JIMMA UNIVERSITY

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JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CONSTRUCTION ENGINEERING AND MANAGEMENT STREAM

INVESTIGATION ON THE EFFECTS OF RECYCLED COARSE AGGREGATES FROM CONCRETE WASTE ON COMPRESSIVE STRENGTH OF C-25 CONCRETE

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Engineering and Management)

By

Yohannes Ayelegne

October 2017

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Approved by Examining Board:

Advisor: ________________ ________________

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Signature Date

Chairperson: ________________ ________________

Signature Date

DECLARATION

I, the undersigned declare that this thesis entitled "Investigation On The Effects Of Recycled Coarse Aggregates From Concrete Waste On Compressive Strength Of C-25 Concrete" is my original work and has not been presented by any other person for any award of a degree in this or any other University, also that all sources of materials used for this research proposal have been duly acknowledged.

Candidate: Yohannes Ayelegne ______________ ______________

Signature Date

As Masters Research Advisors, we hereby certify that we have read and evaluate this MSc research prepared under our guidance, by Yohannes Ayelegne, entitled: "Investigation On The Effects Of Recycled Coarse Aggregates From Concrete Waste On Compressive Strength Of C-25 Concrete" and we recommended that it can be submitted as fulfilling the Requirements for the Degree of Master of Science in Civil Engineering (Construction Engineering and Management).

Advisor: Prof. Emer T. Quezon ______________ ______________

Signature Date

Co-Advisor: Engr. Abebe Eshetu ______________ ______________

Signature Date

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ABSTRACT

The recycled construction materials derived from the wastage materials during construction and wastage due to demolition, rehabilitation, natural and technological disasters are becoming of great interest in most project implementation. The driving force for recycling concrete is three-fold: preserving natural resources, utilizing the growing waste, and saving energy and money. The utilization of recycled aggregate is also an effective solution to the problem of possessing excess waste materials while simultaneously maintaining satisfactory concrete quality; indeed, it may also be a breakthrough towards sustainable development.

It is known that the strength of concrete depends on the quality of ingredients used. Among those elements, the major portion is taken by coarse aggregate. This study utilizes demolished concrete (waste laboratory test cubes for this purpose) by crushing as coarse aggregate often termed as the recycled coarse aggregate (RCA) for investigating the effects on compressive strength and producing industry quality concrete. Large-scale recycling can substantially reduce the consumption of natural aggregate.

*This research investigated the fresh and mechanical properties of 25 MPa recycled aggregate concrete (RAC) made with different RCA replacement levels (i.e., 100%NA+0%RA; 0%NA+100%RA; 50%NA+50%RA; 75%NA+25%RA; 25%NA+75%RA). Concrete mix design (ACI mix design method) having five mix proportions for both natural and recycled aggregate were prepared using a water-cement ratio and cement contents of 0.62, 288.71kg/m^3 respectively. Total of forty-five concrete cubes (150mm*150mm*150mm) was produced and tested at the age of 7, 14 and 28 days. Also, physical properties of all the materials before and after replacement have been assessed.*

This study reveals that, concrete produced with 75%NA+25%RA replacement level had the highest average compressive strength with 28.1MPa. However, the performance of RAC is decreasing with increasing RCA replacement levels, but their overall performance is comparable to natural aggregate concrete (NAC). It can therefore, be concluded from the findings of this research that use of recycled coarse aggregate in the construction industry helps to prevent unnecessary damages to the environment and provide optimum exploitation of the resources and also offers important economic advantages.

Keywords: Recycled aggregate; Recycled aggregate concrete; Compressive strength

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
C&D	Construction and Demolition
EBCS	Ethiopian Building Code Standard
ES	Ethiopian Standard
FM	Fineness Modulus
Kg	Kilogram
KN	Kilo Newton
MPa	Mega Pascal
NA	Natural Aggregate
NAC	Natural Aggregate Concrete
NCA	Natural Coarse Aggregate
OPC	Ordinary Portland Cement
RA	Recycled Aggregate
RAC	Recycled Aggregate Concrete
RCA	Recycled Coarse Aggregate
SSD	Saturated Surface Dry
W/C	Water to cement ratio

CHAPTER ONE

INTRODUCTION

1.1. Background

Environmental control is an increasingly pressing concern in the construction industry. Natural resources are consumed in its day-to-day operations, and waste is generated. Construction activities thereby impose significant environmental impacts over the entire construction life cycle [1, 2]. Demolition of old and deteriorated buildings and traffic infrastructure and their substitution with new ones is a frequent phenomenon today to a significant part of the world. The main reasons for this situation are changes of purpose, structural deterioration, rearrangement of a city, expansion of traffic directions and increasing traffic load, natural disasters (earthquake, fire, and flood) [3].

Concrete is an essential, mass-produced material in the construction industry, as are steel and soil. However, much effort has been made to recycle and conserve precious natural resources, and repeated recycling can be suitable for concrete, as in the case of steel and aluminum [4]. An efficient method would be the use of recycled aggregate (RA) in the production of recycled aggregate concrete (RAC). RA is a particle of stones attached with old cement mortar generated by crushing demolished concrete waste. RAC is created by mixing RA along with other natural ingredients, including cement, water, fine aggregate and other materials. As concrete is composed only of cementitious materials, and the powders generated during the production of RA can be reprocessed as cement resources, repeated recycling is possible. This also enables concrete to be recycled in a fully closed system, thus improving the environment by reducing landfill and concrete waste. Concrete recycling can be accomplished by reusing concrete products, processing into secondary raw materials for applications such as fill, road base, and sub-base course, or aggregate to produce new concrete [5, 6].

Urbanization growth rate in Ethiopia is very high due to industrialization. The growth rate of Ethiopia is reaching 9.6% of GDP. Rapid infrastructure development requires a lot of construction materials and land requirements. For large construction, concrete is preferred as having a longer life, low maintenance cost & better performance. Addis Ababa is one of the examples of Ethiopian cities that have faced with a significant rise in the quantity of construction and demolition waste, smaller structures are demolished & new towers are constructed. Since there are no laws which enforce in compelling clients to record and publish the amount of waste they produce, there are no clear statistical data about the amount of construction waste produced and also their management but it is an evident fact that all the demolished materials provided are dumped on land & not used for any purpose. Nowadays protection of the environment is a basic factor; parameters like environmental consciousness, protection of natural resources and sustainable development play an important role in modern requirements of construction works.

The search for alternative resources instead of existing natural resources, the continuing shortage of landfill sites due to rapid urbanization, the sharp increase in transportation and disposal costs and severe environmental pollution and regulation control have raised a new challenge to planners and engineers to recycle construction and demolition waste (C&D) material [7].

A possible solution to these problems is to recycle demolished concrete and produce an alternative aggregate for structural concrete in this way. Recycled aggregate concrete (RAC) is produced by the two-stage crushing of demolished concrete, and screening and removal of contaminants such as reinforcement, paper, wood, plastics, and gypsum. Concrete made with such recycled concrete aggregate is called recycled aggregate concrete (RAC). The primary purpose of this work is to determine the basic properties of RAC depending on the coarse recycled aggregate content and to compare them to the properties of concrete made with natural aggregate (NAC) as a control concrete. The fine recycled aggregate was not considered for RAC production because its application in structural concrete is not recommended [8, 9].

1.2. Statements of the Problem

Construction and demolition materials can be recovered through recycling. The choice of what and how construction and demolition materials can be recovered depends on many factors including the type of project, working area, and space on the site, cost-effectiveness of recovery, project timeline and experience of contractor [10].

Many building materials from demolition projects can be recycled as part of the materials to construct buildings for a new project, which will then involve both the construction and demolition activities to ensure that certain building materials from demolition activities may be recyclable.

In Ethiopia, concrete has diversified its production. This condition is affecting the aggregate consumption indirectly. Also, demand for current concrete economic conditions is good with an increase in aggregate demand. In these situations, it is not appropriate to rely on one source of aggregate with continuing increase in demand. Thus, several alternatives should be established to reduce the use of limited natural coarse aggregate and also to provide a cost effective solution in terms of present and future concerns.

1.3. Objective of the Study

1.3.1. General Objective

The general research objective was to investigate the effects of recycled coarse aggregate from demolished concrete wastes as recycled aggregate concrete on compressive strength of C-25 concrete.

1.3.2. Specific Objectives

- To assess the fresh and hardened properties of recycled aggregate concrete using different recycled aggregate replacements from those of natural aggregate concrete.
- To analyze the effect of recycled coarse aggregate properties on workability and compressive strength of C-25 concrete.
- To identify optimum mix of concrete by using recycled coarse aggregate.

1.4. Research Questions

The research questions that this study will explain are as follows:

1) How is the assessment between the fresh and hardened properties of RAC made with different recycled coarse aggregate (RCA) replacement levels with those of natural aggregate concrete (NAC)?
2) What is the effect of recycled coarse aggregate properties on workability and compressive strength of C-25 concrete?
3) Which one of the mixes is optimum to use recycled coarse aggregate in concrete?

1.5. Justification of the Study

One of the greatest challenges of our present society is the protection of the environment. Some of the essential elements in this respect are the reduction of the consumption of energy and natural raw materials and use of waste materials. These topics are getting considerable attention under sustainable development nowadays. The use of recycled aggregates from construction and demolition wastes is showing a prospective application in construction as alternative to primary (natural) aggregates.

1.6. Significance of the Study

This study was examining the effectiveness of the use of recycled aggregate produced from concrete waste by conducting strength test. It is hoped that this study will be the beginning of efforts to use recycled aggregate in construction material in the future. Also, the outcome of this study was providing:

1) Providing valuable information on the mechanical properties of RAC to the local ready mix industry.

2) Providing local concrete industry and practitioners' necessary information regarding the application of RAC as a replacement of natural coarse aggregate for producing RAC.

3) Boosting up the confidence level and allow various applications of RAC in the environment.

4) Providing other researchers the findings as a reference for further research on the compressive strength of concrete.

Most importantly, it will reduce the use of limited natural aggregate, and it can provide a cost-effective solution regarding present and future concerns [11].

