FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

JIMMA INSTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY, ETHIOPIA

PARTIAL REPLACEMENT OF SAND IN CONCRETE WITH RECYCLED FINE AGGREGATES FROM CONSTRUCTION AND DEMOLITION WASTES

BY:

LUCY FELEKE NIGUSSIE

DECEMBER, 2019

JIMMA, ETHIOPIA

JIMMA UNIVERSITY SCHOOL OF GRADUATE STUDIES

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THE DEGREE OF DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING

BY:

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FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

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DECEMBER, 2019

DECLARATION

I, **Lucy Feleke Nigussie,** hereby declare that the research project entitled **“partial replacement of sand in concrete with recycled fine aggregates from construction and demolition wastes”** is submitted to Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Jimma, Ethiopia. This Dissertation work was carried out under the supervision of Dr. Mukkades Darwish (Associate professor, Texas Tech University, USA) as main advisor , Dr. Tewodros Ghebrab (Assistant professor, Texas Tech University, USA) as co-advisor. I assure that this is my original research work which I submitted to the Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Civil Engineering (Construction Engineering).

EXAMINATION BOARD DISSERTATION APPROVAL FORM

JIMMA UNIVERSITY SCHOOL OF GRADUATE STUDIES

Dissertation Title: Investigation of the effect of recycled fine aggregate from construction and demolition waste on C-25 concrete

By: Lucy Feleke

Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University

Approved by the examining board

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ABSTRACT

Concrete is one of the most widely used construction material in the world. Concrete is a composite material that consists of binding materials, sand, and gravel. Extraction of sand from the river has socio-economic, cultural and even political consequences. Construction and demolition waste is generated whenever any construction and demolition activities take places. These construction and demolition waste disposals are released in huge quantities as landfills and cause environmental pollution. An attempt has been made to recycle these waste materials into usable material for the production of concrete to sustain limited natural resources and as well as to reduce environmental hazards.

The main objective of this research is to find alternative construction material sources from construction and demolition waste to conserve limited natural resources and prevent environmental hazards due to these waste disposals. It includes extraction of fine aggregate from construction and demolition wastes of hollow concrete block (HCB) found in Ethiopia, investigate physical and chemical properties of recycled fine aggregate. Finally, the replacement amount of river sand by recycled fine aggregate in the production of concrete was determined.

The study was carried out through experimental investigation of basic properties of recycled fine aggregate from HCB wastes and also compare these properties with river sand. The comparative result of the experiments of fresh and hardened concrete with different replacement ratios of natural sand with recycled fine aggregate is presented in this paper. Three types of concrete mixtures were tested: concrete made completely with natural river sand as a control concrete and two others types of concrete made with demolished recycled fine aggregate (DRFA) and construction recycled fine aggregate (CRFA). For both types of concrete, the basic concrete properties like workability, density, and compressive strength of concrete was studied with 25 %, 50 %, 75 %, and 100 % replacement of natural sand with the recycled fine aggregate.

In general, the recycled fine aggregate exhibited relatively lower physical properties than natural river sand but satisfied the American Society for Testing and Materials (ASTM) standard requirements. The DRFA has slightly lower physical properties than CRFA. The properties of fresh and hardened concrete were decreased as percentage replacement of

DRFA and CRFA increased. The optimum percentage replacement of river sand by recycled fine aggregate was lay between 50% to 75% but very closer to 75% for that of recycled from construction (new) and closer to 50% for that of recycled from demolished (old) HCB. Recycling wastes can reduce environmental impact due to sand mining and waste disposal which can conserve the natural resource depletion problem partially.

Keywords: - concrete, construction and demolition wastes, hollow block concrete, recycled fine aggregate

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LIST OF ABBREVIATIONS

ACI	American concrete institute
ASTM	American Society for Testing and Materials
CA	Coarse aggregate
C&D	Construction and Demolition
CRFA	Construction recycled fine aggregate
DRFA	Demolished recycled fine aggregate
DTHL	Degene Tsedale Hebret and Lemlem
EBCS	Ethiopian Building code of standard
EEA	European Environment Agency
ES	Ethiopian Standard
EU	European Union
HCB	Hollow concrete block
OPC	Ordinary Portland cement
RFA	Recycled fine aggregate
RS	River sand
SSD	Saturated surface dry
UN	United Nations
XRD	X-ray diffraction

CHAPTER ONE

INTRODUCTION

1.1. Background

As a result of a change in living standards and an accelerated rate of urbanization, the construction industry is booming globally. Concrete is an excellent and most widely used material to make the long lasting structures in the construction industry. This construction industry is one of the contributors of wastes to the environment since as long as there is construction and demolition (C&D) there is waste generation. There is a large amount of C&D waste generation due to new zoning bylaws, modified settlement patterns, modernization of old road, bridges and demolition or renovation of buildings [1].

The major problem in the construction industry is the disposal of C&D wastes. These waste materials are directly dumped into the environment as a landfills and this causes environmental pollution. Demolition materials comprise a large fraction of waste going to landfills worldwide both in developing and developed countries for example in Australia among waste produced 7.7 million tons were disposed as a landfills [2]. In Ethiopia since the solid waste management proclamation No.513/2007 [3] enforce to refill the wastes from the C&D wastes as a landfill, all wastes are goes to landfill. Utilization of these wastes is possible through recycling to construction materials.

Recycling also used as alternative solution in eliminating environmental problem which can be originated from wastes of construction sectors [4]. Recycling has a number of benefits that have made it a more attractive option in conserving non-renewable natural resources, and in reducing impact of landfill [5, 6]. In order to ensure sustainable development in fast industrialization and urbanization, recycling of C&D wastes has become increasingly important now a day.

1.2. Motivation

There is a fast construction rate in Ethiopia due to the government program on constructing affordable housing [7], different hydropower and industry parks construction, which has a great demand for construction materials as well as a great contribution to the C&D wastes. Concrete is the popular construction material and river sand is one of the concrete ingredients which needs alternative sources. The river sand is extracted from river beds causing many problems like, losing water sand strata, deepening of the river courses and bank slides, loss of vegetation, lowering the underground water table [8]. The river sand is natural sand that can be depleted and causing a serious threat to the environment as well as to society. The C&D wastes consist of mostly inert and non-bio degradable things which can be a hazard to the environment. Conservation of natural resource and prevention of environmental hazards is the essential task of any modern development. Finding an alternative source for this depleting source of natural sand as well as finding a solution for the waste of C&D waste is the driving force for recycling issue. Therefore, recycling of C&D wastes enable to conserve natural resources by provide alternative source for the depleting natural sand, to reduce the impact on dwindling landfill spaces, and to prevent environmental hazards.

1.3. Goal

The C&D is a continuous process due to urbanization, change in living standards as well as due to population growth. To conserve the natural resources and protect the environmental hazards due to C&D waste disposal, there is a growing need to reuse and recycle the waste for different construction purposes so that this will reduce the pressure on natural resources. The goal of this research is to find alternative construction material resources from C&D wastes of hollow concrete block HCB to conserve limited natural resources and prevent environmental hazards. This alternative material resource will enable to conserve the natural resources by reducing the depletion of natural river sand from river bed as well as to minimize the waste disposal to the environment.

1.4. Conceptual frame work

The thesis consisted of three parts: recycled material extraction, material characterization and determining the effect of the recycled materials in concrete.

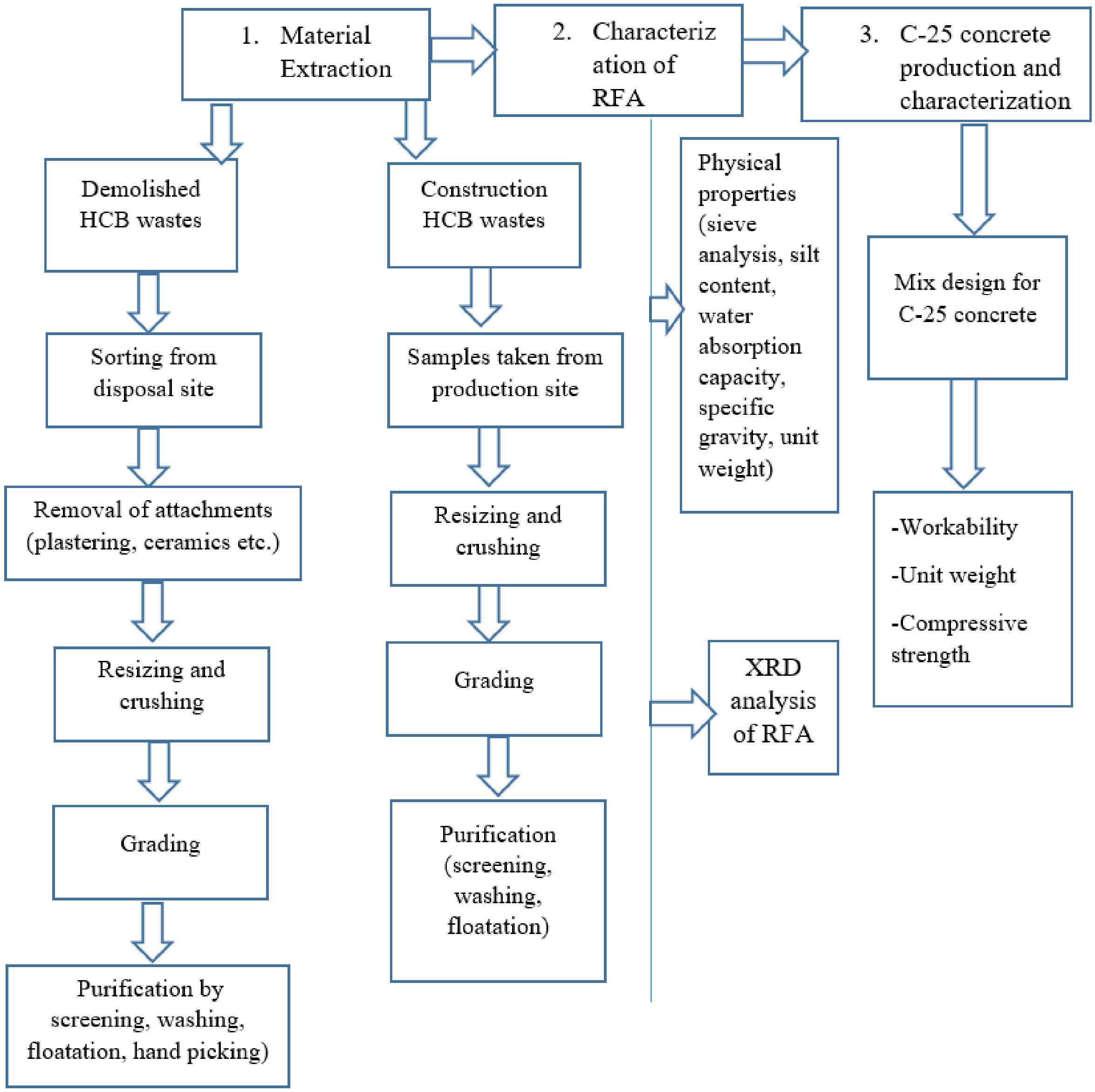


Figure 1: Conceptual frame work

1.5. Research Question

The general research question that answered through this work is “what are the effects of recycled fine aggregate from C&D of HCB wastes has on C-25 concrete”? These are specific questions answered under each specific aims.

1. What are effects of recycling fine aggregate from demolished HCB wastes on engineering properties of C- 25 concrete?
2. What are effects of recycling fine aggregate from Construction HCB wastes on engineering properties of C- 25 concrete?
3. What is the difference in recycled fine aggregate from old and new HCB wastes on engineering properties of C-25 concrete?

1.6. Objective

1.6.1. General objective

To recycle construction and demolition wastes as partial replacement of river sand in a concrete production.

1.6. 2. Specific objectives

In order to answer the aforementioned research question, the following specific aims were established.

1. To investigate the effect of recycled fine aggregate from demolished HCB wastes on engineering properties of C-25 concrete.
2. To investigate the effect of recycled fine aggregate from Construction HCB wastes on engineering properties of C-25 concrete.
3. To examine the comparative effect of recycled fine aggregate from old and new HCB wastes on engineering properties of C-25 concrete.

1.7. Significance

Concrete is one of the most widely used construction material in the world, and it is fundamental material nearly for all structure. Now a day there is high demand for construction due to new zoning bylaws, modified settlement patterns, increased population. River sand is one of the ingredients in concrete that mined from the river bed. Depletion of sand in the streambed and along coastal areas causes the deepening of river and enlargement of river mouths and coastal inlets. Sand mining also affects the adjoining groundwater system and the uses that local people make of the river. The availability of river is not the same for all areas and it is difficult to get river sand nearby for same areas and therefore it requires high transportation cost which can make the price of river sand very expensive. Whenever any Construction and demolition activities take place waste is generated. These waste materials are directly dumped into the environment and this causes environmental pollution. Therefore this research is important in finding a solution for an alternative material for river sand, in environmental protection from construction and demolition waste disposal, as well as to reduce river bed degradation. Therefore recycling of construction and demolition wastes enable to conserve the limited natural resources, to reduce the impact on dwindling landfill spaces of these construction and demolition wastes, to reduce disposal costs of these wastes and may also reduce sand costs. In short, the significance of this study is to conserve the limited natural resource and to reduce the environmental hazards

1.8. Structure of the thesis

This thesis consists five chapters.

Chapter 1 gives general introduction of construction and demolition waste recycling, motivation and objectives of the research.

Chapter 2 gives brief review of the previous researches on construction and demolition wastes recycling as partial replacement or supplementary construction material worldwide and in Ethiopia too. This chapter also includes methodology used throughout the research.

Chapter 3 includes the extraction of recycled fine aggregate from demolished hollow concrete block wastes, characterization of the recycle fine aggregate and investigation of the effect of the recycled material on C-25 concrete.

Chapter 4 discussed on effect of recycled fine aggregate from new construction hollow concrete blocks wastes in C-25 concrete with different replacement percent of recycled fine aggregate.

Chapter 5 consists general discussion, conclusion and recommendation for future researches.

CHAPTER 2

LITERATURE REVIEW

2.1. General

The recycling issue was not new strategy but started at the end of the Second World War by recycling the demolished brick as aggregate by crushing [9]. During this period, the demolished bricks were crushed and used in concrete production as concrete aggregates. In 1970s the, systematic research in laboratories and demonstration projects by the utilization of C&D waste in construction works began. To keep the environment clean and to reserve the natural aggregates, recycling technology were given attention previously and continued until now [9, 10, 11, 12]. Using crushed concrete from demolition waste as aggregate instead of natural resources as well as using demolished concrete pavement to stabilize the road base courses during past decades has been recognized as a most practical and sustainable way of C&D waste handling methods. But most recently various researchers found that how demolished concrete wastes can be used in concrete as structural rather than the base course of roads. Recycling the C&D wastes as coarse aggregate and fine aggregate is a common practice in some countries and at beginning in some other countries or practically non-existing [13]. The issue of recycling C&D waste is very important due to scarcity of natural aggregate and due to environmental impact by waste disposal as well as due to scarcity of landfill.

Some counties have the rules and regulations of waste management monitoring system. European directive [14] planned that by 2020 all wastes including construction and demolition have to be utilize at least 70% by weight by means of re-use, recycle, or any other types of recovery. The exact quantity of (C&D) waste generated were not well known in different countries due to the reason that many of waste disposed or recycled were not tracked [15]. In European countries the amount of waste generated from construction and demolition wastes were determined as value per capita and the contribution of each sector is well defined by the European Environment Agency (EEA) which monitors all available data of the first 15 member State of European union (EU) [13]. In EU about 850 million tons of construction and demolition wastes are generated per year [16]. In Egypt managing C&D wastes through landfills becoming the environmental problem due to huge deposits of construction and demolition wastes. In developed countries laws have been brought into practice to restrict the construction and demolition wastes in the form of prohibition or by creating special taxes for creating waste areas [17, 18]. But in Ethiopia, the concept of recycling the construction and demolition waste is unexercised [19]. The current practice in Ethiopia is disposing of these construction and demolition wastes as landfill as per solid waste management proclamation No. 513/2007 of Ethiopia. The construction and demolition waste management in Ethiopia is undertaken by urban administrations or they may enter into agreement with construction enterprise to refill solid waste disposal sites as a covering or to quarry pits [3]. Quantifying the construction and demolition waste generated is difficulty in Ethiopia due to untracked of the disposed waste. However, this waste has to be reduced by using for different purpose. This can be done through waste hierarchy which aimed to reduce, reuse or recycle waste [20]. The reduction of non-renewable natural resource extraction is of constant concern relating to the preservation of the environment and encourages the use of waste materials by recycling.

Recycled concrete aggregate from C&D wastes was used as a sub base for past decades. Rouyu and Chen [21] investigated on concrete recycling in the U.S. construction industry and they comes out with find of that even if the recycling old concrete is common in the U.S., its application is mostly limited to backfill and pavement base. The demolished brick was also used as stabilizer for cohesive soil with great improvement on CBR value of soil than the virgin soil [22]. But recently the advanced investigation for further utilization was undergoing. Umoh [23] examined the use of demolition waste sandcrete blocks as aggregate in concrete. The fine aggregate was replaced by crushed sandcrete block wastes in various percentage. The finding was, crushed waste sandcrete block can be used as supplementary aggregate materials in concrete. In recycling the demolished concrete waste, Yadhu and Devi [24] reused the demolished concrete waste as fine aggregate. From the study, the compressive strength of concrete with crushed demolished waste as a replacement of fine aggregate had a lower value than the normal concrete. However, it could be used in construction members that do not carry much load. Thus, in general, they concluded that the crushed C&D waste can be used as a replacement of conventional sand as a fine aggregate but needs further investigation into how extensively it can be used as a replacement. In this investigation the crushed demolished wastes were not recommended to be used for structural concrete but there is some investigation made on use of recycled C&D concrete waste as structural concrete. Ashraf et al. [17] examined the recycling of construction and demolition concrete waste as aggregate for structural concrete. They claimed that the replacement of 25% recycled concrete aggregate has no significant adverse effect on structural concrete performance. When the replacement ratio increased to 50%, the compressive strength reduction ranged from 7% to 13%. The C&D wastes are different in their composition, nature and quantities.

To achieve high quality recycled materials, the sample collected have to be clean, quality and which processed through crushing, pre-sizing, sorting, screening and elimination of the contaminants [1]. According to some researches the technique of recycled aggregate extraction needs well established successive crushing techniques. Martinelli et al [25] investigated the procedure of removing impurities of recycled concrete aggregate and examined their influence on physical and mechanical properties of concrete at fresh and hardened states. The researchers came with the feasibility of autogenous cleaning that could remove the surface impurities of recycled concrete aggregate as well as reduce particle heterogeneities. To reduce heterogeneity, they removed the residual wood, plastics, and steels from demolished debris, and to reduce the amount of fine particles attached on the surface of recycled concrete, autogenous cleaning was performed. The cleaning procedure enhanced the recycled aggregate quality, and this improved the properties of the concrete with recycled aggregate at fresh and hardened states. Recycling was advanced by enhancing the quality of the recycled aggregate from time to time. Medhat et al. [26] investigated the properties of the recycled concrete aggregate of high quality that were produced through the technique of preserving the original properties of the aggregate. As per the comparison made on the effect of recycled concrete aggregate and commercial recycled concrete aggregate, the preserved quality had better compressive strength, drying shrinkage, and salt scaling resistance. This investigation enhanced the recycled concrete aggregate quality by preserving the recycled concrete aggregate. Park et al. [27] evaluated the surface modification of recycled fine aggregate to reduce the water absorption rate and increase density by aqueous H_2SiF_6 solution. The modified recycled aggregate showed more improvement than the recycled aggregate before modification in mechanical properties of both compressive and flexural strength. Thus, they concluded that the surface treatment method using the H_2SiF_6 solution is effective in improving high water absorption capacity and low density of recycled fine aggregate. Investigation on properties of recycled fine aggregate were addressed by different researchers like Özalp et al. [4], investigated the effect of recycled aggregates from C&D wastes on mechanical and permeability properties for manufacturing of different concrete products like concrete paving stone, kerb, and concrete pipes. The researchers concluded that with appropriate separation and classification, using recycled concrete aggregate as a secondary raw material in various concrete elements is possible with the related standard.

The characteristics of recycled aggregate have to be compared with the properties of standard aggregate properties stated on ASTM standard to be used as replacement of aggregates. The use of recycled sand obtained from construction and demolition wastes as a component of new concrete mixture requires a thorough understanding of its basic properties. Some of the recycled sand properties may significantly differ from the properties of natural sand. From some researches, the recycled concrete aggregate tends to have a lower specific gravity and bulk density while having a higher water absorption capacity and porosity than the natural aggregate [19, 25, 26, 28]. These properties of aggregate can affect the workability of the concrete. The recycled concrete aggregate has old mortar attachment on the surface [29]. The fine particles attached on the surface of the recycled concrete aggregate increased the water absorption capacity of recycled fine aggregate and so had a lower density than natural aggregate [30] Thus, the compressive strength was less than the conventional concrete due to the high water absorption capacity of the recycled fine aggregate.

2.2.Properties of recycled aggregates

The investigation on properties of recycled concrete aggregate has been undertaken by different researchers. Saidi et al [31] investigated the physical and mechanical properties of the recycled concrete aggregate from demolished waste in concrete. In this research, from test on workability of mortar from recycled fine aggregate, there was a slump loss and they conclude that the recycled fine aggregate has strong water absorption capacity. The study also assert that the fine part of the recycled fine aggregate contributes to the reduction of the mortar workability. The researchers underlined the reduction in mortar workability and the strong water absorption capacity as negative effect of recycled sand. From the investigation they did on the bulk density of the concrete from recycled aggregate, the density of concrete with recycled aggregate is less than that of natural aggregate concrete due to the porosity which cause lightweight concrete and due to less density of recycled aggregate due to old mortar attachment on it and the finer particles. The other researchers [32, 33] also found that the RFA has high water absorption and so the concrete with RFA is less workable than the reference mix. They concluded that the workability of the concrete with natural river sand and RFA is almost the same if the saturated surface dry recycled aggregate is used. The previous research on the influence of parent concrete on the properties of recycled concrete aggregate by Padmini et al [34] was also find out that the specific gravity and bulk density are relatively lower for recycled aggregates and the water absorption was found to be significantly higher. The recycled aggregate also has significant change on the workability of the concrete with recycled aggregate as compared to the conventional aggregate. Researcher on Mechanical Properties of Concrete with Recycled Aggregate by Apurva et al [35] concluded that the workability of concrete reduces as the percentage replacement of recycled aggregates increases.

The compressive strength of recycled aggregate concrete is typically lower than concrete with virgin aggregate [19, 31, 34, 36, 37, 38]. The compressive strength is affected by several factors including the water/cement ratio, the percentage of coarse aggregate replaced with recycled concrete aggregate, and the amount of residual mortar in the recycled concrete aggregate. The researchers agree that the adhered mortar in recycled aggregate affects the strength of the concrete. The compressive strength of concrete made with recycled aggregates was 25% lesser than that of concrete made with natural aggregates at the age of 28 days [36]. Quanmin et al [39] investigated on the influence of recycled coarse aggregate replacement on performance of recycled aggregate concrete and of the investigation was the fatigue life, residual strength, and residual stiffness of the concrete with recycled concrete aggregate decrease with an increase in replacement percentage of recycled coarse aggregate. Carbonation resistance is an important factor affecting the durability of concrete and the researchers [40] found out that the concrete with recycled aggregate is good in carbonation resistance.

