

2021-07

Investigation on Utilization of Steel Slag as a Partial Replacement of Natural River Sand as a Fine Aggregate in Normal strength Concrete Production

Degsera, Fentahun Woldie

<http://ir.bdu.edu.et/handle/123456789/12586>

Downloaded from DSpace Repository, DSpace Institution's institutional repository



BAHIR DAR UNIVERSITY
BAHIR DAR INSTITUTE OF TECHNOLOGY
SCHOOL OF RESEARCH AND GRADUATE STUDIES
FACULTY OF CIVIL AND WATER RESOURCES ENGINEERING
CONSTRUCTION TECHNOLOGY AND MANAGEMENT

**Investigation on Utilization of Steel Slag as a Partial Replacement of
Natural River Sand as a Fine Aggregate in Normal strength Concrete
Production**

By

Degsera Fentahun Woldie

July, 2021

Bahir Dar, Ethiopia



BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND WATER RESOURCE ENGINEERING

**Investigation on Utilization of Steel Slag as a Partial Replacement of
Natural River Sand as a Fine Aggregate in Normal strength Concrete
Production**

BY

DEGSERA FENTAHUN WOLDIE

A Thesis Submitted to Bahir Dar Institute of Technology in Partial Fulfillment of
the Requirements for the Degree of Masters of Science in Civil Engineering

(Construction Technology and Management)

Principal Advisor Name: Mitiku Damite Y. (Ph.D.)

Co- Advisor: Shumet Getahun (MSc.)

July, 2021


Bahir Dar, Ethiopia

Declaration

This is to confirm that the thesis authorized “**Investigation on Utilization of Steel Slag as a Partial Replacement of Natural River Sand as a Fine Aggregate in Normal Strength Concrete Production**”, submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (**Construction Technology and Management**) under (**Faculty of Civil and Water Resources Engineering**), Bahir Dar Institute of Technology.

I, the undersigned, announce that this thesis is my original dissertation, that it has not been submitted for any other university's degree program, and that all sources of materials used in the thesis have been properly acknowledged.

Name of the Candidate: Degsera Fentahun

Signature  _____

Date July 19/2021

©2021

Degsera Fentahun Woldie


ALL RIGHTS RESERVED

BAHIR DAR UNIVERSITY
BAHIR DAR INSTITUTE OF TECHNOLOGY
SCHOOL OF RESEARCH AND GRADUATE STUDIES
FACULTY OF CIVIL AND WATER RESOURCES ENGINEERING

Approval of Thesis for defense

I hereby certify that I have supervised, read, and evaluated this thesis titled "Investigation on Utilization of Steel Slag as a Partial Replacement of Natural River Sand as a Fine Aggregate in Normal Strength Concrete Production" prepared By Degsera Fentahun Woldie under my guidance. I recommend the thesis to be submitted for oral defense.

Mitiku Damite Y. (Ph.D.)




27-07-2021

Advisor's name

Signature

Date

Shumet Getahun (MSc.)



21/07/2021

Co- Advisor's name

Signature

Date

BAHIR DAR UNIVERSITY
BAHIR DAR INSTITUTE OF TECHNOLOGY
SCHOOL OF RESEARCH AND GRADUATE STUDIES
FACULTY CIVIL AND WATER RESOURCES

Approval of Thesis for Defense Result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

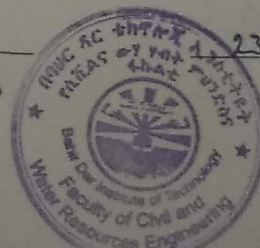
Name of Student: Degsera Fentahun F. Signature Date July 19/2021

As members of the board of examiners, we examined this thesis entitled “**Investigation on Utilization of Steel Slag as a Partial Replacement of Natural River Sand as a Fine Aggregate in Normal Strength Concrete Production**”

By, Degsera Fentahun. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of Science in Construction Technology and Management.

Board of Examiners

Advisor	Signature	Date
<u>Mitiku Damite (Ph.D.)</u>	<u></u>	<u>22-07-2021</u>
External Examiner <u>Bahiru Bewket(PhD)</u>	Signature <u></u>	Date <u>July 15/2021</u>
Internal Examiner <u>Samson Kebede</u>	Signature <u></u>	Date <u>July 19/2021</u>
Chairperson <u>Wambiso Mulugeta</u>	Signature <u></u>	Date <u>21/07/2021</u>
Chair Holder Begashaw Werku Yifru Chair Holder of CGTEM	Signature <u></u>	Date <u>22-07-2021</u>
Faculty Dean <u>Temesgen Enku Nigussie (PhD)</u> Faculty Dean	Signature <u></u>	Date <u>23-07-2021</u>



To my parents

ACKNOWLEDGMENT

First of all, I would like to thank my creature Almighty God, who gave me the commitment and tolerance to pass various problems.

An especial thank goes to my Advisor Mitiku Damite (Ph.D.) for his valuable advice, invaluable suggestions, timely comments, and thorough guidance throughout the time being on the work.

I would like to express my deepest gratitude and appreciation to my Co-Advisor Mr. Shumet Getahun for allowing me to work with him and all his efforts in guiding me through my work and for providing me useful advice. I am also indebted to Mr. Werku Tilahun, Mr. Belete Belay and Mr. Alamrew Bemnet for their collaboration on the laboratory facility.

This research work would not have been feasible without the sincere cooperation and support of the organizations and individuals who have provided me all the relevant information and data. These are, Ethiopian Steel Factory which provide the necessary steel slag material and Bahir University, Mechanical Unit Operation Lab which allow the crushing machine.

Degsera Fentahun

June, 2021

ABSTRACTS

Now a day, Construction work is being carried out on a massive scale all over the world, and the demand for construction materials is growing day by day. Natural river sand is one of the predominant ingredients of concrete and non-renewable resources. In this study, steel slag is used as partial replacement of natural river sand in concrete production. Steel slag is the byproduct of steel-making factories. In Ethiopia, the practice of using alternative ingredients to produce concrete was observed weak in some scenarios, especially using waste materials. In this research experimental study was carried out on how to use steel slag as a partial replacement of natural river sand for the production of normal strength concrete. The research was carried out by conducting laboratory tests for concrete making materials (coarse aggregate, fine aggregate, and steel slag). Concrete mix design was prepared for C-25(normal strength) class of concrete using ACI mix design procedure. The natural river sand was replaced by steel slag at 15%, 30%, 45%, and 60% by weight. The control mix without incorporation of steel slag was prepared, which was used as a reference for comparison of test results with those specimens produced by partial replacement. Generally, five concrete mixes were prepared including the control mix for producing normal strength concrete. The laboratory test results show that workability of concrete decreases with an increase in steel slag content. The test results for compressive strength showed that at 45% replacement of the natural sand by steel slag achieved a higher compressive strength for 7, 28 and 56 days. Similarly, at 30% replacement of the natural sand by steel slag achieved a higher UPV for 28 days, whereas water absorption decreases as replacement of steel slag increase up to 30% replacement for 3days and up to 45% replacement for 7 and 28 days. The results show that sulfate resistance of concrete decreases with an increase in steel slag content. Depending on the test result, it is recommended that the chemical reaction of each element and the optimum content will be investigate. Further investigation on resistance of concrete with steel slag aggregates to alkali-silica reactions, carbonation, seawater attack, harmful chemicals, accelerated corrosion test and resistance to high temperatures are needed.

Keywords: Steel Slag, Natural Sand, Normal Strength Concrete, Compressive Strength, Ultrasonic Pulse Velocity.

Table of Contents

ACKNOWLEDGMENT	vi
ABSTRACTS.....	vii
LIST OF TABLES	x
LIST OF FIGURES	xi
ACRONYMS	xii
ABBREVIATIONS	xiv
CHAPTER ONE	1
Introduction.....	1
1.1. Background	1
1.2. Problem Statement	2
1.3. Research Question.....	3
1.4. Objective	4
1.5. Scope	4
1.6. Study Significance.....	4
1.7. Research Organization	5
CHAPTER TWO	6
Literature Review	6
2.1. Overview	6
2.2. Concrete Technology	6
2.3. Aggregate in Concrete as an Ingredient	7
2.4. Alternative Materials for Fine Aggregate	8
2.5. Global Generation of Steel Slag in the Construction Industry.....	13
2.6. What is Steel Slag?.....	13
2.7. Use of Steel Slag as a Fine and Coarse Aggregate	16
2.8. Steel Slag as a Substitute to Natural Sand	18
2.9. Effects of Steel Slag Fine Aggregate on Concrete Properties.....	21
2.10. Mix Design Selection	24
2.11. Research Summary and Gap Identification	25
CHAPTER THREE	27
Materials and Experimental Design.....	27

3.1. Material Characterization.....	27
3.2. Mix Design.....	32
3.3. Procedures for Mix Preparation	33
3.4. Research Methodology.....	34
CHAPTER FOUR.....	38
Result and Discussion	38
4.1. Workability.....	38
4.2. Compressive Strength Test	39
4.3. Sulfate Resistance	41
4.4. Water Absorption	42
4.5. Ultrasonic Pulse Velocity.....	43
4.6. Statistical Analysis	44
4.7. Price Analysis.....	49
4.8. Analysis of Exploiting Natural Materials.....	51
CHAPTER FIVE	52
5.1. Conclusions and Recommendations.....	52
5.1.1. Conclusion.....	52
5.1.2. Recommendation.....	53
REFERENCE.....	54
APPENDICES.....	63
Appendix-A Material Test Results	64
Appendix-B Mix Design Calculations	85
Appendix-C Compressive Strength, Sulfate attack & Water absorption Test Result	95
Appendix-D Geochemical Test Result of Steel Slag.....	101
Appendix-E Photos	103

LIST OF TABLES

<i>Table 2. 1 Some typical physical properties of steel slag and river sand from some previous research works are presented.</i>	<i>20</i>
<i>Table 3. 1: Chemical Composition of Steel Slag</i>	<i>27</i>
<i>Table 3. 2: Specification of the cement used (Source: manufacturer's specification)</i>	<i>29</i>
<i>Table 3. 3: Natural Sand fine aggregate properties</i>	<i>29</i>
<i>Table 3. 4: Steel Slag fine aggregate properties</i>	<i>30</i>
<i>Table 3. 5: Coarse aggregate properties</i>	<i>32</i>
<i>Table 3. 6: Design Mix for FA Slag Sand and Natural River Sand and Crushed stone sand of Cement Content 386.96 kg/m³</i>	<i>32</i>
<i>Table 3. 7: Types of tests performed on steel slag concrete and its test method.</i>	<i>33</i>
<i>Table 3. 8: The five types of mixes with different proportions of NS and SS</i>	<i>37</i>
<i>Table 4. 1: ANOVA Test on the effects of independent variables</i>	<i>46</i>
<i>Table 4. 2: Average Compressive Strength Comparison Using Parameter Estimate.....</i>	<i>47</i>
<i>Table 4. 3: The HSD Post Hoc Results for SS Replacement</i>	<i>48</i>
<i>Table 4. 4: Cost Analysis of Different Steel Slag Replacement</i>	<i>50</i>
<i>Table 4. 5: Exploited Raw Material Analysis of Concrete</i>	<i>51</i>

LIST OF FIGURES

<i>Figure 2. 1: Process of manufacture of steel slag by BOF process (A) and EAF process (B) (Jigar Patel P, 2006)</i>	<i>14</i>
<i>Figure 3. 1: Gradation curve for natural sand</i>	<i>30</i>
<i>Figure 3. 2: Gradation curve for steel slag fine</i>	<i>31</i>
<i>Figure 3. 3: Coarse aggregate crusher plant at a Chinese production site</i>	<i>31</i>
<i>Figure 3. 4: Methodology flow chart of the thesis</i>	<i>35</i>
<i>Figure 4. 1: Slump of concrete mixes containing different percentage of steel slag aggregate</i>	<i>38</i>
<i>Figure 4. 2: Compressive strength test and failure Mechanism</i>	<i>39</i>
<i>Figure 4. 3: Compressive strength of steel slag concrete different curing ages</i>	<i>40</i>
<i>Figure 4. 4: Sulfate resistance of steel slag concrete mixes at different curing age</i>	<i>42</i>
<i>Figure 4. 5: Water absorption of steel slag concrete at different ages of curing.</i>	<i>43</i>
<i>Figure 4. 6: UPV of steel slag concrete at 28th ages of curing,</i>	<i>44</i>

ACRONYMS

ABS	Air-Cooled Blast Furnace Slag
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BDU	Bahir Dar University
BOS	Basic Oxygen Furnace Slag
BS	British Standard
C-25	Class 25 concrete
CBA	Coal Bottom Ash
C&DW	Construction and Demolished Waste
CH	Calcium Hydroxide
CKD	Cement Klin Dust
CRS	Crushed Rock Sand
C-S-H	Calcium silica Hydrate
CO ₂	Carbon Dioxide
EAF C	Electric Arc Furnace Slag Carbon Steel
EAF S	Electric Arc Furnace Slag Stainless
EAFS	Electric Arc Furnace Slag
EBCS	Ethiopian Building Code of Standard
ETB	Ethiopian Birr
EU	Europe Union
FA	Fine Aggregate
Fig	Figure
FM	Fineness Modulus
GBS	Granulated Blast Furnace Slag
GGBS	Ground Granulated Blast Furnace Slag
IS	Indian Standard
ISF	Imperial Smelting Furnace Slag
Kg	Kilogram
LS	Ladle Furnace Slag
mm	millimeter

MPa	Mega Pascal
NB	Note Be Able
ND	Not Determined
NS	Natural Sand
NSA	National Slag Association
N _o	Number
OPC	Ordinary Portland Cement
PPC	Pozzolana Portland cement
PLC	Private Limited Company
RFA	Recycled Fine Aggregate
SS	Steel Slag
SCC	Self compacting concrete
UPV	Ultrasonic Plus Velocity
UHPC	Ultra-High-Performance Concrete
U.S	United state
VIS	Vertical Shift impact
WA	Wood Ash
WFS	Waste Foundry Sand
W/C	Water to Cement Ratio

ABBREVIATIONS

m^3	Meter cube
M-25	Concrete with 25MPa at 28days of Compressive Strength
μm	micrometer
%	Percent.

CHAPTER ONE

Introduction

1.1. Background

The current booming construction industries demand large reserves of construction materials and skilled workmanship. Having the existence of abundant construction materials is one of the manifestations of the great construction industry.

Natural river sand is an important resource covering the river bed surface and same time exists on the land surface. The human community depends on the sand for construction in concrete production. People benefit from sand and gravel for construction, but they pollute the resource by over-exploiting it to meet their needs.

There is worldwide concern about the environment prompted the researchers, to carry out waste material as an alternative material for construction, to minimize waste disposal, and protect the environment. It seems there is excessive mining for natural river sand for construction in both rural and urban development. River sand is a component of concrete in constructing buildings, dams, pavements, and other concrete structures. River sand is used in most mixtures because it is a strong resource that strengthens the concrete structure by filling the voids between the coarse aggregates (Steven H. et al, 2008).

According to (Fennis, 2010), The green concrete project, by the concrete center from the Danish Technological Institute, aimed at reducing the environmental impact of concrete and developing a technical solution to implement green concrete in the building market. Concrete was defined to be green, when the production process and the mixture composition resulted in at least a 30% reduction of the CO₂ emission or when residual products were used for cement replacement or aggregate replacement.

According to (United Nations, 2019), Construction is one of an activity that connected within making global climate change, so the three major objectives behind the green concept in concrete production are; firstly, to lower greenhouse gas emissions (CO₂ emission from the cement industry, as one ton of cement manufacturing procedure, produces one ton of CO₂). Secondly, to reduce the use of natural resources such as marble, shale, clay, river sand, and natural rocks that are consumed for human growth but are not returned to the ground. Thirdly, the use of waste resources in concrete also avoids the use

of a large area of land for the packing of waste materials, which results in pollution of the air, land, and water.

There is an increasing interest in utilizing waste resources as aggregate substitutes, and extensive research is being conducted on the usage of a variety of materials as aggregate substitutes, including coal ash, blast furnace slag, and steel slag aggregate. The usage of waste material will alleviate aggregate shortages at various building sites while also reducing environmental issues associated with aggregate mining and waste disposal (Saravanan and Suganya, 2015).

Environmental sustainability has been the subject of discourse virtually in all human endeavors, especially in construction industries, where natural raw materials are consumed extremely. The need to alleviate these environmental stresses to make construction more sustainable and reduce rising construction costs has necessitated research into the usage of alternative low-cost materials, especially those that are locally available, to replace traditional ones in concrete production. Agricultural and industrial wastes, as well as concrete rubbles, are common sources of non-conventional aggregates (Olonade et al, 2015.).

All along in Ethiopia, we have been using natural sand and gravel in concrete manufacturing. Natural aggregates are becoming scarce, and they are also becoming more expensive. As a result, wastes and by-products must be used in all sectors, including the construction industry. In general, most studies show that 60 to 75% of concrete is composed of aggregates we must look to make best usage of waste as aggregate input in concrete production.

This research work determined the partial replacement of natural river sand via steel slag on the concrete production process.

1.2. Problem Statement

We look at the current availability and condition of river sand in Ethiopia, one can easily see that it was an alarming issue. According to (Anteneh G/Micheal, 2017) the rapid and constant usage of river sand is leading to environmental problems associated with its depletion. Therefore, it is mandatory to identify alternative sources of sand and study whether it can be as effectively used as a replacement for natural river sand. In this regard,

one possible alternative material that can be used as a replacement for natural river sand is the usage of steel slag.

In addition to these, studies show that natural river sand, which is available today, is deficient in many aspects to be used directly for concrete production. Steel slag has been extensively researched for use in a variety of construction applications. As a result, there is a pressing need to measure the advantages of using such a low-cost material in concrete technology. As a result, there is a pressing need to measure the advantages of using such a low-cost material in concrete technology.

Sand is one of the main construction materials; according to this effect (Nandini Suri et al., 2016,) conclude that sand mining affects the ecology and economy of a country with existing factors according to him, thus include:

- River sand poses the problem of serious/acute shortage in many areas due to large requirements in the construction engineering.
- Speedy and prolonged sand mining causes washing/scouring of river beds and also the damage of natural minerals existing in the river leads to ecological effects.
- The unit price of sand rises day by day and there is a prerequisite for an alternative material.

To that end, this study is being conducted to govern the suitability of using a byproduct of the steel industry as a partial or complete substitute for river sand, which would be both cost-efficient and better for handling its disposal. Lastly, the research was meant to obtain steel slag as a substitute material for natural river sand in normal strength concrete production. The study concentrated on the use of steel slag as partial replacement material by investigating the physical, chemical, and mechanical properties and also durability of steel slag concrete.

1.3. Research Question

The research questions that this study explained as follows:

1. What is the benefit of using steel slag on the mechanical properties and durability of normal strength concrete?
2. Is there any difference between the chemical and physical properties of the steel slag with river sand?

3. How we can obtain a higher compressive strength with an optimal cost by using steel slag as partial replacement river sand?

1.4. Objective

General objective

The general objective of this research is to investigate on utilization of steel slag as a partial replacement of Natural River sand as a fine aggregate in normal strength concrete production.

Specific objective

1. To study the physical and chemical properties of steel slag.
2. To investigate the fresh and mechanical properties of steel slag concrete compared to conventional concrete.
3. To study the durability of steel slag concrete.
4. To determine the price of conventional concrete comprising to steel slag concrete.

1.5. Scope

The scope of this study is limited to harvest concrete with a strength class of normal strength concrete using steel slag. Due to different constraints, the study only assesses the partial substitution of natural sand with a steel slag fine on the workability, strength, durability, and cost of a normal strength concrete. Ingredients used in the test are collected from selected available sources in the Bahir Dar area and the steel slag from Ethiopian Steel Factory followed by a cost comparison taking the market price of these the same material from different sources with study area.

1.6. Study Significance

The successful completion of this study will have significance for the production of concrete,

- The result of this study will show the potential of steel slag as an alternative material for rapidly eradicating natural river sand, and assisting the current fast-growing construction industry, to providing an alternative to the widely used river sand.
- By studying the chemical, physical and mechanical properties of steel slag giving scientific conclusions on usage steel slag in concrete production and studying steel slag effect in fresh and hardened concrete properties.

- The result of this study will also serve as an input for future related studies.

1.7. Research Organization

The research is structured with five chapters and further breakdown into different sections and sub-sections.

Chapter one contains the introduction with background information, statement of the objectives, the significance of the research, and the scope of the research in the first chapter. The *second chapter* consists of the details of concrete and its constituents and the requirement of fine aggregate by referring to and reviewing different works of literature. Constitute of concrete, mix design selection of concrete mixtures, the properties of the fresh and hardened concrete, and properties of steel slag are the main highlight of this chapter.

Chapter three deals with the materials used and methods followed in the research.

Chapter four focuses on the discussion and analysis of the test results by using SPSS, in which the results were presented in tables and graphs, and the discussion and data interpretation were made based on the research findings.

Chapter five comprises the conclusions and recommendations of the research based on the results obtained. Finally, a list of reference material used to assist this research are listed.

CHAPTER TWO

Literature Review

2.1. Overview

This chapter presents the findings from different reviewed literature on the utilization of steel slag aggregates into the concrete mixture. Topics addressed include alternative materials for fine aggregate, global generation of steel slag, its chemical composition (oxides), effects of steel slag fine aggregate on concrete properties, and the conclusions drawn by the different author related to the topic are overviewed and its feasibility for use as a replacement for natural aggregates in concrete. As a result, the literature review attempted to highlight these issues with quality requirements, with a particular emphasis on the workability, compressive strength, and durability of steel slag concrete.

2.2. Concrete Technology

Concrete is a hardening construction material composed of cement, fine aggregates (natural sand), and coarse aggregates mixed with water. Portland cement is the most common form of cement used in concrete production. Concrete technology is the study of concrete properties and their functional applications.

Concrete is used in construction of building foundations, columns, beams, slabs, and other load-bearing components. Other than cement, various types of binding materials are used, such as lime in lime concrete in addition bitumen in asphalt concrete for road construction. Water to cement ratio plays an important role that influences various properties such as workability, strength, and durability. Acceptable water to cement ratio is obligatory for the production of workable concrete.

As water and materials are combined, cement reacts with the water, causing a hydration reaction to occur. This reaction aids the formation of a hard matrix, which holds the materials together to form a long-lasting stone-like material. Currently, the world generates 4.4 billion tons of concrete each year, but by 2050, that figure is projected to exceed 5.5 billion tons as poorer countries increasingly urbanize, according to the Chatham House report. By 2030, emissions from the concrete sector must be decreased by 16 percent from current levels in order to meet the Paris Agreement's goals. The report argues that the target is already an ambitious goal (Jonathan Hilburg, 2019).

2.3. Aggregate in Concrete as an Ingredient

Concrete is an artificial stone-like, the composite material used for various structural purposes and which is produced by mixing cement as well as coarse and fine aggregate as an important constituent. Sand, gravel, or shale is also available in this mixture which is being hardened in the presence of a sufficient amount of water. Other constituents, such as admixtures, pigments, fibers, polymers, and reinforcement, may be added to strengthen concrete to change its properties. The mixture of constituents used determines the properties of plastic and hardened concrete. The process for selecting a specific combination of constituents is known as concrete mix design. Since aggregates make up 70 to 80% of the volume of concrete, they have a significant effect on its various characteristics and properties (Malathy, 2014).

Generally, the global request for sand and gravel is 40 to 50 billion tons per year, a recent UN Environment study finds that aggregate production in rivers has resulted in deforestation, erosion, the lowering of water aquifers, and the worsening of droughts. (United Nations, 2019).

The report sand and sustainability: Seeking New Strategies for Environmental Governance of Global Sand Resources explains how changing consumption habits, rising populations, urbanization, and infrastructure growth have increased demand for sand has risen threefold in the last two decades (United Nations, 2019).

