipment maintain or change?

☐ A. Feeders ☐ B. Screens ☐ C. Conveyors

11. Stockpiles of aggregates

a. Is it placed on concrete ground slab? Yes ☐ No ☐

b. Is segregation observed? Yes ☐ No ☐

c. Is there contamination? Yes ☐ No ☐

d. Is there demarcation between products Yes ☐ No ☐

e. Aggregates are loaded by loaders ☐ laborers ☐

f. Aggregates transported by dump trucks ☐ other means ☐

g. Is stockpiling well planned? Yes ☐ No ☐

12. Is there a quality control in the production process? Yes ☐ No ☐

13. Is its quality checked before used Yes ☐ No ☐

14. How do you check the quality of aggregates? Simple visualization ☐ tests ☐

APPENDIX - B

QUESTIONNAIRE FOR FINE AND COARSE AGGREGATE USERS

- Governmental construction projects ☐
- Private building projects ☐

Respondent code ________

1. Do you know the source (quarry) of sand supplied to the project?

☐ Yes ☐ B. No

2. Which type of supply used from the following sand production sources(locations)

Table B.1 Local sand sources

No.	Source name	Remark
1.	Dimtu	
2.	Halaba	
3.	Hawassa New Airport	
4.	Dore Bafana	
5.	Bilate	
6.	Boricha	
7.	Other source	

3. When sand source is changed are you approved?

☐ A. Yes ☐ B. No

4. What are the criterions for choosing the sand source supplied to your project?

☐ A. Economic factors (Price, transportation, etc.)

☐ B. Properties **(**Ability to accept load as required, weight, durability, quality etc.)

☐ C. Availability and ease of usage

☐ D. Aesthetic and climatic condition

☐ E. Another criteria

5. Do you think or (did observe) significant variation of quality of sand from the same source?

☐ A. Yes ☐ B. No

6. What type of concrete grade is used for this project (in MPa)?
7. Where is the source(s) of your coarse and fine aggregate?

Coarse aggregate: ____

Fine aggregate: ____

8. What kind of fine aggregate do you use for concrete production?

☐ A. Natural sand

☐ B. Crushed aggregate

9. Are you satisfied with the quality of aggregates?

☐ A. Yes ☐ B. No

10. What problem more observed on aggregates?

Coarse aggregate: ____

____

Fine aggregate: ____

____

11. What would you do if test result fails?

____

____

12. What do you propose to maintain the quality of aggregate?

____

____

APPENDIX - C

MATERIALS TEST RESULTS

1.1. Properties of fine aggregates

1.1.1. Sieve analysis

Table C.1 Bilate sand sieve analysis

Sieve size (mm)	Wt of sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)
		BIL 1	BIL 2	BIL 3	BL average				
9.5	585	585	585	585	585	0	0	0	100
4.75	415	429	430	432	430.33	15.33	3.07	3.07	96.93
2.36	455	494	490	500	494.67	39.67	7.933	11.00	89.00
1.18	450	564	560	570	564.67	114.67	22.93	33.93	66.07
0.6	405	598	610	595	601.00	196	39.2	73.13	26.87
0.3	370	475	475	472	474.00	104.00	20.80	93.93	6.07
0.15	270	295	292	290	292.33	22.33	4.47	98.40	1.60
Pan	545	555	553	551	553.00	8.00	1.60	100	0
Total		3995	3995	3995	3995	500	100	313.47	
FM		3.13							

Table C.2 Dimtu sand sieve analysis

Sieve size (mm)	Wt. of sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)			
						Wt retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)
		DIM 1	DIM 2	DIM 3	DM average				
9.5	585	585	585	585	585	0	0	0	100
4.75	415	423	428	425	425.33	10.33	2.067	2.07	97.93
2.36	455	472	470	469	470.33	15.33	3.067	5.13	94.87
1.18	450	514	515	512	513.67	63.67	12.73	17.87	82.13
0.6	405	593	605	600	599.33	194.33	38.87	56.73	43.27
0.3	370	524	520	522	522.00	152.00	30.40	87.13	12.87
0.15	270	319	313	320	317.33	47.33	9.47	96.60	3.40
Pan	545	565	559	562	562.00	17.00	3.40	100.00	0.00
Total		3995	3995	3995	3995	500.00	100.00	265.53	
FM		2.66							

Table C.3 Halaba sand sieve analysis

Sieve size(mm)	Wt of Sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)	Percentage retained(%)	Cumulative coarser (%)	Cumulative passing (%)
		HAL 1	HAL 2	HAL 3	Average				
9.5	585	585	585	585	585	0	0	0	100
4.75	415	428	430	432	430.00	15	3	3	97
2.36	455	483	480	482	481.67	26.67	5.333	8.33	91.67
1.18	450	517	520	518	518.33	68.33	13.67	22.00	78
0.6	405	593	600	592	595.00	190	38	60	40
0.3	370	523	520	522	521.67	151.67	30.33	90.33	9.67
0.15	270	313	310	312	311.67	41.67	8.33	98.67	1.33
Pan	545	553	550	552	551.67	6.67	1.33	100	0
Total		3995	3995	3995	3995	500	100	282.33	
FM		2.82							

1.1.2. Silt content

Table C.4 Fine aggregate silt content

Sample	Amount of silt content(ml)	Amount of clear sand (ml)	Silt content (%)	Average
BIL 1	16.5	125	13.2	12.0
BIL 2	15	125	12.0	
BIL 3	13.5	125	10.8	
DIM 1	9.5	125	7.6	7.5
DIM 2	8.5	125	6.8	
DIM 3	10	125	8.0	
HAL 1	12.5	125	10.0	9.6
HAL 2	12	125	9.6	
HAL 3	11.5	125	9.2	

1.1.3. Specific gravity and water absorption

Table C.5 Fine aggregate specific gravity and water absorption

Sample	Wt. of sample (SSD)(g)	Oven dry wt. of sample (g)=A	Wt. of Pyc + water (g)=B	Wt. of Pyc + water + Sample(g)=C	Bulck Sp. gr	Bulck Sp gr (SSD)	Apparent Sp. gr. (SSD)	Water absorbtion
BIL 1	500	495	1295	1590	2.41	2.44	2.48	1.01
BIL 2	500	490	1295	1590	2.39	2.44	2.51	2.04
BIL 3	500	490	1295	1590	2.39	2.44	2.51	2.04
Average	500	491.67	1295	1590.00	2.40	2.44	2.50	1.70
DIM 1	500	485	1295	1595	2.43	2.50	2.62	3.09
DIM 2	500	485	1295	1595	2.43	2.50	2.62	3.09
DIM 3	500	480	1295	1590	2.34	2.44	2.59	4.17
Average	500	483.33	1295	1593.33	2.40	2.48	2.61	3.45
HAL 1	500	480	1295	1595	2.4	2.50	2.67	4.17
HAL 2	500	480	1295	1590	2.34	2.44	2.59	4.17
HAL 3	500	490	1295	1590	2.39	2.44	2.51	2.04
Average	500	483.33	1295	1591.67	2.38	2.46	2.59	3.46
Formula	Bulck Sp. Gr=A/(B+500-C) Bulck Sp gr (SSD)=500/(B+500-C)			Apparent Sp. gr. (SSD)=A/(A+B-C) Absorbtion capacity=(500-A)*100/A				

1.1.4. Moisture content

Table C.6 Fine aggregate moisture content

Sample	Wt. of original sample (g)=A	Oven dry wt. of sample (g)=B	Moisture content (%)
BIL 1	500	495	1.01
BIL 2	500	495	1.01
BIL 3	500	490	2.04
Average	500	493.33	1.35
DIM 1	500	490	2.04
DIM 2	500	495	1.01
DIM 3	500	490	2.04
Average	500	491.67	1.70
HAL 1	500	485	3.09
HAL 2	500	490	2.04
HAL 3	500	490	2.04
Average	500	488.33	2.39
Formula	Moisture content (%)=(A-B)*100/B		

1.1.5. Bulk density

Table C.7 Fine aggregate compacted bulk density

Sample	Wt. of cylinder (kg)	Wt. of container + Agg(kg)	Height of cylinder (m)	Dia. of cylinder(m)	Wt. of Aggregate=A	Volume of container (m3)=B	Compacted bulk density (kg/m3)
BL 1	14.25	21.81	0.3	0.15	7.56	0.00530	1426.75
BL 2	14.25	21.79	0.3	0.15	7.54	0.00530	1422.98
BL 3	14.25	21.57	0.3	0.15	7.32	0.00530	1381.46
BL Average	14.25	21.72	0.3	0.15	7.47	0.00530	1410.40
DM 1	14.25	21.76	0.3	0.15	7.51	0.00530	1417.32
DM 2	14.25	21.77	0.3	0.15	7.52	0.00530	1419.20
DM 3	14.25	21.71	0.3	0.15	7.46	0.00530	1407.88
DM Average	14.25	21.75	0.3	0.15	7.50	0.00530	1414.80
HL 1	14.25	21.76	0.3	0.15	7.51	0.00530	1417.32
HL 2	14.25	21.75	0.3	0.15	7.50	0.00530	1415.43
HL 3	14.25	21.69	0.3	0.15	7.44	0.00530	1404.10
HL Average	14.25	21.73	0.3	0.15	7.48	0.00530	1412.28
Formla	Compacted bulk density (kg/m3)=(A/B)(kg/m3)						

Table C.8 Fine aggregate loose bulk density

Sample	Wt. of cylinder (kg)	Wt. of container + Agg(kg)	Height of cylinder (m)	Dia. of cylinder (m)	Wt. of Aggregate=A	Volume of container (m3)=B	Loose bulk density (kg/m3)
BL 1	14.25	21.27	0.3	0.15	7.02	0.00530	1324.84
BL 2	14.25	21.15	0.3	0.15	6.90	0.00530	1302.19
BL 3	14.25	21.14	0.3	0.15	6.89	0.00530	1300.31
BL Average	14.25	21.19	0.3	0.15	6.94	0.00530	1309.11
DM 1	14.25	21.16	0.3	0.15	6.91	0.00530	1304.08
DM 2	14.25	21.14	0.3	0.15	6.89	0.00530	1300.31
DM 3	14.25	21.09	0.3	0.15	6.84	0.00530	1290.87
DM Average	14.25	21.13	0.3	0.15	6.88	0.00530	1298.42
HL 1	14.25	21.32	0.3	0.15	7.07	0.00530	1334.28
HL 2	14.25	21.23	0.3	0.15	6.98	0.00530	1317.29
HL 3	14.25	21	0.3	0.15	6.75	0.00530	1273.89
HL Average	14.25	21.18	0.3	0.15	6.93	0.00530	1308.48
Formla	Loose bulk density (kg/m3)=(A/B)(kg/m3)						

1.2. Properties of coarse aggregates

1.2.1. Sieve analysis

Table C.9 Waye Bonge Quarry 25mm nominal maximum aggregate size sieve analysis

Sieve size(mm)	Wt. of sieves	Wt. of sieve & agg (g)				Wt retained (gm)	Percentage retained(%)	Cumulative coarser (%)	Cumulative passing (%)
		WB B1	WB B1	WB B1	WB B average				
37.5	1450	1450	1450	1450	1450	0	0	0	100
25	1455	2450	2425	2735	2536.67	1081.67	21.63	21.63	78.37
20	1395	2515	2810	2625	2650.00	1255.00	25.1	46.73	53.27
14	1180	2985	2760	2745	2830.00	1650.00	33	79.73	20.27
10	1235	2275	2235	2130	2213.33	978.33	19.57	99.30	0.70
5	1185	1215	1205	1205	1208.33	23.33	0.47	99.77	0.23
Pan	775	775	775	775	775.00	0.00	0.00	99.77	0.23
Total		13665	13660	13665	13663.33	4988.33	99.77	347.17	

