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CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR

INVESTIGATION ON THE PROPERTIES OF POROUS CONCRETE USING RECYCLED CONCRETE AGGREGATE AS PARTIAL REPLACEMENT OF COARSE AGGREGATE.

A Research Submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree Master of Science in Construction Engineering and Management.

By

MUNITER MURESA MUDA

February, 2021

Jimma, Ethiopia

DECLARATION

I declare that this research entitled "INVESTIGATION ON THE PROPERTIES OF POROUS CONCRETE USING RECYCLED CONCRETE AGGREGATE AS PARTIAL REPLACEMENT OF COARSE AGGREGATE.'' is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere.`

MUNITER MURESA MUDA -- ------------/----------/------

Candidate Signature Date

As research Advisor, I hereby certify that I have read and evaluated this research paper prepared under any guidance, by Muniter Muresa Muda entitled "INVESTIGATION ON THE PROPERTIES OF POROUS CONCRETE USING RECYCLED CONCRETE AGGREGATE AS PARTIAL REPLACEMENT OF COARSE AGGREGATE'' recommend and would be accepted as a fulfilling requirement for the degree Master of Science in Construction Engineering and Management

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ABSTRACT

Porous concrete is an environmentally friendly concrete that contains zero fine aggregates, creating a significant pore that allows the concrete to be water permeable. Thus, it is an important way to control health and pollution hazards due to surface ponding of water on roadways by allowing water downward through the pores, thereby minimizing flooding risks, reducing runoff, and improving groundwater water recharge. However, this type of concrete has not been considered in the Ethiopian market. Likewise, demand for fresh aggregate is still high while natural resources are reducing. Accordingly, attempts have been made to avoid the gap between demand and supply of fresh aggregates. Therefore, the utilization of recycled coarse aggregates from construction and demolition wastes serves as a sustainable solution, which reduces the overall cost and environmental pollutions.

This study aims to investigate the properties of porous concrete expermentally using recycled concrete aggregate in the ratio of 0%, 15%, 30%, 45%, and 60% replacement by weight of natural coarse aggregate. For this experimental study of concrete grade ranging between 2.8 MPa to 28 MPa , five different groups with 75 cubes of size 150mm 150mm* 150mm and 60 cylinders of size 200mm* 100mm of total 135 samples were casted, and conventional curing method for 7, 14, and 28 days was adopted. To determine the behavior of the concrete, workability (slump and compacting factor test), fresh density, compressive and split tensile strength were evaluated. In addition to those properties, porosity and permeability properties of the concrete were also evaluated.*

The fresh concrete property test result shows that increasing the percentage of RCA decreases the degree of workability and fresh density as compared to the control mix. In a similar manner, compressive and split tensile strength of concrete decreases by 54.70 % and 24% respectively with an increasing percentage of RCA. This indicates that there is an indirect relationship between workability, fresh density, compressive, and split tensile strength with that of RCA. Oppositely, the test result for porosity and permeability shows that increasing the percentage of RCA increases the porosity ratio up to 16%, coefficient of permeability by 35.66%, and decreases concrete strength respectively as compared to the control mix. This also indicates, the strong linear relationship between porosity, permeability, and percentage of RCA. The optimum quantity of RCA for the most favorable compressive strength (17.37MPa) was observed at 30% of RCA. A regression model was also developed to determine the degree of workability using compacting factor test . From the result, cofficent of determination (R^2) shows that compacting factor test values are 88% accurate to determine the workability of fresh porous concrete. Generally, the finding of this research shows that the use of recycled concrete aggregate for porous concrete production and its application is practicable.

Keywords: *Compressive strength, Permeability, Porous concrete, Recycled concrete aggregate.*

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ABBREVIATIONS

ACI	American Concrete Institute
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Standard for Testing Material
BS	British Standard
C & D	Construction and Demolition
CFT	Compacting Factor Test
CFV	Compacting Factor Value
CO_2	Carbon Dioxide
CST	Compressive Strength Test
EPA	Environment Protection agency
ES	Ethiopian Standard
ETB	Ethiopian Birr
GC	Gregorian Calendar
ITZ	Interfacial Transition Zone
JIT	Jimma Institute of Technology
JU	Jimma University
Km	Kilo Meter
LEED	Leadership in Energy and Environmental Design
MPa	Mega Pascal
NCAPC	Normal Coarse Aggregate Porous Concrete
PPC	Portland Pozzolana Cement
R	Reliability
R^2	Coefficient of determination
RCA	Recycled Coarse Aggregate
RCAPC	Recycled Coarse Aggregate Porous Concrete
US	United State
USGBC	United State Green Building Council
W/C	Water Cement Ratio

CHAPTER 1

INTRODUCTION

1.1 Background

Now a days, concrete is one of the most widely used construction materials in the construction industry of Ethiopia, like other countries of the world (Naidu & Edukondalu, 2020). It is a composite material composed of cement, fine aggregate (sand), and coarse aggregates mixed with water which hardens over time (Jayaraman, et al., 2020). The production of concrete making materials or ingredients usually needs high energy, costs, and causes environmental pollution (Warati, et al., 2019). Therefore, it is highly desirable to produce sustainable and eco-friendly concrete that helps to mitigate the carbon footprint of concrete (Luhar & Luhar, 2020). Besides, natural resources are increasingly consumed in today's world due to rapid urbanization and increased demand (Guntakal & Selvan, 2017). This increase in the demand for natural resources leads to the depletion of virgin concrete ingredients, which is a critical issue for all stakeholders of the construction industry for sustainable economic growth, particularly in developing countries (Warati, et al., 2019).

Moreover, environmentally friendly concrete, which uses less energy in its production and less emission of carbon dioxide than normal concrete is called green concrete (Saadoon, et al., 2019). This concrete is characterized by the application of industrial by-products or alternative materials for wise utilization of natural resources. Replacements of materials over nominal concretes are what makes green concrete more environmentally friendly concretes (Sharma, et al., 2020). As a result, it is very often considered to be cheap to produce due to the use of recycled material thereby avoiding the charges for the disposal of waste, less energy consumption, and greater durability (Admute, et al., 2017). Similarly, several studies defined that a large number of wastes are generated every year in the construction industry. These wastes have instigated serious problems both locally and globally (Tongo, et al., 2020). Hence, trends of the last decade were recycling of construction and demolition waste into secondary raw materials to enhance the environmental benefits (Mawed, et al., 2020). This waste has to be stored in a landfill which doesn't have inexhaustible volume capacity and needs solutions in the reuse of old building materials such as concrete or mortar (Sah, et al., 2018). The environmental impact of construction waste management approaches is Disposal, Recycling, Reuse, and Reduction. Moreover, the disposal of waste in landfills is the most detrimental to the environment relative to other waste management approaches (Al-Thani & Park, 2020). As a result, various strategies are being investigated by Engineers to protect and restore natural ecosystems in the world. However, the use of concrete wastes such as recycled concrete aggregate (RCA) for the production of porous concrete can reduce the number of demolition wastes to landfills and the consumption of natural aggregate which is advantageous for the environment. Therefore, porous concrete is an ideal solution gaining popularity as a viable paving material and a tool of sustainable development because of its environmental benefits. Also, it is a very special type of concrete with high porosity made with little to no fine aggregates (Tuan, et al., 2020). Conventional concretes have a very low permeability, in which water simply runs-off its surface (Torres, et al., 2020). But, porous concrete is a special type of concrete with high permeability that allows water from precipitation and other sources to pass directly through thereby reducing the runoff from the site and allowing groundwater recharge (Navaz, et al., 2020). This concrete is being used as paving material, pavement sidewalk, secondary road, to increase groundwater table, parking areas, residential street, and good seepage of stormwater (Hase, et al., 2020). It has been considered as an environmentally friendly construction material that quickly gains recognition as a green building component.

Though, there is a need to provide further attention to construction materials with regards to the economy, wise energy utilization, and environmental protection for sustainable development. Therefore, it is hoped that the results of this study would help in proposing recommendations for stakeholders concerning solving environmental problems, enhancing the recycling of construction demolished wastes for construction purpose, and announcing the applicability of recycled concrete aggregate replaced porous concrete in the Ethiopian construction industry and other developing countries.

1.2 Statement of the Problem

The infrastructure department is the second-largest economic sector in Ethiopia after the agriculture industry. Due to remarkable development in infrastructure and increased development, most of the places in our countries such as parking areas, driveways, residential streets, pedestrian walkways, and tennis courts are getting covered either by impermeable cement concrete or bitumen surfaces (Al Maawali, et al., 2017). This blocks the percolation of water either from rainfall or any other sources and leads to environmental issues such as erosion, floods, groundwater depletion, and pollution of rivers, lakes, and coastal (Ali & Kacha, 2016). Hence, porous concrete is a special type of concrete with a high porosity, which is used for concrete flat works to allow water from precipitation and other sources by allowing surface water to infiltrate downwards through the pores, thereby minimizing flooding risks, reducing runoff and improving groundwater table (Patil, et al., 2020). This concrete is a unique and effective means to address important environmental issues and sustainable growth (Valvi, et al., 2018). The use of larger size coarse aggregates in these concrete mix increases infiltration capacity but decreases in bond strength and using smaller size aggregates exhibits higher strength but lower infiltration capacity (Jayanthi, et al., 2018). Foremost, it is possible to produce sustainable porous concrete with good strength and acceptable infiltration capacity using aggregate size between 4.75 mm and 19 mm of a maximum size 20 mm. Therefore, the use of permeable concrete instead of impermeable concrete is an innovative way for stormwater management and reduces runoff water-related environmental harms.

Similarly, a large amount of construction and demolition wastes are generated every year in Ethiopia’s construction industry due to rapid urbanization and housing demands for residents (Nigussie, et al., 2019). These wastes are generated whenever any construction/demolition activities take places such as renovation or construction of new buildings, roads, bridges, subways, and others (Shivakuma, et al., 2014). Commonly, they are disposed of as landfill and very little of them are reused for construction purpose. The disposal of these wastes causes serious environmental problems and economic impacts. Besides, the demand for fresh aggregates for producing concrete is still high while natural resources are reducing. Therefore, recycling of construction and demolition waste as an alternative construction material is one of the sustainable solutions to reduce environmental pollutions and lowering the dependence on natural and non-renewal resources. In this connection, attempts have been made for the utilization of recycled aggregate in the concrete mix by replacing natural aggregates to avoid the problem of waste disposal land and the gap between demand and supply of fresh aggregates.

Moreover, almost all the pavements, cobblestone roads, parking areas, pedestrian walkways, tennis courts, and residential streets pond surface water during the rainy (summer) season due to lack of permeability. This surface ponding of water causes the formation of mud on the pavement surfaces, health and pollution hazards, excess flood damaging drainage systems, depletion of groundwater level, and other environmental issues affecting the surrounding community and the environment. Therefore, this study focused on investigating the properties of porous concrete using recycled concrete aggregate us partial replacement of natural coarse aggregate to enhance sustainable development as well as announcing benefits of porous concrete in the Ethiopian market.

1.3 Research Questions

The research was aimed to answer the following questions:

1. What are the fresh properties of porous concrete containing RCA as partial replacement of natural coarse aggregate?
2. What are the hardened properties of RCA replaced porous concrete?
3. What is the optimum percentage replacement of RCA in porous concrete?

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of this research was to investigate the properties of porous concrete using recycled concrete aggregate as a partial replacement of natural coarse aggregate.

1.4.2 Specific Objectives

The specific objectives of this study can be stated as follows:

1. To evaluate the fresh properties of porous concrete containing RCA at each replacement level.
2. To evaluate the hardened properties of porous concrete containing RCA at each replacement level
3. To determine the optimum percentage replacement of RCA in porous concrete.

1.5 Significance of the study

This study will able to contribute to construction industries in Ethiopia in various ways like to introduce environmental benefits of porous concrete and helps the the construction industry to use different alternative concrete making materials including recycled concrete aggregate and advanced concrete technologies.Therefore, the final result of the study provides the following information for stakeholders in the construction industry.

- As one of the storm water management systems.
- A way for reduction of bad impact of urbanization on trees.
- Reduce the environmental impact of the fresh aggregate extraction process and
- As a reference for other researchers..etc.

1.6 Scope and limitation of the study

The scope of the study was investigating the workability, fresh density, compressive strength, split tensile strength, porosity, and permeability properties of porous concrete by varying the percentage of RCA from 0% to 60% by weight of natural coarse aggregate for concrete grade ranging between 2.8 MPa to 28 MPa. The finding of the study were limited to the strength and permeability properties of the concrete, therefore durability, freez and thawing resistance of this concrete were not studied. Generally, the scope of the study was only focused on evaluating the effects of recycled concrete aggregate on workability and fresh density of the fresh concrete; compressive strength, split tensile strength, porosity and permeability properties of hardened porous concrete.

CHAPTER 2
LITERATURE REVIEW

2.1 General overview

Concrete is the most commonly used construction material used worldwide. The word concrete comes from the Latin word ‘‘concretus’’ (meaning compact or condensed), the perfect passive participle of ‘‘concrescere’’, from the words ‘‘con’’ (together) and ‘‘crescere’’ (to grow) (PAVAN, et al., 2018). Also, Tito & Gomez-Rivas (2012) defined concrete as, it is a strong, durable, and economic construction material with different engineering applications. The principal components of concrete are coarse and fine aggregates, water, Portland cement, and other bindings, and chemical additives, with a proper mix design and construction procedure, produce the concrete with the required engineering properties. In general, concrete is an environmentally friendly construction material because the components are found locally. However, the elaboration of the Portland cement and natural coarse aggregate, which are a basic component of concrete, requires a large amount of energy and release large quantities of carbon dioxide (CO_2) into the atmosphere (Tito & Gomez-Rivas, 2012).

Though, the worldwide consumption of natural coarse aggregate in mortar/concrete production is very high while natural resources are depelted and several developing countries have faced some problems in the supply of natural coarse aggregate. So, to reach the increasing needs of infrastructural development in present days researchers have done an experimental study on the utility of recycled coarse aggregates as partial replacement of natural coarse aggregate (Ramprasad & Manikanta, 2019). Both methods lead to environmentally friendly material called Green Concrete. Green concrete has nothing to do with color (Kuma, et al., 2017). The raw materials of concrete consist of cement, sand, and crushed aggregates. Partial or 100% replacement of these raw materials by waste products may decrease the cost, reduce energy consumption, and also reduce environmental pollution (Krishnamoorthi & Kumar, 2013). Due to the use of recycled materials thereby avoiding the burdens for the removal of waste, less energy consumption, and greater durability (Sharma, et al., 2020). Green concrete is very often considered to be cheap to produce due to the use of recycled material thereby avoiding the charges for the disposal of waste, less energy consumption, and greater durability (Admute, et al., 2017). Hence in recent years, recycled wastes are necessary to produce a new product for sustainable environmentally friendly construction. However, the use of these aggregate (RCA) in porous concrete is advantageous for the environment. Therefore, porous concrete is an ideal sustainable solution continuing to gain popularity as a viable paving material and a tool for sustainable development because of its environmental benefits. Also, it has been considered as an environmentally friendly building material which quickly gaining recognition as a green building component.

2.2 Historical development of porous concrete

According to Vikram, (2019) study, the historical development of Porous concrete looks that, it was firstly used in the 1800s in Europe as pavement and load-bearing walls. It wasn't so popular in the US until the 1970s and becomes popular in 2000 in India. Now it was widely used in the United States, Japan, and Europe because of its various environmental benefits such as controlling stormwater runoff, restoring groundwater supplies, and reducing water and soil pollution. Apart from this it has the potential to reduce urban heat island effects and can be used to reduce acoustic noise inroads (Khemalapure & Vasatkar, 2016). The US green building council (USGBC) through its Leadership in Energy and Environmental Design (LEED) Green Building rating system promotes sustainable construction of buildings (FILHO, et al., 2020). A porous concrete pavement qualifies for LEED credits and is therefore sought by owners desiring for a high LEED certification an innovative/modified form of cement concrete (Vikram, 2019). Low loading intensity parking pavements, footpaths, and walkways have been built on a large scale in many developed countries and their performance has been found excellent. Recognized as the best management practice by the US Environment Protection Agency (EPA), it is capable of controlling first flush pollution and storm/rainwater overflow by allowing the received water to percolate down to earth and then seeping down to the groundwater table (Khemalapure & Vasatkar, 2016).

2.2.1 Definition of porous concrete

Porous concrete is a light-weight concrete produced by omitting the fine aggregate from conventional concrete (Murthy & Rajeswari, 2018). It has been used in sidewalks and surface pavements since the last decade for the management of urban runoffs (Teymouri, et al., 2020). Hence, it is paving material that permits rain and stormwater runoff to percolate through it rather than flood surrounding areas or storm drains (Valvi, et al., 2018). Typically, it describes a near-zero-slump, open-graded material consisting of Portland cement, coarse aggregate, and water. This concrete is high porosity and allows draining freely unlike dense, high-strength concrete. The high porosity is achieved by the absence or very low content of fine aggregates. Porous concrete has water to cementations materials ratio of 0.28 to 0.40 with a void content of 18 to 35% (Panimayam, et al., 2017). Therefore the correct amount of water in the concrete is critical. Low water to cement ratio will increase the strength of the concrete, but too little water may cause surface failure. As this concrete is sensitive to water content, the mixture should be field checked. Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable,

interconnected voids that drains quickly (Hussain & Kumar, 2018).

Figure 2.1: Porous concrete sample from (Khemalapure & Vasatkar, 2016); (Hussain & Kumar, 2018); (Kumar, 2015) respectively

2.3 Components of porous concrete

Production of porous concrete requires the same components as normal concrete except the quantity of fine (small size) aggregate particles (SESLIJA, et al., 2018). Depending upon the above argument, the main components are coarse aggregate, little or no fine aggregate, cement, and water. Sometimes different types of admixtures are used. In some cases, cementitious materials and recycled concrete aggregates are used as a substitute for Portland cement and natural aggregate respectively to enhance the environmental friendliness of the concrete.

2.3.1 Cement

Portland cement is used as the main binder, and as additives, to Portland cement, the following is often used: fly ash, ground granulated-metallurgical slag, and silica fume. It is recommended to conduct material testing of the mixture to verify compatibility of the mixture and that setting time, workability, strength, and porosity can provide the necessary characteristics for the intended use of concrete (SESLIJA, et al., 2018).

2.3.2 Natural aggregates

Aggregates are generally divided into two: coarse aggregate, which is the fraction of material retained on a No.4 (4.75mm) sieve, and fine aggregate, which is the fraction passing the No.4 sieve but retained on a No. 100 (0.15mm) sieve. So, coarse aggregate is an important constituent in porous concrete. The coarse aggregate gradation, shape, size, and type have been found to affect the properties of porous concrete. Aggregates can have a direct influence on the permeability, surface texture, and appearance of the porous slab. Coarse aggregate is kept to a narrow gradation, with the most common grading of coarse aggregate used in porous concrete meeting the requirements of ASTM C33/C33M. Aggregate grading used in porous concrete is typically either single-sized coarse aggregate or grading between 3/4 and 3/8 inch or 19mm and 9.5mm (Ali & Kacha, 2016). Also, a little amount of fine aggregate can be used (PRAMOD, et al., 2019).

2.3.3 Recycled coarse aggregates

The concept of using RAs as an alternative for the replacement of NAs first emerged in England during World War II, where RAs were mostly used for pavement construction. The difference between RA and virgin aggregate is the hardened cement paste and/or mortar that remains attached to the individual coarse aggregate particles (Hahladakis, et al., 2020). Recycled aggregates are aggregates derived from the processing of materials previously used in construction. Examples include recycled concrete from construction and demolition waste material (C&D) and recycled aggregate from asphalt pavement. It is produced by crushing sound, clean demolition waste of at least 95% by weight of concrete, and having a total contaminant level typically lower than 1% of the bulk mass. Other materials that may be present in RCA are gravel, crushed stone, hydraulic-cement concrete, or a combination deemed suitable for pre-mix concrete production (PAVAN, et al., 2018). These aggregates (RCA) can be used as a replacement of natural aggregates for concrete production to save natural resources and also to decrease the amount of demolition waste that has to be landfilled (Novakova & Mikulica, 2016). Also, it can reduce wastes in landfills and reduce the consumption of natural material resources (Ali & Kacha, 2016). Therefore, the use of waste aggregate such as recycled aggregate (RA) in porous concrete is advantageous for the environment.

2.3.4 Fine aggregate

Fine aggregate is either natural or manufactured aggregate that passes through a 4.75mm sieve. It is an aggregate conforming to ASTM C 33 and free from deleterious materials like clay, silt, and other organic matters.

2.3.5 Water

Water is an important ingredient of concrete that actively participates in a chemical reactions with cement. The water meeting standard requirements can be used for the production of porous concrete. No special requirements in terms of water quality are necessary. The water-cement ratio of porous concrete is determined in the same way as conventional concrete (SESLIJA, et al., 2018). Therefore, the control of water is important in the development of porous concrete mixtures, and the selection of an appropriate w/cm value is important for obtaining the desired strength and void structure in the concrete. A high w/cm can result in the cement paste flowing off of aggregate and filling the void structure, whereas a low w/cm can result in mixing and placement difficulties and reduced durability (Shivakuma, et al., 2014).

a) Small water content b) Optimum water content c) Optimum water content

Figure 2.2: Porous concrete samples with different water content (SESLIJA, et al., 2018)

2.4 Water-Cement ratio

The water-cementitious material ratio (w/cm) is an important consideration for obtaining the desired strength and void structure in pervious concrete. A high w/cm reduces the adhesion of the paste to the aggregate and causes the paste to flow and fill the voids even when lightly compacted. A low/cm will prevent good mixing and tend to cause balling in the mixer, prevent an even distribution of cement paste, and therefore reduce the ultimate strength and durability of the concrete. Experience has shown that w/cm in the range of 0.26 to 0.45 will provide the best aggregate coating and paste stability. The conventional w/cm-versus-compressive strength relationship for normal concrete does not apply to porous concrete. Careful control of aggregate moisture and w/cm is important to produce consistent porous concrete (ACI522R, 2010).

2.5 Characteristics of porous concrete

Porous concrete is usually constituted of normal Portland cement, a coarse aggregate of uniform size, and water, additionally; fine aggregates and admixtures have been utilized in material design if needed (Karthik, 2017). Material design that has been developed excellently is dependent on the attributes of the used materials and may have optimized functionalities with local materials. When compared with conventional concrete, porous concrete exhibits substantially different properties. Some of the noted characteristics of porous or no-fines concrete are:

- Lower unit weight and drying shrinkage
- Higher permeability
- Higher thermal insulation values
- Lower compressive, tensile, and bond strengths
- Lower pressure on formwork during construction and
- Longer curing time required before form removal (Yadav, et al., 2017)

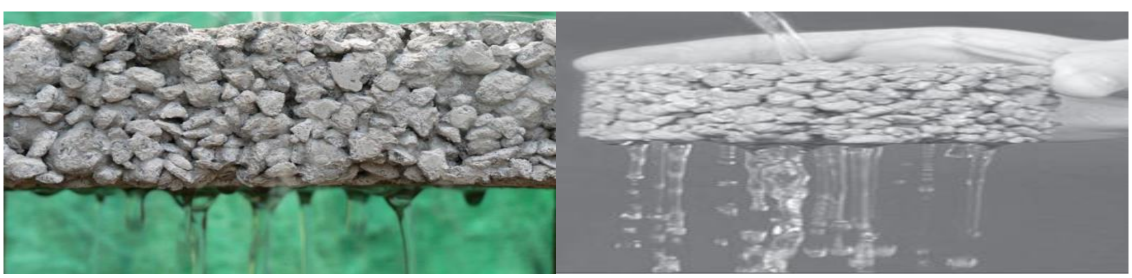


Figure 2.3: Infiltration of water through Porous Concrete from (Yadav, et al., 2017) & (Karthik, 2017)

2.5.1 Characteristics of porous concrete made from recycled aggregate

Properties of aggregates affect the characteristic of fresh and hardened porous concrete in which it is utilized. The majority of studies have demonstrated that a decrease in compressive strength occurs when RA is utilized in making normal concrete. The trend of decrease in compressive and tensile strength in concrete with increased content of RA may be described by the availability of two types of interfacial transition zones (ITZ) in concrete generated from RA. The ITZ stands for the bondage between aggregate and paste and is usually weaker compared to aggregate or cement paste that is hydrated. ITZ is a weakened region that is prone to the occurrence of potential failures. Many ITZ is present in concrete made from RA than in normal concrete since ITZ in RA concretes entails the bondage between aggregate old motor, aggregate new mortar, and old mortar new mortar. The higher the replacement rate of RA, the more the ITZ and the higher the reduction rate in compressive strength. Additionally, the a/c ratio had a vital effect on the compressive strength of RA pervious concrete. The experimental results showed that the properties of pervious concrete were significantly affected by using recycled aggregate. Substituting the recycled aggregate with natural aggregate resulted in a considerable increment in the permeability coefficient. However, it was observed that the mechanical properties of such concretes were adversely influenced up to a certain degree (SESLIJA, et al., 2018).

2.6 Properties of porous concrete

Many porous concrete properties primarily depend on its porosity, which in turn depends on the cement content, water-cement ratio, density, particle size distribution, and general material quality. The pore sizes in the concrete also affect the strength properties. The most important properties and their interdependence, analyzed within this study are:

- Fresh Properties and
- Hardened Properties

2.6.1 Fresh properties

Fresh porous concrete is known to be stiff and also has lower workability than conventional concrete. Values of a slump are below 2cm; hence pumping it is not possible (ACI522R, 2010). The slump is rarely a relevant method applied in the determination of mixture consistency. The workability of porous concrete is supposed to be evaluated using a ball with the hand to determine its mouldability. The porous concrete mouldability is critical to the content of water; therefore, the volume of water must be controlled carefully (Hilal & Hama, 2007).

A. Workability

The American Concrete Institute describes workability as “that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition” (ACI 116R, 2000). It can be measured with the slump test, compaction factor test, flow table test, VeBe test, and Kelly ball test. Hence, it is one of the important parameters of measuring the consistency of the fresh concrete. The slump test is the most commonly used method of measuring the consistency of the concrete.

- **Slump test**

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete (Herki, 2020). The inexpensive test, which measures consistency, is used on job sites to determine rapidly whether a concrete batch should be accepted or rejected. The test method is widely standardized throughout the world, including in ASTM C143 in the United States and EN 12350-2 in Europe. The apparatus consists of a mold in the shape of a frustum of a cone with a base diameter of 8 inches (20cm), a top diameter of 4 inches (10cm), and a height of 12 inches (30cm). Four types of slumps are commonly encountered.

1. **True slump** - where the concrete just subsides, keeping its shape approximately.
2. **Shear slump** - where the top half of the cone shears off and slips sideways down an inclined plane.
3. **Collapse slump** - where the concrete collapses completely.
4. **Zero slump -** no subsidence.

The only type of slump permissible under ASTM C143 is frequently referred to as the "true" slump, where the concrete remains intact and retains an asymmetric shape. A zero slump and a collapsed slump are both outside the range of workability that can be measured with the slump test. Specifically, ASTM C143 advises caution in interpreting that, test results having slump less than ½ inch may not be adequately plastic and slump greater than 9 inches may not be adequately cohesive. If part of the concrete shears from the mass, the test must be repeated with a different sample of concrete. A concrete that exhibits a shear slump in a second test is not sufficiently cohesive and should be rejected (Fowler & Kohler, 2003).