Classification of aggregates

Aggregates can be divided into several categories according to different criteria.

i. In accordance with size:

- *Coarse aggregate: The No. 4 (4.75 mm) sieve retained the majority of the aggregates.*
- *Fine aggregate (natural sand): Aggregates pass through the No. 4 (4.75 mm) sieve but are mostly retained on the No. 200 (75 mm) sieve.*

ii. In accordance with unit weight

- *Lightweight aggregate: An aggregate with unit weight is less than 1120kg/m³. The bulk density of the corresponding concrete is less than 1800 kg/m³.*

- *Normal weight aggregate:* The unit weight of the aggregate ranges from 1520 to 1680 kg/m³. The bulk density of concrete made with this type of aggregate is 2300 to 2400 kg/m³.
- *Heavyweight aggregate:* The unit weight exceeds 2100 kg/m³. The corresponding concrete has a bulk density greater than 3200 kg/m³.

iii. In accordance with sources:

- *Natural aggregates:* This type of aggregate is extracted from natural deposits without being altered in any way during the manufacturing process, such as crushing and grinding.
- *Manufactured aggregates:* This is a type of man-made material that is either the main product or a by-product of an industrial process.

2.4. Alternative Materials for Fine Aggregate

As the demand for fine aggregate in the manufacturing of cement concrete is increasing day by day the search for alternative material has become a crying need. Natural river sand is the most widely used fine aggregate in Ethiopia and the incessant mining of the natural river sand is hampering the environment to a great extent. Moreover, the price of natural river sand aggregate is also going higher as its demand gets higher. Crushed stone can be used as a substitute for natural river sand but it has low availability and higher price. In this existing condition, the waste materials such as steel slag can be considered as a possibility that can be used instead of conventional fine aggregates. Some of the replacement materials for natural river sand are discussed below.

2.4.1. Crushed Rock Sand

Crushed rock sand, are sand particles produced by crushing virgin rocks are generally more angular and have a rougher surface texture than naturally weathered sand particles. (Nataraja M.C. et al, 2018.). Diorite, metamorphic siltstone, granite, limestone, sandstone, and feldspathic quartzite are some of the parent rocks used to make crushed rock sand (Shen W. et al, 2016). According to (Wang J. et al, 2014.) the property of crushed rock sand depends on its lithological character, composition, and production process.

Cone crushers, impact crushers, roll crushers, and rod mills are among the crushing equipment used to produce crushed rock sand. (Chow R.K.K. et al, 2013). The primary

process in the manufacture of crushed rock aggregates is the comminution of rock materials into finer-grained particle sizes through various types of crushing. (Cepuritis R. et al, 2015). For the final result to be obtained, the crushing method must be adapted to the particular rock form and intended end use (Singh et al, 2018). This means that the properties of crushed rock sand are affected by the crushers used and their variations, the number of crushing steps, the feeding, gap setting, and operation of individual crushers, and, of course, the maintenance (Chow R.K.K. et al, 2013) and (Cepuritis R. et al, 2015).

Compression crushers and impact crushers are the two major types of crushing machinery. The vertical shaft impact (VSI) has recently gained popularity (Cepuritis R. et al, 2015). Sand may be screened in a variety of ways, including wet, damp, or dry, with air screening and the hydro-cyclone process being the most common (Singh et al, 2018). The removal of soil, dust, and fines from the sand is aided by screening. The existence of high fines (size 75 μ m) is extremely hazardous because it causes shrinkage in concrete. However, (Nanthagopalan et al, 2010,) The discovery demonstrates that CRS fines result to an increase in paste volume, which is beneficial in the development of self-compacting concrete (SCC). It has been discovered that a w/c ratio of 0.40 to 0.55 is more suitable for CRS-containing concrete, and a superplasticizer dosage of 0.6 percent to 1.5 percent aids in achieving appropriate workability. (Nanthagopalan et al, 2010,) and (Cordeiro G.C. et al, 2016.). According to (Shen W. et al, 2017,) It was discovered that using CRS in concrete makes it dense, and that fine hydration products like calcium sulfoaluminate hydrates/ettringite, calcium hydroxide (CH) and calcium aluminate hydrates mono sulfates, and calcium silica hydrate (C-S-H) gel aid in the manufacturing of ultra-high-strength concrete.

At a constant w/c ratio, the durability parameters such as chloride ion penetration, porosity, carbonation, freeze-thaw, and so on increase as the percentage of replacement of CRS in concrete increases. (Beixing L. et al, 2009) and (Katz A. and Baum H., 2006). Despite improvements in compressive strength, small additions of fines cause an increase in volume change and carbonation rate. (Katz A. and Baum H., 2006).

According to, (Vijayalakshmi M. et al, 2013) report ASTM C 1202 guidelines, the chloride permeability of granite dust concrete is greater than that of conventional

concrete at 180 and 365 days. (Beixing L. et al, 2009) investigated that, when the durability properties of low and high strength crushed limestone concrete were compared, it was discovered that low strength CRS concrete improved its resistance to chloride ion penetration and freeze-thaw more than high strength CRS concrete.

2.4.2. Industrial By-Products

Iron mills, steel mills, thermal power plants, oil-fuel factories, and other industries manufacture industrial by-products. It is stated that only 15% of industrial by-products are used as reserve material and the rest is discarded as landfill (Tiwari A. et al, 2016). Non-availability of land for landfills and increase in the price of landfill is leading to the usage of by-products from industries in construction. Blast furnace slag, waste foundry sand (WFS), coal bottom ash (CBA), cement kiln dust (CKD), and wood ash (WA) are examples of industrial by-products that can be used as fine aggregate in concrete (Singh et al, 2018) and (Dash et al, 2016). Indian standards have also permit steel slag industrial by-products as an ingredient for concrete production (IS: 383, 2016).

The occurrence of high fines in industrial by-products makes concrete more vulnerable to shrinkage and affects its workability. Various phases such as air screening, Hydrocyclone process, etc... are reserved to remove the ultra-fine constituent part. Concrete with WFS has 15 to 25% improve compressive strength (Dash et al, 2016) and (Aggarwal Y. et al, 2014). Usage of steel slag up to 30% as sand in concrete mixes shows improved compressive and tensile strength and well acid resistance than control concrete (Devi S.V. and Gnanavel B.K., 2014). According to (Singh G. and Siddique R., 2012), the reduced contraction strain revealed by bottom ash concrete mixes maybe due to a lower free water-cement ratio. The permeable particles of dry coal bottom ash are preserved as part of the water during the mixing process. (Devi S.V. and Gnanavel B.K., 2014) carried out an acid resistance experimentation of concrete in both sulfuric and hydrochloric acid and detected that the weight reduction is less for 40% substitution of normal sand by steel slag when compared to control concrete.

(Al-Jabri K.S.et al, 2009) stated that up to 40% replacements of sand by copper slag results in a decrease in surface water absorption, and then the water absorption rapidly increases.

As a result, using industrial waste material in concrete is not only an unique way to reduce waste, but it also aids in the manufacturing of value-added products. However, because each industrial by-product has unique physical and chemical properties, their behavior in concrete must be thoroughly investigated before they can be used as fine aggregate.

2.4.3. Recycled Fine Aggregate (RFA)

Recycled aggregates are made by reprocessing mineral waste materials, with C&D waste being the most common source. (Khatib, 2005) and (Mitiku Damtie Y, 2015). The tendency of using recycled fine aggregate (RFA) instead of natural sand is gaining traction. Recycling demolished concrete on a great scale would not only help to solve a rising waste disposal crisis, but it will also help to conserve natural sand. Some of the most common recycled fine aggregates consumed in the construction industry are recycled concrete fine aggregate, recycled brick fine aggregate, recycled glass fine aggregate, recycled bitumen aggregate, and so on (Singh et al, 2018).

According to researchers, the shape and texture of RFA aggregates are primarily determined by the type of crusher used. (Solyman M., 2005.) and (Ulsen C. et al., 2013.). They also noticed that while the (Vertical Shaft Impact) crusher rotational speed did not affect the particle form or particle size spreading of RFA, it did affect other concrete properties (Ulsen C. et al., 2013.). The type of recycled fine aggregate to use depends on the application; for example, recycled bitumen aggregates are consumed in the construction of pavements. The higher fineness of RFA necessitates a wider variety of water reducer admixtures than RS, according to experimental findings. RFA is best suited for mortar or concrete with particle size distribution less than 4 mm and a particle length of 75 m or less.

According to reports, using a higher percentage of RFA in concrete results in less workable and durable concrete. This is because of the existence of old adhering mortar in them. There are few studies on pre-soaking, triple mixing batching, and centrifugal mixing as solutions to water absorption (Singh et al, 2018).

According to (Evangelista L. et al., 2015.), stated that the non-steady chloride migration coefficient increases linearly with the fine aggregate replacement level, reaching a maximum of 34% for total RFA replacement concrete especially in

comparison to conventional concrete with RFA in this case. Nevertheless, (Zhao Y. et al, 2017) suggested that RFA that has been pre-wetted can help to reduce drying shrinkage to a greater degree.

2.4.4. Advantages and disadvantages of alternate sands in construction

2.4.4.1. Advantages of Alternative Sands in Construction

- The abundance of sources allows for the flexibility of manufacturing in nearby construction sites, lowering transportation costs and ensuring timely supply to meet demand.
- Particle size can be adjusted in CRS and RFA.
- All alternative sands are environmentally friendly, emitting little carbon dioxide.
- Do not contain organic or soluble compounds that affect cement setting time and properties, ensuring that the required concrete strength is preserved.
- The presence of impurities such as clay, dust and silt etc, is almost negligible.
- More cost-effective than natural sand.
- Assist in the reduction of waste dumping in landfills.
- Natural sands do not improve the mechanical or durability properties of concrete as much as synthetic sands do.
- Alternative sands come in two grades for concreting and plastering, saving time on sand filtering.
- There is no exploitation of river beds, thus preventing environmental catastrophes like water scarcity, groundwater depletion etc.

2.4.4.2. Disadvantages of Alternative Sands

- **Workability issues:** Natural River sand, which is plane and rounded due to ordinary gradation, may have a coarser and sharp texture than manufactured sand. This can necessitate the usage of extra water and cement to achieve the desired workability, resulting in higher costs.
- **Larger quantity of micro fines:** Because of its manufacturing process, mass-produced sand can comprise more micro fine particles than natural sand. This, too, can impact the screed's or concrete's strength and workability.

- **Low moisture content:** Low moisture content: Moisture is trapped between the particles of naturally available river sand, which is essential for good concreting. Just water washed M-Sand, on the other hand, retains moisture.
- Alternative sands have been found to be adulterated with foreign materials due to their high demand.

2.5. Global Generation of Steel Slag in the Construction Industry

Steel slag experience in numerous applications ever since iron was first melted by humans. Starting in 1589, the Germans used this by-product to cast cannonballs, where the English were constructing wharf buildings (1652) and roads (1813) with the dense rock-like material. (<http://lbm.civil.auth.gr/english/>)

From the start of the twentieth century, the usage of Steel Slag experienced with the introduction of sustainable development. Industrial by-products are now being used in various applications for economic and environmental reasons. The change in perspective regarding Steel Slag has led to modifications in the steel-making process to maximize its use and ensure compliance with specific standards and regulations.

Steel Slag is a non-metallic waste produced during the fabrication of metallic products. The properties of this rock-like material depend on several factors which intervene in the various stages of production. The main factors to determine properties of slag sand depends on the selection of raw material or scrap metal, the maintenance and control of the manufacturing procedure, as well as, the choice of the appropriate cooling treatment (Tossavainen et al., 2006).

2.6. What is Steel Slag?

Steel slag is a by-product of the steel production process. It's what's left over after the useful and useless ore fractions have been separated. Steel slag, is a by-product of iron and it is obtained by quenching the molten iron slag from the blast furnace in water or stream to produce glass, granular product, that is the dries and ground into a fine powder which is used as a substitute for aggregate (like fine aggregate and coarse aggregate) in the construction field, and also steel slag is a waste of steel-making, is produced through the departure of the molten steel from scums in steel-making furnaces. Steel slag is produced in large amounts during steel-making processes that use Electric Arc Furnaces (EAF), and

it can also be manufactured by melting iron ore in a Basic Oxygen Furnace (BOF). (Dieu, 2015)

Steel slag is commonly used as aggregate in concrete mix slab applications, but further research is needed to ascertain the viability of using this industrial by-product more wisely as an aggregate substitute in a conventional concrete mix. Concrete mix volume is up to 75% of aggregates.

According to (Dieu, 2015), Steel slag may replace all or part of natural aggregates, resulting in significant strength and environmental benefits.

Generally, Steel slag is an industrial by-product, its productive use endowments a chance to relocate for the utilization of restricted natural resources on a large scale.

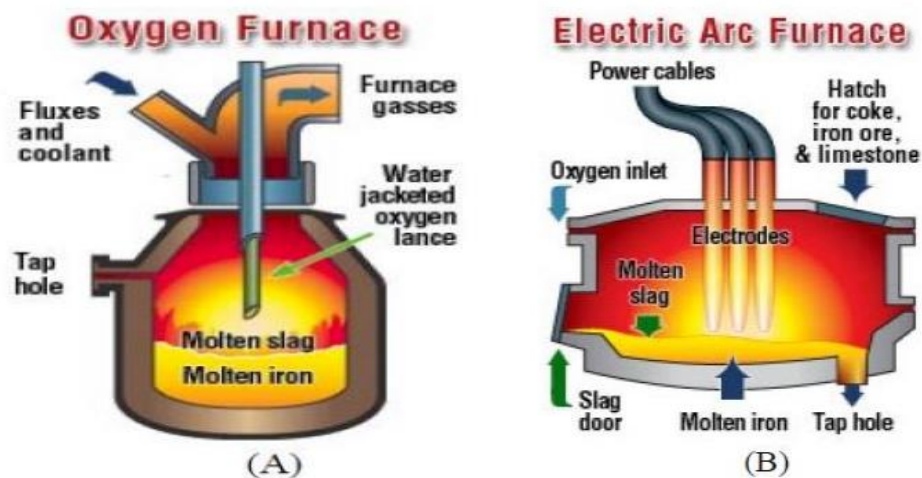


Figure 2. 1: Process of manufacture of steel slag by BOF process (A) and EAF process (B) (Jigar Patel P, 2006)

2.6.1. Why Steel Slag Is Promising?

Steel-making residues are defined as by-products obtained from the conversion process of iron to steel. Steel slag, in particular, accounts for a large percentage of these by-products. For instance, the production of 3 tons of stainless steel is estimated to generate about 1 ton of stainless-steel slag. Consequently, a large quantity of steel slag is yearly produced in the world which is around fifty million tons per annual. (Ferreira, 2015).

So, there is two different sights of the situation. One is our natural resources of the natural river sand is depleting day by day because of the increasing demand and the other sight is

this large number of industrial by-products should not be allowed to go as a complete waste. (Arhab Elahi et al, 2016)

Steel slag, which is expected as the strong waste poison, can be utilized for street development, clinker crude materials, filling materials, and so on. Uses of Steel Slag in Civil Engineering (Samdish Abrol et al, 2016):-

- Steel slag as an alternative of natural aggregates avoid the natural footprint of quarrying and also prevents deforestation.
- When applied in asphalt layers in the laying of roads, steel slag offers a better non-skid-able surface.
- Steel slag can be used for highly acidic soils as a soil neutralizer.
- Steel slag has a better life span and durability than natural aggregates.
- Steel slag is widely used all over the biosphere in landfills which is a good sign of economic progress as well.

According to different scholars, several advantages of using slag aggregates are gained such as

- Reliable quality
- Does not contain materials such as chlorides organic impurities, clay, and Shells
- Increased strength as materials age
- Does not generate alkali-aggregate reactions
- Blast furnace slag fine aggregate contains no materials that may influence concrete's strength and durability, such as chlorides, organic impurities clay, and shells.

Hence the purpose of the study is to somehow correlate these two factors and find a suitable replacement of natural river sand from the waste particles in this case steel slag.

2.6.2. Types of Steel Slag

The manufacturing procedure of metallic products produces various types of ferrous slag, each with specific physical, mechanical and chemical characteristics. The main differences depend on the type of furnace and the phase in which the slag is produced.

The principal types are defined as follows:

- i. *Blast Furnace Slag* obtained through the melting of iron ore in a blast furnace. The chemical reactions take place throughout the molten steel and not only on the

surface. The main types of slag produced are known as air-cooled (ABS) or granulated (GBS).

- ii. *Steel Slag* is characterized in two main types:
 - *Basic Oxygen Furnace Slag (BOS)* is the alteration of hot metal to crude steel
 - *Electric Arc Furnace Slag (EAFS)* is obtained through the melting of scrap metal in an electric arc furnace to produce carbon steel (EAF C) or stainless/high alloy steel (EAF S).
- iii. *Secondary Metallurgical Slag* is obtained after further refinement of crude steel. The most common type is Ladle Furnace Slag (LS).
- iv. *Other Slags*, such as de-sulphureted Slag are also produced, but in smaller quantities.

This work is based on Steel Slag, in particular, Electric Arc Furnace Slag obtained from the manufacturing of carbon steel, as this process is more common than that of stainless or high alloy steel.

2.7. Use of Steel Slag as a Fine and Coarse Aggregate in Concrete

Steel slag has been recovered and used since the invention of the blast furnace process in the 18th century. With the correct techniques and minimal processing, Steel slag can be used in a diversity application from construction to fertilizers. The physical properties of steel slag make it ideal for mechanically stable constructions. For this reason, steel slag is beginning to replace natural materials as an environmentally sound and economically smart construction material.

The main properties of concrete, such as strength, durability, and serviceability, are primarily determined by the properties and quality of the ingredients used in its preparation. As a result, the use of by-products materials in concrete, such as steel slag, may have a positive or negative impact.

Steel slag has been used in concrete mixes to solve some of the issues that have arisen in the concrete industry. As seen here, steel slag was used to enhance the mechanical, physical, and chemical properties of conventional concrete.

There is a significant difference among both steel slag and blast furnace slag; the former is produced by the conversion of iron ore to steel, whereas the latter is manufactured by the oxidation of old steel during arc furnace production.

A tenth of a century ago, slag, a byproduct of steel and iron production processes, was used in civil engineering projects. Portland granulated ground blast furnace slag cement because of its high lime content (40 to 50%), which is made from speedily water-cooled blast furnace slag, has been effectively used in concrete mixes, which possess pozzolanic activity (Neville A. and Brooks J, 2002). ASTM C33 specifies the usage of blast furnace slag as aggregates in concrete, but no standard exists for the usage of steel slag in concrete. Electric arc furnace slag (EAFS), which contains a small percentage of amorphous silica and a high content of ferric oxides and thus has low, or no, pozzolanic actions when compared to blast furnace slag (BFS), is not appropriate for use in blended cement production. Although many studies have been executed on the assessment of steel slag usage in road construction and usage of blast furnace slag in concrete mixes, few kinds of research have been executed regarding the application of steel slag in concrete, (Kamal M et al., 2002).

Shekarchi M. et al, (Shekarchi M. et al, 2003), Executed comprehensive research on the application of steel slag as natural sand in concrete production. They concluded that air-cooled steel slag with low-slung amorphous silica content and a high ferric oxide content is unsuitable for use in blended cement. When compared to conventional aggregate mixes, the use of steel slag as aggregate is beneficial.

A study by Maslehuddin M. et al, (Maslehuddin M. et al, 2003), shows a comparison study of steel slag aggregate concrete and crushed limestone concrete was presented. Only a portion of the coarse aggregate was substituted by slag aggregate in the study. According to the findings of the study, the compressive strength of steel slag aggregate concrete was slightly higher than that of crushed limestone aggregate concrete. Furthermore, there was no significant development in the tensile strength of steel slag concrete.

A study by Manso J, (Manso J, 2004), presents electric arc furnace slag was used to produce higher-quality concrete. It was determined that arc furnace slag can be used to improve the

properties of concrete. However, the authors recommend that special attention be paid to the fine aggregate of steel slag concrete mixes, which can be obtained by mixing fine slag with filler material.

Carried out to evaluate the performance of steel slag as fine aggregate in structural concrete the experiment is conducted by replacing natural sand with steel slag by applying a replacement percentage of 0% up to 100% with 25% interval and the experiment result indicates that such steel slag aggregate concrete has an appreciable influence on compressive strength of concrete containing 25% to 50% slag replacement and also have similar physical properties with low water absorption than sand thus decrease the quantity of water required for concrete containing steel slag, (Olonade. et al, 2015).

Conducted compressive research on part replacement of fine aggregate using steel slag. The experiment is performed by substituting natural sand with steel slag by applying a replacement percentage of 0% to 30% with 10% interval and the experiment result indicates that such steel slag aggregate attained higher values of compressive, tensile, and flexural strength and modulus of elasticity, associated to natural aggregate concrete up to an optimum value of a replacement, (Gaurav Desai et.al, 2018).

According to Chetan Khajuria et al, (Chetan Khajuria et al, 2014), stated that Iron Slag is suitable as natural Sand in Concrete. The experiment is conducted by a replacement percentage of 0% to 30% with a 10% interval. According to their investigation, after adding 10% iron slag in the mix, there was a rise of 26% after 7 days, 50% rise after 28 days, and 43% rise after 56 days as related to the control mix in the strength. Generally, they decided the increase of percentages of iron slag in the concrete mix, the compressive strength also increases and also the early age strength gain is higher as compared to later ages of 30% of fine aggregate is substituted by iron slag.

2.8. Steel Slag as a Substitute to Natural Sand

The production of steel-making slag around the world is increasing over time, despite the onset of the economic crisis. It is therefore critical to investigate applications for this by-product in order to reduce its dumping in landfills and the production of unnecessarily high waste volumes. As a result, there will be less harvesting of natural resources required for those application areas, that would otherwise be substituted by slag.

But in Ethiopia, there is hardly any research work on an alternative material for fine aggregates which relates steel slag whereas around 6 to 8 of steel factory is producing steel in Ethiopia. One ton of steel production process produce 130-200Kg of steel slag (Arhab Elahi et al, 2016). So, to utilize steel slag in Ethiopia, it is compulsory to investigate the opportunity of using this by-product as natural river sand, coarse aggregate, and cement.

Zhang et al, (Zhang et al, 2014), has investigated the impact of microstructure, hydration behavior, volume, and mechanical properties on the sustainable development of UHPC mixes containing steel slag. It has been discovered that when cement is partially changed by SS in UHPC mixes, early age hydration is disrupted, resulting in a decrease in compressive strength. It is also discovered that the addition of SS has no effect on the pattern of autogenous shrinkage improvement, whereas the autogenous shrinkage strain is reduced slightly at higher SS concentrations.

Dash M.K. et al, (Dash M.K. et al, 2016), studies on sustainable use of industrial waste reviewed about the partial substitution of fine aggregate for concrete mixtures. This study observed that there are some industrial wastes like foundry sand, steel slag, copper slag, imperial smelting furnace slag (ISF slag), blast furnace slag, coal bottom ash, ferrochrome slag, and palm oil clinker, etc., which may be used as full or partial replacement of coarse aggregate or fine aggregate.

So, under the lights of the previous studies, I deduce that the further study of this steel making by product, steel slag; needs to be continued and hence their lies the possibility of finding suitable alternatives of conventional concrete technology and make a sustainable world which is the objective of my investigation.

2.8.1. Comparison of physical properties between natural river sand and steel slag fine aggregate

Steel slag aggregates are roughly cubical, angular pieces with flat or elongated shapes. They have a rough vesicular structure with many unconnected cells, giving them a larger surface area than smoother aggregates of equal volume; this characteristic provides an excellent bond with Portland cement.

Steel slag has a high shear strength and a high degree of internal friction. Because of the rough texture and shape, there is little breakdown in handling and construction. (NSA, 2008). Steel slag has a high bulk specific gravity and a water absorption rate of less than 3%. Steel slag aggregates have such a high density, but aside from that, most of their physical properties are superior to hard typical rock aggregates. Below are registered some of the constructive features of steel slag based on different studies strength and durability experimental result.

- i. They are strong and durable.
- ii. They have an extremely good angular shape, which aids in the development of extremely strong interlocking properties.
- iii. They are highly abrasion and impact resistant.

Steel slag aggregates have such a rough surface texture and are extremely angular in shape. They have such a high bulk specific gravity and a low water absorption rate. (U.S. Department of transportation, accessed 2020).

Table 2. 1 Some typical physical properties of steel slag and river sand from some previous research works are presented.