1.7. Scope and Limitation

The study was focused on the effects of the use of recycled aggregate produced from concrete wastes. Moreover, the focus of the study was also being limited to cube compressive strength of different recycled aggregate (RA) replacement levels with the natural ones (NA).

CHAPTER TWO

LITERATURE REVIEW

2.1. General

Due to the vast amount of concrete being produced and the huge amount of demolition waste from old concrete structures, recycling concrete has become a necessity. New standards, design criteria and wear and tear forces forward the demolition of concrete. And to save space at landfills and disposal dumps it is important to take care of this waste in an environmentally friendly way.

As environmental preservation is becoming a primary societal concern, the use of sustainable materials in construction is gaining popularity all over the world. The use of construction wastes for the production of new sustainable concrete is, however, not a new research area. From history, it was found that Romans often used C&D waste or debris for road construction [12]. RAC has been reported to provide environmental benefits through both its production and use, thus, providing a greener and more sustainable solution. By using concrete waste as aggregate for producing new concrete (recycled aggregate concrete), natural resources (e.g., gravel pits, rock quarries) can be preserved, which can eliminate other related manufacturing processes (e.g., excavation/blasting, transportation, crushing, etc.). When an old structure is demolished, the demolition wastes also need to be sent to the landfills. This process involves the cost of material handling, dumping, and transportation cost. The use of C&D waste will substantially reduce the landfill use.

This chapter presents a detailed summary of the existing literature on RAC, in particular, various properties of RAC, comparative analyses on the fresh and hardened properties of NAC and RAC. This chapter presents the existing knowledge on the properties of RAC using useful graphs and tables and systematically discusses their advantages and disadvantages.

2.2. Overview of Construction and Demolition Waste

Environmental control is a pressing issue in the construction industry. Natural resources are consumed in its day-to-day operations, and waste is generated. Construction activities, therefore, impose significant environmental impacts over the entire life cycle [1, 2].

Waste management in the construction industry has not been successfully controlled in the past, and it is challenging environment in which to initiate improvement. It has been thought that the reusing and recycling of materials might provide an effective means to reduce landfill and improve waste management.

Concrete is an essential, mass-produced material in the construction industry, like steel and soil. However, much effort has been made to recycle and conserve precious natural resources. Completed and repeated recycling can be suitable for concrete, as is the case for steel and aluminum [4]. An efficient method would be the use of RA in the production of RAC. RA is a particle of stones attached to old cement mortar, generated by crushing demolished concrete waste (Figure 2.1).

RAC is created by mixing RA with other natural ingredients, including cement, water, fine aggregate and other materials. Since concrete is composed only of cementitious materials, and the powders generated during the production of RA can be reprocessed as cement resources, repeated recycling is possible. This also enables concrete to be recycled in a fully closed system, thus improving the environment by reducing landfill and concrete waste. Concrete recycling can be accomplished by reusing concrete products and processing into secondary raw materials for applications such as fill, road base and sub-base, or aggregate to produce new concrete for nonstructural applications [5, 6].

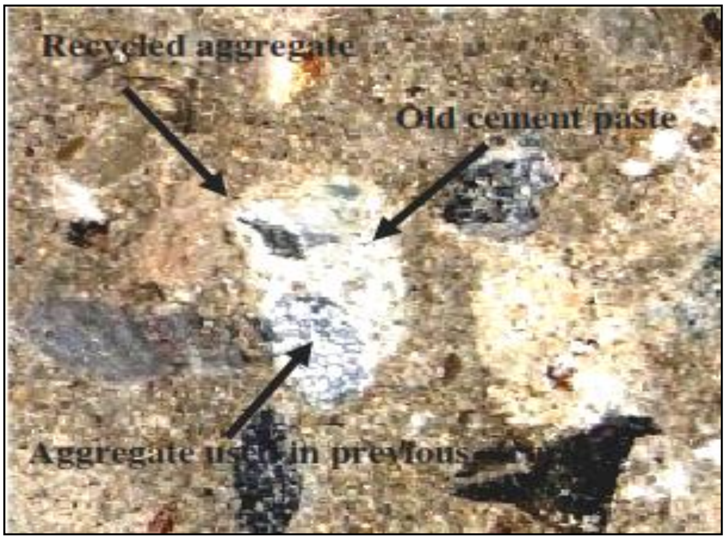

Figure 2.1: Recycled Aggregate

The benefits to the environment of using RAC include economic aspects, a reduction in environmental impacts and a saving of resources [13, 14]. To facilitate waste management by using RA, it is vital to investigate ways in which shortcomings can be overcome.

Various investigations have focused on processing demolished concrete, including mixture design, physical and mechanical properties, and durability. Some of the findings have shown that RAC quality is lower than that of normal aggregate concrete (NAC), which limits the use of RAC [15, 16]. Furthermore, two building projects made from concrete with RA, the Waldaspirale and Vilbeler in Germany, were built by controlling the production process [17]. This highlighted that RAC could be used for concrete applications as efficiently as normal aggregate concrete.

2.3. Green Concrete

Concrete is being used as a construction material for more than 2000 years. In construction industry concrete has become more acceptable for its dependable nature and sustainable property. Other than construction purpose, the contribution of concrete in economic growth, social progress, and environmental protection is often ignored. It was found that energy performances of concrete structure are superior to steel structures [18]. Concrete structures are not only flexible in design but also affordable. Moreover, concrete structures are more environmentally friendly than aluminum or steel structures.

To make the concrete industry more sustainable and environment-friendly, researchers are working continuously, and they came up with the idea of green concrete (recycled concrete). Green concrete or recycled concrete is a sustainable type of concrete resulting from aggregate replacements such as RAC, rubber tire, ceramic waste, tile, glass aggregate, etc. It could also be a result of Portland cement replacements such as fly ash, silica fume, and slag or it could arise from waste material admixtures such as waste latex paint. As a result, RAC has a less environmental impact regarding energy consumption and emission during its manufacturing process [19] and can reduce the cost associated with concrete production.

2.4. Green Concrete and Sustainability

A sustainable material is often defined as a material that produces environmental benefits through both its production and use. However, environmental benefits are not the only aspect that sets out a sustainable material. Social and economic benefits must also be considered before deeming a material sustainable. As a result, the green concrete should provide a sustainable solution for reducing industrial waste through the investigation of its environmental, economic and social benefits.

The environmental benefits of using green concrete can be seen primarily in two ways. Firstly, the benefit of using any amount of recycled concrete aggregate would help limit the amount of industrial waste heading to landfills. Recycled concrete aggregates do not degrade easily and will, therefore, remain in our landfills for long periods of time. By reducing these waste materials, it is possible to limit the size and increase the longevity of our landfills. Secondly, the use of green concrete would contribute to a reduction in our carbon footprint. By using RAC in new concrete, the number of gravel pits/rock quarries can be reduced which would eliminate the massive amount greenhouse gases emitted through the natural aggregate excavation/extraction process [20, 21]. This reduction of gravel pits/rock quarries can also prevent the destruction of our carbon neutralizing ecosystems.

The use of RAC also has significant economic gains. The large costs associated with the extraction of natural aggregate (such as the stripping and blasting) are not present with waste total. The use of recycled aggregate from local landfills will also contribute to a reduction in high transportation costs currently incurred through the use of natural aggregate [22].

The social benefits of using the green concrete may not be as obvious as the environmental or the economic benefits in other regions. It is not desirable to have a landfill in a public community as soil contamination, odors, increased traffic, and land value depreciation can result. By using recycled aggregate in concrete, the amount of landfill space being used could be reduced. Also, landfills are typically operated by local municipalities that carry the costs. These savings could be redirected into social programs to benefit communities.

The reduction in gravel pit sizes can also provide social benefits. Although gravel pits often provide jobs and economic benefits to communities, they come at a cost as gravel pits increase the number of the truck volume in that particular area. The increase in truck traffic can make the roads dangerous for children; reduce the lifespan of roads not designed for the large traffic, impact privacy, and cause noise and air pollution that negatively affects communities. As a result, the reduction of gravel pits can also be seen to benefit communities.

2.5. Production of Green Concrete

Different ingredients used in concrete products include cement as a binder, Sand as fine aggregate and crushed stone, gravel or brick chips as coarse aggregates. Green concrete is a sustainable type of concrete resulting from either aggregate replacements or cement replacements. Green concrete can be produced by three types of replacement:

1) Replacing coarse aggregate
2) Replacing fine aggregate and
3) Replacing cement

Water replacement can be done using waste latex paint. In RAC, coarse aggregate replacement can be done with construction or demolition waste (C&D), ceramic waste, tile, rubber tire, glass waste, etc. Figure 2.2 shows the breakdown of construction and demolition waste stream in a recycled aggregate, where we can see that concrete represents 12% of total construction waste.

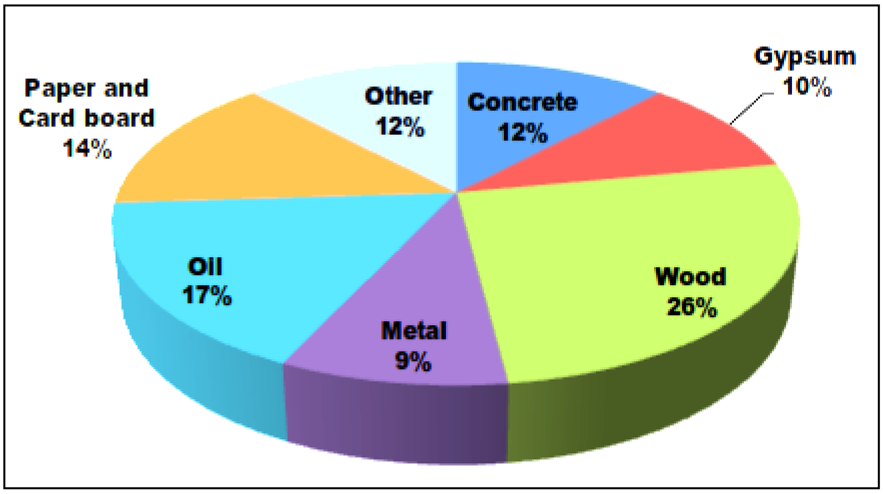

Figure 2.2: Breakdown of construction and demolition waste stream [23]

2.6. Production of Recycled Aggregates Concrete (RAC)

RAC is concrete made with crushed RCA used as partial or full replacement of conventional coarse or fine aggregate in new concrete. Since RAC come from different sources and occupies around 75% of the volume of concrete, it is necessary to maintain the high quality of aggregate during the entire course of the recycling system. This requires a preliminary survey before demolition along with advanced processing techniques using special facilities to control the quality of recycled aggregate [24, 25].