Table C.10 Daete Quarry 25mm nominal maximum aggregate size sieve analysis

Sieve size(mm)	Wt. of sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)			
						Wt retained (gm)	Percentage retained(%)	Cumulative coarser (%)	Cumulative passing (%)
		DT B 1	DTB 2	DTB 3	DT B average				
37.5	1450	1450	1450	1450	1450	0	0	0	100
25	1455	2380	2520	2685	2528.33	1073.33	21.47	21.47	78.53
20	1395	3150	3025	2805	2993.33	1598.33	31.97	53.43	46.57
14	1180	2435	2385	2560	2460.00	1280.00	25.60	79.03	20.97
10	1235	2135	2200	2120	2151.67	916.67	18.33	97.37	2.63
5	1185	1315	1305	1275	1298.33	113.33	2.27	99.63	0.37
Pan	775	775	775	775	775.00	0.00	0.00	99.63	0.37
Total		13640	12210	13670	13656.67	4981.67	99.63	350.93	

Table C.11 Derago Quarry 25mm nominal maximum aggregate size sieve analysis

Sieve size(mm)	Wt. of sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)			
		DG B 1	DG B 2	DG B3	DG B average	Wt retained (gm)	Percentage retained(%)	Cumulative coarser (%)	Cumulative passing (%)
37.5	1450	1450	1450	1450	1450	0	0	0	100
25	1455	2915	3100	3445	3153.33	1698.33	33.97	33.97	66.03
20	1395	3375	3085	3060	3173.33	1778.33	35.57	69.53	30.47
14	1180	2405	2515	2215	2378.33	1198.33	23.97	93.50	6.50
10	1235	1555	1555	1540	1550.00	315.00	6.30	99.80	0.20
5	1185	1185	1185	1190	1186.67	1.67	0.03	99.83	0.17
Pan	775	775	775	775	775.00	0.00	0.00	99.83	0.17
Total		13660	12215	13675	13666.67	4991.67	99.83	396.63	

Table C.12 Waye Bonge Quarry 10mm nominal maximum aggregate size sieve analysis

Sieve size(mm)	Wt. of sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)			
		WB A 1	WB A 2	WB A 3	WB A average	Wt retained (gm)	Percentage retained(%)	Cumulative coarser (%)	Cumulative passing (%)
14	1180	1180	1180	1180	1180.00	0.00	0.00	0.00	100.00
10	1235	2065	1930	1850	1948.33	713.33	35.67	35.67	64.33
5	1185	2350	2490	2565	2468.33	1283.33	64.17	99.83	0.17
Pan	775	775	775	775	775.00	0.00	0.00	99.83	0.17
Total		6370	6375	6370	6371.67	1996.67	99.83	135.50	

Table C.13 Daete Quarry 10mm nominal maximum aggregate size sieve analysis

Sieve size(mm)	Wt. of sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)			
		DT A 1	DT A 1	DT A 1	DT A average	Wt retained (gm)	Percentage retained(%)	Cumulative coarser (%)	Cumulative passing (%)
14	1180	1180	1180	1180	1180.00	0.00	0.00	0.00	100.00
10	1235	1235	1240	1245	1240.00	5.00	0.25	0.25	99.75
5	1185	3180	3180	3175	3178.33	1993.33	99.67	99.92	0.08
Pan	775	775	775	775	775.00	0.00	0.00	99.92	0.08
Total		6370	6375	6375	6373.33	1998.33	99.92	100.17	

Table C.14Derago Quarry 10mm nominal maximum aggregate size sieve analysis

Sieve size(mm)	Wt. of sieve (g)	Wt. of sieve & agg (g)				Wt retained (gm)			
		DGA 1	DGA 2	DGA 3	DG A average	Wt retained (gm)	Percentage retained(%)	Cumulative coarser (%)	Cumulative passing (%)
14	1180	1180	1180	1180	1180.00	0.00	0.00	0.00	100.00
10	1235	1560	1535	1504	1533.00	298.00	14.90	14.90	85.10
5	1185	2835	2825	2896	2852.00	1667.00	83.35	98.25	1.75
Pan	775	775	775	775	775.00	0.00	0.00	98.25	1.75
Total		6350	6315	6355	6340.00	1965.00	98.25	113.15	

1.2.2. Specific gravity and water absorption

Table C.15 Coarse aggregate specific gravity and water absorption

Sample	Wt. of oven dry sample at 105-110◦C (A) (g)	Wt. of SSD sample (B)(g)	Wt. of sample when immersed in water (C) (g)	Specific gravity	Specific gravity (SSD)	Apparent dry specific gravity	Water absorption (%)=
WB A 1	4910	5000	3020	2.48	2.53	2.60	1.83
WB A 2	4920	5000	3055	2.53	2.57	2.64	1.63
WB A 3	4905	5000	3020	2.48	2.53	2.60	1.94
Average	4911.67	5000	3031.67	2.50	2.54	2.61	1.80
WB B 1	4925	5000	3080	2.57	2.60	2.67	1.52
WB B 2	4935	5000	3070	2.56	2.59	2.65	1.32
WB B 3	4935	5000	3075	2.56	2.60	2.65	1.32
Average	4931.67	5000	3075	2.56	2.60	2.66	1.39
DT A 1	4920	5000	3075	2.56	2.60	2.67	1.63
DT A 2	4930	5000	3065	2.55	2.58	2.64	1.42
DT A 3	4925	5000	3065	2.55	2.58	2.65	1.52
Average	4925	5000	3068.33	2.55	2.59	2.65	1.52
DT B 1	4920	5000	3065	2.54	2.58	2.65	1.63
DT B 2	4910	5000	3060	2.53	2.58	2.65	1.83
DT B 3	4920	5000	3065	2.54	2.58	2.65	1.63
Average	4916.67	5000	3063.33	2.54	2.58	2.65	1.69
DG A 1	4910	5000	3050	2.52	2.56	2.64	1.83
DG A 2	4915	5000	3055	2.53	2.57	2.64	1.73
DG A 3	4910	5000	3055	2.52	2.57	2.65	1.83
Average	4911.67	5000	3053.33	2.52	2.57	2.64	1.80
DG B 1	4920	5000	3045	2.52	2.56	2.62	1.63

Sample	Wt. of oven dry sample at 105-110◦C (A) (g)	Wt. of SSD sample (B)(g)	Wt. of sample when immersed in water (C) (g)	Specific gravity	Specific gravity (SSD)	Apparent dry specific gravity	Water absorption (%)=
DG B 2	4930	5000	3060	2.54	2.58	2.64	1.42
DG B 3	4925	5000	3050	2.53	2.56	2.63	1.52
Average	4925	5000	3051.67	2.53	2.57	2.63	1.52
Formula	Specific gravity=A/(B-C) Specific gravity (SSD)=B/(B-C)				Apparent dry specific gravity = A/(A-C) Water absorption (%)=100*(B-A)/(A)		

1.2.3. Moisture content

Table C.16 Coarse aggregate moisture content

Sample	Wt. of original sample (g)=A	Oven dry wt. of sample (g)=B	Moisture content (%)
WB A 1	2000	1995	0.25
WB A 2	2000	1995	0.25
WB A 3	2000	1990	0.50
Average	2000	1993.33	0.33
WB B 1	2000	1985.00	0.76
WB B 2	2000	1990	0.50
WB B 3	2000	1985	0.76
Average	2000	1986.67	0.67
DT A 1	2000	1995	0.25
DT A 2	2000	1995	0.25
DT A 3	2000	1990	0.50
Average	2000	1993.33	0.33
DT B 1	2000	1985	0.76
DT B 2	2000	1980	1.01
DT B 3	2000	1980	1.01
Average	2000	1981.67	0.93
DG A 1	2000	1990	0.50
DG A 2	2000	1985	0.76
DG A 3	2000	1985	0.76
Average	2000	1986.67	0.67
DG B 1	2000	1990	0.50
DG B 2	2000	1985	0.76
DG B 3	2000	1990	0.50
Average	2000	1988.33	0.59
Formula	Moisture content (%)=(A-B)*100/B		

1.2.4. Bulk density

Table C.17 Coarse aggregate compacted bulk density

Sample	Wt. of cylinder (kg)	Wt. of container + Agg(kg)	Height of cylinder (m)	Dia. of cylinder(m)	Wt. of Aggregate=A	Volume of container (m3)=B	Compacted bulk density (kg/m3)
WB A1	14.25	21.47	0.3	0.15	7.22	0.00530	1362.59
WB A2	14.25	21.56	0.3	0.15	7.31	0.00530	1379.57
WB A3	14.25	21.64	0.3	0.15	7.39	0.00530	1394.67
WB A average	14.25	21.56	0.3	0.15	7.31	0.00530	1378.94
DT A1	14.25	21.64	0.3	0.15	7.39	0.00530	1394.67
DT A2	14.25	21.71	0.3	0.15	7.46	0.00530	1407.88
DT A3	14.25	21.69	0.3	0.15	7.44	0.00530	1404.10
DT A average	14.25	21.68	0.3	0.15	7.43	0.00530	1402.22
DG A1	14.25	21.57	0.3	0.15	7.32	0.00530	1381.46
DG A2	14.25	21.61	0.3	0.15	7.36	0.00530	1389.01
DG A3	14.25	21.58	0.3	0.15	7.33	0.00530	1383.35
DG A average	14.25	21.59	0.3	0.15	7.34	0.00530	1384.60
WB B1	14.25	21.74	0.3	0.15	7.49	0.00530	1413.54
WB B2	14.25	21.77	0.3	0.15	7.52	0.00530	1419.20
WB B3	14.25	21.72	0.3	0.15	7.47	0.00530	1409.77
WB B average	14.25	21.74	0.3	0.15	7.49	0.00530	1414.17
DT B1	14.25	21.9	0.3	0.15	7.65	0.00530	1443.74
DT B2	14.25	21.73	0.3	0.15	7.48	0.00530	1411.65
DT B3	14.25	21.95	0.3	0.15	7.70	0.00530	1453.17
DT B average	14.25	21.86	0.3	0.15	7.61	0.00530	1436.19
DG B1	14.25	21.86	0.3	0.15	7.61	0.00530	1436.19
DG B2	14.25	21.84	0.3	0.15	7.59	0.00530	1432.41
DG B3	14.25	21.83	0.3	0.15	7.58	0.00530	1430.53
DG B average	14.25	21.84	0.3	0.15	7.59	0.00530	1433.04
Formula	Compacted bulk density (kg/m3)=(A/B)(kg/m3)						

Table C.18 Coarse aggregate loose bulk density

Sample	Wt. of cylinder (kg)	Wt. of container + Agg(kg)	Height of cylinder (m)	Dia. of cylinder(m)	Wt. of Aggregate=A	Volume of container (m3)=B	Loose bulk density (kg/m3)
WB A1	14.25	20.88	0.3	0.15	6.63	0.00530	1251.24
WB A2	14.25	20.92	0.3	0.15	6.67	0.00530	1258.79
WB A3	14.25	21.02	0.3	0.15	6.77	0.00530	1277.66
WB A average	14.25	20.94	0.3	0.15	6.69	0.00530	1262.56
DT A1	14.25	21.1	0.3	0.15	6.85	0.00530	1292.76
DT A2	14.25	21.02	0.3	0.15	6.77	0.00530	1277.66
DT A3	14.25	21.11	0.3	0.15	6.86	0.00530	1294.64
DT A average	14.25	21.08	0.3	0.15	6.83	0.00530	1288.35
DG A1	14.25	21.01	0.3	0.15	6.76	0.00530	1275.77
DG A2	14.25	20.89	0.3	0.15	6.64	0.00530	1253.13
DG A3	14.25	20.9	0.3	0.15	6.65	0.00530	1255.01
DG A average	14.25	20.93	0.3	0.15	6.68	0.00530	1261.30
WB B1	14.25	21.37	0.3	0.15	7.12	0.00530	1343.71
WB B2	14.25	21.25	0.3	0.15	7.00	0.00530	1321.07
WB B3	14.25	21.23	0.3	0.15	6.98	0.00530	1317.29
WB B average	14.25	21.28	0.3	0.15	7.03	0.00530	1327.36
DT B1	14.25	21.06	0.3	0.15	6.81	0.00530	1285.21
DT B2	14.25	21.09	0.3	0.15	6.84	0.00530	1290.87
DT B3	14.25	21.1	0.3	0.15	6.85	0.00530	1292.76
DT B average	14.25	21.08	0.3	0.15	6.83	0.00530	1289.61
DG B1	14.25	21.09	0.3	0.15	6.84	0.00530	1290.87
DG B2	14.25	21.16	0.3	0.15	6.91	0.00530	1304.08
DG B3	14.25	21.04	0.3	0.15	6.79	0.00530	1281.43
DG B average	14.25	21.10	0.3	0.15	6.85	0.00530	1292.13
Formla	Loose bulk density (kg/m3)=(A/B)(kg/m3)						