	Source	Aggregate type	Specific gravity	Approximate Dry rodded Unit Weight, (in kg/m ³)	Water Absorption
1	(B.Booma Priya et al, 2016)	SS	2.38	1058	0.90%
		NS	2.71	1685	1.01%
2	(D. Satish Kumar et al, 2016)	SS	2.3 - 2.5	1000 - 1100	4 – 6%
		NS	2.6 - 2.8	1300 - 1600	1 – 3%
3	(Mohd Nadeem, and D. Pophal, 2013)	SS	2.38	1058	0.39%
		NS	2.65	1468	0.65%
4	(Keerthi Kumar B et al, 2017)	SS	2.74	1800	3%
		NS	2.74	1820	1.20%
5	(U.S. Department of transportation, accessed 2020)	SS	3.2 - 3.6	1600 - 1920	Up to 3%
		NS	ND*	ND*	ND*
6	(Tanya Richte, June 2013)	SS	3.3 - 3.8	1600 - 1920	1%
		NS	ND*	ND*	ND*

NB ND* indicates for 'Not Determined' by the author in his published journal.

2.9. Effects of Steel Slag Fine Aggregate on Concrete Properties

Literature shows that the practice of using steel slag as a full or partial replacement of natural sand on the concrete production affects the fresh and hardened concrete properties. Some of these basic properties are the workability of the fresh concrete and also, compressive strength and durability of hardened concrete. Many researchers as sequentially discussed below, tried to find the effect of using steel slag on these properties.

2.9.1. Fresh Concrete

i. Workability

Workability is a broad term that refers to the properties of fresh concrete. Workability is frequently defined as the amount of mechanical work required for complete concrete compaction without segregation.

A research by Roopa Baliga. B et.al, (Roopa Baliga. B et.al, 2018), He investigated the effect of partially replacing river sand with slag sand on the workability, compressive strength, and flexural strength of M-25 grade concrete. The concrete prepared by replacing river sand with slag sand by 50% and 75% is workable. Since bleeding was observed 100% replacement of concrete prepared by replacing river sand with slag sand by 100%, an addition of suitable dosage of admixture would contribute to better workability. The result showed that increasing percentage replacement of steel slag fine decreased the workability. Another research by (Subathra Devi and Gnanavel, 2014) studies that, workability of concrete decreases as the proportion of replacement increases. Fine aggregate replacement is further workable than coarse aggregate replacement.

Research by Elavenil (Elavenil, 2019) investigates that; Workability of steel slag added concrete is lying in moderate when it used up to 30 percentage and 40 percentages replacement to fine and coarse aggregates.

2.9.2. Hardened Properties

i. Compressive Strength

Compressive strength is one of the furthest common properties of hardened concrete. The compressive strength of concrete specimens is affected by different factors like water-cement ratio, degree of compaction, and curing temperature. Besides, the addition of pozzolanic materials into the mix affects the strength of hardened concrete.

As Rahmawati and Saputro (Rahmawati and Saputro., 2017), test result indicated that concrete using steel slag as substitution material replacing a part of natural sand have the potential to produce better concrete performance than ordinary concrete, concrete with high strength and good performance can be obtained with 20% replacement of fine aggregate by steel slag sand reached a highest compressive strength than others concrete mix.

A thorough investigation of results by (Sultan A. et al, 2014,) indicates that the amount of compressive strength increase at 7 days is much greater than the amount of increase at 28 days for all types of aggregate replacement. This suggests that the added slag can act as an accelerator at a young age, but the effect reduced after 28 days.

The fine slag replacement scores the highest effect since, the sand amount is not significant compared to other aggregate types, the effect of sand replacement on enhancing compressive strength is minimum.

ii. Sulfate Resistance

Sulfate attack is caused by a sequence of chemical reactions among sulfate ions and hardened concrete components. As these reactions can cause cracking, spalling, or strength loss in concrete structures, right test methods are required to determine concrete resistance to sulfate exposure.

Therefore, to forecast the resistance to sulfate attack of concrete, it is compulsory to develop a practice that takes into account the type of exposure and separates the several mechanisms. For instance, absorption of sulfate solution, diffusion of sulfates into the pore structure, and chemical reaction between the sulfates and the hydration products cannot all be tested in one measurement.

Three types of tests can be found in the literature (Skalny J.et al, 2002):

- Internal attack
- External attack under constant exposure
- Partial or cyclic exposure

The chemical reactions between sulfates and cement paste constituents have been recognized as the major cause of the deterioration of concrete. In principle, the sulfate salt ionizes in water to attack the cement hydrates, typically $\text{Ca}(\text{OH})_2$, calcium silicate hydrate (C-S-H), and calcium aluminate hydrates. The actual reaction process depends on the type

According to Dora Foti et al, (Dora Foti et al., 2019,) the percentage of water absorbed by fly ash, steel slag, and ordinary concrete specimens were investigated generally he notice that the higher amount of absorbed is obtained for the ordinary concrete, but the percentage of absorbed water to the total weight is equal to 4.84% for ordinary concrete and 4.20% and 4.03% for fly ash and steel slag concrete respectively.

iv. Ultrasonic Pulse Velocity (UPV)

An ultrasonic pulse velocity test is a non-destructive, in-situ examination of the quality of hardened concrete. This test measures the velocity of an ultrasonic pulse passing through with a concrete structure or natural rock formation to assess the strength and quality of the concrete or rock. This test is conducted by passing an ultrasonic wave pulse through the concrete to be tested and measure the time it covers for the pulse to pass through the structure. Higher velocities show good material quality and continuity, whereas slower velocities may show concrete with numerous cracks or voids.

Ultrasonic Pulse Velocity measurements are conducted on concrete specimens to gauge the internal structure of the specimen. The test is used to assess the existence of any damages/cracks, material discontinuities, and the level of deterioration for a given exposure time. The measurements are obtained by measuring the time it covers an ultrasonic pulse to travel between transducers at opposite ends of the given material (direct method). When the distance among the transducers and the travel time are known, the pulse velocity can be calculated by dividing the distance by the travel time. Higher or faster levels of velocity indicate that the material has a higher density, integrity, and quality.

2.10. Mix Design Selection

2.10.1.General

Concrete mix design refers to the process of choosing appropriate concrete ingredients and identifying their relative amounts in order to produce a concrete with the required strength, durability, and workability as economically as possible. The proportioning of concrete ingredients is governed by the required performance of concrete in two states, namely plastic and hardened. Plastic concrete cannot be properly placed and compacted if it is not workable. As a result, the property of workability becomes critical. The compressive strength of hardened concrete, which is widely regarded as an indicator of its other properties, is affected by different factors, including the quality and quantity of cement,

water, and aggregates used; batching and mixing; placement, compaction, and curing (Nataraja M.C, 2000).

Different factors need to be considered while preparing the mix design. Some of the factors are strength margin, measurement of workability, free water, and W/C ratio, aggregate type and grading, cement content, and aggregate size.

2.10.2.Method of Specifying Concrete Mixes

There are four methods to specify concrete mixes namely designed mix, prescribed mix, standard mix, and designated mix.

- i. **Designed mix:** - is specified by the designer in terms of strength, cement content, and water to cement ratio. Compliance relies on strength testing.
- ii. **Prescribed mix:** - is specified by the designer in terms of the nature and proportions of mix ingredients. When specific concrete properties are required, the use of prescribed mixes is advantageous.
- iii. **Standard mix:** - is based on ingredients and proportions fully listed in codes and standards. In the Ethiopian context, mix proportions for grade C-5 to C-30 are specified in *EBCS 2-1995 of section 8.2*.
- iv. **Designated mix:** - the concrete producer selects the water-cement ratio and the minimum cement content. This method is only applicable if the concrete producer possesses a special certificate of product conformity based on product testing and surveillance, as well as quality assurance certification.

2.11. Research Summary and Gap Identification

2.11.1.Research Summary

Steel slag is a non-metallic byproduct produced during the fabrication of metallic products (Arhab Elahi et al, 2016). The physical and chemical properties of steel slag depend on several factors which intervene in the various stage of production. The common physical properties of steel slag are their lower water absorption which contributes to impermeable concrete. In addition to this chemically steel slag has high silicon dioxide which makes its chemical properties comparable to natural sand.

If used in concrete, steel slag could have several advantages by replacing the costly ingredient of concrete, natural sand, with steel slag the concrete price, thermal

conductivity, and sound insulation could be decreased, since about 5 to 10 of the total number of steel industry produce a steel slag aggregate in a milling operation, based on this steel slag is available per year in steel plants located in the region of Debre Zeit and Akaki Kality east of Addis Ababa, Ethiopia.

Researchers conducted on the practice using steel slag as a partial replacement of natural sand on the production of concrete. According to (Rahmawati and Saputro, 2018) the sand can be replaced by steel slag up to 20% to yield concrete with the 1:2:3 Ratio Mixing Method which results in increasing 1.37% for compressive strength and 1.13% for flexural strength. (Krishna Rao et al, 2015), investigated that sand can be replaced by steel slag up to 25% to produce concrete. (Hisham Qasrawi et al, 2008), studied that the sand can be replaced by steel slag up to 30% but the best results are obtained for replacement ratios of 30 to 50% for tensile strength and 15 to 30% for compressive strength to produce concrete. Moreover, steel slag as replacement natural sand material in concrete production has been found to show different properties on the physical, mechanical, and durability of the fresh and hardened concrete; especially on workability, compressive, tensile, and flexural, and durability of concrete.

The availability of steel slag is good in Ethiopia and the steel milling industry sector is growing for the manufacturing of steel products. However, there are no studies that explains on the utilization of steel slag as a replacement for natural sand in the manufacturing of concrete which is conducted in Ethiopia.

2.11.2. Gap Identification

This research studies the possibility of replacing natural sand with steel slag to produce normal strength concrete and to study the workability, compressive strength, and durability tests UPV, Sulfate attack (external attack), and water absorption of normal strength concrete.

This paper is limited to asses only on the partial replacement of river sand with steel slag due to time and financial constraint, it does not study on replacement of cement or coarse aggregate with steel slag. The properties (physical and chemical), and mix proportion of the material has significant effect on the strength of concrete. There is no standard to obtain consistence result in concrete to utilize steel slag as an aggregate.

CHAPTER THREE

Materials and Experimental Design

3.1. Material Characterization

The physical properties of materials are assessed for the present experimental investigation. According to the correct international standards of practice, characterization will be done for concrete. For the two types of sand, i.e., steel slag sand and natural river sand used in this experimental investigation mix proportion will be accompanied as indicated terms in typical guidelines.

3.1.1. Chemical Composition of Steel Slag

The sample of steel slag is collected from steel plants that are located in the region of Debre Zeit (Bishoftu) and Akaki Kaliti east of Addis Ababa. The chemical Composition was tested in Ethiopia Geological Survey to be determined major oxides and minor oxides. The chemical analysis result shows below in the tabulated form.

Table 3. 1: Chemical Composition of Steel Slag

Materials	Mass (%)
Silica (SiO ₂)	55.08
Iron Oxide (Fe ₂ O ₃)	15.96
Manganese oxide (MnO)	14.02
Alumina (Al ₂ O ₃)	9.53
Lime (CaO)	3.38
Magnesia (MgO)	2.06
Titanium (TiO ₂)	0.53
Water (H ₂ O)	0.25
Phosphorus pentoxide (P ₂ O ₅)	0.11
Sodium oxide (Na ₂ O)	0.08
Potassium oxide (K ₂ O)	<0.01
LOI	<0.01

3.1.2. Physical Properties of Aggregates

As stated in the general objective, the main aim of the research is to study the feasibility of utilizing steel slag as a partial replacement of natural river sand as fine aggregate in normal

strength concrete production on the workability, strength, durability, and cost of the produced concrete. Specifically, the two quoted properties of fresh and hardened concrete are greatly affected by the properties of the constituent ingredients.

Different physical parameters of aggregates are required to be within certain limits by different standards so that concrete from a given aggregate will give the intended performance. Physical parameters are important an input for mix design. Therefore, the following properties of aggregates were conducted.

- Gradation of fine and coarse aggregates was conducted as per *ASTM C136* for both coarse aggregates and natural sand.
- Gradation of steel slag was conducted as per *ASTM C330* since it is a lightweight aggregate.
- Density, relative density, and absorption of natural sand, steel slag, and coarse aggregate were conducted as per *ASTM C127* and *128*.
- Based on *ASTM* standards the test results obtained were used as input for mix proportioning.
- Silt Content, a simple test that can be made on-site to give a guide to the amount of silt in natural sand is the ‘field settling’ test. For crushed rock sands, this test should not be used. According to the Ethiopian Standard, if the silt content exceeds 6%, the sand should be washed or rejected (Abebe Dinku, 2002).
- Fineness Modulus (FM), it is a numerical index that is frequently computed using the sieve analysis results. According to *ASTM C 125*, the fineness modulus (FM) of fine or coarse aggregate is computed by summing the cumulative percentages by mass retained on each of a stipulated series of sieves and divide by the total by 100. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 according to *ASTM C 33* (Steven H., 2003.).

a. Cement

Ordinary Portland cement (OPC) Dangote cement brands 42.5R was utilized in the production of the concrete. The cement was bought from a cement distributing shop in Bahir Dar City.

Table 3. 2: Specification of the cement used (Source: manufacturer’s specification)

Parameters	EN – 197-1-2000 specification requirement
Cement Type	CEM I
Compressive strength (28) days	≥ 42.5 MPa
Compressive strength (2) days	≥ 20 MPa
Setting Time: Initial	≥ 60 min
Final	≤ 600 min
Soundness Expansion mm	Not more than 10mm
Loss on ignition (LOI)	$\leq 5.0\%$

b. Fine aggregate

The fine aggregate's purpose is to fill vacuums in the coarse aggregate and to act as a workability agent. Two types of fine aggregates are used in this research; natural sand and Steel Slag fine.

i. Natural river sand

The characterization of natural river sand is done and the properties are achieved such as water absorption, bulk density, specific gravity, and others are evaluated based *ASTM*, and Gradation of natural river sand was conducted as per *ASTM C136* but the FM is calculated based on *ASTM C125* by comparing results with *ASTM C33* to classify as fine aggregate.

Table 3. 3: Natural Sand fine aggregate properties

Properti es	Impurities (Mainly Silt and Clay) (%)		Unit Weight (kg/m ³)	Fineness Modulus (FM)	Specific Gravity	Absorption Capacity (%)	Moisture Content (%)
	Before Washing	After Washing					
Value	27.77	1.805	1915	2.6	2.76	1.01	1.7
Test methods	ASTM C33		ASTM C29	ASTM C136	ASTM C128	ASTM C128	ASTM C566

As shown in Table 3.3, the impurities (mainly silt and clay) of the sand were very high (see Figure 2(a) in Appendix D) and it was washed to fulfill the requirements of ASTM C40, which is a maximum of 5%. A gradation test result shows that the fine aggregate is a little

coarser and does not completely fulfill the requirement stated in ASTM C33. Therefore, the fine aggregate was separated by sieving into different sizes and re-blended based on the requirements set.

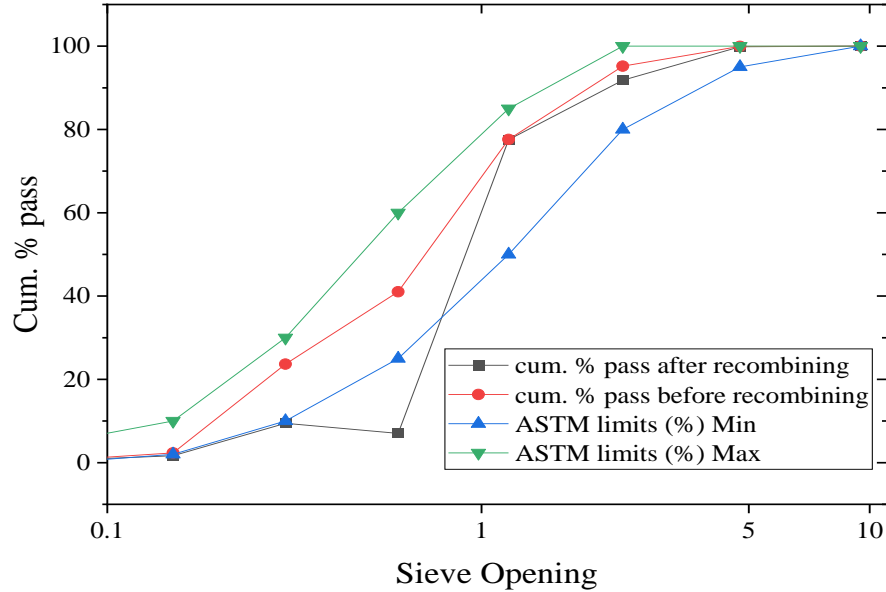


Figure 3. 1: Gradation curve for natural sand

ii. Steel slag fine

Steel slag sand is used as a replacement for natural river sands mentioned in the current investigation in concretes. This steel slag sand was collected from the region of Bishoftu east of Addis Ababa. Thorough categorization of steel slag sand is conducted as per ASTM standards similar to natural river sand, but the gradation of steel slag was conducted as per *ASTM C33* since it is lightweight aggregate, but the FM is calculated based on *ASTM C125* by comparing results with *ASTM C33* to classify as fine aggregate. Their fundamental detail of characterization is noted below.

Table 3. 4: Steel Slag fine aggregate properties

Properties	Unit Weight (kg/m ³)	Fineness Modulus (FM)	Specific Gravity	Absorption Capacity (%)	Moisture Content (%)
Value	1550.34	2.96	2.63	3.7075	1.41
Test methods	ASTM C 29	ASTM C 136	ASTM C 128	ASTM C 128	ASTM C 566

A gradation test result shows that the steel slag fine contains excessive fines and does not completely fulfill the requirement stated in ASTM C33. Therefore, the steel slag fine was separated by sieving into different sizes and re-blended based on the requirements set.

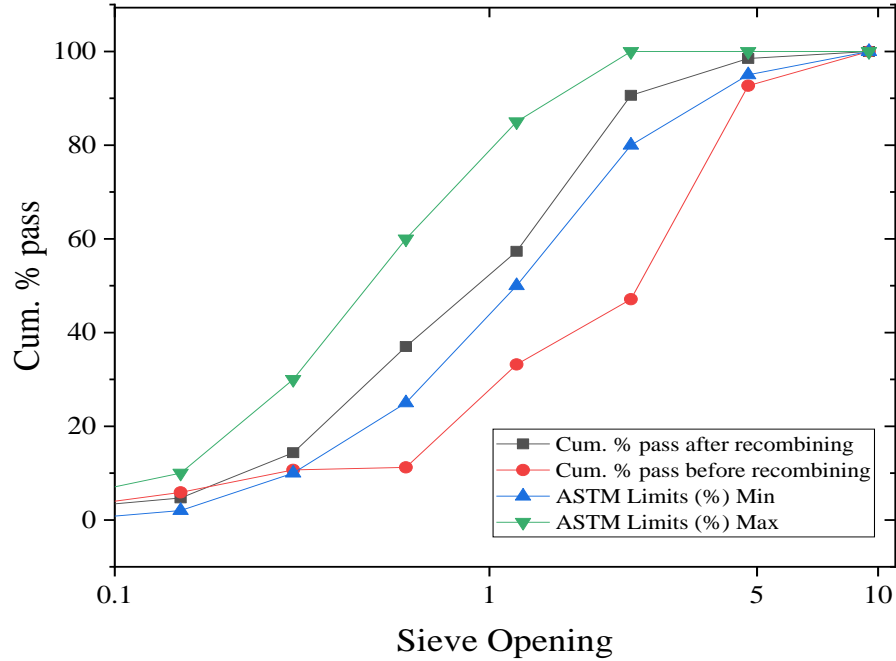


Figure 3. 2: Gradation curve for steel slag fine

c. Coarse aggregate

Coarse Aggregate is made up of crushed stone with a particle size of 4.75mm or larger. The coarse aggregate used for this research is bought from a crusher plant at a Chinese production site (inside of Bahir Bar city at IFH Engineering).



Figure 3. 3: Coarse aggregate crusher plant at a Chinese production site at Bahir Dar city [meshentie quarry site]

Experimental investigation of coarse aggregate is done with aspects of parameters such as water absorption, bulk density, specific gravity as guidelines indicated in *ASTM C127* and *128*, and also the Gradation of coarse aggregate was conducted as per *ASTM C136* observations are in below table 5.

Table 3. 5: Coarse aggregate properties

Properties	Unit Weight (kg/m³)	Specific Gravity	Absorption Capacity (%)	Moisture Content (%)
Value	1660	2.69	1.51	1.18
Test methods	ASTM C29	ASTM C127	ASTM C127	ASTM C566

d. Water

Water that is clean and uncontaminated available in the laboratory gratifying the requisite is utilized for concrete, supplied by Bahir Dar Water and Sewerage Authority was used for concrete mixing and curing in the study.

3.2. Mix Design

A mix design for normal strength (M-25) concrete which has a slump of 25-50mm and a nominal maximum aggregate size of 19 mm was made using *ACI 211.1* mix design procedure by utilizing Fine Aggregate Steel slag sand with 0%, 15%, 30%, and 45% of partial replacement for 386.96kg/m³ cement content. Corresponding Design mix for 0%, 15%, 30%, 45% and 60% Natural River Sand are designated in *table3.6*.

Table 3. 6: Design Mix for FA Slag Sand and Natural River Sand and Crushed stone sand of Cement Content 386.96 kg/m³

Sand Proportion	Mix code	Ingredients (in Kg/m³)				
		Cement	Water	Natural Sand (NS)	Steel slag Fine (SS)	Coarse Aggregate
100% NS	MS0	386.96	188.32	764.07	-	1074.94
15% SS +85% NS	MS1	386.96	191.7	648.32	114.41	1073.26
30% SS +70% NS	MS2	386.96	195.04	539.77	231.33	1056.46
45% SS +55% NS	MS3	386.96	198.37	425.51	348.14	1048.06
60% SS +40% NS	MS4	386.96	201.85	312.21	468.32	1037.99

3.3. Sample Preparation and Test Program

The detailed concrete study of which comparison with 0%, 15%, 30%, 45%, and 60% usage of fine aggregates i.e., slag sand, natural river sand for Normal Strength Concrete (M-25) grade, the content of cement as 386.96kg/m^3 with the concrete mix are designed as stated by ASTM C143 is tested for workability, specimens have been cast as per strength characteristics requisites and parameters of durability.

Characteristics strength of concrete mixes for compressive strength of 3rd, 7th, 28th and 56thdays have been considered first. The water absorption test was conducted for 3rd, 7th, and 28thdays, and UPV (Ultrasonic Plus Velocity) test was conducted for 28thdays of curing. The mechanical and durability tests of specimens were carried on the (150 x 150 x 150) mm cubic specimens at the age of 3rd, 7th, 28th and 56thdays of curing. Lastly, Sulfate resistance test was conducted for 3rd, 7th, and 28th days,

3.3. Procedures for Mix Preparation

Preparation of concrete cube was carried out with great care and before mixing mold preparation was follow by cleaning the molds and oiling the surface after that sample was weight with respective percent replacements of aggregate, adding materials into the mixer, next to adding materials dry mix of ingredient performed, lastly by adding the required water mixing the materials (with constant $w/c \approx 0.49$) and casting into cubes. After casting by using a table vibrator the sample was compacted, using a sharp edge trimming the extra concrete from mold, leveling the sample with identifications, after all covering the casted concrete with cloth for 24Hrs and after 24Hrs removal of the mold, then cure the samples in water tank following ASTM C511 for 3days, 7days, 28days, and 56days.

Table 3. 7: Types of tests performed on steel slag concrete and its test method.

Type of Test	Test Method
Workability	STMC143
Compressive test	ASTM C39/C39M
Sulfate Attack	ASTM C1012
Water Absorption	ASTMC642
Ultrasonic Plus Velocity	ASTM C597

3.4. Research Methodology

The objective of this chapter is to explain the methodology followed to characterize the physical properties and chemical composition of steel Slag, as well as, the series of tests applied to determine its physical, mechanical properties, and durability of normal strength concrete. The outcomes of these tests are discussed in the following chapter.

The experimental campaign is divided into three major phases, each of which focuses on a different aspect of steel slag and its potential use as a fine aggregate in the manufacturing of normal strength concrete. The first section, conceptualization, starts by identifying the problem statement, reviewing different works of literature, followed by material preparation and experimental work on how the material was characterized from a physical and chemical perspective, the potential percentage of replacement of the steel slag and studying of its workability, strength, and durability of normal strength concrete production. The final block focuses on result analysis and discussion of the partially replacement of the steel slag on normal strength concrete production and finally conclusion and recommendations were drawn based on the findings.