Recycled aggregate refining and replacing methods are two recycling methods which are currently being used for the production of aggregate from demolished concrete [25, 26]. Aggregate refining method is a closed-loop concrete recycling system in which the adhered cement in RAC is made fragile by a thermal treatment to about 300 ^{0}C and is removed selectively from original aggregate by rubbing crushed concrete. The retained coarse and fine aggregates can be applied to the concrete mix. The by-product powder, which has a large specific surface area, can be used as clinker raw material, cement production and deep or shallow ground improvement as a partial substitute for cement. Figure 2.3, shows the schematic diagram of the closed-loop concrete recycling system [26].

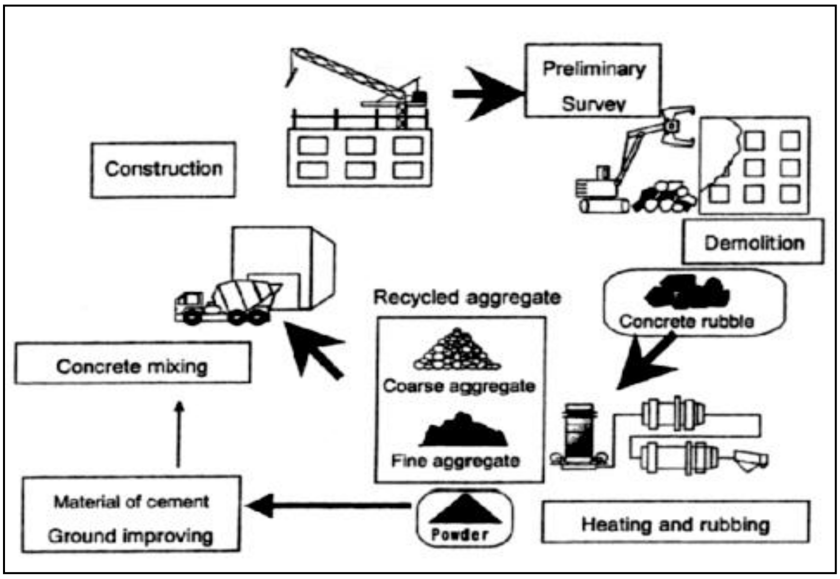

Figure 2.3: Closed-Loop Concrete System

It is believed that this method provides the highest quality control throughout the process, from aggregate production to concrete placement, while the original coarse aggregate does not lose its integrity and has the equivalent quality to natural coarse aggregate.

Refining method would contribute to preserve natural resources and to decrease carbon dioxide emissions from cement production. However, it needs more energy and advanced facilities to remove the original cement and reuse of recycled fine aggregate and fine powder by-products [25].

For this reason, the aggregate replacing method, which does not remove the original mortar, is more effective. In this manufacturing process, the demolished original concrete undergoes crushing with a jaw crusher and foreign materials such as steel reinforcement are separated magnetically. The aggregate with the larger size than 20 mm goes through secondary crushing with an impact crusher and after impurity removal by human power, coarse and fine recycled aggregates are separated based on their sizes. The ratio of original coarse aggregate replacement by recycled coarse aggregate is determined by relative quality value method according to the desired construction specifications. The remaining fine recycled aggregates can be used for manufacturing of precast concrete products. The advantages of this system are simple manufacturing process with mobile and general purpose facilities. Figure2.4 shows a schematic of the recycling system for aggregate replacing method [25].

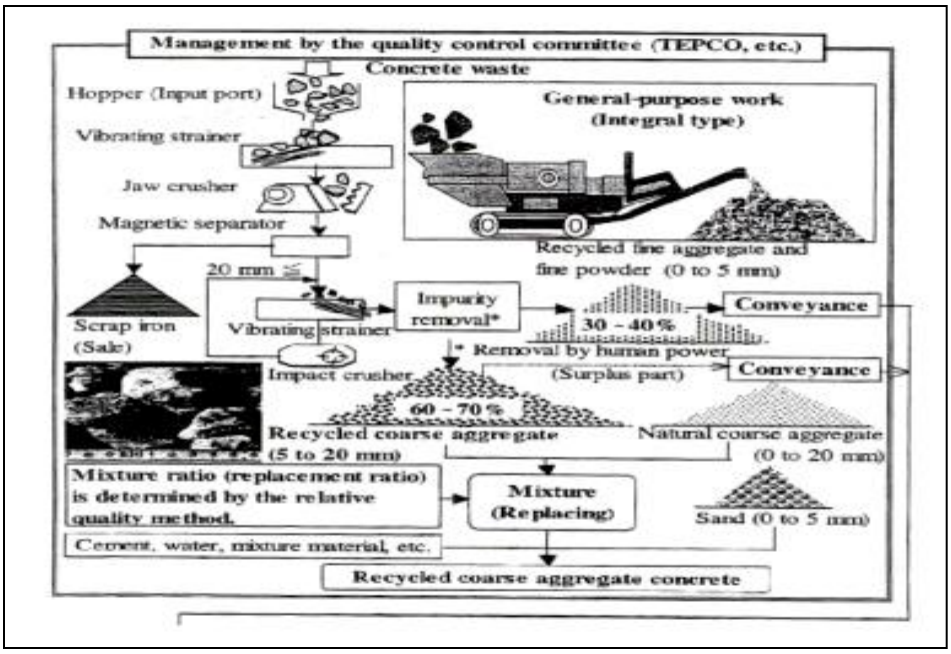

Figure 2.4: Aggregate replacing method [25]

2.7. Utilization of Recycled Aggregate Concrete

Recycled aggregates have been successfully used in concrete production for more than half-century. In Europe, recycling waste industries are well established. After the Second World War, European countries have been utilizing the C&D waste for concrete production. The European Demolition Association calculated that approximately 200 million tons of wastes are generated every year in Europe [12]. But currently, only 30% of the waste is being recycled. In Europe, recycling and reusing of C&D waste is a popular and well-supported program by the European Commission on Management of Construction and Demolition Waste. The target levels of recycling C&D waste of different European Union members are varied from 50% to 90% [12]. On the other hand, some of the European Union countries are still struggling to achieve this high recycling rate such as the recycling rate of Spain and Greece is less than 20% where Ireland, Germany, Netherland, and Denmark, effectively achieve recycling rate which is higher than 70% [27].

Historically, RA is also used in building construction, such as foundation floor for the Melbourne casino, the Sydney Olympic buildings, and 100% RA in premix concrete at the Werribee foreshore in Victoria [28]. A new high school in Norway has been constructed by using RA in its foundation, basement walls, and columns [29]. In the late 1990s, two building projects made from concrete with RA – the Waldaspirale and Vilbeler, in Germany – were built by controlling the production process [17].

To minimize construction waste generated from construction activity, three main waste minimization strategies – reuse, recycle and reduce – are employed. Concrete recycling, in particular, is a method that has some benefits that make it an attractive option for greater environmental awareness, an environmental laws, and the desire to keep construction cost down. Furthermore, using concrete waste as aggregate solve the critical shortage of natural aggregate anticipated for the near future [30]. Recycled aggregate could also be a reliable alternative to natural aggregate in the construction industry today.

Currently, in the USA, around 2.2 billion tons of virgin aggregates are being produced every year [10], and about 10-15% of this quantity is used for pavements. Also, other maintenance and construction work for roads are required further 20-30% of aggregate. The rest amount of aggregate is consumed for structural applications, which is about 60-70%. In the USA, 50% of recycled aggregate is produced by natural aggregate producer, 14% by debris recycling center, and 36% by contractors. Many initiatives were taken to facilitate the application of recycled aggregate, but initially, the use was limited to road construction as base or filler material [31]. A geological survey carried out in 2000 revealed that every year almost 100 million tons of recycled concrete aggregate is produced in the US. This massive amount of recycled concrete aggregate is utilized by various sectors such as asphalt pavement (9%), new concrete production (6%), riprap (14%), base materials (68%), and other (7%) [32]. California, Michigan, Texas, Minnesota, and Virginia are taking the initiative regarding the utilization of recycled aggregate in new concrete [33]. Minnesota Department of Transportation succeeds to save $600,000 by using recycled aggregate to construct a 16 miles plain concrete pavement in 1980 [34]. It is possible to save $11 in every 1000 kg by using recycled concrete aggregate instead of natural aggregate [11].

Among the Asian countries, Japan has a very fascinated and enriched research history regarding RAC. Due to the structural safety requirement minimal amount of recycled aggregate is being used in the real case scenario/field. Never the less in 1991 recycling law was established by Japan government, to encourage the reuse of demolition waste especially the waste concrete. After this initiative, the rate of application of recycled aggregate increased from 48% (1990) to 96% in 2000, though they were mostly as a sub-base material for concrete pavement [35].

Every year 14 million tons of wastes are generated in Hong Kong. Earlier, non-hazardous wastes were used for land reclamation process. Due to various difficulties, this recycling process was hindered. SAR government of Hong Kong started a pilot project incorporating recycling facility of C&D waste where daily recycling capacity was 2400 tons. They successfully reused recycled aggregate in different appropriate government projects [36].

Like other countries, Taiwan introduced some comprehensive program to fascinate and promote the application of recycled aggregate in the production of new concrete. In 1999 they utilized RAC during the rehabilitation program of infrastructures after a devastating earthquake. Almost 30 million tons of C&D waste was generated during rehabilitation program. This unexpected situation was overcome by successfully recycling 80% of those waste, and 30% of those recycled materials were used as pavement base [36]. Table 2.1 presents a summary of the overall condition of waste management through recycling and incineration around the world.