1.2.5. Flakiness Index (FI) and Elongation Index (EI)

Table C.19 Waye Bonge Quarry FI and EI

Sieve size(mm)		Sample wt. (g)=A				Wt. agg. Passing thickness gauge=B				Wt. non flaky agg retained on thickness gauge=C				Wt. agg. Retained on elongation gauge =D			
Passing	Retained	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average
37.5	28	800	620	720	713	290	195	247.5	244.17	510	425	472.5	469.17	115	0	62.5	59.17
28	20	1220	1210	1225	1218	220	410	320	316.67	1000	800	905	901.67	320	210	270	266.67
20	14	925	1075	1010	1003	220	205	217.5	214.17	705	870	792.5	789.17	285	335	315	311.67
14	10	610	600	615	608	100	105	107.5	104.17	510	495	507.5	504.17	315	300	312.5	309.17
10	6.3	55	60	68	61	10	15	17.5	14.17	45	45	50	46.67	40	30	40	36.67
Total		3610	3565	3638	3604	840	930	910	893.33	2770	2635	2727.5	2710.83	1075	875	1000	983.33
Flakiness Index (FI)					24.79					Elongation Index (EI)				36.27			

Table C.20 Daete Quarry FI and EI

Sieve size(mm)		Sample wt. (g)=A				Wt. agg. Passing thickness gauge=B				Wt. non flaky agg retained on thickness gauge=C				Wt. agg. Retained on elongation gauge =D			
Passing	Retained	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average
37.5	28	305	405	365	358	30	115	77.5	74.17	305	290	287.5	294.17	0	0	0	0.00
28	20	1370	1320	1355	1348	85	175	135	131.67	1285	1145	1220	1216.67	325	280	307.5	304.17
20	14	1030	1010	1030	1023	110	120	120	116.67	920	890	910	906.67	350	375	367.5	364.17
14	10	595	605	610	603	80	75	82.5	79.17	515	530	527.5	524.17	255	270	267.5	264.17
10	6.3	180	135	168	161	15	10	17.5	14.17	165	125	150	146.67	120	90	110	106.67
Total		3480	3475	3528	3494	320	495	432.5	415.83	3190	2980	3095	3088.33	1050	1015	1052.5	1039.17
Flakiness Index (FI)					11.90					Elongation Index (EI)				33.65			

Table C.21 Derago Quarry FI and EI

Sieve size(mm)		Sample wt. (g)=A				Wt. agg. Passing thickness gauge=B				Wt. non flaky agg retained on thickness gauge=C				Wt. agg. Retained on elongation gauge =D			
Passing	Retained	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average	WB B1	WB B2	WB B3	WB B average
37.5	28	860	620	750	743	150	120	140	136.67	710	500	610	606.67	60	65	67.5	64.17
28	20	1445	1760	1612.5	1606	215	405	315	311.67	1230	1355	1297.5	1294.17	385	495	445	441.67
20	14	1125	1115	1130	1123	235	170	207.5	204.17	890	945	922.5	919.17	455	475	470	466.67

14	10	310	320	325	318	65	55	65	61.67	245	265	260	256.67	175	195	190	186.67
10	6.3	15	20	28	21	0	5	10	5.00	15	15	17.5	15.83	15	15	20	16.67
Total		3755	3835	3845	3812	665	755	737.5	719.17	3090	3080	3107.5	3092.50	1090	1245	1192.5	1175.83
Flakiness Index (FI)					18.87					Elongation Index (EI)				38.02			

1.2.6. Aggregate Impact Values (AIV)

Table C.22 Coarse aggregate AIV

Samples code	Wt. of dry sample (A)(g)	Wt. of portion passing 2.36mm sieve (B)(g)	Wt. of portion retained on 2.36mm sieve(C)	ACI (%)=(B/A)*100
WB A1	325	61.9	263.1	19.05
WB A2	319.9	57.7	262.2	18.04
WB A3	323.4	61.5	261.9	19.02
WB A average	322.77	60.37	262.40	18.70
WB B1	330.9	38.1	292.8	11.51
WB B1	333.9	42.2	291.7	12.64
WB B1	333.4	42.15	291.25	12.64
WB B average	332.73	40.82	291.92	12.27
DT A1	314	49	265	15.61
DT A2	322	47	275	14.60
DT A3	318	51	267	16.04
DT A average	318	49.00	269.00	15.41
DT B1	337.9	33.9	304	10.03
DT B2	333.1	34.3	298.8	10.30
DT B3	336.5	36.1	300.4	10.73
DT B average	335.83	34.77	301.07	10.35
DG A1	310	52	258	16.77
DG A2	321	45	276	14.02
DG A3	317	51	266	16.09
DG A average	316	49.33	266.67	15.63
DG B1	326	38	288	11.66
DG B2	335	39	296	11.64
DG B3	332	41	291	12.35
DG B average	331	39.33	291.67	11.88

APPENDIX - D

MIX DESIGN FOR PLAIN CONCRETE

1.1. Mix design for C- 30 concrete grade

Table D.1 Mix design for BLWB C-30 concrete batch

Item No	Variables	Reference or Calculation	Values
Stage 1 (Selection of target free-water/cement ratio)			
1.1 Characteristic Strength, f_c………specified…………………..30 N/mm^2 at 28 days, proportion defective 5%			
1.2 Standard Deviation, s…………Figure 3………………………….s = 8N/mm^2			
1.3 Margin, C1……… C1=k × s Where k=1.64 for 5% defectives C_1 =1.64×8N/mm^2=13.12 N/mm^2			
1.4 Target mean strength, C2…………….C2=f_c+ ks ………………. C2=30 N/mm^2 +13.12N/mm^2 =43.12N/mm^2			
1.5 Cement Strength Class…………. Specified…………………………… ….42.5 (OPC)			
1.6 Aggregate Type : Coarse ………..Specified ……………………………Crushed			
Aggregate Type : Fine …………...Specified …………………………….Uncrushed (Zone 1)			
1.7 Free-water / cement ratio…..Table 2, Figure 4 ……………..…0.54 , use the value=0.54			
1.8 Max free-water / cement ratio…….Specified………………0.65			
Stage 2 (Selection of the free-water content)			
2.1 Slump ………………………………..Specified ……..Slump = 30 - 60mm			
2.2 Maximum aggregate size………..Specified…………………………………...25mm			
2.3 Free-water Content (W)………… Table 3 By interpolation……………..185kg/m^3			
Stage 3 (Determination of Cement Content)			
3.1 Cement Content, C3…………. $C_{3=}$ Water content/w-c ratio ....$C_{3=}$ 185/0.54 =343 kg/ m^3			
3.2 Minimum Cement Content………….. Specified……………………275 kg/m^3			
(use 3.1 if > 3.2) ……………………………………………………...343 kg/m^3			
3.4 Modified free-water / cement ration No need since 343kg/ m^3 >275kg/ m^3			
Stage 4 (Determination of total aggregate Content)			
4.1 Relative density of aggregate (SSD)…… Specified ………………….. 2.52			
4.2 Concrete density (D)…………….Figure 5………………………………..2310 kg/m^3			
4.3 Total aggregate Content, C4……. C4= (D-Total-W)…………. C4=(2310-343-185) = 1782 kg/m^3			

Item No	Variables	Reference or Calculation	Values
Stage 5 (Selection of fine and coarse aggregate Contents)			

5.1 Grading of fine aggregate………………...Zone 1

5.2 Proportion of fine aggregate……………..Figure 6……(by interpolation)……………. 45%

5.3 Fine aggregate content,C5…C5=C4 x proportion of fines=1782 kg/m^3×45%= 793 kg/m^3

5.4 Coarse aggregate Content,C5………..C5=C4 - fine aggregate content=1782- 793=989 kg/m^3

Stage 6 (Moisture correction)

6.1 Fine aggregate content= 793+(793×0.0135) – (793×0.017) = 791 kg/m^3

6.2 Coarse aggregate content= 989 + (989 ×0.0067) – (989 ×0.0139 =982 kg/m^3

6.3 Water content=185-793×0.0135-989×0.0067+793×0.017+989×0.0139=195kg/m^3

Weight of all materials used for this trial mix could be summarized as:

Quantities (Kg)	Cement	water	Fine aggregate	Coarse aggregate
Per 1 m^3	343	195	791	982
Per 0.105m^3	36	20.48	83.06	103

Table D.2 Mix design summery for C-30 concrete batch

Concrete batches	Cement(Kg)	Water(Kg)	Fine aggregates(Kg)	Coarse aggregates(Kg)
BLWB	36.02	20.48	83.06	103.11
BLDT	36.02	20.48	83.06	103.11
BLDG	36.02	20.69	83.06	102.90
DMWB	36.02	21.53	70.35	115.82
DMDT	36.02	21.53	70.35	115.82
DMDG	36.02	21.74	70.35	115.71
HLWB	36.02	21.03	72.24	113.30
HLDT	36.02	21.11	72.24	113.30
HLDG	36.02	21.32	72.24	113.09

1.2.Mix design for C- 50 concrete grade

Table D.3 Mix design for BLDG C-50 concrete batch

Item No	Variables	Reference or Calculation	Values

Stage 1 (Selection of target free-water/cement ratio)

1.1 Characteristic Strength, f_c………specified…………………..50 N/mm^2 at 28 days, proportion defective 5%

1.2 Standard Deviation, s…………Figure 3…………………………s= 8N/mm^2

1.3 Margin, C1……… C1=k × s Where k=1.64 for 5% defectives C_1 =1.64×8N/mm^2=13.12 N/mm^2

1.4 Target mean strength, C2…………….C2=f_c+ ks ………………. C2=50 N/mm^2 +13.12N/mm^2 =63.12N/mm^2

1.5 Cement Strength Class…………. Specified…………………………… ….42.5 (OPC)

1.6 Aggregate Type : Coarse ………..Specified ……………………………Crushed

Aggregate Type : Fine …………...Specified …………………………….Uncrushed (Zone 1)

1.7 Free-water / cement ratio…..Table 2, Figure 4 ………….…0.40 , use the value=0.40

1.8 Max free-water / cement ratio…….Specified………………0.45

Stage 2 (Selection of the free-water content)

2.1 Slump ………………………………..Specified ……..Slump = 30 - 60mm

2.2 Maximum aggregate size………..Specified………………………………...10mm

2.3 Free-water Content (W)………… Table 3 By interpolation……………..214kg/m^3

Stage 3 (Determination of Cement Content)

3.1 Cement Content, C3…………. $C_{3= \text{Water content/w-c ratio}}$ ……………$C_{3=}$ 214/0.40 =535 kg/ m^3

3.2 Minimum Cement Content………….. Specified……………………400 kg/m^3

(use 3.1 if > 3.2) …………………………………………………...535 kg/m^3

3.4 Modified free-water / cement ration No need since 535kg/ m^3 >400kg/ m^3

Stage 4 (Determination of total aggregate content)

4.1 Relative density of aggregate (SSD)…… Specified ………………….. 2.50

4.2 Concrete density (D)…………….Figure 5………………………………..2270 kg/m^3

4.3 Total aggregate Content, C4……. C4= (D-Total-W)…………. C4=(2270-535-214) = 1521 kg/m^3

Stage 5 (Selection of fine and coarse aggregate contents)