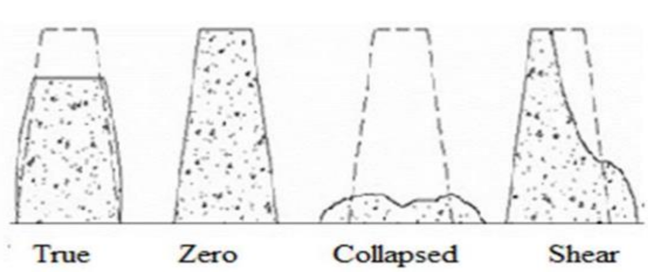


Figure 2.4: Types of a slump and its apparatus

- **Compacting factor test**

Drier mixes do not give a slump. Therefore, a compaction factor test should be done to determine the degree of compaction (compacting factor) by making the mix fall through successive hoppers with standard height using a compaction factor test apparatus.

$$\text{Compacting Factor} = \frac{weight-of-partially-dry-compacted-concrete}{weight-of-fully-compacted-concrete} \quad \text{.......Equation.1}$$

Table 2.1 Permissible Values of the compacting Factor **(Shetty, 2005)**

Workability	**Compacting factor**
Good workability	0.95
Medium Workability	0.92
Low workability	0.85
Very low workability	0.78

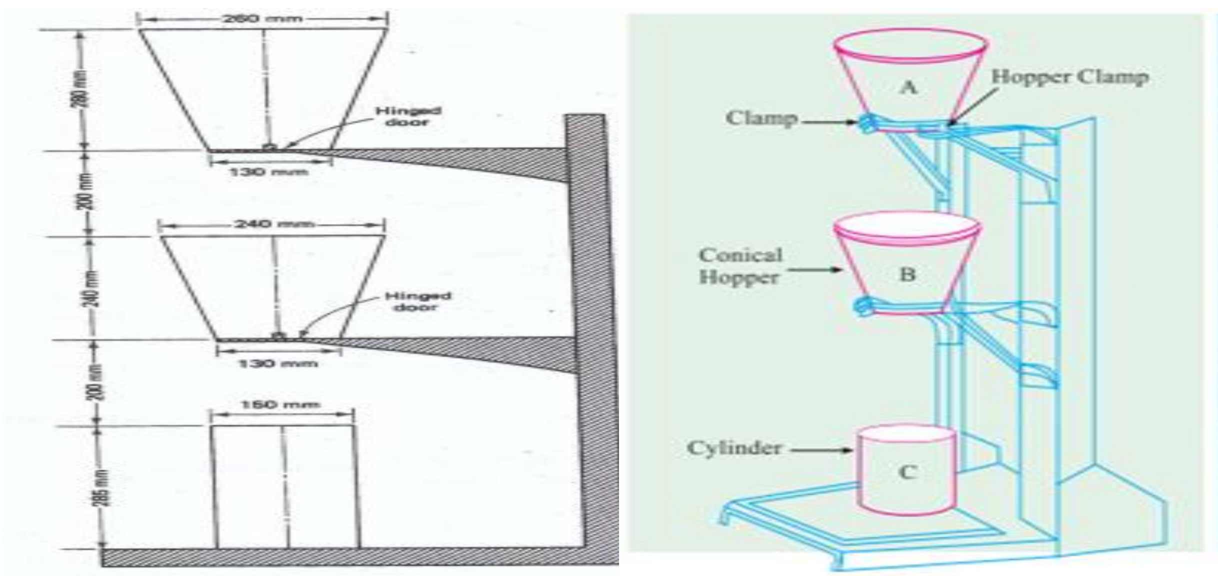


Figure 2.5: Compacting factor apparatus (Shetty, 2005)

For different placing conditions, degree of workability (extremely low, very low, medium, and high), and aggregate sizes, corresponding values of the compacting factor are given as standard to compare with.

2.6.2 Hardened properties

The properties of fresh concrete are important only in the first few hours of its history whereas the properties of hardened concrete assume an importance that is retained for the remainder of the life of the concrete. The important properties of hardened concrete are strength, deformation under load, durability, permeability, and shrinkage. In general, strength is considered to be the most important property and the quality of concrete is often judged by its strength. In most cases, an improvement in strength results in an improvement of the other properties of concrete but there are exceptions. For example, increasing the cement content of a mix improves strength but results in higher shrinkage which in extreme cases can adversely affect durability and permeability. Since the properties of concrete change with age and environment, it is not possible to attribute absolute values to any of them.

Strength: - The strength of concrete is defined as the maximum loads (stress) it can carry. As the strength of concrete increases, its other properties usually improve and since the tests for strength, particularly in compression, are relatively simple to perform (Rahman, 2007).

A. Compressive strength

Concrete is employed primarily to resist compressive stresses. Concrete compressive strength is commonly used in the construction industry for specification and quality control. Porous concrete compressive strength is relatively reduced because of the large content of voids. Also, the sequence of the increase of the aggregate size, the values or mixture ratios as well as effort invested in compaction during casting of the concrete have the most effect on the compressive strength of porous concrete. Hence, the total content of cementitious material, the presence of additives such as polymeric additives and mineral admixtures lead to an increase in the development of compressive strength porous (SESLIJA, et al., 2018). In connection with this, several researchers have examined the aspects linked to the compressive strength of porous concrete but not standard methods are available. As a result, drilled cores have been regarded as a relevant method for the determination of site porous concrete compressive strength. Porous concrete compressive strength is known to be lower than that of traditional concrete because of its high porosity. Because of that, the compressive strength ranges between 2.8 MPa to 28 MPa with ideal values of (17 MPa) (Hilal & Hama, 2007).

Generally, the compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. The specimen was placed in the machine in such a manner that the load was applied to opposite sides of the cubes i.e., not top and bottom. The applied load was increased continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and no longer can be sustained. The maximum load applied to the specimen was recorded. Lastly, the load at the failure divided by the area of specimen gives the compressive strength of concrete (Lidiya, 2018).

$$\delta c = \frac{P}{A} \text{ (N/mm}^2\text{)} \quad \text{……………………………………………………………Equation.2}$$

Where δc = compressive strength of the concrete

P = maximum load and

A = cross-sectional area

B. Flexural strength

Porous concrete flexural strength can range from 1.0 MPa to 3.8 MPa. Many elements control the flexile strength, considerable diploma of consolidation, porosity, and additionally the mixture/cement proportions (Vikram, 2019).

C. Spilt tensile strength test

Concrete is a comparatively brittle material that is relatively weak in tension. This test is conducted by a compressive testing machine placing cylindrical specimens of the concrete. So, its axis is horizontal between the plates of the testing machine. The experimental setup for the split tensile test is that the load will be applied at a constant rate until failure by splitting along the vertical diameter. The load at which the specimen failed is recorded and the splitting tensile stress is obtained using the following formula (Achal & Chandak, 2017).

$$T = \frac{2P}{\pi DL} \quad \text{……………………………………………………………… Equation.3}$$

Where,

T= the spilt tensile strength of the concrete L= length of the cylinder

P= compressive load on the cylinder D= diameter of the cylinder

D. Permeability

The most important feature of the porous concrete is allowing the percolation of water passing the porous medium. The placing operation and materials were depending on the rate of flow via permeable concrete 0.2cm/s to 0.54cm/s are the typical flow rate of water by the rate of up to 1.2cm/s (Vikram, 2019). The permeability rate or the permeability coefficient of the pervious concrete is particularly related to the size of the aggregate used for the mixture, water-cement ratio, and the number of pores (SESLIJA, et al., 2018). For porosity from 20 to 25%, the permeability coefficient is about 0.01 m/s. The test is done by the constant head method and the Falling head method (Yogeswari & Krishnan, 2019).

1. Falling-head method

The standpipe over the mixed samples of porous concrete is placed, they are tightly sealed over the top of the sample surface to avoid water loss at sides. The permeability test on the samples is carried by the water-filled into the sample along the standpipe as the top level is reached and the other side of the outlet is closed to maintain the water level. The waterfalls once the valve is opened. The falling of water from initial and the time is noted as zero and when the head reached the final level of water the time is noted as shown in Fig. 2.6. The time is used to determine permeability by the formula:

$$K = \frac{a.L}{A.t} \ln \frac{ho}{ht}$$ ………………………………………………………………...Equation.4

Where K= coefficient of permeability (cm/sec)

a = stand pipe area (cm^2)

L= sample length (cm)

A= sample surface area (cm^2)

t= elapsed time of the test (sec)

h_o= head at the start of the test (cm)

h_t= head at end of the test (cm)

Figure 2.6: Test setup for falling head method

2. **Constant head method**

The standpipe over the mixed samples of porous concrete is placed, they are tightly sealed over the top of the sample surface to avoid water loss at sides. The permeability test for samples is done by flowing the water in the standpipe at the constant quantity of water level maintaining and allowing the water flow into the samples along the standpipe. Water level maintained at the desired water head in the inlet pipe. The water flowing in maintained by the outlet valve. The discharging water can be determined by the measured volume of water collects in the water container over some time at a constant head of flowing water as shown in Figure 2.7. The coefficient of permeability **k** in cm/s is calculated by:

$$K = \frac{QL}{Aht} \quad \text{………………………………………………………………………Equation.5}$$

Where, K= coefficient of permeability (cm/sec)

Q = volume of water collected in total (mm^3)

L= sample length (mm)

A = cross-sectional area of samples (mm^2)

h = constant water head (mm)

t = taken time (sec)

Figure 2.7: Test setup for constant head method

E. Porosity(void content)

The ratio of voids in the porous concrete to the total volume of the sample is the porosity. The porosity is measured in hardened Porous Concrete specimens as per the ASTM C1754. The test is performed by taking the oven-dried weight of the sample (Md). The size of the sample (height and width) to obtain the volume of the sample (V). The density of the hardened sample is obtained as the oven-dried mass to the volume of the sample ratio (Md/V). To find obtained porosity, each sample was submerged in a water tank for a minimum of 30 min, after 30 min the submerged mass of each sample was noted (Mw). The porosity of the solids was obtained by dividing the difference between the dried and submerged weight by the water density (ρw) as porosity (P) was calculated using the formula and the setup (Yogeswari & Krishnan, 2019).

$$P = \left(1 - \frac{Md - Mw}{\delta_w \times v}\right) \times 100 \quad \text{……Equation.6}$$

To ensure that water will percolate through pervious concrete, the void content, both in the design of the mixture and measured as the percent air by ASTM C138/C138M (the gravimetric method) should be 15% or greater. At a void content lower than 15%, there is no significant percolation through the concrete. It is believed that below15% voids, there is not sufficient interconnectivity between the voids to allow for rapid percolation. Hence, the higher the void content, the higher the percolation rate, and the lower the compressive strength. The lower the void content, the lower the percolation rate, and the higher the compressive strength. Also, the compressive strength increases as the nominal maximum size aggregate decreases. The compressive strength of pervious concrete is also a function of the aggregate strength, paste bonding characteristics, and strength of the cement paste (ACI522R, 2010).

F. Density

Density is the most important "special" porous concrete property. Concrete density in the completely dry condition is a mass per volume unit of concrete dried at temperatures of 105-110 °C until a constant mass is obtained. The density of porous concrete usually is 1600-2000 kg/m^3 (SESLIJA, et al., 2018).

2.7 Application areas of porous concrete

Porous concrete is having many applications but the only drawback is, it lacks durability. Due to this constraint, the use of porous concrete is restricted to low traffic volume roads like pathways, secondary roads, parking areas, residential streets, pedestrian walkways, and greenhouses. Due to rapid development and urbanization, in city's most of the area is covered either by cement concrete or bitumen surfaces and affecting the runoff and the groundwater table. Therefore, porous concrete has got its extensive application in use for a reduced runoff on city roads and tremendous ability to recharge groundwater (Al Maawali, et al., 2017). It also reduces the bad impact of urbanization on trees because porous concrete ground surface allows the transfer of water and air to root systems allowing trees to flourish (Jibhenkar, et al., 2015). So, it is an important application for sustainable construction and is one of the techniques used for groundwater recharge.

2.8 Advantages and disadvantages of porous concrete

2.8.1 Advantages

Porous concrete demonstrates the following advantages, benefiting the environment

- Allows the water to flow freely through the surface which reduces glare, especially at night when the road is wet.
- Reduce surface ponding of water i.e. decrease flooding possibilities
- Reduction of stormwater runoff
- Recharging the groundwater level
- Supporting vegetation growth
- Improving water quality through infiltration capacity

- Reduces or eliminates the need for storm sewers or retention ponds
- High absorption of sound and heat
- Reduces tire noise in the pavement due to open interconnected air void structure (Choudhary, et al., 2017) ; (Rakesh, et al., 2019).

2.8.2 Disadvantages

The disadvantages of porous concrete are:

- Many engineers and contractors lack expertise with porous concrete technology
- Lower compressive strength due to high porosity
- Limited use as a load-bearing unit due to its low strength
- Extended curing and formwork stripping time
- Require high maintenance management because of the clogging effect (Jibhenkar, et al., 2015) ; (Choudhary, et al., 2017).

2.9 Maintenance Management Practice

Over time, sand, dirt, vegetation, and other debris can be collected in porous concrete's voids and the voids will be clogged because of longer service life, wind, and runoff water which reduce its porosity, which can negatively affect the functionality of the system (Ma, et al., 2020). Thus, periodic maintenance may be needed to remove surface debris and restore infiltration capacity. Two common maintenance methods are pressure washing and power vacuuming (Panimayam, et al., 2017). This type of maintenance process can restore 80% to 90% of the permeability under some conditions (Yogeswari & Krishnan, 2019).

2.10 Study variables

Two types of variables are used in this paper. Those are dependent variables and independent variables.The dependent variable of this study is a response variable or output of the character that has been changed because of variations in the independent variables. This means that if the value of the independent variable changes due to any factor, its effect may consequently observe on the output. Independent variables are factors or parameters that affect the output of dependent variables.

CHAPTER 3

RESEARCH MATERIALS AND METHODS

3.1 Research area

This research was conducted in the South-Western part of Ethiopia at Oromia Regional State Jimma Zone at a distance of 345 km from Addis Ababa. The geographical location of the town is 7° 39′ 0″ N and 36° 52’ 30’’ E and elevation vary from 1700m-2000 m above sea level. All the tests conducted for material quality determination and concrete property were carried out in Jimma University Institute of Technology, Civil and Environmental Engineering Department, construction material laboratory.

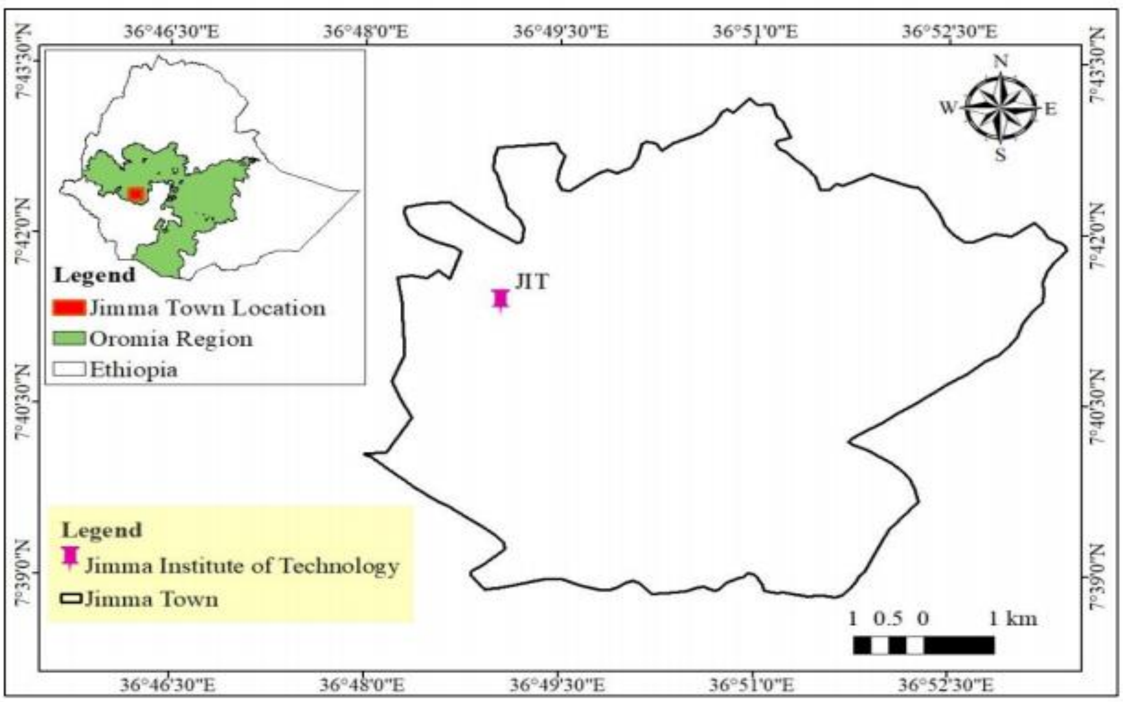


Figure 3. 1 Study area lactation **(**Meshesha, 2020**)**.

3.2 Research design

After the identification of the research problem and setting the objectives of the research, the experimental research design method was carefully designed to achieve the mentioned objectives. This design was used to analyze the effect of recycled concrete aggregate on workability, fresh density, compressive strength, split tensile strength, porosity, and permeability properties of porous concrete and the optimum percentage replacement that should have to be used without compromising the specified quality of the concrete. Also, different experimental works were conducted on material properties to prove the suitability of the materials used for concreting work, and finally, tests on concrete specimens were made to decide and recommend the future adaptability of porous concrete in construction industries of developing countries.

3.3 Study variables

Two types of variables are used in this paper. Those are dependent variables and independent variables.

A. Dependent variable

The dependent variable of this study is a response variable or output of the character that has been changed because of variations in the independent variables. This means that if the value of the independent variable changes due to any factor, its effect may consequently observe on the output. Therefore the dependent variable of this study was:

- Properties of porous conctere

B. Independent variables

Independent variables are factors or parameters that affect the output of dependent variables. In this study the common factors affecting the performance of porous concrete are:

- Physical properties of material
- Percent of RCA
- Aggregate size
- Aggregate cement ratio
- Water cement ratio

3.4 Sample size and sampling procedures

The study used the purposive sampling technique and the procedure was taken according to ASTM and ACI standards which means a minimum of cube samples per each test day was 3 as per standard except for porosity. The samples for compressive strength, tensile strength, and permeability of all 5 groups such as 0 %, 15%, 30%, 45%, and 60 of RCA was cured by ponding method and test taken at 7^{th}, 14^{th} and 28^{th} days. For all compressive and tensile strength tests on NCAPC and RCAPC, the cube size was 150mm*150mm*150mm, and the cylinder of size 100 mm diameters and 200mm length was cast respectively. Hence, the study has a total of 75 cubes and 60 cylinders = 135 test samples as illustrated in the following table 3.1.

Table 3.1 The samples required to determine the test result

No	Test type	% of RCA by weight of aggregate	Code of sample	Testing Days			
				7	14	28	Sum
1	Compressive Strength(N/mm^2)	0%	NCAPC (C_0)	3	3	3	9
		15%	RCAPC (C_1)	3	3	3	9
		30%	RCAPC (C_2)	3	3	3	9
		45%	RCAPC (C_3)	3	3	3	9
		60%	RCAPC (C_4)	3	3	3	9
2	Split tensile Strength(N/mm^2)	0%	NCAPC (T_0)	3	3	3	9
		15%	RCAPC (T_1)	3	3	3	9
		30%	RCAPC (T_2)	3	3	3	9
		45%	RCAPC (T_3)	3	3	3	9
		60%	RCAPC (T_4)	3	3	3	9
3	Porosity ratio (%)	0%	NCAPC (P_0)	2	2	2	6
		15%	RCAPC (P_1)	2	2	2	6
		30%	RCAPC (P_2)	2	2	2	6
		45%	RCAPC (P_3)	2	2	2	6
		60%	RCAPC (P_4)	2	2	2	6
4	Co-efficient of Permeability (cm/s)	0%	NCAPC (CP_0)	-	-	3	3
		15%	RCAPC (CP_1)	-	-	3	3
		30%	RCAPC (CP_2)	-	-	3	3

		45%	RCAPC (CP_3)	-	-	3	3
		60%	RCAPC (CP_4)	-	-	3	3
							Total = **135**

Note: The test result was compared with each other especially, with zero percent recycled coarse aggregate (control) test and the conclusion was drawn based on the result and standards.

3.5 Data source and collection processes

In this study, descriptive and analytical methods of the data collection process were followed. In the descriptive data collection method, secondary sources of data from different published journals, books, reports, and standard manuals were assessed. Whereas, primary data collection methods like field study for material source determination and laboratory investigation to determine the physical properties of materials were used. Also, the specimens that were placed in the laboratory for different curing and testing age with different percentage ratios of RCA were tested in their chronological order of curing and casting time, then the data was registered with their code tagged on it for 7, 14, and 28 days.

3.6 Data presentation and analysis

After collecting the necessary apparatus and materials for the production of porous concrete those are cement, aggregates (natural and recycled), and clean water, the laboratory experiment was continued. By using the results obtained from the laboratory the researcher analyzed the data by comparing and contrasting the effects of RCA with the control group which has 0% of RCA using Microsoft word and excel 2013. The analyzed data then presented using charts, figures, and tables. In addition to those presentation methods, the Regression model was also developed to check the reliability of the test results for compacting factor test and permeability. Furthermore, this research paper was present the facts of laboratory result and recommend the optimum percentage of RCAs that must be used as a partial replacement in porous concrete.

3.7 Materials used and test methods

The materials used for this experimental program (Cement, Natural Coarse aggregate, Recycled concrete aggregate, and water) were described concerning their source and relevant physical properties. All the laboratory investigations on properties of materials that govern ratio proportioning of concrete ingredients were investigated in Jimma University Institute of Technology, Civil and Environmental Engineering Department, construction material laboratory. This test determines the quality of material before starting the mix design procedures which is vital for the study. All the tests are followed as per national and international test standards and the apparatus used was also confirmed with the standards.

3.7.1 Cement

Dangote, Portland Pozzolana Cement (PPC) manufactured according to Ethiopian standards ES 1177-1 CEM II/B-P 32.5R confirming ES ISO-9001:2015 and complies with ASTM C150 was used in the preparation of the concrete mixtures. The cement of this factory was available in Addis Ababa, Ethiopia, and procured from Jimma town construction materials shopping center.

Figure 3. 2 PPC Dangote cement grade of 32.5R

The laboratory physical property tests which include the normal consistency, setting time (both initial and final setting time), fineness, and specific gravity, were determined using the standard specifications of ASTM C187, ASTM C191, ASTM C184, and ASTM C188, respectively. The detailed procedures and calculations are indicated below.

A. Normal consistency

The normal consistency of hydraulic cement refers to the amount of water required to make a neat paste of satisfactory workability (Dinku, 2002). This test method is intended to be used to determine the correct amount of water required to prepare hydraulic cement pastes for testing (ASTM C187, 2004). It is determined using the Vicat Apparatus. This apparatus measures the resistance of the paste to the penetration of a plunger of the needle of 200gm released at the surface of the paste (Dinku, 2002).

Apparatus used: Vicat apparatus, Weighs and weighing device, Graduated Cylinder, Mixing Dish, and Trowel were used to perform the test.

Test procedure: A 400gm of cement sample is carefully mixed with a measured quantity of clean water for 3min. Using a trowel, quickly form the cement paste in the approximate shape of a ball by tossing 6 times from one hand to another through a free path of about 6in (150mm) to produce a neatly spherical mass that may be easily inserted into the Vicat ring mold, immediately after filling the mold, level the paste and lower the plunger gently, and bring it in contact with the surface of the paste, tighten the screw setting the movable indicator to the upper zero marks of the scale and release the plunger immediately, thirty seconds after releasing the plunger record its penetration, the paste said to be of normal consistency when the rod settles 10+ or -1mm below the original surface within thirty seconds, repeat the above procedures varying the proportion of water until a paste of normal consistency obtained, The amount of water required for normal consistency then expressed as a percentage weight of the dry cement.

$$\%Water = \frac{\text{Weight of water in gm}}{\text{Weight of cement in gm}} * 100 \quad \text{Equation.7}$$

Hence, the usual range of water-cement ratio for normal consistency is between 26% and 33% (Dinku, 2002).

Table 3.2 Observed normal consistency test result

Trials	Wt. of cement (gm)	Amount of Water (ml)	W/C ratio	Penetration Depth(mm)
1	400	105	0.26	8.5
2	400	115	0.29	9.32
3	400	125	0.31	10

Finally, the observed test result shows that the penetration depth of 8.5mm, 9.32mm, and 10mm when the water-cement ratio was 0.26 (26%), 0.29(29%), and 0.31(31%) respectively. Hence, the normal consistency of cement was found 10mm at the 3rd trial when the water-cement ratio was 0.31(31%) which is between the limited range (10 ± 1mm). Therefore, the result shows that the water demand for this cement is moderate. This means it requires medium water to prepare a paste of satisfactory workability (normal consistency).

Figure 3. 3 Determination for normal consistency of cement

B. Setting time

These testing methods define the time of setting of hydraulic cement using a Vicat needle (ASTM C191, 2008). The cement forms a solid and hard mass when mixed with water upon hydration. This phenomenon is known as the setting of cement. The duration a cement paste requires to undergo setting is its setting time. As the setting is the consequence of hydration of cement, it is affected by the amount of water used to prepare cement paste, i.e. water-cement ratio. Cement pastes with different water-cement ratios will, generally, have different setting times but it is the setting time of cement paste with normal consistency (Dinku, 2002).

There are two types of set times to be determined in the laboratory:

i. **Initial setting time:** This is regarded as the time elapsed between the moments that the water is added to the cement up to the time that the paste starts losing its plasticity or the duration of cement paste related to 25mm penetration of the Vicat needle into the paste in 30 seconds after it is released.

ii. **Final setting time:** Is the time elapsed between the moment at which the water is added to the cement and when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure. This means the time that related to zero penetration of the Vicat needle into the paste (ASTM C191, 2008).

Apparatus used: Vicat apparatus, weighing balance, Mixing dish or Tray, Stopwatch, Graduated cylinder, Trowel, and Hand glove.

Test procedure: Prepare a neat 400gms of cement paste by gauging the cement with 0.85 times the water required to give a paste of normal consistency. Start a stop-watch at the instant when water is added to the cement. Insert the paste into the conical ring and remove the excess with a sharpened trowel. Invert the larger ring on the glass plate and cut off the excess paste on the smaller end with a sharpened trowel. Immediately after molding, allow the sample to stay in the moist room for 30 minutes after molding without disturbing. Lower the needle gently until it comes in connection with the surface of the test specimen. Release the rod quickly & allow it to penetrate the paste for 30seconds. Determine the dispersion of the 1mm needle at this time and every 15min thereafter until penetration of 25mm or less is gained. The time between the initial contact of cement and the penetration of 25mm is the initial time of setting. The final setting time: - is determined by replacing the needle for the Vicat apparatus with the final set needle, which has an annular attachment at the end. The final setting time is when the needle does not bowl visibly into the paste (Dinku, 2002). Finally, the observed test results were recorded as follow:

Table 3.3 Observed setting time data

Trial	cement (gm)	Water(ml)	w/c ratio	T_0	T1	T2	Initial setting time(T3)	Final setting time(T4)
S_1	400	118	0.31	2:30	180	195	188.57(min)	316.2(min)
				Penetration depth(mm)	26.2	24.1		
S_2	400	118	0.31	2:30	165	180	182(min)	280(min)
				Penetration depth(mm)	28.7	23.8		

Where:

T_0 = Time in an hour at which water is first added to the cement

T1 = Time in a minute at which the needle penetrates the paste to a depth of 26.2mm.

T2 = Time in a minute at which the needle penetrates the paste to a depth of 24.1mm.