2.3.Recycling construction and demolition waste in Ethiopia

From the previous studies in worldwide, recycling C&D waste as concrete aggregate for concrete production were investigated to a significant level. Unlike in Ethiopia, the recycling of C&D waste concept developed to the extent of enhancing the performance of recycled concrete aggregate to remove the impurities and using for structural elements. Ethiopia is one of the developing countries in Africa, and using these researches in developing countries like Ethiopia is impossible due to technology transfer gap between developed and developing countries. In Ethiopia the concept of recycling C&D waste has not yet been familiar [19]. In Ethiopia, the solid waste management proclamation No. 513/2007 enforces the disposal of C&D waste to be used as landfill. This can be an indicator to the status of C&D waste recycling practice in Ethiopia. However, for the last seven years, some researches were carried out on recycling C&D waste as concrete aggregate in Ethiopia in local techniques [19, 41, 42]. Woubishet [19, 42] assessed the suitability of recycled aggregate in concrete and the effect of recycled concrete aggregate on concrete properties. The crushed concrete as coarse aggregate in concrete was checked for workability, compressive strength, and permeability properties as compared to the control mix. The researcher concluded that the recycled concrete aggregate has lower physical and mechanical properties than natural concrete aggregate but in the range of normal weight aggregate. Generally, the study comes with the suitability of recycled concrete aggregate in the production of new concrete in Ethiopia.

The previous researches in Ethiopia investigated on the C&D concrete structure to recycled concrete aggregate but not addressed HCB wastes, which is most abundantly available waste in construction site and demolished buildings. Even if there is no research done on characterization of the waste generated from construction and demolition activities in Ethiopia, it is possible to identify which materials are used in construction sector abundantly. In Ethiopia, the popular material used for wall construction, for both internal and external wall, is HCB [43]. Therefore, the construction site, as well as the demolished buildings, has abundantly HCB wastage. HCB wastage also found on production site which can break during loading and unloading. This study aimed to recycle the C&D waste to fine aggregate by enhancing the quality of the recycled fine aggregate and to investigate the effect of recycle fine aggregate on the properties of concrete at fresh and hardened state. In recycling, homogenization of demolished HCB waste and construction HCB waste, cleaning, floatation and washing were the procedures to enhance the quality of the recycled fine aggregate.

CHAPTER 3

METHODS

1.1.Introduction

Since the research is on recycling of construction and demolition wastes generated while demolition, construction, as well as from production site to produce sand which can be utilized for preparation of concrete by replacing river sand. These construction and demolition wastes were collected from their sources.

3.2. Data source and data types

All required data for this study were collected from both primary and secondary sources. The primary data were collected from construction and demolition sites and production sites. The demolished HCB were collected from disposal site of Jimma University in main campus which consisted the demolished student dormitory. The demolished wastes of residential building was selected to avoid chemical contaminants. The construction waste of HCB were taken from production site of HCB which found in Jimma city. Secondary data were by reviewing of all available recently published research works.

3.3. Sampling technique and sampling size

The sampling technique is according ASTM standard requirement. The sample were only HCB from demolished and production site and the experimental tests were undertaken in Jimma Institute of technology and partially in Adama Science and technology University. The sample size for experimental investigation were 81 specimens for both types of samples. For each percentage replacement 9 specimens were cast for three different curing periods and for each curing period three specimens were used for replication purpose. The specimens for compressive strength cubic specimen with 150*150*150mm. each specimens have different coding according to the replacement material types and amount. C, CRFA25, CRFA50, CRFA75, CRFA100, DRFA25, DRFA5, DRFA75 and DRFA100 for control, for construction recycled fine aggregate and demolition recycled fine aggregate with 25, 50, 75 and 100% replacement respectively.

3.4.Data collection and analysis

The data was collected from Jimma City for both demolition HCB wastes and construction HCB wastes. The demolished HCB wastes were from demolished residential building which were student dormitory for 10years. The demolished HCB wastes were collected from Jimma University main campus disposal site. For construction HCB wastes, the sample were collected from HCB production site known as DTHL (Degene Tsedale Hebret and Lemlem) found in Jimma city. DTHL Company is a micro that produce HCB and supply to Jimma and around Jimma construction companies. These collected C&D wastes HCB were used as a source for recycled fine aggregate extraction through crushing and screening. The extraction of the recycled fine aggregate from the collected samples were undertaken through different techniques and purification techniques were also applied. The properties of the produced recycled sand were characterized as compared to the standard requirements for fine aggregate. The effect of recycled fine aggregate on concrete properties were investigated through experimental studies on fresh and hardened properties of C-25 concrete.

3.5. Extraction of fine aggregate from construction and demolition wastes in Ethiopia

Construction and demolition have a great role in the contribution of waste generation to the environment. To recycle the waste generated collecting from different sources such as demolition of the old structure, destruction of building due to the natural or man made accident, destructive methods of testing of existing structure and due to production of HCB. To produce sand from these collected wastes from different sources the following steps will be followed:-

1. Collecting from the source and sorting in their types (hollow concrete block from demolition, and from production sites,).
2. Pre sizing and crushing of hollow concrete blocks
3. Screening and contaminant elimination.

Further cleaning is necessary to ensure the recycled sand product is free of dirt, clay, wood, plastic and organic materials. This was done by washing floatation and handpicking the sand.

Sorting

Sorting is an essential component of solid waste management. It is a kind of activity which is separating different types of wastes in their respective nature. It makes waste management easy and simple. Separating different types of wastes components helps to sort recyclable materials from non-recyclable materials and identify decomposable materials from non-decomposable materials.

Pre-sizing /crushing

Construction and demolition wastes collected from sites were crushed by crushing machine. The output from crushing machine has different size which needs grading to get appropriate size of required sand. The recycled sand needs further purification through variety of methods including screening, hand picking, and water floatation.

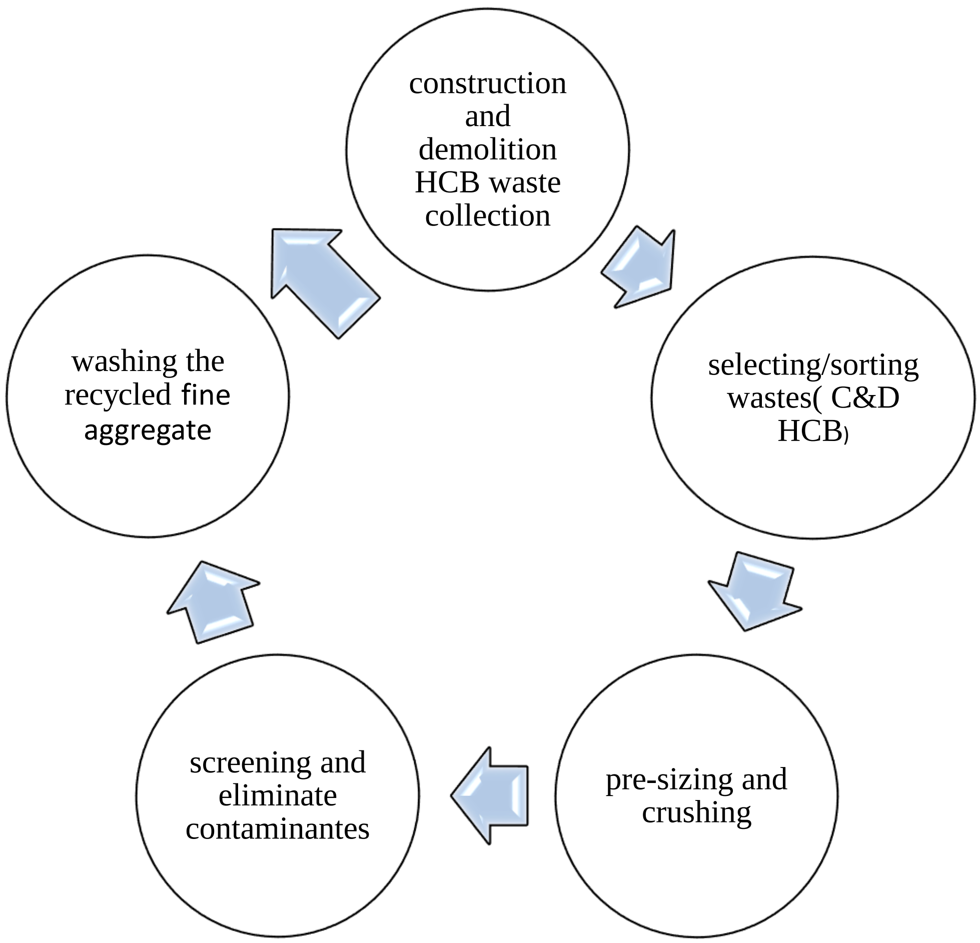


Figure 2: Process of construction and demolition waste recycling

3.6. Properties of recycled fine aggregate

The physical properties of recycled fine aggregate was investigated in the laboratory. Among the physical properties the silt content, gradation, density moisture content and water absorption were investigated.

Silt content

To measure the silt content of the recycled fine aggregate following equipment were used.

- Measuring cylinder
- Water and recycled fine aggregate

$$\text{Silt Content} = \frac{V1}{V2} \times 100$$ ………………….......…….Equation 1

Where V1 is the volume of silt layer alone

V2 is the volume of fine aggregate in ml

Silt content can measured by washing and more accurate.

Silt content in % $= \frac{B-C}{B} * 100$ ………………………………..………..…Equation 2

Where B is the original dry mass of sample in g.

C is the dry mass of sample after washing in g.

The test procedure was repeated 3 times and the average result was taken

Sieve analysis

Sieve analysis or gradation test is a practice or procedure used to assess the particle size distribution for sand. Gradation affects many properties of fine aggregates. With careful selection of the gradation, it is possible to achieve high bulk density and low permeability. The gradation can decide about the sand to be used. The degree of gradation also called fineness modulus of sand. This is done by passing the materials through a set of sieves with openings of different diameter, #4, #8, #16, #30, #50, and #100 sieves. By separating larger from smaller particles we can calculate the percentage of passing each sieve.

Sieving procedure as per ASTM C136

1. Dry the sample at 110^0c
2. Measure the pan weight
3. Measure the pan and the sample
4. Select sieves
5. Agitate sample in size
6. Measure and record

Minimum test size for dry fine aggregate is300g.

Sieving duration- less than 1% by mass of the material retained on any individual sieve will pass that sieve during 1minute sieving.

Then the fineness modulus of the fine aggregate was added, the cumulated percentage of each sieve and divide by 100, that is

Fineness modulus $= \frac{\mathbf{m1+m2+m3+m4+m5+m6}}{\mathbf{100}}$) where m_i are mass retained on each sieves.

Unit weight/density

Unit weight is used to determine bulk density values used in selecting proportions for concrete mixes and for mass/volume relationships for conversions. Unit weight can be determined by loose or compacted density. Loose unit weight is used when specifically stipulated unless use compact unit weight by rodding or by digging. Rodding procedure used for aggregate having a nominal size of 37.5mm or less and digging procedure used for aggregate having a nominal size greater than 37.5mm and not exceeding 150mm. Since the aggregate size is less than 37.5mm as per ASTM Designation C-29 [44] rodding procedure is undertaken by filling the measure up to one third and leveling by finger. Then rod the layer of aggregate 25 strokes with tamping rod. Fill the measure up to two third, level, and rod the layer. Fill up to overflow and again rod. Then calculate the unit weight by the following equation.

$$M=\frac{(G-T)}{V}$$ ……………………………………..……………………...Equation 3

Where M= unit weight of fine aggregate in kg/m^3

G= mass of aggregate plus the measure in kg

T= mass of the measure in kg

V= volume of measure in m^3

Specific gravity and water absorption

Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity determined on the saturated surface dry basis is used if the aggregate is wet, that is, if its absorption has been satisfied. The bulk specific gravity determined on the oven dry basis is used for computation of when the aggregate is dry or assumed to dry as per ASTM Designation C 128-93 [45]. The oven dry DRFA were used in calculating the bulk specific gravity as follows

$$\text{Bulk sp. gr. (D)} = \frac{A}{(B+S-C)}$$ …………………………………………………...Equation 4

Where A=mass of oven dry specimen in air, g (1000)

B= mass of pycnometer filled with water, g

C= mass of pycnometer with specimen and water to calibration mark, g

S= mass of saturated surface dry specimen, g

Calculate the bulk specific gravity on the basis of the mass of saturated surface dry aggregate

$$\text{Bulk Sp. Gr. (SSD)} = \frac{S}{(B+S-C)}$$ …………………..…………...……………Equation 5

The water absorption of buildings materials is important to know due to its influence on durability [46]. Water absorption values are used to calculate the change in the mass of aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition. This is possible when the aggregate has been in contact with water long enough to satisfy most of the absorption potential.

Specimen preparation was done as per ASTM C 128-88 [45].

Specimen preparation

- Obtain 1kg of fine aggregate from sample(A)
- Dry it at a temperature of 110 ±5°c. allow it to cool to comfortable handling temperature. Cover with water and stand for 15 to 19hrs.
- Decant the excess water and spread the sample on flat non-absorbent surface until achieving saturated surface dry condition as per ASTM C 128-88.

Calculate the water absorption of the recycled sand by the following formula

Absorption %= $\frac{(S-A)}{A} * 100$ ……………………...……………………………………Equation 6

Where, A= weight of oven dry specimen in the air, g.

S= weight of the saturated surface dry specimen,

This test method used to determine the percentage of evaporable moisture on the surface of aggregate and in the pores of aggregate which can evaporate during drying as per ASTM C 566 [47]. This percentage of moisture of aggregate is used in adjusting the batch ingredients proportion in concrete mixing. Surface moisture content is the difference between total evaporable moisture and absorption capacity.

$P = \frac{100(W-D)}{D}$……………………………………………………………...……….Equation 7

Where P is total evaporable moisture content of sample in %

W mass of original sample in g

D mass of oven dried sample

XRD analysis

The radiographic phase analysis can clearly identify the crystalline materials qualitatively. So, it was used in this study to investigate the different phases of which the DRFA consisted such as Quartz, calcite and Gypsum. The method is by diffraction of X-rays on the crystal lattices. The diffractions depend on the space between the network levels of the phase, which are different for every phase. So, the phase can be identified according to its X-ray diffractions. To perform this test, the sample is oven dried for 24hrs and ground to about 40μm particle size to become a powder. This powder is put on a round sample container, which, is supported in the measurement circle of the diffractometer device and then the measurement starts. Phase identification was carried out by Origin Software, identifying the presence of different amounts of crystalline phases that corresponded to the original aggregates and to the cement paste adhered to them. The different XRD analysis and their parameters are presented in qualitative analysis on Figure 6. The samples were run once over a 2θ drive axis at scan range of 10°–80° with a continuous scanning mode. The scan speed was 3.0deg/min with sampling pitch of 0.020deg. The graph is drawn between 2θ and intensity. The components of the sample were identified by comparing them with standards established by the International Centre for Diffraction Data.

Cement properties

As a binding material, Dangote Ordinary Portland Cement with strength class of 42.5N was used. The Cement properties were tested for compliance of specification for Ordinary Portland Cement. The fineness, setting time and normal consistency of cement were checked as per standards.

Specimen preparation for concrete

Concrete was prepared based on the specification for C-25 concrete. The batching of concrete will be carried out by weight. For the preparation of concrete mix with the recycled sand replacement of 0%, 20%, 40%, 60%, 80% and 100% by mass instead of river sand. From this mix, the properties of fresh concrete and the mechanical properties of hardened concrete, were investigated for different mixes produced with natural sand and recycled sand. The specimen will prepared for each types of recycled sand obtained from different sources, for both concrete and HCB from all sources (demolition, construction and production sites). To investigate the properties of fresh concrete made of recycled sand laboratory test will be conducted. These include workability, slump loss, and air content.

Workability test

Common workability tests are slump test, compaction factor test, flow test, Vebe test. Slump test is the most common technique for evaluating workability. Settlement of concrete from molded truncated cone shape is measured and called as the slump. The wetter mix possesses greater slump.

Unit weight

To investigate the properties of hardened recycled fine aggregate concrete the laboratory test conducted was included the hardened unit weight of concrete. The cubes after casting were immersed in water for 7th, 14th and 28th day curing period. Then take the specimen out of the bath and measure the weight of surface dry specimen. The weights and the dimension of the concrete cubes were measured before testing the moulds for compressive strength. Unit weight is the density of a specific unit of material which equals to the ratio of mass to the volume it will occupy. As per ASTM C 138 [48]

$$Density, = \frac{mass\ (kg)}{volume} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 8}$$

Compressive strength

The determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive stresses. For compressive strength test, the concrete specimen casted in 150mm*150mm*150mm cube steel mold and the test was performed at 7, 14 and 28 days. Testing takes place by universal testing machine. The block specimen will be cured at room temperature in a water bath until tested. A uniform rate of loading is maintained. The maximum load to failure at which the specimen breaks and the pointer start moving back is noted. The mean value strength will be recorded. The compressive strength value will be reported to the nearest two decimal places.

$$\text{Compressive strength} = \frac{\text{crushing (maximum)load(N)}}{\text{cross sectional area of cube (mm2)}} \ldots\ldots\ldots\ldots \text{Equation 9}$$

Data Quality Assurance

The quality of the data was assured through replication of the samples by using standard operating procedures. To check the accuracy and validity of the data, the error bar were checked by calculating standard deviation among the samples from the mean value. The closer the samples value to the mean value is the more accurate the value and the more spread out mean the samples value is not closer to each other.

Generally, in order to assure the quality of data, care were taken as per standards throughout the work

The proportioning for different samples was conducted properly.

All parameters that were kept constant was checked.

The curing and production processes was followed up continuously by the researcher.

The test results were filled and checked properly by using the table for compressive strength placed at the appendixes.

Ethical consideration

The data was collected after getting letter of permission from Jimma University, Jimma Institution of Technology Postgraduates Research and Publication Director Office for continuation of the study. The data collected is used only for the research purpose.

Plan for dissemination

The dissertation findings will be disseminated to Jimma University Institute of Technology, Civil and environmental Engineering Department. It will kept in Jimma University, Jimma institute of Technology library for all who want to use. This can use as base to undertake further study on recycling of construction and demolition wastes. The find can also use for the concerned stake holder for further action.

CHAPTER 4

Investigation of the effect of recycling demolished hollow concrete blocks on C-25 concrete

4.1. Abstract

Recycling demolished waste is one of the viable solutions to reduce environmental pollutions and makes construction sustainable by lowering the dependence on natural and non-renewable resources. In this study, the effect of recycled fine aggregate from the demolished HCB on the workability, density, and compressive strength of concrete was studied. A comparative analysis of the experimental results of fresh and hardened concrete properties with different replacement ratios of natural river sand by recycled fine aggregate is presented. Concrete mixes containing 25 %, 50 %, 75 %, and 100 % replacement of natural sand with demolition recycled fine aggregate (DRFA) were tested. The test results indicated have lower physical properties than the control, but they have satisfied the ASTM requirements. The replacement of natural river sand by recycled demolition HCB wastes slightly affected the workability, density, and compressive strength of the concrete. The performance of the concrete containing DRFA decreased with an increase in the percentage of replacement of DRFA, and the targeted compressive strength was met up to 50 % replacement. Therefore, this work demonstrated that the suitability of using demolished hollow concrete block as fine aggregate in concrete, and this could reduce the environmental impact due to waste disposal and sand mining.

Keywords: Compressive strength; Concrete; Demolition hollow concrete blocks; Recycling; Demolition recycled fine aggregate,

4.2. Introduction

Demolition of old buildings and traffic infrastructure, and substitution them with new one, is a frequent activity in the world. Since construction is a cyclic process, there is always demolition of deteriorated buildings and construction of new buildings due to changes of purpose, rearrangement of a city, expansion of traffic directions and increasing traffic load. In this cyclic process there is material demand and waste generation. Recycling of the demolished waste can reduce the waste dumping and provide alternative material sources which can decrease the utilization of primary resources. Utilization of demolished wastes and having alternative resources for primary resources have an important contribution to

Ensure Sustainable Consumption and Production patterns ,which is the Goal -12 of Transforming Our World, the 2030 UN Agenda on Sustainable Development [49]. The goal is focused on economic growth based on efficient use of natural resource, low environmental degradation and reduction of waste generation through prevention, reduction, recycling and reuse of the natural resources while improving the well-being of people.

Recycling of demolition debris was long lasting activity in the world after 2nd world war [30] but, in Ethiopia there is no sustainable solid waste management systems (reuse, recycle, composting, and incineration) [50]. The demolition wastes in Ethiopia contain large amount of demolished HCB that goes to landfill. This needs to be recycled to be used in concrete productions to reduce the environmental impact due to waste disposal and sand mining. The deposits of natural sand, especially those located near capital city, Addis Ababa, will run down or lead to very high operating costs due to method of quarrying is very old and transporting to the nearby loading station is by animal transportation system [51]. Therefore, finding alternative material resource for the natural resources will reduce the impact of sand mining on the environment and sand mining difficulty as well as the land used for disposal purpose.

The objective of this study is 1st to examine the capability of recycling demolished hollow concrete block wastes for production of new concrete by characterizing the physical properties of recycled fine aggregate, 2nd investigate the effect of replacement of recycled fine aggregate in the production of concrete and 3rd determining the optimum replacement percentage of river sand by recycled fine aggregate. The test was checked as per ASTM standard requirements.

4.3. Materials used

In the material selection and quality assurance, the Ethiopian technical specification [52] elaborated which standard to be used and means of measurement.

4.3.1. Cement

As a binding material, Dangote Ordinary Portland cement with a strength class of 42.5 N was used. The cement obtained from a single batch was used throughout the test with compliance to ASTM standard specifications. The cement specific gravity, fineness, and normal consistency were conducted as per the ASTM standards. The properties of cement summarized in Table 1. The fineness of the cement affects the hydration rate. The fine cement reacts faster with water, and the rate of strength development is also high. The fineness of the OPC was tested as per ASTM C 184 [53], and for OPC, the percentage of residue retained after sieving by No. 200 sieve should not exceed 10% by weight. From Table 1 the fineness of cement is within the required limit. The setting time of the OPC 42.5R was checked as per ASTM C 191 [54], and the initial setting shall not be less than 30 min and for final setting time not greater than 600min which satisfied the requirements. The normal consistency property of OPC was tested to determine the optimum amount of mixing water required to prepare hydraulic cement pastes for tests as per ASTM C 187 [55].

Table 1: Summary of Cement Properties and standard used

Test types	Test result	Test method/ standard used
Fineness (%)	4.5	ASTM C 184 [53]
Initial setting time (min)	230	ASTM C 191 [54]
Final setting time (min)	314	ASTM C 191 [54]
Normal consistency (%)	33	ASTM C 187 [55]

4.3.2. Coarse aggregate

The coarse aggregate with a maximum aggregate size of 20 mm was used. The physical properties of the coarse aggregate were summarized in Table 2. The unit weight of coarse aggregate is within the range of 1200-1760kg/m^{3,} and it fulfills the ASTM requirement. As per ASTM C 33, bulk specific gravity at SSD of coarse aggregate have to be within the range of 2.4 to 3.0, and the aggregate is satisfied the requirement. The absorption capacity for coarse aggregate has to be from 0.2% to 4% and in Table 2 the absorption capacity of coarse aggregate satisfies the requirement of ASTM C 33 [56].