5.1 Grading of fine aggregate………………...Zone 1

5.2 Proportion of fine aggregate……………..Figure 6……(by interpolation)……………. 55%

5.3 Fine aggregate content,C5…C5=C4 x proportion of fines=1521 kg/m^3×55%= 836.55 kg/m^3

5.4 Coarse aggregate Content,C5………..C5=C4 - fine aggregate content=1521- 836.55= 684kg/m^3

Item No	Variables	Reference or Calculation	Values
Stage 6 (Moisture correction)			
6.1 Fine aggregate content= 836.55+(836.55×0.0135) – (836.55×0.017) = 834 kg/m^3 6.2 Coarse aggregate content= 684 + (684 ×0.0033) – (684 ×0.018) =675 kg/m^3 6.3 Water content=214-836.55×0.0135-684 ×0.0067+836.55×0.017+684 ×0.0139=195kg/m^3			
Stage 7 (Admixture)			
7.1 Consider 15% reduction in water = 195 – (195×0.15) = 193 kg/m^3 7.2 Cement content = 192.94 kg/m^3 /0.40 = 483 kg/m^3 7.3 Admixture (1% by weight of cement) = 0.01 × 482.35 = 4.82 kg/m^3			
Weight of all materials used for this trial mix could be summarized as:			

Quantities (Kg)	Cement	water	Fine aggregate	Coarse aggregate
Per 1 m^3	483	193	834	675
Per $0.105m^3$	51	20.27	87.57	71

Table D.4 Mix design for summery C-50 concrete batch

Concrete batches	Cement(Kg)	Water(Kg)	Fine aggregates(Kg)	Coarse aggregates(Kg)	Admixture (Kg)
BLWB	50.72	20.27	87.57	70.88	0.51
BLDT	50.30	20.16	87.57	71.09	0.50
BLDG	50.19	20.06	87.57	71.09	0.50
DMWB	53.24	21.32	72.24	85.05	0.53
DMDT	52.82	21.11	73.19	86.42	0.53
DMDG	52.61	21.05	73.19	86.42	0.53
HLWB	52.08	20.90	74.34	83.48	0.52
HLDT	51.66	20.69	75.29	84.84	0.52
HLDG	51.56	20.69	75.29	84.84	0.52

APPENDIX - E

EXPERIMENTAL RESULTS

1.1. Concrete workability

1.1.1. Compaction factor test

Table E.1 Compaction factor test result for C-30

Concrete batches	Samples	Empty wt. of cylinder(Kg)=W1	Wt. of partialy compacted (Kg)=W2	Wt. of fully compacted (Kg)=W3	Compaction factor
BLWB	1	8070	17650	19630	0.829
	2	8070	17720	19560	0.840
	Average	8070	17685	19595	0.834
BLDT	1	8070	17710	19400	0.851
	2	8070	18015	19410	0.877
	Average	8070	17862.5	19405	0.864
BLDG	1	8070	17860	19570	0.851
	2	8070	17890	19530	0.857
	Average	8070	17875	19550	0.854
DMWB	1	8070	18300	19320	0.909
	2	8070	18200	19360	0.897
	Average	8070	18250	19340	0.903
DMDT	1	8070	18630	19310	0.940
	2	8070	18230	19430	0.894
	Average	8070	18430	19370	0.917
DMDG	1	8070	18520	19560	0.909
	2	8070	18570	19550	0.915
	Average	8070	18545	19555	0.912
HLWB	1	8070	17960	19440	0.870
	2	8070	18275	19470	0.895
	Average	8070	18117.5	19455	0.883
HLDT	1	8070	18450	19700	0.893
	2	8070	18250	19600	0.883
	Average	8070	18350	19650	0.888
HLDG	1	8070	18265	19500	0.892
	2	8070	18250	19630	0.881
	Average	8070	18257.5	19565	0.886
Formula		Compaction factor = (W2-W1)/(W3-W1)			

Table E.2 Compaction factor test result for C-50

Concrete batches	Samples	Empty wt. of cylinder(Kg)=W1	Wt. of partialy compacted (Kg)=W2	Wt. of fully compacted (Kg)=W3	Compaction factor
BLWB	1	8070	16940	19040	0.809
	2	8070	16670	18890	0.795
	Average	8070	16805	18965	0.802
BLDT	1	8070	17050	19150	0.810
	2	8070	17460	19110	0.851
	Average	8070	17255	19130	0.830
BLDG	1	8070	17630	19560	0.832
	2	8070	17390	19620	0.807
	Average	8070	17510	19590	0.819
DMWB	1	8070	17830	19310	0.868
	2	8070	17790	19310	0.865
	Average	8070	17810	19310	0.867
DMDT	1	8070	18170	19430	0.889
	2	8070	18240	19370	0.900
	Average	8070	18205	19400	0.895
DMDG	1	8070	18140	19180	0.906
	2	8070	17855	19250	0.875
	Average	8070	17997.5	19215	0.891
HLWB	1	8070	17720	19420	0.850
	2	8070	18060	19470	0.876
	Average	8070	17890	19445	0.863
HLDT	1	8070	18550	19800	0.893
	2	8070	18300	19950	0.861
	Average	8070	18425	19875	0.877
HLDG	1	8070	18410	19640	0.894
	2	8070	17950	19640	0.854
	Average	8070	18180	19640	0.874
Formula		Compaction factor = (W2-W1)/(W3-W1)			

1.1.2. Slump cone test

Table E.3 Slump cone test result for C-30

Concrete batches	Sample 1 (mm)	Sample 2 (mm)	Average (mm)
BLWB	28	26	27
BLDT	31	33	32
BLDG	29	31	30
DMWB	37	39	38
DMDT	47	45	46
DMDG	39	41	40
HLWB	34	36	35
HLDT	37	39	38
HLDG	36	38	37

Table E.4 Slump cone test result for C-50

Concrete batches	Sample 1 (mm)	Sample 2 (mm)	Average (mm)
BLWB	22	24	23
BLDT	32	30	31
BLDG	29	27	28
DMWB	46	48	47
DMDT	56	54	55
DMDG	53	51	52
HLWB	35	37	36
HLDT	46	44	45
HLDG	42	40	41

1.2.Hardened density and compressive strength

Table E.5 Hardened density and compressive strength test result for C-30

Concret batches	Curing days	Sample	Dimensions(m) L	W	H	Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
BL WB C-30	3 days	BLWB 1 C-30	0.15	0.15	0.15	22.5	8.6	0.00338	425.377	18.906	2548.15
		BLWB 2 C- 30	0.15	0.15	0.15	22.5	8.41	0.00338	436.258	19.389	2491.85
		BLWB 3 C-30	0.15	0.15	0.15	22.5	8.46	0.00338	427.560	19.003	2506.67
		Average	0.15	0.15	0.15	22.5	8.49	0.00338	429.732	19.099	2515.56
	7 days	BLWB 1 C-30	0.15	0.15	0.15	22.5	8.45	0.00338	545.881	24.261	2503.70
		BLWB 2 C- 30	0.15	0.15	0.15	22.5	8.64	0.00338	546.144	24.273	2560.00
		BLWB 3 C-30	0.15	0.15	0.15	22.5	8.39	0.00338	539.121	23.961	2485.93
		Average	0.15	0.15	0.15	22.5	8.49	0.00338	543.715	24.165	2516.54
	28 days	BLWB 1 C-30	0.15	0.15	0.15	22.5	8.51	0.00338	720.639	32.028	2521.48
		BLWB 2 C- 30	0.15	0.15	0.15	22.5	8.49	0.00338	745.752	33.145	2515.56
		BLWB 3 C-30	0.15	0.15	0.15	22.5	8.5	0.00338	742.669	33.008	2518.52
		Average	0.15	0.15	0.15	22.5	8.50	0.00338	736.353	32.727	2518.52
BL DT C-30	3 days	BLDT 1 C-30	0.15	0.15	0.15	22.5	8.16	0.00338	503.443	22.375	2417.78
		BLDT 2 C-30	0.15	0.15	0.15	22.5	8.21	0.00338	502.692	22.342	2432.59
		BLDT 3 C-30	0.15	0.15	0.15	22.5	8.33	0.00338	545.881	24.216	2468.15
		Average	0.15	0.15	0.15	22.5	8.23	0.00338	517.339	22.978	2439.51
	7 days	BLDT 1 C-30	0.15	0.15	0.15	22.5	8.3	0.00338	615.000	27.333	2459.26
		BLDT 2 C-30	0.15	0.15	0.15	22.5	8.09	0.00338	563.533	25.046	2397.04
		BLDT 3 C-30	0.15	0.15	0.15	22.5	8.45	0.00338	589.785	26.213	2503.70
		Average	0.15	0.15	0.15	22.5	8.28	0.00338	589.439	26.197	2453.33
	28 days	BLDT 1 C-30	0.15	0.15	0.15	22.5	8.62	0.00338	813.974	36.177	2554.07
		BLDT 2 C-30	0.15	0.15	0.15	22.5	8.9	0.00338	796.889	35.417	2637.04
		BLDT 3 C-30	0.15	0.15	0.15	22.5	8.51	0.00338	833.354	37.038	2521.48
		Average	0.15	0.15	0.15	22.5	8.68	0.00338	814.739	36.211	2570.86
BL DG C-30	3 days	BLDG 1 C-30	0.15	0.15	0.15	22.5	8.13	0.00338	522.183	23.208	2408.89
		BLDG 2 C-30	0.15	0.15	0.15	22.5	8.48	0.00338	533.300	23.702	2512.59
		BLDG 3 C-30	0.15	0.15	0.15	22.5	8.59	0.00338	503.555	22.380	2545.19
		Average	0.15	0.15	0.15	22.5	8.4	0.00338	519.679	23.097	2488.89
	7 days	BLDG 1 C-30	0.15	0.15	0.15	22.5	8.64	0.00338	541.713	24.076	2560.00
		BLDG 2 C-30	0.15	0.15	0.15	22.5	8.37	0.00338	533.300	23.702	2480.00
		BLDG 3 C-30	0.15	0.15	0.15	22.5	8.52	0.00338	579.907	25.774	2524.44
		Average	0.15	0.15	0.15	22.5	8.51	0.00338	551.640	24.517	2521.48

	Curing days	Sample	Dimensions(m)			Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
			L	W	H						
	28 days	BLDG 1 C-30	0.15	0.15	0.15						
		BLDG 2 C-30	0.15	0.15	0.15	22.5	8.33	0.00338	714.361	31.749	2468.15
		BLDG 3 C-30	0.15	0.15	0.15	22.5	8.56	0.00338	747.281	33.210	2536.30
		Average	0.15	0.15	0.15	22.5	8.56	0.00338	745.731	33.143	2536.30
DMWB C-30	3 days	DMWB 1 C-30	0.15	0.15	0.15	22.5	8.58	0.00338	535.140	23.784	2542.22
		DMWB 2 C- 30	0.15	0.15	0.15	22.5	8.67	0.00338	532.511	23.667	2568.89
		DMWB 3 C-30	0.15	0.15	0.15	22.5	8.45	0.00338	576.865	25.638	2503.70
		Average	0.15	0.15	0.15	22.5	8.57	0.00338	548.172	24.363	2538.27
	7 days	DMWB 1 C-30	0.15	0.15	0.15	22.5	8.25	0.00338	667.030	29.646	2444.44
		DMWB 2 C- 30	0.15	0.15	0.15	22.5	8.72	0.00338	619.211	27.520	2583.70
		DMWB 3 C-30	0.15	0.15	0.15	22.5	8.79	0.00338	625.602	27.805	2604.44
		Average	0.15	0.15	0.15	22.5	8.59	0.00338	637.281	28.324	2544.20
	28 days	DMWB 1 C-30	0.15	0.15	0.15	22.5	8.64	0.00338	791.207	35.165	2560.00
		DMWB 2 C- 30	0.15	0.15	0.15	22.5	8.78	0.00338	802.158	35.651	2601.48
		DMWB 3 C-30	0.15	0.15	0.15	22.5	8.53	0.00338	823.344	36.593	2527.41
		Average	0.15	0.15	0.15	22.5	8.65	0.00338	805.570	35.803	2562.96
DMDT C-30	3 days	DMDT 1 C-30	0.15	0.15	0.15	22.5	8.47	0.00338	517.977	23.021	2509.63
		DMDT 2 C- 30	0.15	0.15	0.15	22.5	8.31	0.00338	476.853	21.193	2462.22
		DMDT 3 C-30	0.15	0.15	0.15	22.5	8.49	0.00338	533.563	23.714	2515.56
		Average	0.15	0.15	0.15	22.5	8.42	0.00338	509.464	22.643	2495.80
	7 days	DMDT 1 C-30	0.15	0.15	0.15	22.5	8.34	0.00338	647.068	28.759	2471.11
		DMDT 2 C- 30	0.15	0.15	0.15	22.5	8.8	0.00338	648.571	28.825	2607.41
		DMDT 3 C-30	0.15	0.15	0.15	22.5	8.43	0.00338	617.331	27.437	2497.78
		Average	0.15	0.15	0.15	22.5	8.52	0.00338	637.657	28.340	2525.43
	28 days	DMDT 1 C-30	0.15	0.15	0.15	22.5	8.57	0.00338	943.280	41.924	2539.26
		DMDT 2 C- 30	0.15	0.15	0.15	22.5	8.84	0.00338	894.431	39.752	2619.26
		DMDT 3 C-30	0.15	0.15	0.15	22.5	8.86	0.00338	937.322	41.659	2625.19
		Average	0.15	0.15	0.15	22.5	8.76	0.00338	925.011	41.112	2594.57
DMDG C-30	3 days	DMDG 1 C-30	0.15	0.15	0.15	22.5	8.32	0.00338	461.642	20.517	2465.19
		DMDG 2 C- 30	0.15	0.15	0.15	22.5	8.21	0.00338	497.546	22.113	2432.59
		DMDG 3 C-30	0.15	0.15	0.15	22.5	8.37	0.00338	474.487	21.088	2480.00
		Average	0.15	0.15	0.15	22.5	8.3	0.00338	477.892	21.239	2459.26