T3 = Time in a minute at which the needle penetrates the paste to a depth of 25mm. Which was computed by **interpolation** for S1 as follow:

$$180 = 26.2\text{mm}$$

$$X = 25\text{mm}$$

$$195 \ = \ 24.1\text{mm}$$

X = 188.57 minute

T4 = Time at which the final set needle makes only an impression (i.e. D=0).

The initial setting time of the cement was 188.57minutes = 3:14(3 hr. and 14 minutes).

The final setting time can be estimated by the equation:

Final setting time (in minutes) = 90 + 1.2 × (Initial setting time)

= 90 + 1.2 × (188.57) = 316.2 minutes = 5:27(5 hrs. and 27 minute)

Finally, Ethiopian Standard recommends that the initial setting time for cement not to be less than 45 minutes and the final setting time not to exceed 10 hours (Dinku, 2002). Herein, the initial setting time of this cement is more than 45 min; but, it is somewhat late due to more mixing water and the final setting time of this cement was not more than the recommended time (10hr).

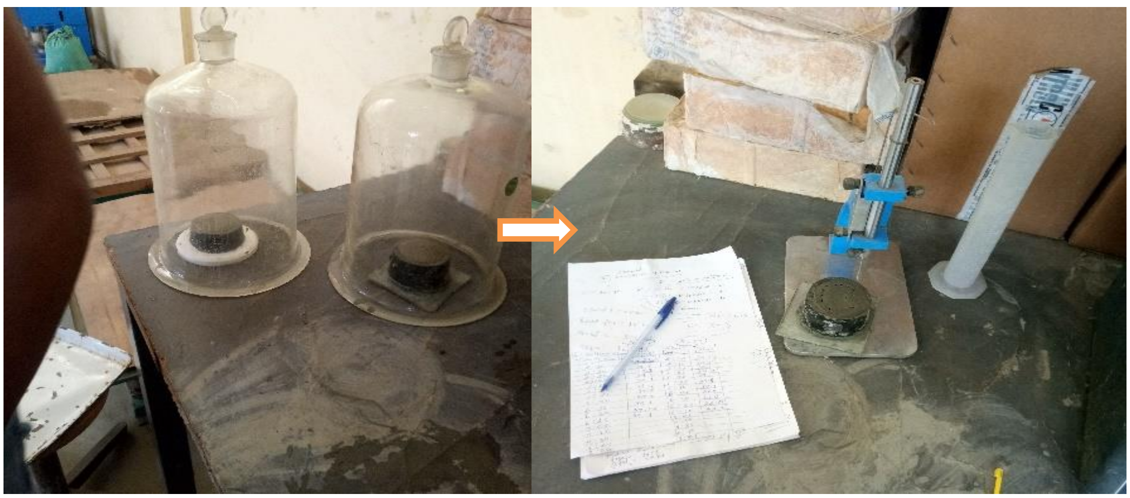


Figure 3. 4 Determination for setting time of cement

C. The fineness of hydraulic cement by sieve analysis

The degree of fineness of cement is a measure of the mean size of the grains. The finer cement has a quicker reaction with water and gains early strength without a change in the ultimate strength. This means the rate of hydration of cement increases with increasing fineness which leads to both a higher rate of strength gain and a higher rate of evolution of heat.

Apparatus used: 150 µm (No. 100) standard sieve, Pan, Weighing balance, and Brush.

Test procedure: Accurately weigh 100gram (W1) of the cement sample and place it over the test sieve. Shake the sieve with the pan by a means of shaker for a period of 10 to 15 minutes. After 10 to 15 minutes weighing the residue left over the sieve and record as (W2).

Observations:

- Weight of cement taken = 100gm
- Weight of cement retained after sieving = 1.5g
- Fineness % = $[\frac{1.5}{100}]*100 = 1.5\% < 5\%$............ok!

Conclusion: The Fineness of this cement is correctly balanced with the amount of coarseness. Generally, the following table 3.4 summarizes all the observed test results for the physical properties of Portland Pozzolana cement (PPC).

Table 3.4 Summarized test results for physical properties of cement

Test type	Test result	ASTM Standard	Remark
Specific gravity	2.9	Near 2.9	ok
Standard Consistency (%)	31%	26% up to 33%	ok
Initial Setting Time (min)	188.57	more than 45 min	ok
Final Setting Time (min)	316.20(5 hr and 27minute)	not more than 10hr	ok
Fineness (%)	1.5%	<5%	ok

3.7.2 Coarse aggregates

Dinku, (2002) argued that coarse aggregates are aggregates those grading between 75mm up to 4.75mm. Also, he suggested that, the possibility of using gravel, crushed rock, and blast furnace slag as aggregates. Consequently, both crushed stone gravel of natural basaltic origin and recycled concrete aggregates confirming ASTM C 33 are used as coarse aggregate.

A. Natural coarse aggregate

According to ACI 522R (2010) committee report, coarse aggregate used in porous concrete are

typically either single-sized or grading between 3/4 and 3/8 in.(19mm and 9.5 mm). Therefore, all aggregates grading between 20mm and 4.75mm are included in this study to reduce the extra porosity of the final concrete. Hence, the maximum nominal size of coarse aggregate used was

20mm which was bought from Jimma around Yetebaberut, at the back of Orthodox Michael church market site of small-scale suppliers. Subsequently, the relevant tests were made to identify the quality of the aggregates used for the study. After that, corrective measures were taken in advance before proceeding to the mix proportioning, like blending the aggregates to meet the grading requirement, washing the aggregates to make them free from impurities like silt, clay, dirt, or organic matter are conducted as shown in following figure 3.5.

Figure 3. 5 Natural coarse aggregate treatment processes

B. Recycled concrete aggregate

The recycled concrete aggregate which is obtained from demolished building concrete structures was used as a partial replacement by specified percentage weight of natural coarse aggregate after crushing it to the specified grade. The demolished concrete structures were collected from the demolished building of Jimma University Hotel and Truism project and Jimma palace renovation and new building project sites. These old buildings were used as offices before thirty and above years. In recycling processes of concrete structures, several impurities were eliminated using the following techniques: sorting the demolished concrete waste from the site before disposal, removing unnecessary attachments, crushing by jackhammer, loading and transporting into the laboratory, again crushing it by hammer to the desired sizes and washing to remove the fine particles and some of surrounding old mortars.

Figure 3. 6 Recycling and treatment processes for RCA

3.7.3 Physical property tests on natural and recycled coarse aggregate

Subsequently, the relevant tests were made to identify the physical properties of the aggregates used for the study. These are the determination of the particle size distribution (grading), unit weight, specific gravity, and water absorption capacity, moisture content, impact value, and abrasion value for both natural and recycled aggregate were determined as follow:

I. Gradation for both NCA and RCA

Sieve analysis was conducted for the determination of the particle size distribution (grading) of aggregates, fineness modulus, and uniformity of the aggregate using a series of square meshes starting with the largest size at the top and pan at the bottom. This test method is mainly used to determine the classification of materials proposed for use as aggregates or being used as aggregates (ASTM C136-93, 1993). It is conducted to check whether it fulfilled the standard specification for concrete production (ASTM C 33-93, 1993). The test result of the grain size distribution of the coarse aggregate is indicated in Table 3.5.

Table 3.5 Gradation of natural coarse aggregate (gravel)

Sieve Size (mm)	Cumulative % Retained	Cumulative % passed	Cumulative % Pass (ASTM C33) limit		Remark
			Lower	Upper	
37.5	0	100	100	100	ok
25*	2.82	97.18	90	100	ok
19	23.11	76.89	40	85	ok
12.5*	65.06	34.94	0	40	ok
9.5	91.46	8.54	0	15	ok
4.75	99.94	0.06	0	5	ok
Pan	100	0	-	-	ok

Also, the grain size distribution of the coarse aggregate is indicated in Figure 3.7.

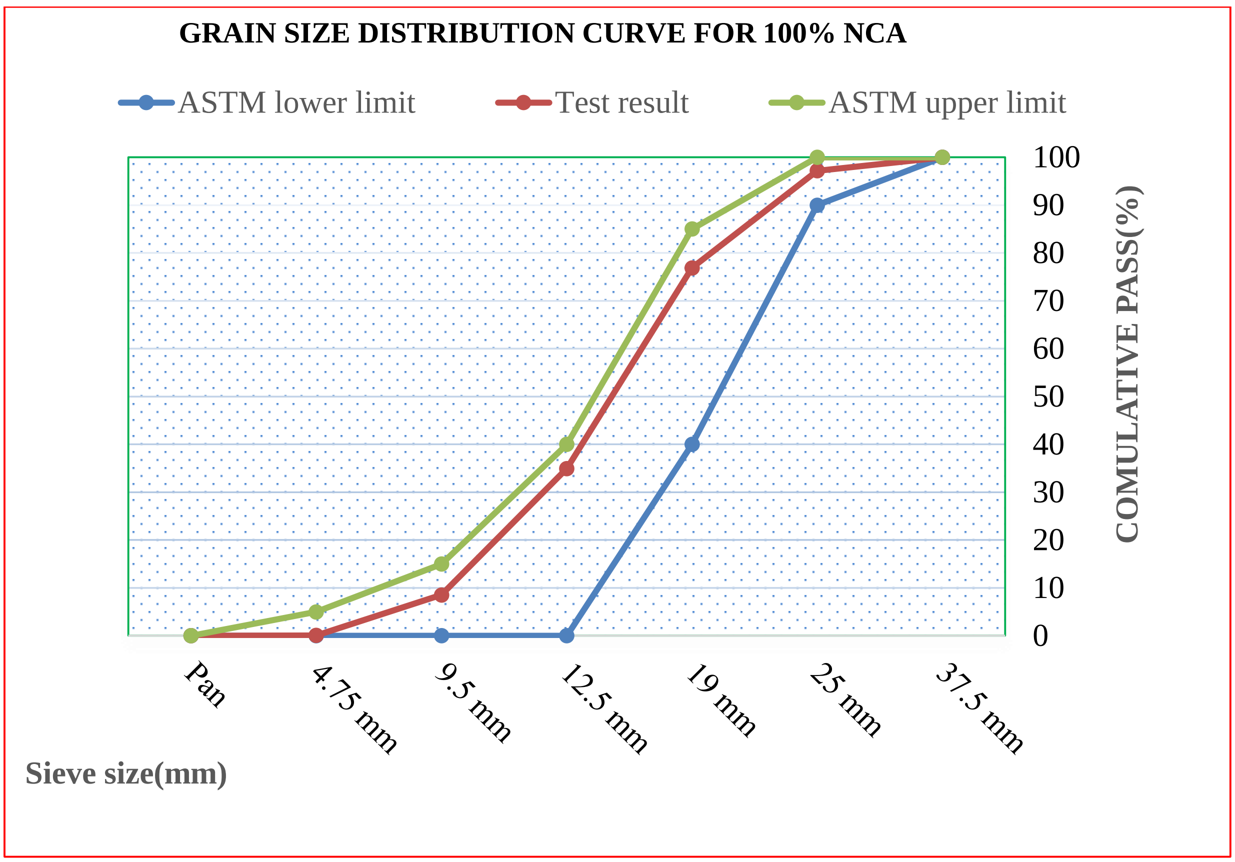


Figure 3. 7 Natural coarse aggregate grain size distribution curve

Table 3. 6 Gradation of recycled concrete aggregate

Sieve Size (mm)	Cumulative % Retained	Cumulative % passed	Cumulative % Pass (ASTM C33) limit		Remark
			Lower	Upper	
37.5	0	100	100	100	ok
25*	5.11	94.89	90	100	ok
19	27.01	72.99	40	85	ok
12.5*	69.59	30.41	0	40	ok
9.5	93.49	6.51	0	15	ok
4.75	99.97	0.03	0	5	ok
Pan	100	0	-	-	ok

The test result of the grain size distribution of the recycled coarse aggregate is indicated in Figure 3.8.

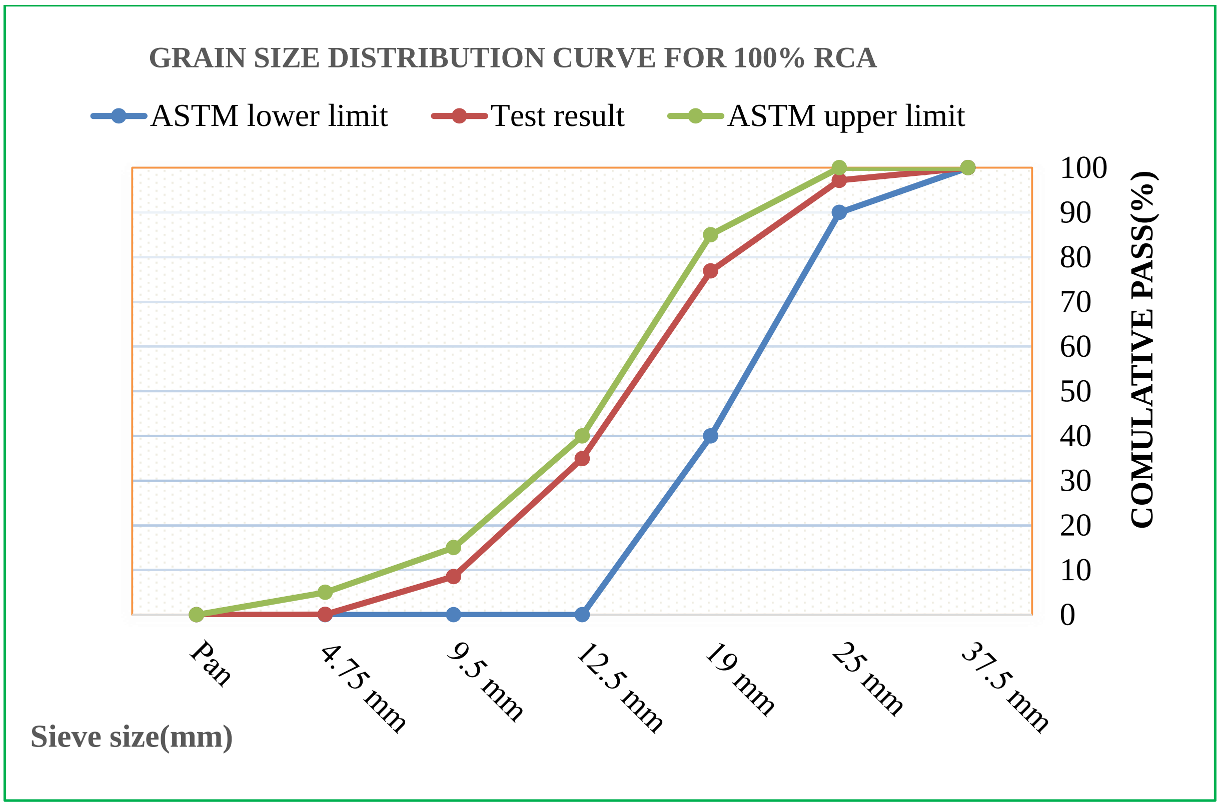


Figure 3. 8 Recycled concrete aggregate grain size distribution curve

The same procuders were done for every 15% replacement of RCA by weight of natural coarse aggregate and the percentage amount of aggregate size ranges between ACI 522R,2010 standard (between 19mm and 9.5mm) are discussed as in the following table. Detail in annex 1.

Table 3.7 Percentage amount of aggregate size ranging between ACI 522R,10 standards

Sive size(mm)		100% NCA & 0% RCA	85% NCA & 15% RCA	70% NCA & 30% NCA	55%NCA & 45% RCA	40%NCA & 60% RCA
Above	37.5	0	0	0	0	0
	25*	2.81	6.91	6.02	7.09	8.93
Between	19	20.294	29.30	26.24	25.79	23.34
	12.5*	41.95	32.66	33.11	31.36	33.25
	9.5	26.399	23.05	25.55	26.61	26.07
Below	4.75	8.48	8.57	8.92	8.96	8.33
Sum of retained aggregate sizes ranging between ACI standard(%)		**88.64%**	**85.01%**	**84.90%**	**83.76%**	**82.88%**
Remark		As percent of RCA increases, more corser the aggregate which was the indication of high porosity and permeability rate and decreased strength of the final concrete.				

II. Determination for the unit weight (bulk density) of coarse aggregate

The unit weight of aggregate is defined as the weight of an aggregate filling up in a container of known volume and the voids between particles. It is thus a density measurement and also known as bulk density (Dinku, 2002). The test was determined according to the specified ASTM code standard which is often used for the determination of compacted or loose unit weight values and calculated voids between particles that are necessary for use for many methods of selecting proportions for concrete mixtures (ASTM C 29, 1991). The loose unit weight was determined simply by filling the sample into a container of known volume and weighing it. But the compacted unit weight was determined by placing three layers of air-dry aggregate in a container of 0.01m3 (10 L) volume, rodding each layer 25 times with a tamping rod, leveling off the surface, and determining the mass of the container. The mass of the container is subtracted to find the net mass of the aggregate, then the bulk density was calculated by dividing the net mass of aggregate at each replacement level to an equal volume of the container using the following formula.

Unit Weight (Kg/m^3) $= \frac{B-A}{C}$……………………………………………................…...Equation.8

Where A = Weight of Container (Kg)

B = Weight of Container + Sample (Kg)

C = Volume of container (m^3)

Figure 3. 9 Unit weight of aggregate determination cylinder

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

Information regarding specific gravity and absorption capacity is necessary for the design of concrete mixes and is useful for calculating void contents in aggregate (Warati, et al., 2019).

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. Also, it is an expression of the relative density of a substance. In this definition, the substance or material is assumed to be solid. In opposition, aggregates contain pores in their structure, therefore the specific gravity of aggregate depends on whether the pores are included in the measurement or not. Hence:

- The apparent specific gravity of an aggregate refers to the solid materials excluding the pores, and
- The bulk specific gravity refers to the total volume, including the pores of the aggregate.

If the specific gravity is above or below normal for a particular type of aggregate, it is an indication of the change of shape and grading. The absorption capacity is a measure of the porosity of an aggregate. The water absorption value is the difference in mass between the saturated surface dry sample and oven-dry sample expressed as a percentage of the dry mass of the sample. Knowing the water absorption value of an aggregate is important for calculating the total water to be added to the mixes. In some cases, it is slightly affected by the size of the aggregate, becoming higher the bigger the aggregate is (ASTM C127-88, 1993).

In this study, the specific gravity (relative density) and absorption capacity of coarse aggregate were computed for two trials, each with a 2kg sample using an equipped specific gravity frame of the wire basket, watertight tank, balance, and suspender. All calculations are performed using the following equations in detail in Annex 1.

Bulk Specific Gravity (OD) = $\frac{A}{B-C}$ ………………………………….……….………. Equation.9

Bulk Specific Gravity (SSD) = $\frac{B}{B-C}$ …………………………………………...Equation.10

Apparent Specific Gravity= $\frac{A}{A-C}$ ……………..……………………….………...Equation.11

Absorption Capacity (%) = $\frac{B-A}{A}*100$ ………………..……………………….………...Equation.12

Where A= Mass of Oven-Dry Aggregate (OD) in gr

B=Mass of Saturated Surface Dry Aggregate in Air (MssD) in gr

C= Mass of Aggregate in Water (MW) in gr

Figure 3. 10 Specific gravity determination processes and frame

IV. Determination for moisture content of coarse aggregate

During the concrete mix design process, an aggregate was considered to be as free from water and never absorbing moisture from the environment. This means the moisture content of aggregate affects the water-cement ratio and aggregate needed for the mix design. But in most cases, aggregates from different sources do not comply with this i.e. Wet aggregate gives water to the mix and drier aggregates (those with low saturation level moisture content) take water from the mix then both workability and strength of concrete can be affected. Therefore, studying the moisture content of aggregate before starting the concrete mix is important to determine the water-cement ratio, to adjust the batch weight of ingredients, and to correct the discrepancies of concrete workability and strength (ASTM C 566-89, 1989).

Therein, the moisture content of coarse aggregate was computed according to the specified standard code by oven drying 2000g of coarse aggregate for 24hrs with a machine temperature of 110 + 5 ˚C and cooling it at room temperature for 1 ½ hour. Finally, the percentage of moisture content of aggregate was calculated by dividing the weight difference by oven-dry weight and multiplying the result by a hundred shown as follow:

$$M.C\ (\%) = \frac{A-B}{B}*100 \quad \text{...Equation.13}$$

Where: M.C = Total evaporable moisture content of the sample in (%),

A = Weight of the original sample in (g)

B = Weight of oven-dried sample (g)

V. Determination of aggregate impact value

The aggregate impact value gives a relative measure of the resistance of an aggregate to shock or impact loading. This test is made on a single-sized aggregate passing 12.5-mm sieve and retained on 10.0 mm ASTM test sieve. The aggregate is placed in a cylindrical mold and then the impact load applied is by dropping a hammer at a height of 380 mm. The material crushed to finer than 2.36mm sieve is separated and expressed as a percentage of the original weight taken in the mold. This percentage is referred to as aggregate impact value which shall not exceed 45% by weight for aggregate used for concrete other than wearing surface and 30% by weight, for concretes for wearing surface such as runways, roads, and pavements (Dinku, 2002).

In this study, the experimental program was computed by measuring aggregate passing 12.5mm sieve and retained on 10.0mm then filling one-third full of the cylinder with the aggregate using a scoop and tamping with the rod 25 times, by allowing the tamping rod to fall freely from a height of about 50mm above the surface of the aggregate. Then the surplus aggregate was removed by rolling the tamping rod across, and in contact with, the top of the container, and the net mass (Weight of cylinder with sample minus weight of the cylinder) of aggregate in the measure was recorded as mass (A). Thereafter the sample of standard aggregate kept in the mold is subjected to fifteen (15) blows of a metal hammer of weight 14 kgs falling from a height of 380 mm (38cm). Then remove the crushed aggregate, by holding the cup and hammering on the outside, into a clean tray. Sieve the whole of the sample in the tray on the 2.36mm (ASTM) test sieve until no further significant amount passes in 1 min. This quantity of passing indicates the toughness of the aggregate. Then weigh the fractions passing 2.36mm sieve and retained on the pan to an accuracy of 0.l gram and record as mass (B). Finally, the percentage of aggregate impact value was calculated by dividing the mass of the fraction passing the 2.36mm sieve to the mass of the surface dry sample and multiplying the result by the hundred as shown below:

$$AIV\ (\%) = \frac{B}{A} * 100 \qquad \text{Equation.14}$$

Where: AIV = Aggregate impact value (percentage fines) in (%),

A = Net mass of surface-dry sample in (g)

B = Mass of the fraction passing 2.36mm sieve for separating the fines (g)

Figure 3. 11 Aggregate impact value test

VI. Determination of aggregate crushing value

The aggregate crushing test gives a relative measure of the confrontation of an aggregate to crushing under a gradually applied compression load. The test is used to value the crushing strength of available coarse aggregate to make sure that minimum specified values are maintained. The value varies from 5% for hard aggregates to 30% for weaker aggregates (Dinku, 2002).

In this study, surface dried aggregate sample passing 12.5mm and retained on 9.5mm ASTM sieve were taken and filled into the base plated standard cylindrical measure in three layers approximately of equal depth following 25 timestamping using the tamping rod. Then, the net weight of the sample contained in the cylinder measure is taken as (M1). Continuously, the cylinder filled with aggregate in a standard manner is put in position on the base-plate and the aggregate is carefully leveled and the plunger inserted horizontally on this surface. Following that, the cylinder with the test sample and plunger in position is placed on the compression testing machine and is loaded uniformly up to 400 KN in 10 minutes. The load is then released and the whole of the material is removed from the cylinder and sieved on a 2.36 mm ASTM sieve. The friction passing the sieve is recorded as weight (M2). Finally, the percentage of aggregate crushing value was calculated by dividing the mass of the fraction passing the 2.36mm sieve to the net mass of the surface-dry sample and multiplying the result by the hundred as shown below:

$$ACV\ (\%) = \frac{M_2}{M_1}*100 \quad \text{.......Equation.15}$$

Where: ACV = Aggregate crushing value in (%),

M_1 = Net mass of surface-dry sample in (g)

M_2 = the mass of the fraction passing 2.36mm sieve for separating the fines (g)

Figure 3. 12 Aggregate crushing value determination processes

VII. Aggregate abrasion value

Abrasion test is the test used to know how the aggregate is sufficiently hard to resist the abrasive effect of traffic such as wearing action at the top over its service life. Hence, resistance to wearing or hardness is an essential property for aggregates, especially when used in the wearing course. The most widely used abrasion test is the **Los Angeles Abrasion Test** which involves the use of a steel drum, revolving on the horizontal axis, into which the test sample of chippings is loaded together with steel balls (spheres) of 46.8 mm diameter depending on the grade of the aggregate sample. The LAAV is the percentage of fines passing the 1.7mm sieve after a specified number of revolutions (500 revolutions) of the drum at a specified speed. The value should not be more than 30% for wearing surface and not more than 50% for concrete other than wearing surface (ASTM C 131-89, 1989).

In this study, the LAAV were computed for both natural and recycled coarse aggregates, by sieving aggregate sample for grade "B" and taking 2500gm sample retained on both sieve size 12.5mm and 9.5mm of the total weight of 5000gm to put into abrasion machine of 500 revolutions. The number of steel spheres used was 11 depending upon the specified grade of aggregate in table 3.8.

Table 3.8 Number of steel spheres (charges) for different grade of aggregate (ASTM C 131-89)

Sieve sizes		Mass of indicated sizes (g)			
		Grading			
Passing	Retained on	"A" 12 spheres	"B" 11 spheres	"C" 8 spheres	"D" 6 spheres
37.5 mm	25 mm	1250 ±25	---	---	---
25 mm	19 mm	1250 ±25	---	---	---
19 mm	12.5 mm	1250 ±10	2500 ±10	---	---
12.5 mm	9.5 mm	1250 ±10	2500 ±10	---	---
9.5 mm	6.3 mm	---	---	2500 ±10	---
6.3 mm	4.75 mm	---	---	2500 ±10	---
4.75 mm	2.36 mm	---	---	---	5000 ±10
Total		5000± 25	5000 ±10	5000 ±10	5000 ±10
Grading A: Suitable for graded crushed stone and natural gravel for base course Grading B: Suitable for chippings for surface dressing					

Grading C: Suitable for chippings for surface dressing
Grading D: Suitable for chippings for surface dressing

Finally, the LAAV were calculated using the following formula:

$$L.A.A.V = \frac{M_2}{M_1} * 100 \quad \text{.......................Equation.16}$$

Where, M1 = Weight of sample before abrasion

M2 = Weight of friction passing 1.7mm sieve after abrasion

Figure 3. 13 Los Angeles Abrasion value test processes

Generally, all the physical property test results of coarse aggregate used in this investigation are summarized in the following table 3.9.

Table 3.9 Summary of properties of coarse aggregate

Test Parameters	Test Results		Active ASTM Code Standards
	NCA	RCA	
Shape	Angular	Angular	Recommended
Grade	B	B	Depending on size
Fineness modules	3.82	3.95	ASTM C136-93
Unit weight(kg/m^3)	1579.9	1537.1	ASTM C29, 1991
Apparent specific Gravity	2.8763	2.6233	ASTM C127-88 1993
Bulk specific Gravity	2.8117	2.5720	ASTM C127-88 1993
Moisture content (%)	0.980	1.617	ASTM C 566-89, 1989
Water absorption (%)	1.2399	1.735	ASTM C127-88 1993
Impact value (%)	4.805	9.659	ASTM D 5874-95
Crushing Value (%)	12.475	18.747	No ASTM standard, but I have used: BS 812: Part 110:1990
Los Angeles Abrasion Value (%)	10.80	16.960	ASTM C 131-89, 1989

3.7.4 Water

Tap water from Jimma town water supply and sewerage authority, which was supplied to the laboratory by Jimma University water supply office was used during the entire experimental programs like aggregate washing, concrete mixing, curing, and testing.