Table 2: Summary of properties of coarse aggregate

Test type	Test Result	Standards used
Fineness modulus (%)	6.34	ASTM C-136 [57]

Unit weight (kg/m^3)	1605	ASTM C-29 [58]
Moisture content (%)	0.35	ASTM C-566 [47]
Bulk specific gravity (SSD)	2.65	ASTM C-127 [59]
Bulk Specific gravity dry basis	2.63	ASTM C-127 [59]
Apparent Specific gravity	2.70	ASTM C-127 [59]
Absorption capacity (%)	0.98	ASTM C-127 [59]

SSD: Saturated-surface dry

It can be observed that from Figure 1 the gradation curve of coarse aggregate is between the upper limit and lower limit, which show that the coarse aggregate is well graded.

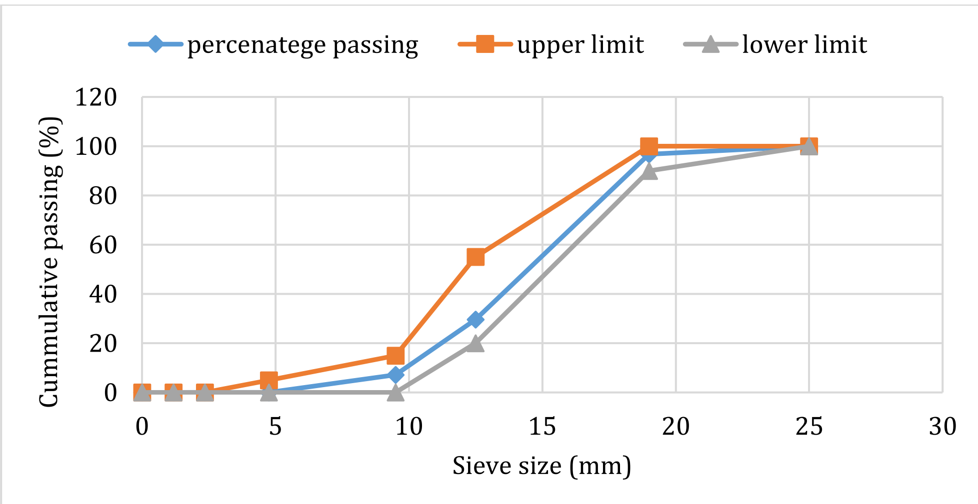


Figure 3: Grading curve of coarse aggregate laying between upper and lower limit of ASTM C 33

4.3.3. River sand

Locally available river sand from Chewaka was used in throughout the experimental works. The silt content of river sand was checked as per ASTM standard ASTM C 117 [60]. The silt content of river sand is 2.87% as show in Table 3, which is within the required limit in silt content and no need to wash it.

Table 3: Silt content of river sand

Determination of silt content

Observation sheet				
S. No.	Description	Sample No.		
		Sample 1	Sample 2	Sample 3
1	Original dry mass of sample in g.	1000	1000	1000
2	Dry mass of sample after washing in g	979	978	957
3	Percentage of silt= $\frac{B-C}{B} * 100$	2.1	2.2	4.3
Average		2.87%		

The water absorption capacity of fine aggregates have to be within the range of 0.2 to 2% [56] and on Table 4 the result of river sand, 1.73%, is within the range which satisfies the requirement.

Table 4: Summary of river sand properties

Test type	Test Result DRFA River sand	Test method/ standards used
Silt content (%)	2.87	ASTM C 117 [60]
Fineness modulus (%)	2.78	ASTM C 136 [57]
Unit weight (kg/m^3)	1505	ASTM C 29 [44]
Moisture content (%)	0.2	ASTM C 566 [47]
Bulk specific gravity (SSD)	2.55	ASTM C 128 [45]
Bulk Specific gravity dry basis	2.5	ASTM C 128 [45]
Apparent Specific gravity	2.62	ASTM C 128 [45]
Absorption capacity (%)	1.73	ASTM C 128 [45]

Table 5: Sieve analysis of river sand

ASTM sieve designation and	Weight retained (gm.)	Average weight			Specification % passing

Sieve size (mm)	Sample 1	Sample 2	Sample 3	retained (g)	Cumulative retained (%)	Percentage passing (%)	(ASTM C33) [56]
3/8(9.50mm)	0	0	0	0	0	100	100
No.4 (4.75mm)	0	0	0	0	0	100	95-100
No.8(2.36mm)	71	70.5	92.5	78	4	96	80-100
No.16(1.18mm)	319	283	283	295.0	19	81	50-85
No.30(600μm)	1052	932	903	957	66	34	25-60
No.50(300μm)	406	510	543	486.0	91	9	5-30
No.100(150μm)	122	172	148	147	98	2	0-10
Pan	46	30	2	34	100	0	N/A
SUM	2000	2000	2000		278		

The fineness modulus of the river sand was calculated from the cumulative retained in Table 5 as follows:

$$\text{FM} = \frac{\sum \text{Commulative Retained \%}}{100}$$

Fineness modulus $= \frac{278}{100} = 2.78$

From Figure 2 the gradation curve of river sand is lay between the upper limit and lower limit which is well graded.

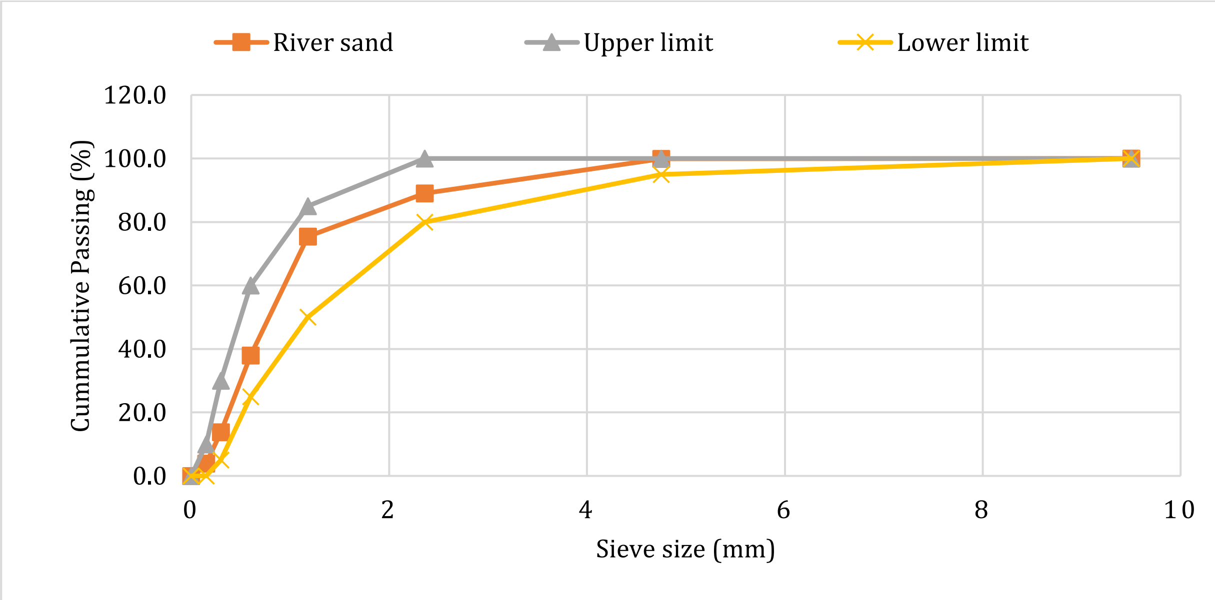


Figure 4: Grading curve of river sand

4.3.4. Water

Potable tap water was used for concrete mix and curing. No chemical admixtures were employed in the mixes.

4.3.5. Recycled fine aggregate

The recycled fine aggregate from demolished HCB was used as a replacement for river sand. The data required for extraction of the fine aggregate were collected separately from demolished disposal site by hand picking to avoid the other wastes The demolished materials of residential house (student dormitory of Jimma University) were disposed in the University compound. The demolished HCB wastes has some impurities attached to the surface. These attachments were plastering, wall Ceramic from toilet and bath room, and different painting. These attached impurities have to be removed and crushing of the rubble into suitable and desirable particle size can be carried out using appropriate mechanical devices [6]. In recycling the demolished HCB for fine aggregates, the following techniques were used:

1. Sorting: - sorting is a means of separating different types of wastes in their respective nature to manage the wastes easily and simply. Separating different types of wastes components enable to identify the recyclable materials from non-recyclable materials and decomposable materials from non-decomposable materials. In the sorted

materials there are also unnecessary materials attached to demolish HCB which have to be removed before crushing. Therefore, from demolition disposal site which filled with different waste materials, HCB were sorted and then unnecessary attachments on HCB like ceramics from toilet and shower rooms were removed by chiseling

2. Re-sizing /crushing. Resizing was important due to the crushing machine capacity and also enable to remove unnecessary components which pass the sorting stage. Re-sizing was done by rock hammer to the size appropriate for crushing machine. Then the crushing machine was crushed to different size which has both fine and coarse aggregate size. The Jaw crushing technique was found more efficient, than hammer technique [61].
3. Grading: - at this stage, the recycled aggregate with different size were identified to recycled fine and coarse aggregate through sieving. The recycled aggregate pass through 4.75mm sieve size were considered as fine aggregate which used for this investigation and above 4.75mm is considered as coarse aggregate.
4. Removal of contaminants - the DRFA has several foreign materials like gypsum, clay, wood, ceramic, and organic materials. Further cleaning is necessary to ensure the recycled fine aggregate product was free of dirt, clay, wood, and organic materials. This was done through a variety of methods including screening, hand picking, floatation and washing recycled fine aggregate. Gypsum in DRFA may be found in powder form and/or in large size as peeled. The large in size were picked by hand and the powdered gypsum and mortar were sieved through 75 µm sieve size and then washed.

Figure 5: Sorting sample from disposal site

Figure 6: Extraction of fine aggregate from demolished HCB wastes

4.3.6. Properties of DRFA

The properties of recycled fine aggregate material were tested as per ASTM standard procedures.

Silt content

The maximum silt content of fine aggregate for all concrete types as per ASTM C 33 is 6% [56] if the silt content exceeds 6%, the sand has to be washed before use. The silt content of RFA from the demolished HCB was done after sieved as per ASTM C 117-90

[60]. The fine particles/ silt content in the DRFA are more than the limit (6%), which is 14.2%. This is due to cement powder from mortar and dust of fracture during the crushing process. Therefore, the RFA has to be washed so that these fine particles will get reduced. During the silt content test water-soluble materials will be removed.

Table 6: Silt content of DRFA after washed

Determination of silt content				
Observation sheet				
S. No.	Description	Sample No.		
		Sample 1	Sample 2	Sample 3
1	Original dry mass of sample in g.	1000	1000	1000
2	Dry mass of sample after washing in g	944	961	969
3	Percentage of silt= $\frac{B-C}{B} * 100$	5.6	3.9	3.1
Average		4.2%		

After washing measurements showed that silt content is reduced to 4.2%, which is less than 6% and within a desirable level of use. As silt content increase the stiffness of the specimen increased due to dry unit weight and density increment [62].

Unit weight/ Density

The unit weight of the DRFA was less than that of river sand but within the acceptable range, and this was attributed to the porous cement mortar adhered to the DRFA [63]. The fine aggregate with density less than 1120kg/m^3 is called lightweight and DRFA was not in this range, which is greater than 1120kg/m^3.

Specific gravity and water absorption

The bulk density of DRFA is less than that of natural river sand, and the same phenomena existed with former researchers [17, 19, 23]. The reason is the presence of mortar adhered to the natural sand and fine particle from the mortar [31, 63].

The water absorption capacity of fine aggregates have to be within the range of 0.2 to 2% [56] and the water absorption capacity of the DRFA is higher than the range specified [6]. This high-water absorption capacity (6.84%) is due to the fine particles and adhered mortar.

Moisture content

The moisture content of recycled fine aggregate from the demolished waste of hollow concrete block is taken after washed, and due to this, the moisture content is higher than that of river sand. As per ASTM C 33 [56] requirement, all properties listed in the table above are within the range.

Table 7: Summary of properties of DRFA

Test type	Test Result of DRFA	Test method/ standards used
Silt content (%)	4.2	ASTM C 117 [60]
Fineness modulus (%)	2.9	ASTM C 136 [57]
Unit weight (kg/m^3)	1229.1	ASTM C 29 [44]
Moisture content (%)	0.5	ASTM C 566 [47]
Bulk specific gravity (SSD)	2.35	ASTM C 128 [45]
Bulk Specific gravity dry basis	2.2	ASTM C 128 [45]
Apparent Specific gravity	2.59	ASTM C 128 [45]
Absorption capacity (%)	6.84	ASTM C 128 [45]

DRFA: Demolished recycled fine aggregate, SSD: Saturated-surface dry,

Gradation/Sieve analysis

Sieve analysis or gradation test is used to assess the particle size distribution of aggregate. Gradation affects many properties of fine aggregates. With careful selection of the gradation, it is possible to achieve high bulk density and low permeability. The degree of gradation also called fineness modulus of sand. This is done by passing the materials through a set of sieves with openings of different diameter, #3/4, #4, #8, #16, #30, #50, #100, and #200 sieves as per ASTM C 136 [57]. By separating larger from smaller particles we can calculate the percentage of passing each sieve.

Then the fineness modulus of the fine aggregate was, the cumulated percentage retained of each sieve of coarser than #100 and divide by 100, that is

Fineness modulus = $(\frac{m1+m2+m3+m4+m5+m6}{100})$ where m_i are mass retained on each sieves. Fineness modulus of fine aggregate varies from 2 to 3.5mm. Fine aggregate with fineness modulus more than 3.2 is not considered as fine aggregate.

The fineness modulus of recycled fine aggregate from demolished HCB is 2.9 which means the value is between the 2nd sieve and the 3rd sieve. When the sieve named from 0.15mm to 4.75mm as 1-6. Therefore, the sand type is medium sand since it is in the range of 2.6-2.9.

Table 8: Sieve analysis of DRFA

ASTM sieve Designation and Sieve size (mm)	Weight retained (gm.)			Average weight Retained (g)	Cumulative retained (%)	Percentage passing (%)	Specification % passing (ASTM C33) [56]
	Sample 1	Sample 2	Sample 3				
3/8(9.50mm)	0	0	0	0	0	100	100
No.4 (4.75mm)	2.5	2	1	1.8	0.1	99.9	95-100
No.8(2.36mm)	109	197	236	180.7	9.1	90.9	80-100
No.16(1.18mm)	397	412	504	437.7	31	69.0	50-85
No.30(600µm)	801	744	695	746.7	68.3	31.7	25-60
No.50(300µm)	442	427	372	413.7	89	11.0	5-30
No.100(150µm)	213	186	167	188.7	98.5	1.5	0-10
Pan	35	29.5	26.5	30.3	100	0.0	N/A
SUM	2000	2000	2000		290		

The fineness modulus of the DRFA was calculated from the cumulative retained in Table 8 as follows:

$$FM = \frac{\sum Commulative\ Retained\ \%}{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Equation 10

Fineness modulus $=\frac{296}{100}$ = 2.9

As shown in Figure 5 the gradation curve of DRFA lays between upper and lower limit, which satisfy the ASTM standard requirement and is well graded. The fineness modulus of DRFA 2.9, calculated as per ASTM C 136 [57], lays in the range of 2.6-2.9, which is a medium sand type.

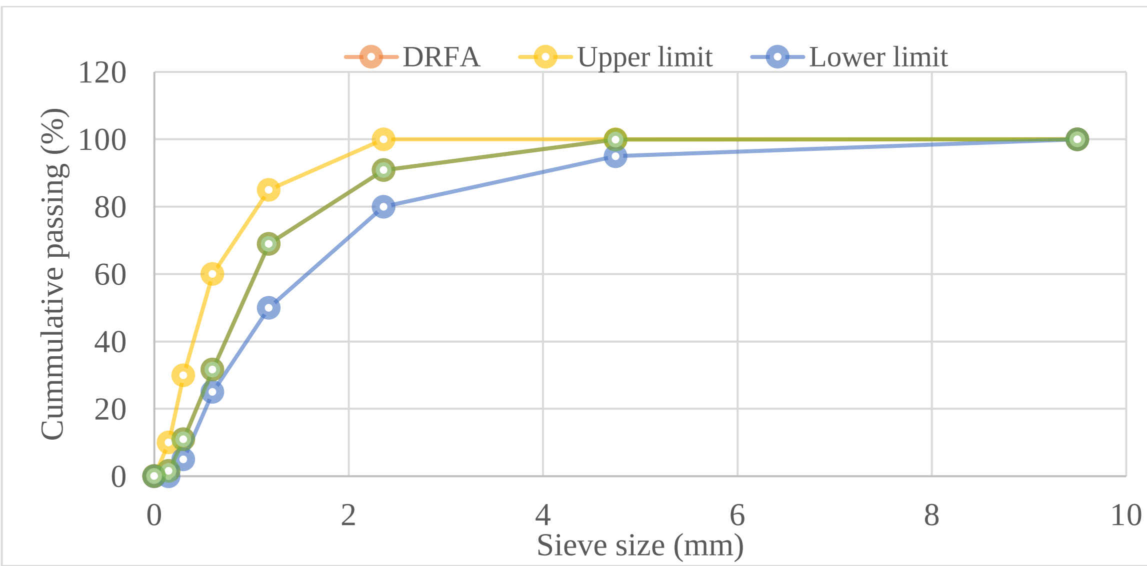


Figure 7: Grading curve of DRFA laying between upper and lower limit of ASTM C 33

X- Rays diffraction analysis test

The radiographic phase analysis can clearly identify the crystalline materials qualitatively. So, it was used in this study to investigate the different phases of which the DRFA consisted such as Quartz, calcite and Gypsum. The graph show that which chemical composition is found predominantly in the recycled fine aggregate from demolished HCB wastes.

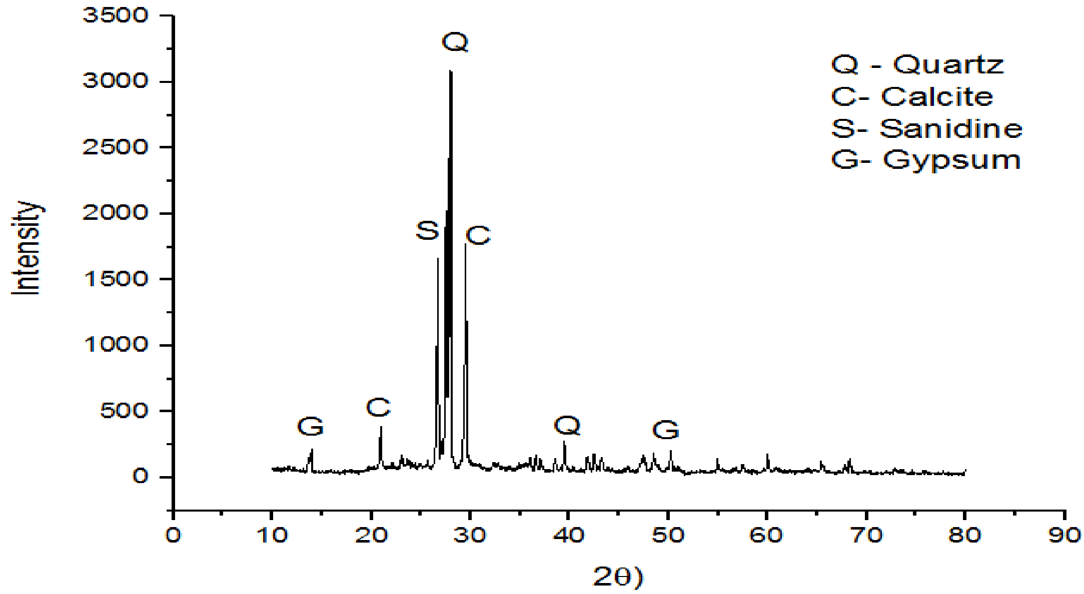


Figure 8: Graph of x-ray diffraction analysis for DRFA

4.4. Experimental procedures

The effect of recycled fine HCB aggregate on the compressive strength of concrete was studied. The mix design was done to achieve a compressive strength of 25 MPa with different percentage of replacement of river sand with DRFA. This is the comparative study of control mix with different percent replacement of DRFA. The following properties of the materials were tested.

Cement: - fineness, setting time, normal consistency

Coarse aggregate: - silt content, gradation, density, specific gravity, and water absorption

River sand: - silt content, gradation, density, specific gravity, and water absorption

Recycled fine aggregate: - silt content, gradation, density, specific gravity, and water absorption were tested as per ASTM standard.

Mix design

Characteristic compressive strength (f_{ck}) 20 MPa, which is C-25 [64] Normal strength concrete

Choice of slump set to be 25 - 50 mm (minimum slump possible)

Maximum aggregate size 20 mm.

Mixing water requirement 185kg/m^3 as per ACI table.3.8 for the slump range 25- 50mm

Water to cement ratio 0.5

Cement content 370Kg =185/0.5.

Coarse aggregate content: 995.1 kg/m^3 of coarse aggregates

Fine aggregate content 805kg/m^3

Water after adjustment 204kg/m^3

The concrete mix was performed based on weight proportions and prepared by replacing river sand by recycled fine aggregate with 0%, 25%, 50%, 75%, and 100% by mass. The mixes were designed for C-25 MPa as per ACI 301 for 28-day compressive strength [65]. The compressive strength of concrete is determined from tests on 150mm cubes at the age of 28th day in accordance with Ethiopian Standards [64]. In Ethiopia the commonly used concrete grade for the structural part is C-25. There are five types of mix with the coding of C, DRFA25, DRFA50, DRFA75 and DRFA100 which represent control (0%), 25 %, 50 %, 75 % and 100 % replacement percentage of river sand by DRFA respectively. The non-air entrained concrete with the consistent placement of minimum slump (25mm-50mm) is selected. For the mixes, the properties of fresh concrete as per ASTM C 143 for slump test, the settlement of concrete from molded truncated cone shape was measured [66]. The compressive strength at the age of 28days frequently used as a parameter for structural design [67]. For compressive strength test, the concrete specimen was cast in a 150mm*150mm*150mm cube steel mold, and the tests were performed at 7, 14, and 28 curing periods. The specimens were demolded after 24hrs of casting and placed in a water bath. The specimens were cured at the room temperature (23°C) in a water bath until tested. These experiment tests were undertaken in December 2018 in Jimma University Construction laboratory. The density of concrete was measured before the compressive strength test. During the testing of compressive strength, a calibrated compression machine with a uniform rate of 5 MPa per second loading was maintained, and the maximum load to failure at which the specimen breaks and the pointer start moving back was noted.

Table 9: The mix composition of concrete cubes

Mixes	Cement (kg/m3)	Water (kg/m3)	RS (kg/m3)	DRFA (kg/m3)	CA (kg/m3)
C	370	203.57	792.70	0.00	1001.26
DRFA25	370	209.54	594.53	198.18	1001.26
DRFA50	370	215.50	396.35	396.35	1001.26
DRFA75	370	221.48	198.18	594.53	1001.26
DRFA100	370	227.45	0.00	792.70	1001.26

C: control, DRFA: Demolished recycled fine aggregate, RS: river sand, CA: coarse aggregate

4.5. Results and Discussions

4.5.1. Fresh concrete properties

4.5.1.1. Workability test

Slump test is the most common technique for evaluating workability. The freshly mixed concrete were placed in a mold shape as frustum and compacted by rodding. Settlement of concrete from molded truncated cone shape is measured and called as the slump. The test procedures was as per ASTM Designation C 143 [66], the cone was filled with freshly prepared concrete in three stages; each layer was tamped 25 times using a rod of standard dimensions 16mm. As per ASTM C 143 concrete having slump value less than 15mm may not be adequately plastic as well as concrete with slump value greater than 230mm may not be adequately cohesive.