At this moment, concrete made with RAC is not commonly used for structural purposes. Their poor structural properties can be the ultimate reason. Of the various types of C&D waste, concrete waste makes up the major proportion. RAC can be produced with RA and other natural ingredients. RA can be accomplished by reusing concrete products, processing into secondary raw materials for use as fill, road base and sub base, or aggregate for the production of new concrete for non-structural applications [6].

Table 2.1: Existing Application of RAC

Country	Source	Waste generation (million tons)	Recycled (%)	Waste sent to landfills or Incinerated (%)
USA	[10]	243	33.8	66.2
Europe	[12]	200	30	70
China	[37]	120	50	50
Japan	[38]	79	98	2
Austria	[39]	19	55	45
India	[40]	10-12	50	50

Up to now, RAC is mostly used in non-structural applications. In unbound form, it is used as sub-base for slabs on ground, gravel for roads and in under concrete pavements. There are examples of using it in buildings, e.g., the Shanghai ecological building [41]. And in the enterprise park at Stapleton in Denver, Colorado [42]. In Singapore, RCA concrete has been utilized in several projects. One of these projects is the Wop Hup Building. In this office building, 30% RAC and 30% washed copper slag is used in its superstructure [43].

Thus, recycling of concrete waste should be the best methodology to improve the construction industry and the environment.

2.8. Effect of Physical Properties of Recycled Aggregate

In Portland cement concrete, 60% to 75% of the concrete volume and 70 – 85% of the mass is made up of aggregates. Aggregates occupy a large portion of concrete volume and its properties significantly influence the properties of concrete. In case of RAC, it is very difficult to get clear and appropriate idea about its quality because the origin of the recycled aggregate is often unknown. The application of recycled aggregate in new concrete is not only fascinating but also challenging. Due to the variation in sources, the recycled concrete aggregate may possess impurities along with the adhered mortar content. This significantly influences the properties of RAC and makes it difficult to predict the properties of new concrete [11]. German committee of a reinforced concrete structure has specified the maximum permissible limit of different harmful ingredients that can be presented in recycled aggregate [44]. Later Greek standard adopted this limit in their standard. Table 2.2 represents the permissible maximum limit of different harmful ingredients that can present in recycled aggregate.

Table 2.2: Allowable Maximum Limits of Different Harmful Substances in Recycled Aggregate [45]

Substance	**Arsenic As**	**Lead Pb**	**Cadmium Cd**	**Chromium Cr**	**Copper Cu**	**Nickel Ni**	**Iodine I**	**Zinc Zn**
Limit (μg/l)	50	100	5	100	200	100	2	400

Also, due to this higher porous nature of adhered mortar, the physical and mechanical properties of RA and concrete made with this aggregate are significantly different from ordinary concrete. For instance, the workability of fresh concrete decreases with increase in the surface area of recycled aggregate. In turn, the surface area is influenced by grading, shape, texture and maximum size of the recycled aggregate [46, 47]. Therefore, for the successful use of RAC in fresh concrete production, the properties of RCA must be accurately determined.

2.8.1. Gradation, Shape, and Texture of Recycled Aggregate

The properties of RAC are significantly affected by the gradation, shape, and texture of the recycled aggregate used. Grading of recycled aggregates can influence the mix proportioning, workability, porosity, durability and strength of concrete. Gradation of recycled aggregates is determined from sieve analysis in which the aggregates are passed through a series of superimposed wire-mesh sieves with the square opening arranged in decreasing sizes. The maximum size of coarse aggregate is defined as the smallest sieve opening through which the entire particular aggregate passes.

Since recycled aggregates can be obtained from different sources, their shape and textures are likely to vary over a wide range. Salem et al. [34], found that recycled aggregate possesses hundred percent crushed faces as aggregates are produced from primary and secondary crushing. Also, Katz [48], found that the gradation and attached mortar content of recycled aggregates are not influenced by the crushing strength and the age of parent concrete. According to Corinaldesi et al. [49] the size of recycled aggregate is dropped down to 50mm by the primary crushing process, and all types of metal impurities are removed by using electromagnets while transferring from primary to a secondary crusher. Then particle size is reduced to 14-20 mm during the secondary crushing process. The adherent mortar contains fine and coarse aggregate are 25% and 6.5%, respectively [48]. Table 2.3 presents the variation of attached mortar contents with the particle size of recycled aggregate.

Table 2.3: Variation of Attached Mortar Contents with the Particle Size of Recycled Aggregate

Particle size	Attached mortar (by volume)	Source
20-30 mm	20%	[50]
16-32 mm	25% - 35%	[51]
14-20mm	25% - 6.5%	[48]
8-16 mm	40%	[51]
5-25 mm	35.5%	[52]
4-8 mm	60%	[51]

In practice, it is common to use a nominal maximum size, which is the smallest sieve opening that most (not all) of the aggregate pass through [47, 53, 54]. The choice of the nominal maximum size of an aggregate used in reinforced concrete depends on the size and shape of the concrete member and the amount and distribution of reinforcing steel. The ASTM and CSA standards limit the maximum size of coarse aggregate for different applications. For example, in reinforced concrete, the maximum aggregate size should not exceed three-fourths of the minimum clear distance between the bars or one- half of the specified cover depth for concrete exposed to chlorides [53].

A particle-size distribution curve is obtained by plotting the logarithm of the sieve opening size on the x-axis, and the percentage of the particle, by weight, coarser than or finer than the particular sieve on the y-axis. A linear shape (dense) of the curve shows a good gradation recommended by the standard. A horizontal or vertical shift away from the linear shape shows missing or using more a percentage of one size.

In Gap-graded aggregate one or more aggregate sizes are intentionally missing. The small aggregates, which can block the voids between the larger aggregates, are omitted in opengraded aggregates. In a one-sided distribution, the large part of aggregates is made up of the same size and causes a vertical drop in the curve. In Figure 2.5, typical aggregate grain size distribution curves are illustrated [54].

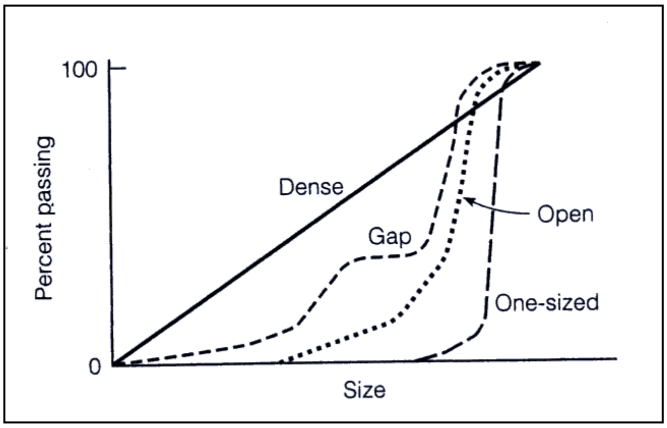

Figure 2.5: Types of Particle-Size Distribution Curves [54]

Regarding shape and texture, crushing demolished concrete produces angular particles with a rough surface texture. Thus, RCA has a larger surface area than round natural aggregate and may provide better interlock and adhesion to cement paste [54].

Also regarding workability of fresh concrete during mixing and placing, the inter-particle friction in concrete incorporating RCA might more increase than that of in concrete made with rounded natural aggregate. Also, in addition to high porosity, the angular shape of RCA increases the void content between aggregate particles. So, the fresh concrete mix incorporating recycled concrete as aggregate may require more water and cementitious material than those of normal fresh concrete mix to produce a workable concrete [46, 47, 51].

2.8.2. Specific Gravity

In comparison to natural aggregates, a recycled concrete aggregate has higher water absorption and a lower specific gravity due to adhered mortar content. Since recycled aggregate is porous, the volume of pores should be considered in the measurement of total volume.

The natural aggregate has a specific gravity of around 2.7. On the other hand recycled aggregate's specific gravity is less than the natural aggregate. It is explained that the presence of attached mortar on the surface of recycled aggregate is responsible for this reduced specific gravity of recycled aggregate [34, 48]. The specific gravity of different types of aggregates is shown in Table 2.4.

Table 2.4: Specific Gravity of Different Types of Aggregates

Aggregate Type	Specific Gravity	Source
Natural Coarse Aggregate	2.11	[55]
Natural Coarse Aggregate	2.65	[56]
Natural Coarse Aggregate	2.67	[34]
Natural Coarse Aggregate	2.71	[57]
Natural Coarse Aggregate	2.74	[57]
Natural Coarse Aggregate	2.7	[48]
Recycled Coarse Aggregate	2.59	[48]
Recycled Coarse Aggregate	2.4	[56]
Recycled Coarse Aggregate	2.4	[34]
Recycled Coarse Aggregate	2.5	[57]
Recycled Coarse Aggregate	2.42	[57]
Recycled Coarse Aggregate	2.03	[55]
Recycled Coarse Aggregate	2.2	[45]

The bulk specific gravity of RCA is an essential parameter for concrete mix design because it is representative of the unit volume of aggregate containing both permeable and impermeable pores. The fresh unit weight and the workability of concrete decrease with increasing the amount of RA [46]. According to the report made by cement association of Japan [58], the density of the coarse recycled concrete is between 2120 kg/m^3 and 2430 kg/m^3 while the density of the recycled concrete made with fine recycled aggregate is between 1970 kg/m3 and 2140 kg/m^3. As the proportion of recycled concrete aggregate increases, the density and unit weight decrease in the hardened concrete. Through the research performed by Topcu et al. [59], it was observed that the unit weight of concrete incorporating 50% of waste concrete as aggregate was higher (2301 kg/m^3) than the one for concrete made with whole waste concrete aggregate which was 2251 kg/m^3.

2.8.3. Water Absorption

A lower absorption capacity is observed by natural coarse aggregate which is around 0.3%. RCA has a higher absorption capacity than natural coarse aggregate due to the attached mortar. 3.2% to 12% range of water absorption is seen in the case of fine and coarse recycled aggregates [48]. The absorption capacity of recycled fine aggregate is higher than that of RCA [34, 36, 48, 60]. The absorption capacities of different types of aggregates are given below in Table 2.5.