	Curing days	Sample	Dimensions(m)			Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
			L	W	H						
	7 days	DMDG 1 C-30	0.15	0.15	0.15						
		DMDG 2 C- 30	0.15	0.15	0.15	22.5	8.45	0.00338	617.331	27.437	2503.70
		DMDG 3 C-30	0.15	0.15	0.15	22.5	8.36	0.00338	597.784	26.568	2477.04
		Average	0.15	0.15	0.15	22.5	8.36	0.00338	612.745	27.233	2478.02
	28 days	DMDG 1 C-30	0.15	0.15	0.15	22.5	8.77	0.00338	884.797	39.324	2598.52
		DMDG 2 C- 30	0.15	0.15	0.15	22.5	8.82	0.00338	880.469	39.132	2613.33
		DMDG 3 C-30	0.15	0.15	0.15	22.5	8.66	0.00338	856.912	38.085	2565.93
		Average	0.15	0.15	0.15	22.5	8.75	0.00338	874.059	38.847	2592.59
HLWB C-30	3 days	HLWB 1 C-30	0.15	0.15	0.15	22.5	8.19	0.00338	503.443	22.375	2426.67
		HLWB 2 C- 30	0.15	0.15	0.15	22.5	8.26	0.00338	476.853	21.193	2447.41
		HLWB 3 C-30	0.15	0.15	0.15	22.5	8.45	0.00338	519.517	23.090	2503.70
		Average	0.15	0.15	0.15	22.5	8.3	0.00338	499.938	22.219	2459.26
	7 days	HLWB 1 C-30	0.15	0.15	0.15	22.5	8.57	0.00338	603.459	26.820	2539.26
		HLWB 2 C- 30	0.15	0.15	0.15	22.5	8.63	0.00338	624.812	27.769	2557.04
		DMWB 3 C-30	0.15	0.15	0.15	22.5	8.69	0.00338	655.150	29.118	2574.81
		Average	0.15	0.15	0.15	22.5	8.63	0.00338	627.807	27.902	2557.04
	28 days	HLWB 1 C-30	0.15	0.15	0.15	22.5	8.61	0.00338	789.099	35.071	2551.11
		HLWB 2 C- 30	0.15	0.15	0.15	22.5	8.69	0.00338	787.255	34.989	2574.81
		HLWB 3 C-30	0.15	0.15	0.15	22.5	8.7	0.00338	781.799	34.747	2577.78
		Average	0.15	0.15	0.15	22.5	8.67	0.00338	786.051	34.936	2567.90
HLDT C-30	3 days	HLDT 1 C-30	0.15	0.15	0.15	22.5	8.27	0.00338	514.860	22.883	2450.37
		HLDT 2 C- 30	0.15	0.15	0.15	22.5	8.4	0.00338	541.713	24.076	2488.89
		HLDT 3 C-30	0.15	0.15	0.15	22.5	8.59	0.00338	579.907	25.774	2545.19
		Average	0.15	0.15	0.15	22.5	8.42	0.00338	545.493	24.244	2494.81
	7 days	HLDT 1 C-30	0.15	0.15	0.15	22.5	8.32	0.00338	634.323	28.192	2465.19
		HLDT 2 C- 30	0.15	0.15	0.15	22.5	8.6	0.00338	641.842	28.526	2548.15
		HLDT 3 C-30	0.15	0.15	0.15	22.5	8.67	0.00338	601.429	26.730	2568.89
		Average	0.15	0.15	0.15	22.5	8.53	0.00338	625.865	27.816	2527.41
	28 days	HLDT 1 C-30	0.15	0.15	0.15	22.5	8.72	0.00338	870.346	38.682	2583.70
		HLDT 2 C- 30	0.15	0.15	0.15	22.5	8.61	0.00338	857.627	38.117	2551.11
		HLDT 3 C-30	0.15	0.15	0.15	22.5	8.85	0.00338	851.305	37.836	2622.22
		Average	0.15	0.15	0.15	22.5	8.73	0.00338	859.759	38.212	2585.68

Concrete batches	Curing days	Sample	Dimensions(m)			Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
			L	W	H						
HLDG C-30	3 days	HLDG 1 C-30	0.15	0.15	0.15	22.5	8.35	0.00338	452.516	20.112	2474.07
		HLDG 2 C- 30	0.15	0.15	0.15	22.5	8.23	0.00338	497.021	22.090	2440.89
		HLDG 3 C-30	0.15	0.15	0.15	22.5	8.52	0.00338	474.149	21.073	2524.44
		Average	0.15	0.15	0.15	22.5	8.37	0.00338	474.562	21.092	2479.80
	7 days	HLDG 1 C-30	0.15	0.15	0.15	22.5	8.7	0.00338	640.977	28.488	2577.78
		HLDG 2 C- 30	0.15	0.15	0.15	22.5	8.3	0.00338	634.286	28.190	2459.26
		HLDG 3 C-30	0.15	0.15	0.15	22.5	8.46	0.00338	592.038	26.313	2506.67
		Average	0.15	0.15	0.15	22.5	8.49	0.00338	622.434	27.664	2514.57
	28 days	HLDG 1 C-30	0.15	0.15	0.15	22.5	8.83	0.00338	829.516	36.867	2616.30
		HLDG 2 C- 30	0.15	0.15	0.15	22.5	8.64	0.00338	848.181	37.697	2560.00
		HLDG 3 C-30	0.15	0.15	0.15	22.5	8.65	0.00338	809.345	35.971	2562.96
		Average	0.15	0.15	0.15	22.5	8.71	0.00338	829.014	36.845	2579.75

Table E.6 Hardened density and compressive strength test result for C-50

Concrete batches	Curing days	Sample	Dimensions(m)			Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
			L	W	H						
BLWB C-50	3 days	BLWB 1 C-50	0.15	0.15	0.15	22.5	8.49	0.00338	730.602	32.471	2515.56
		BLWB 2 C- 50	0.15	0.15	0.15	22.5	8.61	0.00338	763.246	33.922	2551.11
		BLWB 3 C-50	0.15	0.15	0.15	22.5	8.31	0.00338	694.436	30.864	2462.22
		Average	0.15	0.15	0.15	22.5	8.47	0.00338	729.428	32.42	2509.63
	7 days	BLWB 1 C-50	0.15	0.15	0.15	22.5	8.31	0.00338	817.36	36.327	2462.22
		BLWB 2 C- 50	0.15	0.15	0.15	22.5	8.45	0.00338	874.26	38.856	2503.70
		BLWB 3 C-50	0.15	0.15	0.15	22.5	8.67	0.00338	913.602	40.605	2568.89
		Average	0.15	0.15	0.15	22.5	8.48	0.00338	868.41	38.60	2511.60
	28 days	BLWB 1 C-50	0.15	0.15	0.15	22.5	8.44	0.00338	1078.087	47.915	2500.74
		BLWB 2 C- 50	0.15	0.15	0.15	22.5	8.43	0.00338	998.101	44.36	2497.78
		BLWB 3 C-50	0.15	0.15	0.15	22.5	8.59	0.00338	1022.158	45.429	2545.19
		Average	0.15	0.15	0.15	22.5	8.49	0.00338	1032.782	45.901	2514.57

Concrete batches	Curing days	Sample	Dimensions(m)			Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
			L	W	H						
BLDT C-50	3 days	BLDT 1 C-50	0.15	0.15	0.15	22.5	8.22	0.00338	849.272	37.745	2435.56
		BLDT 2 C-50	0.15	0.15	0.15	22.5	8.23	0.00338	793.088	35.248	2438.52
		BLDT 3 C-50	0.15	0.15	0.15	22.5	8.48	0.00338	865.642	38.473	2512.59
		Average	0.15	0.15	0.15	22.5	8.31	0.00338	836.000	37.155	2462.22
	7 days	BLDT 1 C-50	0.15	0.15	0.15	22.5	8.47	0.00338	918.811	40.836	2509.63
		BLDT 2 C-50	0.15	0.15	0.15	22.5	8.53	0.00338	855.707	38.031	2527.41
		BLDT 3 C-50	0.15	0.15	0.15	22.5	8.62	0.00338	903.335	40.148	2554.07
		Average	0.15	0.15	0.15	22.5	8.54	0.00338	892.617	39.671	2530.37
	28 days	BLDT 1 C-50	0.15	0.15	0.15	22.5	8.52	0.00338	1112.086	49.426	2524.44
		BLDT 2 C-50	0.15	0.15	0.15	22.5	8.67	0.00338	1099.247	48.855	2568.89
		BLDT 3 C-50	0.15	0.15	0.15	22.5	8.59	0.00338	1138.178	50.586	2545.19
		Average	0.15	0.15	0.15	22.5	8.59	0.00338	1116.503	49.622	2546.17
BLDG C-50	3 days	BLDG 1 C-50	0.15	0.15	0.15	22.5	8.64	0.00338	808.367	35.927	2560.00
		BLDG 2 C-50	0.15	0.15	0.15	22.5	8.52	0.00338	790.153	35.118	2524.44
		BLDG 3 C-50	0.15	0.15	0.15	22.5	8.29	0.00338	781.799	34.747	2456.30
		Average	0.15	0.15	0.15	22.5	8.48	0.00338	793.439	35.264	2513.58
	7 days	BLDG 1 C-50	0.15	0.15	0.15	22.5	8.56	0.00338	904.122	40.183	2536.30
		BLDG 2 C-50	0.15	0.15	0.15	22.5	8.34	0.00338	946.465	42.065	2471.11
		BLDG 3 C-50	0.15	0.15	0.15	22.5	8.69	0.00338	965.651	42.918	2574.81
		Average	0.15	0.15	0.15	22.5	8.53	0.00338	938.746	41.722	2527.41
	28 days	BLDG 1 C-50	0.15	0.15	0.15	22.5	8.37	0.00338	1104.029	49.068	2480.00
		BLDG 2 C-50	0.15	0.15	0.15	22.5	8.61	0.00338	1061.747	47.189	2551.11
		BLDG 3 C-50	0.15	0.15	0.15	22.5	8.68	0.00338	1092.62	48.561	2571.85
		Average	0.15	0.15	0.15	22.5		0.00338	1086.132	48.272	2534.32
DMWB C-50	3 days	DMWB 1 C-50	0.15	0.15	0.15	22.5	8.48	0.00338	917.499	40.778	2512.59
		DMWB 2 C- 50	0.15	0.15	0.15	22.5	8.54	0.00338	873.695	38.831	2530.37
		DMWB 3 C-50	0.15	0.15	0.15	22.5	8.39	0.00338	898.043	39.913	2485.93
		Average	0.15	0.15	0.15	22.5	8.47	0.00338	896.412	39.840	2509.63
	7 days	DMWB 1 C-50	0.15	0.15	0.15	22.5	8.88	0.00338	959.918	42.663	2631.11
		DMWB 2 C- 50	0.15	0.15	0.15	22.5	8.75	0.00338	977.529	43.446	2592.59
		DMWB 3 C-50	0.15	0.15	0.15	22.5	8.46	0.00338	977.604	43.449	2506.67
		Average	0.15	0.15	0.15	22.5	8.70	0.00338	971.683	43.186	2576.79
	28 days	DMWB 1 C-50	0.15	0.15	0.15	22.5	8.79	0.00338	1153.426	51.263	2604.44
		DMWB 2 C- 50	0.15	0.15	0.15	22.5	8.55	0.00338	1126.13	50.05	2533.33
		DMWB 3 C-50	0.15	0.15	0.15	22.5	8.81	0.00338	1104.669	49.096	2610.37
		Average	0.15	0.15	0.15	22.5	8.72	0.00338	1128.075	50.136	2582.72