The test was done for all different concrete mixes, including the control mix. Slump value of concrete with recycled fine aggregate was below the minimum (25mm) which is 12mm for 25 % replacement, 9mm for 50 % replacement. The lesser slump value than the control mix is due to the high water absorption capacity of RFA. This high absorption capacity is due to the fine particles in the recycled fine aggregate, which results from the old mortar in it. The amount of these fine particles was reduced through washing and sieving by 150micro sieve. Adjusting for moisture and absorption capacity of recycled fine aggregate enables to attain uniform workability of concrete. The workability of the mixes was consistent since the water required for the DRFA was adjusted during mixing. From previous researcher [32] the of concrete with recycled aggregate can have almost same workability as concrete with natural river sand if the saturated surface dry recycled aggregate is used. But in this investigation the water required for by recycled aggregate to be saturated were added to the mix during mixing of the concrete.

Water-cement ratio

In cement hydration water is very essential to give concrete its mechanical strength, but it must be dosed correctly. Too much water increases the concrete's porosity, thus decreasing its mechanical performance and durability. A shortage of water in the mix will lead to incomplete cement hydration reactions and a reduction of the fresh concrete's workability [68]. As shown in Table 10 the water-cement ratio varies for each percentage of replacement of the recycled fine aggregate. Due to the absorption capacity of the recycled fine aggregate, the amount of water required increase as the percentage of replacement increases. The gradual increment of the water-cement ratio is to maintain the same workability range of concrete with recycled aggregate. The water-cement ratio ranges from 0.55 to 0.65. The water to cement ratio was varied to balance the water demand in a mix due to the high absorption capacity of DRFA to maintain the same workability. In the previous study, adding the same amount of water required for the absorption of RFA to the mix during mixing or using saturated surface dried recycled aggregate can have the same workability [32]. In this study, the water to cement ratio varies from 0.55 to 0.65 due to adjustment required for the absorption capacity of the DRFA.

Table 10: Slump result and water-cement ratio

Specimen	Slump (mm)	Adjusted w/c
C	30	0.55
DRFA25	30	0.57
DRFA50	30	0.60
DRFA75	29	0.62
DRFA100	29	0.65

4.5.2. Properties of hardened concrete

4.5.2.1.Unit weight of hardened concrete

The unit weight of hardened concrete with recycled fine aggregate with different percentage was compared to the control specimen. There was a slight decrement of unit weight of hardened concrete as a percentage of replacement of recycled fine aggregate increased [4]. This decrement was due to the less density of the DRFA. The research on physical and mechanical properties of recycled aggregate from construction demolition wastes in concrete [31] also find out that the recycled concrete aggregate density is less than that of the natural aggregate due to porosity which causes the lightweight concrete and this result was due to the density of recycled aggregate.

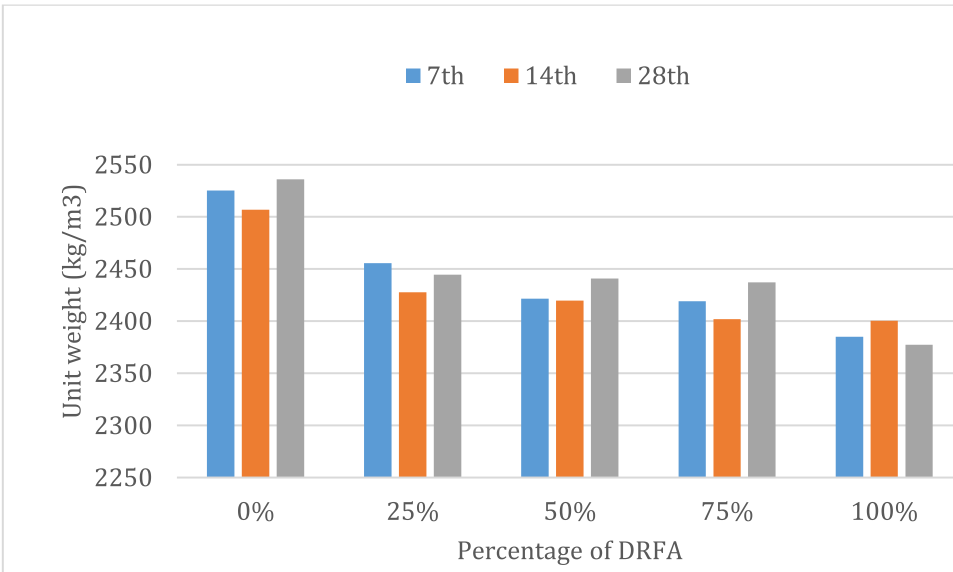
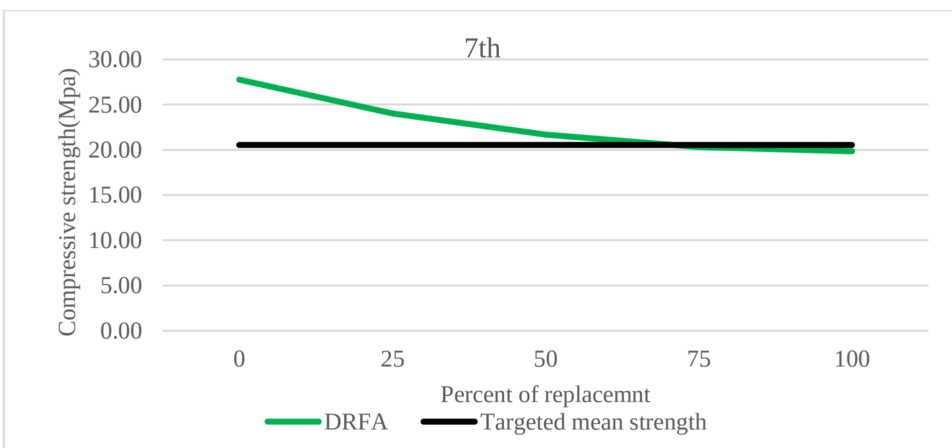


Figure 9: Unit weight of hardened concrete

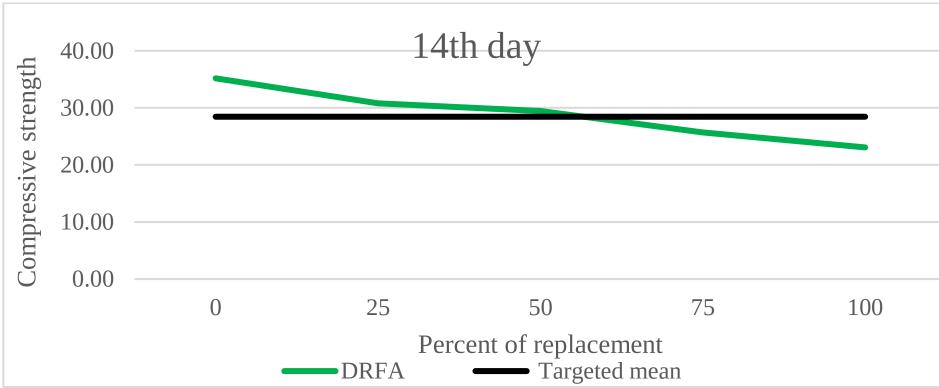
4.5.2.2.Compressive strength

The determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive stresses. Compressive strength of concrete at the age of 7th, 14th day, and 28th day curing periods are given in figure 4. The concrete gain 65 % of its compressive strength on the 7th day, 90 % on the 14th day, and 99 % on the 28th day of curing. The trends in the development of compressive strength in recycled aggregate concrete were also similar to those in natural aggregate concrete [69].The compressive strength decreased as the percentage of replacement of recycled fine aggregate increased [70]. But the replacement of recycled fine aggregate up to 50 % attained the mean target strength. The 28th average compressive strength of the control specimen is 37.50 N/mm^2. The compressive strength of concrete specimen with recycled fine aggregate with percentage replacement of 25 %, 50 %, 75 %, 100 % is 32.10 N/mm^2, 31.19 N/mm^2, 27.25 N/mm^2, and 26.86 N/mm^2 respectively. The compressive strength result obtained for RFA replacement percentage of 25 % and 50 % was above 99 % of the targeted mean strength on 28th days of curing periods. But the replacement above 50 % DRFA has a lower result than mean targeted strength.

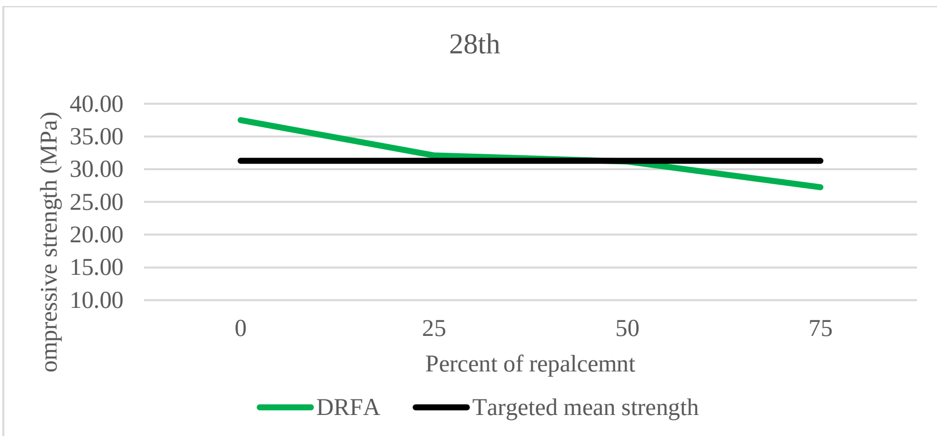
The compressive strength of concrete specimen with DRFA of 25 %, the replacement had 16.82 % reduction from the control mix, and the 50 % DRFA replacement had 20.24% reduction from the control mix. The compressive strength decreased with percentage replacement of recycled fine aggregate due to the waste from painting, gypsum, and fine particles from old cement. The investigation on the suitability of recycled concrete aggregate in concrete production in Ethiopia [19] concluded that the compressive strength of C-25 concrete with recycled concrete aggregate is diminished by 17 % and 9 % at the age of 7 and 28 days respectively as compared to the reference mix but attained the targeted mean strength.



a. 7th day compressive strength



b. 14th day compressive strength



c. 28th day compressive strength

Figure 10: a, b and c show variation of Compressive strength with DRFA replacement

The compressive strength test result is the average of three samples for each percentage and each curing period. This replication is for accuracy and consistency of the consecutive results. The Figures 8, 9, & 10 shows the relationship between the compressive strength and the percentage of replacement of RFA on 7th, 14th, and 28th day of curing periods. As the coefficient of determination (R^2-value) getting closer to 1, it indicates the degree of accuracy of the determined slopes and the R^2-value on Figure 8, 9, & 10 ranges from 0.904 to 0.9819. That is, the properties of the concrete have consistency throughout the test of different percentage replacement.

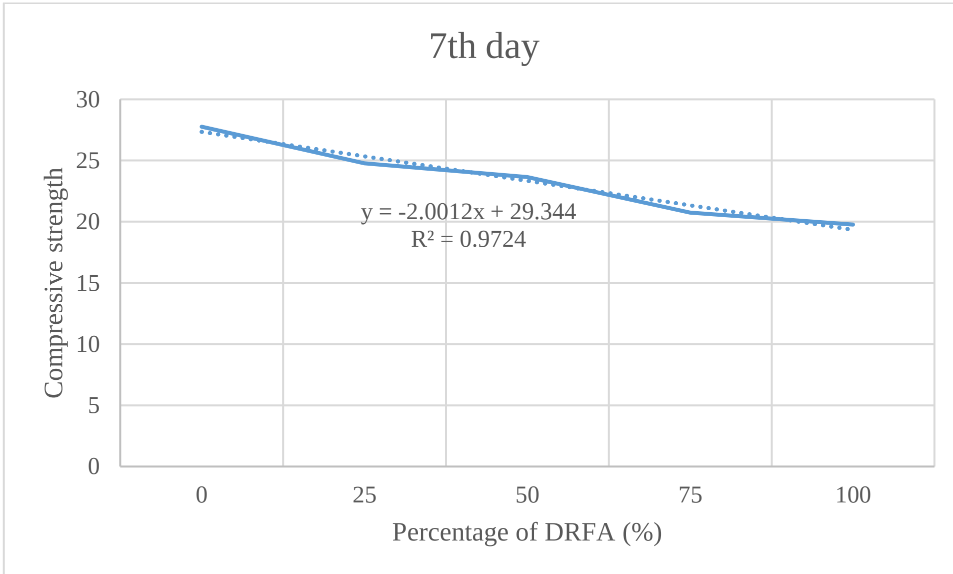


Figure 11: The relation between 7th-day compressive strength and percentage of DRFA replacement

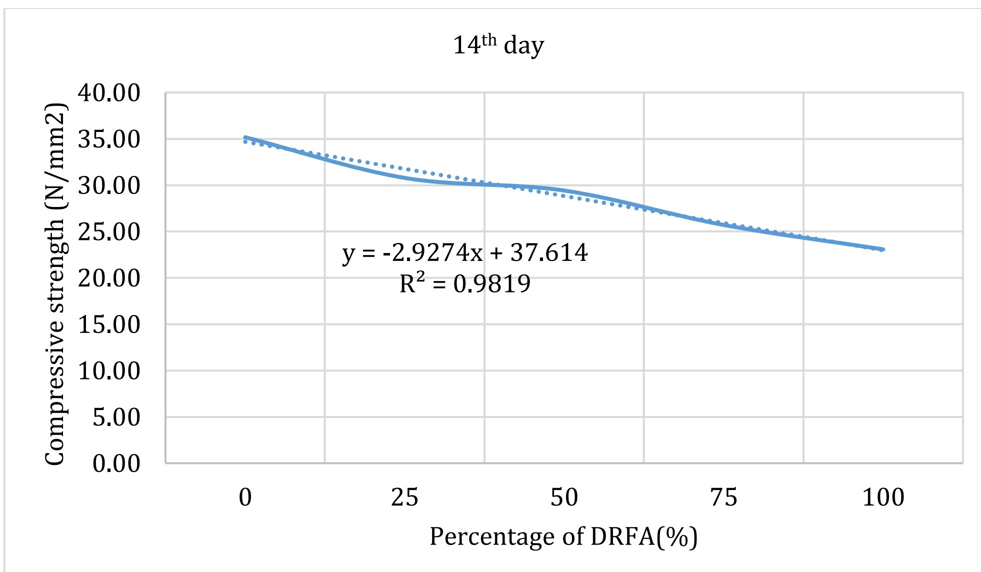


Figure 12: The relation between 14th-day compressive strength and percentage of DRFA replacement

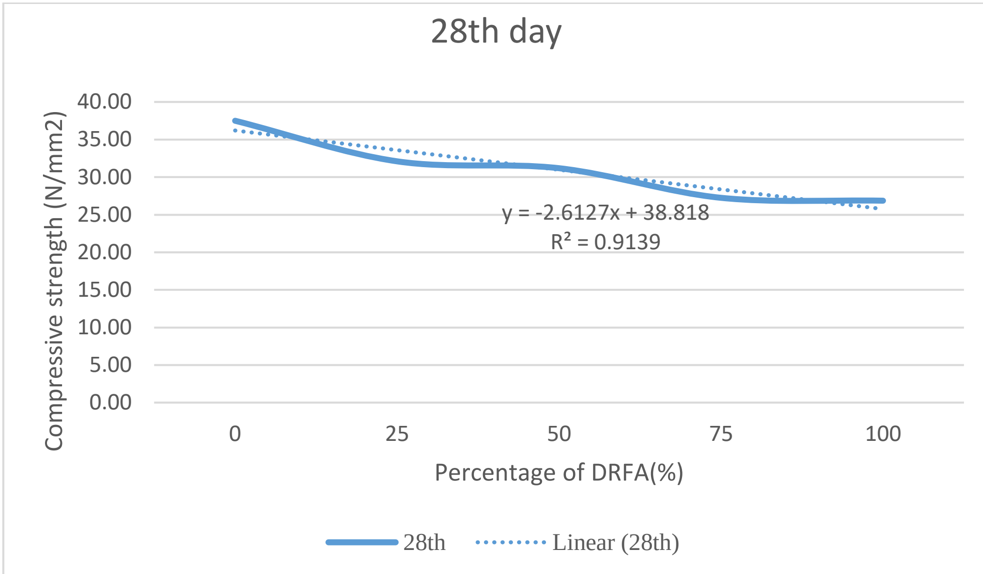


Figure 13: The relation between 28th-day compressive strength and percentage of DRFA replacement

The error bar for the compressive strength of 7th day, 14th day, and 28th day are shown below in Figure 11, 12, and 13. This show how much the measurements of the samples are spread out from the average result. If the value of the standard deviation is less than 1, that is low variance, and if the standard deviation is greater than 1, the samples were spread out. From the figures, the values of the three samples were closer to each other.

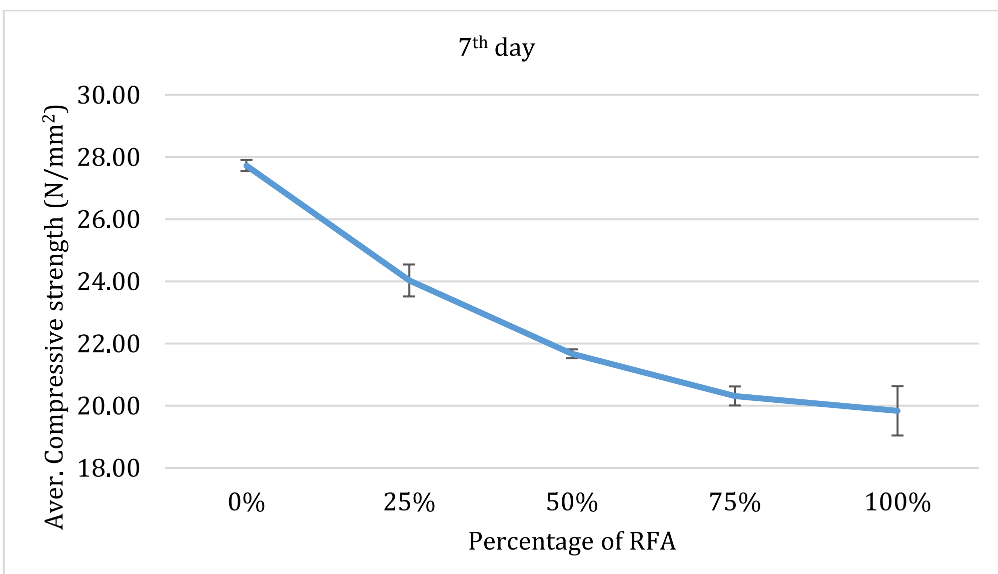


Figure 14: Error bar for 7th day compressive strength

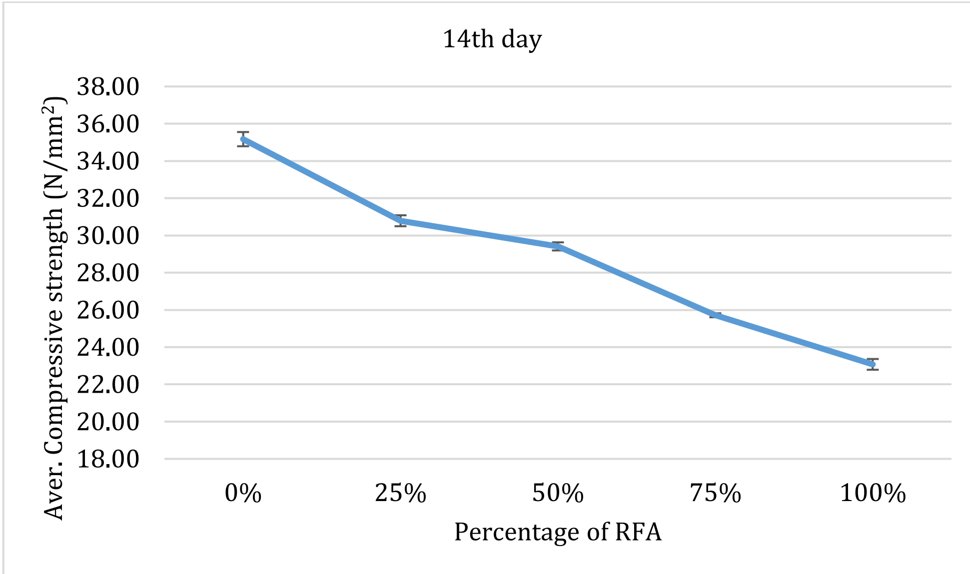


Figure 15: Error bar for 14th day compressive strength

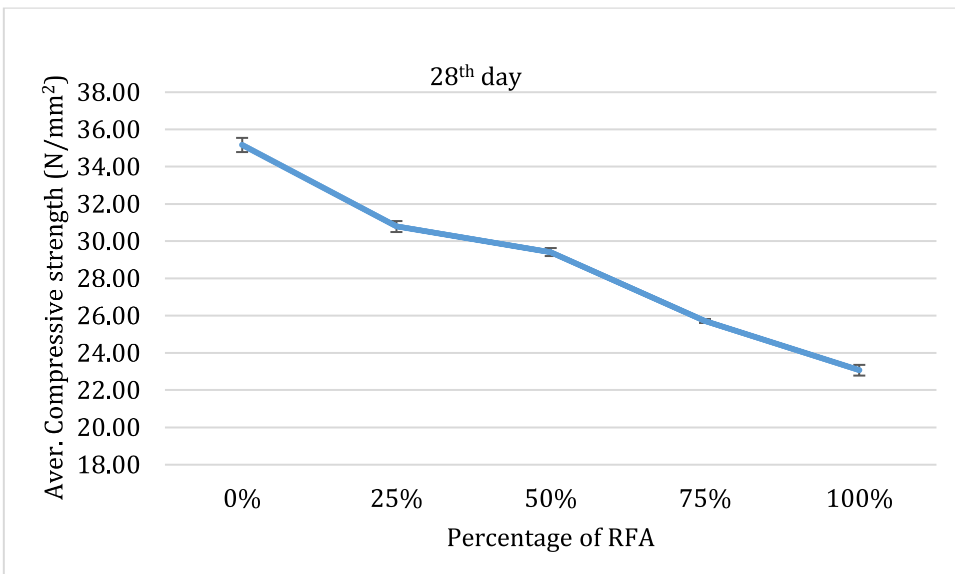


Figure 16: Error bar for 28th day compressive strength

4.6. Conclusion

In this research, the RFA from demolished HCB waste has been extracted using crushing machine (jaw crusher). The suitability of RFA from demolished HCB in new concrete production and the properties of RFA as compared to natural river sand was examined. The DRFA has slightly lower physical properties as compared to the natural river sand but within required standard. The DRFA has high silt content, high water absorption and less unit weight than natural sand. The effect of RFA on concrete properties such as: workability, density, and compressive strength of C-25 MPa was also checked. The compressive strength decreased as the percentage replacement of DRFA increased. The DRFA can replace the river sand up to 50 %, which can attain the targeted mean strength of C-25 concrete.