3.8 Mix design and trial mix preparation

In this study, the mix design for porous concrete and maximum aggregate size of 20mm was done as per ACI 522R-10 design procedures using the weighing method. Hence, five mixtures were prepared in five categories with a total cement content of 350kg/m^3 per mix and those represent the percentage replacement value of recycled concrete aggregate mixtures. For each substitution ratio, 3 sets (3 x 3 = 9) and 2 sets (2 x 3 = 6) of mortar specimens were prepared for a destructive test (compressive strength) and split tensile strength porosity and permeability conducted at the age of 7, 14 and 28 days respectively. Mixtures under each category were prepared using natural and recycled coarse aggregate grade between 20mm and 4.75mm with no fine aggregates. The water-cement ratio ranging from 0.39 to 0.41 was used to keep cement content constantly. These means as aggregate replacement percentage increases, the water absorption capacity of aggregate increase and water-cement ratio decrease and via verse. From the five categories of the mixture, one mixture with 100% NCA or 0% RCA was prepared without recycled concrete aggregate to stand as a control mixture or as a benchmark for this investigation. Also, four mixtures were prepared with 15% RCA, 30% RCA, 45% RCA, and 60% RCA respectively with their mixture I.D. to explore the effect of recycled concrete aggregate on the porous green concrete. Details of the mix proportions for cubes, cylinders, and the necessary computations plus steps for the mixture were found in Annex 2. Table 3.10 shows the summary of material proportioning per one cubic meter for all aggregate replacement percentages computed in this study.

Table 3.10 Mix design proportions

NCA (%) / RCA (%)	W/C Ratio	Proportion (%)		Weight in kg /m^3 (for 1m^3)				Mix proportion
		NCA	RCA	Cement	Water	NCA	RCA	
100%NCA + 0%RCA	0.39	100	0	350	136.95	1579.48	0	1: 4.51: 0
85%NCA + 15%RCA	0.40	85	15	350	138.76	1340	236.55	1: 3.83: 0.68
70%NCA + 30%RCA	0.40	70	30	350	138.76	1102.14	472.35	1: 3.15: 1.35
55%NCA + 45%RCA	0.40	55	45	350	142.38	864.57	707.38	1: 2.47: 2.02
40%NCA + 60%RCA	0.41	40	60	350	144.17	627.75	941.63	1: 1.79: 2.69

Using the above mix proportions 75 standard concrete cubes and 60 cylinders of a total of 135 samples were cast each for the five categories of recycled coarse aggregate percentage replacement (0%, 15%, 30%, 45%, and 60%).

3.9 Experimental program

The experimental program can be grouped into four main categories as follow: (1) Material property testing which was previously discussed, (2) Concrete mix and sample preparation, (3) Fresh concrete testing, and (4) Harden concrete testing.

3.9.1 Concrete mix and preparation

A conventional drum mixer with a maximum capacity of 0.06m3 was utilized for the concrete mixer. The concrete making materials; cement, natural coarse aggregate, and recycled concrete aggregate were mixed in their dry condition approximately for 5 minutes. Water was then added gradually while the mixing processes continued for an additional 5 minutes. Immediately upon completion of the mixing processes for concrete, the workability was measured by using a slump cone. The specimen was then placed into the oil-brushed mold of standard size 150mm x 150mm x 150mm cube and 200 x 100mm cylinder with three different layers tamped 25 times with a tamping rod. Finally, the top surface of the specimen was leveled and the molds were left intact for 24 hours at room temperature before they were disassembled. Then the concrete specimen was kept in the curing tank until they become ready for testing. The detailed processes were illustrated in figure 3.14

. Figure 3. 14 Concrete specimen preparation processes

A. Fresh concrete tests performed

Immediately after mixing, fresh concrete properties including workability and unit weight (fresh density) were tested according to ASTM standards.

I. Workability test

Workability is the property of concrete that determines the amount of useful internal work necessary to produce full compaction or ease with which concrete can be compacted a hundred percent having regard to the mode of compaction and place of deposition. Most of the time the word consistency indicates the degree of fluidity or degree of mobility used for workability (Shetty, 2005).

Hence, the workability of porous concrete was checked by slump cone test and compacting factor test method at each replacement percentage of recycled concrete aggregate (0%, 15%, 30%, 45%, and 60%) in the production of porous concrete.

a) Slump cone test

Conventionally, the workability of concrete is measured by slump test which is a measure of the settling of fresh concrete filled in a 300mm high, 200mm diameter at the top, and 100mm diameter at the bottom while uplifting the cone vertically upward. Therefore, the workability of porous concrete was tested by slump cone which is the same as that of the conventional one.

Procedure for slump cone test

Make sure the cone is clean, free from hardened concrete, dry inside, and place it on a rigid, non-absorbent flat surface or base plate. Then, stand with your feet on the footrests. Using the scoop fill the cone with three different layers and rod this layer of concrete exactly 25 times using the tamping rod. After rodding the top layer make sure that there is a slight surcharge of concrete, i.e. Strike off the surplus concrete using steel float. Take hold of the handles and pushing downwards remove your feet from the footrests. Very carefully lift the cone straight up, turn it over, and put it down on the base plate next to the mound of concrete. As soon as the cone is lifted the concrete will slump to some extent. Rest the tamping rod across the top of the empty inverted cone and measure the slump using the ruler from the underside of the rod to the highest point of the concrete, to the nearest 5mm. That was the slump (Dinku, 2002).

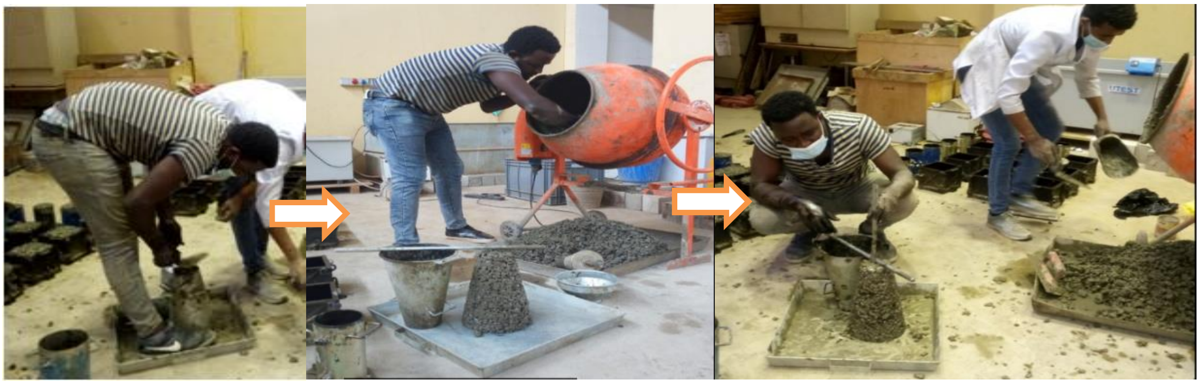


Figure 3. 15 Slump test processes

Note: Slump test is not a suitable method for very wet or very dry concrete mix (Shetty, 2005). In case, porous concrete is concrete that is made up of a little amount of water or dry mix which have zero slumps as indicated in figure 3.15. Such dry concrete is insensitive to slump test. So, performing the compacting factor test is obligatory to check the workability of the concrete.

b) Compacting factor test

The compactor factor test is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability. The degree of compaction called the compacting factor is measured by the density ratio i.e., the ratio of density achieved in the test to the density of the same concrete fully compacted (Shetty, 2005).

Procedure for compacting test factor

Check that the apparatus is clean and free of hardened concrete and weigh the cylinder empty. The sample of concrete to be tested is placed in the upper hopper up to the brim. Then, open the trap-door so that the concrete falls into the lower hopper. Also, the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder.

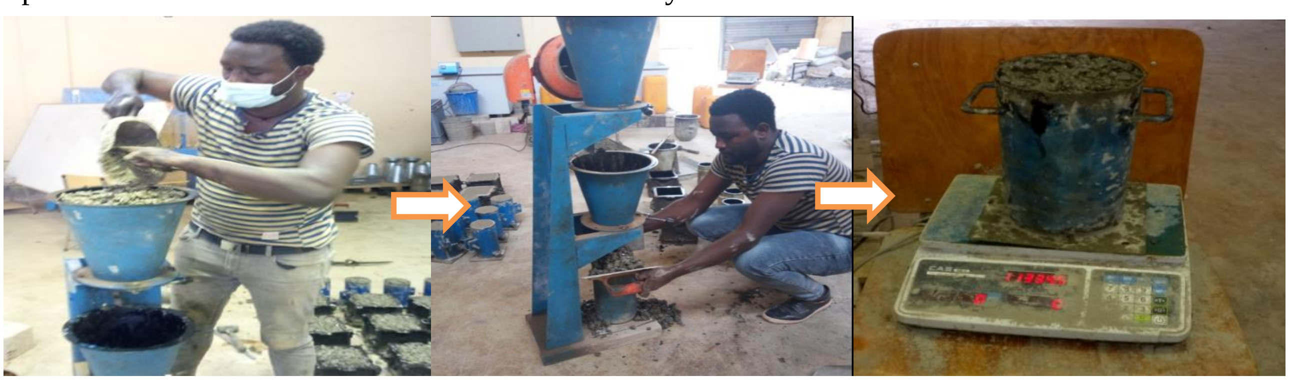


Figure 3. 16 Compacting factor test processes

The concrete is filled up exactly up to the top level of the cylinder and weighted to the nearest 10gms. By subtracting the weight of the cylinder when clean and empty from the weight of the cylinder when full of concrete, obtain the **'weight of partially compacted concrete'.** The cylinder is emptied and then refilled with the concrete from the sample in 50mm layers, hand-ramming each layer 25 times to obtain full compaction. The top surface of the fully compacted is then carefully struck off level using a tamping rod and weight to the nearest 10gms to obtain the weight of **fully compacted concrete** (Dinku, 2002). Finally, the compacting factor is calculated as follow:

$$\text{Compacting factor} = \frac{\text{weight of the partially compacted concrete}}{\text{weight of fully compacted concrete}}$$ ……………...Equation.17

c) Unit weight(fresh density) of fresh concrete

The unit weight of fresh concrete was measured by checking that the cylinder is clean and free of hardened concrete and weigh the empty cylinder. Then, the sample of concrete to be tested is placed into a cylinder with known volume in three layers and hand tamping each layer 25 times by tamping rod. The top surface of the fully compacted concrete is then carefully struck off level using a tamping rod and weight to the nearest 10gms to obtain the **weight of cylinder plus fresh concrete.** By subtracting the weight of the cylinder when clean and empty from the weight of the cylinder when full of concrete, to obtain the **net weight of fresh concrete.** Finally, the unit weight of fresh concrete was computed by dividing the net weight of fresh concrete by an equal volume of cylinder as follow:

Unit weight (Density) of fresh concrete= $\frac{M}{V}$ …………………………………...Equation.18

Where; M= Net weight of fresh concrete

V= Volume of Cylinder

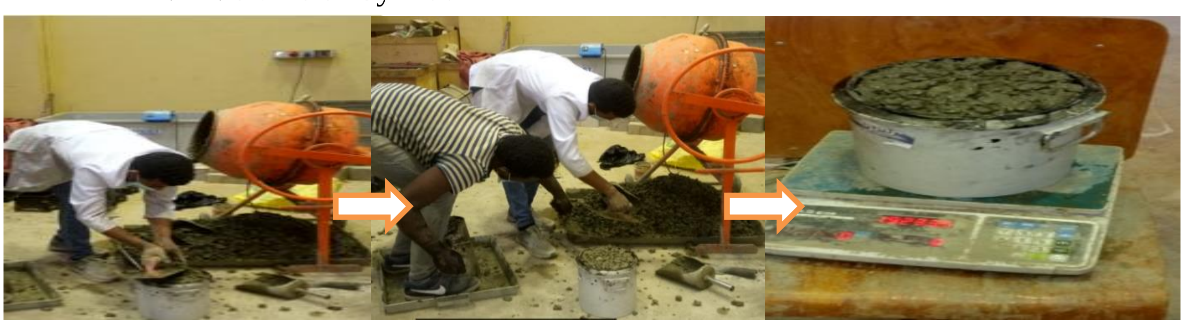


Figure 3. 17 Determination for unit weight of fresh concrete

B. Hardened concrete test

I. Compressive strength test

The mechanical properties of hardened concrete were investigated for each replacement percentage of recycled concrete aggregate through studying compressive strength of cubes and split tensile strength of cylinders at 7,14 and 28 days respectively as per the following standards.

The compressive strength test of concrete cubes was conducted at 7,14 and 28 days for determination of compressive strength of concrete cubes by dividing the maximum load attained during the test by the cross-sectional area of the specimen on the universal compressive testing machine (ASTM C 39, 1993).

$$\delta c = \frac{P}{A} \quad \text{……………………………………………………………….………...Equation.19}$$

Where, δc = Compressive strength

P = is the maximum load and

A = is the cross-sectional area.

Figure 3. 18 Compressive strength determination using a universal testing machine

The result obtained from the compression test of hardened concrete cubes were used to determine the optimum allowable replacement percentage of recycled concrete aggregate with natural coarse aggregate without violating the minimum compressive strength requirement on the 28th day as per the mix design.

II. Splitting tensile strength test

Different researchers argued that a direct measurement of the tensile strength of concrete is difficult. Hence a method of determining the tensile strength of concrete using a cylinder that splits across the vertical diameter is an indirect method of testing the tensile strength of concrete (Shetty, 2005). So, it was conducted at 7, 14, and 28 days according to ASTM C 39-93a for determination of tensile strength of cylinders by multiplying the maximum load attained during the test two times then dividing for the cross-sectional area of the cylinder on the universal compressive testing machine.

Test procedures: Draw diametric lines on each end of the specimen using a suitable device that will ensure that they are in the same axial plane. Then, determine the diameter of the test specimen by averaging three diameters measured near the ends and the middle of the specimen lying in the plane containing the lines marked on the two ends and the length of the specimen by averaging at least two length measurements taken in the plane containing the lines marked on the two ends. Carefully, center one of the plywood strips along the center of the lower bearing block. Place the specimen on the plywood strip and align so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip. Similarly, place a second plywood strip lengthwise on the cylinder, centered on the lines marked on the ends of the cylinder. Continuously, adjust the parameter of the machine into tensile strength and apply the load continuously and without shock, at a constant rate until failure of the specimen (Dinku, 2002).

Finally, the load was applied on the vertical diameter of the cylinder subjected to horizontal stress until the failure of the cylinder and the split tensile strength was calculated using the following formula:

$$T = \frac{2P}{\pi DL} \qquad \text{...Equation.20}$$

Where:

T = splitting tensile strength [KN/m^2] 1 = length [m]

P = maximum applied load [KN] d = diameter [m]

Figure 3. 19 Determination for split tensile strength

III. Porosity test

Porosity is the ratio of voids in concrete to the total volume (V) of the sample. The test was performed by dividing the difference between the oven-dry weight of the sample (Md) and weight of the submerged sample in the water tank for a minimum of 30 minutes (Mw) by the water density(δw) as porosity(P) using the following formula (ASTM C1754, 2012).

$$P=1-\left(\frac{Md-Mw}{\delta w * V}\right)*100\% \quad \text{......Equation.21}$$

Where, P = Porosity

Md = Mass of oven-dried sample

Mw = Mass of the submerged sample in the water tank for a minimum of 30 min.

δ_w = Density of water

V = Total volume of sample

Figure 3. 20 Determination for the porosity of concrete

IV. Permeability test

The most important feature of the porous concrete is allowing the percolation of water passing the porous medium. The test was conducted using a constant head method (ASTM D2434-68, 1994). The coefficient of permeability was deduced from Darcy's law, which was preliminary used as a falling head test to obtain its coefficient as per the standard (Zhu, et al., 2020).

Test procedure: Wrap plastic around the specimen to avoid water leakage. Then seal the top internal edge part of the specimen with **stucco** to avoid leakage. Pour one liter of water for pre-wetting and discharge it out. Pour 1.5 litter \ water by maintaining the head 15-25mm. immediately, start the stopwatch when water touches the specimen and stop it when there is no water left on the top (FILHO, et al., 2020). Finally, the coefficient of permeability (k) can be computed as:

$$K = \frac{QL}{Aht} \quad \text{......Equation.22}$$

Where Q = Quantity of water discharged cm^3

K = Coefficient of permeability (cm/s)

L = Length of specimen (cm)

t = Total time of discharge (sec)

A = Cross section area of specimen (cm^2)

h = Difference in head on manometer (cm)

Figure 3. 21 Permeability test processes

3.10 Construction Waste management practices adapted during the study

There are several approaches to construction waste management. The most common approach to the management of construction waste is dumping in landfill sites. However, it is estimated that overall of 35% of construction and demolition waste is landfilled globally, therefore, effective management is crucial to minimize the detrimental impacts on the environment. Despite these many strategies for construction and demolition waste management are well-developed (Kabirifar, et al., 2020). Such a strategy has the potential to divert waste from landfill sites as well as prevent the use of raw materials for material production.

The strategies of reduction, recovery, reuse, and recycling(4Rs) all have the same goal; to ensure that nothing from the construction process is left that may cause a negative environmental impact including avoiding depletion of natural resources (Mawed, et al., 2020). The most used waste minimization technique found in the 4R concept would be a waste reduction (Nanera & Solanki, 2020). Recycling operations are relevant to reduce CO_2 emission and save energy as well as create job opportunities. For successful recycling operations, the existence of committed construction professionals to sort the waste materials are vital. Also, waste recycling operations have assisted communities to have free space in their landfill site. In besides, Recovery(disposal) of waste to landfills is the most problem to the environment relative to other waste management approaches (Al-Thani & Park, 2020).

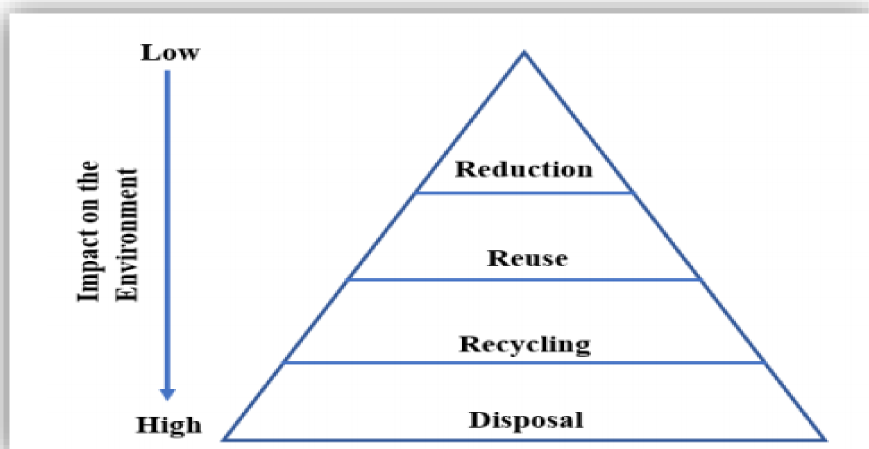


Figure 3. 22 Construction waste management strategies

In this study, both the recycling and reuse operations have been conducted for recycled concrete aggregate and wastewater. First, demolished concrete structures was crushed and the aggregate was collected from, then resized to the desired size. The old mortar left after crushing and collection of aggregate was transported to a rural road in front of the laboratory near the power house for maintaining the ponding places of the road i.e. reuse process. Also, the wastewater was collected into jars and re-used for washing concreting materials after casting of each concrete group

Figure 3. 23 Recycled aggregate waste reuse processes

3.11 Ethical consideration

A formal letter was obtained from JU, JIT postgraduate and research program office, and submitted to JiT laboratory office for official permission and for facilitating of the laboratory to conduct different physical property tests for materials used in this study. Credits were given for different authors previously conducted a study on porous concrete and standards. They were acknowledged by citing their name and referencing their materials. The author may not plagiarize others' work without citation.

3.12 Data quality assurance

The quality of data was enhanced and checked by taking trial mixes and enough number of specimens for each replacement level according to the standards. Similarly, the testing instrument was checked before and on ongoing progress to avoid the error that occurred during the experimentation. Also, a well-prepared checklist or sheet was prepared to record the results of the samples to avoid later confusions happen during the writing of the final paper.

3.13 Plan for dissemination

The result of the study was presented to Jimma University Institute of Technology, Faculty of Civil and Environmental Engineering for Post Graduate Program in Construction Engineering and Management Department, and a copy of it were be kept in Jimma University Institute of Technology library for all concerned individuals.

3.14 The structural framework of the study

Generally, the methodology which was carried out during the study is presented in the form of sequential steps as illustrated in the following figure 3.24.

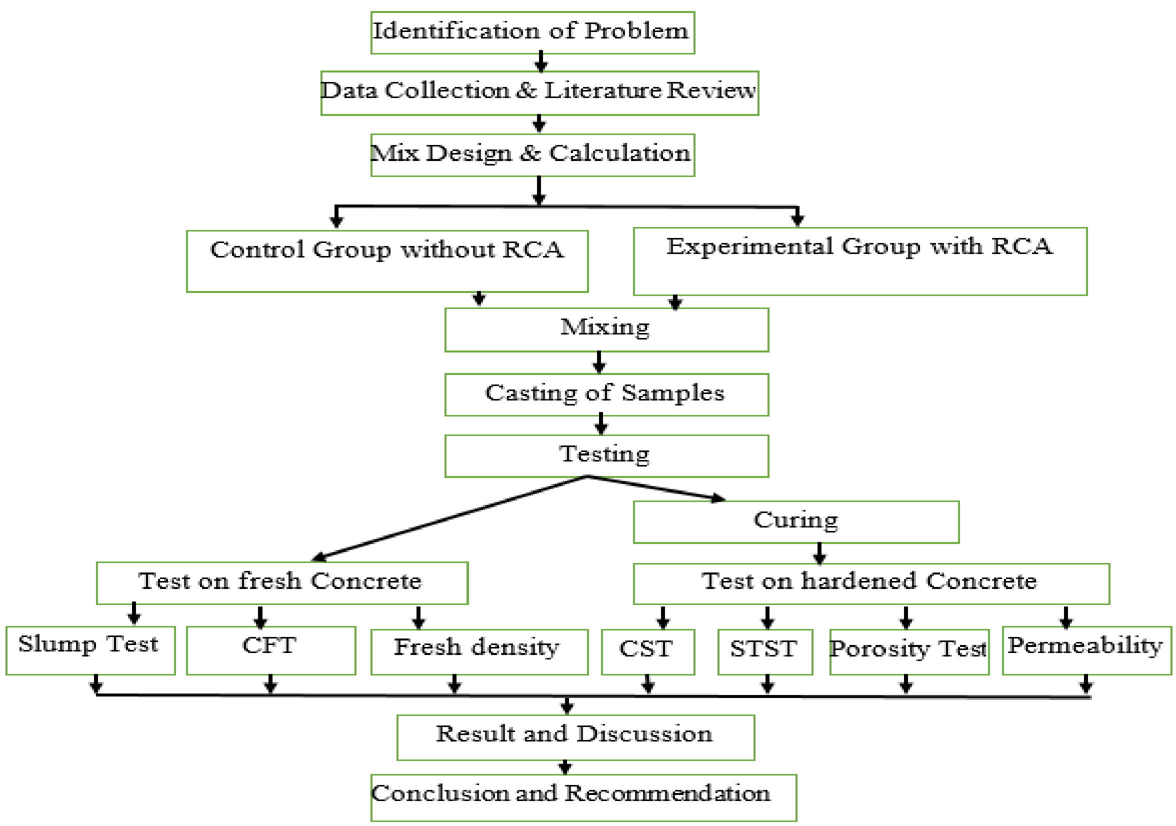


Figure 3. 24 General methodologies

CHAPTER 4

RESULTS AND DISCUSSION

The experimental work conducted in this study includes three major sections that comprise material quality test, fresh and hardened concrete test results. Therefore, the results carried out during the experimental work are proved and discussed in this chapter except the material test which was discussed in chapter 3.

4.1 Fresh concrete properties

The fresh concrete properties have been evaluated to examine the effect of water to cement ratio, aggregate to cement ratio, replacement percentage of recycled aggregate on slump (workability), and fresh density of the concrete. Therefore, this section deals about test results of fresh concrete properties conducted on samples of fresh porous concrete with different aggregate replacement percentage are presented and discussed as follow.

4.1.1 Workability of fresh concrete

A. Slump test results

The workability of concrete mixed with a different percentages of recycled aggregate was tested by standard slump cone height. The test result for five mixtures with different water-cement ratios and aggregate replacement percentages is listed in table 4.1. The porous concrete mixtures were designed to represent the degree of workability as poor, medium, and high workable concrete which aligns with the results obtained for the control mixture. Full data was presented in appendix A: annex 3.

Table 4. 1 Slump test results for recycled concrete aggregate replaced porous concrete

Designation		Water cement ratio	Measured slump value(mm)	Type of slump	Degree of workability
NCA	RCA				
100%	0%	0.39	14	Approximate to zero	Poor
85%	15%	0.39	0	Zero	Poor
70%	30%	0.40	0	Zero	Poor
55%	45%	0.40	0	Zero	Poor
40%	60%	0.41	0	Zero	Poor

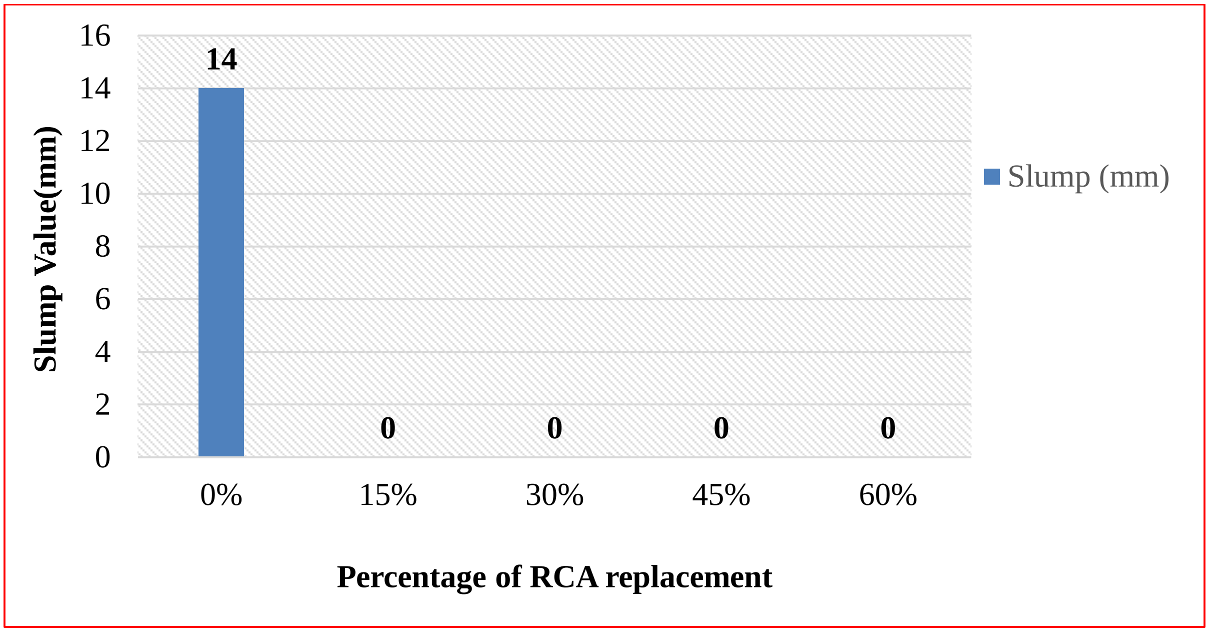


Figure 4.1 Slump classified by coarse aggregate replacement percentage

Normally, the slump test is a suitable method for slumps of medium to high workability with the height of slump ranges between 25-125mm. Also, the test fails to determine the difference in workability for a very wet or very dry concrete mix which has zero slump or collapse slumps. In case, porous or no-fines concrete is concrete which is made up of a little amount of water causing a zero slump. However, upon closer inspection of the results shown in figure 4.1, it can be noticed that the control mixture with 0% RCA, w/c of 0.39, and 350kg cement of the five mixtures fall between a range of 0 and 25mm slump. This is due to the low water absorption capacity of natural coarse aggregate and all the left four mixtures gave a zero slump as an increment in the percentage of RCA followed by high water absorption due to the presence of old mortars on the surface of RCA.