For this research normal strength conventional concrete was selected. The concrete for cube preparation was prepared in five series of concrete mixes compared to conventional mix methods, one of which will be ordinary mix and the remaining four concrete mixes will be prepared with partial sand replacement with steel slag in the percentages of 15%, 30%, 45 percent, and 60% by weight of natural sand. The whole experimental campaign has been executed in the mechanical unit operation Laboratory (crushing of steel slag), Construction materials laboratories, and structural engineering laboratories of the Bahir Dar University Institute of Technology (BDU), Bahir Dar, Ethiopia. The main tasks done in this research are summarized below as given in Figure 3.4.

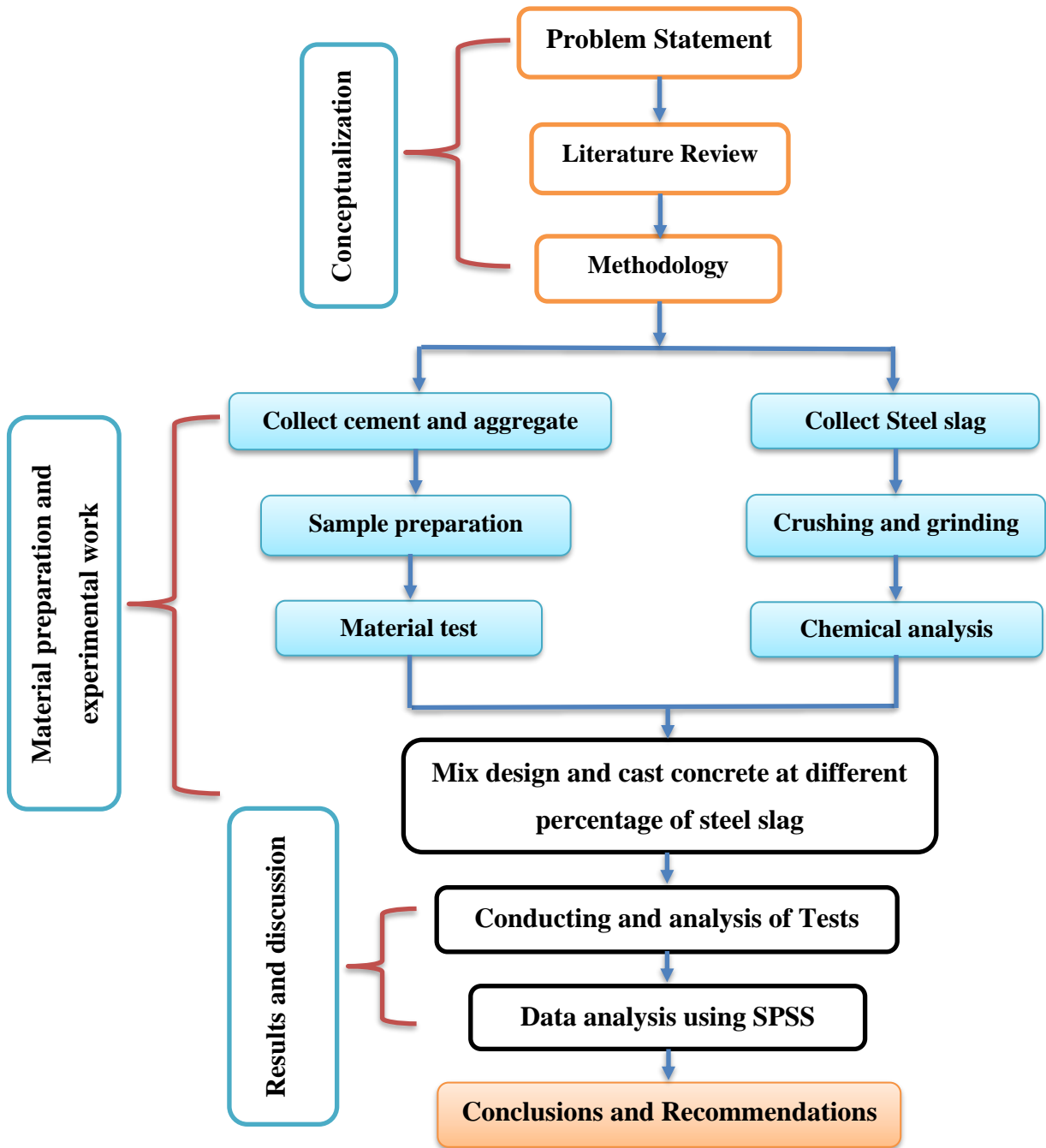


Figure 3. 4, Methodology flow chart of the thesis

3.4.1. Preferred Best Practice

The preferred best practice that is used for attaining the objective of this study is laboratorial testing. The conventional and nonconventional concrete manufacturing processes both involve the selection and preparation of source materials, as well as the controlled mixing and blending of raw materials (including cement binders). Divergent mechanical tests on concrete such as workability test, compressive strength tests, and durability tests etc. are used to convince the quality of the concrete that is provided for a given requirement.

Experimental Procedures

The methods that are followed to attain the objectives are:

- a. Sample of natural sand and steel slag fine is collected from well-intended specific sources and the physical properties of ingredients are tested.
- b. Mix designs were carried out for each batch of proportioning of natural sand and steel slag fine using the same types of cement, coarse aggregate, and water.
- c. Workability tests were conducted by slump test and Test cubes were cast for each specific mix.
- d. Finally, compressive strength, water absorption, and sulfate attack, Ultrasonic Plus Velocity test were conducted for each specific mix.

The present examination is aimed at studying the properties of concrete where natural sand is partially replaced by steel slag fine. The properties of the ingredients of concrete were assessed. Based on the findings, mix designs were prepared as per ACI 211.1 Standard. As per the mix designs, all materials were weighed and mixed using a drum mixer. Slump tests were conducted for each batch and the standard concrete cubes (150mm x 150mm x 150mm) were cast by table vibrator compaction. The specimens were de-mold after 24 hrs, cured in water for 3, 7, 28, and 56 days, and then tested for their compressive strength as per the ASTM standard. Three specimens were tested for 3, 7, 28, and 56 days with each proportion of crushed rock fine replacement as shown in Table 3.1.

Table 3. 8: The five types of mixes with different proportions of NS and SS

Mix Number	Mix code	NS (%)	SS (%)
1	MS-0	100	0
2	MS-1	85	15
3	MS-2	70	30
4	MS-3	55	45
5	MS-4	40	60

3.4.2. Cost Comparison

The material cost of produced concrete per unit volume was calculated for each proportion of steel slag fine replacements based on the base price of the materials from different sources within the city and compared with the cost of the control mix.

CHAPTER FOUR

Result and Discussion

4.1. Workability

Workability of the cement mixes with steel slag fine aggregates of 0%, 15%, 30%, 45%, and 60% usage has been assessed by slump test as guidelines indicated in ASTM C143. In all cases of fine aggregate, a comparison slump has been maintained 25 to 50 mm. Fresh concrete is filled in form of layers to slump cone and every layer is compacted by using a compacting rod.

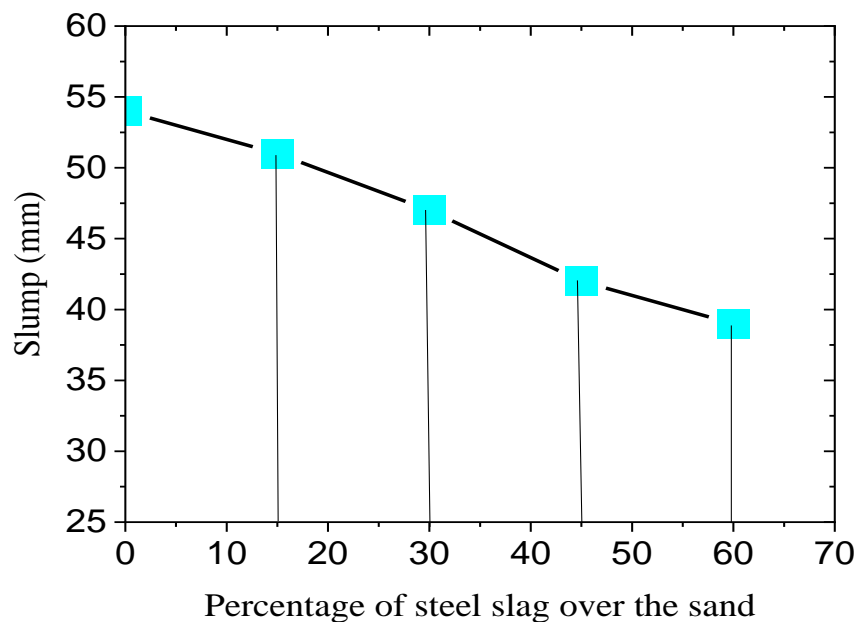


Figure 4. 1: Slump of concrete mixes containing different percentage of steel slag aggregate

As shown in *figure 4.1*, the slump of the concrete decrease when the amount of steel slag replacement percentage content in concrete increases at constant water to cement ratio of 0.49. The study by (Hisham Qasrawi et al., 2009,) shows that the loss of workability is due to the substitution of sand with a finer, more absorbent material; additionally, the higher the percentage of fines, the lower the workability, as depicted in Figure.

According to (Prof. Pankaj Bhausheb Autade, 2016), the percentage of fine aggregate replaced by steel slag increases, workability decreases. This is due to steel slag's higher water absorption potential than the natural fine aggregate.

4.2. Compressive Strength Test

The test results show the concrete mix achieved good compressive strength efficiency with which percent replacement of steel slag fine aggregate. Steel slag fine aggregate, as compared to natural river sand, performs better in the test and can be used to cover up to 45% of the natural river sand. As compared to natural river sand, slag sand performs better following a 28th day curing period, however, it does not achieve the same degree of results. It does, however, display equal capacity to the strength of natural river sand. According to (Rakesh Kumar P. et al, 2017,), the increase in compressive strength could be due to enhancement information of C-S-H gel when GBS reacted with various hydration products. The compressive strength of concrete was measured on 3rd, 7th, 28th, and 56th days of curing, using compressive strength testing machine according to ASTM C39/C39M describes a standard test method for compressive strength of cylindrical concrete specimens, for cube test of specimens, used cubes of 150mmx150mmx150mm.



Figure 4. 2: Compressive strength test and failure Mechanism

The following precautions were taken:

- a) The top surface must be smooth, if not, capping is provided.
- b) A base plate and top plate are applied to ensure uniform load distribution.
- c) The load rate adopted from the standard (0.023MPa/s) is to be maintained throughout the crushing.
- d) After each test, the base plate of the machine is to be wiped for crushed particles.

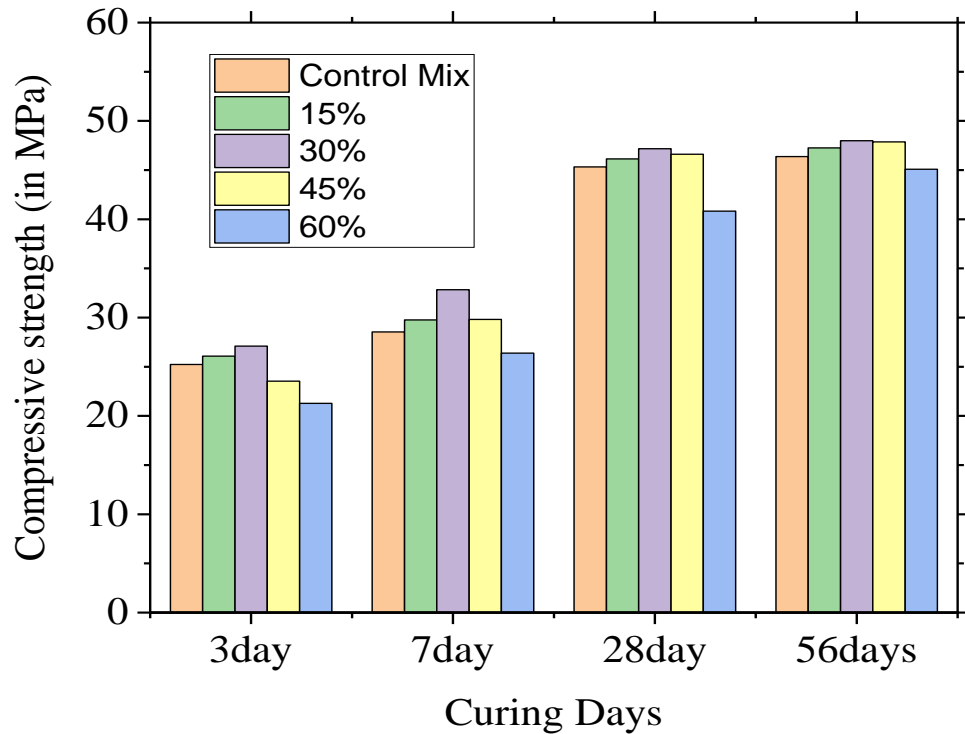


Figure 4. 3: Compressive strength of steel slag concrete different curing ages

Based on *Figure 4.3*, The strength development of the control (Natural River sand) mix was increased starting from 3rd days of concrete mixing. However, the strength of steel slag concrete increases up to 30% replacement with 7.33% from its control mix at 3 days of curing only, but for 7th, 28th and 56th days of curing compressive strength of steel slag concrete increases up to 45% replacement with 4.45%, 2.85% and 3.19% from its control mix. But for 3th, 7th, 28th and 56th days of curing as compared to the control mix, steel slag concrete decreases at 60% replacement. the maximum compressive strength is obtained at 30% replacement for all days of curing. However, at 45% replacement the compressive strength is obtained better than control mix at 45% replacement for 7, 28, and 56 days of curing. Because of this, the addition of steel slag material in concrete increases the strength development of concrete from its control mix, and the strength of the concrete is achieved at 28 days of curing period. It reveals that steel slag materials achieve their strength development at later days as long as there is a high amount of SiO₂ and Fe₂O₃. According to (Kou S-C, 2011) and (Berndt ML, 2009) When the GGBFS content in concrete mixtures increases, the

compressive strength of the concrete decreases, and the pozzolanic effect of GGBFS usually occurs at a later age. In this case, the decrease in compressive strength was less pronounced at the 28th day. This implies that the pozzolanic reaction between SiO₂ and calcium hydroxide, which promotes the formation of hydrated calcium silicate, is the key explanation for the increase in concrete compressive strength in later age.

4.3. Sulfate Resistance

The sulfate resistance test results are shown in *Figure 4.4*. The compressive strength test employed on concrete specimens immersed in sulfate solution was tested for 3rd, 7th, and 28th days with a w/c ratio of 0.49. The sulfate resistance of 3rd days of curing for the control mix is 22.28MPa, which reduced to 13.73MPa, 13.17MPa, 10.93MPa, and 10.25MPa which shows 38.38%, 40.89%, 50.94% and 53.99% lower value than the control mixes respectively. The compressive strength of steel slag concrete specimens immersed in sulfate solution for 7th days of curing was decreasing, the strength decreases from its control mix at a constant 0.49 w/c ratio. It decreases to 20.42% with the addition of 15% steel slag but it is further decreased to 27.22%, 32.70%, and 39.13%, lower than the control mixes for 30%, 45%, and 60% replacement of steel slag respectively. Similarly, for 28th days of curing with a 0.49 w/c ratio, 0% steel slag the compressive strength is 47.54MPa which further reduced to 44.73MPa, 42.20MPa, 40.83MPa, and 36.85 MPa which shows 5.91%, 11.23%, 14.15% and 22.49% lower than the control mixes respectively. The formation of ettringite causes an increase in solid volume, which causes expansion, cracking, and mass loss. In the high replacement of steel slag, softening and loss of mass and strength in the steel slag concrete is observed, especially when restrained and the formation of gypsum is observed. (Binici et al, 2012), studied that the performance of concrete comprising steel slag as fine aggregate decreases after immersion in a sodium sulfate solution. Steel slag was used at a replacement percentage of 0%, 15%, 30%, 45%, and 60% by weight of sand, and the samples were kept in 5% Na₂SO₄ solution for 3rd, 7th, and 28th days. The outcomes of the study confirmed that the sulfate resistance of the concrete specimens decrease with the addition of steel slag aggregates.

According to (A.A. Ramezani pour et al., 2008), Except for the control mixes, which experienced a decrease in resistance or consistency in the growth rate of resistance at the age of 180 days and showed some signs of corruption, all of the concrete samples showed

improvement in compressive resistance until the age of 180th days, and after 270days the samples containing 35percent of GGBS (Ground Granulated Blast Furnace Slag), in addition to all control forms, began to lose compressive resistance. The experimentation was investigated with different w/c ratios, but the samples containing 50 percent GGBS didn't only lose resistance but also gained more compressive resistance in the sodium sulfate solution.

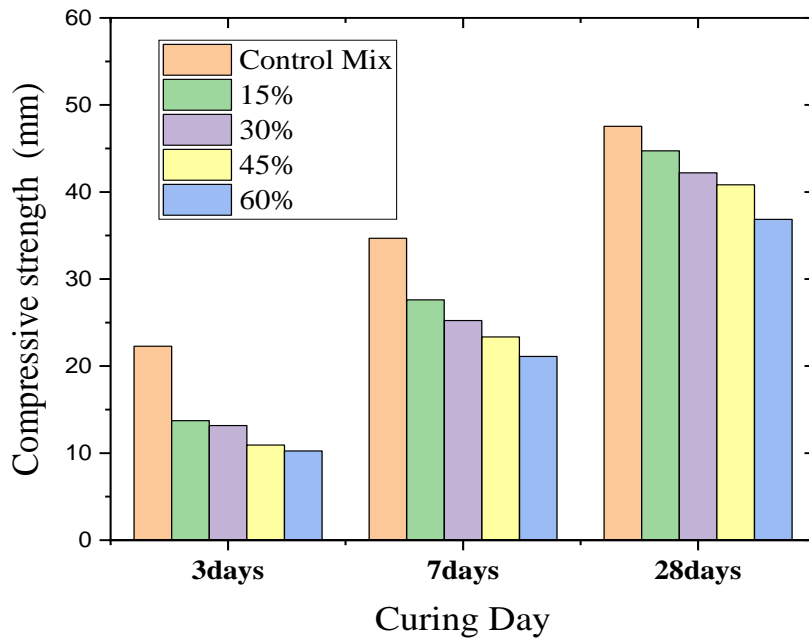


Figure 4. 4: Sulfate resistance of steel slag concrete mixes at different curing age

4.4. Water Absorption

Water absorption of different steel slag concrete mixes with constant 0.49 w/c and different proportions of steel slag is given in *Figure 4.5* below.

The water absorption of 28th days curing for the control mix at 0.49 w/c ratio was 5.71%. It decreases to 5.15% with the accumulation of 15% Steel slag at a constant w/c ratio of 0.49. It is further decreased to 4.39% with 30% addition of Steel slag. At 45% replacement level the water absorption is also decreasing to 4.27%, but at 60% replacement level, the water absorption is observed to be increased. For the constant w/c ratio of 0.49, it is 5.17%. It is due to the presence of fewer voids in the case of concrete mixes with the increasing percentage of steel slag. The decrease in water absorption value is observed with the increasing incorporation of steel slag but, it

decreases up to 30% replacement for 3rd days of curing and up to 45% replacement for 7th and 28th days of curing. This decrease in the water absorption caused an increase in the compressive strength of concrete. This indicates that concrete having less compressive strength contains more voids, and hence, absorbs more water, hence, concrete that has higher strength absorbs less water.

According to (Dora Foti et al, 2019), The water absorption test results showed that the mean values of water absorbed by the different concrete specimens were lower for slag and fly-ashes (or micro-silica) concretes in comparison with ordinary concrete, and slag and micro-silica concrete concerning slag and fly-ashes concrete.

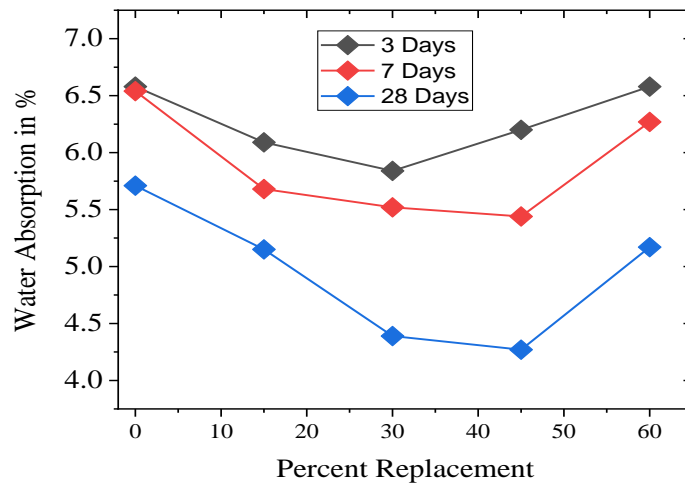


Figure 4. 5: Water absorption of steel slag concrete at different ages of curing.

4.5. Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (UPV) test was carried out as per ASTM C597-02. There are three basic ways in which the transducers may be arranged direct transmission, semi-direct transmission, and indirect transmission from these methods, From the perspective of both transit time and path length estimation, the direct approach is the most reliable. The result of the test (Direct transmission) is given in Figure 4.6. For 28th days of curing with a 0.49 w/c ratio and 0% steel slag, the UPV value is 4.69. For same w/c ratio and 15%, 30%, 45%, and 60% Steel slag the values of UPV are 4.76, 4.83, 4.80, and 4.82 km/s which shows enhancement of 1.49%, 2.99%, 2.35%, and 2.77% than the concrete having 0% steel slag respectively. The maximum value of UPV is obtained from 30% replacement of steel slag. The fibrous particles present in

steel slag helps to fill the void which decreases the time of travel of wave through the specimen increasing the velocity.

(M. Shariq et al., 2013), investigates those changes in the hardened cement paste, which is determined by the water/cement ratio, affect the UPV of concrete. The UPV moves faster through water-filled voids than through concrete with air-filled voids, as has been observed and documented. As a result, the UPV is influenced by the moistness of the concrete. The UPV test can be used to determine the strength of concrete despite these limitations.

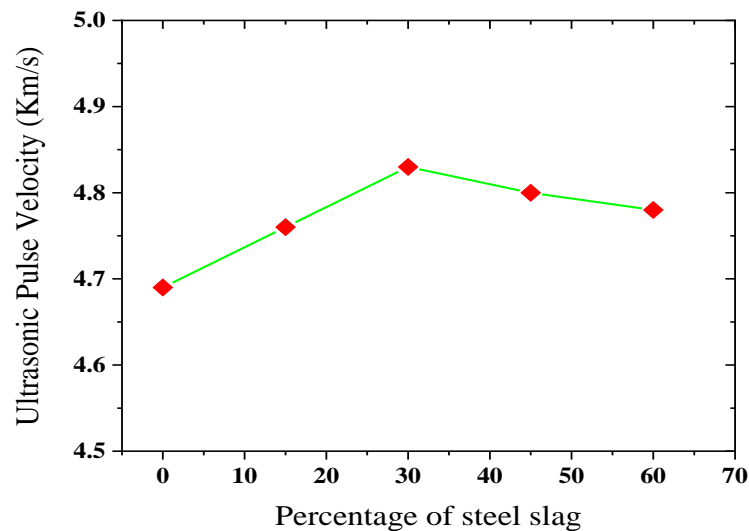


Figure 4. 6: UPV of steel slag concrete at 28th ages of curing,

4.6. Statistical Analysis

This section focuses on the statistical analysis, which was done using the laboratory test results. SPSS version 23 was used to perform a Two-Way Factorial Analysis of Variance (ANOVA) based on the dependent variable (compressive strength) and independent variables (testing age and percentage of SS replacement level).

4.6.1. Hypotheses Testing

Hypothesis testing of the variable is appropriate to support or reject the formulated hypothesis based on empirical evidence. In this study hypothesis testing was used to determine whether the independent variables are affecting the dependent variable or not. Here there are two types of hypotheses, the null (Ho) and the alternative hypothesis (Ha). In this study, the following hypotheses were made:

Null Hypothesis (Ho):

Ho: μ_1 = SS replacement doesn't affect the compressive strength of concrete.

Ho: μ_2 = The compressive strength of concrete does not affect the testing age

Ho: μ_3 = Both SS replacement and testing age doesn't affect the compressive strength of concrete.

Based on the P-value, the null hypothesis is accepted or rejected. In order to obtain p-value, utilization of probability distribution known as the F-distribution is important. The Calculations of the ANOVA F-test can be done by using statistical software (SPSS 23). The 95 percent confidence interval, i.e. significant level (α) =0.05, is used in this study to examine the factors that influence the compressive strength of concrete. If p-value > 0.05, then the null hypothesis is accepted and the variable is not significant i.e., the variable doesn't affect the compressive strength of the concrete. Whereas if P-value <0.05, then the null hypothesis is rejected and the variable is significant factor i.e. the variable is a significant factor which affects the compressive strength of the concrete.