Therefore, form this research work, it can be concluded that the demolished HCB can be used as RFA to replace river sand in the production of new concrete [71]. The DRFA can be used up to 50% replacement percentage and this research can benefit in conserving the non-recyclable natural resources and environmental protection from demolition waste disposal.

CHAPTER 5

Investigation of the effect of recycled fine aggregate from new construction wastes in C-25 concrete in Ethiopia

5.1. Abstract

Wherever there are construction activities, there is waste generation. In Ethiopia, the popular material for wall construction is a hollow concrete block that can be broken on the production site or construction site during loading and unloading. This research aims at searching for alternative construction materials through recycling and examines the properties of recycled fine aggregate from construction (new) hollow concrete block (HCB) wastes. The study examined the effect of the recycled HCB on the fresh and hardened C-25 concrete properties and the possible replacement percentage of river sand by construction recycled fine aggregate (CRFA). The replacement percentage is in steps of 25%, starting from 25% up to 100%, and 0% represents the reference mix. The compressive strength test for concrete specimens of 150mm cube were performed at 7th, 14th, and 28th day of the curing period. In general, the recycled fine aggregate exhibited relatively lower physical properties than natural river sand but satisfied the ASTM standard requirements. The properties of fresh and hardened concrete were decreased as percentage replacement of CRFA increased. The optimum percentage replacement of river sand by CRFA was lay between 50% and 75% but very closer to 75%. Recycling wastes can reduce environmental impact due to sand mining and waste disposal and can conserve the natural resource depletion partially.

Keywords: Concrete, Construction hollow concrete block wastes, Compressive strength, Construction recycled fine aggregate.

5.2. Introduction

The construction industry is one of the sectors that contribute wastes to the environment in large quantities. The waste generated from the construction industry in developing countries is enormous due to poor management practices and the rate of construction is high due to quick urbanization, industrialization, and economic development [19]. To better preserve the environment for sustainable development, finding all possibilities and opportunities for reducing the waste products of work areas has to be a major concern [26, 31]. Construction wastes are originated from new materials during construction as well as during production on precast sites. The properties of the construction waste are less mixed not much contaminated and easier in preparation of recycling.

For the construction of walls, the popular material used in Ethiopia is HCB [43]. Most construction sites, as well as HCB production sites, have plenty of HCB wastes. HCB can be broken on production sites or construction sites during the loading and unloading, which of itself can create wastage. These wastes are found collectively in a site with different sizes and different amounts and disposed to the disposal site as a landfill. The recycling of concrete structures as concrete aggregate in Ethiopia was investigated, and promising results were found [19, 41, 42]. The physical properties of recycled concrete aggregate are within the range of normal weight aggregate. However, the properties of recycled concrete aggregate are lower than the properties of natural coarse aggregate. Recycling of wall materials, HCB wastes, is very crucial due to their abundance in demolished as well as in construction/production site wastes.

5.3. Materials

In this section, the materials used for experimental purposes are elaborated. The properties of all materials used were checked as per standards. Further treatment occurred after crushing to enhance the quality of recycled fine aggregate from construction wastes. Tests were conducted to determine the properties of recycled fine aggregate from construction HCB wastes. In this study, 45 experimental samples were prepared for five different tests of fresh and hardened concrete properties. The data were collected from Jimma, Ethiopia, and experimental studies were undertaken in Jimma University's construction laboratory. All experiments were conducted and compared to the ASTM, ACI, and ES standards according to the local technical specification [52].

5.3.1. Cement

As a binding material, Dangote Ordinary Portland cement with a strength class of 42.5 N was used. The cement obtained from a single batch was used throughout the test with compliance to ASTM standard specifications. The cement specific gravity, fineness, and normal consistency were conducted as per the ASTM standards. The properties of cement summarized in table 11. The fineness of the OPC was tested as per ASTM C 184 [53], and for OPC, the percentage of residue retained after sieving by No. 200 sieve should not exceed 10% by weight. From table 11 the fineness of cement is within the required limit. The setting time of the OPC 42.5R was checked as per ASTM C 191 [54], and the initial setting shall not be less than 30 min and for final setting time not greater than 600min which satisfied the requirements. The normal consistency property of OPC was tested to determine the optimum amount of mixing water required to prepare hydraulic cement pastes for tests as per ASTM C 187 [55].

Table 11: Summary of Cement properties

Test types	Test result	Test method
Fineness (%)	4.5	ASTM C 184 [53]
Initial setting time (min)	230	ASTM C 191 [54]
Final setting time (min)	314	ASTM C 191 [54]
Normal consistency (%)	33	ASTM C 187 [55]

5.3.2. Water

Potable tap water was used for concrete mixing and curing of the specimen throughout the experiment.

5.3.3. Coarse aggregate

For the coarse aggregate, locally available crushed stone aggregate with a nominal size of 20 mm was used. The specific gravity, water absorption, and fineness modulus properties of coarse aggregates were checked as per the ASTM standard [56] and summarize in table 12. The coarse aggregate used in this experiment was attained the ASTM requirement of coarse aggregate and all properties lay within normal range.

Table 12: Summary of properties of coarse aggregate

Test type	Test Result	Standards used
Fineness modulus (%)	6.34	ASTM C-136 [57]
Unit weight (kg/m^3)	1605	ASTM C-29 [58]
Moisture content (%)	0.35	ASTM C-566 [47]
Bulk specific gravity (SSD)	2.65	ASTM C-127 [59]
Bulk Specific gravity dry basis	2.63	ASTM C-127 [59]
Apparent Specific gravity	2.70	ASTM C-127 [59]
Absorption capacity (%)	0.98	ASTM C-127 [59]

SSD: Saturated-surface dry

It can be observed that from Figure 14 the gradation curve of coarse aggregate is between the upper limit and lower limit, which show that the coarse aggregate is well graded.

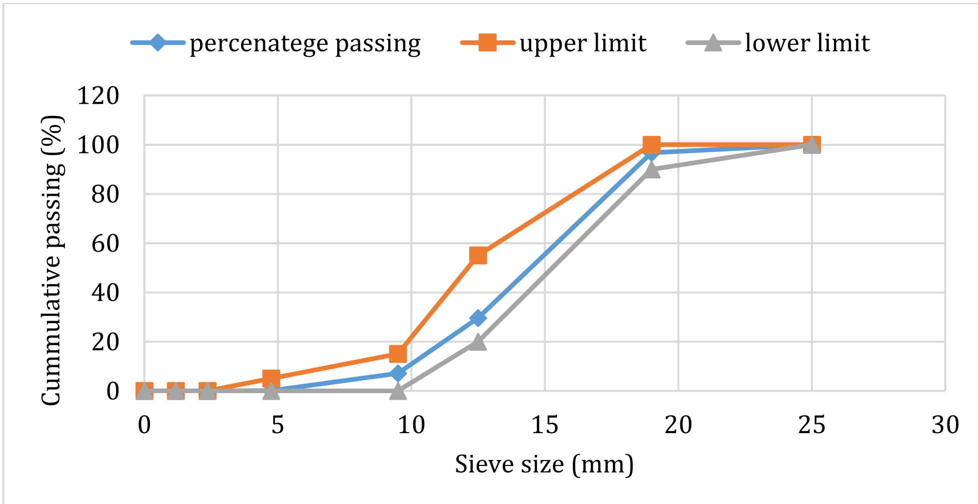


Figure 17: Gradation curve of coarse aggregate

5.3.4. Sand

There were two types of sand used for this research work, locally available river sand and recycled fine aggregate. The locally available river sand was taken from chewaka and checked for silt content, gradation, absorption capacity, moisture content, unit weight, and bulk specific gravity as per ASTM standards and the summarized in Table 13.

Table 13: Summary of river sand properties

Test type	Test Result DRFA River sand	Test method/ standards used
Silt content (%)	2.87	ASTM C 117 [60]
Fineness modulus (%)	2.78	ASTM C 136 [57]
Unit weight (kg/m^3)	1505	ASTM C 29 [44]
Moisture content (%)	0.2	ASTM C 566 [47]
Bulk specific gravity (SSD)	2.55	ASTM C 128 [45]
Bulk Specific gravity dry basis	2.5	ASTM C 128 [45]

Apparent Specific gravity	2.62	ASTM C 128 [45]
Absorption capacity (%)	1.73	ASTM C 128 [45]

Table 14: Sieve analysis of river sand

ASTM sieve designation and Sieve size (mm)	Weight retained (gm.)			Average weight retained (g)	Cumulative retained (%)	Percentage passing (%)	Specification % passing (ASTM C33) [56]
	Sample 1	Sample 2	Sample 3				
3/8(9.50mm)	0	0	0	0	0	100	100
No.4 (4.75mm)	0	0	0	0	0	100	95-100
No.8(2.36mm)	71	70.5	92.5	78	4	96	80-100
No.16(1.18mm)	319	283	283	295.0	19	81	50-85
No.30(600µm)	1052	932	903	957	66	34	25-60
No.50(300µm)	406	510	543	486.0	91	9	5-30
No.100(150µm)	122	172	148	147	98	2	0-10
Pan	46	30	2	34	100	0	N/A
SUM	2000	2000	2000		**278**		

The fineness modulus of the river sand was calculated from the cumulative retained in Table 14 as follows:

$$\text{FM} = \frac{\sum \text{Commulative Retained \%}}{100}$$

Fineness modulus $= \frac{278}{100} = 2.78$

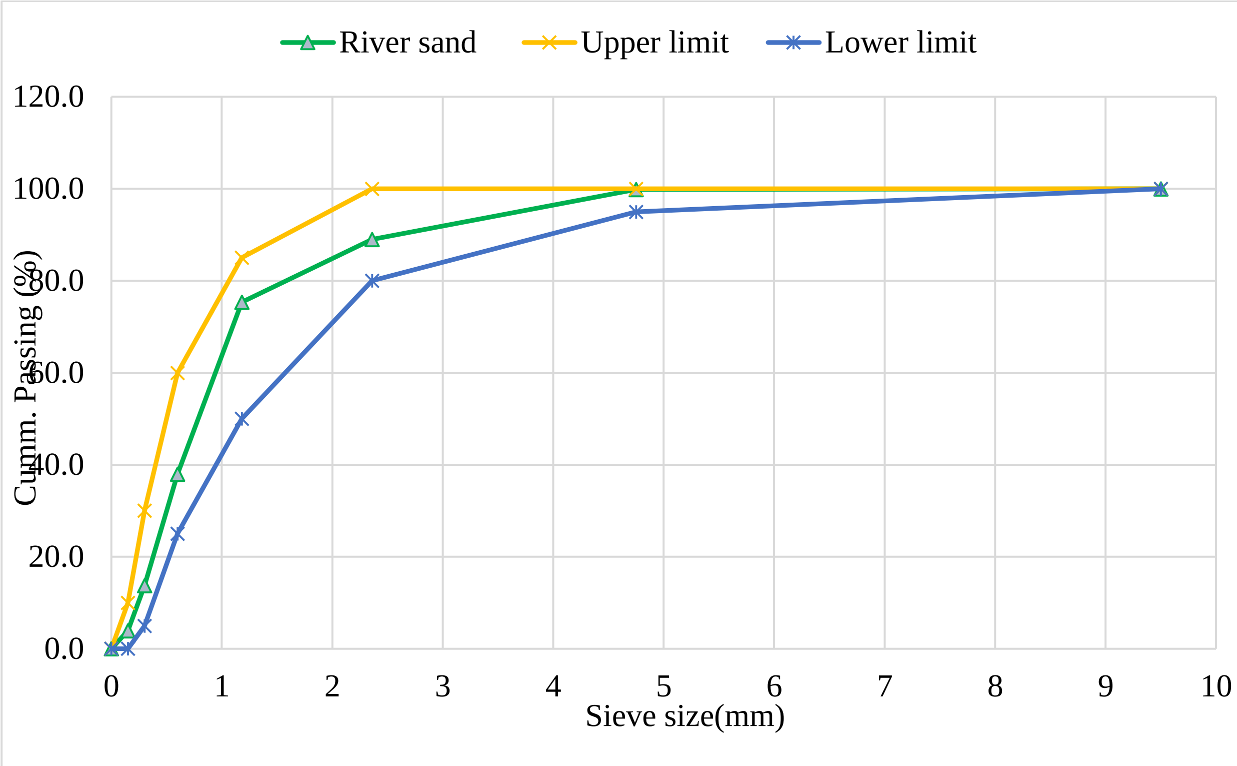


Figure 18: Gradation curve of Chawaka river sand

5.3.5. Recycled fine aggregate

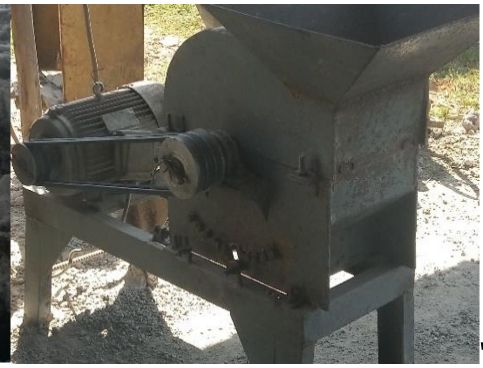
5.3.5.1.Extraction of Construction RFA

The recycled fine aggregate from the construction waste of HCB was collected from HCB production sites found in the city of Jimma, which is called Degene Tsedale Hebret and Lemlem (DTHL) production site, as shown in Figure 16, to avoid contamination in construction sites such as mortar, gypsum, and painting. The HCB used for this experimental purpose had an age of two months and was stocked to be used in construction. The HCB was processed to get recycled fine aggregate as per the following steps and as shown in Figure 17.

1. Selection: non-load bearing HCB, which was manufactured according to the specification of ASTM C 129–70 [72], and those that had the same aging were selected. According to ES 596–2001, a non-load bearing HCB used for partition was selected to be recycled.

2. Re-sizing/crushing: re-sizing included breaking the HCB by rock hammer to the appropriate size for the crushing machine. Then, the crushing machine was crushed to a different size, which had both fine and coarse aggregate sizes;
3. Grading: identifying different sizes of recycled aggregate to recycled fine and coarse aggregate through sieving. The recycled aggregates that passed through 4.75 mm sieve size were considered as fine aggregate, and fine particles that passed through sieve size No.100 (150 μm) were avoided;
4. Washing and floatation: the crushed recycled fine aggregate had the fine particle from mortar and some lightweight floating materials. Washing the recycled fine aggregate reduced the silt content and increased the quality of the materials.

Figure 19: Production site of the sample collected



a. Sorting from disposal site b. crushing machine for grinding c. Screening.

d. Washing and floatation

Figure 20: a, b, c, and d are different phases of preparing recycled fine aggregate.

5.3.5.2. Properties of CRFA

The physical properties of recycled fine aggregate from construction HCB wastes, silt content, sieve analysis, unit weight, moisture content, specific gravity, and water absorption were tested as per the ASTM standard, and the results are summarized in Table 15. The silt content of extracted CRFA before washing was very high which is 12.57 %, but the silt content was reduced by washing CRFA to attain the limit. In CRFA, the cement in HCB and the fracture dust during crushing were the cause for high fine particles that passed through the 150 µm sieve size [35, 71]. The silt content test was done by washing the finer particle less than 75 µm as per ASTM C 117–90 [60]. From Table 15, the silt contents of CRFA is reduced to 3.9%.

The unit weight of the CRFA is less than that of river sand due to the attached mortar and mortar pieces which is the same as previous research findings [19, 34, 73]. Less unit weight is due to the porous cement mortar materials attached on the surface of CRFA and the finer particles from old cement. The unit weight of CRFA is within an acceptable range of ASTM standards, and the test was done as per ASTM Designation C- 29 procedure [58].

The water absorption capacity of CRFA was checked since the water absorption capacity is one of the vital criteria for mix design. As per ASTM requirements, the water absorption capacity of CRFA (5.1%). is higher due to fine particles and due to adhered mortar on it.

Table 15: Summary of properties of CRFA

Test type	Test Result of CRFA	Standard applied
Silt content (%)	3.9	ASTM C-117 [60]
Fineness modulus	2.83	ASTM C-136 [57]
Unit weight (Kg/m3)	1202	ASTM C-29 [58]
Moisture content (%)	0.6	ASTM C-566 [47]
Bulk specific gravity(SSD)	2.36	ASTM C-128 [45]
Bulk Specific gravity dry basis	2.24	ASTM C-128 [45]
Apparent Specific gravity	2.53	ASTM C-128 [45]
Absorption capacity (%)	5.10	ASTM C-128 [45]

CRFA- Construction recycled fine aggregate

The sieve analysis of the CRFA were undertaken and the gradation was satisfying the ASTM requirement. In the Table 16 the percentage passing each sieve size of CRFA has compared to the ASTM specification requirement and all are within required standard. The fineness modulus of the sand varies from fine sand 2.2-2.6, medium sand from 2.6-2.9, and coarser sand from 2.9-3.2. The fineness modulus of CRFA lies in the range of 2.6-2.9, which is medium sand type.

Table 16: Sieve analysis of CRFA

ASTM Sieve Designation and Sieve size (mm)	Weight retained (gm.)			Average weight Retained (g)	Cumulative retained (%)	Percentage passing (%)	Specification % passing (ASTM C33)
	Sample 1	Sample 2	Sample 3				
3/8(9.50mm)	0	0	0	0	0	100	100
No.4 (4.75mm)	2.5	2.5	3	2.7	0.1	99.9	95-100
No.8(2.36mm)	163	133	115	137	7	93	80-100
No.16(1.18mm)	300	408	401	369.7	25.5	74.5	50-85
No.30(600µm)	798	756	745	766.3	63.8	36.2	25-60
No.50(300µm)	497	465	490	484	88	12	5-30
No.100(150µm)	221	215	225	220.3	99	1	0-10
Pan	14	20	18	18.3	100	0	N/A
SUM	2000	2000	2000		**283.4**		

The fineness modulus of the CRFA was calculated from the cumulative retained in Table 16 as follows:

$$\text{FM} = \frac{\sum \text{Commulative Retained \%}}{100}$$

$$\text{Fineness modulus} = \frac{28.34}{100} = 2.83$$

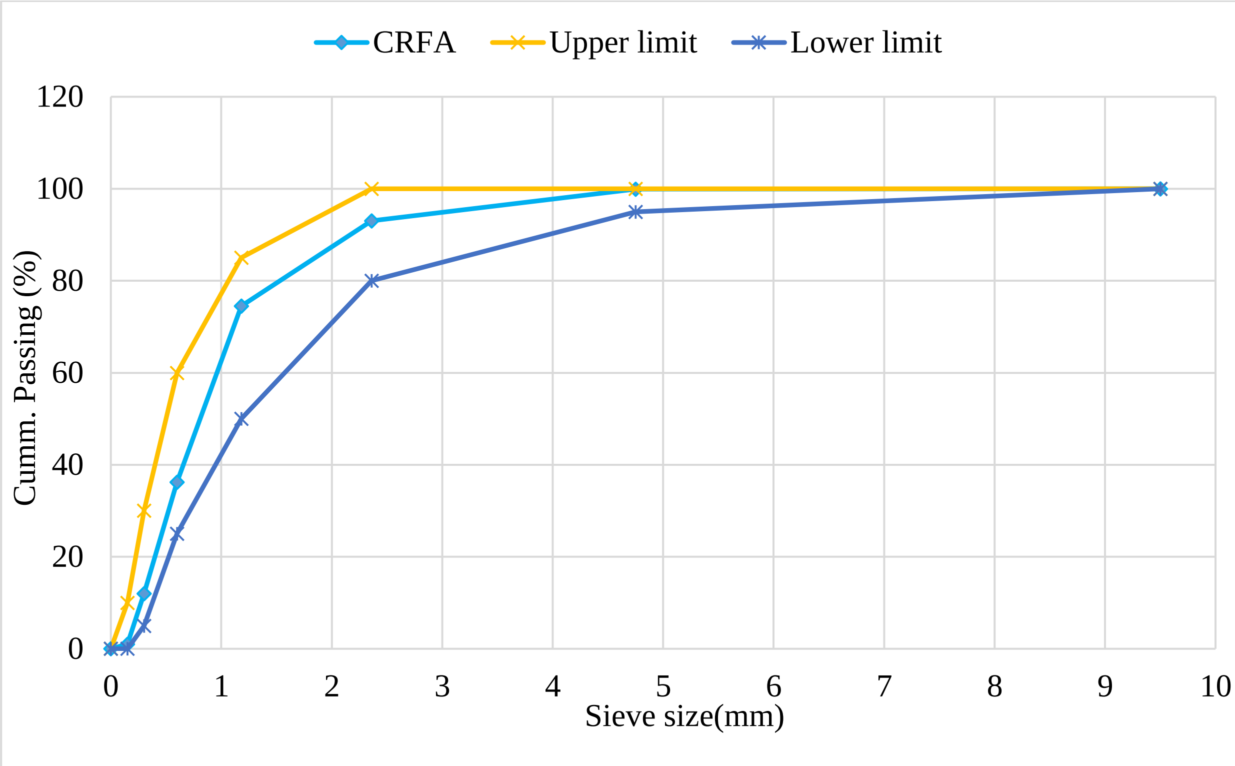


Figure 21: Gradation curve of CRFA

X-ray diffraction analysis test

XRD Analysis is used to clearly identify the crystalline minerals qualitatively and to determine the minerals components. This technique is mostly used to identify the intensity and structure of crystalline materials. The phase can be identified according to its X-ray diffractions. Therefore, the XRD was used in this study to investigate the different phases of the recycled fine aggregates from construction HCB wastes consists such as quartz, lime and gypsum. The procedures in XRD analysis is; the CRFA samples were oven dried for 24hrs in laboratory and grounded to fine powder. Then put the grounded fine powder in a sample container in 1mm thick layer, which is supported in the measurement circle of the diffractometer device. Then the measurement starts and the diffractometer used was computer controlled. The samples were run once over a 2θ drive axis at scan range of 10°–80° with a continuous scanning mode. The scan sped was 3.0deg/min with sampling pitch of 0.020deg.The results from the scan were used to do a qualitative analysis of the samples. The qualitative analysis was done using the software for the XRD. The graph is drawn between 2θ and intensity. The components of the sample were identified by comparing them with standards established by the International Centre for Diffraction Data. The graph show that which chemical composition is found predominantly in the recycled fine aggregate from production site HCB wastes.