The findings of this research confirm a report on previous concrete conducted by ACI committee 522R, (2010) and concrete technology book entitled as Concrete Technology Theory and Practice page 218-297 by Shetty, (2005) because the authores argued that, porous or no fines concrete have a zero slump due to its harsh mix. Such a dry concrete mix is insensitive to slump height less than 25mm. Therefore; performing a compacting factor test is obligatory to check the degree of workability and compaction method to be used for the final concrete placing work at the site.

Figure 4.2 Mixtures with zero slump

B. Compacting factor test results

As discussed above under section 4.1.1 of this chapter, very dried and wet mixes are not achieving the correct slump height and not suitable for the conventional compaction method. As a result, the compaction factor test was done to determine the degree of workability by making the mix fall through successive hoppers with standard height using a compaction factor test apparatus. This test is a suitable method for compacting factor test limits of very low to high workability with the permissible values of 0.78, 0.85, 0.92, and 0.95 which means very low, low, medium, and high workability respectively. The test results observed from the ratio of the weight of partially compacted concert to the weight of fully compacted concrete for every five mixtures of different water-cement ratio and aggregate replacement percentage are listed in table 4.2. Detail calculation in annex 3.

Table 4.2 Test results for compacting factor value.

Designation		Water cement ratio	Compacting factor value	Degree of workability	Remark
NCA	RCA				
100%	0%	0.39	0.924	Medium	All observed test values fall within permissible range
85%	15%	0.39	0.853	Low	
70%	30%	0.40	0.82	Low	
55%	45%	0.40	0.80	Very low	
40%	60%	0.41	0.79	Very low	

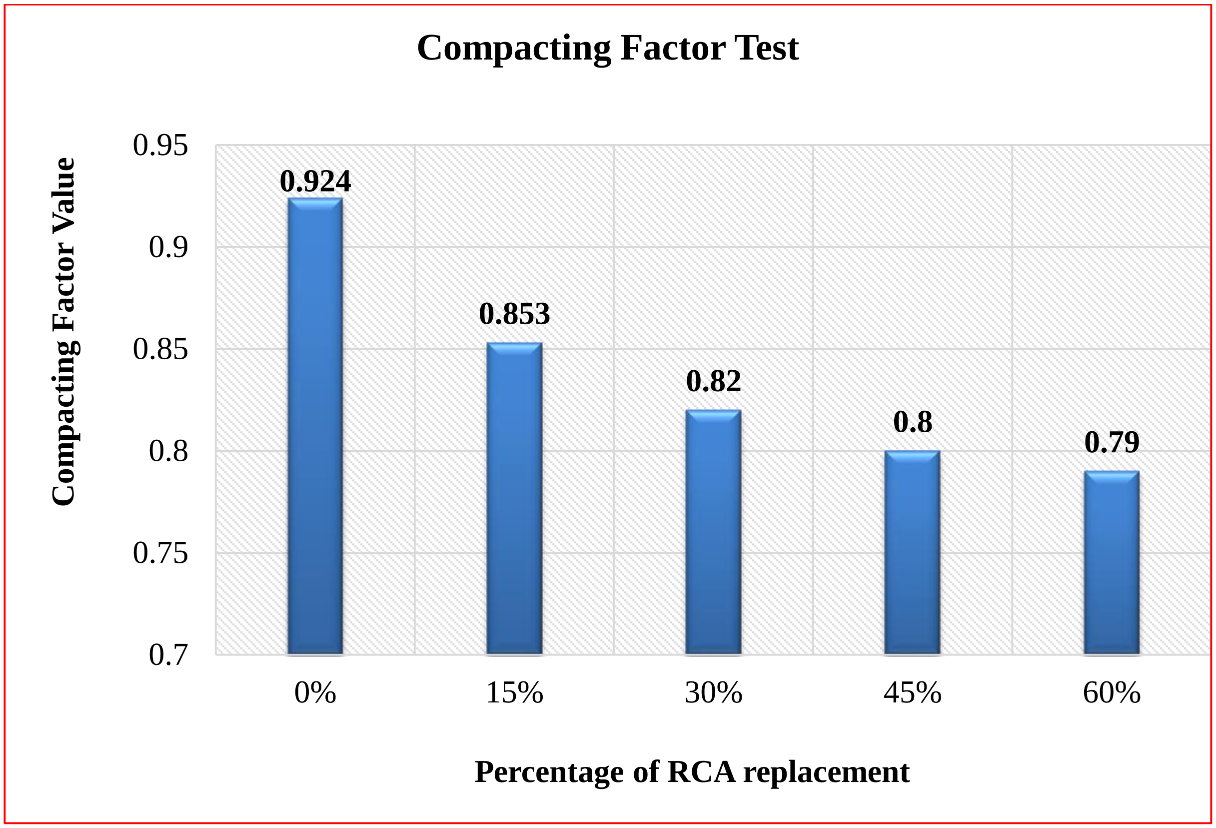


Figure 4.3 Test result for compacting factor test

The test result shows that the degree of workability of the concrete slightly decreases from medium to very low as the amount of recycled concrete aggregate increases. This confirms research conducted by Malesev, et al., (2014) because the authors point out that as the percentage of recycled aggregate increases:

- The water absorption from cement paste increase when the aggregate is dry due to a high void ratio
- Release of water in the interfacial transition zone when the aggregate is moist and
- Penetration of cement materials into the pore as compared to natural coarse aggregate.

Finally, this type of concrete (harsh mix) needs a roller compacting technique.

B-1 Checking for the reliability of CFT values by linear regression analysis

Based on the observed compacting factor value, Linear regression analysis was made using Microsoft Excel 2013 as shown in table 4.3. The full data for the compacting factor test was presented in appendix A: Annex 3.

Table 4.3 Linear regression analysis result

Summary	Output
Regression statistics	
Multiple R	0.938805202
R Square	0.881355207
Adjusted R Square	0.841806943
Standard Error	0.021502713
Observations	5

Most of the time the multiple R-value ranges between 0 and 1.**i.e.** if the R-value is closer to 1, it indicates more reliability of the data and if it is close to 0, it indicates the data is not reliable to the real world. Hence the R-value is 0.938805202 which is very close to 1. These indicated that there is a strong linear relationship between a dependent variables and independent variables. Whereas R^2(coefficient of variance) is a measure of the proportion of variance in the dependent variable Y (workability of concrete) that can be explained by the independent variable X (% of RCA). As indicated in table 4.3, the value of R^2= 0.881355207 which indicated that the independent variable X is 88% accurate to estimate the dependent variable Y (workability of the concrete by compacting factor test). The standard error is approximate to zero, okay! The detail for the outputs is found in Annex 3.

4.1.2 The fresh density of porous concrete

The fresh density of porous concrete at the fresh state for a different proportions of recycled aggregate replaced concrete were determined using ASTM C1688/C1688M. It is directly related to the void content of the mixture which determines the porosity of the hardened porous concrete involving volumetric procedure and the corresponding test results are illustrated in table 4.4 below. Detail calculation in annex 3.

Table 4.4 Fresh density of porous concrete

Designation	100% NCA + 0%RCA	85% NCA + 15%RCA	70% NCA + 30%RCA	55% NCA + 45%RCA	40% NCA + 60%RCA
Weight of empty cylinder in (kg) = **A**	4.612	4.612	4.612	4.612	4.612
The volume of the cylinder(m^3) V = $\pi d^2 h/4$ = 3.14*(0.2)2*0.23/4 = **B**	0.007222	0.007222	0.007222	0.007222	0.007222
Weight of fresh concrete plus cylinder(kg) = **C**	19.3805	19.294	19.234	19.1915	18.675
Net weight of fresh concrete in (kg) = **D = C-A**	14.77	14.68	14.662	14.58	14.06
$\text{Fresh density} = \frac{D}{B}$	2045.14	2032.68	2029.91	2018.76	1946.83

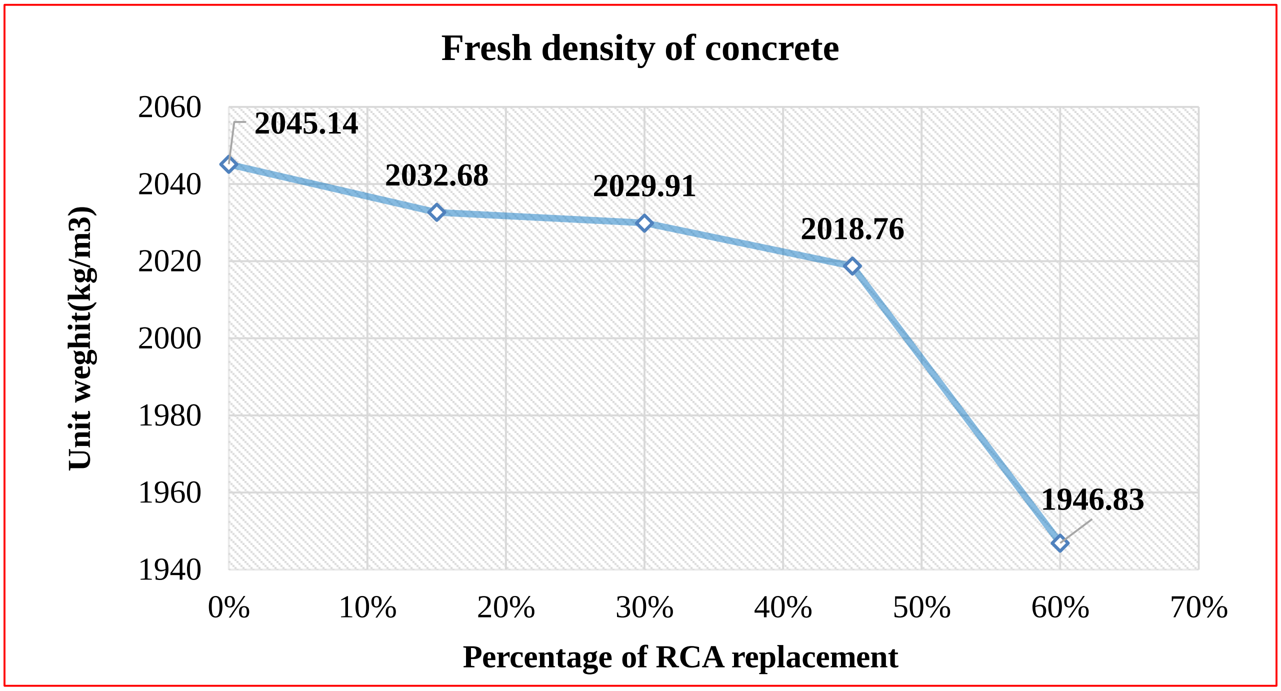


Figure 4.4 Test result for the fresh density of concrete

The results show that the fresh density for concrete containing varying amounts of RCA was in the range of 1946.83-2045.14 kg/m^3. The fresh density of concrete decreases as the percentage of recycled aggregate increases; due to the lower unit weight and porosity of recycled aggregate which makes it lightweight concrete. The decrease in fresh density was 0.61, 0.74, 1.29, and 4.81% for concrete containing 15, 30, 45, and 60% RCA, respectively compared to control. This reduction in the unit weight of concrete also decreases the compressive strength and thus is the main drawback of this concrete for application as a high load-bearing structure. This confirms research conducted by Nassar, et al., (2020) who suggested that reduced density of lightweight aggregate concrete is viewed as a major source of economical design of structural members as the lower concrete density will result in a reduction of self-weight of the structural members, which will allow the economical structural design of such members with smaller cross-sections. Similar results have been reported by Herki, (2020), who pointed that the density of concrete has greatly affected by grading of aggregate, mix proportions, cement content, water-cement ratio, method of compaction, and curing condition.

4.2 Hardened concrete properties

To evaluate the effect of recycled concrete aggregate on the hardened properties of porous concrete, the compressive strength of cubes, porosity of cubes, split tensile strength of cylinders, and permeability of cylinders were investigated. Then the test results are presented and discussed under this section.

4.2.1 Compressive strength

The compressive strength for both cubes of recycled aggregate replaced concrete and natural aggregate concrete (control) was tested at the ages of 7th, 14^{th,} and 28th day using the universal compressive testing machine. The average compressive strength test result of the samples for each curing periods of 7th, 14^{th,} and 28th days was presented as follow:

A. Compressive strength test result for 7th day

The 7th-day average compressive strength test result for control mix was 14.73MPa and recycled aggregate replaced concrete with 15%, 30%, 45%, and 60% were found 13.80MPa, 10.72MPa, 7.86MPa, and 7.02MPa respectively These shows that there is a decrease in average compressive strength with an increase in the amount of recycled aggregate replaced concrete as compared with that of the control sample. It means the average compressive strength of concrete for recycled aggregate replacement of 15%, 30%, 45%, and 60% was decreased by 6.314%, 27.223%, 46.640%, and 52.342% respectively as compared to the control mix. It is seen that the increased amount of RCA affects the strength development of the concrete; due to the high void ratio and high water absorption capacity of old mortars surrounding the RCA which affects the bond between cement paste and aggregate.

Similarly, the findings of the present study confirm the research conducted by Haripriya, et al., (2020). The author pointed that, the adhered mortar presence at the surface of an overwhelmed concrete mixture usually degrades the great of the recycled mixture and therefore the fresh and hardened residences of concrete crafted from it compared to natural aggregates. Detailed calculations were presented in Annex 4.

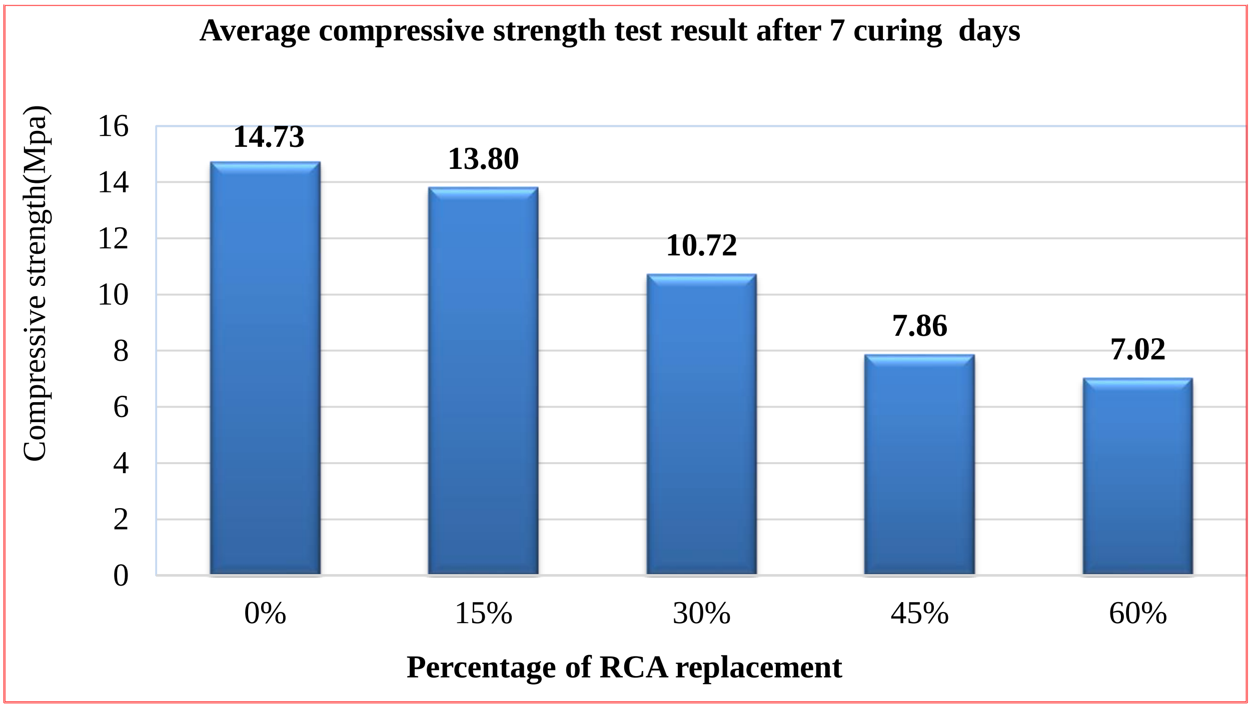


Figure 4. 5 Compressive strength for the seventh day with labeled data

B. Compressive strength test result for 14th day

The 14th-day average compressive strength test result for the control mix was 17.41MPa and recycled aggregate replaced concrete with 15%, 30%, 45%, and 60% were found 17.26MPa, 12.78MPa, 12.68MPa, and 10.53MPa respectively. This shows that there is a decrease in average compressive strength with an increase in the amount of recycled aggregate replaced concrete as compared with that of the control sample. The decrease in compressive strength was 0.86%, 26.59%, 27.17% and 39.52% for concrete containing 15, 30, 45 and 60% RCA, respectively compared to control. This indicates that the increased amount of RCA affects the strength development of the concrete; due to the high void ratio and high water absorption capacity of old mortars surrounding the RCA which affects the strength development of the concrete by reducing the bond between cement paste and aggregate as well as the formation of different interfacial transition zones. This finding also confirms the research conducted by Haripriya, et al., (2020). Detailed calculations were presented in Annex 4.

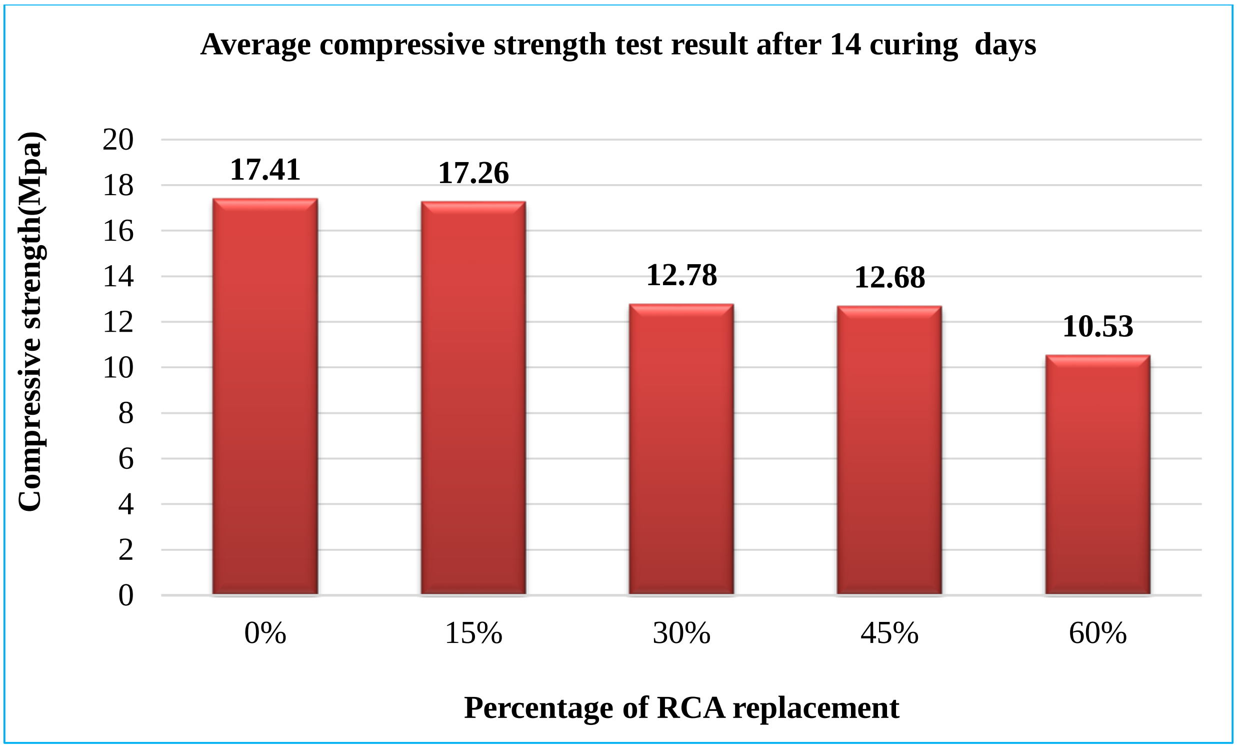


Figure 4.6 Compressive strength of concrete for fourteen-day with labeled data

C. Compressive strength test result for 28th day

The 28th-day average compressive strength test result for the control mix was 25.63MPa and recycled aggregate replaced concrete with 15%, 30%, 45%, and 60% were found 21.42MPa, 17.37MPa, 14.96MPa, and 11.61MPa respectively. Detailed calculations were presented in Annex 4.

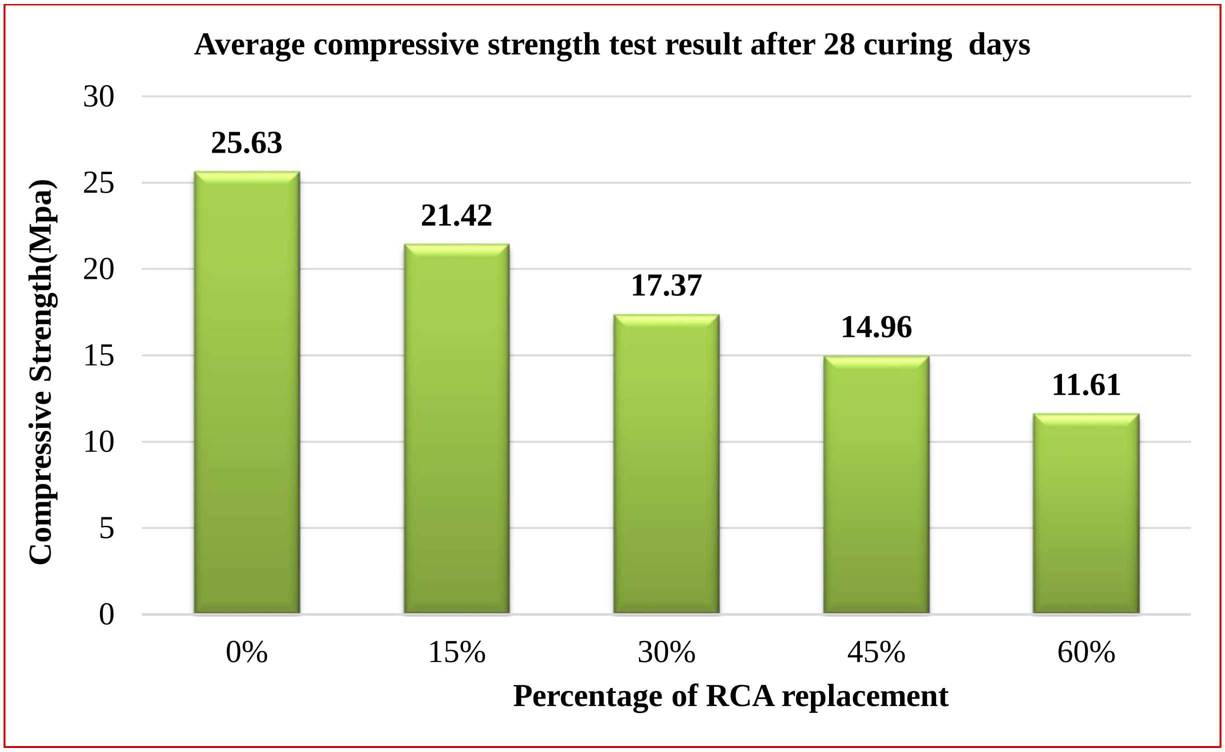


Figure 4.7 Compressive strength of concrete for twenty-eight day with labeled data

This shows that; there is a decrease in average compressive strength with an increase in the amount of recycled aggregate. The decrease in compressive strength was 16.43%, 32.23%, 41.63% and 54.70% (16 to 55%) for concrete containing 15, 30, 45 and 60% RCA, respectively compared to control mix. This is due to the presence of a high void ratio of adhered mortar at the surface of RCA and high water absorption capacity of recycled aggregate which affects the bond between cement paste and aggregate as well as the formation of different interfacial transition zones.

This finding supports the research conducted by Haripriya, et al., (2020) pointed that, the adhered mortar presence at the surface of an overwhelmed concrete mixture usually degrades the great of the recycled mixture and therefore the fresh and hardened residences of concrete crafted from it compared to natural aggregates. Similar results have been reported by Guo, et al., (2020) and Ramana, et al., (2019) who argued that the compressive strength decreases with an increase in recycled aggregate and porosity increases. However, the 28-day strength for the concrete mix containing 15-60% RCA in the present study is in the range of 11.61-21.42 MPa. According to ACI 522R, (2010) the minimum and maximum compressive strength required for porous concrete made up of natural aggregate ranges between **2.8** and **28** MPa respectively with typical values of about **17**Mpa which is suitable for a wide range of applications such as light traffic roads, parking lots, residential streets and pavement side walkways. Hence, all the obtained results fall between the specified ranges. Therefore, a target compressive strength of 17.37 MPa at 30% replacement of RCA is suitable for the intended use.

Compressive strength development and discussions

The average compressive strength results of cubes for both natural aggregate mix and recycled aggregate replaced mix were conducted and evaluated on the 7th, 14^{th,} and 28th days by crushing the samples using a Universal Testing Machine and the corresponding mean strength was presented in the chart. From this, it is observed that, as the number of RA increases in the mixes, the cube compressive strength is decreasing. For natural aggregate mix (0% RCA), the 28th-day compressive strength was 25.63Mpa. This mix is considered as a reference mix for comparison of another mix (RCA replaced mix). For RA mix the 28th-day compressive strength was 21.42MPa, 17.37MPa, 14.96MPa, and 11.61MPa for 15%, 30%, 45%, and 60% RCA mix. This means the compression strengths are decreasing from 16.43% to 54.70 % (for RA content of 15 to 60%) when compared to the control mix. As per ACI 522R, 2010 guidelines the compressive strength of natural aggregate porous concrete ranges between **2.8** to **28** MPa with typical values of about 17Mpa which is suitable for a wide range of applications such as light traffic pavements, parking lots, residential streets, and pavement side walkways. So, in this experimental study, the strong results for all RCA replacement levels noticed that the results fall between the stipulated ranges.

For 45% and 60% RCA replacement levels, the compression strength result after the 28th day was less than the typical value suitable for the required application areas. This indicates that those percentages are not recommended to attain the mix design of 17MPa. But for 15% and 30% RCA replacement levels, the result was higher than the typical value. This implies that those percentage replacements of RCA are recommended to achieve the desired strength of the specification, and it was more than enough for the mix design of 17MPa porous concrete which is suitable for a wide range of applications such as light traffic pavements, parking lots, residential streets and pavement side walkways. This means 30% replacement of recycled concrete aggregate is the optimum level of RCA replacement for porous concrete.

As seen in figure 4.7 of the chart the compression strength test results are decreasing; due to the increase in recycled aggregate percentage which reduces the bond strength between cement paste and aggregates. Also, these affect the strength development of the concrete at the microstructure level by forming different Interfacial Transition Zones (**ITZ**) during the strength development stages of the concrete. Therefore, the RCA should not have a rough surface structure (old mortar) which is the main drawback for decreasing in strength for recycled aggregate replaced porous concrete.