The mix design of RCA concrete is carried out based on the water-cement ratio and considering the higher water absorption of RCA. Hence, it is necessary to increase the proportion of water to compensate the high water absorption of recycled aggregate. Although the workability of a concrete mixture can be improved in this way, the increase in the water content enhances the volume of capillary pores and the permeability and reduces the compressive strength of hardened concrete [60, 61].

Table 2.5: Absorption Capacity of Different Types of Aggregates

Aggregate Type	Absorption (%)	Source
Natural Coarse Aggregate	2.28	[56]
Natural Coarse Aggregate	0.30	[34]
Natural Coarse Aggregate	2.17	[55]
Natural Coarse Aggregate	0.34	[57]
Natural Coarse Aggregate	0.89	[57]
Natural Coarse Aggregate	1.24-1.25	[61]
Recycled Coarse Aggregate	4.35	[56]
Recycled Coarse Aggregate	4.70	[34]
Recycled Coarse Aggregate	3.3-5.4	[57]
Recycled Coarse Aggregate	5.23	[55]
Recycled Coarse Aggregate	3.2-3.4	[48]
Recycled Coarse Aggregate	3	[45]
Recycled Coarse Aggregate	6.28-7.56	[61]

The amount of water absorbed by aggregate pores does not participate in the cement hydration and, therefore, does not contribute to the workability of the fresh concrete mix. The potential of water absorption and adsorption for recycled coarse (16-32 mm maximum nominal size) is typically lower than recycled fine (4-8mm maximum nominal size) aggregates [51]. The degree of RCA fineness and its effect on decreasing the workability is another aspect that should be considered. Greater surface area and higher water absorption of the fine fraction of RCA provide more potential for higher water demand leading to decreasing the workability.

2.8.4. Abrasion resistance

The resistance of aggregates to degradation caused by loads, stockpiling, mixing, placing and compacting of freshly mixed concrete is defined as abrasion resistance [54]. Recycled concrete as the aggregate has lower strength compared to natural aggregate due to the presence of weak mortar adhered to the aggregate particles. Accordingly, the assessment of abrasion loss in mass of recycled aggregate indicates the general characteristic of its quality particularly when it is subjected to wear or impact during the mixing or after concrete placement.

According to Sagoe - Crential et al. [28] virgin aggregate abrasion resistance are 12% higher than that of recycled aggregate. The recycled aggregate has the abrasion resistance of 20% to 45%, and sometimes it can be as high as 50% [62]. Abou- Zeid et al. [63] found that replacement pattern of recycled aggregate (full or partial) does not influence the abrasion resistance of aggregate. Table 2.6 shows the abrasion resistance of natural and recycled aggregate. It reflects the difference between the initial mass and the final mass of the tested samples concerning the percentage of the initial mass.

Table 2.6: Abrasion Resistance

Aggregate Type	Abrasion Resistance	Source
Natural Coarse Aggregate	20%	[56]
Recycled Coarse Aggregate	25% - 35%	[56]
Recycled Coarse Aggregate	25% - 6.5%	[62]

The mechanical wearing of the recycled aggregate surface caused by friction during mixing can increase the presence of silt on the surface of aggregate. This, in turn, can lower the bond characteristics, increase the water demand of concrete mix and increase scaling off the concrete during the finishing.

2.9. Properties of Recycled Aggregate Concrete

Properties of concrete made with recycled aggregates can be defined on the performance requirements and property specifications. For instance, the waste concrete applied for grading and base material for road and highway pavement should possess little movement under the load impacts, while the recycled concrete used for a highway bridge should contain appropriate strength, sufficient rigidity, and adequate durability.

Presently in new construction, only a small portion of RAC is used as there is a lack of sufficient technical specification and guidelines for producing good quality RAC. As a result, lots of research works are being conducted all over the world to investigate the properties of RAC. These results will intensify the industrial production of recycling concrete. There are five existing specifications for recycled concrete made with used concrete [4, 26, 41, 45]. These five are Greek Specification Concrete technology (GSCT), Chinese technical code (DG/TJ07-008), RILEM (RILEM 1994a), BS8500 (2002), and Japanese Industrial Standards (JIS). Table 2.7 represents the specification limit for RAC of GSCT, JIS, DG/TJ07-008, and BS8500 and also another proposed specification limit for RAC for Egypt [64].

Table 2.7: RAC Specifications Limit

RAC specification	GSCT*	JIS*		DG/TJ07-008**		BS8500**	Egypt*
		Coarse	Fine	Type I	Type II		
Specific gravity (kg/m^3)	2.2 (min)	2.5 (min)	2.5 (min)				
Water absorption (%)	3 (max)	3 (max)	3.5 (max)	7 (max)	10 (max)		7 (max)
Foreign ingredients (%)	1 (max)	1 (max)	1 (max)	1 (max)		1 (max)	
Foreign ingredients (kg/m^3)							2 to 10
Organic ingredients (%)	0.5 (max)			0.5 (max)			
Sulphate ingredients (%)	1 (max)			1 (max)		1 (max)	
Amount of sand (%)	5 (max)						
Amount of filler (%)	2 (max)						
Los Angeles abrasion (%)	40 (max)	35 (max)					40 to 50
Soft granules (%)	3 (max)						
Soundness or loss (%)	10 (max)						
Sand equivalent (%)	80 (min)						
Solid volume (%)		55 (max)	53 (max)				
Material passing 75µm (%)		1 (max)	7 (max)				
10% fineness value (kN)							50 to 150
Chloride content		0.04 (max)	0.4 (max)	0.25 (max)			
ASR		Harmless	Harmless				
Flakiness index (%)							40

*[11] **[41]

2.9.1. Properties of RAC in Fresh Concrete

2.9.1.1. Workability

It was found that commercially produced recycled aggregates are smoother and spherical than recycled aggregates which are usually produced for laboratory work [28]. This type of shape increases the workability of commercially produced RAC than that of laboratory-produced RAC. Due to the higher absorption capacity of recycled aggregate, the concrete mixes become stiffer and less workable compared to NAC [34]. Some researchers observed that RAC requires 5-10% extra free water to achieve the same workability than that of NAC though it is significantly influenced by the quality of recycled aggregate [51].

2.9.1.2. Slump

Slump value represents the consistency and workability of fresh concrete. Topcu and Sengel [58] showed that at a fixed water-cement (w/c) ratio, the workability decreases with the increased amount of recycled aggregate replacement which consequently decreases the slump value of RAC. The loss of slump is higher in case of over dry recycled aggregate at similar w/c ratio. Yang et al. [65] studied the mechanical and durability properties of RAC. Regarding the fresh concrete properties such as slump, they found that as the percentage (%) of recycled aggregate increased in the concrete, the concrete slump slightly decreased. However, since the reduction in the slump was very small, it can be offset with the use of admixtures. Poon et al. [61] found that after adjusting the required amount of water content of air dry RAC as per its actual moisture state, the slump value was 100 mm for RAC made with 50% RAC where it was 110-100mm for NAC.

2.9.1.3. Initial and Final Setting Time

Hansen and Hedegkd [51] found that admixtures of parent concrete do not influence the initial and final setting time of RAC.

2.9.1.4. Air content

A similar observation was found by Katz [48] and Salem et al. [34] in which the air content of RAC is higher than NAC. This means that RAC contains the high amount of entrapped air compared to NAC.

2.9.2. Properties of RAC in Hardened Concrete

Hardened concrete properties reveal the strength and durability properties of concrete. In an experimental study, Tavakoli and Soroushian [66] showed that several factors are correlated with the strength of RAC. Original/parent concrete strength has a significant impact on the strength of RAC. RAC strength properties are also affected by coarse aggregate replacement level. They found that the values of flexural, compressive and splitting tensile strength of RAC differed from conventional concrete.

Also, it has been demonstrated that replacement of natural aggregates with RCA which has lower strength than that of natural aggregate causes a reduction in mechanical properties such as compressive, tensile and flexural strengths of RCA concrete. In table 2.8 the mechanical properties of concrete made with recycled aggregate (RAC) and natural aggregates are compared [28].

Table 2.8: Concrete relative properties made with natural and RAC [28]

Concrete property	RAC concrete compared to natural aggregate concrete
Slump control	Higher water demand in RAC
Flexural strength	RAC comparable to NAC
Compressive strength at equal w/c	Less than 90% of NAC
Strength development to 7 days	RAC comparable with NAC
Modulus of elasticity	RAC lower than NAC
Drying shrinkage	RAC higher than NAC
Expansion	RAC comparable with NAC

The following section discusses the different types of mechanical properties of RAC.

2.9.2.1. Compressive Strength

Of the major mechanical properties, the compressive strength is considered as the most significant property because reinforced concrete structures are mostly required to bear against compressive loads, and the other strength properties of concrete constructions are dependent on compressive strength.

The compressive strength of RAC is greatly influenced by the recycled aggregate replacement ratio and the effective w/c ratio [67]. Higher variation regarding the compressive strength is observed for 100% replacement where it is comparatively small for lower replacement levels such as 20% to 50%. Alam et al. [55] found that nearly 15% reduction in compressive strength as compared to control mix for 25% to 50% RCA concrete.

Yang et al. [65] used different recycled aggregate replacement levels (30%, 50%, and 100%) to produce 40 MPa concrete with recycled aggregate and a water-cement ratio of 50% by weight. They found that any replacement level of recycled concrete aggregate will produce concrete with the same compressive strength as what is typically found for NAC. Figure 2.6 shows the results of compressive strength of RAC with different RCA replacement levels found by Yang et al. [65]. From this figure, it is evident that irrespective of RCA replacement levels, the compressive strength remains almost constant.