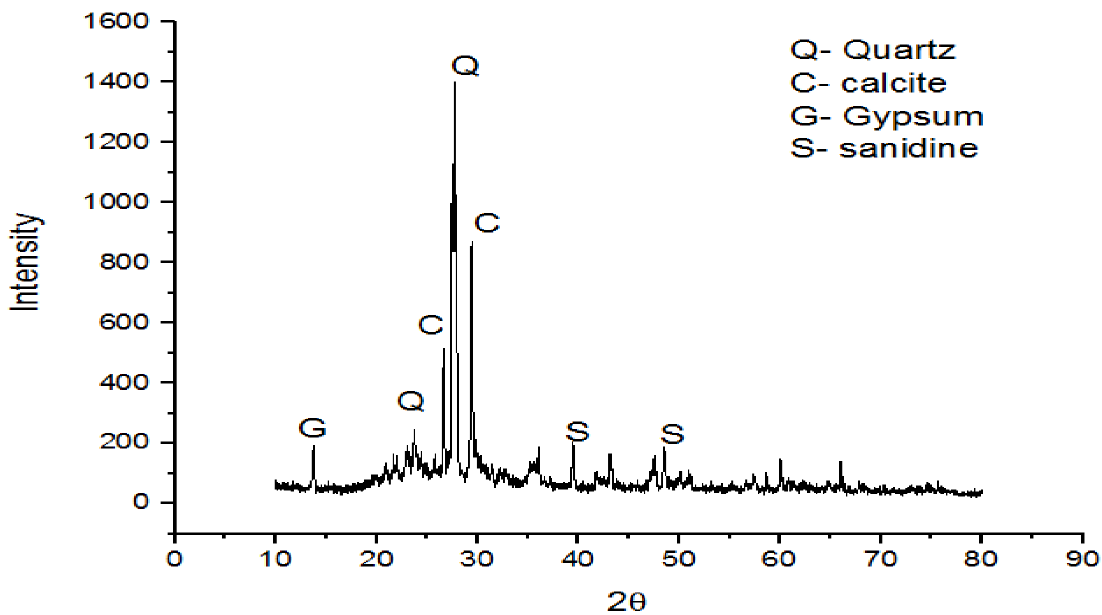


Figure 22: Graph of x-ray diffraction analysis for CRFA

5.4. Tests

For the result obtained from crushed and processed demolished and Construction HCB wastes, three different mixtures were designed to analyze the properties of fresh and hardened concrete. The concrete mix type with only natural sand is used as a control mix or reference mix with 'Co' designation. ‘CRFA’ is a mixture type with recycled fine aggregate from construction HCB wastes with different replacement percent. The mixtures with recycled fine aggregate with replacement percent of 25%, 50%, &75%, and 100% were designed by CRFA25, CRFA50, CRFA75, and CRFA100 respectively. All the concrete mixes were prepared according to the weight-based batching system as per ACI 211.1.91 [74]. All ingredients are the same for all mixes except the w/c ratio and the fine aggregate proportions. The reference mix samples were produced with 370kg/m^3 cement and 0.55 w/c ratio. But for concrete with recycled fine aggregate, the additional water was poured during the mixing to compensate the water absorption capacity according to the test result of water absorption capacity of CRFA in Table 15.

A slump test is the most common technique for evaluating the workability. The freshly mixed concrete was placed in a mold shape as frustum and compacted by rodding. The cone with a 10cm top diameter, 20cm bottom diameter, and 30cm height, was filled with freshly prepared concrete in three stages. Each layer was tamped 25 times using a rod of standard dimensions 16mm [66]. The settlement of concrete measured from molded truncated cone.

The mix design was done to achieve a compressive strength of 25 MPa with different percentages of replacement of CRFA for non-air entrained normal strength concrete. C-25 concrete is commonly used in Ethiopia in structural members like beams, columns, and slabs [64]. For the compressive strength test, the concrete specimens were cast in a 150mm*150mm*150mm cube steel mold, and the experiments were performed at 7^{th}, 14^{th}, and 28^{th} day of the curing period. The specimens were demolded after 24hrs of casting and placed in a water bath at room temperature (23^{0}c) until tested. The tests were undertaken in Jimma University Construction laboratory in December 2018. During the testing of compressive strength, a calibrated compression machine with a uniform rate of 5N/mm^2 per second loading was maintained, and the maximum load to failure at which the specimen breaks were noted. The compressive machine also provides the compressive strength directly or can be found by dividing peak load by area of the sample using equation 7.

$$\text{Compressive strength} = \frac{crushing\ (maximum) load (N)}{cross\ sectional\ area\ of\ cube\ (mm2)} \quad \text{…...Equation 11}$$

Table 17: The mix composition of concrete cubes

Mixes	Cement(kg/m3)	w/c	Water (kg/m3)	RS (kg/m3)	CRFA(kg/m3)	CA (kg/m3)
C0	370	0.55	203.57	792.70	0.00	1001.26
C25%	370	0.57	209.54	594.53	198.18	1001.26
C50%	370	0.58	215.50	396.35	396.35	1001.26
C75%	370	0.60	221.48	198.18	594.53	1001.26
C100%	370	0.61	227.45	0.00	792.70	1001.26

RS=river sand, CRFA=Construction recycled fine aggregate, CA= coarse aggregate

5.5. Results and Discussions

This section reports the summary of the experimental test result with the discussion of properties of concrete with CRFA as compared to the reference mix at the fresh and hardened state.

5.5.1. Fresh concrete properties

5.5.1.1.Workability test

Slump test is the most common technique for evaluating workability. The freshly mixed concrete were placed in a mold shape as frustum and compacted by rodding. Settlement of concrete from molded truncated cone shape is measured and called as the slump. The test procedures was as per ASTM Designation C 143 [66], the cone was filled with freshly prepared concrete in three stages; each layer was tamped 25 times using a rod of standard dimensions 16mm. As per ASTM C 143 concrete having slump value less than 15mm may not be adequately plastic as well as concrete with slump value greater than 230mm may not be adequately cohesive.

The consistency of the concrete mixes at a fresh stage was determined in the laboratory by the slump test as per ASTM C 143 [66]. The slump value for the concrete with CRFA with a constant w/c ratio (0.55) was less than 15mm. As per ASTM C143, concrete that had a slump value of less than 15mm may not be adequately plastic as well as concrete with a slump value higher than 230mm may not be sufficiently cohesive. The workability of the concrete mix is mostly affected by consistency. The wetter the mix, the more workable the concrete. A concrete mix with the same consistency may vary in workability. The mix was dry due to the water absorption capacity of the CRFA. Adjusting for moisture and the water absorption capacity of the CRFA enables to attain uniform workability of concrete. So the water required for the mix increased as the percentage of replacement of CRFA increased [17, 75].

Table 18: Slump value and water-cement ratio

Specimen	Slump(mm)	w/c
Control	30	0.55
CRFA25	30	0.56
CRFA50	30	0.58
CRFA75	30	0.6
CRFA100	30	0.62

Figure 23: Slump test for concrete

Water-cement ratio: The water-cement ratio varies for each percentage replacement of the CRFA due to the absorption capacity of the CRFA. The amount of water required increased as the percentage of replacement of recycled fine aggregate increased. To maintain the same workability of concrete with CRFA, the water-cement ratio ranges from 0.55 for reference mix to 0.61 for the mix with 100% CRFA. The reason for the increment of w/c is due to the high absorption capacity of CRFA, which is 5.1%. The previous studies also agreed on the high water absorption capacity of the recycled fine aggregate due to the dust and the hardened porous cement mortar adhered to it [6, 19, 76, 77]. The water absorption capacity of recycled fine aggregates was higher than the normal aggregates, and the researcher [4] found that recycled aggregate can have 8-10% water absorption capacity. For uniform workability the water to cement ratio increased as percentage of replacement of CRFA increased as shown from Figure 20.

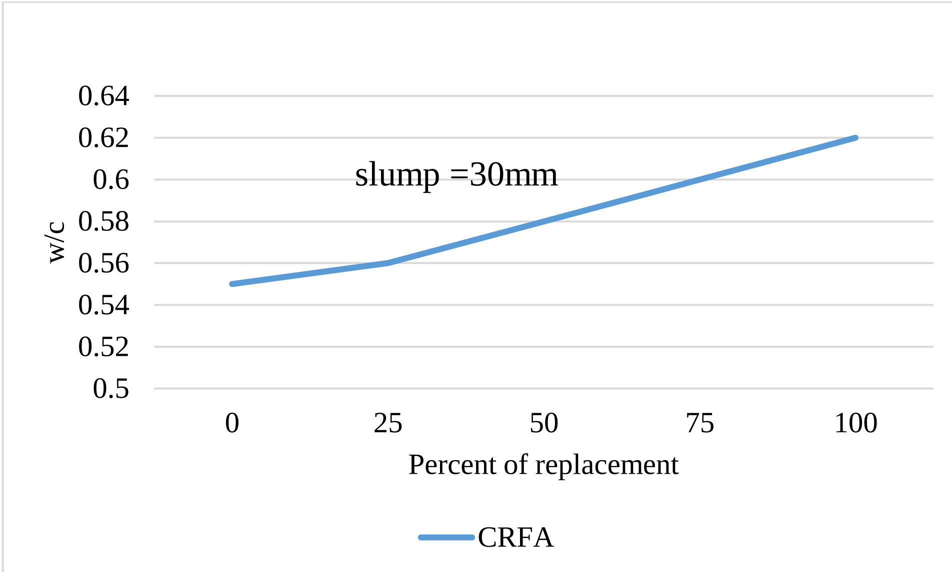


Figure 24: Relationship of Water-cement ratio to replacement percent of CRFA

5.5.2. Properties of hardened concrete

5.5.2.1. Unit weight of hardened concrete

The unit weight of hardened concrete was measured before the compressive strength test. The unit weight of hardened concrete with recycled fine aggregate with different percentage was compared to the control/reference specimen. There was a decrement of unit weight of hardened concrete as a percentage of replacement of CRFA increased [4, 19, 78]. This decrement was due to fine particles from mortar and old mortar attached to it. From the material unit weight test, it was checked that the unit weight of the CRFA (1202kg/m^3) was less dense than the natural river sand (1605kg/m^3). Therefore, the unit weight of the hardened concrete from CRFA had lesser density than the reference mix of hardened concrete. This is due to the porous material from old mortar on the CRFA and the fine particles from crushed mortar [4, 31].

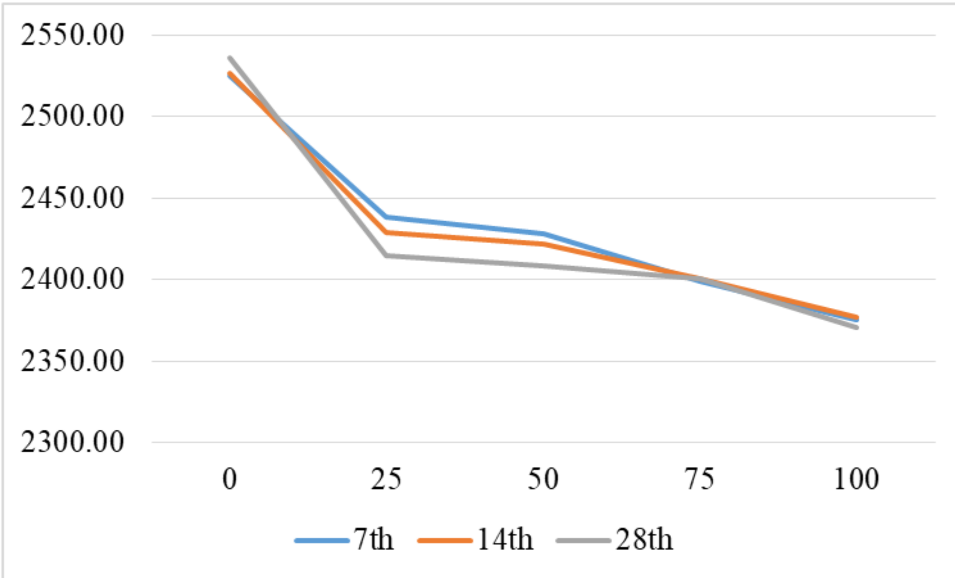
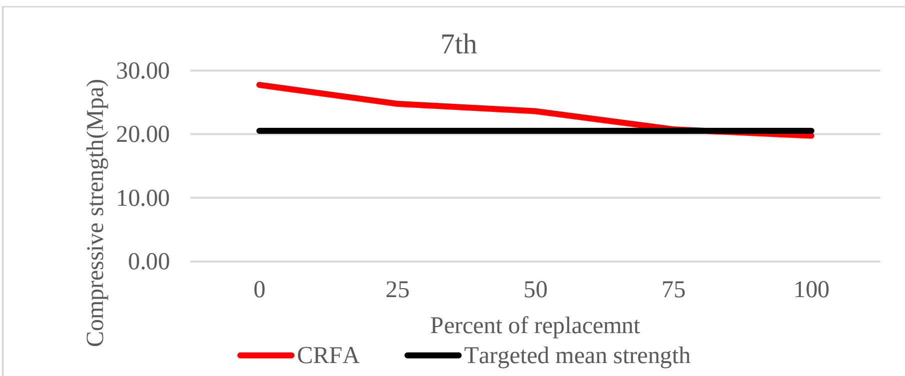


Figure 25: Unit weight of hardened concrete

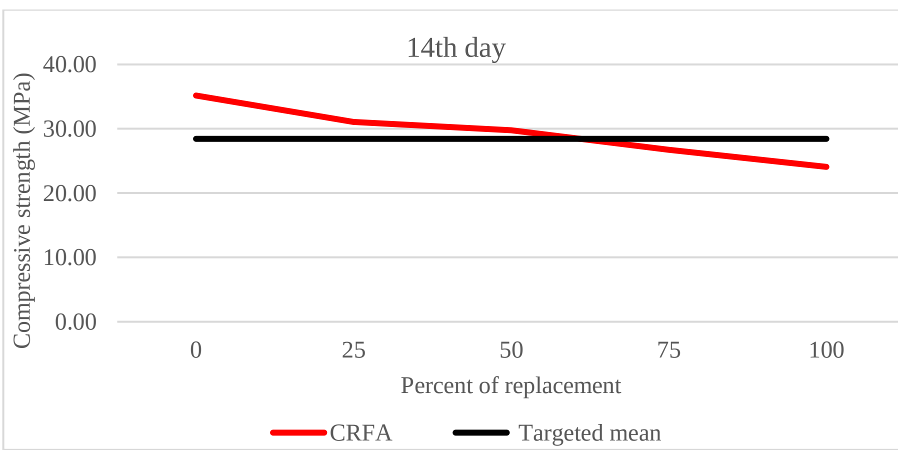
5.5.2.2 Compressive strength

The compressive strength test was performed using 150mm*150mm*150mm specimens. In a compressive strength test, to be accurate and consistent, replication of the consecutive results was applied by taking three samples for each percentage and each curing period. Figure 22 provides the result of the compressive strength test of reference mix and mixes with CRFA. The compressive strength result of the reference sample for 7th, 14th, and 28th days of hydration period has increment from day to day due to ongoing hydration process. As can be observed from figure 22, the compressive strength of concrete samples with CRFA has less compressive strength value than the control mix. For 28th day compressive strength, the sample with CRFA was reduced by 9.43% from the reference mix for 25% replacement, and by 16.1% for 50% replacement. So the compressive strength decreased as the percentage of the replacement of the CRFA increased. Additional water was added to the mix due to water required for the compensation of the high water absorption capacity of CRFA. This extra water added to the mix was increased the w/c ratio. From a previous study [25], the compressive strength of concrete with recycled aggregate concrete was reduced by 20% than the reference mix, and they conclude that this is due to the high amount of absorption compensation water that increased the w/c ratio.

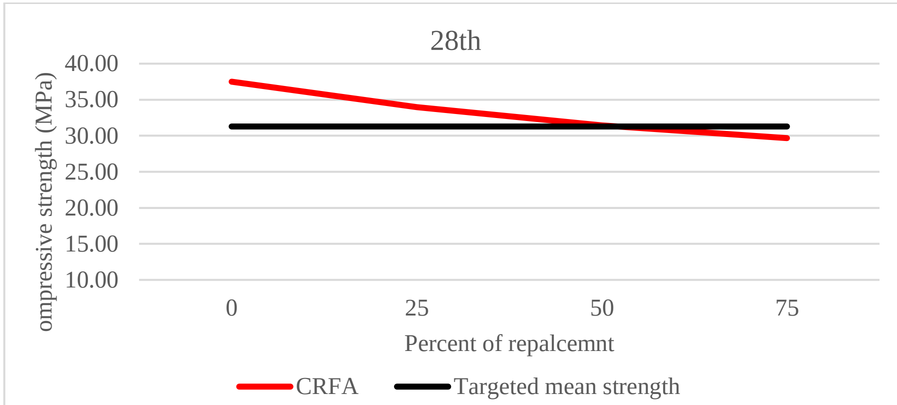
The compressive strength of concrete with 25% and 50% CRFA replacement was attained the targeted mean strength of C-25 concrete, but for concrete, with 75% CRFA, it fails to attain. The optimum percentage of replacement of CRFA falls between 50% and 75% but closer to 75%. So it needs to investigate in small interval replacement percentage from 50% to 75% to find the exact optimum replacement percent. From previous researches, the optimum percent of replacement of crushed waste sandcrete blocks [76] was 50%. According to researcher [79] recycled concrete aggregate with 30% replacement has no significant change on the performance of concrete, but for 50% and 100% replacement level the lower performance was observed. From Figures 22 the relationship between the compressive strength and the rate of replacement of recycled fine aggregate on 7th, 14th, and 28th day of curing can be easily observed.



a, 7th day compressive strength



b. 14th day compressive strength



c. 28th day compressive strength

Figure 26: a, b and c variation of compressive strength with CRFA replacement

In this experiment of different mixes for different percentages of recycled fine aggregate replacement for 7th, 14th, and 28th, the consistency among the value was checked and shown in figure 23, 24, and 25. The coefficient of determination (R^2-value) ranges from 0.9725 to 0.986. The results are closer to 1 (one), which implies that the concrete properties have a high degree of consistency throughout the tests and accuracy.

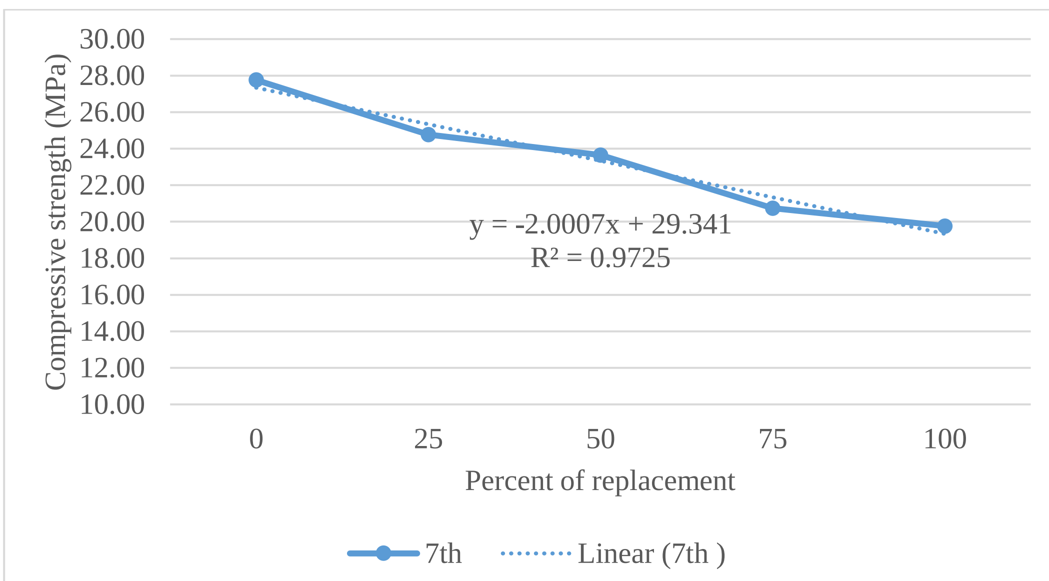


Figure 27: Relationship of Compressive strength with CRFA replacement at 7th day

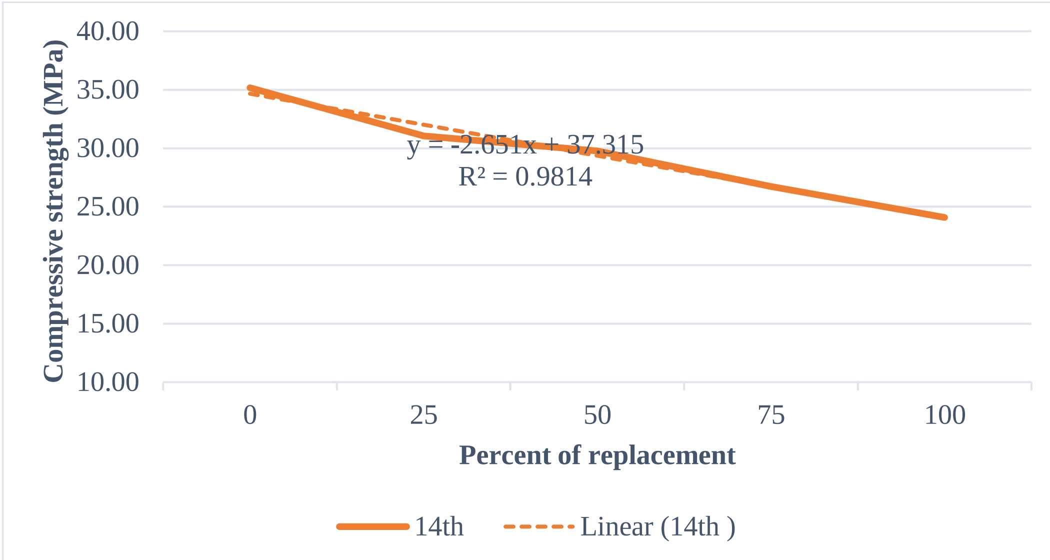


Figure 28: Relationship of Compressive strength with CRFA replacement at 14th day

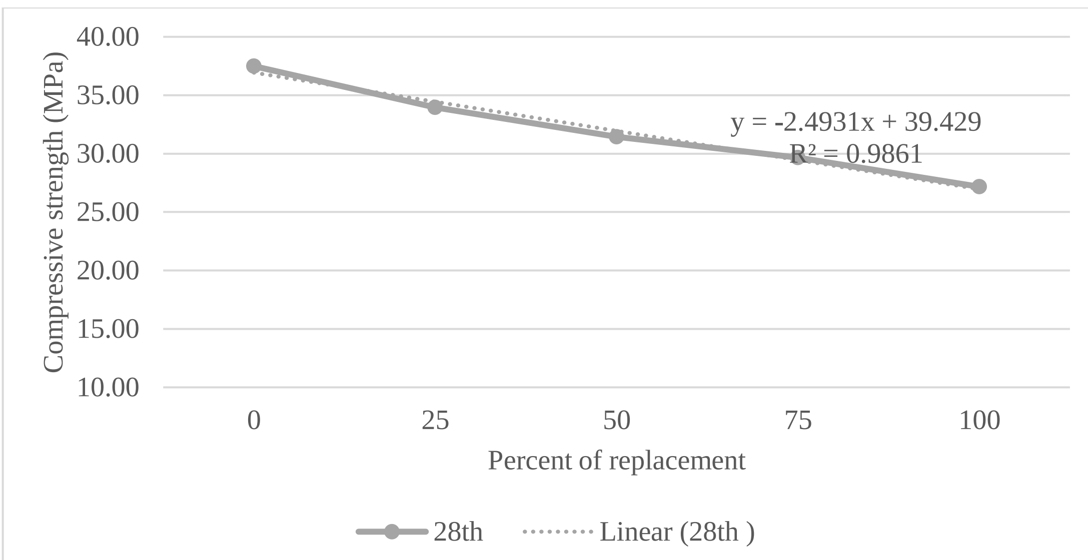


Figure 29: Relationship of Compressive strength with CRFA replacement at 28th day

Figures 26-28 show the error bar for the compressive strength of the seventh day, the 14th, and the 28th day. This shows how much the measurements of the samples were spread out from the average result. For different samples of concrete mix, the error bar shows how much the data varied and how much they scattered.