Concrete batches	Curing days	Sample	Dimensions(m)			Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
			L	W	H						
DMDT C-50	3 days	DMDT 1 C-50	0.15	0.15	0.15	22.5	8.6	0.00338	888.485	39.488	2548.15
		DMDT 2 C- 50	0.15	0.15	0.15	22.5	8.62	0.00338	812.506	36.111	2554.07
		DMDT 3 C-50	0.15	0.15	0.15	22.5	8.47	0.00338	912.778	40.568	2509.63
		Average	0.15	0.15	0.15	22.5	8.56	0.00338	871.256	38.722	2537.28
	7 days	DMDT 1 C-50	0.15	0.15	0.15	22.5	8.57	0.00338	983.15	43.696	2539.26
		DMDT 2 C- 50	0.15	0.15	0.15	22.5	8.31	0.00338	973.333	43.259	2462.22
		DMDT 3 C-50	0.15	0.15	0.15	22.5	8.73	0.00338	964.302	42.858	2586.67
		Average	0.15	0.15	0.15	22.5	8.54	0.00338	973.595	43.271	2529.38
	28 days	DMDT 1 C-50	0.15	0.15	0.15	22.5	8.7	0.00338	1310.445	58.242	2577.78
		DMDT 2 C- 50	0.15	0.15	0.15	22.5	8.76	0.00338	1330.56	59.136	2595.56
		DMDT 3 C-50	0.15	0.15	0.15	22.5	8.83	0.00338	1294.946	57.533	2616.30
		Average	0.15	0.15	0.15	22.5	8.76	0.00338	1311.983	58.303	2596.54
DMDG C-50	3 days	DMDG 1 C-50	0.15	0.15	0.15	22.5	8.52	0.00338	793.578	35.27	2524.44
		DMDG 2 C- 50	0.15	0.15	0.15	22.5	8.38	0.00338	856.234	38.055	2482.96
		DMDG 3 C-50	0.15	0.15	0.15	22.5	8.49	0.00338	850.514	37.801	2515.56
		Average	0.15	0.15	0.15	22.5	8.46	0.00338	833.442	37.042	2507.65
	7 days	DMDG 1 C-50	0.15	0.15	0.15	22.5	8.74	0.00338	1012.003	44.978	2589.63
		DMDG 2 C- 50	0.15	0.15	0.15	22.5	8.54	0.00338	998.776	44.39	2530.37
		DMDG 3 C-50	0.15	0.15	0.15	22.5	8.61	0.00338	941.856	41.86	2551.11
		Average	0.15	0.15	0.15	22.5	8.63	0.00338	984.211	43.742	2557.04
	28 days	DMDG 1 C-50	0.15	0.15	0.15	22.5	8.63	0.00338	1319.114	58.627	2557.04
		DMDG 2 C- 50	0.15	0.15	0.15	22.5	8.79	0.00338	1301.964	57.865	2604.44
		DMDG 3 C-50	0.15	0.15	0.15	22.5	8.77	0.00338	1307.33	58.104	2598.52
		Average	0.15	0.15	0.15	22.5	8.73	0.00338	1309.469	58.198	2586.67
HLWB C-50	3 days	HLWB 1 C-50	0.15	0.15	0.15	22.5	8.69	0.00338	896.5	39.844	2574.81
		HLWB 2 C- 50	0.15	0.15	0.15	22.5	8.38	0.00338	900.037	40.002	2482.96
		HLWB 3 C-50	0.15	0.15	0.15	22.5	8.44	0.00338	855.218	38.01	2500.74
		Average	0.15	0.15	0.15	22.5	8.50	0.00338	883.918	39.285	2519.51
	7 days	HLWB 1 C-50	0.15	0.15	0.15	22.5	8.48	0.00338	942.081	41.87	2512.59
		HLWB 2 C- 50	0.15	0.15	0.15	22.5	8.65	0.00338	983.525	43.712	2562.96
		DMWB 3 C-50	0.15	0.15	0.15	22.5	8.51	0.00338	952.123	42.317	2521.48
		Average	0.15	0.15	0.15	22.5		0.00338	959.243	42.633	2532.35
	28 days	HLWB 1 C-50	0.15	0.15	0.15	22.5	8.53	0.00338	1070.633	47.584	2527.41
		HLWB 2 C- 50	0.15	0.15	0.15	22.5	8.4	0.00338	1081.551	48.069	2488.89
		HLWB 3 C-50	0.15	0.15	0.15	22.5	8.76	0.00338	1059.526	47.09	2595.56

		Average	0.15	0.15	0.15	22.5		0.00338	1070.57	47.581	2537.28
Concrete batches	Curing days	Sample	Dimensions(m)			Area of Crushing Face (m)2	Weight(Kg)	Volume (m)3	Failure load (KN)	Compressive strength (Mpa)	Concrete density(Kg/m3)
			L	W	H						
HL DT C- 50	3 days	HLDT 1 C-50	0.15	0.15	0.15	22.5	8.45	0.00338	796.174	35.386	2503.70
		HLDT 2 C- 50	0.15	0.15	0.15	22.5	8.74	0.00338	833.618	37.05	2589.63
		HLDT 3 C-50	0.15	0.15	0.15	22.5	8.31	0.00338	865.003	38.445	2462.22
		Average	0.15	0.15	0.15	22.5		0.00338	831.598	36.960	2518.52
	7 days	HLDT 1 C-50	0.15	0.15	0.15	22.5	8.48	0.00338	1002.71	44.565	2512.59
		HLDT 2 C- 50	0.15	0.15	0.15	22.5	8.38	0.00338	959.43	42.641	2482.96
		HLDT 3 C-50	0.15	0.15	0.15	22.5	8.69	0.00338	1010.13	44.895	2574.81
		Average	0.15	0.15	0.15	22.5		0.00338	990.756	44.033	2523.46
	28 days	HLDT 1 C-50	0.15	0.15	0.15	22.5	8.65	0.00338	1158.133	51.473	2562.96
		HLDT 2 C- 50	0.15	0.15	0.15	22.5	8.47	0.00338	1169.804	51.991	2509.63
		HLDT 3 C-50	0.15	0.15	0.15	22.5	8.62	0.00338	1137.048	50.535	2554.07
		Average	0.15	0.15	0.15	22.5		0.00338	1154.995	51.333	2542.22
HL DG C- 50	3 days	HLDG 1 C-50	0.15	0.15	0.15	22.5	8.49	0.00338	850.627	37.806	2515.56
		HLDG 2 C- 50	0.15	0.15	0.15	22.5	8.56	0.00338	879.491	39.088	2536.30
		HLDG 3 C-50	0.15	0.15	0.15	22.5	8.46	0.00338	870.497	38.689	2506.67
		Average	0.15	0.15	0.15	22.5		0.00338	866.871	38.527	2519.51
	7 days	HLDG 1 C-50	0.15	0.15	0.15	22.5	8.66	0.00338	943.28	41.924	2565.93
		HLDG 2 C- 50	0.15	0.15	0.15	22.5	8.41	0.00338	968.349	43.038	2491.85
		HLDG 3 C-50	0.15	0.15	0.15	22.5	8.53	0.00338	965.201	42.898	2527.41
		Average	0.15	0.15	0.15	22.5		0.00338	958.943	42.62	2528.40
	28 days	HLDG 1 C-50	0.15	0.15	0.15	22.5	8.47	0.00338	1086.107	48.271	2509.63
		HLDG 2 C- 50	0.15	0.15	0.15	22.5	8.64	0.00338	1078.539	47.935	2560.00
		HLDG 3 C-50	0.15	0.15	0.15	22.5	8.56	0.00338	1120.821	49.814	2536.30
		Average	0.15	0.15	0.15	22.5		0.00338	1095.155	48.6733	2535.31

1.3. Splitting tensile strength

Table E.7 Splitting tensile strength test results for C-30

Concrete batches	Samples	Applied compressive load (KN)= P	Split tensile strength (Mpa)
BLWB C-30	BLWB 1 C-30	181.876	2.574
	BLWB 2 C- 30	182.366	2.581
	BLWB 3 C-30	180.181	2.550
	Average	181.474	2.569
BLDT C-30	BLDT 1 C-30	203.994	2.887
	BLDT 2 C-30	203.025	2.874
	BLDT 3 C-30	202.524	2.867
	Average	203.181	2.876
BLDG C-30	BLDG 1 C-30	187.340	2.652
	BLDG 2 C-30	188.508	2.668
	BLDG 3 C-30	189.601	2.684
	Average	188.483	2.668
DMWB C-30	DMWB 1 C-30	199.246	2.820
	DMWB 2 C- 30	199.284	2.821
	DMWB 3 C-30	198.983	2.816
	Average	199.171	2.819
DMDT C-30	DMDT 1 C-30	230.482	3.262
	DMDT 2 C- 30	229.013	3.242
	DMDT 3 C-30	228.184	3.230
	Average	229.226	3.245
DMDG C-30	DMDG 1 C-30	224.378	3.176
	DMDG 2 C- 30	222.946	3.156
	DMDG 3 C-30	221.552	3.136
	Average	222.959	3.156
HLWB C-30	HLWB 1 C-30	197.852	2.800
	HLWB 2 C- 30	198.267	2.806
	HLWB 3 C-30	196.760	2.785
	Average	197.626	2.797
HLDT C-30	HLDT 1 C-30	212.509	3.008
	HLDT 2 C- 30	215.034	3.044
	HLDT 3 C-30	217.822	3.083
	Average	215.122	3.045
HLDG C-30	HLDG 1 C-30	206.443	2.922
	HLDG 2 C- 30	204.258	2.891
	HLDG 3 C-30	205.614	2.910
	Average	205.438	2.908

Table E.8 Splitting tensile strength test results for C-50

Concrete batches	Samples	Applied compressive load (KN)= P	Split tensile strength (Mpa)
BLWB C-50	BLWB 1 C-50	238.056	3.370
	BLWB 2 C- 50	238.809	3.380
	BLWB 3 C-50	238.244	3.372
	Average	238.370	3.374
BLDT C-50	BLDT 1 C-50	253.580	3.589
	BLDT 2 C-50	250.980	3.552
	BLDT 3 C-50	251.356	3.558
	Average	251.972	3.566
BLDG C-50	BLDG 1 C-50	244.913	3.467
	BLDG 2 C-50	245.554	3.476
	BLDG 3 C-50	244.537	3.461
	Average	245.001	3.468
DMWB C-50	DMWB 1 C-50	261.040	3.695
	DMWB 2 C- 50	255.614	3.618
	DMWB 3 C-50	254.898	3.608
	Average	257.184	3.640
DMDT C-50	DMDT 1 C-50	276.074	3.908
	DMDT 2 C- 50	277.769	3.932
	DMDT 3 C-50	278.975	3.949
	Average	277.606	3.929
DMDG C-50	DMDG 1 C-50	270.384	3.827
	DMDG 2 C- 50	271.515	3.843
	DMDG 3 C-50	274.642	3.887
	Average	272.180	3.853
HLWB C-50	HLWB 1 C-50	241.711	3.421
	HLWB 2 C- 50	243.255	3.443
	HLWB 3 C-50	241.409	3.417
	Average	242.125	3.427
HLDT C-50	HLDT 1 C-50	262.698	3.718
	HLDT 2 C- 50	265.298	3.755
	HLDT 3 C-50	262.133	3.710
	Average	263.376	3.728
HLDG C-50	HLDG 1 C-50	247.777	3.507
	HLDG 2 C- 50	249.133	3.526
	HLDG 3 C-50	248.870	3.523
	Average	248.593	3.519