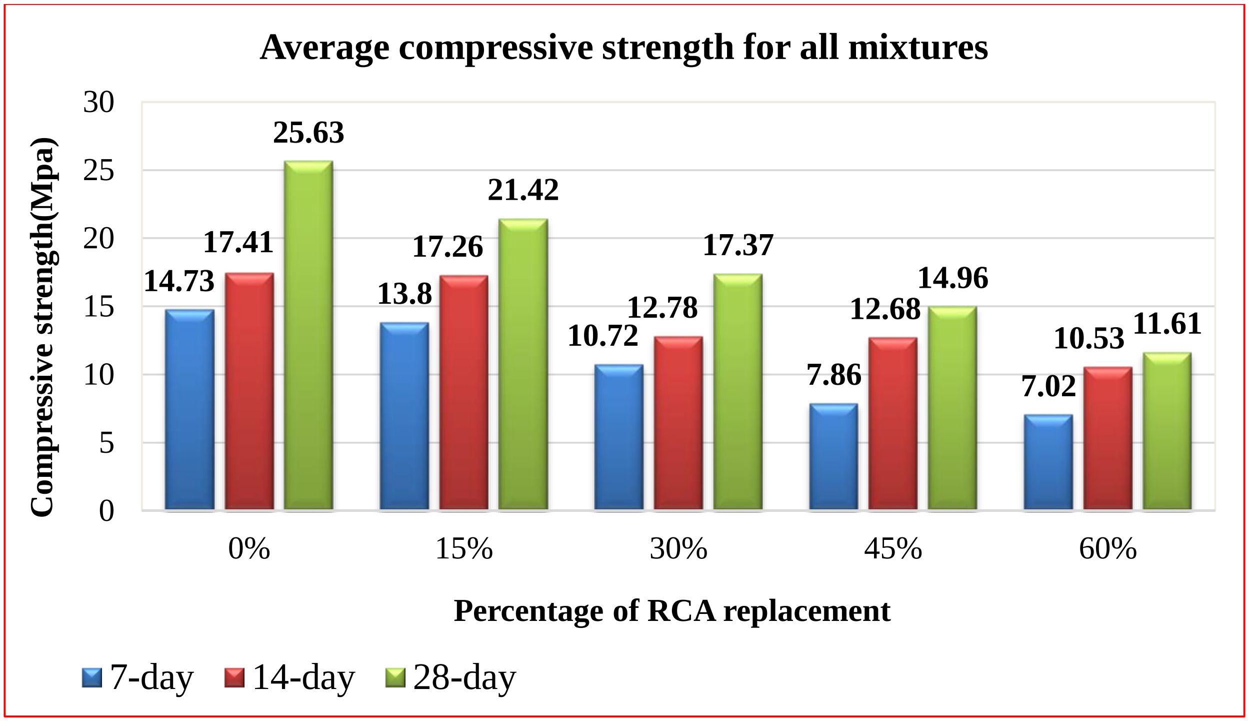


Figure 4.8 Compressive strength test result for all mixtures

4.2.2 Split tensile strength of the cylinder

The split tensile strength of cylinder for all mixes was tested according to ASTM C 39-93a, at an age of 7, 14, and 28 days for 0%, 15%, 30%, 45%, and 60% replacement percentage of RCA and the corresponding average test results are shown in charts in figure 4.9, 4.10 and 4.11 respectively. From the test results labeled on the charts after 28 days, it is noticed that the split tensile strength slightly decreases with an increase in recycled concrete aggregate replacement ratio. The decrement was 6.06%, 11.78%, 21.55% and 23.57% for15%, 30%, 45% and 60% respectively as compared with control. This decrement was approximately in the range of 6% to 24% for RCA content of 15% to 60% as compared to the control mix. Hence, the maximum decrease in split tensile strength decrease was recorded at 60% replacement of recycled aggregate; this may be due to a decrease in bond strength between cement paste and aggregates as well as the formation of different Interfacial Transition Zones **(ITZ)** during strength development stages of the concrete at a microstructure level. Detailed calculations were presented in Annex 4.

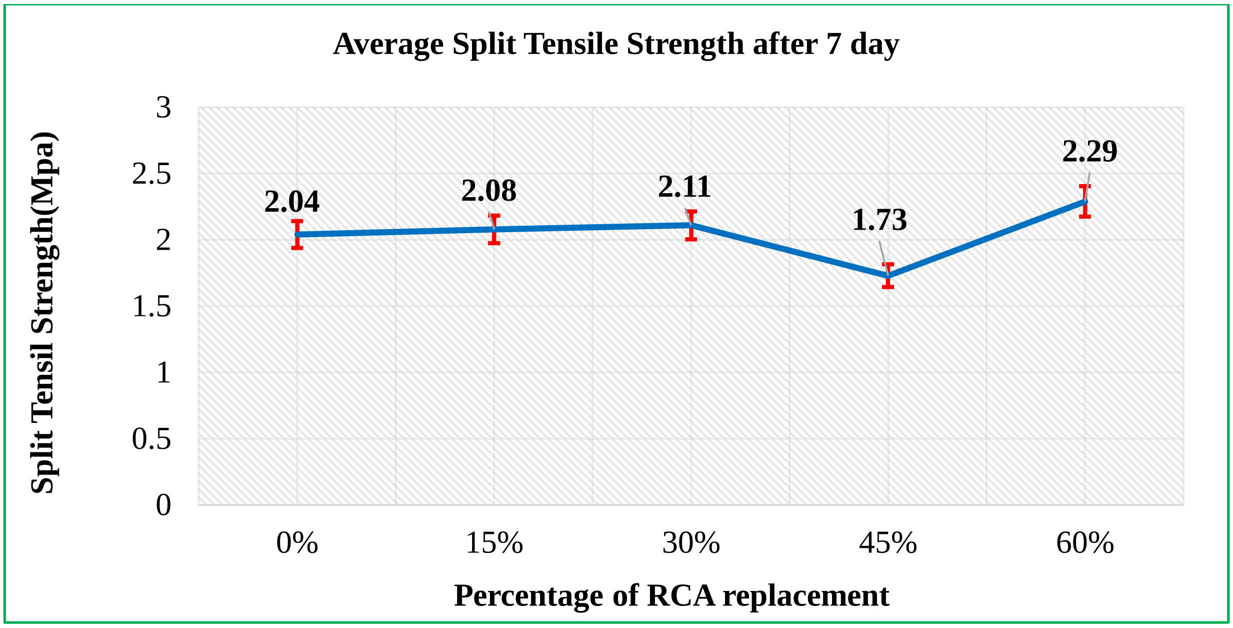


Figure 4.9 Split tensile strength at 7 days curing with error bar

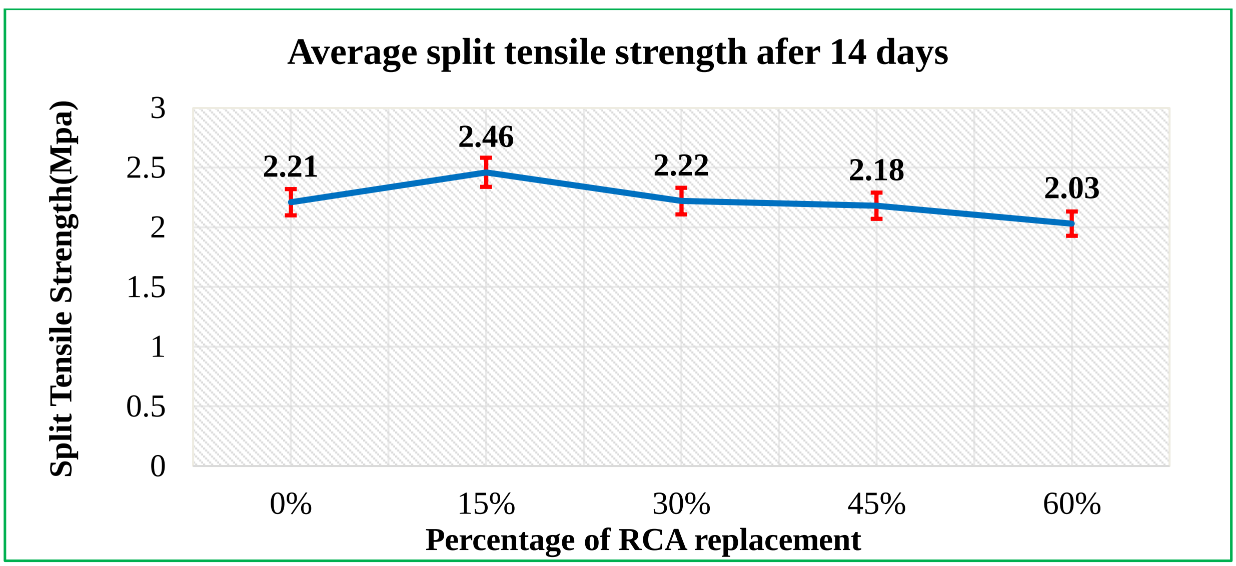


Figure 4.10 Split tensile strength at 14 days curing with error bar

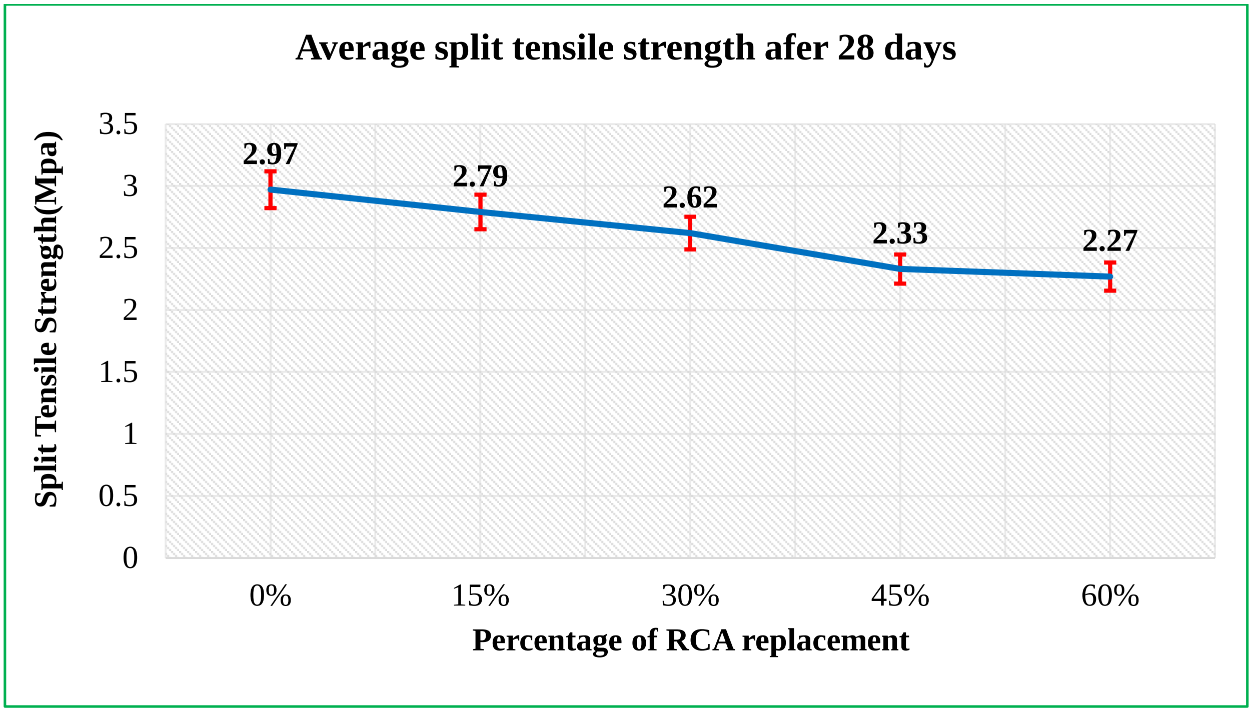


Figure 4. 11 Split tensile strength at 28 days curing with error bar

Also, from the results labeled on the charts for 7 and 14 days, it is noticed that; the split tensile strength is the same or in some cases exceeds that of natural aggregate concrete or control. This finding confirms a research study made by Hahladakis, et al.(2020) because the authors of the study argued that, the split tensile strength of RA concrete is dependent upon multiple factors, such as RA quality, replacement ratio, water-binder ratio, type of cement, and curing ages. They have also found that, for a replacement ratio of up to 30%, RAC's tensile strength is the same or even in some cases exceeds that of virgin aggregate concrete. Similarly, they demonstrated that the split tensile strength of concrete tends to become constant as the replacement ratio reaches 100%. Also, similar results are obtained by Ramana, et al., (2019). Therefore, they argued that the split tensile strength of concrete is improved as curing age increases which were also happened in the case of this study.

4.2.3 The porosity of hardened concrete

Porosity (void ratio) in concrete to the total volume of the sample were tested for specified cubes of recycled aggregate replaced porous concrete and natural aggregate porous concrete (control) at the ages of 28^{th} day. The test was performed as per ASTM C1754, by dividing the difference between 24hr oven-dried weight of the sample (Md) and the weight of the submerged sample in the water tank for a minimum of 30 minutes (Mw) by the water density. The corresponding test result on the 28th day for 0%, 15%, 30%, 45%, and 60% RCA replacement are approximately the same values as shown in table 4.5 and detailed calculation in Annex 4.

Table 4.5 Average porosity ratio for recycled aggregate replaced porous concrete

Designation		**Porosity ratio (%)**		
NCA (%)	**RCA (%)**	**7th day**	**14th day**	**28th day**
100%	0%	36.59	36.56	36.62
85%	15%	39.70	39.70	40.00
70%	30%	42.67	42.37	42.07
55%	45%	43.02	43.26	43.05
40%	60%	43.50	43.76	43.73

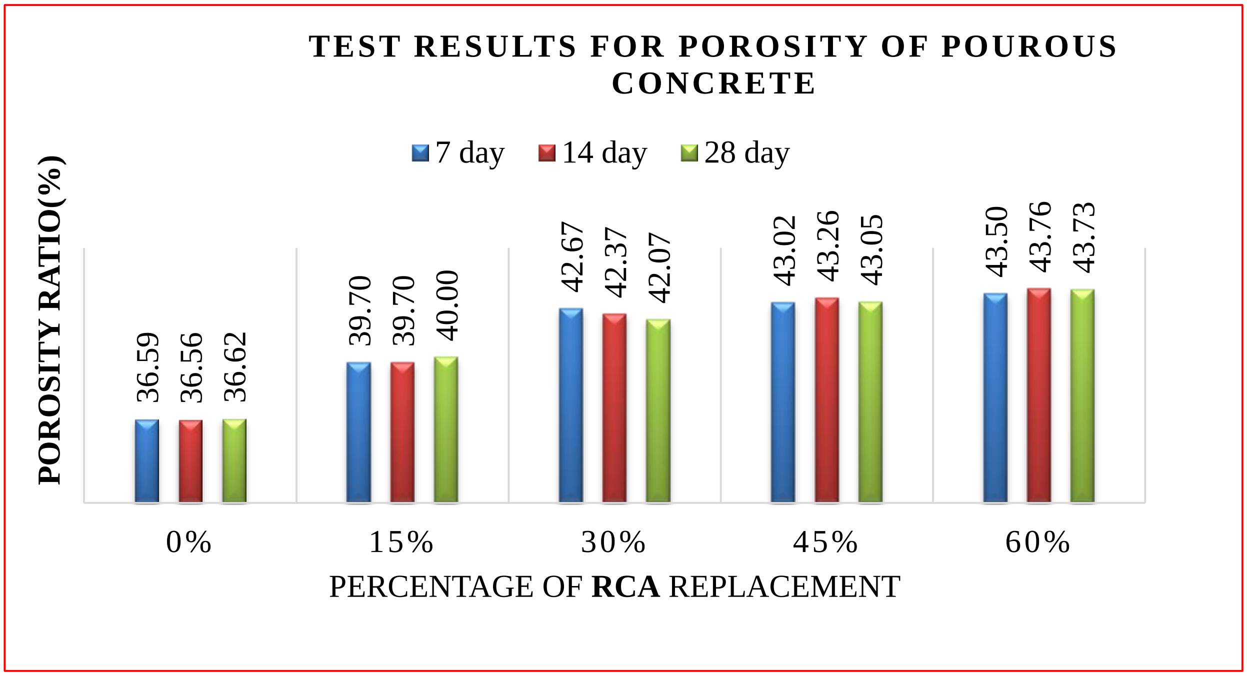


Figure 4.12 Porosity of porous concrete

Figure 4.12 shows that; the void ratio of recycled concrete aggregate replaced porous concrete was higher than that of normal aggregate porous concrete. This means for every 15% increase in the RCA replacement ratio in the concrete; the porosity ratio of porous concrete increases. For example, the increment for 28 days with an increase in recycled concrete aggregate was 8.45%, 12.95%, 14.94%, and 16.26% for 15%, 30%, 45%, and 60% of RCA respectively as compared with the control mix. This increment was approximately in the range of 8% to 16% for RCA content of 15% to 60%. This indicates that porous concrete with recycled aggregate contains not only the virgin aggregate but also hydrated cement paste which reduces specific gravity and increases porosity. Also, the void ratio of this concrete was beyond an acceptable range of 36-43% which affects the workability and strength of the concrete. This extra porosity was happened due to a lack of fine aggregate (sand) and uniform sized coarse aggregate during mix design. So, the workability of fresh concrete was affected by the presence of old mortar pores that absorbs a high amount of water during mixing. This indicates that having high-water absorption of RA decreases the workability of fresh concrete and bonding strength of hardened concrete due to the presence of old mortar on its surface.

Therefore, this finding confirms the research conducted by García-González, et al., (2016) recycled aggregate are of higher porosity than natural aggregates, which can decrease the mechanical properties and durability of the concrete. The authors also argued that higher porosity results in poor performance concerning:

- Compressive strength
- Modulus of elasticity
- Shrinkage and
- Resistance to freeze-thaw cycles.

4.2.4 Permeability (infiltration capacity) of hardened concrete

The permeability of porous concrete is an important parameter that evaluates the suitability of using porous concrete as pavement sidewalks, residential streets, tennis courts, light traffic roads, and parking lots. Mainly it depends on the size and pore structures of the concrete. It is achieved by providing sufficient voids through which water can drain or pass safely into the sub-base or subgrade layers of the pavement. Since different researchers argued that, porous concrete generally owns a much higher permeability compared to normal dense concrete and the permeability test method for conventional concrete was not suitable for testing porous concrete. So, by keeping this in view a test was conducted to estimate the permeability coefficient of porous concrete.

Hence, the apparatus required for the test was not available at Jimma University Jimma Institute of Technology, construction material laboratory. Therefore, the researcher conducted the percolation rate determination test procedures by himself using locally available materials by watching different related videos, published journals, and related standards that were appropriately cited. Therefore, to determine the infiltration capacity, a 200mm X 100mm cylindrical specimen of porous concrete was wrapped in plastic on the circumference. Then the sample was tightened by plastic material to inhibit water leakage along the sides and the top of the sample was covered by a diameter of 110mm pipe. After that; the internal edge part of the specimens was also sealed with a sealing material (**Stucco**= local name) and placed on a bracket of the cylinder. After that, the water level difference was stabilized and the amount of overflow water quantity in the time was measured by using a stopwatch. The detailed experimentation procedures followed including supportive pictures are discussed in chapter three of this study.

Finally, to estimate the coefficient of permeability, Darcy's equation was adopted and the constant head permeability test method was performed only at 28 days on three cylindrical specimens for each of all mixes containing 0%, 15%, 30%, 45%, and 60% of RCA and the averages of three results was taken. This is because the permeability properties of the concrete are not time-dependent. The corresponding average values for the specified percentage replacement values of RCA are 1.84, 2.22, 2.35, 2.62, and 2.86 respectively. Then, the infiltration test for water to pass through pores of porous concrete was expressed in centimeter per second (cm/sec) as per ASTM-C1701 standards. The detailed calculation was presented in Annex 4.

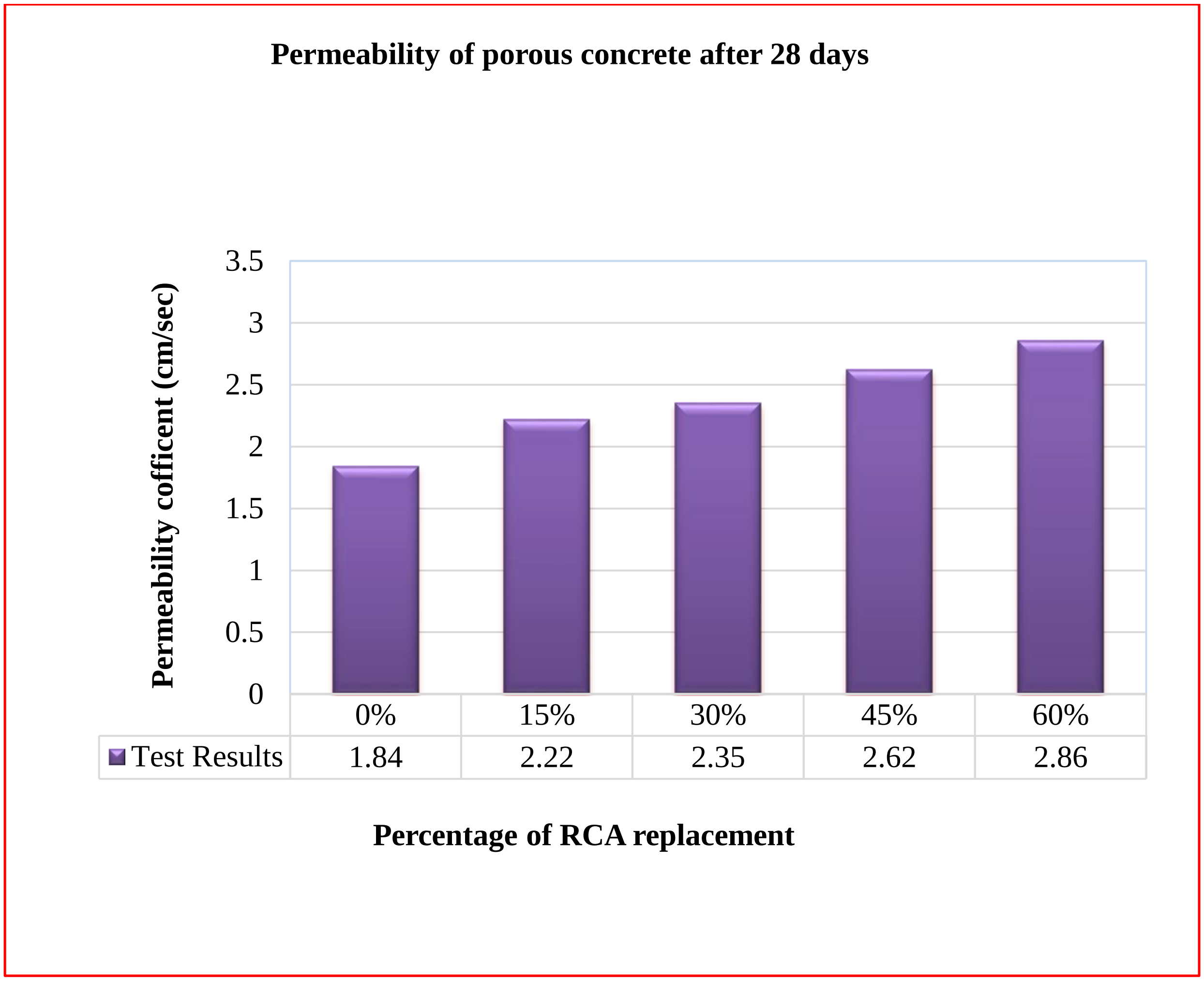


Figure 4.13 Permeability coefficient with data table

From the chart, it is clear to notice that; as the amount of RCA increase in the mix, the permeability of the concrete increases due to increasing void ratio or porosity of the concrete as discussed under section 4.2.3. This indicates the direct relationship between porosity and permeability with that of the RCA replacement amount. In another way figure, 4.13 shows that; the coefficient of permeability (k) increases for every 15% inclusion of RCA by 17.12% to 35.66%. The maximum permeability value of 2.86cm/sec was observed by 60% replacement of RCA by weight of natural coarse aggregate for the production of porous concrete. This indicates that the inclusion of RCA in the mix affects the minimum permeability requirement of 0.2cm/sec to 1.20cm/sec as per ACI 522R, 2010 standards. So, this test result shows that the rate of permeability ranges from 1.84 to 2.86cm/sec and the provided mix was achieved a good permeability or infiltration capacity.

Hence, the findings of this research contradict a report on previous concrete conducted by ACI committee 522R, (2010) because the authors argued that the minimum permeability requirement for porous concrete made up of natural coarse aggregate and zero fine aggregates, ranges between 0.2cm/sec to 1.20cm/sec. But in this study, the permeability value ranges between 1.84 to 2.86cm/sec which was beyond the standard by 10.87 to 41.96% due to the high porosity ratio of recycled concrete aggregate. Furthermore, research conducted on the effect of sand on pervious concrete by PRAMOD, et al., (2019) argued that porosity and permeability of pervious concrete decrease with the increase of sand content, but the mechanical properties (strength) of the concrete increases.

A. Checking reliability for the coefficient of permeability values by linear regression analysis

Based on the observed permeability rate, linear regression analysis was made using Microsoft Excel 2013 as shown in table 4.6. The full data for the compacting factor test was presented in appendix A: Annex 4.

Table 4. 6 Linear regression analysis result for permeability rate

Summary	Output
Regression Statistics	
Multiple R	0.991116828
R Square	0.982312566
Adjusted R Square	0.976416755
Standard Error	0.059777365
Observations	5

As discussed before, the multiple R-value ranges between 0 and 1.**i.e.** if the R-value is closer to 1, it indicates the more reliability of the data to the real world and if it is close to 0, it indicates the data is not reliable to the real world. Hence the R-value 0.991116828 is very close to 1. These indicated that there is a strong linear relationship between a dependent variable and independent variables. Whereas R^2(coefficient of variance) is a measure of the proportion of variance in the dependent variable Y (permeability rate) that can be explained by the independent variable X (%

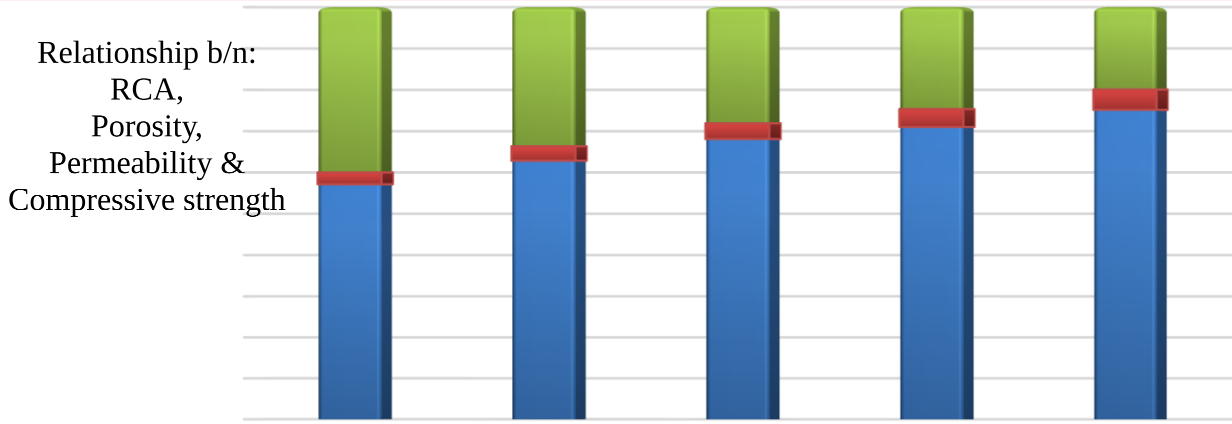
of RCA). As indicated in table 4.6, the value of R^2= 0.982312566 which indicated that the independent variable X is 98% accurate to estimate the dependent variable Y (coefficient of permeability). The standard error = 0.059777365 is approximate to zero, okay! The detail for the outputs is found in Annex 4.