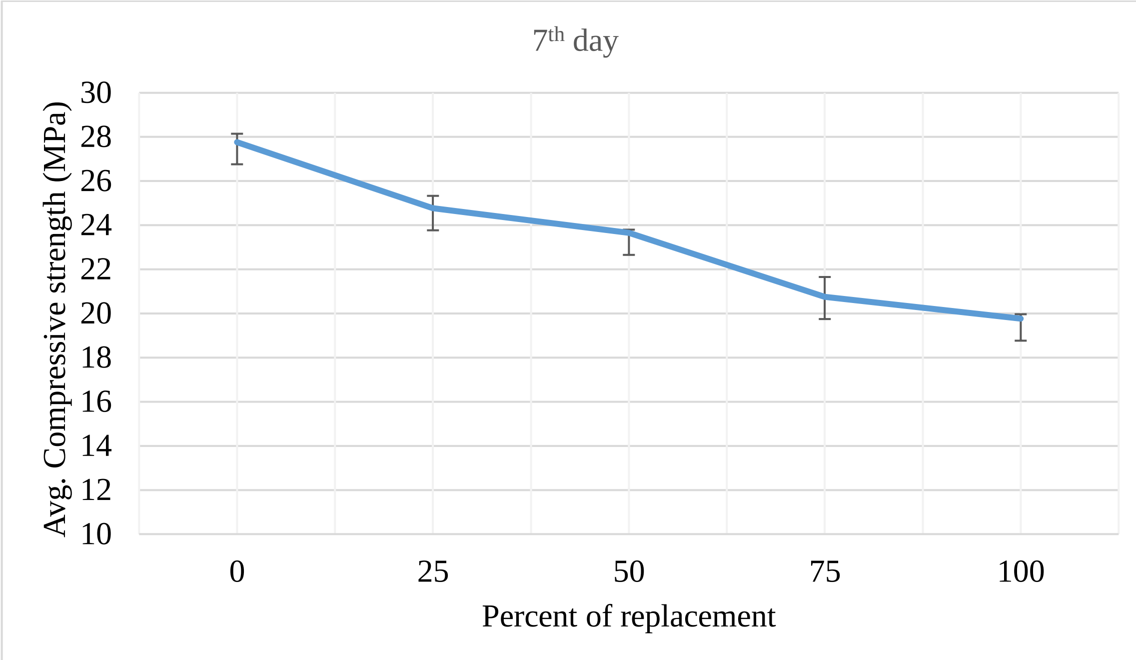


Figure 30**:** Error bar for the 7th day compressive strength.

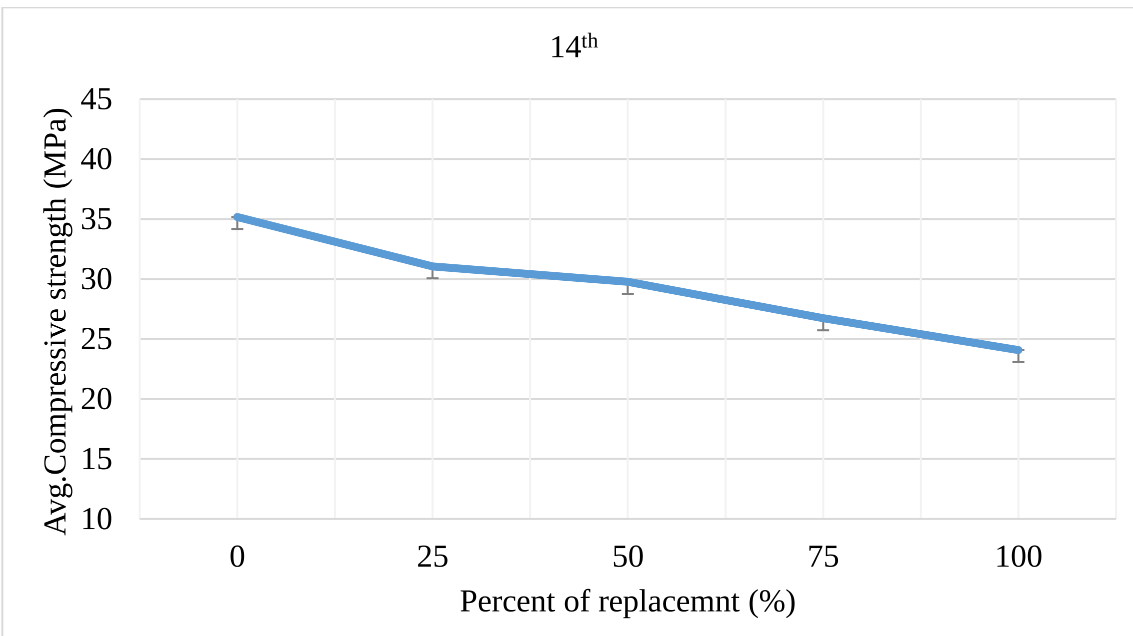


Figure 31: Error bar for the 14th day compressive strength.

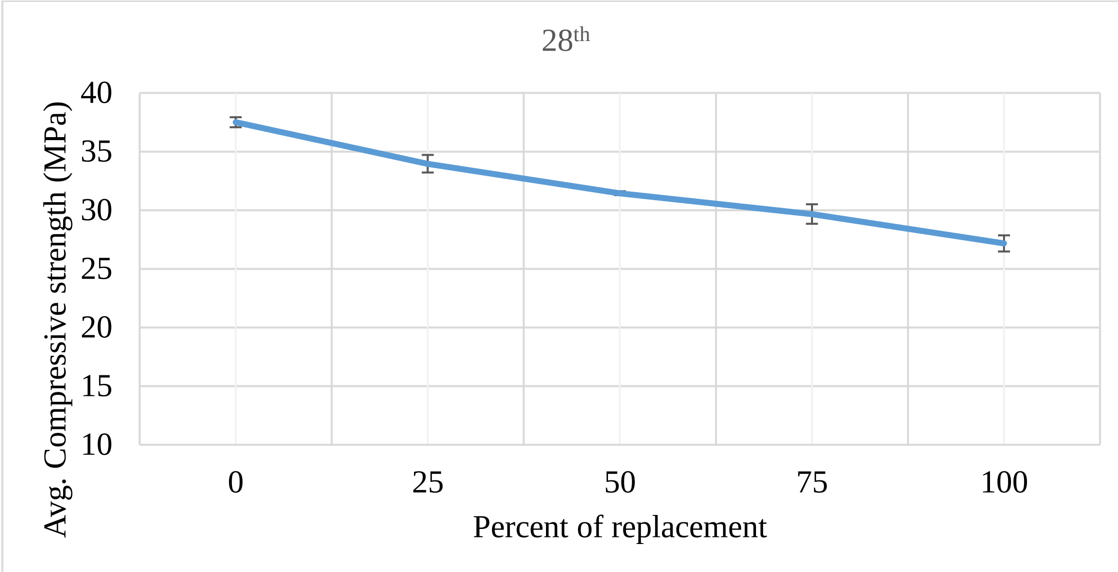


Figure 32: Error bar for the 28th day compressive strength.

5.6. Conclusion

In this research the CRFA were extracted from newly produced HCB for construction to avoid waste contamination on construction site. The properties of recycled fine aggregate were check as per standard and has attained the standard requirements. But in general the CRFA exhibited relatively lower physical properties than the natural river sand. The CRFA has higher silt content than natural sand due to the fine particles from crushing and from the mortar in the HCB and this is a cause for high water absorption capacity of the recycled fine aggregate. The concrete with CRFA has relatively lower properties than the reference concrete. For uniform workability, the water to cement ratio increase as percentage of replacement of CRFA increased. The compressive strength decreased as the percentage of replacement of CRFA increased and CRFA can replace the natural river sand more than 50% but not up to 75%. The utilization of construction waste as recycled fine aggregate can create an alternative source of construction material and can minimize the waste disposed to the environment.

CHAPTER 6

GENERAL DISCUSSION

6.1. Overall message

Recycling the construction and demolition wastes has viable solution for the environment to reduce the waste materials and to deal with the scarcity of natural aggregates [80, 81]. Their use can also solve the problem of their disposal which can conserve the disposal land and has advantages in conserving the natural resource depletion. Hence, their utilization is a beneficial proposition which is economical and environment friendly.

6.1.1. Recycling Demolished HCB

In recycling demolished waste selection of the material before extraction have to be given attention. The reason is demolished wastes are full of different contaminating wastes. To increase the quality of recycled material before recycling selection or homogenization is recommended. In preparation of recycled demolished fine aggregate before crushing, removal of attached unnecessary materials will increase the quality of recycled material. The crushing of demolished HCB is better if in jaw crusher than hammer crushing. This will help in crushing the mortar and can reduce the mortar attachment on DRFA by crushing in to small size. Hand crushing by hammer may not crush fully the mortar. For the crushed material some purification techniques have to be provided to enhance the properties of the DRFA before using. Avoiding the fine particle from cement in old mortar by sieving, washing and floatation to avoid some lightweight material are among the technique to enhance the physical properties like silt content, moisture content and water absorption.

In general, the DRFA has low physical properties than river sand but within required limits of ASTM standards.

- The DRFA has high silt content than desired by ES standard. So washing the DRFA before using is recommended to reduce the silt content.
- The water absorption capacity of DRFA is higher than the natural river sand due to the attached old mortar and the fine particles from the old cement.
- The unit weight of DRFA is relatively lower than the natural sand due to the porous materials in it.

- The phase composition of the DRFA is from the original aggregate and cement.

The effect of DRFA as replacement of the river sand in different percentage on properties of C-25 concrete were investigated by experiments undertaken on workability, density, and compressive strength.

- In fresh concrete DRFA replacement has significant effect in reducing the workability. As percentage replacement of DRFA increase the workability of the concrete decrease. So adjustment for the additional water required for the saturation of the DRFA have to be added to the mix during mixing to compensate the water demand.
- Using DRFA as river sand replacement has decreased the unit weight of the concrete slightly as a percentage of replacement increased.
- The compressive strength decreased as the percentage replacement of DRFA increased. The replacement of river sand by 25% DRFA has slight decrement from the reference mix but it is above the targeted mean strength. The DRFA can replace the river sand up to 50 % and using the DRFA replacement above 50% was failed to attain the targeted mean strength with the properties in this study.

Finally, from the experimental investigation, the suitability of using DRFA from demolished HCB in new concrete production as a replacement of river sand was checked and can be possible up to 50% replacement in weight with the specific properties of the recycled material used in this investigation. Using the recycled demolished HCB in Ethiopia can contribute in the reduction of demolished waste disposal to the environment as landfill. As well as using the recycled fine aggregate up to 50% can reduce the river sand mining by introducing an alternative source of fine aggregate and so this research can benefit in conserving the non-recyclable natural resources and environmental protection from demolition waste disposal This research has advantages in initiating the local construction sectors and material manufacturers to use demolished wastes in new concrete production since the experiment was performed in Ethiopia in local technology

6.1.2. Recycling Construction HCB

The construction waste used in this investigation are relatively free from different waste contaminants and this enhance the quality of recycled materials. But the extraction methods and the purification techniques used can affect the quality of the recycle fine aggregate. In recycling construction waste to increase the quality of the recycled fine aggregate, purification procedures such as identifying the wastes in their category, and types; selection of crushing technique, washing the crushed materials, and floatation. The CRFA has the fine particles during crushing and from the cement in the mortar of HCB. So washing and floatation can reduce those fine particles and some light weight particle floating on top of the water during washing. In this research, the properties of the recycled fine aggregate from a production site of HCB were examined and compared with the ASTM standard requirement of fine aggregates.

The physical properties CRFA such as gradation, silt content, specific gravity, water absorption capacity, moisture content, and bulk density were examined and in general satisfies the ASTM requirements.

- The recycled fine aggregated used in this experiment was well graded.
- The CRFA has higher silt content than the natural river sand and also than the required limit by standard. High silt content is due to fine particles from crushing and from the mortar in the HCB.
- The CRFA has high water absorption capacity as compared to the river sand used in the investigation as well as, as compared to the standard used.
- The CRFA has lower unit weight than the natural river sand and so the density of hardened concrete also lower than the reference mix unit weight, and this is due to the old mortar in HCB. CRFA phase composition is from the inherent materials in it.
- The concrete with CRFA demand high water amount than the reference mix for uniform workability. So to attain uniform consistency the water to cement ratio increased as percentage replacement of CRFA increased.
- As the percentage of replacement of CRFA increased, the compressive strength decreased. The compressive strength of concrete with 25% and 50%CRFA replacement has attained the targeted mean strength and failed to attain at 75% replacement. The optimum percentage of replacement of CRFA falls between 50% and 75% but closer to 75%.

6.1.3. Comparison of CRFA and DRFA

The recycled fine aggregate from demolished HCB (old) wastes has slightly less physical properties than the construction (new) HCB wastes.

- The DRFA has higher silt content and water absorption capacity than the CRFA. The DRFA has higher silt content, and high water absorption capacity is due to different sources wastes and fine particles such as plastering, gypsum, painting, and joint mortar of HCB construction. The fine particles increased the water absorption capacity of the DRFA which is 6.84% and CRFA has 5.1%. The silt content and the water absorption capacity of recycled fine aggregate can directly affect the fresh and hardened concrete properties.
- The DRFA has lower unit weight than the CRFA and so the concrete with DRFA has lower unit weight than the concrete with CRFA. The less unit weight of DRFA is due to the porous materials from plastering, gypsum and mortar which remains in DRFA after purification.
- For uniform workability and the same percentage replacement of river sand by DRFA and CRFA, the concrete with DRFA has higher water to cement ratio than the concrete with CRFA.
- The compressive strength of concrete with DRFA has relatively lower than the concrete with CRFA. The concrete mix with both types of recycled fine aggregates has attained the targeted mean strength at 25% and 50% replacement and fails to attain at 75% replacement. But the compressive strength of concrete with DRFA at 50% replacement is less than that of concrete with CRFA at 50% replacement. The CRFA can replace the natural sand above 50 %, but the DRFA may not replace natural sand above 50% without further treatment.

6.2. Strength and limitation

The strength of this thesis is the extraction of recycled fine aggregate from C&D HCB wastes in good quality and using as a partial replacement of river sand. The extracted fine aggregate properties were checked as per ASTM standards. The investigation of the concrete with recycled fine aggregate were limited to the workability, unit weight and compressive strength and scanning electro- microscope investigation can help on identification the phase in chemical composition of the concrete with recycled fine aggregate.

6.3. Conclusion

From this research, the properties of the recycled fine aggregate from construction and demolition HCB wastes are slightly lower than the natural sand but within the required limit of ASTM standards. From the experimental investigation the recycled aggregate from both demolished and construction HCB wastes can replace the natural river sand up to 50%. And this can reduce the environmental impact due to waste disposal and river sand mining. The recycled fine aggregate from demolished HCB waste has slightly lower physical properties than the construction HCB wastes due to the fine particles from different sources which affect the workability and compressive strength of concrete.

6.4. Recommendations

Recommendation for policy maker

- The policy maker have to develop rules that enforce recycling C&D waste than disposing to landfills
- There should be rules for C&D wastes not to dispose to landfills

For construction stake holder

- In construction site, the wastes produced have to be sorted according to their types
- Demolishing process of building have to be as per the material types

For future research

- Investigation on the cost of recycling C&D wastes as compared to the cost of natural river sand in Ethiopia
- The RFA can be used up to 50% by replacing natural river sand, but the specific application area has to be investigated.
- Investigation on C&D waste generation rate and characterization of the waste generated in Ethiopia.
- Investigation on C&D waste impacts on environment.

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Appendix A

Pictures

Figure 33: Removal of fine particles through sieving

Appendix B

Materials properties

a. Silt content

Table 19: Silt content of DRFA before washing

Determination of silt content				
Observation sheet				
S. No.	Description	Sample No.		
		Sample 1	Sample 2	Sample 3
1	Original dry mass of sample in g.	1000	1000	1000
2	Dry mass of sample after washing in g	846	858	867
3	Percentage of silt= $\frac{B-C}{B} * 100$	15.4	14.2	13.3
Average		14.2		

Table 20: Silt content of CRFA before washing

Determination of silt content				
Observation sheet				
S. No.	Description	Sample No.		
		Sample 1	Sample 2	Sample 3
1	Original dry mass of sample in g.	1000	1000	1000
2	Dry mass of sample after washing in g	876	878	869
3	Percentage of silt= $\frac{B-C}{B} * 100$	12.4	12.2	13.1
Average		12.57		

b. Gradation/ sieve analysis

Table 21: Sieve analysis of DRFA

	Weight retained (gm.)				

ASTM sieve designation and Sieve size (mm)				Average weight Retained (g)	Cumulative retained (%)	Percentage passing (%)	Specification % passing (ASTM C128)
	Sample 1	Sample 2	Sample 3				
3/8(9.50mm)	0	0	0	0	0	100	100
No.4 (4.75mm)	2.5	2	1	1.8	0.1	99.9	95-100
No.8(2.36mm)	109	197	236	180.7	9.1	90.9	80-100
No.16(1.18mm)	397	412	504	437.7	31	69.0	50-85
No.30(600μm)	801	744	695	746.7	68.3	31.7	25-60
No.50(300μm)	442	427	372	413.7	89	11.0	5-30
No.100(150μm)	213	186	167	188.7	98.5	1.5	0-10
Pan	35	29.5	26.5	30.3	100	0.0	N/A
SUM	2000	2000	2000		290		

Table 22: Sieve analysis of CRFA

ASTM sieve designation and Sieve size (mm)	Weight retained (gm.)			Average weight Retained (g)	Cumulative retained (%)	Percentage passing (%)	Specification % passing (ASTM C33)
	Sample 1	Sample 2	Sample 3				
3/8(9.50mm)	0	0	0	0	0	100	100
No.4 (4.75mm)	2.5	2.5	3	2.7	0.1	99.9	95-100
No.8(2.36mm)	163	133	115	137	7	93	80-100
No.16(1.18mm)	300	408	401	369.7	25.5	74.5	50-85
No.30(600μm)	798	756	745	766.3	63.8	36.2	25-60
No.50(300μm)	497	465	490	484	88	12	5-30
No.100(150μm)	221	215	225	220.3	99	1	0-10
Pan	14	20	18	18.3	100	0	N/A
SUM	2000	2000	2000		283.4		

Table 23: Sieve analysis of river sand

ASTM sieve designation and Sieve size (mm)	Weight retained (gm.)			Average weight retained (g)	Cumulative retained (%)	Percentage passing (%)	Specification % passing (ASTM C33)
	Sample 1	Sample 2	Sample 3				
3/8(9.50mm)	0	0	0	0	0	100	100
No.4 (4.75mm)	0	0	0	0	0	100	95-100
No.8(2.36mm)	71	70.5	92.5	78	4	96	80-100
No.16(1.18mm)	319	283	283	295.0	19	81	50-85
No.30(600μm)	1052	932	903	957	66	34	25-60
No.50(300μm)	406	510	543	486.0	91	9	5-30
No.100(150μm)	122	172	148	147	98	2	0-10
Pan	46	30	2	34	100	0	N/A
SUM	2000	2000	2000		278		

Table 24: Sieve analysis of coarse aggregate

ASTM sieve designation	Sieve size (mm)	Weight retained (gm.)			Average retained (g)	Cumulative retained (%)	Cumulative passing (%)	ASTM C33
		Sample 1	Sample 2	Sample 3				
3	75	-	-	-		-		-
2	50	-	-	-	-			-
11/2	37.5	0	0	0	0	0		100
1	25	0	0	0	0	0	100	100
33/4	19	76	255	154	162	3.2	96.8	90-100
½	12.5	3238	3409	3428	3358	70.4	29.6	20-55
3/8	9.5	1213	988	1166	1122	92.8	7.2	0-15
No.4	4.75	470	345	245.5	354	99.9	0.1	0-5

Pan		4	1	1.5	2	100	0	0
SUM	5000	5000	5000	5000	5000	100	633.6	

c. Specific gravity and water absorption

Table 25: Specific gravity and water absorption of DRFA

Description		Sample No	
		Sample 1	Sample 2
Mass of sample taken, (gm.)	S(gm.)	500	500
Mass of oven dry sample	A(gm.)	470	466
Mass of pycnometer filled with water	B(gm.)	1555	1555
Mass of pycnometer with specimen and water	C(gm.)	1841	1843
Bulk Specific gravity = $\frac{A}{(B+S-C)}$		2.2	2.2
Bulk specific gravity (SSD basis) = $\frac{500}{(B+500-C)}$		2.34	2.36
Apparent specific gravity = $\frac{A}{(B+A-C)}$		2.55	2.62
Water absorption, WA = $\frac{500-A}{(A)}100\%$		6.38	7.3
Average values	Specific gravity	2.2	
	Apparent specific gravity	2.59	
	Water absorption	6.84%	

Table 26: Specific gravity and water absorption of CRFA

Description		Sample No	
		Sample 1	Sample 2
Mass of sample taken, (gm.)	S(gm.)	500	500
Mass of oven dry sample	A(gm.)	487	478.5
Mass of pycnometer filled with water	B(gm.)	1555	1555
Mass of pycnometer with specimen and water	C(gm.)	1844	1842
Bulk Specific gravity = $\frac{A}{(B+S-C)}$		2.24	2.25
Bulk specific gravity (SSD basis) = $\frac{500}{(B+500-C)}$		2.37	2.35
Apparent specific gravity = $\frac{A}{(B+A-C)}$		2.57	2.50
Water absorption, WA = $\frac{500-A}{(A)}100\%$		5.71	4.49
Average values	Specific gravity	2.24	
	Apparent specific gravity	2.53	
	Water absorption	5.1%	

Table 27: Specific gravity and water absorption of river sand

Description		Sample No	
		Sample 1	Sample 2
Mass of sample taken, (gm.)	S(gm.)	500	500
Mass of oven dry sample	A(gm.)	492	491
Mass of pycnometer filled with water	B(gm.)	1555	1555

Mass of pycnometer with specimen and water	C(gm.)	1858	1859.5
Bulk Specific gravity = $\frac{A}{(B+S-C)}$		2.50	2.51
Bulk specific gravity (SSD basis) = $\frac{500}{(B+500-C)}$		2.54	2.56
Apparent specific gravity = $\frac{A}{(B+A-C)}$		2.60	2.63
Water absorption, WA = $\frac{500-A}{(A)}$100%		1.63	1.83
Average values	Specific gravity	2.50	
	Apparent specific gravity	2.62	
	Water absorption	1.73	

Table 28: Specific gravity and water absorption of coarse aggregate

Description		Sample No	
		Sample 1	Sample 2
Mass of sample taken, (gm.)	gm.	2000	2000
Mass of oven dry sample	A(gm.)	1986	1988
Mass of SSD sample in air	B(gm.)	2005	2008
Mass of saturated sample in water	C(gm.)	1250	1250
Bulk Specific gravity = $\frac{A}{(B-C)}$		2.63	2.62