1.4. Durability

1.4.1. Water absorption

Table E.9 Water absorption results for C-30

Concrete batches	Samples	After curing of 28 days		
		Initial mass (Kg)	Oven dry mass (Kg)	Percentage (%)
BLWB	BLWB 1 C-30	8.50	7.83	8.56
	BLWB 2 C- 30	8.57	7.94	7.93
	BLWB 3 C-30	8.53	7.87	8.39
	Average	8.53	7.88	8.29
BLDT	BLDT 1 C-30	8.45	7.83	7.92
	BLDT 2 C-30	8.68	8.10	7.16
	BLDT 3 C-30	8.84	8.23	7.41
	Average	8.66	8.05	7.49
BLDG	BLDG 1 C-30	8.74	8.08	8.17
	BLDG 2 C-30	8.38	7.76	7.99
	BLDG 3 C-30	8.59	7.94	8.19
	Average	8.57	7.93	8.12
DMWB	DMWB 1 C-30	8.43	7.80	8.08
	DMWB 2 C- 30	8.72	8.13	7.26
	DMWB 3 C-30	8.69	8.07	7.68
	Average	8.61	8.00	7.67
DMDT	DMDT 1 C-30	8.28	7.73	7.12
	DMDT 2 C- 30	8.86	8.35	6.11
	DMDT 3 C-30	8.71	8.17	6.61
	Average	8.62	8.08	6.60
DMDG	DMDG 1 C-30	8.39	7.81	7.43
	DMDG 2 C- 30	8.76	8.22	6.57
	DMDG 3 C-30	8.64	8.07	7.06
	Average	8.60	8.03	7.01
HLWB	HLWB 1 C-30	8.56	7.91	8.22
	HLWB 2 C- 30	8.63	8.02	7.61
	HLWB 3 C-30	8.61	7.97	8.03
	Average	8.60	7.97	7.95
HLDT	HLDT 1 C-30	8.21	7.62	7.74
	HLDT 2 C- 30	8.86	8.31	6.62
	HLDT 3 C-30	8.75	8.17	7.10
	Average	8.61	8.03	7.14
HLDG	HLDG 1 C-30	8.24	7.65	7.71
	HLDG 2 C- 30	8.61	8.06	6.82
	HLDG 3 C-30	8.72	8.14	7.13
	Average	8.52	7.95	7.21

Table E.10 Water absorption test results for C-50

Concrete batches	Samples	After curing of 28 days		
		Initial mass (Kg)	Oven dry mass (Kg)	Percentage (Kg)
BLWB	BLWB 1 C-50	8.60	8.14	5.65
	BLWB 2 C- 50	8.41	7.99	5.26
	BLWB 3 C-50	8.47	8.02	5.61
	Average	8.49	8.05	5.51
BLDT	BLDT 1 C-50	8.31	7.87	5.59
	BLDT 2 C-50	8.65	8.25	4.85
	BLDT 3 C-50	8.54	8.11	5.30
	Average	8.50	8.08	5.24
BLDG	BLDG 1 C-50	8.30	7.85	5.73
	BLDG 2 C-50	8.62	8.21	4.99
	BLDG 3 C-50	8.33	7.89	5.58
	Average	8.42	7.98	5.43
DMWB	DMWB 1 C-50	8.31	7.89	5.32
	DMWB 2 C- 50	8.53	8.15	4.66
	DMWB 3 C-50	8.74	8.33	4.92
	Average	8.53	8.12	4.97
DMDT	DMDT 1 C-50	8.77	8.37	4.78
	DMDT 2 C- 50	8.41	8.05	4.47
	DMDT 3 C-50	8.84	8.45	4.62
	Average	8.67	8.29	4.62
DMDG	DMDG 1 C-50	8.35	7.95	5.04
	DMDG 2 C- 50	8.58	8.22	4.39
	DMDG 3 C-50	8.79	8.40	4.66
	Average	8.57	8.19	4.69
HLWB	HLWB 1 C-50	8.33	7.87	5.80
	HLWB 2 C- 50	8.44	8.02	5.20
	HLWB 3 C-50	8.68	8.23	5.43
	Average	8.48	8.04	5.47
HLDT	HLDT 1 C-50	8.48	8.07	5.12
	HLDT 2 C- 50	8.67	8.30	4.50
	HLDT 3 C-50	8.61	8.21	4.91
	Average	8.59	8.19	4.84
HLDG	HLDG 1 C-30	8.32	7.88	5.65
	HLDG 2 C- 30	8.65	8.25	4.91
	HLDG 3 C-30	8.45	8.02	5.43
	Average	8.47	8.05	5.32

1.4.2. Sulfate attack resistance tests

Table E.11 Sulfate attack resistance mass loss and compressive strength loss test results for C-30

Concrete batches	Samples	Weigth before immession(Kg)	Weigth after immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
BL WB C-30	BLWB 1 C-30	8.790	8.771	0.019	0.217	32.028	28.292	3.736	11.66
	BLWB 2 C- 30	8.500	8.483	0.017	0.200	33.145	29.226	3.919	11.82
	BLWB 3 C-30	8.680	8.663	0.017	0.196	33.008	29.903	3.105	9.41
	Average	8.657	8.639	0.018	0.204	32.727	29.140	3.587	10.96
BLDT C-30	BLDT 1 C-30	8.230	8.217	0.013	0.158	36.177	33.104	3.073	8.49
	BLDT 2 C-30	8.470	8.458	0.012	0.142	35.417	34.206	1.211	3.42
	BLDT 3 C-30	8.410	8.397	0.013	0.155	37.038	31.515	5.523	14.91
	Average	8.370	8.357	0.013	0.152	36.211	32.942	3.269	9.03
BLDG C-30	BLDG 1 C-30	8.740	8.719	0.021	0.241	34.469	29.863	4.606	13.36
	BLDG 2 C-30	8.530	8.510	0.020	0.235	31.749	26.976	4.773	15.03
	BLDG 3 C-30	8.460	8.443	0.017	0.201	33.210	30.376	2.834	8.53
	Average	8.577	8.557	0.019	0.226	33.143	29.713	3.430	10.35
DM WB C-30	DMWB 1 C-30	8.530	8.515	0.015	0.176	35.165	30.911	4.254	12.10
	DMWB 2 C- 30	8.620	8.604	0.016	0.186	35.651	32.152	3.499	9.81
	DMWB 3 C-30	8.570	8.555	0.015	0.175	36.593	34.009	2.584	7.06
	Average	8.573	8.558	0.015	0.179	35.803	32.357	3.446	9.62
DM DT C-30	DMDT 1 C-30	8.250	8.238	0.012	0.146	41.924	39.433	2.491	5.94
	DMDT 2 C- 30	8.640	8.626	0.014	0.162	39.752	36.254	3.498	8.80
	DMDT 3 C-30	8.510	8.497	0.013	0.153	41.659	39.781	1.878	4.51
	Average	8.467	8.454	0.013	0.154	41.112	38.489	3.446	6.38
DM DG C-30	DMDG 1 C-30	8.270	8.259	0.011	0.133	39.324	35.961	3.363	8.55
	DMDG 2 C- 30	8.750	8.739	0.011	0.126	39.132	35.424	3.708	9.48
	DMDG 3 C-30	8.720	8.708	0.012	0.138	38.085	37.013	1.072	2.81
	Average	8.580	8.569	0.011	0.132	38.847	36.133	2.714	6.99
HL WB C-30	HLWB 1 C-30	8.660	8.642	0.018	0.208	35.071	31.836	3.235	9.22
	HLWB 2 C- 30	8.740	8.722	0.018	0.206	34.989	31.773	3.216	9.19
	HLWB 3 C-30	8.590	8.571	0.019	0.222	34.747	30.934	3.813	10.97
	Average	8.663	8.645	0.018	0.212	34.936	31.514	3.421	9.79

Concrete batches	Samples	Weigth before immession(Kg)	Weigth after immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
HLDT C-30	HLDT 1 C-30	8.310	8.297	0.013	0.157	38.682	34.989	3.693	9.55
	HLDT 2 C- 30	8.730	8.717	0.013	0.149	38.117	35.747	2.370	6.22
	HLDT 3 C-30	8.670	8.656	0.014	0.162	37.836	35.093	2.743	7.25
	Average	8.570	8.557	0.013	0.156	38.212	35.276	2.935	7.68
HLDG C-30	HLDG 1 C-30	8.660	8.645	0.015	0.174	36.867	33.210	3.657	111.01
	HLDG 2 C- 30	8.530	8.515	0.015	0.176	37.697	33.089	4.608	113.93
	HLDG 3 C-30	8.490	8.474	0.016	0.189	35.971	34.747	1.224	103.52
	Average	8.560	8.545	0.015	0.179	36.845	33.682	3.163	8.58

Table E.12 Sulfate attack resistance mass loss and compressive strength loss test results for C-50

Concrete batches	Samples	Weigth before immession(Kg)	Weigth before immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
BL WB C-50	BLWB 1 C-50	8.570	8.562	0.008	0.093	47.915	42.373	5.542	11.57
	BLWB 2 C- 50	8.460	8.454	0.006	0.071	44.360	41.644	2.716	6.12
	BLWB 3 C-50	8.540	8.534	0.006	0.070	45.429	42.911	2.518	5.54
	Average	8.523	8.517	0.007	0.078	45.901	42.081	3.820	8.32
BLDT C-50	BLDT 1 C-50	8.560	8.554	0.006	0.070	49.426	46.465	2.961	5.99
	BLDT 2 C-50	8.610	8.602	0.008	0.093	48.855	45.879	2.976	6.09
	BLDT 3 C-50	8.550	8.544	0.006	0.070	50.586	46.227	4.359	8.62
	Average	8.573	8.567	0.007	0.078	49.622	46.032	3.590	7.24
BLDG C-50	BLDG 1 C-50	8.280	8.270	0.010	0.121	49.068	44.721	4.347	8.86
	BLDG 2 C-50	8.630	8.623	0.007	0.081	47.189	45.088	2.101	4.45
	BLDG 3 C-50	8.710	8.704	0.006	0.069	48.561	44.758	3.803	7.83
	Average	8.540	8.532	0.008	0.090	48.273	44.593	3.680	7.62
DM WB C-50	DMWB 1 C-50	8.570	8.567	0.003	0.035	51.263	47.779	3.484	6.80
	DMWB 2 C- 50	8.530	8.526	0.004	0.047	50.050	46.359	3.691	7.37
	DMWB 3 C-50	8.760	8.757	0.003	0.034	49.096	45.526	3.570	7.27
	Average	8.620	8.617	0.003	0.039	50.136	46.687	3.449	6.88