4.3 The optimum percentage of RCA

Test results of both fresh and hardened properties of porous concrete for every 15% incremental replacement level of RCA by weight of normal coarse aggregate was evaluated and compared with typical values of porous concrete suitable for a wide range of applications. Depending upon ACI 522R 2010 standards of porous concrete; the average compressive strength test result for 0% RCA and 15% RCA was more than 17Mpa which is the typical value of porous concrete suitable for a wide range of applications such as light traffic pavements, parking areas, residential streets, tennis courts, and pavement side walkways. Hence, an average compressive strength value of 17.37 MPa was recorded at the 30% replacement level of RCA. Therefore, 30% replacement of recycled concrete aggregate is the optimum (most favorable) amount for recycled aggregate replaced porous concrete with satisfactory porosity and permeability properties.

4.4 Relationship between RCA, strength, porosity, and permeability properties

The main challenges encountered during porous concrete mixture proportioning were determining aggregate size, aggregate cement ratio, water-cement ratio, a balance between an acceptable compressive strength, porosity, and water percolation rate. ACI 522R, 2010 suggests that; the strength properties of porous concrete decrease with an increase in aggregate size which is an indirect relationship. But the porosity has a direct relationship with permeability and RCA replacement percentage. So, increasing the percentage of RCA increases the porosity; then discharge of water through the pore of concrete faster, and consequently, compressive strength decreases. Therefore, by combining all the sizes of coarse aggregates between 20mm - 4.75mm and 30% RCA by weight of natural coarse aggregate; the required compressive strength(17MPa), sufficient porosity, and permeability requirements were achieved for this study. Figure 4.14 illustrates their relationship after 28 days.



	0% RCA	15% RCA	30% RCA	45% RCA	60% RCA
Compressive strength	25.63	21.42	17.37	14.96	11.61
Permeability	1.84	2.22	2.35	2.62	2.86
Porosity	36.62	40	42.07	43.05	43.73

Figure 4.14**:** Relationship between RCA, Porosity, Permeability and Compressive strength

4.5 Economic benefits of porous concrete.

As elaborated in the literature review part of the study, porous concrete requires a periodic maintenance practice like pressure washing or power vacuuming due to the clogging effects of the pores. This maintenance cost might be higher than that of conventional concrete. While there are counter cost-saving practices for projects because the need for storm drains, underground pipes, retention ponds, and other stormwater management systems are eliminated. Also, it saves all the costs budgeted for fine aggregate (sand) as compared to conventional concrete. Additionally, the practicability of the porous concreting system was preferable to conventional concrete under the following environments:

- Areas of numerous flooding or rainy zones
- Areas need the high cost of drainage and plumbing system
- Areas causing corrosion of conventional drainage systems
- Areas causing health and pollution hazards due to surface ponding of water on roadways
- High risk of accidents and consequential economic losses due to water accumulation on roadsides.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The research aimed to study the properties of porous concrete using different proportioning values of 0%, 15%, 30%, 45%, and 60% recycled concrete aggregate as a partial replacement of normal coarse aggregate. Furthermore, to achieve the aim of this study the researcher collected related literature and conducted different tests of materials and specimens to determine the effects of using RCA on concrete quality. Therefore, based on the findings of the study the following conclusions are drawn:

- Almost all the concrete mixes have zero slumps except the control mix which has a slump value of 14mm. This indicates that all the performed mixes were dry because of the high water absorption capacity of RCA.
- Degree of workability using compacting factor test ranges between very low to medium. The multiple R-value (0.94) and the coefficient of reliability R^2 indicates that the independent variable X is 88% accurate to estimate the dependent variable Y.
- The fresh density of porous concrete decreases as the percentage of recycled concrete aggregate increases from 0.61-4.81% due to lower unit weight and porosity of RCA.
- The average compressive strength of the 28th-day decrease from 16.43% to 54.70 % for every 15% increase of RCA when compared to the control mix. This is due to the presence of adhered mortar on RCA which absorbs designed mixing water and reduces the amount of cement paste i.e. reduces bonding strength between cement paste and coarse aggregate.
- The cube compressive strength test result of the 28th day for 15% and 30% RCA replacement levels was higher than the typical value (17MPa) of 21.42 MPa and 17.37 MPa respectively. This implies that; 30% replacement of RCA is the optimum replacement value for porous concrete which is suitable for the intended use.
- Split tensile strength on the 28th day was slightly decreasing with an increase in RCA; with the range of 6% to 24% for the content of 15% to 60% RCA as compared to the control mix.

- Porosity of the concrete slightly increases for every 15% increase in RCA at the range of 8% to 16% due to an increased corseness of aggregate in the mix and luckof fine aggregate in the mixs as discussed in chapter three table 3.7. This indicates that; there is a direct relationship between RCA content and the void ratio of the produced porous concrete.
- Permeability of porous concrete increases with an increment of RCA content by 17.12% to 35.66%; due to increased void ratio. Its value ranges from 1.84 to 2.86cm/sec which is high enough to be used as a drainage system.
- Also, it was observed that porosity, permeability, and RCA replacement percentage have a direct relationship with each other. This means a higher percentage of RCA, a higher porosity, and a faster permeability rate of water through the pores of the concrete.

Generally; the researcher concludes that porous concrete is an environmentally friendly, unique, and innovative solution to support the sustainable development of the construction industry because use of this concrete can effectively control the surface ponding of water and runoff as well as saving the cost invested for sand and construction of drainage systems on the intended application areas.

5.2 Recommendations

In Ethiopia, the scarcity of conventional concrete making material is gradually increasing with an increase in population and urban development's which causes continuous increment in environmental pollutions implying more work to be done on the area. Therefore, based on the findings of the study, the following recommendations are drawn for the intended parties:

A. For the Ethiopian construction industry

The major stakeholders in construction industries have to turn their face towards advanced construction technologies by keeping in mind the scarcity of natural resources, improved culture of using environmentally friendly construction materials, and enhancement of sustainability. Also, some of the known standard testing machines and methods for conventional concrete are not all applicable for porous concrete. Hence, either new or modified testing methods need to be established that take into consideration the unique features of porous concrete. Therefore it is recommended to include standards for porous concrete in the Ethiopian Building Code Standards with clear guidelines for production and its application areas.

B. For Jimma University, Jimma Institute of Technology

Jimma University Institute of Technology, School of Civil and Environmental Engineering, and for Construction Engineering and Management laboratory, should deliver additional testing machines to evaluate the performance of porous concrete for wider applications. These machines are a constant head method and falling head method for permeability determination, flexural testing machine, and electro-microscopic testing machine to determine durability, void structure, and strength development properties of the concrete. If the university provides those listed machines, another researcher may solve any other shortcomings not done in this study.

C. For another Researcher

In Ethiopia, there is a great need for porous concrete because the flood, as well as surface ponding of water, comes in the summer season in urban areas, due to the lack of proper discharge facility of rainwater in the intended areas. Therefore, other researchers can use the findings of this study as a reference to improve and dig out other properties of this concrete from an environmental perspective. Hence, some of the focus areas for future study are:

- Study on improving the mechanical properties of porous concrete using locally available materials to enhance green concept.

- Study on long-term properties of RCA replaced porous concrete like durability and freeze and thawing action.
- Investigation on the effect of sand and different admixtures on the properties of RCA replaced porous concrete.
- Electromicroscopic studies on void structure of RCA replaced porous concrete.

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APPENDIX: A

ANNEX 1: MATERIAL PHYSICAL PROPERTIES

1. Properties of Portland Pozzolana Cement(PPC) grade 32.5R

1.1 Normal consistency of cement

This test is carried out to determine the correct amount of water required to prepare a standard cement paste (satisfactory workability). The usual range of water-cement ratio for normal consistency is between 26% and 33% by weight of cement. Therefore; cement paste is said to be normal consistency when the rod penetrates 10±1mm below the original surface within thirty seconds. Table A.1.1 shows the observed normal consistency for PPC cement

Trials	Wt. of cement (gm)	Amount of Water (ml)	Water-cement ratio	Penetration Depth(mm)
1	400	112	0.28	8
2	400	115	0.29	9.32
3	400	118	29.5	10.5

1.2 Setting time of cement

There are two types of set times to be determined in the laboratory, initial and final setting times.

Table A.1.2 shows the observed durations for both the initial and final set of PPC cement

Setting Time of portland pozolana cement paste (PPC 32.5R)																			
Time, (minutes)	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300
Penetration depth (mm)	40	39.7	39.5	39.3	39.4	36.5	36.3	36.3	32.9	28.4	26.2	24.1	21.6	15.7	11.4	5.2	2.1	_	_
	40	39.9	39.8	39.3	39.3	39.1	38.6	36.7	33.5	28.7	23.8	19.7	17.2	13.8	10.3	4.6	1.9	_	_

Trial	cement (gm)	Water(ml)	w/c ratio	T_0	T1	T2	Initial setting time(T3)	Final setting time(T4)
1	400	118	0.295	2:30	180	195	188.57(min)	316.2(min)
Penetration depth(mm)					26.2	24.1		
2	400	118			165	180	182(min)	280(min)
Penetration depth(mm)					28.7	23.8		

1.3 The fineness of cement by sieve analysis

Laboratory Observations for fineness of cement

- Weight of cement taken(W1) = 100gm
- Weight of cement retained on 90µm after sieving for 10 minute(W2) = 1.5g

Fineness % = $\frac{w2}{w1} * 100$

- Fineness % = $\frac{1.5}{100} * 100$= 1.5% < 5%............ok!

2. Properties of coarse aggregate

2.1 Sieve Analysis for 100% NA+0% RCA

Sample= 5000 gm

Sieve Size (mm)	Weight Retained (gm)		Average mass Retained (gm)	(%) of Retained	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative % Pass (ASTM C33)	
	S_1	S_2					Lower limit	Upper limit
37.5	0	0	0	0	0	100	100	100
25*	145	134	141	2.82	2.82	97.18	90	100
19	1036.4	993	1014.7	20.29	23.11	76.89	40	85
12.5*	2026.4	2168.5	2097.45	41.95	65.06	34.94	0	40
9.5	1429.4	1210.5	1319.95	26.40	91.46	8.54	0	15
4.75	357.5	490.5	424	8.48	99.94	0.06	0	5
2.36	3.5	2.5	3	0.06	100	0	0	0
1.18	0	0	0	0	100	0	0	0
600µm	0	0	0	0	100	0	0	0
300µm	0	0	0	0	100	0	0	0
150µm	0	0	0	0	100	0	0	0

Total			5000	100	714.51	0	0	0

Fineness Modulus (FM)= ∑Cum. % Retained /100= 714.51/100 = 7.1451≈ 7.14

2.2 Sieve Analysis for 0% NCA+100% RCA

Sieve Size (mm)	Weight Retained (gm)		Average mass Retained (gm)	(%) of Retained	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative % Pass (ASTM C33)	
	S_1	S_2					Lower limit	Upper limit
37.5	0	0	0	0	0	100	100	100
25*	284	227	255.5	5.11	5.11	94.89	90	100
19	753.5	1436	1094.75	21.90	27.01	72.99	40	85
12.5*	2231.5	2026.8	2129.15	42.58	69.59	30.41	0	40
9.5	1300.5	1089	1194.75	23.90	93.49	6.51	0	15
4.75	429	219	324	6.48	99.97	0.03	0	5
2.36	1.5	2.2	1.85	0.04	100	0	-	-
The same to that of above table				0	720.47			

Fineness Modulus (FM) = ∑Cum. % Retained /100= 720.47/100 = 7.2047≈ 7.2

2.3 Sieve Analysis for 85% NCA +15% RCA

Sieve Size (mm)	Weight Retained (gm)		Average mass Retained (gm)	(%) of Retained	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative % Pass (ASTM C33)	
	S_1	S_2					Lower limit	Upper limit
37.5	0	0	0	0	0	100	100	100

25*	299	320	309.5	6.19	6.19	93.81	90	100
19	1472	1457.75	1464.875	29.30	35.49	64.51	40	85
12.5*	1600.5	1665.5	1633	32.66	68.15	31.85	0	40
9.5	1155	1150	1152.5	23.05	91.20	8.80	0	15
4.75	460	397.25	428.625	8.57	99.77	0.23	0	5
2.36	13.5	9.5	11.5	0.23	100	0	0	0
The same procedure			5000	0	726.46	0	0	0

Fineness Modulus (FM) = ∑Cum. % Retained /100= 726.46/100 = 7.2646≈ 7.3

2.4 Sieve Analysis for 70% NCA +30% RCA

Sieve Size (mm)	Weight Retained (gm)		Average mass Retained (gm)	(%) of Retained	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative % Pass (ASTM C33)	
	S_1	S_2					Lower limit	Upper limit
37.5	0	0	0	0	0	100	100	100
25*	294.6	307	300.8	6.02	6.02	93.98	90	100
19	1186	1438.15	1312.075	26.24	32.26	67.74	40	85
12.5*	1710	1601	1655.5	33.11	65.37	34.63	0	40
9.5	1366	1189.35	1277.675	25.55	90.92	9.08	0	15
4.75	435	457.45	446.225	8.92	99.84	0.16	0	5
2.36	8.4	7.05	7.725	0.16	100	0	0	0
Following the same procuder			5000	0	723.02	0	0	0

Fineness Modulus (FM) = ∑Cum. % Retained /100= 723.02/100 =7.2302≈ 7.23

2.5 Sieve Analysis for 55% NCA +45% RCA

Sieve Size (mm)	Weight Retained (gm)		Average mass Retained (gm)	(%) of Retained	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative % Pass (ASTM C33)	
	S1	**S2**					Lower limit	Upper limit
37.5	0	0	0	0	0	100	100	100
25*	347.54	361	354.27	7.09	7.09	92.91	90	100
19	1286.87	1292	1289.435	25.79	32.88	67.12	40	85
12.5*	1549.86	1586.45	1568.155	31.36	64.24	35.76	0	40
9.5	1360.87	1300.55	1330.71	26.61	90.85	9.15	0	15
4.75	443.86	452	447.93	8.96	99.81	0.19	0	5
2.36	11	8	9.5	0.19	100	0	0	0
Following the same procuder			5000	0	723.54	0	0	0

Fineness Modulus (FM) = ∑Cum. % Retained /100= 723.54/100 =7.2354≈ 7.24

2.6 Sieve Analysis for 40% NCA +60% RCA

Sieve Size (mm)	Weight Retained (gm)		Average mass Retained (gm)	(%) of Retained	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative % Pass (ASTM C33)	
	S_1	S_2					Lower limit	Upper limit
37.5	0	0	0	0	0	100	100	100
25*	425.96	467	446.48	8.93	8.93	91.07	90	100
19	1102	1232.37	1167.185	23.34	32.27	67.73	40	85

12.5*	1662.52	1662.33	1662.425	33.25	65.52	34.48	0	40
9.5	1406	1201.05	1303.525	26.07	91.59	8.41	0	15
4.75	398.22	434.5	416.36	8.33	99.92	0.08	0	5
2.36	5.3	2.75	4.025	0.08	100	0	0	0
Following the same procuder			5000	0	723.78	0	0	0

Fineness Modulus (FM) = ∑Cum. % Retained /100= 723.78/100 =7.2378≈ 7.24

3. Unit Weight of coarse aggregate

A. For replacement level of 100% NCA + 0%RCA

Compacted method	Sample 1	Sample 2
Weight of cylinder in Kg(A)	7.683	7.683
Weight of cylinder + sample in Kg (B)	23.431	23.534
Net Weight of the sample in Kg (C) = B-A	15.748	15.8510
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1574.8	1585.10
Average in (Kg/ m^3)	**1579.95**	
Loose method	**Sample 1**	**Sample 2**
Weight of cylinder in Kg (A)	7.683	7.683
Weight of cylinder + sample in gram(B)	21.768	21.840
Net Weight of sample in gram(C) = B-A	14.085	14.157
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1408.5	1415.7
Average in (Kg/ m^3)	**1412.10**	

B. For replacement level of 85% NCA + 15%RCA

Compacted method	Sample 1	Sample 2
Weight of cylinder in Kg(A)	7.683	7.683
Weight of cylinder + sample in Kg (B)	23.4142	23.4222
Net Weight of the sample in Kg (C) = B-A	15.7312	15.7392
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1573.12	1573.92
Average in (Kg/ m^3)	**1573.52**	
Loose method	**Sample 1**	**Sample 2**
Weight of cylinder in Kg (A)	7.683	7.683
Weight of cylinder + sample in gram(B)	21.791	21.688
Net Weight of sample in gram(C) = B-A	14.108	14.005
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1410.81	1400.53
Average in (Kg/ m^3)	**1405.67**	

C. For replacement level of 70% NCA + 30%RCA

Compacted method	Sample 1	Sample 2
Weight of cylinder in Kg(A)	7.683	7.683
Weight of cylinder + sample in Kg (B)	23.3203	23.3877
Net Weight of the sample in Kg (C) = B-A	15.6373	15.7047
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1563.73	1570.47

Average in (Kg/ m^3)	**1567.10**	
Loose method	**Sample 1**	**Sample 2**
Weight of cylinder in Kg (A)	7.683	7.683
Weight of cylinder + sample in gram(B)	21.6203	21.7445
Net Weight of sample in gram(C) = B-A	13.9373	14.0615
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1393.73	1406.15
Average in (Kg/ m^3)	**1399.94**	

D. For replacement level of 55% NCA + 45%RCA

Compacted method	**Sample 1**	**Sample 2**
Weight of cylinder in Kg(A)	7.683	7.683
Weight of cylinder + sample in Kg (B)	23.2591	23.3203
Net Weight of the sample in Kg (C) = B-A	15.5761	15.6373
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1557.61	1563.73
Average in (Kg/ m^3)	**1560.67**	
Loose method	**Sample 1**	**Sample 2**
Weight of cylinder in Kg (A)	7.683	7.683
Weight of cylinder + sample in gram(B)	21.5203	21.4715
Net Weight of sample in gram(C) = B-A	13.8373	13.7885
Volume of Cylinder in m^3(D)	0.01	0.01

Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1383.73	1378.85
Average in (Kg/ m^3)	**1381.29**	

E. For replacement level of 40% NCA + 60%RCA

Compacted method	**Sample 1**	**Sample 2**
Weight of cylinder in Kg(A)	7.683	7.683
Weight of cylinder + sample in Kg (B)	23.2305	23.2203
Net Weight of the sample in Kg (C) = B-A	15.5475	15.5373
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1554.75	1553.73
Average in (Kg/ m^3)	**1554.24**	
Loose method	**Sample 1**	**Sample 2**
Weight of cylinder in Kg (A)	7.683	7.683
Weight of cylinder + sample in gram(B)	21.3603	21.2653
Net Weight of sample in gram(C) = B-A	13.6773	13.5823
Volume of Cylinder in m^3(D)	0.01	0.01
Unit weight of coarse aggregate in Kg/ m^3 (E) = C/D	1367.73	1358.23
Average in (Kg/ m^3)	**1362.98**	

4. **Specific Gravity, Absorption capacity and Moisture content of coarse aggregate**

Designation	**100% NCA + 0%RCA**	**85% NCA + 15%RCA**	**70% NCA + 30%RCA**	**55% NCA + 45%RCA**	**40% NCA + 60%RCA**
Sample in gm(A)	2000	2000	2000	2000	2000
Mass of Saturated Surface Dry Aggregate in air (MssD)	2000.5	2001	2002.25	2005	2007.5
Mass of Oven-Dry Aggregate (OD)	1976	1969.49	1962.83	1959.16	1954.53

Mass of saturated surface dry specimen in water plus basket (gm)	1735	1730	1728.5	1726	1722
Mass of basket in gm	446	446	446	446	446
Mass of Aggregate in water after deduction of the mass of basket (MW)	1289	1284	1282.5	1280	1276
Bulk Specific Gravity (Oven dry basis) = OD/(MssD-MW)	2.777	2.7468	2.7392	2.7023	2.6720
Bulk Specific Gravity (SSD basis) = MssD/(MssD-MW)	2.8117	2.7908	2.7837	2.7655	2.7444
Apparent Specific Gravity = OD/ (OD- MW)	2.8763	2.8731	2.8851	2.8847	2.8805
Absorption Capacity (%) = (MssD- OD)/(OD)*100	1.2399	1.6001	1.97	2.34	2.71
Average moisture content (%) = (A-OD)/OD* 100	0.980	1.231	1.490	1.742	1.993

5. Additional tests computed only for 100%NCA and 100%RCA

A. Impact value	**NCA**		**RCA**	
	S_1	**S_2**	**S_1**	**S_2**
Weight of Cylinder + surface-dry sample passing 12.5-mm and retained on 10.0 mm ASTM test sieve and compacted 2 layers 25 times in (gm) = M1	3816	3837	3717	3706
Weight of empty Cylinder in (gm)=M2	3031	3031	3031	3031
Net weight of sample passing 12.5mm and retained on 10mm ASTM sieve(gm) = A = M1-M2	785	806	686	675
Weight of the fraction passing the ASTM sieve 2.36mm after 15 times blowing of impact load = B	36.5	40	69	62.5
Aggregate Impact Value(AIV) in (%)= (B/A)*100	4.65	4.96	10.058	9.259
Average	**4.805**		**9.659**	
B. Crushing Value	**NCA**		**RCA**	
	S_1	**S_2**	**S_1**	**S_2**

Weight of Cylinder + base plate + sample in (gm)= M1	13840.5	13848	13516	13521.25
Weight of Cylinder + base plate in (gm)=M2	11147.5	11147.5	11147.5	11147.5
Net weight of sample passing 12.5mm and retained on 9.5mm ASTM sieve(gm) = A = M1-M2	2693	2700.5	2368.5	2373.75
Mass of the fraction passing the ASTM sieve 2.36mm after applying of 400KN load per 10 minute in (gm) = B	334	339	447.5	441.5
Aggregate crushing Value(ACV) in (%)= (B/A)*100	12.40	12.55	18.894	18.599
Average	**12.475**		**18.747**	
C. Loss Angeles Abrasion value	**NCA**		**RCA**	
	S_1	**S_2**	**S_1**	**S_2**
Mass of sample retained on both sieve size 12.5mm and 9.5mm (2 * 2500) (g) = A	5000	5000	5000	5000
Mass of sample passing 1.7mm ASTM Sieve after adding 11 standard balls for grade “B” and 500 revolutions (g) = B	553	527	845	851
L.A.A.V (%) = (B/A)*100	11.06	10.54	16.90	17.02
Average	**10.80**		**16.960**	

ANNEX 2: CONCRETE MIX DESIGNS

Mix design for porous concrete strength ranging between 2.8 to 28 MPa was done as per ACI 522R, 2010 following eight standard steps

Note: The same steps were used for all replacement percentage of RCA depending upon the obtained material properties as follow:

I. **For aggregate replacement level of 100%NCA and 0%RCA (control)**

Material physical property records used for mix design

Physical Properties	**Test records**	
Specific Gravity of Dangote PPC32.5R cement	2.9	
Specific Gravity of coarse aggregate	2.81	
Maximum size of aggregate	20 mm	
The dry rodded (Compacted) density of coarse aggregate	1579.95 kg/m3	
The water absorption capacity of coarse aggregate	1.23 %	
The moisture content of coarse aggregate	0.98%	
Assume the percentage of voids by volume	15 %	
Water cement ratio selected for exposure condition	0.39	
Aggregate impact value(AIV)	**NCA**	**RCA**
	4.805	9.659
Aggregate crushing value(ACV)	12.475	18.747
Loss Angeles Abrasion value(LAAV)	10.80	16.960
Coarse aggregate surface texture	Rough	
The particle shape of coarse aggregate	Angular	
Fine aggregate.	Nil (not used)	

Step 1: Choice of the maximum size of aggregate

The size of aggregate used in these studies was a range between 4.75mm-19mm) with a maximum size of 20 mm depending on ACI 522R-10.

Step 2: Determine coarse aggregate weight (Wa) For stone with no fine aggregate, ACI 522R-10 table 6.1 recommends b/bo of 0.99 for number 67 aggregate, with dry-rodded density given as 1579.95 kg/m^3

Table 6.1Effective b/bo values

Percent fine aggregates	b/b_o	
	ASTM C33/C33M Size No. 8	ASTM C33/C33M Size No. 67
0	0.99	0.99
10	0.93	0.93
20	0.85	0.86

- W_a = Dry rodded density x b/bo
  = 1579.95 kg/m^{3}X 0.99 m^3
  = 1564.15Kg

Where, b/b_o = dry-rodded volume of coarse aggregate in a unit volume of concrete

b = solid volume of coarse aggregate in a unit volume of concrete and

b_o = solid volume of coarse aggregate in a unit volume of coarse aggregate.

Step- 3: Adjust to SSD weight (Wssd) of coarse aggregate

Wssd = W_a x moisture content

= 1564.15Kg X 0.980%

= 1564.15Kg X 1.0098

= 1579.48 Kg

Step 4: Selection of water-cement ratio

The conventional w/cm-versus-compressive strength relationship for normal concrete does not apply to porous concrete. Careful control of aggregate moisture and w/cm is important to produce consistent pervious concrete. As per ACI 522R-10 guideline, the W/C ratio for porous concrete ranges between 0.26 and 0.45. But experiences in different journals show that a w/cm ratio of 0.38 is good for strength and workability.

Step 5: Determination of cement content in Kg

ACI 522R-10 Table 6.2 shows the typical ranges of material proportions per cubic meter in porous concrete. Hence the quantity of cement per cubic meter ranges between 270 to 415 kg/m^3. Talk 350kg/m^3

Step-6: Determination of water content(C) in Kg

Once the cement content and w/cm is selected, the water quantities can be determined from the following relationships.

W/cm = Weight of water/ Weight of Cement

Weight of water = W/cm * Weight of cement

Wt of water = 0.38 *350 = 133 kg

Step 6.1: Adjustments for mixing water needed due to aggregate absorption capacity

Mixing water needed from coarse aggregate = 1563.705 Kg (0.98%-1.23%)….0.98% moisture and 1.23% absorption respectively.