Bulk specific gravity (SSD basis) = $\frac{B}{(B-C)}$		2.66	2.65
Apparent specific gravity = $\frac{A}{(A-C)}$		2.70	2.69
Water absorption, WA = $\frac{B-A}{(A)}100\%$		0.96	1.01
Average values	Specific gravity	2.63	
	Apparent specific gravity	2.65	
	Water absorption	0.98%	

d. Unit weight of materials

For river sand

G=8580g

T=1054g

V=5L

M=$\frac{(17736-1683.5)}{10L}$ =1505.2g/l

M=<u>1505.2kg/m3</u>

For DRFA

G=7550g

T=1054g

V=5L

M=$\frac{(7550-1054)}{5L}$ =1299.1g/l

M=<u>1299.1kg/m3</u>

For CRFA

G=11009g

T=5000g

V=5L

M=$\frac{(11009-5000)}{5L}$ =1201.8g/l

M=<u>1202kg/m3</u>

For Coarse aggregate

G=17736g

T=1684g

V=10L

M=$\frac{(17736-1683.5)}{10L}$ =1605g/l

M=<u>1605kg/m3</u>

e. Moisture content

For river sand

Sample taken =500g

Oven dry sample= 490

Moisture content=$\frac{(500-490)}{490} * 100$=**0.2**

For DRFA

Sample taken =500g

Oven dry sample= 497.5

Moisture content=$\frac{(500-497.5)}{497.5} * 100$=**0.5**

For CRFA

Sample taken =500g

Oven dry sample= 490

Moisture content=$\frac{(500-497)}{497} * 100$=**0.6**

For coarse aggregate

Sample taken =2000g

Oven dry sample= 1993

Moisture content=$\frac{(2000-1993)}{1993} * 100$=**0.35**

Table 29: Silt content of river sand

Determination of silt content				
Observation sheet				
S. No.	Description	Sample No.		
		Sample 1	Sample 2	Sample 3
1	Original dry mass of sample in g.	1000	1000	1000
2	Dry mass of sample after washing in g	979	978	957
3	Percentage of silt= $\frac{B-C}{B} * 100$	2.1	2.2	4.3
Average		2.87		

Table 30: Initial setting time of Cement

No. of Drop	Time (min)	Weight of cement(g)	Weight of water (g)	Penetration (mm)
#1	0	300	99	39.2
#2	10	300	99	39.1

#3	20	300	99	39.1
#4	30	300	99	39.1
#5	40	300	99	39.1
#6	50	300	99	38.9
#7	60	300	99	39.1
#8	70	300	99	39.0
#9	80	300	99	39.3
#10	90	300	99	39.0
#11	100	300	99	39.2
#12	110	300	99	39.1
#13	120	300	99	39.3
#14	130	300	99	39.1
#15	140	300	99	39.1
#16	150	300	99	39.0
#17	160	300	99	39.0
#18	170	300	99	38.9
#19	180	300	99	39.1
#20	190	300	99	39.0
#21	200	300	99	39.1
#22	210	300	99	39.1
#23	220	300	99	39.1
#24	230	300	99	39.0
#25	240	300	99	18.0

Initial setting time at 3hr and 50min

Table 31: Final setting time of cement

Final setting time				
#25	240	300	99	18
#26	242	300	99	17.6

#27	244	300	99	16.9
#28	246	300	99	13.9
#29	248	300	99	09.1
#30	250	300	99	06.7
#31	252	300	99	06.1
#32	254	300	99	05.3
#33	256	300	99	05.5
#34	258	300	99	03.2
#35	260	300	99	03.2
#36	262	300	99	03.1
#37	264	300	99	02.3
#38	266	300	99	02.9
#39	268	300	99	02.5
#40	270	300	99	03.0
#41	272	300	99	03.7
#42	274	300	99	04.4
#43	276	300	99	05.6
#44	278	300	99	05.5
#45	280	300	99	06.6
#46	282	300	99	04.6
#47	284	300	99	02.9
#48	286	300	99	02.8
#49	288	300	99	01.3
#50	290	300	99	01.9
#51	292	300	99	01.2
#52	294	300	99	00.7
#53	296	300	99	02.2
#54	298	300	99	01.8
#55	300	300	99	03.9
#56	302	300	99	02.3

#57	304	300	99	01.2
#58	306	300	99	00.2
#59	308	300	99	00.7
#60	310	300	99	01.0
#61	312	300	99	00.3
#62	314	300	99	End

Final setting time was attained at 5hr and 14 min

Appendix C

Mix design procedures

The mix design for C-25 non-air entrained normal strength concrete was done as per ACI 211.1. Mix design procedure manual.

Step-1: Choice of slump: consistent to the method of placement the slump was set to be 25 - 50 mm (minimum slump possible) is selected

Step-2: Maximum size of aggregate: Maximum size was fixed to be 20 mm.

Step 3: Target mean strength calculation

From ACI 301 table 4.2.3.3C seen below for a 28-day compressive strength, when no test data is available.

f_c', MPa	f_{cr}', MPa
Less than 21	$f_c' + 7$
21 to 35	$f_c' + 8.3$
Over 35	$1.1f_c' + 5$

*When data are not available to establish standard deviation.

Step-4: Mixing water requirement: Based on the ACI table.3.8 for the slump rang of 25-50 mm and a maximum size of 20 mm aggregates; the required mixing water is 185 kg. Therefore, for the first trial mix the mixing water required was 185 kg of water.

Step 5: water to cement (W/C) ratio

For 30 MPa W/C ratio is 0.55 and for 35 MPa W/C ratio is 0.48. The W/C ratio can be found by interpolation as follows from table 3.1 of ACI 211.1.81:

Table 32: Relation between w/c and average compressive strength of concrete

Table 3-1 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Target mean 33.5 Mpa

$$\frac{w}{c} = \left[\frac{0.55 - 0.48}{30 - 35}\right](33.3 - 30) + 0.55 = 0.5$$

Step-6: Determining Cement content: From this ratio the amount of cement required will be about 370KGs (185/0.5).

Step-7: Estimation of Coarse aggregate content: The dry mass of coarse-aggregate required for a cubic meter of concrete is equal to the value from ACI 211-Table 3.11 multiplied by the dry-rodded unit mass of the aggregate in kg/m^3. In sieve analysis, it was found that the fines modulus of fine aggregate was 2.83. The unit weight of the dry rodded coarse aggregates is 1605KG/m3. From the table the percentage by volume of coarse aggregate with a nominal maximum size of 20 mm is about 62%. This intern gives a mass of (0.62*1605) =995.1 Kg of coarse aggregates.

Table 33: Dry bulk volume of Coarse Aggregate

Table 3-11 Dry bulk volume of coarse aggregate per unit volume of concrete as given by ACI 211.1-81

Maximum Size of Aggregate (mm)	Dry Bulk Volume of Rodded Coarse Aggregate Per Unit Volume of Concrete for Different Fineness Modulus of Sand			
	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Note. The values will produce a mix with a workability suitable for reinforced concrete construction. For less workable concrete, e.g., that used in road construction, the values may be increased by about 10%. For more workable concrete, such as may be required for placing by pumping, the values may be reduced by up to 10%.

Table 34: First estimate of density of fresh concrete

Table 3-12 First estimate of density (unit weight) of fresh concrete as given by ACI 211.1-81

Maximum Size of Aggregate (mm)	First Estimate of Density (Unit Weight) of Fresh Concrete (kg/m^3)	
	Non-Air Entrained	Air Entrained
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

Step-8: Fine aggregate content: it is clear that the estimated weight of the fresh Non air entrained concrete is 2355 KG. Deducting the weight of all the known ingredients gives the weight of the sand (2355-185-370-995.1) =805 Kg

Step 9: Adjustments for moisture

Table 35: Water adjustment for controlled mix

	Cement Kg/M3	Water	Fine Aggregate	Coarse Aggregate	Total Kg/M3

		(Kg/M3or Lit/M3)	(Kg/M3)	(Kg/M3)	
Materials Per M^3	370	185	805	995.1	2355
Free moisture %			0.2	0.35	
Absorption capacity			1.73	0.98	
Adjustment		+	-1.53	-0.63	
Adjusted per M^3	370	203.569	12.312	6.26	

Table 36: Water adjustment for 25% CRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3) 75%	CRFA (Kg/m^3) 25%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	805*75%	805*25%	995.1
Free moisture %			0.2	0.603	0.35
Absorption capacity			1.73	5.1	0.98
Adjustment		+	1.53*75%	4.496*25%	-0.63
Adjusted per M^3	370	209.545	9.235	9.05	6.26

Table 37: Water adjustment for 50% CRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3) 50%	CRFA (Kg/m^3) 50%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	805 *50%	805*50%	995.1
Free moisture %			0.2	0.603	0.35
Absorption capacity			1.73	5.1	0.98
Adjustment		+	1.53*50%	4.496*50%	-0.63
Adjusted per M^3	370	215.512	6.156	18.1	6.26

Table 38: Water adjustment for 75% CRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3) 25%	CRFA (Kg/m^3) 75%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	805 *25%	805*75%	995.1
Free moisture %			0.2	0.603	0.35
Absorption capacity			1.73	5.1	0.98
Adjustment		+	1.53*25%	4.496*75%	-0.63
Adjusted per M^3	370	221.5	3.078	27.15	6.26

Table 39: Water adjustment for 100% CRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3)0%	CRFA (Kg/m^3) 100%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	0	805	995.1
Free moisture %			0.2	0.603	0.35
Absorption capacity			1.73	5.1	0.98
Adjustment		+	1.53*0%	4.496*100%	-0.63
Adjusted per M^3	370	227.5	0	36.2	6.26

Table 40: Water adjustment for 25% DRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3) 75%	DRFA (Kg/m^3) 25%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	805*75%	805*25%	995.1

Free moisture %			0.2	0.503	0.35
Absorption capacity			1.73	6.84	0.98
Adjustment		+	1.53*75%	6.337*25%	-0.63
Adjusted per M^3	370	213.246	9.235	12.754	6.26

Table 41: Water adjustment for 50% DRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3) 50%	DRFA (Kg/m^3) 50%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	805 *50%	805*50%	995.1
Free moisture %			0.2	0.503	0.35
Absorption capacity			1.73	6.84	0.98
Adjustment		+	1.53*50%	6.337*50%	-0.63
Adjusted per M^3	370	222.922	6.156	25.51	6.26

Table 42: Water adjustment for 75% DRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3) 25%	DRFA (Kg/m^3) 75%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	805 *25%	805*75%	995.1
Free moisture %			0.2	0.503	0.35
Absorption capacity			1.73	6.84	0.98
Adjustment		+	1.53*25%	6.337*75%	-0.63
Adjusted per M^3	370	232.6	3.078	38.263	6.26

Table 43: Water adjustment for 100% DRFA replacement

	Cement Kg/M3	Water (Kg/M3or Lit/M3)	River sand(RS) (Kg/m^3)0%	DRFA (Kg/m^3) 100%	Coarse Aggregate (Kg/M3)
Materials Per M^3	370	185	0	805	995.1
Free moisture %			0.2	0.503	0.35
Absorption capacity			1.73	6.84	0.98
Adjustment		+	1.53*0%	6.337*100%	-0.63
Adjusted per M^3	370	242.274	0	57.274	6.26

Appendix D

Experimental result of properties of concrete

Unit weight of concrete

Table 44: The 7th day dry density of concrete with DRFA

Sample code	Weight of cube			Average weight (Kg)	Volume in (m^3)	Dry density in (Kg/m^3)
	Sample 1 (Kg)	Sample 2 (Kg)	Sample 3 (Kg)			
Co	8.523	8.533	8.513	8.523	$3.375*10^{-3}$	2525.33
DRFA-25	8.380	8.588	7.896	8.288	$3.375*10^{-3}$	2507.16
DRFA-50	8.241	8.136	8.1415	8.173	$3.375*10^{-3}$	2421.58
DRFA-75	8.0145	8.254	8.226	8.165	$3.375*10^{-3}$	2419.21
DRFA-100	8.186	8.074	7.889	8.05	$3.375*10^{-3}$	2385.08

Table 45: The 14th day dry density of concrete with DRFA

Sample code	Weight of cube			Average weight (Kg)	Volume in (m^3)	Dry density in (Kg/m^3)
	Sample 1 (Kg)	Sample 2 (Kg)	Sample 3 (Kg)			
Co	8.490	8.57	8.524	8.528	$3.375*10^{-3}$	2526.815
DRFA-25	8.28	8.20	8.102	8.194	$3.375*10^{-3}$	2427.852
DRFA-50	8.15	8.115	8.235	8.167	$3.375*10^{-3}$	2419.753
DRFA-75	8.27	8.01	8.04	8.107	$3.375*10^{-3}$	2401.98
DRFA-100	8.018	8.137	8.149	8.101	$3.375*10^{-3}$	2400.4

Table 46: The 28th day dry density of concrete with DRFA

Sample code	Weight of cube			Average weight (Kg)	Volume in (m^3)	Dry density in (Kg/m^3)
	Sample 1 (Kg)	Sample 2 (Kg)	Sample 3 (Kg)			
Co	8.582	8.55	8.54	8.558	$3.375*10^{-3}$	2535.70
DRFA-25	8.224	8.29	8.24	8.252	$3.375*10^{-3}$	2445.14
DRFA-50	8.22	8.19	8.30	8.24	$3.375*10^{-3}$	2440.84
DRFA-75	8.319	8.11	8.25	8.225	$3.375*10^{-3}$	2437.1
DRFA-100	8.0314	8.02	8.01	8.0224	$3.375*10^{-3}$	2377.01

Table 47: The 7th day dry density of concrete with CRFA

Sample code	Weight of cube			Average weight (Kg)	Volume in (m^3)	Dry density in (Kg/m^3)
	Sample 1 (Kg)	Sample 2 (Kg)	Sample 3 (Kg)			
Co	8.582	8.55	8.54	8.558	$3.375*10^{-3}$	2535.70
CRFA-25	8.354	8.031	8.303	8.229	$3.375*10^{-3}$	2438.321
CRFA-50	8.217	8.148	8.218	8.194	$3.375*10^{-3}$	2427.95
CRFA-75	8.134	8.104	8.054	8.097	$3.375*10^{-3}$	2399.21
CRFA-100	7.825	8.122	8.101	8.016	$3.375*10^{-3}$	2375.11

Table 48: The 14th day dry density of concrete with CRFA

Sample code	Weight of cube			Average weight (Kg)	Volume in (m^3)	Dry density in (Kg/m^3)
	Sample 1 (Kg)	Sample 2 (Kg)	Sample 3 (Kg)			
Co	8.490	8.57	8.524	8.528	$3.375*10^{-3}$	2526.815
CRFA-25	8.275	8.037	8.280	8.197	$3.375*10^{-3}$	2428.84
CRFA-50	8.392	7.916	8.213	8.174	$3.375*10^{-3}$	2421.83
CRFA-75	8.159	8.121	8.024	8.101	$3.375*10^{-3}$	2400.4
CRFA-100	8.102	7.95	8.01	8.021	$3.375*10^{-3}$	2376.50

Table 49: The 28th day dry density of concrete with CRFA

Sample code	Weight of cube			Average weight (Kg)	Volume in (m^3)	Dry density in (Kg/m^3)
	Sample 1 (Kg)	Sample 2 (Kg)	Sample 3 (Kg)			
Co	8.582	8.55	8.54	8.558	$3.375*10^{-3}$	2535.70
CRFA-25	8.18	8.13	8.14	8.151	$3.375*10^{-3}$	2415.01
CRFA-50	8.054	8.316	8.015	8.128	$3.375*10^{-3}$	2408.40
CRFA-75	8.201	8.116	7.991	8.1027	$3.375*10^{-3}$	2400.79
CRFA-100	8.139	8.01	7.857	8.0	$3.375*10^{-3}$	2370.62

Compressive strength

Table 50: The 7th day compressive strength of concrete with DRFA

Sample code	Load in KN			Average Load(KN)	Area (mm^2)	Compressive strength (MPa)
	Sample 1	Sample 2	Sample 3			
Co	623.85	596.46	653.64	624.65	22500	27.76
DRFA-25	533.43	557.01	531.6	540.68	22500	24.03
DRFA-50	483.16	490.69	488.9	487.583	22500	21.67
DRFA-75	466.52	450.31	454.36	457.063	22500	20.31
DRFA-100	433.83	471.57	433.52	446.307	22500	19.84

Table 51: The 14th day compressive strength of concrete with DRFA

Sample code	Load in KN			Average Load(KN)	Area (mm^2)	Compressive strength (Mpa)
	Sample 1	Sample 2	Sample 3			
Co	757.1	803.06	813.91	791.356	22500	35.177

DRFA-25	691.25	685.5	701.5	692.75	22500	30.79
DRFA-50	655.9	667.87	661.5	661.76	22500	29.41
DRFA-75	578.39	575.59	581.46	578.48	22500	25.71
DRFA-100	525.5	510.21	521.76	519.157	22500	23.07

Table 52: The 28th day compressive strength of concrete with DRFA

Sample code	Load in KN			Average Load(KN)	Area (mm^2)	Compressive strength (Mpa)
	Sample 1	Sample 2	Sample 3			
Co	853.08	833.85	844.3	843.73	22500	37.49
DRFA-25	723.7	732.61	710.5	722.27	22500	32.09
DRFA-50	705	702.3	697.9	701.733	22500	31.19
DRFA-75	608.49	613.15	607.52	609.72	22500	27.253
DRFA-100	623.56	615.18	574.52	604.42	22500	26.86

Table 53: The 7 day compressive strength of concrete with CRFA

Sample code	Load in KN			Average Load(KN)	Area (mm^2)	Compressive strength (MPa)
	Sample 1	Sample 2	Sample 3			
Co	623.85	596.46	653.64	624.65	22500	27.76
CRFA-25	608.3	519.41	544.22	557.31	22500	24.77
CRFA-50	535.92	530.94	529.82	532.23	22500	23.65
CRFA-75	475	443.63	481.84	466.82	22500	20.76
CRFA-100	409.12	480.2	444.96	444.76	22500	19.77

Table 54: The 14th day compressive strength of concrete with CRFA

Sample code	Load in KN			Average Load(KN)	Area (mm^2)	Compressive strength (MPa)
	Sample 1	Sample 2	Sample 3			
Co	757.1	803.06	813.91	791.356	22500	35.177
CRFA-25	712.17	688	696.28	698.82	22500	31.06
CRFA-50	670.87	664.61	673.9	669.79	22500	29.77
CRFA-75	607.39	603.49	593.13	601.34	22500	26.73
CRFA-100	535.65	549.61	540.08	541.78	22500	24.08

Table 55: The 28th day compressive strength of concrete with CRFA

Sample code	Load in KN			Average Load(KN)	Area (mm^2)	Compressive strength (MPa)
	Sample 1	Sample 2	Sample 3			
Co	853.08	833.85	844.3	843.73	22500	37.49
CRFA-25	783.16	750.96	758.37	764.163	22500	33.99
CRFA-50	708.5	703.59	710.85	707.65	22500	31.45
CRFA-75	683.27	646.94	672.76	667.66	22500	29.68
CRFA-100	612.02	595.47	626.41	611.3	22500	27.17

Table 56: Standard deviation for concrete with DRFA

	Sample code	Sample 1	Sample 2	Sample3	Average	STDev.
	C0	27.73	27.40	28.16	27.76	0.38
	DRFA25	23.71	24.76	23.63	24.03	0.63
	DRFA50	21.47	21.81	21.73	21.67	0.17
	DRFA75	20.73	20.01	20.19	20.31	0.37
7th day	DRFA100	19.28	20.96	19.27	19.84	0.97
	C0	34.09	35.69	35.73	35.17	0.93

14th day	DRFA25	30.72	30.47	31.18	30.79	0.36
	DRFA50	29.15	29.68	29.40	29.41	0.27
	DRFA75	25.71	25.58	25.84	25.71	0.13
	DRFA100	23.36	22.68	23.19	23.07	0.35
28th day	C0	37.91	37.06	37.52	37.50	0.43
	DRFA25	32.16	32.56	31.58	32.10	0.49
	DRFA50	31.33	31.21	31.02	31.19	0.16
	DRFA75	27.04	27.25	27.00	27.10	0.13
	DRFA100	27.71	27.34	25.53	26.86	1.17

Table 57: Standard deviation for concrete with CRFA

	Sample code	Sample 1	Sample 2	Sample 3	Average	STDev
7th day	C0	27.73	27.40	28.16	27.76	0.38
	CRFA25	24.81	25.31	24.19	24.77	0.56
	CRFA50	23.82	23.60	23.55	23.65	0.14
	CRFA75	21.11	19.72	21.42	20.75	0.91
	CRFA100	19.96	19.56	19.78	19.77	0.20
14th day	C0	34.09	35.69	35.73	35.17	0.93
	CRFA25	31.65	30.58	30.95	31.06	0.55
	CRFA50	29.82	29.54	29.95	29.77	0.21
	CRFA75	27.00	26.82	26.36	26.73	0.33
	CRFA100	23.81	24.43	24.00	24.08	0.32
28th day	C0	37.91	37.06	37.52	37.50	0.43
	CRFA25	34.81	33.38	33.71	33.96	0.75
	CRFA50	31.49	31.27	31.59	31.45	0.16
	CRFA75	30.37	28.75	29.90	29.67	0.83
	CRFA100	27.20	26.47	27.84	27.17	0.69

Appendix E

Author‘s curriculum vitae

Personal Information	
Name	Lucy Feleke Nigussie
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Marital status	Single
email	Lucyfeleke2012@gmail.com
Field of specialization	Construction Engineering and management
Academic rank	Lecturer
Position	Ph.D. candidate in Civil Engineering specialization in construction Engineering, JiT and Texas Tech University
Work place	Jimma University Institute of Technology
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Lucy Feleke Nigussie received a B.Sc. degree in Civil Engineering from Addis Ababa University, Addis Ababa, Ethiopia, in 2012 and M.Sc. degree in Construction Engineering and Management from Jimma University, Jimma, Ethiopia, in 2016. Since 2017, she is a lecturer at the Department of civil engineering, Jimma institute of Technology, Jimma University, Jimma, Ethiopia. Starting from 2012 after graduating she joined construction company as assistance site engineer up to 2013 as office engineer from 2013 up to 2014 in Rama construction and after 2014 up to 2017 as project coordinator at consulting company of Habtamu International consulting PLC.

Currently, she is PhD candidate in Construction Engineering under the supervision of Dr. Muge Mukadddes at Department of Civil, Environmental, and Construction Engineering, Texas Tech University. She also visited Bremen University for 3 months from June 2017 up to September 2017. My current research interests include Partial Replacement of Sand in Concrete with Recycled fine Aggregates from Construction and Demolition Wastes. She is the author of 2 published and 1 submitted articles in international journals. Article I: Recycling Fine Aggregate from Demolished Hollow Concrete Block for Green Concrete in Ethiopia, on Global Journal of Engineering Sciences

Article II: Comparative Investigation of the Effect of Recycled Fine Aggregate from New and Old Construction Wastes in C-25 Concrete in Ethiopia on journal of sustainability, MDPI-Switzerland

Article III: XRD analysis of recycled fine aggregate from construction and demolition on material and structural, springer.

Her recent research will be presented in international conference will be held Huston Texas February 2020.

Declaration

Declaring that no portion of the work entitled ‘Partial Replacement of Sand in Concrete with Recycled fine Aggregates from Construction and Demolition Wastes’ has been submitted in support of an application for another degree or qualification of this in any University or other institute of learning. I assured that this is the original work I submitted to Jimma University institute of Technology.

PI: Lucy Feleke Nigussie

Signature_____________________ Date_________________________

Supervisor: Dr.-Muge Mukaddes Darwish (PhD)

Signature_____________________Date__________________________

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