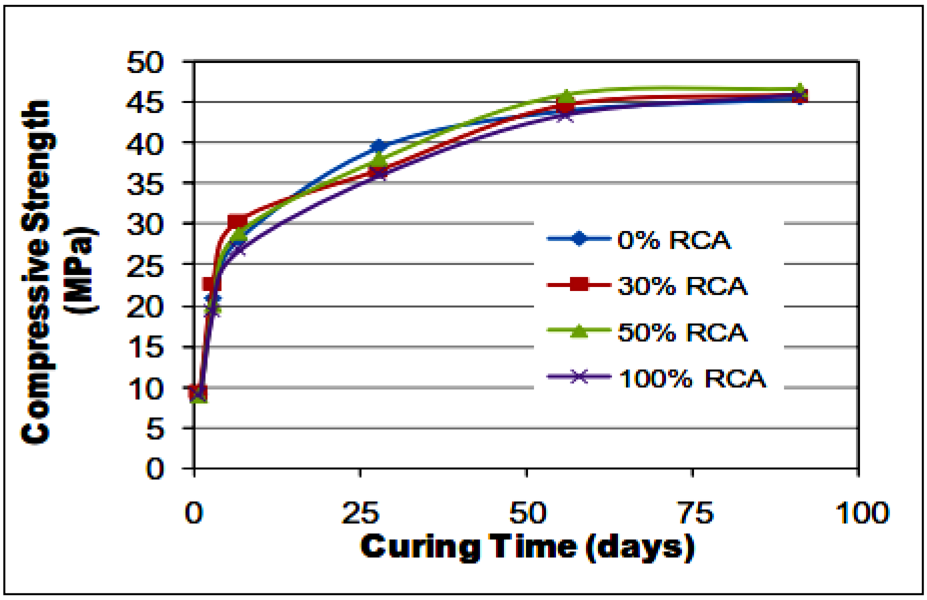

Figure 2.6: The effect of recycled aggregate concrete on concrete compressive strength [65]

Test result by Hansen and Narud [51] indicated that if all other factors are kept constant, then RAC compressive strength is greatly influenced by the w/c ratio of original/parent concrete. The strength of RAC will be equivalent or better than NAC if its w/c ratio is lower or at least similar to that of original concrete.

With 30% RCA, Limbachiya et al. [68] achieved a compressive strength of 80 MPa at the 28th day. They aimed to produce high-strength concrete (50 MPa or more) using RCA. They used rejected precast structural concrete elements as RCA. Their study showed that there was no significant effect on concrete strength up to 30% replacement of coarse aggregate by RCA. They suggested that if more than 30% RCA replacement levels are used, it can reduce the strength of RAC. Table 2.9 shows the variations of compressive strength of RAC with different RAC replacement levels compared to NAC.

Table 2.9: Variation in Compressive Strength of RAC

Replacement Level	Variation in Compressive Strength as compared to natural concrete	Source
25%	9% Increase	[69]
25%	15% Decrease	[55]
30%	10% Decrease	[65]
30%	9.5% Decrease	[70]
30%	Similar	[68]
50%	11% Increase	[69]
50%	14.7% Decrease	[55]
50%	5% Decrease	[65]
50%	5% Decrease	[68]
60%	30% Decrease	[70]
100%	7.7% Increase	[69]
100%	11% Decrease	[65]
100%	2.4% Increase	[34]
100%	8.9% Decrease	[68]

2.9.2.2. Flexural Strength

Several researchers concluded that use of recycled aggregates in concrete production decreases the flexural strength of RAC [48, 55]. Poon et al. [61] found that concrete made with 100% recycled concrete aggregate flexural strength was13% higher than virgin concrete. Conversely, Alam et al. [55] found a reduction of 16% in flexural strength of RAC made with 25% RCA. Table 2.10 provides a summary of the variation in flexural strength as a function of RAC replacement level obtained by different researchers.

Table 2.10: Variation in Flexural Strength of RAC

Replacement Level	Variation in Flexural Strength as compared to natural concrete	Source
25%	2.2% Increase	[61]
25%	16% Decrease	[55]
50%	6.25% Increase	[61]
50%	32% Decrease	[55]
75%	10.8% Increase	[61]
100%	13% Increase	[61]
100%	31% Decrease	[48]

2.9.2.3. Effect of Mix Proportion on the Strength of RAC

Hansen et al. [51] found that the compressive strength of RCA concrete can be reduced from 5 to 24% in comparison with ordinary concrete. However, it can be increased to the same or even higher level than in normal concrete if the water-cement ratio of the RCA concrete remains at the lower or constant level of that in normal concrete [51].

Topcu [58], performed compressive tests on cylindrical samples at 7 and 28 days age with the water-cement ratio of 0.6. The results showed an inverse relationship between concrete compressive strength and using waste concrete as aggregate (Figure 2.7).

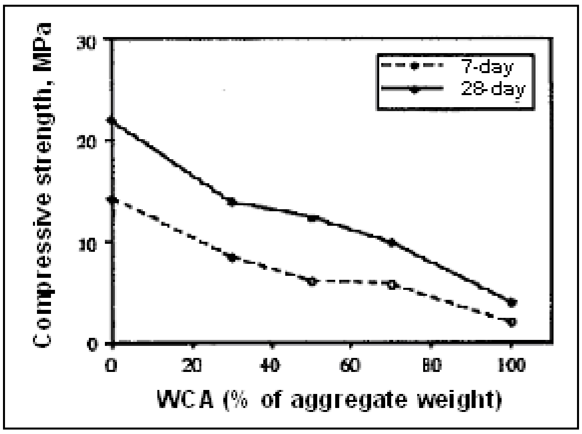

Figure 2.7: Changes in Compressive Strength with the Amount of WCA [58]

However, the compressive strength of recycled concrete could reach to 85-95% of normal concrete if it is produced with coarse recycled and fine natural aggregates [58, 59].

Partially replacement of up to 20% natural coarse aggregate with RCA did not have any influence on the compressive strength reduction of concrete cube samples which Limbachia [68] investigated, while there was a gradual reduction in strength with increasing the recycled concrete aggregate content [68].

2.9.2.4. Effect of Crushing Age on the Strength of RAC

The shorter time gap between crushing a recent cast concrete (1 to 3 days) and using crushed aggregates in new concrete, can improve the strength of concrete due to the additional hydration of the old cement in new RCA concrete [48]. A very well hydrated cement paste with a finer pore structure is stronger than an unhydrated paste containing coarser pore structure. But in spite of RAC strength, the cementing potential of the unhydrated cement remaining in the recycled concrete aggregates might improve the strength of new concrete as well. According to the results of Katz [48], the 3- days crushed cast concrete used as RAC was combined the advantages of both strength and cementing capability which could produce a stronger RAC concrete compared to the concrete made with crushed recycled concrete aggregates at age 1 or 28 days.

2.9.2.5. Effect of Curing on the Strength of RAC

RCA concrete properties are as sensitive to setting characteristics and initial strength gain (kinetics aspects of cement hydration) as normal concrete. Thus, the correlation between compressive strength and curing time in recycled concrete and normal concrete are similar. Figure 2.8, shows the strength development of RAC and normal concrete with curing time [35].

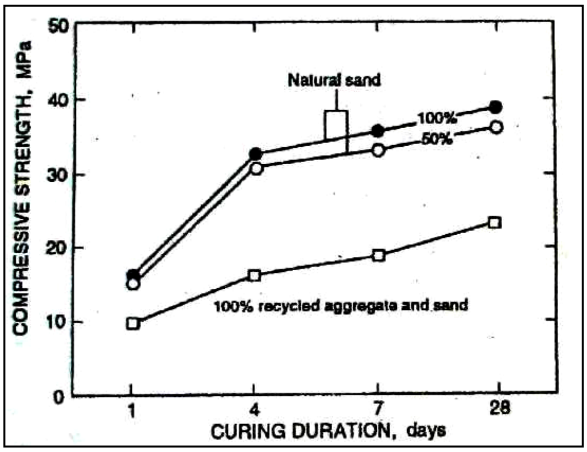

Figure 2.8: Strength Development Curves of RAC and Ordinary Concrete [35]

CHAPTER THREE

MATERIALS AND RESEARCH METHODOLOGY

3.1. General

The following methodology has been employed to achieve the objectives of the research:-

Stage 1: Literature Review

A comprehensive literature review is made to understand the previous efforts, which include the review of textbooks, periodicals and academic journals, seminar, conference and research papers.

Stage 2: Main Research

The methods followed to achieve the objectives are:-

- Tests were conducted using natural coarse aggregate, recycled coarse aggregate and a combination of both with same types of cement, fine aggregate, and water.
- The results were presented in graphical form and interpretation, and discussion was made on the research findings.
- An economical aspects of concrete produced using partial or full replacement of the natural coarse aggregate with recycled coarse aggregate was shown.
- Based on the findings conclusions are drawn, and recommendations are forwarded.

Stage 3: Writing the Research Report

This stage involves compiling and writing up the thesis.

NB: The results of this thesis work will be helpful for:-

- Educational institutions, which use the information for academic purposes.
- Private/governmental organizations or construction firms that use the data for construction purposes to minimize the use of the scarce resource of natural coarse aggregate and to produce comparable, even better quality of concrete.

3.2. Study Area

The study has been explored relevant information concerning the effect of recycled aggregate from concrete waste on compressive strength of C-25 concrete in Addis Ababa which is the capital city of Ethiopia. And also, Addis Ababa is the largest city in Ethiopia which lies at an altitude of 7,546 feet (2,300 meters) and located at 9°1'48″N 38°44'24″E9.03°N 38.74°E coordinates.

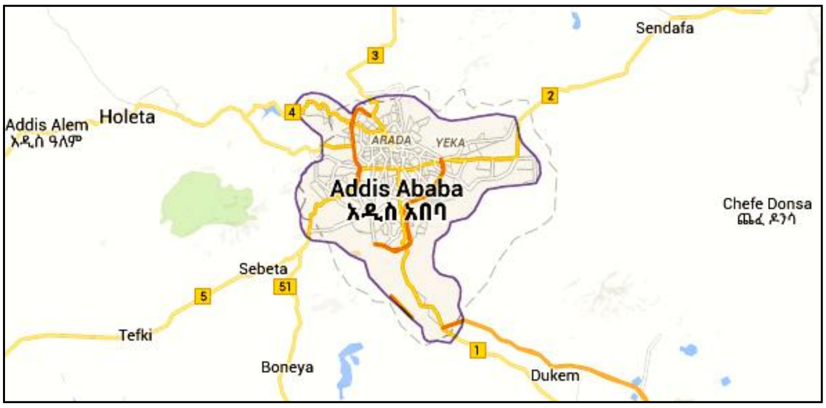

Figure 3.1: Geographical Map of Addis Ababa

3.3. Study Period

The research has been carried out for six months, and it was started in April 2016, and it was ended in September 2016, which was including from data collection up to the final paper submission.