4.6.2. Two-way ANOVA (Analysis of Variance)

The two-way ANOVA compares mean differences between groups based on two independent variables (called factors). The primary objective of a two-way ANOVA is to determine whether or not independent variables have an effect on the dependent variable. There are two independent variables (testing age and percentage of SS replacement) affecting one dependent variable (compressive strength).

The effects of independent variables can be categorized as Main effects and interaction effects. The main effect is the effects of a single independent variable on a dependent variable whereas the Interaction effect is the simultaneous effects of multiple independent variables on a dependent variable. The ANOVA test result is as shown in Table 4.1.

Table 4.1: ANOVA Test on the effects of independent variables

Source	Type III sum of squares	Df	Mean square	F	Sig
Corrected Model	5140.365 ^a	19	270.546	513.387	.000
Intercept	77286.962	1	77286.962	146659.678	.000
SS	222.079	4	55.520	105.354	.000
Age	4881.051	3	1627.017	3087.426	.000
SS * age	37.235	12	3.103	5.888	.000
Error	21.079	40	.527		
Total	82448.406	60			
Corrected total	5161.444	59			
a. R Squared = .996 (Adjusted R Squared = .994)					

As shown in Table 4.1, the main effects i.e., curing age and SS replacement level were statistically significant, since the P-values of both independent variables were less than 0.05; it shows the rejection of the null hypothesis. Therefore, the testing age and replacement of SS to the natural river sand have a statistically significant effect on the compressive strength of concrete. In addition, the interaction effect (SS*Age) was also statistically significant; because the p-value was less than 0.05, this leads to the rejection of the null hypothesis. Moreover, the compressive strength of concrete made with and without partial replacement of natural river sand with steel slag can be compared using the parametric estimate as in Table 4.2 below.

Table 4.2: Average Compressive Strength Comparison Using Parameter Estimate

Parameter	B	Std. Error	Sig.	95% confidence Interval	
				Lower Bound	Lower Bound
[100% NS control = 1]	.257	.593	.433	.667	-.941
[15% SS =2]	3.983	.593	6.720	.000	2.785
[30% SS =3]	4.443	.593	7.496	.000	3.245
[45% SS =4]	1.683	.593	2.840	.007	.485
[60% SS =5]	0 ^a
[3day]	-20.853	.593	-35.182	.000	-22.051
[7day]	-15.753	.593	-26.578	.000	-16.951
[28day]	-1.313	.593	-2.216	.032	-2.511
[56day]	0 ^a

a This parameter is set to zero because it is redundant.

From Table4.2, comparing the 60% SS with 100% control, 15% SS, 30% SS, and 45% SSSS the average compressive strength of concrete was increasing by 0.257, 3.983, 4.443, and 1.683Mpa respectively but for 60% SS the compressive strength is getting to zero, given that the other things remain constant. On the other hand, compared to the 56th day compressive strength of concrete with 3rd, 7th and 28th days, the average compressive strength of concrete decreased by 20.853, 15.753, and 1.313Mpa respectively, given that other things remain constant.

4.6.3. Post Hoc Tests

The post hoc test presents the result of the comparison between all the possible pairs between the percentages of replacement of natural river sand with SS. As Table4.4 below shows; independent factor (percentages of replacement of NS with SS) has Five categorical groups, a total of twenty pairs of comparisons are tabulated; from here twelve pairs are mirror images (100% NS control - 15% replacement and 15% replacement - 100% SS control, 100% SS control - 30% replacement and 30% replacement - 100% SS control, and the like). Tukey HSD is one of the common types of post hoc test methods and therefore used in this study.

Table 4.3: The HSD Post Hoc Results for SS Replacement

(i)% age of SS	(j)% age of SS	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval	
					Lower Bound	Lower Bound
100% NS control	15% SS	-1.6858*	.29636	.000	-2.5323	-.8394
	30% SS	-3.0442*	.29636	.000	-3.8906	-2.1977
	45% SS	-.5717	.29636	.319	-1.4181	.2748
	60% SS	2.7208*	.29636	.000	1.8744	3.5673
15% SS	100% NS	1.6858*	.29636	.000	.8394	2.5323
	30% SS	-1.3583*	.29636	.000	-2.2048	-.5119
	45% SS	1.1142*	.29636	.005	.2677	1.9606
	60% SS	4.4067*	.29636	.000	3.5602	5.2531
30% SS	100% NS	3.0442*	.29636	.000	2.1977	3.8906
	15% SS	1.3583*	.29636	.000	.5119	2.2048
	45% SS	2.4725*	.29636	.000	1.6261	3.3189
	60% SS	5.7650*	.29636	.000	4.9186	6.6114
45% SS	100% NS	.5717	.29636	.319	-.2748	1.4181
	15% SS	-1.1142*	.29636	.005	-1.9606	-.2677
	30% SS	-2.4725*	.29636	.000	-3.3189	-1.6261
	60% SS	3.2925*	.29636	.000	2.4461	4.1389
60% SS	100% NS	-2.7208*	.29636	.000	-3.5673	-1.8744
	15% SS	-4.4067*	.29636	.000	-5.2531	-3.5602
	30% SS	-5.7650*	.29636	.000	-6.6114	-4.9186
	45% SS	-3.2925*	.29636	.000	-4.1389	-2.4461

* The mean difference is significant at the .05 level.

Based on the post hoc test result of Table 4.3, the p-value of 100% NS control paired with 15% SS, 30% SS, and 60% SS; P-value of 15% SS paired with 100% NS control, 30% SS, and 60% SS; P-value of 30% SS paired with 100% NS control, 15% SS, 45% SS and 60% SS; P-value of 45% SS paired with paired with 15% SS, 30% SS and 60% SS, and also P-value of 60% SS paired with paired with 100% NS control, 15% SS, 30% SS and 45% SS

is 0.000 for all of respected paired values; in which all the P-values are less than 0.05, hence there is statistically significant difference between the paired wise comparisons.

On the other hand, the p-value of 100% SS control paired with 45% SS is 0.319, In this case the p-values are greater than 0.05, hence there is no statistically significance difference between the paired comparisons. Similarly, the same conclusion can be made based on the results of lower and upper bound value of percentage of SS replacement i.e., if the lower and upper bound have the same sign, then there is a statistically significant difference between the comparisons of variables; if it has a different sign, there is no statistically significant. In accordance with this principle, there is a statistical significance difference between 15% SS and 45% SS; hence the lower and upper bounds have the same sign (0.2677 and 1.9606 i.e., both have a positive sign).

The mean difference column shows the difference between the average compressive strength of the different categories (percentage of SS replacement level). Here, for example, we can see the mean compressive strength difference between 15% SS control and 45% SS is 1.1142; it shows that the average compressive strength of 15% SS control is greater than 45% SS replacement level by 1.1142 units because it is a positive number.

4.7. Price Analysis

The cost of Dangote OPC cement was taken based on local current market price. The cost of water and coarse aggregate was taken from the local water utility tariff and local coarse aggregate retailers' respectively. And also, the costs for the natural sand and coarse aggregate are both with transportation cost to the required place.

In the production of steel slag concrete, due to the unavailability of data required for grinding and crushing of the steel slag, only cost for transportation from Habesha steel producers was assumed. The price shown is ETB per quintal and per m³ of cement and aggregate, respectively, and the cost of the material was as recent as of January 2021. The summary of the cost analysis of steel slag concrete is shown below in *Table 4.4*.

Table 4.4: Cost Analysis of Different Steel Slag Replacement

Mix code	Description	Raw Materials (Kg/m3)				
		Cement	Water	Natural Sand	Steel Slag	Coarse aggregate
Control Mix	Quantity (Kg/m3)	386.96	188.32	764.07	-	1074.94
	Cost/Kg (ETB)	5.6	0.08	1.27	-	0.67
	Cost/m ³ (ETB)	2166.98	15.07	970.37	-	720.21
	Total Cost/m ³ (ETB)	3872.63 ETB				
	Total Cost/Kg (ETB)	3.87 ETB				
Cost saving compared to Control Mix		0%				
15% Steel Slag Concrete	Quantity (Kg/m3)	386.96	191.7	648.32	114.41	1073.26
	Cost/Kg (ETB)	5.6	0.08	1.27	0.85	0.67
	Cost/m ³ (ETB)	2166.98	15.34	823.37	97.25	719.10
	Total Cost/m ³ (ETB)	3822.04 ETB				
	Total Cost/Kg (ETB)	3.82 ETB				
Cost saving compared to Control Mix		1.32%				
30% Steel Slag Concrete	Quantity (Kg/m3)	386.96	195.04	539.77	231.33	1056.46
	Cost/Kg (ETB)	5.6	0.08	1.27	0.85	0.67
	Cost/m ³ (ETB)	2166.98	15.60	685.51	196.63	707.83
	Total Cost/m ³ (ETB)	3772.55 ETB				
	Total Cost/Kg (ETB)	3.77 ETB				
Cost saving compared to Control Mix		2.65%				
45% Steel Slag Concrete	Quantity (Kg/m3)	386.96	198.37	425.51	348.14	1048.06
	Cost/Kg (ETB)	5.6	0.08	1.27	0.85	0.67
	Cost/m ³ (ETB)	2166.98	15.87	540.40	295.92	702.20
	Total Cost/m ³ (ETB)	3726.37 ETB				
	Total Cost/Kg (ETB)	3.73 ETB				
Cost saving compared to Control Mix		3.92%				
60% Steel Slag Concrete	Quantity (Kg/m3)	386.96	201.85	389.79	468.32	1037.99
	Cost/Kg (ETB)	5.6	0.08	1.27	0.85	0.67
	Cost/m ³ (ETB)	2166.98	16.15	495.03	398.07	695.45
	Total Cost/m ³ (ETB)	3771.68 ETB				
	Total Cost/Kg (ETB)	3.77 ETB				
Cost saving compared to Control Mix		2.68%				

From Table 4.4, the cost of concrete made with the partial replacement of natural river sand with steel slag is lower than the control mix. Comparing the cost of concrete made with natural sand control with 15% Steel slag, 30% Steel slag, 45% Steel slag, and 60% Steel slag, the cost of concrete was decreased by 1.32, 2.65, 3.92, and 2.68% respectively, given that the other things (equipment cost, labor cost, and profit) remains constant.

4.8. Analysis of Exploiting Natural Materials

Concrete production consumes a massive volume of natural resources due to exploiting for production of aggregate. The partial replacements of natural river sand with steel slag can substantially reduce the exploiting of natural resources. *Table 4.2* shows the calculation of exploited natural materials.

Different assumptions were made to calculate exploiting natural material saving. These are as follows:

- Using of steel slag for preparation of steel slag aggregate is not included exploited natural material, because it is an industrial waste.
- International trade in sand and gravel is increasing due to high demand in regions lacking local sand and gravel resources, and is expected to grow at a rate of 5.5 percent per year as urbanization and infrastructure development trends continue. (United Nations, 2019).

Table 4.5: *Exploited Raw Material Analysis of Concrete*

Mix Code	Row Materials (Kg/m ³)							Exploited Material	Saving %
	Cement	Steel Slag	Water	Fine Aggregate	Coarse Aggregate	Total			
MS0	386.96	-	188.32	764.07	1074.94	2414.29	2414.29	0.00	
MS1	386.96	114.41	191.7	648.32	1073.26	2414.65	2300.24	4.97	
MS2	386.96	231.33	195.04	539.77	1056.46	2409.56	2178.23	10.62	
MS3	386.96	348.14	198.37	425.51	1048.06	2407.04	2058.90	16.91	
MS4	386.96	468.32	201.85	312.21	1037.99	2407.33	1939.01	24.15	

From *Table 4.5*, using fine steel slag as a partial replacement of natural river sand can save the exploitation of natural materials. The partial replacement of steel slag with natural river sand in concrete production in the percentage of 15%, 30%, 45%, and 60% can save 4.97%, 10.62%, 16.91% and 24.15% of the exploited natural materials respectively when compared with 100% SS control mix. Therefore, using of steel slag as a partial replacement of natural river sand in concrete production can reduce the exploitation of natural raw materials and helps to sustain natural river sand production.

CHAPTER FIVE

5.1. Conclusions and Recommendations

The general objective of this research was to study the feasibility of utilizing steel slag as a partial replacement of natural river sand fine aggregate in the production of normal strength concrete by replacing part of the natural aggregates with an aggregate produced from the steel industry (steel slag).

From the test results of the sample, as compared to the respective control concrete properties, the following conclusions and recommendations are drawn out.

5.1.1. Conclusion

The final argument found on the experimental investigation carried out by taking steel slag sand as the alternative material of fine aggregate for replacement of natural river sand can be done based on different parameter results down below.

- Steel slag from the Ethiopian Steel Factory used for the study satisfies the chemical standard requirement for partial replacement of natural river sand, and the physical property of the steel slag is comparable with that of the physical property of natural river sand to be used as a partial replacement in concrete production. Hence, the properties of a steel slag concrete aggregates line up with standards suitable for concrete production.
- Based on the initial fundamental test conducted on the fresh properties of concrete in relation to workability test, the partial replacement of steel slag concrete as natural sand achieved with, a slump of 25 to 50mm, the required workability of concrete as the ASTM standard.
- Compressive strength results on steel slag concrete showed good values in compression to the strength of the control mix. The 28 days compressive strength of concrete specimens are found to be increased with the increasing percentage of steel slag up to 45% replacement. The increased compressive strength could be due to enhancement in the formation of C-S-H gel when steel slag reacts with various hydration products. This indicates that concrete containing steel slag is following a similar trend with natural aggregate concrete.

- The sulfate resistance of steel slag concrete specimens is decreased with the addition of steel slag aggregate, it is due to the development of thaumasite at low temperatures and in the presence of soluble carbonate and reactive silicate.
- The steel slag concrete indicated less water absorption especially with 45% replacement content at 28th days of curing than the control mix with 4.27% of water absorption. The improvement of the strength of steel slag concrete could be conducted from the outcomes of nondestructive parameters of concrete. The enhancement of UPV values of concrete comprising steel slag is pragmatic in up to 30% replacement of steel slag.
- It is possible to save 146.26 Birr or 3.92% of the cost for a meter cube of concrete in Bahir Dar, Ethiopia using steel slag by replacing 45% of sand in the concrete without compromising the desired strength.

Generally, many of these inquiries were made in terms of all phases, as well as a chemical test for steel slag in Normal strength concrete. Finally, it can be claimed that steel slag sand can be used as a replacement for natural river sand. Steel slag concrete has greater strength than control mixes up to 45% replacement with the increment of 4.45%, 2.85%, and 1.44% for 7th, 28th, and 56th age of curing of control mix.

5.1.2. Recommendation

In this research, the only study of using steel slag as a replacement of natural sand on the production of normal strength concrete is investigated; therefore, further investigations are required on the following areas.

- Study on the use of steel slag with Superplasticizers by partial or full replacement with natural sand to produce normal strength concrete.
- Investigation on-resistance of concrete with steel slag aggregates to alkali-silica reactions, carbonation, seawater attack, harmful chemicals, and resistance to high temperatures are needed.
- Further study on accelerated corrosion test on steel slag concrete to check durability of concrete with steel slag aggregate are needed.

REFERENCE

- Rahmawati and Saputro. (2017). The Effects of Substitution of The Natural Sand by Steel Slag in The Properties of Eco-Friendly Concrete with The 1:2:3 Ratio Mixing Method. IOP Conference Series: Universitas Sebelas Maret, Indonesia: Materials Science and Engineering.
- Rahmawati and Saputro. (2018,). The Effects of Substitution of The Natural Sand by Steel Slag in The Properties of Eco-Friendly Concrete with the 1:2:3 Ratio Mixing Method. IOP Conf. Series: Materials Science and Engineering 333.
- Ramezaniyanpour et al. (2008). Durability of Concretes Containing Ground Granulated Blast Furnace GGBS Against Sulfate Attack. Sustainable Construction Materials and Technology.
- Abebe Dinku. (2002). Construction Laboratory Manual. Addis Ababa, Ethiopia; Addis Ababa University.
- Abebe Dinku. (2005). The Need for Standardization of Aggregates for Concrete Production in Ethiopian Construction Industry. 16.
- Aggarwal Y. et al. (2014). Microstructure and Properties of Concrete Using Bottom Ash and Waste Foundry Sand As Partial Replacement of Fine Aggregates. Construction and Building Materials. 54, pp.210–223.
- Alizadeh R et al., (1996,). Utilization of Electric Arc Furnace Slag as Aggregates in Concrete – Environmental Issue. Tehran: CMI Report.
- Al-Jabri K.S.et al. (2009). Performance of High-Strength Concrete Made With Copper Slag as a Fine Aggregate. Construction and Building Materials, 23(6), pp.2132–2140.
- Al-Negheismish et al. (1996). Utilization of Local Steel-Making Slag in Concrete. J. King Saud Univ. Eng. Sci., 9, 39-55.
- Anteneh G/Micheal. (2017). Suitability of Crushed Jema Sandstone for Concrete Production as Alternative To River Sand. Addis Ababa University Master’s Thesis, unpublished.
- Arhab Elahi, M. A. (2016). Utilization of Steel Slag In Concrete. *Islamic University of Technology*.

- Krishna Rao et al. (2015). Replacement of Natural Fine Aggregate With Air-Cooled Blast Furnace Slag an Industrial By Product. ISSN, pp.36-40.
- B.Booma Priya et al. (2016). Experimental Investigation on Concrete Using Marble Waste Powder and Steel slag. International Research Journal of Engineering and Technology (IRJET), pp.631-635.
- Beixing L. et al. (2009). Effect of Limestone Fines Content in Manufactured Sand on Durability of Low- and High-Strength Concretes. Construction and Building Materials, 23(8), pp.2846–2850., pp.2846–2850.
- Berndt ML. (2009). Properties of Sustainable Concrete Containing Fly Ash, Slag, and Recycled Concrete Aggregate. Constr Build Mater 23, pp.2606–2613.
- Binici et al. (2012). Investigation of Durability Properties of Concrete Pipes Incorporating Blast Furnace Slag and Ground Basaltic Pumice as Fine Aggregates. Sci. Iran., 19(3), pp.366-372.
- BS 812. (1990). Testing Aggregates Methods for Determination of Particle Shape; Part 105.
- CCA T60. (2008). Guide To Use Manufactured Sand Concrete. Cement Concrete & Aggregate. Australia.
- Cepuritis R. et al. (2015). 32. Cepuritisand Production With VSI Crushing and Air Classification: Optimising Fines Grading For Concrete Production With Micro-Proportioning. Minerals Engineering, 78, pp.1–14.
- Charles.Camp,. ([Online] 2014. [Cited: June, 2020]., june). Fresh Concrete Properties. Retrieved June 26, 2020, from www.ce.memphis.edu:
[http://www.ce.memphis.edu1101/notes/concrete/PCA manual/Chap05.pdf](http://www.ce.memphis.edu1101/notes/concrete/PCA%20manual/Chap05.pdf)
- Chen, W.F. and Liew, J.Y. (2003). The Civil Engineering Hand Book. Washington, D.C.: CRC Press.
- Chetan Khajuria and Rafat Siddique. (2014). Use of Iron Slag as Partial Replacement of Sand to Concrete, International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 6, pp1877-1880.
- Chow R.K.K. et al. (2013). 31. Chow, R.K.K., Yip, S.W.S. and Kwan, A.K.H., 2013. Processing Crushed Rock Fine To Produce Manufactured Sand For Improving

- Overall Performance of Concrete. HKIE Transactions Hong Kong Institution of Engineers, 20(4), pp.240–249.
- Cordeiro G.C. et al. (2016.). Rheological and Mechanical Properties of Concrete Containing Crushed Granite Fine Aggregate. *Construction and Building Materials*, 111, pp.766–773.
- Satish Kumar et al. (2016). Converting Granulated Blast Furnace Slag into Fine Aggregate. *International Journal of Civil Engineering Research*, pp. 91-103.
- Lewis. (1982). *Properties and Uses of Iron and Steel Slag*. South Africa: National Slag Association (NSA).
- Dash M.K. et al. (2016). A Review. Sustainable Use of Industrial-Waste as Partial Replacement of Fine Aggregate for Preparation of Concrete. *International Journal of Sustainable Built Environment*.
- David M. Suchorski, C. (August 2007). *Aggregates For Concrete*. American: American Concrete Institute.
- De Schepper M. et al. (2015). Use of Secondary Slags in Completely Recyclable Concrete. *J. Mater. Civ. Eng.* 27(5), pp.1–9.
- Devi S.V. and Gnanavel B.K. (2014). Properties of Concrete Manufactured Using Steel Slag. *Procedia Engineering*. 97, pp.95–104.
- Dieu, G. (2015). A Review of Use Steel Slag in Concrete Mixes For Rigid Pavement. *Internal Journal of Advance Engineering and Research Development*, pp.78–86.
- Dora Foti et al. (2019). Mechanical Characteristics and Water Absorption Properties of Blast-Furnace Slag Concretes with Fly Ashes or Microsilica Additions Applied Sciences,
- Dora Foti et al. (2019,). Mechanical Characteristics and Water Absorption Properties of Blast Furnace Slag Concrete with Fly Ashes or Micro Silica Additions. *Applied Sciences* 9, 1279; DOI:10.3390/app9071279, pp.1-9.
- Elavenil, A. W. (2019). Technical Feasibility of Sustainable Steel Slag Mixed Concrete. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, pp.883-887.
- Elavenil, S. and Vijaya, B. (2013). Manufactured Sand, A Solution and an Alternative to River sand. *Journal of Engineering, Computers*.

- Evangelista L. et al. (2015.). Physical, Chemical, and Mineralogical Properties of Fine Recycled Aggregates Made From Concrete Waste. *Construction and Building Materials*. 86, pp.178–188.
- Ferreira, V. e. (2015). Evaluation of the Steel Slag Incorporation as Coarse Aggregate For Road Construction: Technical Requirements and Environmental Impact Assessment. . *Journal of Cleaner Production*.
- Freedonia. (2014). The World Asphalt (Bitumen): Industry Study with Forecasts for 2017 & 2022. Available at: <https://www.freedoniagroup.com/industry-study/world-asphalt-bitumen-3129.htm>.
- Gaurav Desai et.al. (2018). Partial Replacement Of Fine Aggregate Using Steel slag, *International Journal of Engineering Development and Research(IJEDR)*, Volume 6, Issue 2, pp.730-732.
- Hisham Qasrawi et al. (2009,). Use of Low CaO Unprocessed Steel Slag in Concrete as Fine Aggregate. *Science Direct, Construction and Building Materials* 23, 1118-1125.
- Illnston J. and Domone P. (2002.). *Construction Materials*. 3rd Edition. New York: Spon Press.
- IS 383. (2016). Specification For Coarse and Fine Aggregates From Natural Sources For Concrete. Bureau of Indian Standards, New Delhi, India.
- Saravanan and N. Suganya. (2015). J. Saravanan and N. Suganya Mechanical Properties of Concrete Using Steel Slag Aggregate. *International Journal of Engineering Inventions*, pp.07-16.
- Jigar Patel P. (2006). Broader Use of Steel Slag Aggregates in Concrete. A thesis submitted for Masters in Civil Engineering, Fenn College of Engineering at Cleveland State University.
- Jonathan Hilburg. (2019). Concrete Production Produces Eight Percent of The World's Carbon Dioxide Emissions. [https://www.archpaper.com/2019/01/concrete-production-eight-percent-CO₂-emissions/](https://www.archpaper.com/2019/01/concrete-production-eight-percent-CO2-emissions/): Architecture, International, News, Sustainability.