Water content =0.38*350=133

=1579.48 Kg (0.0098-0.0123) = -3.950 Kg

Water = 133kg + 3.95kg = 136.95kg

Step 7: Determine solid volume (Vs)

- Volume of gravel (Va)= Wssd/(Specific gravity of aggregate x density of water)
  = 1579.48 Kg /(2.81 x 1000Kg/m^3)

  = 0.56m^3

- Volume of Cement(Vc) = Cwt/(Specific gravity of cement x density of water)
  = 350 Kg/ (2.9 x 1000Kg/m^3)

  = 0.12m^3

- Volume of water(Vw) =Wwt/ density of water
  = 136.95 Kg/1000Kg/m^3

  = 0.14m^3

Total solid volume (V_T) = Vc.a + Vc + Vw+ Vair

= (0.56 + 0.12 + 0.14) m^3 = 0.82 m^3

Step 8: Determination of percentage of voids (Pv)

Percent voids = $[V_T - V_S)/V_T]*100 = [1m^3 - 0.82\ m^3)/1m^3]*100 = 18\ \%$

Step-9: Iterative trial batching per cubic meter

The following are the trial batch weight per cubic meter of concrete:

Ingredient's	Quantity(kg/m^3)	Total weight(Kg/m^3)
Cement	350	2066.43
Gravel	1579.48	
Water	136.95	
Mix Ratio	1: 4.51: 0.39	

Trial batch for 12 cubes and 12 cylinders

- Volume for fifteen cubes of 150mm x 150mm x150mm = 12*(0.15m x 0.15m x 0.15m) = $0.0405m^3$
- Twelfth cylinders of diameter 100mm and 200mm length = $12(\pi d^2h)/4$ = $12(3.14 \times (0.1m)^2 \times 0.2m/4 = 0.01884m^3$

Total volume of 12 cubes + 12 cylinders = $(0.0405+.01884)\ m^3 = 0.05934\ m^3$

Dry quantity of 12 cubes + 12 cylinders = $1.55*0.05934\ m^3 = 0.091977\ m^3$

Sum of ratio = 1+ 4.51 = 5.51

Volume of cement= $1/5.51 * 0.091977\ m^3 = 0.01669274m^3$

1 bag of cement = 50kg

50kg = $0.0347\ m^3$

X = $0.0183954\ m^3$

X= $50kg * 0.0183954\ m^3/ 0.0347\ m^3$

Mass of cement = 24.05kg

Mass of Gravel = 4.51*24.05kg = 108.55 kg

Mass of water = 0.39*24.05kg = 9.41 kg

Ingredients	Quantity (kg)	5% wastage	Total quantity(kg)
Cement	24.05	1.05*24.05	25.26
Gravel	108.55	1.05*108.55	113.97
Water	9.41	1.05*9.41	9.88

II. For aggregate replacement level of 85%NCA and 15%RCA

Material physical property records used for mix design

Physical Properties	Test records	
Specific Gravity of Dangote PPC32.5R cement	2.9	
Specific Gravity of coarse aggregate	2.79	
Maximum size of aggregate	20 mm	
The dry rodded (Compacted) density of coarse aggregate	1573.52 kg/m3	
The water absorption capacity of coarse aggregate	1.60 %	
The moisture content of coarse aggregate	1.23%	
Assume the percentage of voids by volume	15 %	
Water cement ratio selected for exposure condition	0.40	
Aggregate impact value(AIV)	**NCA**	**RCA**
	4.805	9.659
Aggregate crushing value(ACV)	12.475	18.747
Loss Angeles Abrasion value(LAAV)	10.80	16.960
Coarse aggregate surface texture	Rough	
The particle shape of coarse aggregate	Angular	
Fine aggregate.	Nil (not used)	

Obtained result for 12 cubes and 12 cylinders

Ingredients	Quantity (kg)	5% wastage	Total quantity(kg)
Cement	24.05	1.05*24.05	25.26
Gravel	108.36	1.05*108.48	113.78
Water	9.54	1.05*9.54	10.01

III. For aggregate replacement level of 70%NCA and 30%RCA

Material physical property records used for mix design

Physical Properties	Test records	
Specific Gravity of Dangote PPC32.5R cement	2.9	
Specific Gravity of coarse aggregate	2.78	
Maximum size of aggregate	20 mm	
Dry rodded (Compacted) density of coarse aggregate(kg/m3)	1567.10	
The water absorption capacity of coarse aggregate	1.97%	
The moisture content of coarse aggregate	1.49%	
Assume the percentage of voids by volume	15 %	
Water cement ratio selected for exposure condition	0.40	
	NCA	**RCA**
Aggregate impact value(AIV)	4.805	9.659
Aggregate crushing value(ACV)	12.475	18.747
Loss Angeles Abrasion value(LAAV)	10.80	16.960
Coarse aggregate surface texture	Rough	
The particle shape of coarse aggregate	Angular	
Fine aggregate.	Nil (not used)	

Obtained result for 12 cubes and 12 cylinders

Ingredients	Quantity (kg)	5% wastage	Total quantity(kg)
Cement	24.10	1.05*24.10	25.30
Gravel	108.45	1.05*108.45	113.86
Water	9.64	1.05*9.64	10.12

IV. **For aggregate replacement level of 55%NCA and 45%RCA**

Material physical property records used for mix design

Physical Properties	Test records
Specific Gravity of Dangote PPC32.5R cement	2.9
Specific Gravity of coarse aggregate	2.76
Maximum size of aggregate	20 mm

Dry rodded (Compacted) density of coarse aggregate(kg/m3)	1560.67	
The water absorption capacity of coarse aggregate	2.34%	
The moisture content of coarse aggregate	1.74%	
Assume the percentage of voids by volume	15 %	
Water cement ratio selected for exposure condition	0.40	
	NCA	**RCA**
Aggregate impact value(AIV)	4.805	9.659
Aggregate crushing value(ACV)	12.475	18.747
Loss Angeles Abrasion value(LAAV)	10.80	16.960
Coarse aggregate surface texture	Rough	
The particle shape of coarse aggregate	Angular	
Fine aggregate.	Nil (not used)	

Obtained result for 12 cubes and 12 cylinders

Ingredients	Quantity (kg)	5% wastage	Total quantity(kg)
Cement	24.14	1.05*24.14	25.35
Gravel	108.39	1.05*108.39	113.81
Water	9.82	1.05*9.82	10.31

V. **For aggregate replacement level of 40%NCA and 60%**

Material physical property records used for mix design

Physical Properties	Test records
Specific Gravity of Dangote PPC32.5R cement	2.9
Specific Gravity of coarse aggregate	2.74
Maximum size of aggregate	20 mm
Dry rodded (Compacted) density of coarse aggregate(kg/m3)	1554.24
The water absorption capacity of coarse aggregate	2.71%

The moisture content of coarse aggregate	1.99%	
Assume the percentage of voids by volume	15 %	
Water cement ratio selected for exposure condition	0.41	
	NCA	**RCA**
Aggregate impact value(AIV)	4.805	9.659
Aggregate crushing value(ACV)	12.475	18.747
Loss Angeles Abrasion value(LAAV)	10.80	16.960
Coarse aggregate surface texture	Rough	
The particle shape of coarse aggregate	Angular	
Fine aggregate.	Nil (not used)	

Obtained result for 12 cubes and 12 cylinders

Ingredients	Quantity (kg)	5% wastage	Total quantity(kg)
Cement	24.18	1.05*24.18	25.39
Gravel	108.35	1.05*108.35	113.76
Water	9.92	1.05*9.92	10.41

ANNEX 3: TEST RESULTS FOR FRESH POROUS CONCRETE

I. WORKABILITY TEST

A. Slump test results

Mix Designation		W/C	Measured slump value(mm)	Type of slump	Degree of workability
NCA	**RCA**				
100%	0%	0.39	14	Approximate to zero	Poor
85%	15%	0.39	0	Zero	Poor
70%	30%	0.40	0	Zero	Poor
55%	45%	0.40	0	Zero	Poor
40%	60%	0.41	0	Zero	Poor

Observed test results for compacting factor test

B. Compacting factor test(CFT

Designation	100% NCA + 0%RCA	85% NCA + 15%RCA	70% NCA + 30%RCA	55% NCA + 45%RCA	40% NCA + 60%RCA
Weight of empty cylinder in (kg) = A	3.247	3.247	3.247	3.247	3.247
Weight of partially compacted concrete + weight of cylinder in (kg) = B	11.3425	11.4085	11.298	11.1875	11.4085
Net weight of partially compacted concrete in (kg) C = B-A	9.204	8.593	8.05	7.94	8.09
Weight of fully compacted concrete + weight of cylinder in (kg) = D	13.217	13.316	13.078	13.1445	13.316
Net weight of fully compacted concrete in (kg) E = D-A	9.97	10.07	9.83	9.90	10.25
$CFT = \frac{C}{E}$	**0.924**	**0.853**	**0.82**	**0.80**	**0.79**

Linear regression summary for the reliability of compacting factor test value and workability of concrete using Microsoft Excel 2013.

Regression Statistics	
Multiple R	**0.938805202**
R Square	**0.881355207**
Adjusted R Square	0.841806943
Standard Error	0.094331116
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.198304922	0.198304922	22.2855598	0.018004393
Residual	3	0.026695078	0.008898359		
Total	4	0.225			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.748817059	0.731781194	5.122866082	0.01439953	1.419962701	6.077671417	1.419962701	6.077671417
X Variable 1	-4.118482277	0.872419627	-4.720758393	0.018004393	-6.894910897	-1.342053658	-6.894910897	-1.342053658

C. The fresh density of porous concrete					
Designation	**100% NCA + 0%RCA**	**85% NCA + 15%RCA**	**70% NCA + 30%RCA**	**55% NCA + 45%RCA**	**40% NCA + 60%RCA**
Weight of empty cylinder in (kg) = **A**	4.612	4.612	4.612	4.612	4.612
The volume of a cylinder(m^3) $V = \pi d^2 h/4$ = 3.14*(0.2)2*0.23/4 = **B**	0.007222	0.007222	0.007222	0.007222	0.007222
Weight of fresh concrete plus cylinder(kg) = **C**	19.3805	19.294	19.234	19.1915	18.675
Net weight of fresh concrete in (kg) = **D = C-A**	14.77	14.68	14.662	14.58	14.06
$Fresh\ density = \frac{D}{B}$	**2045.14**	**2032.68**	**2029.91**	**2018.76**	**1946.83**

ANNEX 4: TEST RESULTS FOR HARDENED POROUS CONCRETE

A. Compressive Strength

Summary of compressive strength test results for 100% NCA and 0% RCA

No	Test Age (days)	Dimensions (m)			Volume (m^3)	Weight (kg)	Failure Load (kN)	Comp. Strength (MPa)	Unit weight of concrete(kg/m^3)
		L	W	H	L*W*H				
S_1	7^{th}	0.15	0.15	0.15	0.003375	7.31	328.88	14.62	2165.93
S_2		0.15	0.15	0.15	0.003375	7.45	371.17	16.5	2207.41
S_3		0.15	0.15	0.15	0.003375	7.13	294.30	13.08	2112.59
Mean							331.45	14.73	
S_1	14^{th}	0.15	0.15	0.15	0.003375	7.50	449.66	19.99	2222.22
S_2		0.15	0.15	0.15	0.003375	7.10	317.89	14.14	2103.11
S_3		0.15	0.15	0.15	0.003375	7.57	407.26	18.11	2242.96
Mean							391.60	17.41	
S_1	28^{th}	0.15	0.15	0.15	0.003375	7.63	547.90	24.35	2260.74
S_2		0.15	0.15	0.15	0.003375	7.82	612.75	27.24	2317.04
S_3		0.15	0.15	0.15	0.003375	7.38	569.00	25.30	2186.67
Mean							576.55	25.63	

Summary of compressive strength test results for 85% NCA and 15% RCA

No	Test Age (days)	Dimensions (m)			Volume (m^3)	Weight (kg)	Failure Load (kN)	Comp. Strength (MPa)	Unit weight of concrete(kg/m^3)
		L	W	H	L*W*H				
S_1	7^{th}	0.15	0.15	0.15	0.003375	7.66	362.47	16.11	2270.81
S_2		0.15	0.15	0.15	0.003375	7.52	303.88	13.51	2228.15

S_3		0.15	0.15	0.15	0.003375	7.41	489.00	11.77	2195.56
Mean							385.12	13.80	
S_1	14th	0.15	0.15	0.15	0.003375	7.47	393.35	17.49	2213.33
S_2		0.15	0.15	0.15	0.003375	7.23	342.97	15.25	2142.22
S_3		0.15	0.15	0.15	0.003375	7.33	428.42	19.05	2171.85
Mean							388.25	17.26	
S_1	28th	0.15	0.15	0.15	0.003375	7.93	469.48	20.88	2349.63
S_2		0.15	0.15	0.15	0.003375	7.59	489.00	21.74	2248.89
S_3		0.15	0.15	0.15	0.003375	7.51	487.11	21.65	2225.19
Mean							481.86	21.42	

Summary of compressive strength test results for 70% NCA and 30% RCA

No	Test Age (days)	Dimensions (m)			Volume (m^3)	Weight (kg)	Failure Load (kN)	Comp. Strength (MPa)	Unit weight of concrete(kg/m^3)
		L	W	H	L*W*H				
S_1	7th	0.15	0.15	0.15	0.003375	7.33	261.41	11.62	2171.85
S_2		0.15	0.15	0.15	0.003375	7.38	244.27	10.87	2186.67
S_3		0.15	0.15	0.15	0.003375	7.54	217.73	9.68	2234.07
Mean							241.14	10.72	
S_1	14th	0.15	0.15	0.15	0.003375	7.22	272.06	12.10	2139.26
S_2		0.15	0.15	0.15	0.003375	7.24	274.41	12.20	2145.19
S_3		0.15	0.15	0.15	0.003375	7.14	315.82	14.04	2115.56

Mean							287.43	12.78	
S_1	28^{th}	0.15	0.15	0.15	0.003375	7.20	366.48	16.29	2133.33
S_2		0.15	0.15	0.15	0.003375	7.23	385.95	17.15	2142.22
S_3		0.15	0.15	0.15	0.003375	7.31	419.83	18.66	2165.93
Mean							450.75	17.37	

Summary of compressive strength test results for 55% NCA and 45% RCA

No	Test Age (days)	Cube Dimensions (m)			Volume (m^3)	Weight (kg)	Failure Load (kN)	Comp. Strength (MPa)	Unit weight of concrete(kg/m^3)
		L	W	H	L*W*H				
S_1	7^{th}	0.15	0.15	0.15	0.003375	7.45	183.78	8.17	2207.41
S_2		0.15	0.15	0.15	0.003375	7.62	157.45	7.00	2257.78
S_3		0.15	0.15	0.15	0.003375	7.30	188.89	8.40	2162.96
Mean							176.71	7.86	
S_1	14^{th}	0.15	0.15	0.15	0.003375	7.13	252.90	11.24	2112.59
S_2		0.15	0.15	0.15	0.003375	7.01	263.75	11.73	2077.93
S_3		0.15	0.15	0.15	0.003375	7.31	284.15	12.63	2165.93
Mean							266.93	12.68	
S_1	28^{th}	0.15	0.15	0.15	0.003375	7.42	353.76	15.72	2198.52
S_2		0.15	0.15	0.15	0.003375	7.58	337.28	14.99	2245.93
S_3		0.15	0.15	0.15	0.003375	7.44	318.50	14.16	2205.63
Mean							336.51	14.96	

Summary of compressive strength test results for 40% NCA and 60% RCA

No	Test Age (days)	Dimensions (m)			Volume (m^3)	Weight (kg)	Failure Load (kN)	Comp. Strength (MPa)	Unit weight of concrete (kg/m^3)
		L	W	H	L*W*H				
S_1	7^{th}	0.15	0.15	0.15	0.003375	6.95	146.38	6.54	2059.26
S_2		0.15	0.15	0.15	0.003375	7.10	169.15	7.52	2103.70
S_3		0.15	0.15	0.15	0.003375	7.09	157.14	6.99	2100.74
Mean							157.56	7.02	
S_1	14^{th}	0.15	0.15	0.15	0.003375	7.24	242.44	10.79	2145.19
S_2		0.15	0.15	0.15	0.003375	6.94	219.46	9.76	1896.30
S_3		0.15	0.15	0.15	0.003375	7.23	248.48	11.05	2142.22
Mean							236.79	10.53	
S_1	28^{th}	0.15	0.15	0.15	0.003375	7.04	261.68	11.64	2085.93
S_2		0.15	0.15	0.15	0.003375	7.42	268.12	11.93	2198.52
S_3		0.15	0.15	0.15	0.003375	7.11	253.10	11.25	2106.67
Mean							260.97	11.61	

B. Split tensile strength results

Summary of split tensile strength results for 100% NCA and 0% RCA

No	Test Age (days)	Dimensions (m)		Volume (m^3)	Weight (kg)	Failure Load (kN)	Split Tensile Strength (MPa)
		D	H	$\Pi D^2 H/4$			
S_1	7^{th}	0.1	0.2	0.00157	3.27	68.42	2.14
S_2		0.1	0.2	0.00157	3.22	63.02	2.01
S_3		0.1	0.2	0.00157	3.29	61.65	1.97

Mean						64.36	2.04
S_1	14th	0.1	0.2	0.00157	3.24	63.33	2.02
S_2		0.1	0.2	0.00157	3.36	71.41	2.27
S_3		0.1	0.2	0.00157	3.25	73.85	2.35
Mean						69.53	2.21
S_1	28th	0.1	0.2	0.00157	3.45	85.96	2.75
S_2		0.1	0.2	0.00157	3.34	101.80	3.25
S_3		0.1	0.2	0.00157	3.24	90.95	2.90
Mean						92.90	2.97

Summary of split tensile strength results for 85% NCA and 15% RCA

No	Test Age (days)	Dimensions (m)		Volume (m^3)	Weight (kg)	Failure Load (kN)	Split Tensile Strength (MPa)
		D	H	$\Pi D^2 H/4$			
S_1	7th	0.1	0.2	0.00157	3.42	80.20	2.56
S_2		0.1	0.2	0.00157	3.19	55.38	1.77
S_3		0.1	0.2	0.00157	3.32	60.15	1.92
Mean						65.24	2.08
S_1	14th	0.1	0.2	0.00157	3.37	83.36	2.66
S_2		0.1	0.2	0.00157	3.36	70.58	2.25
S_3		0.1	0.2	0.00157	3.46	77.53	2.47
Mean						77.16	2.46
S_1	28th	0.1	0.2	0.00157	3.34	85.11	2.72

S_2		0.1	0.2	0.00157	3.24	90.95	2.90
S_3		0.1	0.2	0.00157	3.30	86.61	2.76
Mean						87.56	2.79

Summary of split tensile strength results for 70% NCA and 30% RCA

No	Test Age (days)	Dimensions (m)		Volume (m^3)	Weight (kg)	Failure Load (kN)	Split Tensile Strength (MPa)
		D	H	$\Pi D^2 H/4$			
S_1	7^{th}	0.1	0.2	0.00157	3.37	62.20	1.98
S_2		0.1	0.2	0.00157	3.38	69.71	2.22
S_3		0.1	0.2	0.00157	3.43	66.95	2.14
Mean						66.29	2.11
S_1	14^{th}	0.1	0.2	0.00157	3.43	62.21	1.99
S_2		0.1	0.2	0.00157	3.47	69.58	2.22
S_3		0.1	0.2	0.00157	3.36	72.65	2.45
Mean						68.15	2.22
S_1	28^{th}	0.1	0.2	0.00157	3.45	90.42	2.88
S_2		0.1	0.2	0.00157	3.43	74.64	2.38
S_3		0.1	0.2	0.00157	3.40	82.01	2.61
Mean						82.36	2.62

Summary of split tensile strength results for 55% NCA and 45% RCA

No	Test Age (days)	Dimensions (m)		Volume (m^3)	Weight (kg)	Failure Load (kN)	Split Tensile Strength (MPa)
		D	H	$\Pi D^2H/4$			
S_1	7^{th}	0.1	0.2	0.00157	3.43	59.08	1.88
S_2		0.1	0.2	0.00157	3.19	68.34	2.18
S_3		0.1	0.2	0.00157	3.29	35.59	1.14
Mean						54.34	1.73
S_1	14^{th}	0.1	0.2	0.00157	3.38	64.10	2.04
S_2		0.1	0.2	0.00157	3.33	72.72	2.32
S_3		0.1	0.2	0.00157	3.46	68.41	2.18
Mean						68.41	2.18
S_1	28^{th}	0.1	0.2	0.00157	3.46	80.40	2.57
S_2		0.1	0.2	0.00157	3.33	73.20	2.33
S_3		0.1	0.2	0.00157	3.40	65.66	2.09
Mean						73.09	2.33

Summary of split tensile strength results for 40% NCA and 60% RCA

No	Test Age (days)	Dimensions (m)		Volume (m^3)	Weight (kg)	Failure Load (kN)	Split Tensile Strength (MPa)
		D	H	$\Pi D^2H/4$			
S_1	7^{th}	0.1	0.2	0.00157	3.39	73.19	2.33
S_2		0.1	0.2	0.00157	3.33	72.02	2.29

S_3		0.1	0.2	0.00157	3.29	70.87	2.26
Mean						72.03	2.29
S_1	14th	0.1	0.2	0.00157	3.35	64.46	2.06
S_2		0.1	0.2	0.00157	3.20	52.40	1.18
S_3		0.1	0.2	0.00157	3.41	74.02	2.36
Mean						63.63	2.03
S_1	28th	0.1	0.2	0.00157	3.23	64.65	2.07
S_2		0.1	0.2	0.00157	3.31	71.33	2.31
S_3		0.1	0.2	0.00157	3.39	75.57	2.42
Mean						70.52	2.27

C. Porosity

The test is performed by dividing the difference between the oven-dry weight of the sample (Md) and the weight of the submerged sample in the water tank for a minimum of 30 minutes (Mw) by the water density(δw) as porosity(P) using the following formula.

$$P = \frac{(1 - Md - Mw)}{\delta w * V} * 100\%$$

Where, P = Porosity

Md = Mass of oven-dried sample

Mw = Mass of the submerged sample in the water tank for a minimum of 30 min.

δw = Density of water

V = Total volume of sample.

Then, the porosity of sample after seven curing day were calculated as:

V = 150mm X 150mm X 150mm = 0.003375m^3

Observed test results(Average of two samples)

Designation		Density (kg/m^3)	Volume (m^3)	Testing age					
				7th		**14th**		**28th**	
NCA	RCA			Weight	Porosity	Weight	Porosity	Weight	Porosity
100%	0%	1000	0.00375	Md = 7.132 Mw = 7.367	36.59	Md = 7.421 Mw = 7.656	36.56	Md = 7.423 Mw = 7.659	36.62
85%	15%	1000	0.003375	Md = 7.08 Mw = 7.42	39.70	Md = 7.06 Mw = 7.40	39.70	Md = 7.08 Mw = 7.43	40.00
70%	30%	1000	0.003375	Md = 6.97 Mw = 7.41	42.67	Md = 6.88 Mw = 7.31	42.37	Md = 6.56 Mw = 6.98	42.07
55%	45%	1000	0.003375	Md = 6.87 Mw = 7.322	43.02	Md = 6.841 Mw = 7.301	43.26	Md = 6.867 Mw = 7.320	43.05
40%	60%	1000	0.003375	Md = 6.758 Mw = 7.226	43.50	Md = 6.741 Mw = 7.220	43.76	Md = 6.712 Mw = 7.188	43.73

D. Permeability rate of porous concrete

The test was done by the constant Head method using Darcy's formula as follow:

K= QL/AHt

Where K = Coefficient of permeability (cm/sec)

Q = volume of water collected in total (cm^3)

L = Length of test specimen (cm)

A = Cross-sectional area of the cylinder (cm^2)

H = constant water head (cm)

T = taken time (sec)

Summary for the coefficient of permeability of porous concrete after 28th day

For 100% NCA and 0% RCA						
S.no	**Quantity of water passed (cm3)**	**Length of the sample(cm)**	**Area of the sample (cm2)**	**Constant water head(cm)**	**Time is taken (sec)**	**Coefficient of permeability(K) in (cm/sec)**
S_1	1395	20	78.50	4.5	40	1.97
S_2	1431	20	78.50	4.5	47	1.72
S_3	1427	20	78.50	4.5	44.4	1.82
Average						**1.84**
For 85% NCA and 15% RCA						
S_1	1418	20	78.50	4.5	39.6	39.6
S_2	1395	20	78.50	4.5	35.6	35.6
S_3	1400	20	78.50	4.5	32.88	32.88
Average						**2.22**
For 70% NCA and 30% RCA						
S_1	1406	20	78.50	4.5	32.5	32.5
S_2	1411	20	78.50	4.5	35.9	35.9
S_3	1419	20	78.50	4.5	34	34
Average						**2.35**
For 55% NCA and 45% RCA						

S_1	1431	20	78.50	4.5	29	29
S_2	1441	20	78.50	4.5	32.6	32.6
S_3	1435	20	78.50	4.5	31.7	31.7
Average						**2.62**
For 40% NCA and 60% RCA						
S_1	1421	20	78.50	4.5	26.8	3.00
S_2	1433	20	78.50	4.5	28.15	2.88
S_3	1435	20	78.50	4.5	30.22	2.69
Average						**2.86**

Linear regression summary for the reliability of permeability rate test value of the concrete using Microsoft Excel 2013

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.991116828
R Square	0.982312566
Adjusted R Squar	0.976416755
Standard Error	0.059777365
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.59536	0.59536	166.612	0.001003706
Residual	3	0.01072	0.00357		
Total	4	0.60608			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.89	0.046303348	40.8178	3.2E-05	1.742642082	2.0373579	1.742642082	2.037357918
X Variable 1	1.626666667	0.12602175	12.9078	0.001	1.225609214	2.0277241	1.225609214	2.027724119

ANNEX 5: PHOTO GALLERY

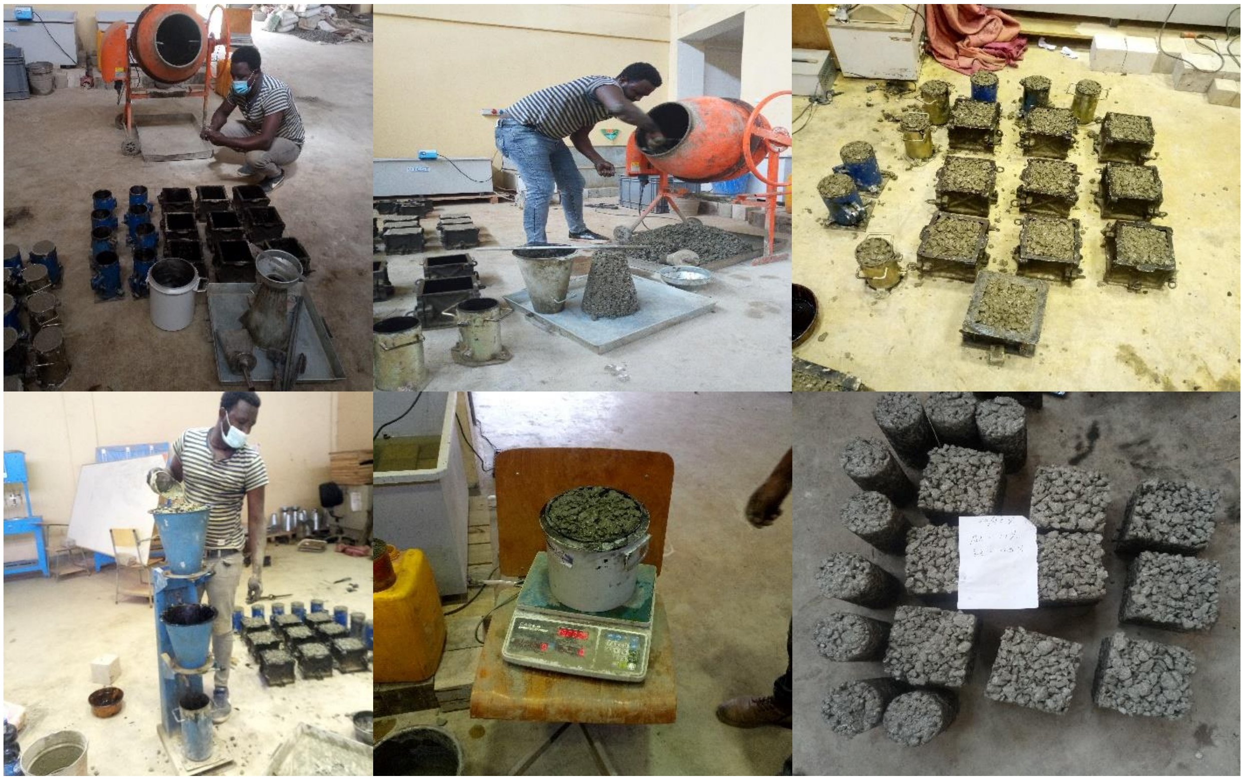
During site survey for construction and demolished wastes

During aggregate recycling processes

During physical property test for cement

During physical property test for coarse aggregate

During concrete preparation and fresh concrete tests



During hardened concrete tests

During waste management practice