3.4. Study Design

The experimental design was used for this research during the study period. To provide the most reliable proof the quality of the raw materials of concrete were studied, mainly quality of natural coarse aggregate, recycled coarse aggregate and a combination of both with the same type of cement, fine aggregate, and water and identified their effect on concrete properties such as workability and compressive strength.

3.5. Study Population

The sample frame or target population of this research was recycled aggregate which was produced by crushing the wastes of laboratory test cubes and cylinders by using 0.2 mm adjusted crusher.

3.6. Sampling Techniques

The sampling technique used for this research was a non-probability Sampling technique which is the purposive method. This sampling technique was proposed based on the information that the researcher has and the aim or goal of the researcher to be achieved.

3.7. Study Variables

- **Independent variable:-** Properties of recycled coarse aggregate and combination of both recycled and natural coarse aggregate (gradation, water absorption, unit weight, specific gravity and moisture content).
- **Dependent variables:-** Effects of recycled aggregate on compressive strength and workability.

3.8. Sources of Data

Both primary data sources and secondary data sources were used. Secondary data needed for this research was collected from different journals, book, and website during the literature review and primary sources of data for this study was conducted through recording the output of each laboratory tests.

3.8.1. Materials for Laboratory Experimental Works

- **Cement:-** "Dangote" Ordinary Portland Cement (OPC) whose Grade is 42.5R, which is locally available cement.
- **Recycled Coarse Aggregate:-** a 25mm maximum nominal size that was produced by using waste concrete cubes and cylinders in Ethiopian Construction Design and Supervision Works Corporation, Research Laboratory.
- **Natural Coarse aggregate:-** "Legehar" crushed stone which is a 25mm maximum nominal size that was commonly available in Addis Ababa (obtained from Goro site).
- **Sand:-** "Legehar" sand which was commonly available in Addis Ababa (obtained from Metehara).
- **Water:-** Drinkable water (potable water) obtained from Ethiopian Construction Design and Supervision Works Corporation, Research Laboratory water supply.

3.8.2. Procedure for Laboratory Experimental Works

Stage 1: Sample preparation stage

Figure 3.2: RA Production

Figure 3.3: RA Quartering

Stage 2: Laboratory tests on constituent of concrete

- Tests on coarse aggregate according to ASTM and ES Standard Procedures. (i.e., sieve analysis, water absorption, unit weight, specific gravity and moisture content)
- Tests on fine aggregate according to ASTM and ES Standard Procedures. (i.e., sieve analysis, water absorption, unit weight, specific gravity and moisture content)
- Tests on cement (i.e., Consistency test, initial and final setting time and fineness of cement test).

Figure 3.4: Specific Gravity for RA and NA

Figure 3.5: Unit Weight for Fine Aggregate

Stage 3: Concrete mix design preparation and mixing of concrete

- C-25 Concrete Mix-Design Prepared for each aggregate replacement ratio according to the ACI Methods. The slump test was done to check the workability of the concrete, and also nine samples of concrete cubes were cast for each replacement percent of recycled aggregate in which forty-five cubes samples were cast by using 150mm*150mm*150mm cube.

- De-molding Specimen and coding (identification) the sample concrete cubes done after 24 hrs. And curing of the concrete cube samples proceeded.

Figure 3.6: Preparation of Concrete Mix

Figure 3.7: De-molding and Coding

Stage 4: Compressive strength test

- After 7, 14 and 28 days cured of the concrete cube sample, the Compressive strength test of the concrete cubes was taken place by using Universal Testing Machine.

Figure 3.8: Curing of Concrete Cubes

Figure 3.9: Compressive Strength Test

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. General

As the principal objective of the research work is to study the effects of recycled coarse aggregate on the properties of concrete produced with it, analyses on the effects of recycled coarse aggregate, natural coarse aggregate and a combination of both were made.

Different mixes were targeting at characteristics compressive strength of 25 MPa were made. The influence of recycled coarse aggregate on the compressive strength development was studied. Accordingly, different values of strengths with the variable proportion of recycled, natural or a combination of the two were obtained.

All the physical tests of the materials and compressive strength tests were carried out in Ethiopian Construction Design and Supervision Works Corporation, Research Laboratory.

4.2. Material Properties

The physical characteristics of concrete making materials (Cement, Fine aggregate, Coarse aggregate, and Water) used for the research were examined, and appropriate mix design was made.

4.2.1. Cement

Table 4.1: Summarized Test Results for Dangote Cement (OPC)

Item no.	Description		Test Result
1	Fineness of Cement		95% passing
2	Specific Gravity		3.15
3	Cement Consistency Test	W/C ratio (%)	32%
		Water (gm)	160
		Penetration (mm)	9.3
4	Setting Time	Initial	48 min.
		Final	8hr. 38min.

Type of Cement used in the concrete mix was 'Dangote'- Ordinary Portland cement (OPC) whose Cement Grade 42.5R which is locally available cement. It was decided upon as the most suitable cement type since it is widely used in the construction industry at the current time.

Ethiopian standard recommends that the initial setting time for Portland cement not to be less than 45 minutes and the final setting time does not exceed 10 hours. From this experiment, we get the exact penetration value (of 25mm) at 48minutes and the final setting 8hrs 38min hence the initial setting time is approximately acceptable.

4.2.2. Aggregates Used for the Experiment

Aggregate samples were washed to minimize or eliminate the effects of impurities before used for concrete mix and sun-dried on a clean platform. All aggregates tests were done by the Ethiopian standards and conform to the ASTM requirements.

4.2.2.1. Properties of Coarse Aggregate

Table 4.2: Summarized Test Results for Coarse Aggregate

Item no.	Description		Test Results (With Different Replacement Levels)				
			100%NA + 0%RA	0%NA + 100%RA	50%NA + 50%RA	75%NA + 25%RA	25%NA + 75%RA
1	Maximum Aggregate Size (mm)	Max.	37.5	37.5	37.5	37.5	37.5
		Nominal	25	25	25	25	25
2	Specific Gravity	Bulk	2.91	2.36	2.62	2.74	2.57
		Bulk (SSD)	2.91	2.38	2.63	2.75	2.59
		Apparent	2.92	2.41	2.65	2.77	2.62
3	Unit Weight (kg/m^3)	Loose	1607	1507	1535	1564	1521
		Compacted	1721	1579	1650	1683	1607
4	Absorption Capacity		0.14%	0.73%	0.58%	0.32%	0.61%
5	Moisture Content		1.3%	1.6%	1.5%	1.4%	1.45%
6	Shape		Angular	Angular	Angular	Angular	Angular
7	Texture		Rough	Rough	Rough	Rough	Rough

The aggregates coming from the crusher site (Goro site) and produced in the laboratory was washed thoroughly and dried in air. The size of coarse aggregate used for experimental investigation was a maximum size of 37 mm diameter, and it was used in all the concrete mix designs because using a single type of coarse aggregate ensured that any variations in concrete properties were not due to this material. The test findings are shown above in Table 4.2, and also the summary of gradations is shown below in Figure 4.1.

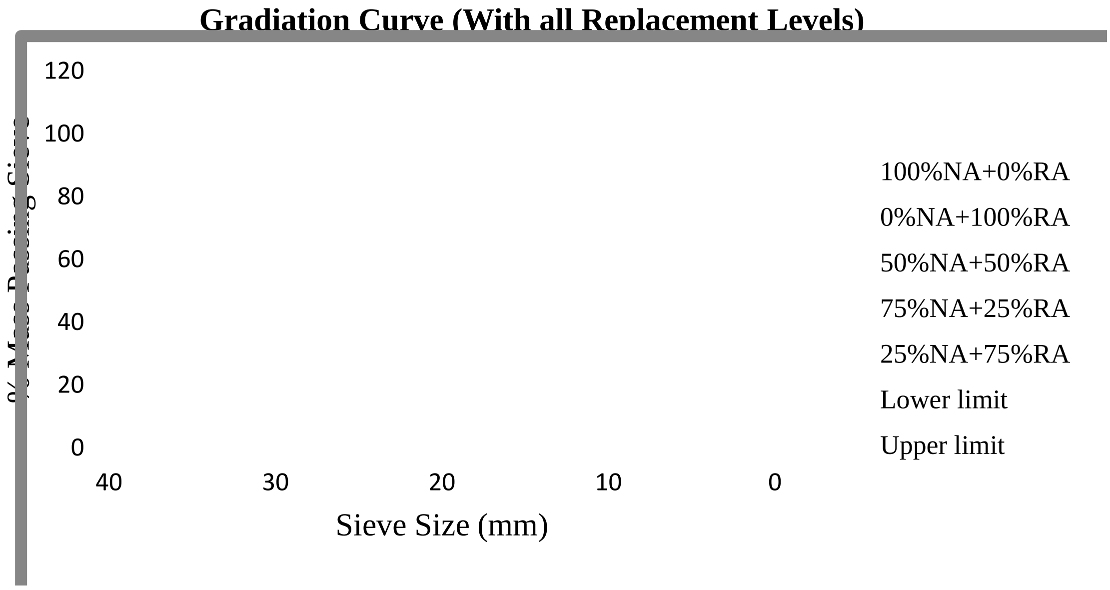

Figure 4.1: Gradation Curve of Coarse Aggregate With all Replacement Levels

Each replacement levels of coarse aggregate gradations together with their curve are shown in Appendix-A. The evaluation of the physical properties of coarse aggregate was made by ASTM C 136-96a (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates) which approximately satisfied the limitation.

4.2.2.2. Properties of Fine Aggregate

The fine aggregate used in the concrete productions was natural river sands. It was "Legehar" sand which was commonly available in Addis Ababa (originally obtained from Metehara). The fine aggregate was dried to be saturated, and surface dry (SSD) state before any test was carried out. Also the type of fine aggregate used for experimental investigation was the same for all the concrete mix designs because using a single type of fine aggregate ensured that any variations in concrete properties were not due to this material. The test findings and gradation curve are shown below in Table 4.3 and Figure 4.2.