- Karthik Mani, S. K. (2019). Experimental Study on Concrete as a Partial Replacement of Steel Slag as Fine Aggregate. *IJRST –International Journal for Innovative Research in Science & Technology*, Volume 5, Issue 11, pp26-31.
- Olonade et al. (2015). Performance of Steel Slag as Fine Aggregate in Structural Concrete. *Nigerian Journal of Technology (NIJOTECH)*, pp.452 – 458.
- Kamal M, Gailan AH, Haatan A, Hameed H. (2002). Aggregate Made From Industrial Unprocessed Slag. Amman, Jordan; In Proceeding of the 6th International Conference on Concrete Technology For Developing Countries, Amman, Jordan; 2002.
- Katz A. and Baum H. (2006). Effect of High Levels of Fines Content on Concrete Properties, *ACI Materials Journal*, 103(6), pp.474–482.
- Keerthi Kumar B et al. (2017). Experimental Study on Partial Replacement of Coarse Aggregate by Iron Slag in Cement Concrete (M25). *International Journal of ChemTech Research*, pp 716-724.
- Khatib, J. (2005). Properties of Concrete Incorporating Fine Recycled Aggregate. *Cement and Concrete Research*, 35(4), pp.763–769.
- Kim, H. (1999). A Study on The Characteristics of LD Slag Aggregates. *J. Rist*, 13, 285-289.
- Kou S-C, P. C.-S. (2011). Comparisons of Natural and Recycled Aggregate Concrete Prepared with The Addition of Different Mineral Admixtures. *Cem Concr Compos* 33, 788–795.
- Maslehuddin et al. (2003). Comparison of Properties of Steel Slag and Crushed Limestone Aggregate Concrete. *Construction and Building Materials* 17, 105-112.
- Shariq et al. (2013). Studies in Ultrasonic Pulse Velocity of Concrete Containing GGBFS. *Construction and Building Materials* 40, 944–950.
- Dash et al. (2016). Sustainable Use of Industrial-Waste as Partial Replacement of Fine Aggregate For Preparation of Concrete - A Review, *Int. J. Sustain. Built Environ.* 5, pp484–516. DOI:10.1016/j.ijbe.2016.04.006.
- Malathy, P. (2014). Utilization of Steel Slag in Concrete as A Partial Replacement Material for Fine Aggregate. *International Journal of Innovative Research in Science, Engineering and Technology*, 3(4), pp.11585–11592.

- Manso J, G. J. (2004). Electric Furnace Slag in Concrete. *Mater Civil Eng ASCE*, pp 639–645.
- Marck C Wayn. (1998). *Property of Freshly Mix Concrete*. Canada, Blenty Publishers.
- Maslehuddin M. et al. (2003). Comparison of Properties of Steel Slag and Crushed Limestone Aggregate Concretes. *Constr Build Material* vol. 17:, 105–12.
- Mikiyas Abayneh. (1987). *Construction Material*, Addis Ababa: Addis Ababa university press.
- Mitiku Damtie Y. (2015). *Recycled Coarse Concrete Aggregate for Structural Concrete Production: A Case Study in Bahir Dar Area*. A Thesis Submitted for Masters in Civil Engineering, Institute of Technology at Bahir Dar University.
- Mohd Nadeem, and D. Pophal. (2013). Granular Slag Potential Sustainable Material Alternative to Fine Aggregate in Construction Applications. *Gazi University Journal of Science* 26(2), 269-278.
- Nandini Suri et al. (2016,). Experimental Investigations on Partial Replacement of Steel Slag as Coarse Aggregates and Eco Sand as Fine Aggregate. *International Journal of Civil Engineering and Technology (IJCIET)*, pp. 322–328.
- Nataraja M.C. (2000). *Concrete Mix Design*. CRC Press.
- Nataraja M.C. et al. (2018,). Characterization of Crushed Fine Aggregate For Use in Concrete Based on Methylene Blue Test, *The Indian Concrete Journal*, 92 (5), pp. 18-25.
- Neville A. and Brooks J. (2002). *Concrete Technology*. 2nd Edition. UK, Longman.
- NSA. (2008). *Utilization of Steel Slag as an Aggregate in Construction*. National Slag Association.
- Nanthagopalan. et al. (2010,). Fresh and Hardened Properties of Self-Compacting Concrete Produced with Manufactured Sand. *Cement and Concrete Composites*. 33, pp.353-358.
- Kothai and Malathy. (2013). Enhancement of Concrete Properties by Steel Slag as a Partial Replacement Material for Coarse Aggregates. *Australian Journal of Basic and Applied Sciences*, pp.278-285.

- Pankaj Bhusaheb Autade. (2016). Effect of Steel Slag as a Replacement of Fine Aggregate in M40 Grade of Concrete. *International Journal of New Innovations in Engineering and Technology*, Volume 5 Issue 4, 17-26.
- Anusuya et al. (2001). Experimental Study on Concrete by Replacement of Fine Aggregate with Copper Slag, GGBS and M- sand.
- Rakesh Kumar P. et al. (2017,). Properties of Concrete Incorporating Granulated Blast Furnace Slag as Fine Aggregate. *Advances in Concrete Construction*, Vol. 5, No. 5, 437-450.
- Ramachandran VS. (1981). Waste and By-Products as Concrete Aggregates. CBD-215. NRCC: Canadian Building Digest.
- Roopa Baliga. B et.al., (2018). Effect of Partial Replacement of River Sand By Slag Sand on Workability, Compressive Strength, and Flexural Strength of M-25 Grade Concrete, *International Journal of Advances in Science Engineering and Technology*, pp128-132.
- Fennis. (2010). Design of Ecological Concrete by Particle Packing Optimization. Ministry of Infrastructure and the Environment, Netherlands: Research Gate.
- Singh et al. (2018). Agenda For Use of Alternative Sands in India. *Indian Concrete Institute Journal*. 19 (3), pp1-11.
- Samdesh Abrol et al. (2016). Effect of Steel Slag in Concrete. *International Journal of Civil Engineering (IJCE)*, Volume 3, Issue 2 (2016).
- Schneider et al. (2002). The Influence of Cement on the Sulfate Resistance of Mortar and Concrete. *Cem. Int.*1, pp 2–16.
- Shekarchi M. et al. (2003). Study on Electric Arc Furnace Slag Properties To Be Used as Aggregates in Concrete. Bucharest, Romania: In CANMET/ACI international conference on recent advances in concrete technology.
- Shen W. et al. (2016). Characterization of Manufactured Sand; Particle Shape, Surface Texture, and Behavior in Concrete. *Construction and Building Materials*, 114, pp 595–601.
- Shen W. et al. (2017,). 24. Shen, W., Liu, Y., Cao, L., Hua, X., Yang, Z., Zhou, C., He, P. and Lu, Z. 2017. Mixing Design and Microstructure of Ultra-High-Strength

- Concrete With Manufactured Sand. *Construction and Building Materials*, 143, pp.312–321.
- Shewaferaw Dinku. (2006). Thesis on The Use of Manufactured Sand in Concrete Production. Addis Ababa: Addis Ababa University.
- Sidney Mindess et al. (2003). *Concrete*, Prentice Hall.
- Singh G. and Siddique R. (2012). Abrasion Resistance and Strength Properties of Concrete Containing Waste Foundry Sand (WFS), *Construction and Building Materials*. 28, pp. 421– 426.
- Skalny J. et al. (2002). *Sulfate Attack on Concrete*. Spon Press, London.
- Solyman M. (2005.). Classification of Recycled Sands and their Applications as Fine Aggregates for Concrete and Bituminous Mixtures Klassifizierung von recycling.
- Sonja A.A.M. Fennis, Joost C. Walraven and Joop A. den Uijl . (2009). The Use of Particle Packing Models to Design Ecological Concrete. *Heron* Vol. 54, pp 185-204.
- Steven H. (2003.). Steven H., *Design and Control of Concrete Mixtures*. USA: 4thEdition, Illinois USA: Portland Cement Association.
- Steven H.Kosmatka, Beatrix Kerkhoff and William C.Panares. (2008). *Design and Control of Concrete*. United States of America: Portland Cement Association, 14th Edition.
- Sultan A. Tarawneh, E. S. (2014,). Effect of Using Steel Slag Aggregate on Mechanical Properties of Concrete. *American Journal of Applied Sciences* 11 (5), 700-706.
- Tanya Richte. (June 2013). *An Environmental Study of the Use of Steel Slag Aggregate in Gabion Cages*. Barcelona.
- Tiwari A. et al. (2016). Feasibility Assessment For Partial Replacement of Fine Aggregate to Attain Cleaner Production Perspective in Concrete: A Review. *Journal of Cleaner Production*. pp. 1-9., pp. 1-9.
- Tossavainen, Engstrom, Yang, & Menad. (2006). Characteristics of Steel Slag Under Different Cooling Conditions. In E. Y. Tossavainen, *Waste Management*.
- U.S. Department of transportation. (accessed 2020). *Steel Slag-Material Description*. Arlington, Virginia: Federal Highway Administration.

- Ulsen C. et al. (2013.). 44. Ulsen, C.,Kahn, H., Hawlitschek, G., Masini, E.A., Production of Recycled Sand From Construction and Demolition Waste, *Constr. Build. Mater.* 40, DOI:10.1016/j.conbuildmat.2012.02.004., pp.1168–1173.
- United Nations, E. P. (2019). *Sand and Sustainability: Finding New Solutions For Environmental Governance of Global Sand Resources*. Geneva, Switzerland: United Nations Environment Programme (UNEP).
- Subathra Devi and B. K. Gnanavel. (2014). Properties of Concrete Manufactured Using Steel Slag. *Science Direct*, pp.95–104.
- Vijayalakshmi M. et al. (2013). Strength and Durability Properties of Concrete Made With Granite Industry Waste. *Construction and Building Materials* 46, pp.1–7.
- Wagaman, T, and W.J.Stanley. (2005). *Slag: The Ultimate Renewable Resource*. Pit and Quarry.
- Wang J. et al. (2014.). Effects of The Lithologic Character of Manufactured Sand on Properties of Concrete. *Journal Wuhan University of Technology, Materials Science Edition*, 29(6), pp.1213–1218.
- Zhang et al. (2014). Evaluation of Relationship between Water Absorption and Durability of Concrete Materials. *Advances in Materials Science and Engineering*.
- Zhao Y. et al. (2017). Properties of Recycled Aggregate Concrete With Different Water Control Methods. *Construction and Building Materials*. 152, pp.539–546.
- Zongjin L. (2011). *Advanced Concrete Technolgy*. New Jersey: John Wiley & Sons inc.

APPENDICES

Appendix-A

Material Test

Results

A. Tests for Fine Aggregate

I. Determination of gradation and fineness modulus of fine aggregate

Objective:

This test method covers the determination of particle size distribution of coarse and all-in aggregates by sieving.

Theory:

According to ASTM C136, the term fine aggregate is used for particles smaller than 4.75mm.

Apparatus:

- Balance – Digital balance with an accuracy of 0.1gm.
- Sieves – ASTM standard sieve size 9,5mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, 75 µm (No. 4, 8, 16, 30, 50, 100 and 200).

Sampling:

The samples were prepared with the quartering method and riffle box as appropriate.

Procedure:

- The sieve and the pan were weighed and recorded after proper cleaning.
- The air-dry sample was weighed and sieved successively on the appropriate sieves starting with the largest size sieve. Care was taken to ensure that the sieves were clean before use.
- Sieving was carried out with a nest of sieves on a sieve shaker for at least 10 mins.
- The retained materials on each successive sieve were weighed together with the sieve and recorded.

Observation and Calculation:

1. Natural River sand (NRS)

Before blending: Taken sample size (3050 gm)

Table A.1: Gradation of natural sand before blending

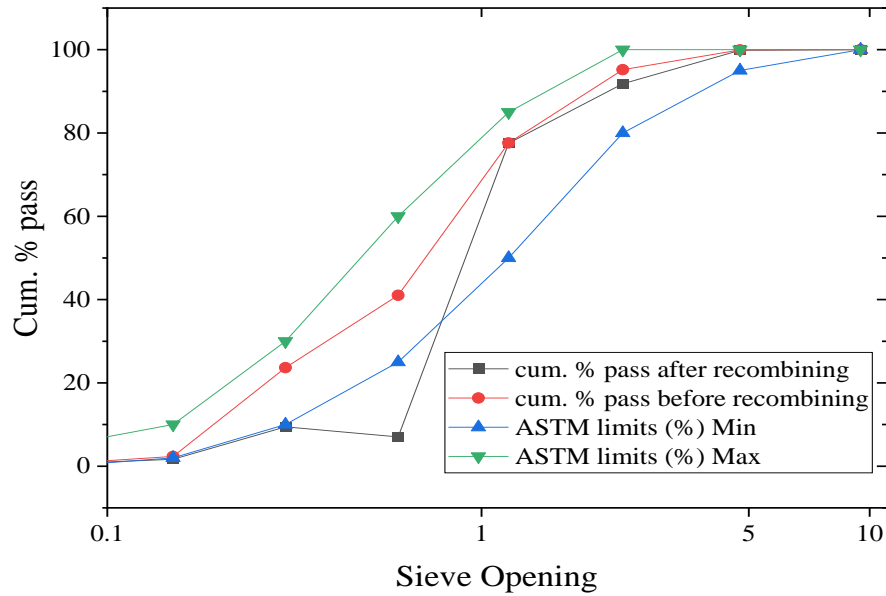
Sieve Size	Sieve Wt. (gm)	Sieve and sample wt (gm)	Wt. of sample retained (gm)	Cum. Wt. retained (gm)	Cum. % retain	Cum. % pass	ASTM Limits (%)		Remark
							Min	Max	
9.5					0	100	100	100	Ok
4.75	750	754.5	4.5	4.5	0.15	99.85	95	100	Ok
2.36	739	982.5	243.5	248	8.18	91.82	80	100	Not ok
1.18	616.5	1049	432.5	680.5	22.46	77.54	50	85	Ok
0.6	603.5	2740.5	2137	2817.5	92.97	7.03	25	60	Not ok
0.3	577	603.5	26.5	2744	90.56	9.44	10	30	Not ok
0.15	570.5	706	135.5	2979.5	98.33	1.67	2	10	Not ok
0075	539.5	572	32.5	3012	99.41	0.59	0	5	Ok
Pan	303	321	18	3030	100		-	-	
Total			3030						

After blending: Taken sample size (3050 gm)

Table A.2: Gradation of natural sand aggregate after blending

Sieve Size	Sieve Wt. (gm)	Sieve and sample wt (gm)	Wt. of sample retained (gm)	Cum. Wt. retained (gm)	Cum. % retain	Cum. % pass	ASTM limits (%)		Remark
							Min	Max	
9.5					0	100	100	100	Ok
4.75	750	751.5	1.5	1.5	0.05	99.95	95	100	Ok
2.36	739	882.5	143.5	145	4.79	95.21	80	100	Ok
1.18	616.5	1149	532.5	677.5	22.38	77.62	50	85	Ok
0.6	603.5	1711	1107.5	1785	58.97	41.03	25	60	Ok
0.3	577	1103	526	2311	76.35	23.65	10	30	Ok
0.15	570.5	1215.5	645	2956	97.65	2.35	2	10	Ok
0.075	539.5	592.5	53	3009	99.4	0.6	0	5	Ok
Pan	303	321	18	3027	0	100	-	-	
Total			3027						

Note: Standard sieve size for fineness modulus are 75.0, 37.5, 19.0, and 9.5 mm (3, 1.5, 3/4, and 3/8 in.) and 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, and 150 µm (No. 4, 8, 16, 30, 50, and 100).



$$\text{Fineness Modules (FM)} = \frac{\sum \text{cum. \% retained}}{100} = \frac{260.15}{100} = 2.6015 \approx 2.6$$

Figure A.1: Gradation curve for natural river sand before blending and after blending

b. Steel Slag fine aggregate (SSFA)

Before blending: Taken sample size is (4200gm)

Table A.3: Gradation of Steel Slag fine before blending

Sieve Size	Sieve Wt. (gm)	Sieve and sample wt (gm)	Wt. of sample retained (gm)	Cum. Wt. retained (gm)	Cum. % retain	Cum % pass	ASTM Limits (%)		Remark
							Min	Max	
9.5							100	100	
4.75	750	1136.5	386.5	386.5	7.31	92.69	95	100	Not ok
2.36	739	3150.5	2411.5	2798	52.89	47.11	80	100	Not ok
1.18	616.5	1352.5	736	3534	66.80	33.2	50	85	Not ok
0.6	603.5	1767	1163.5	4697.5	88.79	11.21	25	60	Not ok
0.3	577	6054	27	4724.5	89.30	10.7	10	30	Ok
0.15	570.5	824	253.5	4978	94.10	5.9	2	10	Ok
0075	539.5	711.5	172	5150	97.34	2.66	0	5	Ok
Pan	303	443.5	140.5	5290.5	100	0	-	-	
Total			5290.5						

After blending: Taken sample size (5300 gm)

Table A.4: Gradation of Steel Slag aggregate after blending

Sieve Size	Sieve Wt. (gm)	Sieve and sample wt(gm)	Wt. of sample retained d(gm)	Cum. Wt. retained (gm)	Cum. % retain	Cum % pass	ASTM Limits (%)		Remark
							Min	Max	
9.5	0	0	0	0	0	100	100	100	
4.75	750	828.5	78.5	78.5	1.51	98.49	95	100	ok
2.36	739	1148.5	409.5	488	9.36	90.64	80	100	Ok
1.18	616.5	2352.5	1736	2224	42.67	57.33	50	85	Ok
0.6	603.5	1663	1059.5	3283.5	62.99	37.01	25	60	Ok
0.3	577	1758	1181	4464.5	85.65	14.35	10	30	Ok
0.15	570.5	1074	503.5	4968	95.31	4.69	2	10	Ok
0.075	539.5	651.5	112	5080	96.92	2.54	0	5	Ok
Pan	303	435.5	132.5	5212.5	100	0	-	-	
Total			5212.5						

Note: Standard sieve size for fineness modulus is 75.0, 37.5, 19.0, and 9.5 mm and 4.75mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm, and 150 μm.

$$Fineness\ Modules\ (FM) = \frac{\sum cum.\% \text{ retained}}{100} = \frac{296.49}{100} = 2.9649 \approx 2.96$$

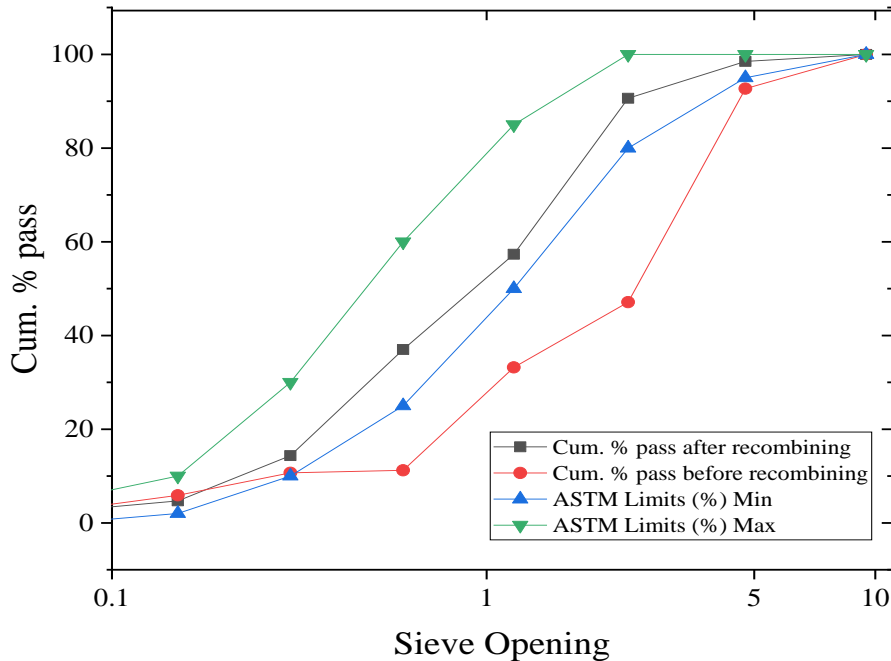


Figure A.2: Gradation curve for Steel Slag fine before blending and after blending

II. Determination of bulk unit weight of fine aggregate

Objective:

To determine the bulk density of fine aggregate.

Theory:

The bulk density or unit weight of a fine aggregate is the mass of the aggregate divided by the volume of particles and the voids between particles. It is measured by weighing a container of known volume filled with aggregate. The mass of the container is subtracted to give the mass of the aggregate, and the bulk density is the aggregate mass divided by the volume of the container. The value will depend on the grading, which will govern how well the particles fit together, and on how well the aggregate is compacted.

The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and voids between them. Since the weight of the aggregate is dependent on the moisture content of the aggregate, the constant moisture content is required.

Apparatus:

- Cylindrical metal container of known volume
- Balance with an accuracy of 0.1gm and adequate capacity

Procedure:

First, measure the weight of an empty container having a volume of 0.003m³. Then, the container is filled in three layers, each layer being tamped with 25 blows with a standard tamping rod. Finally, the excess layer is trimmed off and weighed.

Observation and Calculation:

A. Natural sand

Weight of container (A) = 2960.5g

Wt of container and Wt of Aggregate (B) = 8705.5

Mass of fine aggregate = B – A = 8705.5g - 2960.5g = **5745g**

Volume of container = 0.003m³

$$\text{Bulk unit weight} = \frac{\text{mass of fine aggregate}}{\text{Volume of container}}$$

$$\text{Bulk unit weight} = \frac{5.745\text{Kg}}{0.003\text{m}^3} = \mathbf{1915\text{Kg/m}^3}$$

A. Steel Slag Fine

Weight of container (A) = 2960.5g

Wt of container and Wt of Aggregate (B) = 7611.5g

Mass of fine aggregate = B – A = 4651g

The volume of container =

$$\text{Bulk unit weight} = \frac{\text{mass of fine aggregate}}{\text{Volume of container}}$$

$$\begin{aligned} \text{Bulk unit weight} &= \frac{4.651\text{kg}}{0.003\text{m}^3} \\ &= \mathbf{1550.34\text{Kg/m}^3} \end{aligned}$$

III. Determination of specific gravity of fine aggregate

Objective:

To determine the bulk and apparent specific gravity of fine aggregates.

Theory:

The specific gravity of a substance is the ratio of the mass (or weight) in the air of a unit volume of the material to the mass of the same volume of water at a stated temperature. Values are dimensionless.

Bulk specific gravity (at Saturated-surface-dry) – Is the ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 24 hrs. (But not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

Apparatus:

- **Balance** - A device for determining mass; that is sensitive, readable, and has an accuracy of 0.1gm.
- **Water tank** - A watertight tank in which the sample container may be placed while suspended underneath the balance.
- **Pycnometer** - a flask or another suitable container into which the fine aggregate test sample can readily be placed.

- **Mold** - a metallic apparatus in the form of a frustum of a cone 38mm in top diameter, 89mm in bottom diameter, and 74mm in height with the metal having a minimum thickness of about 0.9mm.
- **Tamper** - a metal tamper weighing 340 ± 15 g and having a flat circular face 25 ± 3 mm in diameter.

Preparation of test sample:

The test sample was obtained by use of sample splitter (riffle box) and quartering method as appropriate. Using a suitable pan, the sample was dried in an oven. Then the dried sample was covered with water for about 15 hrs. after cooling. After the sample approaches to free-flowing condition, it was spread on a flat surface and was exposed to gently moving warm air. Next, the partially dried sample was placed loosely into the mold and tamped 25 times with a tamper. Finally, the mold was lifted vertically. The drying process was repeated until the sample partially flows when the mold is lifted vertically. This indicates that the sample has reached a surface dry condition.

Procedure:

- i. 250 g of fine aggregate sample was added to the pycnometer and filled with water to approximately 90% of its capacity.
- ii. To eliminate all air bubbles, the pycnometer was rolled, inverted, and agitated. Finally, the level of water was brought to the calibrated capacity of the pycnometer.
- iii. Then the total weight of the pycnometer, the sample, and water was determined and recorded.
- iv. The fine aggregate was removed from the pycnometer; dried in an oven, cooled at room temperature for about an hour, and then weighed.

Observation and Calculation:**Observation sheet**

Table 18: Specific Gravity of fine aggregate

	Description	Natural Sand (NS)		Steel Slag (SS)	
A	Weight of empty pycnometer “W ₁ ” (g)	460	462.5	462.5	464
B	Weight of pycnometer + Sample “W ₂ ” (g)	1258	1298.5	1049	944
C	Wt of pycnometer + Aggregate + water “W ₃ ” (g)	2104	2140	1965	1896.5
D	Wt of pycnometer + water “W ₄ ” (g)	1598	1604.5	1601	1599
E	Specific gravity $= \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.7328	2.7820	2.6360	2.6301
	Average	2.7574 ≈ 2.76		2.6331 ≈ 2.63	

Conclusion and Recommendation:

The specific gravity of suitable fine aggregates varies from 2.6 to 2.8. Hence the sample having a bulk specific gravity of 2.76 and 2.63 for natural sand and steel slag respectively, is suitable for concrete.