Concrete batches	Samples	Weigth before immession(Kg)	Weigth before immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
DM DT C-50	DMDT 1 C-50	8.560	8.559	0.001	0.012	58.242	55.737	2.505	4.30
	DMDT 2 C- 50	8.740	8.737	0.003	0.034	59.136	54.734	4.402	7.44
	DMDT 3 C-50	8.810	8.808	0.002	0.023	57.533	55.695	1.838	3.19
	Average	8.703	8.701	0.002	0.023	58.304	55.389	2.915	5.00
DM DG C-50	DMDG 1 C-50	8.510	8.508	0.002	0.024	58.627	54.152	4.475	7.63
	DMDG 2 C- 50	8.720	8.718	0.002	0.023	57.865	54.891	2.974	5.14
	DMDG 3 C-50	8.650	8.647	0.003	0.035	58.104	56.542	1.562	2.69
	Average	8.627	8.624	0.002	0.027	58.199	55.195	3.004	5.16
HL WB C-50	HLWB 1 C-50	8.660	8.652	0.008	0.092	47.584	42.616	4.968	10.44
	HLWB 2 C- 50	8.510	8.502	0.008	0.094	48.069	44.458	3.611	7.51
	HLWB 3 C-50	8.380	8.371	0.009	0.108	47.090	44.220	2.870	6.09
	Average	8.517	8.508	0.008	0.098	47.581	43.765	3.816	8.02
HLDT C-50	HLDT 1 C-50	8.450	8.444	0.006	0.071	51.473	48.092	3.381	6.57
	HLDT 2 C- 50	8.630	8.624	0.006	0.070	51.991	48.750	3.241	6.23
	HLDT 3 C-50	8.490	8.483	0.007	0.083	50.535	47.299	3.236	6.40
	Average	8.523	8.517	0.006	0.074	51.333	48.047	3.286	6.40
HLDG C-50	HLDG 1 C-50	8.380	8.374	0.006	0.072	48.271	44.395	3.876	8.03
	HLDG 2 C- 50	8.480	8.474	0.006	0.071	47.935	45.566	2.369	4.94
	HLDG 3 C-50	8.660	8.653	0.007	0.081	49.814	45.158	4.656	9.35
	Average	8.507	8.500	0.006	0.075	48.673	45.040	3.634	7.47

1.4.3. Chloride attack

Table E.13 Chloride attack resistance mass loss and compressive strength loss test results for C-30

Concrete batches	Samples	Weigth before immession(Kg)	Weigth after immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
BL WB C-30	BLWB 1 C-30	8.570	8.555	0.015	0.175	32.028	28.206	3.822	11.93
	BLWB 2 C- 30	8.600	8.586	0.014	0.163	33.145	30.658	2.487	7.50
	BLWB 3 C-30	8.500	8.486	0.014	0.165	33.008	29.723	3.285	9.95
	Average	8.557	8.542	0.014	0.168	32.727	29.529	3.198	9.77
BLDT C-30	BLDT 1 C-30	8.400	8.386	0.014	0.167	36.177	31.749	4.428	12.24
	BLDT 2 C-30	8.720	8.704	0.016	0.184	35.417	33.210	2.207	6.23
	BLDT 3 C-30	8.490	8.477	0.013	0.153	37.038	34.469	2.569	6.94
	Average	8.537	8.522	0.014	0.168	36.211	33.360	2.851	7.87
BLDG C-30	BLDG 1 C-30	8.750	8.730	0.020	0.229	34.469	31.504	2.965	8.60
	BLDG 2 C-30	8.460	8.441	0.019	0.225	31.749	30.359	1.390	4.38
	BLDG 3 C-30	8.380	8.364	0.016	0.191	33.210	30.012	3.198	9.63
	Average	8.530	8.512	0.018	0.215	33.347	30.350	2.997	8.99
DM WB C-30	DMWB 1 C-30	8.670	8.658	0.012	0.139	35.165	30.658	4.507	12.82
	DMWB 2 C- 30	8.310	8.297	0.013	0.157	35.651	34.292	1.359	3.81
	DMWB 3 C-30	8.920	8.908	0.012	0.135	36.593	33.519	3.074	8.40
	Average	8.633	8.621	0.012	0.143	35.803	32.823	2.980	8.32
DM DT C-30	DMDT 1 C-30	8.530	8.521	0.009	0.106	41.924	39.577	2.347	5.60
	DMDT 2 C- 30	8.850	8.839	0.011	0.124	39.752	38.087	1.665	4.19
	DMDT 3 C-30	8.710	8.700	0.010	0.115	41.659	39.187	2.472	5.93
	Average	8.697	8.687	0.010	0.115	41.112	38.950	2.161	5.26
DM DG C-30	DMDG 1 C-30	8.570	8.561	0.009	0.105	39.324	37.322	2.002	5.09
	DMDG 2 C- 30	8.780	8.771	0.009	0.103	39.132	36.314	2.818	7.20
	DMDG 3 C-30	8.410	8.400	0.010	0.119	38.085	35.976	2.109	5.54
	Average	8.587	8.577	0.009	0.109	38.847	36.537	2.310	5.95
HL WB C-30	HLWB 1 C-30	8.650	8.634	0.016	0.185	35.071	31.616	3.455	9.85
	HLWB 2 C- 30	8.730	8.714	0.016	0.184	34.989	32.765	2.224	6.36
	HLWB 3 C-30	8.520	8.503	0.017	0.200	34.747	31.522	3.225	9.28
	Average	8.633	8.617	0.016	0.190	34.936	31.968	2.968	8.50

Concrete batches	Samples	Weigth before immession(Kg)	Weigth after immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
HLDT C-30	HLDT 1 C-30	8.440	8.427	0.013	0.154	38.682	36.481	2.201	5.69
	HLDT 2 C- 30	8.740	8.726	0.014	0.160	38.117	35.136	2.981	7.82
	HLDT 3 C-30	8.620	8.607	0.013	0.151	37.836	35.573	2.263	5.98
	Average	8.600	8.587	0.013	0.155	38.212	35.730	2.482	6.49
HLDG C-30	HLDG 1 C-30	8.590	8.578	0.012	0.140	36.867	34.218	2.649	7.19
	HLDG 2 C- 30	8.850	8.838	0.012	0.136	37.697	34.762	2.935	7.79
	HLDG 3 C-30	8.770	8.757	0.013	0.148	35.971	33.081	2.890	8.03
	Average	8.737	8.724	0.012	0.141	36.845	34.020	2.825	7.67

Table E.14 Chloride attack resistance mass loss and compressive strength loss test results for C-50

Concrete batches	Samples	Weigth before immession(Kg)	Weigth before immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
BLWB C-50	BLWB 1 C-50	8.370	8.364	0.006	0.072	47.915	43.679	4.236	8.84
	BLWB 2 C- 50	8.460	8.455	0.005	0.059	44.360	42.021	2.339	5.27
	BLWB 3 C-50	8.610	8.605	0.005	0.058	45.429	42.676	2.753	6.06
	Average	8.480	8.475	0.005	0.063	45.901	42.531	3.370	7.34
BLDT C-50	BLDT 1 C-50	8.670	8.667	0.003	0.035	49.426	47.779	1.647	3.33
	BLDT 2 C-50	8.540	8.535	0.005	0.059	48.855	45.526	3.329	6.81
	BLDT 3 C-50	8.690	8.687	0.003	0.035	50.586	46.597	3.989	7.89
	Average	8.633	8.630	0.004	0.042	49.622	46.482	3.140	6.33
BLDG C-50	BLDG 1 C-50	8.620	8.611	0.009	0.105	49.068	45.093	3.975	8.10
	BLDG 2 C-50	8.330	8.324	0.006	0.072	47.189	44.790	2.399	5.08
	BLDG 3 C-50	8.510	8.505	0.005	0.059	48.561	45.303	3.258	6.71
	Average	8.487	8.480	0.007	0.079	48.273	45.062	3.211	6.65
DMWB C-50	DMWB 1 C-50	8.640	8.636	0.004	0.046	51.263	47.619	3.644	7.11
	DMWB 2 C- 50	8.670	8.665	0.005	0.058	50.050	47.087	2.963	5.92
	DMWB 3 C-50	8.830	8.826	0.004	0.045	49.096	46.495	2.601	5.30
	Average	8.713	8.709	0.004	0.050	50.136	47.067	3.069	6.12

Concrete batches	Samples	Weigth before immession(Kg)	Weigth before immession(Kg)	Mass loss (Kg)	Mass loss (%)	Compressive strength before immersion (KN)	Compressive strength after immersion (KN)	Compressive strength loss (KN)	Compressive strength loss (%)
DMDT C-50	DMDT 1 C-50	8.810	8.808	0.002	0.023	58.242	56.092	2.150	3.69
	DMDT 2 C- 50	8.640	8.639	0.001	0.012	59.136	56.039	3.097	5.24
	DMDT 3 C-50	8.790	8.789	0.001	0.011	57.533	55.438	2.095	3.64
	Average	8.747	8.745	0.001	0.015	58.304	55.856	2.447	4.20
DMDG C-50	DMDG 1 C-50	8.550	8.548	0.002	0.023	58.627	55.025	3.602	6.14
	DMDG 2 C- 50	8.750	8.748	0.002	0.023	57.865	55.208	2.657	4.59
	DMDG 3 C-50	8.680	8.679	0.001	0.012	58.104	57.046	1.058	1.82
	Average	8.660	8.658	0.002	0.019	58.199	55.619	2.580	4.43
HLWB C-50	HLWB 1 C-50	8.440	8.434	0.006	0.071	47.584	44.803	2.781	5.84
	HLWB 2 C- 50	8.570	8.565	0.005	0.058	48.069	45.133	2.936	6.11
	HLWB 3 C-50	8.720	8.715	0.005	0.057	47.090	43.216	3.874	8.23
	Average	8.577	8.571	0.005	0.062	47.581	44.384	3.197	6.72
HLDT C-50	HLDT 1 C-50	8.680	8.677	0.003	0.035	51.473	49.695	1.778	3.45
	HLDT 2 C- 50	8.740	8.736	0.004	0.046	51.991	47.277	4.714	9.07
	HLDT 3 C-50	8.530	8.527	0.003	0.035	50.535	48.310	2.225	4.40
	Average	8.650	8.647	0.003	0.039	51.333	48.427	2.906	5.66
HLDG C-50	HLDG 1 C-50	8.490	8.484	0.006	0.071	48.271	44.803	3.468	7.18
	HLDG 2 C- 50	8.650	8.645	0.005	0.058	47.935	46.460	1.475	3.08
	HLDG 3 C-50	8.580	8.575	0.005	0.058	49.814	45.133	4.681	9.40
	Average	8.573	8.568	0.005	0.062	48.673	45.465	3.208	6.59

APPENDIX - F

SAMPLE PHOTO GALLARY TAKEN DURING THE STUDY

Figure F.1 Reducing aggregate sample for test

Figure F.2 Silt content test

Figure F.3 Sieve analysis test

Figure F.4 Moisture content, specific gravity and water absorption tests

Figure F.5 Bulk density test

Figure F.6 Flakiness Index and Elongation Index

Figure F.7 Aggregate Impact Value (AIV) test

Figure F.8 Cement storage

Figure F.9 Electronic weight batching

Figure F.10 Hand mixing of fresh concrete

Figure F.11 Slump cone test

Figure F.12 Compaction factor test

Figure F.13 Adjustable steel molds

Figure F.14 Casting of concrete specimens

Figure F.15 Curing of concrete specimens

Figure F.16 Compressive strength test

Figure F.17 Splitting tensile strength

Figure F.18 Oven dry concrete cubes

Figure F.19 Sodium sulfate powder

Figure F.20 Concrete cubes immersion in 5% Sodium sulfate solution

Figure F.21 Sodium chloride powder

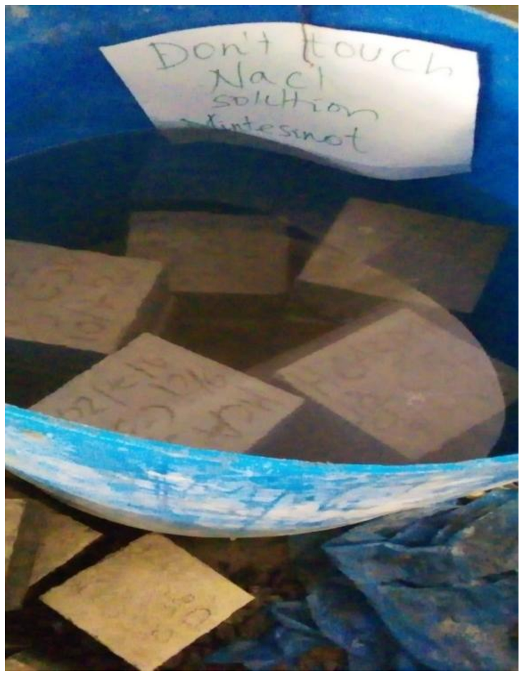

Figure F.22 Concrete cubes immersed in 5 % Sodium chloride solution