IV. Determination of absorption capacity of fine aggregate**Objective:**

To determine the absorption capacity of fine aggregates.

Theory:

Absorption is a measure of the total pore volume accessible to water. To calculate the mixing water content of concrete, the absorption of the aggregates and their total moisture content must be known. Absorption is computed as a percentage by subtracting the oven-dry mass from the saturated-surface-dry mass, dividing by the oven-dry mass, and multiplying by 100. In concrete technology, aggregate moisture is expressed as a percentage of the dry weight of the aggregate.

Apparatus:

- Balance- A weighing device that is sensitive, readable, and with an accuracy of 0.1gm.
- Sample container-Metallic pan
- Oven

Sampling:

A portion of fine aggregate from the sample mass was obtained using a sample splitter.

Procedure:

1. Soak the sample of sand, which is obtained by using a sample splitter for 24 hrs. in water.
2. Weigh the sand at SSD condition.
3. After weighing, dry it in an oven at a temperature of 105-115°C for 24 hrs.
4. Finally, take out the sample from the oven and cool it at room temperature until it was comfortable to handle and then weighed.

Test Results:

A= Weight of the SSD sample in air = 600g

B= Weight of the oven-dried sample in air = 588.93g

Calculation:

$$\text{Absorption, \%} = \frac{A - B}{B} * 100\%$$

A. For natural sand

A= Weight of the SSD sample in air = 501.5g

B= Weight of the oven-dried sample in air = 496.5g

$$\text{Absorption, \%} = \frac{501.5 - 496.5}{496.5} * 100\% = 1.007\%$$

B. For steel slag

A= Weight of the SSD sample in air = 503.5g

B= Weight of the oven-dried sample in air = 485.5g

$$\text{Absorption, \%} = \frac{503.5 - 485.5}{485.5} * 100\% = 3.7075\%$$

V. Determination of moisture content of fine aggregate

Objective:

The objective of this test is to determine the moisture content of fine aggregate.

Theory:

Moisture content is the total amount of water present in the aggregate; i.e., both internally (inside the pores) and externally at the surface. Corrections are needed to compensate for the moisture in aggregates. In practice, aggregates contain some measurable amount of moisture. The dry-batch weights of aggregates, therefore, have to be increased to compensate for the moisture that is absorbed in and contained on the surface of each particle and between particles. The mixing water added to the batch must be reduced by the amount of free moisture contributed by the aggregates. The free moisture content can be calculated as the difference between the total moisture content and absorption. The value can either be positive or negative.

Apparatus:

- Balance
- Dish
- Oven

Procedure:

1. A sample of fine aggregate from the sample splitter was taken and weighed.
2. The sample was then oven-dried for 24 hrs. at a temperature of 105⁰C – 110⁰C.
3. After 24 hrs. of drying the samples were removed from the oven and cooled for about an hour (without absorbing water from the atmosphere).
4. Then the oven-dried aggregate was weighed after cooling.

Test Results:

i. Natural Sand (NS)

A = weight of original sample = 658g

B = weight of oven-dry sample = 647g

Calculation:

$$\text{Moisture Content, \%} = \frac{(A - B)}{B} * 100\%$$

$$\text{Moisture Content, \%} = \frac{(658 - 647)}{647} * 100\% = 1.7\%$$

ii. Steel Slag Fine (SSF)

A = weight of original sample = 503.5g

B = weight of oven dry sample = 496.5g

Calculation:

$$\text{Moisture Content, \%} = \frac{(A - B)}{B} * 100\%$$

$$\text{Moisture Content, \%} = \frac{(503.5 - 496.5)}{496.5} * 100\% = 1.409 = 1.41\%$$

VI. Determination of impurities (mainly silt and clay) of fine aggregate

Objective:

To determine the impurities (mainly silt and clay) of a fine aggregate sample.

Theory:

It is important to use clean aggregate for concrete. If the aggregates are coated with dirt, silt, or clay, it will result in poor concrete; because the dirt will prevent the cement from setting and also weaken the bond between the aggregates and the cement paste. In the field vision test, simply picking up a little sample of sand and rubbing it between hands will show the impurities (mainly silt and clay) somehow. If the palm stays clean, the sand is alright from the cleanliness point of view. If it is stained, something is wrong and an impurity test must be performed.

Apparatus:

- Funnel
- Glass jar
- Clean water
- Small size spoon

Procedure:

- Take a graduated cylinder or jar having a capacity greater than 100ml
- Pour in the sand to the cylinder.
- Fill approximately 3/4th of the cylinder with water.
- Shake the cylinder vigorously for about a minute.

- Leave the cylinder for about an hour to allow the impurity to settle on top of the sand.
- Measure the number of fines forming a separate layer on the top of the washed sand.

Test Results:

A = amount of impurity deposited above the sand = 25ml

B = amount of clean sand = 65ml

Calculation:

$$\text{Silt Content, \%} = \frac{A}{A + B} * 100\%$$

$$\begin{aligned} \text{Silt Content, \%} &= \frac{25}{65 + 25} * 100\% \\ &= \underline{\underline{27.77 \approx 27.8}} \end{aligned}$$

Conclusion and Recommendation:

ASTM C 33, "Concrete Aggregates," limits the percentage of material finer than a 75µm (No. 200) sieve to, 5% for fine aggregate used in any other concrete. Beyond this limit, the sand should be washed before using for concrete making. The sample is natural sand and the content of impurity is 27.8%. Therefore, it should be washed (the result is beyond 5%) before use.

B. Tests for Coarse Aggregate

I. Determination of gradation of coarse aggregate

Objective:

This test method covers the determination of particle size distribution of coarse aggregates by the sieve analysis method.

Theory:

According to ASTM C136, the term coarse aggregate is used to describe particles larger than 4.75 mm (retained on No. 4 sieve).

Apparatus:

- Balance – Digital balance with an accuracy of 0.1gm.
- Sieves – ASTM standard sieve size of 37.5 mm, 22.5 mm, 19.0 mm, and 9.5 mm; 4.75 mm, 2.36 mm and pan.

Sampling:

The samples of 5100 gm were prepared with the quartering method and riffle box as appropriate.

Procedure:

- The sieves and the pan were weighed and recorded after proper cleaning.
- The air-dry sample was weighed and sieved successively on the appropriate sieves starting with the largest size sieve. Care was taken to ensure that the sieves were clean before use.
- Sieving was carried out with a nest of sieves on a sieve shaker for at least 10 mins.
- The retained materials on each successive sieve were weighed together with the sieve and recorded

Observation and Calculation:**Before Blending:**

Table B.1: Gradation of coarse aggregate before blending

Sieve Size	Sieve Wt. (gm)	Sieve and sample wt (gm)	Wt. of sample retained (gm)	Cum. Wt. retained (gm)	Cum. % retain	Cum. % pass	ASTM limits (%)		Remark
							Min	Max	
37.5	713.5	0	0	0	0	100	100	100	Ok
25	710	0	0	0	0	100	95	100	Ok
19	713	860	147	147	4.72	95.28	40	85	Not ok
12.5	661	2009	1348	1495	45.48	54.52	10	40	Not ok
9.5	684	2245	1561	3056	92.97	7.03	0	15	Ok
4.75	748.5	937.5	189	3245	98.72	1.28	0	5	Ok
Pan	303	347	42	3287	100	0	-	-	
Total			3287						

After Blending

Table B.2: Gradation of coarse aggregate after blending

Sieve Size	Sieve Wt. (gm)	Sieve and sample wt (gm)	Wt. of sample retained (gm)	Cum. Wt. retained (gm)	Cum. % retain	Cum. % pass	ASTM Limits (%)		Remark
							Min	Max	
37.5	713.5	713.5	0	0	0	100	100	100	ok
25	710	710	0	0	0	100	95	100	Ok
19	713	1205.5	492.5	492.5	15.15	84.85	40	85	Ok
12.5	661	2193	1532	2024.5	62.29	37.71	10	40	Ok
9.5	684	1524.5	840.5	2865	88.15	11.85	0	15	Ok
4.75	748.5	1108	359.5	3224.5	99.22	0.78	0	5	Ok
Pan	303	328.5	25.5	3250	100	0	-	-	
Total			3250						

$$\text{Fineness Modules (FM)} = \frac{\sum \text{cum. \% retained}}{100} = \frac{264.78}{100} = 2.6478$$

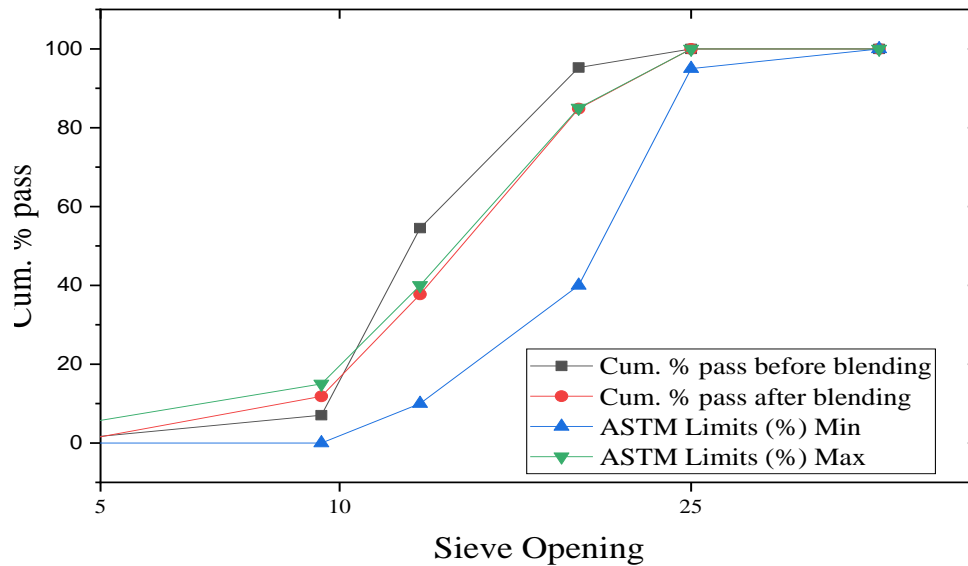


Figure B.1: Gradation curve for Coarse Aggregate before blending and after blending

II. Determination of bulk unit weight of coarse aggregate

Objective:

This test method covers the determination of the compact weight of coarse aggregate.

Theory:

Unit weight can be defined as the weight of a given volume of graded aggregate. It is a density measurement and is also known as bulk density. It includes the aggregates and the void between them.

Apparatus:

- Balance
- Tamping rod
- Cylindrical metal container with a capacity of 0.01m³

Procedure:

First, fill the container about one-third full with the thoroughly mixed coarse aggregate utilizing a shovel.

Then, compact it with a tamping rod (25 times), each blow being given by allowing the tamping rod to fall freely from a height of 50 mm above the surface of the aggregate; the blows being evenly distributed over the surface. Then add a further similar quantity of aggregate in the same manner and give the same number of blows.

Finally, fill the container to overflowing, tamp it again with the same number of blows, and remove the surplus aggregate by rolling the tamping rod across and in contact with the top of the container; any aggregate which impedes its progress being removed by hand, and add the aggregate to fill any obvious depressions. Then, determined the mass of the aggregate in the container.

Calculation and Observation:

The following data are the results of the test.

a) Trial one

Description	Density	Weight in kg
Weight of container, Kg	A	4.8805
Weight of aggregate plus container, Kg	B	16.773
Volume of the container, m ³	C	0.007

For trail (a)

$$\text{Bulk unit weight} = \frac{(B - A)}{C}$$

Where: A= Weight of container

B= Weight of aggregate plus container

C= volume of container

For normal strength concrete,

$$\text{Bulk unit weight} = \frac{(16.773 - 4.8805)}{0.007} = 1699 \text{Kg/m}^3$$

b) Trial two

Description	Den. ¹	Weight in kg
Weight of container, Kg	A	4.8805
Weight of aggregate plus container, Kg	B	16.235
Volume of the container, m ³	C	0.007

For trail (b)

$$\text{Bulk unit weight} = \frac{(16.235 - 4.8805)}{0.007} = 1622.07 \text{Kg/m}^3$$

Take the average of the two

$$\text{Bulk unit weight} = \frac{1699 + 1622.07}{2} = 1660 \text{Kg/m}^3$$

III.Determination of specific gravity and absorption capacity of coarse aggregate

Objective:

This test method covers the determination of specific gravity and absorption capacity of coarse aggregate. The specific gravity may be expressed as bulk specific gravity or apparent specific gravity.

Theory:

- **Absorption-** the increase in the weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry weight.
- **Specific gravity-** the ratio of the mass (or weight in air) of a unit volume of material of the mass of the same volume of water at a stated temperature.

- **Apparent specific gravity**- the ratio of the weight in air of unit volume of the impermeable portion of the aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.
- **Bulk specific gravity (at Saturated-Surface-Dry)**- the ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 24 hrs. (but not including the voids between particles) at a stated temperature; compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.
- **Bulk specific gravity**- the ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight in air of equal volume of gas-free distilled water at a stated temperature. For mix design, this parameter is used.

Apparatus:

- **Balance** - A weighing device that is sensitive, readable, and with an accuracy of 0.1gm.
- **Sample Container** - A wire basket of 3.35mm or finer mesh, or a bucket of approximately equal breadth and height.
- **Water Tank** - A watertight tank in which the sample container may be placed while suspended underneath the balance.

Procedure:

- The sample is soaked in water for 24hrs.
- The test sample was removed from the water and rolled in a large absorbent cloth until all visible films of water were removed. The larger particles were wiped individually. To avoid evaporation of water from aggregate pores during the surface dry operation the sample was covered. The test sample was in the saturated surface dry (SSD) condition and the weight was recorded to the nearest 0.1gm.
- A wire mesh basket, which is hanged from the balance, was immersed in the container and the weight was tarred.

- Then, immediately the SSD test sample was put in the basket and immersed in the container and the weight is recorded at room temperature.
- The test sample was dried to a constant temperature of 110°C for 24hrs and cooled until the aggregate is cool enough to handle and weigh.

Calculations and Observations:

The following data were found from the test.

Description	Den. ¹	Weight in kg
Weight of oven-dry sample in air	A	1986
Weight of saturated-surface dry sample in air	B	2016
Weight of saturated-surface dry sample in water	C	1265.5

Bulk specific gravity for saturated surface dry is calculated as:

$$\text{Bulk Sp. Gr. (SSD)} = \frac{B}{(B - C)}$$

$$\text{Specific Gr. (SSD)} = \frac{A}{(B - C)}$$

$$\text{Apparent Sp. Gr. (SSD)} = \frac{A}{(A - C)}$$

$$\text{Absorption, \%} = \frac{(B - A)}{A} * 100\%$$

Where: A= Weight in gm of oven-dry sample in air

B= Weight in gm of saturated-surface-dry sample in air

C= Weight in gm of saturated-surface-dry sample in water

For normal concrete,

$$\text{Bulk Sp. Gr. (SSD)} = \frac{2016}{(2016 - 1265.5)} = \mathbf{2.69}$$

$$\text{Specific Gr. (SSD)} = \frac{1986}{(2016 - 1265.5)} = \mathbf{2.65}$$

$$\text{Apparent Sp. Gr. (SSD)} = \frac{1986}{(1986 - 1265.5)} = \mathbf{2.76}$$

$$\text{Absorption, \%} = \frac{(2016 - 1986)}{1986} * 100\% = \mathbf{1.51\%}$$

Conclusion and Recommendation:

The relative density range is 2.30 to 2.90 and the absorption is 0.5% to 4%. The sample absorption and relative density are all within the range and can be used for concrete.

IV. Determination of moisture content of coarse aggregate

Objective:

This method covers the determination of moisture content of coarse aggregate by an oven-dry method. This method is sufficiently accurate for a usual purpose such as for adjusting batch weights of concrete.

Definition:

Moisture content is the total amount of water present in the aggregate; i.e., both internally (inside the pores) and externally at the surface.

Apparatus:

- Balance of suitable capacity, readable with an accuracy of 0.1 gm.
- Container
- Oven-well ventilated, thermostatically controlled to maintain a temperature of $105 \pm 5^\circ\text{C}$.
- Metal tray for use in quartering and riffle box.

Procedure:

- First, clean the container, dry, weigh and tare it. Weigh the collected wet sample and denote it as A.
- Place the container with the test specimen in the oven and leave it to dry at a temperature of 110°C . Also, maintain this temperature until the test specimen has reached a constant mass for 24hrs.
- Remove the container and test specimen from the oven and allow it to cool until it is possible to handle and weigh; after which, weigh the sample on another tarred container and denote as B.

Observation and Calculation:

The following data were found from the test.

Description	Den. ¹	Weight in kg
Weight of wet sample (tarred)	A	2016
Weight of the oven-dried sample (tarred)	B	1992.5

The moisture content as a percentage of the dry mass can be calculated from the following equation.

$$\text{Moisture Content, \%} = \frac{(A - B)}{B} * 100\%$$

Where: A= Weight of wet sample excluding container

B= Weight of oven-dry sample excluding container

$$\text{Moisture Content, \%} = \frac{(2016 - 1992.5)}{1992.5} * 100\% = 1.18\%$$

Appendix-B

Mix Design

Calculations

Concrete Mixture Proportion

I. Natural Sand (100%)

The mix design for C-25 non-air entrained normal strength concrete is done as per ACI 211.1.

The data from test results, which are important for mix design, are:

- ❖ Properties of coarse aggregate from the test results in Appendix A.
 - Nominal maximum size = 19mm
 - Unit weight = 1660
 - Specific gravity = 2.69
 - Absorption = 1.51
 - Moisture content = 1.18
- ❖ Properties of fine aggregate from the test results in Appendix A.
 - Unit weight = 1915
 - Fineness modulus = 2.6
 - Specific gravity = 2.76
 - Absorption = 1.01
 - Moisture content = 1.7

Step 1: Slump

A range of 25 - 50mm (minimum slump possible) is selected.

Step 2: Maximum size of aggregate

The nominal maximum size is fixed to be 19 mm.

Step 3: Target mean strength calculation

Table1: Required Average Compressive Strength when data are not available to establish a sample Standard Deviation.

Specified Compressive Strength (N/mm ²)	Required Average Compressive Strength (N/mm ²).
$f'_c < 21$	$f'_{cr} = f'_c + 7$
$21 \leq f'_c < 35$	$f'_{cr} = f'_c + 8.5$
$f'_c > 35$	$f'_{cr} = f'_c + 5$

According to Table1 above, the required compressive strength (mean strength) at 28-days age is,

$$f'_{cr} = 25 + 8.5 = 33.5 \text{ N/mm}^2.$$

Step 4: W/C ratio

For 30MPa W/C ratio is 0.54 and for 35 MPa W/C ratio is 0.47. The W/C ratio for 33.5 MPa can be found by interpolation as follows:

$$\frac{W}{C} = \frac{35 - 30}{0.47 - 0.54} (33.5 - 30) + 0.54 = \mathbf{0.49}$$

Step 5: Mixing water amount

For a nominal maximum size of aggregate of 19 mm, slump 25 to 50mm (minimum range) and non-air entrained concrete the mixing water requirement is;

$$\text{Mixing water} = 190\text{kg/m}^3 \quad \text{and} \quad \text{Entrapped air} = 2\%$$

Step 6: Cement Amount

$$\text{Cement content} = \frac{190\text{kg/m}^3}{0.49} = 386.96\text{kg/m}^3$$

Step 7: Coarse aggregate amount

For nominal maximum size aggregate of 19 mm and sand fineness modulus of 2.6, the dry bulk volume can be obtained directly as 0.64

$$\text{Coarse aggregate amount} = 0.64 * 1660 = 1062.4\text{kg/m}^3$$

Step 8: Fine aggregate amount

$$\text{Fine aggregate} = 2.76 * \left[1000 - \left(190 + \frac{386.96}{3.15} + \frac{1062.4}{2.69} + 20 \right) \right] = \mathbf{751.3 \text{ kg/m}^3}$$

Step 9: Moisture correction

	Cement Kg/m ³	Water (kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)
Per m ³	386.96	190	751.3	1062.4
Free moisture %	-	-	1.7-1.01=0.69	1.18-1.51= -0.33
Adjustment	-	-1.68	5.18	-3.5
Adjusted per m ³	386.96	188.32	751.3*1.017=764.07	1062.4*1.0118=1074.94

II. 15% SS + 85% NS

The mix design for C-25 non-air entrained normal strength concrete is done as per ACI 211.1.

The data from test results, which are important for mix design, are:

- ❖ Properties of coarse aggregate from the test results in Appendix A.
 - Nominal maximum size =19mm
 - Unit weight = 1660
 - Specific gravity = 2.69
 - Absorption = 1.51
 - Moisture content = 1.18
- ❖ Properties of fine aggregate from the test results in Appendix A.
 - Unit weight = 1860.3
 - Fineness modulus = 2.61

- Specific gravity = 2.75
- Absorption = 1.42
- Moisture content = 1.66

Step 1: Slump

A range of 25 - 50mm (minimum slump possible) is selected.

Step 2: Maximum size of aggregate

The nominal maximum size is fixed to be 19 mm.

Step 3: Target mean strength calculation

Table1: Required Average Compressive Strength when data are not available to establish a sample Standard Deviation.

Specified Compressive Strength (N/mm ²)	Required Average Compressive Strength (N/mm ²).
$f'_c < 21$	$f'_{cr} = f'_c + 7$
$21 \leq f'_c < 35$	$f'_{cr} = f'_c + 8.5$
$f'_c > 35$	$f'_{cr} = f'_c + 5$

According to Table1 above, the required compressive strength (mean strength) at 28-days age is,
 $f'_{cr} = 25 + 8.5 = 33.5$ N/mm².

Step 4: W/C ratio

For 30MPa W/C ratio is 0.54 and for 35 MPa W/C ratio is 0.47. The W/C ratio for 33.5 MPa can be found by interpolation as follows:

$$\frac{W}{C} = \frac{35 - 30}{0.47 - 0.54} (33.5 - 30) + 0.54 = \mathbf{0.49}$$

Step 5: Mixing water amount

For a nominal maximum size of aggregate of 19 mm, slump 25 to 50mm (minimum range) and non-air entrained concrete the mixing water requirement is;

$$\text{Mixing water} = 190\text{kg/m}^3 \quad \text{and} \quad \text{Entrapped air} = 2\%$$

Step 6: Cement Amount

$$\text{Cement content} = \frac{190\text{kg/m}^3}{0.49} = 386.96\text{kg/m}^3$$

Step 7: Coarse aggregate amount

For nominal maximum size aggregate of 19 mm and sand fineness modulus of 2.61, the dry bulk volume can be interpolated between fineness modulus of 2.6 and 2.8 as:

$$\begin{pmatrix} 2.6 & 0.64 \\ 2.61 & X \\ 2.8 & 0.62 \end{pmatrix} =$$

$$\text{Dry bulk volume} = \frac{0.64 - 0.62}{2.6 - 2.8} (2.61 - 2.8) + 0.62 = 0.639$$

$$\text{Coarse aggregate amount} = 0.639 * 1660 = 1060.74 \text{kg/m}^3$$

Step 8: Fine aggregate amount

$$\text{Fine aggregate} = 2.75 * [1000 - (190 + \frac{386.96}{3.15} + \frac{1060.74}{2.69} + 20)] = 750.28 \text{kg/m}^3$$

Step 9: Moisture correction

	Cement Kg/m ³	Water (kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)
Per m ³	386.96	190	750.28	1060.74
Free moisture %	-	-	1.66-1.42= 0.24	1.18-1.51= -0.33
Adjustment	-	1.7	1.8	-3.5
Adjusted per m ³	386.96	191.7	750.28*1.0166= 762.73	1060.74*1.0118= 1073.26

III. 30% SS+ 70% NS

The mix design for C-25 non-air entrained normal strength concrete is done as per ACI 211.1.

The data from test results, which are important for mix design, are:

- ❖ Properties of coarse aggregate from the test results in Appendix A.
 - Nominal maximum size =19mm
 - Unit weight = 1660
 - Specific gravity = 2.69
 - Absorption = 1.51
 - Moisture content = 1.18
- ❖ Properties of fine aggregate from the test results in Appendix A.
 - Unit weight = 1805.6
 - Fineness modulus = 2.71
 - Specific gravity = 2.72
 - Absorption = 1.82
 - Moisture content = 1.61

Step 1: Slump

A range of 25 - 50mm (minimum slump possible) is selected.

Step 2: Maximum size of aggregate

The nominal maximum size is fixed to be 19 mm.

Step 3: Target mean strength calculation

Table1: Required Average Compressive Strength when data are not available to establish a sample Standard Deviation.

Specified Compressive Strength (N/mm ²)	Required Average Compressive Strength (N/mm ²).
$f'_c < 21$	$f'_{cr} = f'_c + 7$
$21 \leq f'_c < 35$	$f'_{cr} = f'_c + 8.5$
$f'_c > 35$	$f'_{cr} = f'_c + 5$

According to Table1 above, the required compressive strength (mean strength) at 28-days age is,

$$f'_{cr} = 25 + 8.5 = 33.5 \text{ N/mm}^2.$$

Step 4: W/C ratio

For 30MPa W/C ratio is 0.54 and for 35 MPa W/C ratio is 0.47. The W/C ratio for 33.5 MPa can be found by interpolation as follows:

$$\frac{W}{C} = \frac{35 - 30}{0.47 - 0.54} (33.5 - 30) + 0.54 = \mathbf{0.49}$$

Step 5: Mixing water amount

For a nominal maximum size of aggregate of 19 mm, slump 25 to 50mm (minimum range) and non-air entrained concrete the mixing water requirement is;

$$\text{Mixing water} = 190 \text{ kg/m}^3 \quad \text{and} \quad \text{Entrapped air} = 2\%$$

Step 6: Cement Amount

$$\text{Cement content} = \frac{190 \text{ kg/m}^3}{0.49} = 386.96 \text{ kg/m}^3$$

Step 7: Coarse aggregate amount

For nominal maximum size aggregate of 19 mm and sand fineness modulus of 2.71, the dry bulk volume can be interpolated between fineness modulus of 2.6 and 2.8 as:

$$\begin{pmatrix} 2.6 & 0.64 \\ 2.71 & X \\ 2.8 & 0.62 \end{pmatrix} =$$

$$\text{Dry bulk volume} = \frac{0.62 - 0.64}{2.8 - 2.6} (2.71 - 2.8) + 0.62 = 0.629$$

$$\text{Coarse aggregate amount} = 0.629 * 1660 = 1044.14 \text{ kg/m}^3$$

Step 8: Fine aggregate amount

$$\text{Fine aggregate} = 2.72 * \left[1000 - \left(190 + \frac{386.96}{3.15} + \frac{1044.14}{2.69} + 20 \right) \right] = \mathbf{758.88 \text{ kg/m}^3}$$

Step 9: Moisture correction

	Cement Kg/m ³	Water (kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)
Per m ³	386.96	190	758.88	1044.14
Free moisture %	-	-	1.61-1.82= -0.21	1.18-1.51= -0.33
Adjustment	-	5.04	-1.59	-3.45
Adjusted per m ³	386.96	195.04	758.88*1.0161= 771.1	1044.14*1.0118= 1056.46

IV. 45% SS+ 55% NS

The mix design for C-25 non-air entrained normal strength concrete is done as per ACI 211.1.

The data from test results, which are important for mix design, are:

- ❖ Properties of coarse aggregate from the test results in Appendix A.
 - Nominal maximum size =19mm
 - Unit weight = 1660
 - Specific gravity = 2.69
 - Absorption = 1.51
 - Moisture content = 1.18
- ❖ Properties of fine aggregate from the test results in Appendix A.
 - Unit weight = 1753.9
 - Fineness modulus =2.76
 - Specific gravity = 2.7
 - Absorption = 2.23
 - Moisture content = 1.58

Step 1: Slump

A range of 25 - 50mm (minimum slump possible) is selected.

Step 2: Maximum size of aggregate

The nominal maximum size is fixed to be 19 mm.

Step 3: Target mean strength calculation

Table1: Required Average Compressive Strength when data are not available to establish a sample Standard Deviation.

Specified Compressive Strength (N/mm ²)	Required Average Compressive Strength (N/mm ²).
$f'_c < 21$	$f'_{cr} = f'_c + 7$
$21 \leq f'_c < 35$	$f'_{cr} = f'_c + 8.5$
$f'_c > 35$	$f'_{cr} = f'_c + 5$

According to Table1 above, the required compressive strength (mean strength) at 28-days age is,

$$f'_{cr} = 25 + 8.5 = 33.5 \text{ N/mm}^2.$$

Step 4: W/C ratio

For 30MPa W/C ratio is 0.54 and for 35 MPa W/C ratio is 0.47. The W/C ratio for 33.5 MPa can be found by interpolation as follows:

$$\frac{W}{C} = \frac{35 - 30}{0.47 - 0.54} (33.5 - 30) + 0.54 = \mathbf{0.49}$$

Step 5: Mixing water amount

For a nominal maximum size of aggregate of 19 mm, slump 25 to 50mm (minimum range) and non-air entrained concrete the mixing water requirement is;

$$\text{Mixing water} = 190\text{kg/m}^3 \quad \text{and} \quad \text{Entrapped air} = 2\%$$

Step 6: Cement Amount

$$\text{Cement content} = \frac{190\text{kg/m}^3}{0.49} = 386.96\text{kg/m}^3$$

Step 7: Coarse aggregate amount

For nominal maximum size aggregate of 19 mm and sand fineness modulus of 2.76, the dry bulk volume can be interpolated between fineness modulus of 2.6 and 2.8 as:

$$\begin{pmatrix} 2.6 & 0.64 \\ 2.76 & X \\ 2.8 & 0.62 \end{pmatrix} =$$

$$\text{Dry bulk volume} = \frac{0.62 - 0.64}{2.8 - 2.6} (2.76 - 2.8) + 0.62 = 0.624$$

$$\text{Coarse aggregate amount} = 0.624 * 1660 = 1035.84\text{kg/m}^3$$

Step 8: Fine aggregate amount

$$\text{Fine aggregate} = 2.7 * [1000 - (190 + \frac{386.96}{3.15} + \frac{1035.84}{2.69} + 20)] = 761.62\text{kg/m}^3$$

Step 9: Moisture correction

	Cement Kg/m ³	Water (kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)
Per m ³	386.96	190	761.62	1035.84
Free moisture %	-	-	1.58-2.23= -0.65	1.18-1.51= -0.33
Adjustment	-	8.37	-4.95	-3.42
Adjusted per m ³	386.96	198.37	761.62*1.0158= 773.65	1035.84*1.0118= 1048.06

V. 60% SS+ 40% NS

The mix design for C-25 non-air entrained normal strength concrete is done as per ACI 211.1.

The data from test results, which are important for mix design, are:

- ❖ Properties of coarse aggregate from the test results in Appendix A.

- Nominal maximum size =19mm
 - Unit weight = 1660
 - Specific gravity = 2.69
 - Absorption = 1.51
 - Moisture content = 1.18
- ❖ Properties of fine aggregate from the test results in Appendix A.
- Unit weight = 1696.2
 - Fineness modulus =2.82
 - Specific gravity = 2.69
 - Absorption = 2.63
 - Moisture content =1.53

Step 1: Slump

A range of 25 - 50mm (minimum slump possible) is selected.

Step 2: Maximum size of aggregate

The nominal maximum size is fixed to be 19 mm.

Step 3: Target mean strength calculation

Table1: Required Average Compressive Strength when data are not available to establish a sample Standard Deviation.

Specified Compressive Strength (N/mm ²)	Required Average Compressive Strength (N/mm ²).
$f'_c < 21$	$f'_{cr} = f'_c + 7$
$21 \leq f'_c < 35$	$f'_{cr} = f'_c + 8.5$
$f'_c > 35$	$f'_{cr} = f'_c + 5$

According to Table1 above, the required compressive strength (mean strength) at 28-days age is,
 $f'_{cr} = 25 + 8.5 = 33.5$ N/mm².

Step 4: W/C ratio

For 30MPa W/C ratio is 0.54 and for 35 MPa W/C ratio is 0.47. The W/C ratio for 33.5 MPa can be found by interpolation as follows:

$$\frac{W}{C} = \frac{35 - 30}{0.47 - 0.54} (33.5 - 30) + 0.54 = \mathbf{0.49}$$

Step 5: Mixing water amount

For a nominal maximum size of aggregate of 19 mm, slump 25 to 50mm (minimum range) and non-air entrained concrete the mixing water requirement is;

$$\text{Mixing water} = 190\text{kg/m}^3 \quad \text{and} \quad \text{Entrapped air} = 2\%$$

Step 6: Cement Amount

$$\text{Cement content} = \frac{190\text{kg/m}^3}{0.49} = 386.96\text{kg/m}^3$$

Step 7: Coarse aggregate amount

For nominal maximum size aggregate of 19 mm and sand fineness modulus of 2.82, the dry bulk volume can be interpolated between fineness modulus of 2.6 and 2.8 as:

$$\begin{pmatrix} 2.8 & 0.62 \\ 2.82 & X \\ 3.0 & 0.6 \end{pmatrix} =$$

$$\text{Dry bulk volume} = \frac{0.6 - 0.62}{3.0 - 2.8} (2.82 - 3.0) + 0.6 = 0.618$$

$$\text{Coarse aggregate amount} = 0.618 * 1660 = 1025.88\text{kg/m}^3$$

Step 8: Fine aggregate amount

$$\text{Fine aggregate} = 2.69 * \left[1000 - \left(190 + \frac{386.96}{3.15} + \frac{1025.88}{2.69} + 20 \right) \right] = 768.77\text{kg/m}^3$$

Step 9: Moisture correction

	Cement Kg/m ³	Water (kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)
Per m ³	386.96	190	768.77	1025.88
Free moisture %	-	-	1.53-2.63= -1.1	1.18-1.51= -0.33
Adjustment	-	11.85	-8.46	-3.39
Adjusted per m ³	386.96	201.85	768.77*1.0153= 780.53	1025.88*1.0118= 1037.99

Appendix-C
Compressive
Strength, Sulfate
attack & Water
absorption Test
Result

Table C.1: Compressive test results for different testing days

% Replacem ent	Tria l	3day							7day						
		Dimensions of cube (cm)			Weight (gm)	Volu me (cm ³)	Failure load (KN)	Compressive Strength (MPa)	Dimensions of cube (cm)			Weight (gm)	Volu me (cm ³)	Failure load (KN)	Compressive Strength (MPa)
		L	W	H					L	W	H				
100% NS	1	15	15	15	8886.0	3375	557.66	24.78	15	15	15	8802.5	3375	650.15	28.89
	2	15	15	15	8977.0	3375	567.11	25.20	15	15	15	8892.5	3375	649.49	28.86
	3	15	15	15	9094.5	3375	579.26	25.74	15	15	15	8973.0	3375	627.19	27.87
Average Strength (KN)		25.24							28.54						
15%SS & 85%NS	1	15	15	15	9008.5	3375	588.26	26.14	15	15	15	8963.0	3375	677.38	30.10
	2	15	15	15	9053.0	3375	591.41	26.28	15	15	15	8795.5	3375	676.48	30.06
	3	15	15	15	8928.5	3375	581.06	25.82	15	15	15	8690.0	3375	643.85	28.61
Average Strength (KN)		26.08							29.76						
30%SS & 70%NS	1	15	15	15	8885	3375	591.64	26.29	15	15	15	8994.0	3375	736.34	32.72
	2	15	15	15	9199.5	3375	627.42	27.88	15	15	15	9013.0	3375	736.11	32.71
	3	15	15	15	9024.5	3375	610.09	27.11	15	15	15	8886.0	3375	744.22	33.07
Average Strength (KN)		27.09							32.83						
45%SS & 55%NS	1	15	15	15	8847.0	3375	518.50	23.04	15	15	15	8951.0	3375	682.6	30.34
	2	15	15	15	8848.5	3375	525.02	23.33	15	15	15	8783.5	3375	669.4	29.75
	3	15	15	15	8882.5	3375	545.73	24.25	15	15	15	8730.5	3375	660.5	29.35
Average Strength (KN)		23.54							29.81						
60%SS & 40%NS	1	15	15	15	8974.5	3375	483.17	21.47	15	15	15	8742.5	3375	607.39	26.99
	2	15	15	15	8845.0	3375	475.51	21.13	15	15	15	8698.0	3375	578.81	25.72
	3	15	15	15	8893.5	3375	477.99	21.24	15	15	15	8712.0	3375	594.79	26.43
Average Strength (KN)		21.28							26.38						

% Replacem ent	Tria l	28day							56day						
		Dimensions of cube (cm)			Weight (gm)	Volu me (cm ³)	Failure load (KN)	Compressive Strength (MPa)	Dimensions of cube (cm)			Weight (gm)	Volu me (cm ³)	Failure load (KN)	Compressive Strength (MPa)
		L	W	H					L	W	H				
100% NS	1	15	15	15	9127.0	3375	1009.30	44.86	15	15	15	9252.0	3375	962.98	46.80
	2	15	15	15	9049.5	3375	1017.17	45.21	15	15	15	9136.5	3375	946.33	46.06
	3	15	15	15	9129.5	3375	1032.93	45.91	15	15	15	9193.0	3375	951.95	46.28
Average Strength (KN)		45.32							46.39						
15%SS & 85%NS	1	15	15	15	8824.0	3375	1014.70	45.52	15	15	15	8913.0	3375	1019.68	47.32
	2	15	15	15	8836.5	3375	1025.90	46.12	15	15	15	9055.0	3375	1043.30	46.87
	3	15	15	15	8938.0	3375	1073.80	47.72	15	15	15	9118.0	3375	1049.83	47.59
Average Strength (KN)		46.14							47.26						
30%SS & 70%NS	1	15	15	15	9067.0	3375	1031.00	45.82	15	15	15	9212.0	3375	1061.30	47.67
	2	15	15	15	8927.5	3375	1098.90	48.84	15	15	15	9141.0	3375	1055.45	48.11
	3	15	15	15	8864.0	3375	1054.10	46.85	15	15	15	8998.0	3375	1027.10	48.16
Average Strength (KN)		47.17							47.98						
45%SS & 55%NS	1	15	15	15	9201.5	3375	1037.68	46.12	15	15	15	8988.0	3375	972.65	47.23
	2	15	15	15	9191.5	3375	1033.55	45.94	15	15	15	9120.0	3375	990.20	48.01
	3	15	15	15	8990.0	3375	1075.20	47.78	15	15	15	9166.5	3375	994.70	48.31
Average Strength (KN)		46.61							47.86						
60%SS & 40%NS	1	15	15	15	9156.5	3375	891.12	39.66	15	15	15	8968.0	3375	935.08	45.56
	2	15	15	15	9124.0	3375	920.60	40.91	15	15	15	9098.5	3375	949.03	45.18
	3	15	15	15	9086.5	3375	942.66	41.89	15	15	15	9107.5	3375	959.83	44.50
Average Strength (KN)		40.82							45.08						

Table D.1: Water absorption of steel slag concrete test results at different ages of curing.

% Replaceme nt	Trial	3days			7days			28days		
		Weight (gm)		Water Absorption (%) $[(W3 - W1)/W1]$ *100	Weight (gm)		Water Absorption (%) $[(W3 - W1)/W1]$ *100	Weight (gm)		Water Absorption (%) $[(W3 - W1)/W1]$ *100
		Oven Dry(W1)	After Fully Immersed (W3)		Oven Dry(W1)	After Fully Immersed (W3)		Oven Dry(W1)	After Fully Immersed (W3)	
100% NS	1	8134.5	8663.5	6.50	8092.5	8625.0	6.58	8278.5	8716.0	5.28
	2	8023.5	8559.0	6.67	8118.5	8641.5	6.44	8029.5	8536.0	6.31
	3	8117.0	8650.5	6.57	8059.0	8590.5	6.60	8187.0	8640.5	5.54
Average Strength (%)				6.58	6.54			5.71		
15% SS & 85% NS	1	7989.5	8394.0	5.06	7854.0	8284.0	5.47	8327.0	8752.0	5.10
	2	7926.0	8444.0	6.54	7931.0	8398.0	5.89	8358.5	8776.5	5.00
	3	7835.5	8357.0	6.66	7912.5	8362.0	5.68	8194.5	8633.0	5.35
Average Strength (%)				6.09	5.68			5.15		
30% SS & 70% NS	1	7992.5	8470.5	5.98	7926.0	8370.5	5.61	8286.5	8657.5	4.48
	2	8042.0	8508.0	5.80	7891.5	8321.5	5.45	8230.0	8589.0	4.37
	3	8036.0	8497.0	5.74	7956.5	8394.0	5.50	8204.5	8559.0	4.32
Average Strength (%)				5.84	5.52			4.39		
45% SS & 55% NS	1	7985.5	8494.0	6.37	7848.0	8281.0	5.52	8192.5	8549.5	4.36
	2	7828.5	8312.0	6.18	7897.0	8321.0	5.38	8310.0	8660.0	4.21
	3	7968.0	8450.0	6.05	7972.5	8404.5	5.42	8255.5	8605.5	4.24
Average Strength (%)				6.20	5.44			4.27		
60%SS & 40%NS	1	7856.5	8376.5	6.62	7856.0	8352.5	6.32	8210.5	8642.5	5.26
	2	7894.5	8413.0	6.57	7896.5	8386.0	6.20	8227.5	8648.5	5.12
	3	7906.5	8424.5	6.55	7908.0	8405.5	6.29	8146.0	8563.5	5.13
Average Strength (%)				6.58	6.27			5.17		

TableC.2: Sulfate attack test results for different testing days

% Replace ment	Trial	3day							7day						
		Dimensions of cube (cm)			Weight (gm)	Volume (cm ³)	Failure load (KN)	Compressive Strength (MPa)	Dimensions of cube (cm)			Weight (gm)	Volume (cm ³)	Failure load (KN)	Compressive Strength (MPa)
		L	W	H					L	W	H				
100% NS	1	15	15	15	8884.5	3375	649.8	20.39	15	15	15	8852.0	3375	1091.00	35.03
	2	15	15	15	8762.0	3375	734.2	23.03	15	15	15	8821.5	3375	1086.64	34.89
	3	15	15	15	8749.0	3375	747.0	23.43	15	15	15	8789.5	3375	1062.66	34.12
Average Strength (KN)		22.28							34.68						
15%SS & 85%NS	1	15	15	15	8664.0	3375	437.1	13.71	15	15	15	9001.5	3375	844.96	27.13
	2	15	15	15	8643.0	3375	418.58	13.18	15	15	15	8992.0	3375	894.06	28.67
	3	15	15	15	8671.0	3375	456.2	14.31	15	15	15	8987.5	3375	840.82	27.00
Average Strength (KN)		13.73							27.60						
30%SS & 70%NS	1	15	15	15	8740.0	3375	438.7	13.76	15	15	15	8772.0	3375	811.17	24.63
	2	15	15	15	8670.0	3375	412.2	12.93	15	15	15	8908.5	3375	765.26	26.07
	3	15	15	15	8853.0	3375	408.85	12.83	15	15	15	8823.5	3375	777.69	25.02
Average Strength (KN)		13.17							25.24						
45%SS & 55%NS	1	15	15	15	8664.5	3375	346.8	10.87	15	15	15	8830.5	3375	749.32	24.13
	2	15	15	15	8579.5	3375	353.7	11.01	15	15	15	8788.5	3375	702.13	23.24
	3	15	15	15	8424.0	3375	347.8	10.91	15	15	15	8691.0	3375	720.94	22.65
Average Strength (KN)		10.93							23.34						
60%SS & 40%NS	1	15	15	15	8576.5	3375	322.30	10.11	15	15	15	8782.5	3375	651.44	21.06
	2	15	15	15	8541.5	3375	314.33	9.86	15	15	15	8754.5	3375	670.89	21.67
	3	15	15	15	8612.0	3375	343.66	10.78	15	15	15	8678.0	3375	636.77	20.60
Average Strength (KN)		10.25							21.11						


% Replace ment	Trial	28day						
		Dimensions of cube (cm)			Weight (gm)	Volume (cm ³)	Failure load (KN)	Compressive Strength (MPa)
		L	W	H				
100% NS	1	15	15	15	8853.0	3375	1062.43	47.21
	2	15	15	15	8854.0	3375	1077.05	47.86
	3	15	15	15	8854.5	3375	1070.08	47.55
Average Strength (KN)		47.54						
15%SS & 85%NS	1	15	15	15	8776.5	3375	997.40	44.32
	2	15	15	15	8734.5	3375	996.26	44.27
	3	15	15	15	8844.5	3375	1026.42	45.61
Average Strength (KN)		44.73						
30%SS & 70%NS	1	15	15	15	8742.5	3375	940.45	41.79
	2	15	15	15	8850.5	3375	960.93	42.70
	3	15	15	15	8824.5	3375	947.65	42.11
Average Strength (KN)		42.20						
45%SS & 55%NS	1	15	15	15	8776.5	3375	914.35	40.63
	2	15	15	15	8775.0	3375	909.62	40.42
	3	15	15	15	8785.0	3375	932.58	41.44
Average Strength (KN)		40.83						
60%SS & 40%NS	1	15	15	15	8842.5	3375	834.00	37.06
	2	15	15	15	8798.0	3375	822.98	36.57
	3	15	15	15	8821.5	3375	830.86	36.92
Average Strength (KN)		36.85						

Appendix-D

Geochemical

Test Result of

Steel Slag



GEOLOGICAL SURVEY OF ETHIOPIA		Doc Number: GLD/F5.10.2	Version No: 1
GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1	
Document Title: Complete Silicate Analysis Report	Effective date:	May, 2017	

Issue Date: 23/07/2020
 Request No:- GLD/RQ/27/20
 Report No:- GLD/RN/446/20

Customer Name: Degeera Fentahun.

Sample type: Steel Slag

Date Submitted: 21/07/2020

Sample Preparation: - 200 Mesh
 Number of Sample:- One (1)


Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides


Analytical Method: LiBO₃ FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS


Collector's code	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI
Steel Slag	55.08	9.53	15.96	3.38	2.06	0.08	<0.01	14.02	0.11	0.53	0.25	<0.01

Note - This result represent only for the sample submitted to the laboratory.

Analysist
Lidet Endeshaw
Yohannes Getachew

Checked By

Yohannes Getachew

Approved By

Gosa Haile

Quality Control

Negash Worku


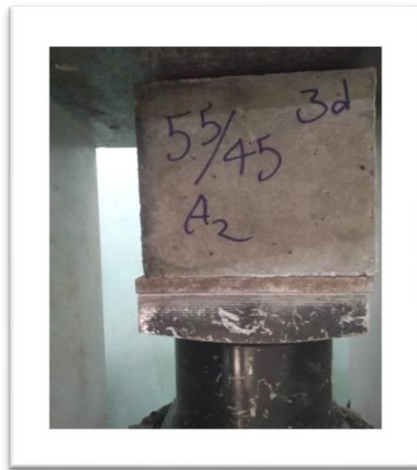


Figure C.1 Geological laboratory complete silicate analysis report format for chemical composition of Steel slag

Appendix-E

Photos



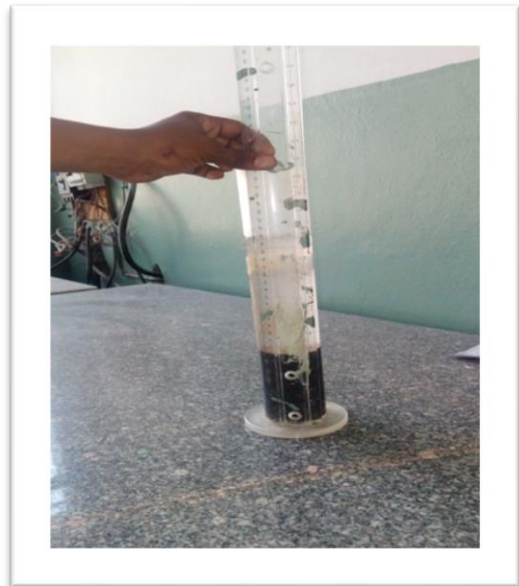
a) *Compressive strength test*





b) Most cubes failure way

Fig C.1: Compressive strength test of the prepared cubes



a) Impurity content before and after washing



b) Coarse aggregate specific gravity test



c) Natural sand and steel slag specific gravity test (sand @ the left and steel slag @ the right)

Figure C.2: Sand and coarse aggregate material test



Figure C.3: Putting the sample (sand and steel slag) and cubes for water absorption in the oven