Table 4.3: Summarized Test Results for Fine Aggregate

Item no.	Description		Test Results
1	Fineness Modulus		2.96
2	Silt Content		1.66
3	Absorption Capacity		1.3%
4	Moisture Content		2%
5	Specific Gravity	Bulk	2.3
		Bulk (SSD)	2.34
		Apparent	2.38
6	Unit Weight (kg/m^3)	Loose	1280
		Compacted	1340

The evaluation of the physical properties of fine aggregate was made by ASTM C 136-96a (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates) which was satisfied the limitation. As can be seen from the material test results, the lesser amount of fines is seen in the sand, and also the silt content of the sand was well below the permissible limit, which doesn't necessitate washing of the material. The summary of gradation is shown below in Figure 4.2.

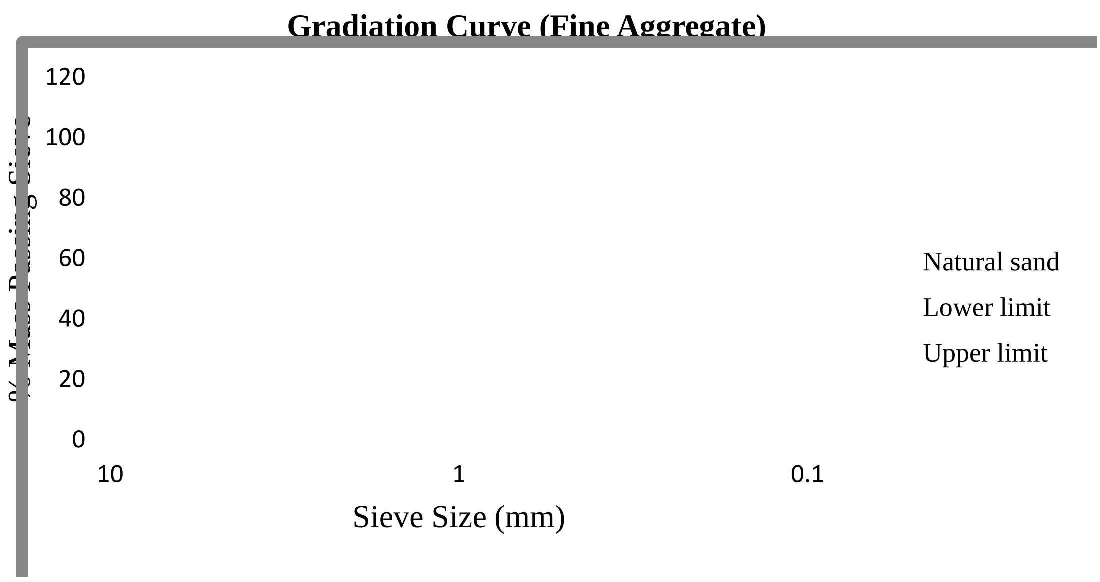

Figure 4.2: Gradation Curve of Fine Aggregate

4.2.3. Water

Drinkable water (potable water) obtained from Ethiopian Construction Design and Supervision Works Corporation, Research Laboratory, which is supplied from the Addis Ababa water supply and sewerage Authority, is used for all concrete mix.

4.3. Mix Proportions

To analyze the effects of recycled aggregate and a combination with natural aggregate at different replacement levels on properties of concrete, different mixes with a characteristic strength of normal strength (C-25) were prepared.

4.3.1. Concrete Mix Design

In this research work, the ACI Method of mix design was used in designing the mix proportions. On this bases, five different types of mix-design were prepared based on the recycled aggregate replacement levels which are; 100%NA+0%RA, 0%NA+100%RA, 50%NA+50%RA, 75%NA+25%RA and 25%NA+75%RA. For each concrete batch produced, it was decided that nine cubes were to be cast to allow for 7, 14 and 28 days test for the compressive strength test. As a result, the total of 45 concrete cube specimens was produced.

For all the concrete mixes, the same w/c ratio was used to ensure that any variations in the properties of the concrete were because of the recycled aggregate used and not any other external factors. A summary of mix proportions for 1m^3 of concrete mixes is shown below in Table 4.4.

Table 4.4: Summarized Mix Proportions

Coarse Aggregate Replacement Levels	Cement Type	W/C Ratio	Water (kg)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
100%NA+0%RA	Dangote OPC	0.50	160.57	358	766.16	1151
0%NA+100%RA	Dangote OPC	0.50	165.46	358	651.59	1059
50%NA+50%RA	Dangote OPC	0.50	164.12	358	708.88	1105
75%NA+25%RA	Dangote OPC	0.50	161.96	358	735.13	1126
25%NA+75%RA	Dangote OPC	0.50	164.61	358	720.81	1077

4.3.2. Preparation of Specimens and Mixing Procedure

Cement, which was produced locally by Dangote cement factory, was used throughout the mixing process and graded aggregate fulfilling Ethiopian standards which confirm to ASTM requirements are also used for mix preparation of the samples.

The preparation of the constituent materials was made by using weight measurement. After determining the relative amounts of materials be used for specimens, the aggregates and cement were mixed dry for one minute by using a mobile mixer. After the addition of water, all the material mixed for another two minutes. Then immediately after mixing the concrete, the workability is measured filling the standard slump cone with three layers and rodding each layer with 25 times according to ASTM C143. The specimens were then put on a firm and level surface of prepared molds and well compacted in three layers with the help of a tamping rode, by rodding each layer 25 times and also side compaction of the molds was carried out by using tire hammer. After compaction, the top surface is finished using a trowel.

The concrete mix was cast in the molds for the first 24 hours. After that, the concrete was removed from the molds and placed in a water bath at a temperature of $23 \pm 1^{o}C$ for curing to take place until the testing age was reached. After 7, 14 and 28 days of curing period the concrete cubes specimens were removed from the water bath then placed in dry surface until the specimens were surface dried, in the meantime the concrete cubes specimens were weighted to determine the unit weight of the concrete cube. Finally, the specimens were tested by standard compression testing machine.

4.4. Test Results and Discussion

It was known that the main objectives of the laboratory test specimens were to:-

- Determine if a suitable workability and strength can be achieved in concrete containing recycled coarse aggregate as a partial or complete replacement for natural coarse aggregate.
- Determine the rate of strength gain for the concrete with and without recycled coarse aggregate.

In the following sections, the test results are presented and evaluated in light of the requirements of concrete strength and workability.

4.4.1. Sieve Analysis

Fresh and hardened properties of concrete can be affected by the gradation of aggregate. Improper gradation can affect the air content, slump, and result in excessive voids in the hardened concrete. Sieve analyses of aggregates were performed according to ASTM. The upper and lower limits in ASTM C 136-96a were used to check the gradation standard of different types of aggregates used in this study.

In this study, various percentages of RCA were used as a substitute of natural coarse aggregate. It was also critical to check whether its gradation falls within the ASTM limits as their parent concrete source was unknown. The summarized gradation of RCA is illustrated in Figure 4.1, according to that all the aggregate satisfied the limitation on the sieve sizes 4.75mm, 19mm, 25mm and 37.5mm and failed to meet on the sieve sizes 9.5mm and 12.5mm. But as per ES C.D3.201, all the aggregates satisfied the limitation except sieve sizes 9.5mm. The results of sieve analysis for all aggregate samples used in the concrete mix are attached in Appendix-A.

4.4.2. Specific Gravity and Absorption Capacity

The specific gravity (relative density) and absorption capacity of natural and recycled coarse aggregates were determined according to ASTM C 127-88. The results of different types of aggregate properties tests are shown in Table 4.2. The specific gravity of RCA was 18.21% lower than that of natural coarse aggregate. It is due to the adhered mortar of RCA. The adhered mortar also increased the absorption capacity of RCA which was 5.21 times higher than that of natural coarse aggregate. The results of specific gravity, absorption and moisture content for all aggregate samples used in the mix are attached in Appendix-A.

4.4.3. Fresh Concrete Properties

Five different concrete mixes were designed with varying levels of RCA replacement. The RCA content used to replace a portion of the natural coarse aggregate varies from 25-100 % with a 0% RCA replacement as the control mix (Mix-1). Control mix made with conventional aggregate (NA) was required to facilitate the proper comparison between RCA concrete and NAC. The control specimens also facilitated as a reference for comparison. The results of the fresh concrete properties are provided below in Table 4.5. This table shows that the slump value of different concrete mixes remained unaffected due to the utilization of different replacement levels of RCA.

Table 4.5: Properties of Fresh Concrete

Mix-no.	Coarse Aggregate Replacement Levels	Slump (mm)
Mix-1	100%NA+0%RA	35
Mix-2	0%NA+100%RA	30
Mix-3	50%NA+50%RA	32
Mix-4	75%NA+25%RA	35
Mix-5	25%NA+75%RA	33

4.4.4. Hardened Concrete Properties

The most common tests carried out on concrete specimens is compressive strength test due to the fact that: a) structural design codes are based mainly on compressive strength of concrete; b) it is assumed that most of the important properties of concrete are directly related to compressive strength, and c) the test is easy and relatively inexpensive to carry out.

The compressive strength of the concrete specimens was determined by testing concrete cubes of size 150mm according to ASTM C39-90. All specimens were weighed and measured to determine the area of the cube and density of the concrete. The hardened properties of the concrete have been determined at the ages of 7, 14 and 28 days. At each age, a minimum of three specimens was tested to ensure the accuracy of test results. The use of recycled coarse aggregate by replacing wholly or partially the natural coarse aggregate had shown an effect on the compressive strength of concrete. The results are presented in Figure 4.3 and Table 4.6.

Compressive strength versus age graph is depicted in Figure 4.3 illustrating that as the percentage of RCA replacement increases the compressive strength decreases. Inadequate hydration and weak interfacial transition zone (ITZ) between the components of concrete cluster caused by the high amount of attached mortar on the surface of recycled aggregate are the major reasons behind the strength degradation of RAC with the increased replacement level of RCA [65]. It is also influenced by the low bulk density (unit weight) and adhered mortar of RCA.

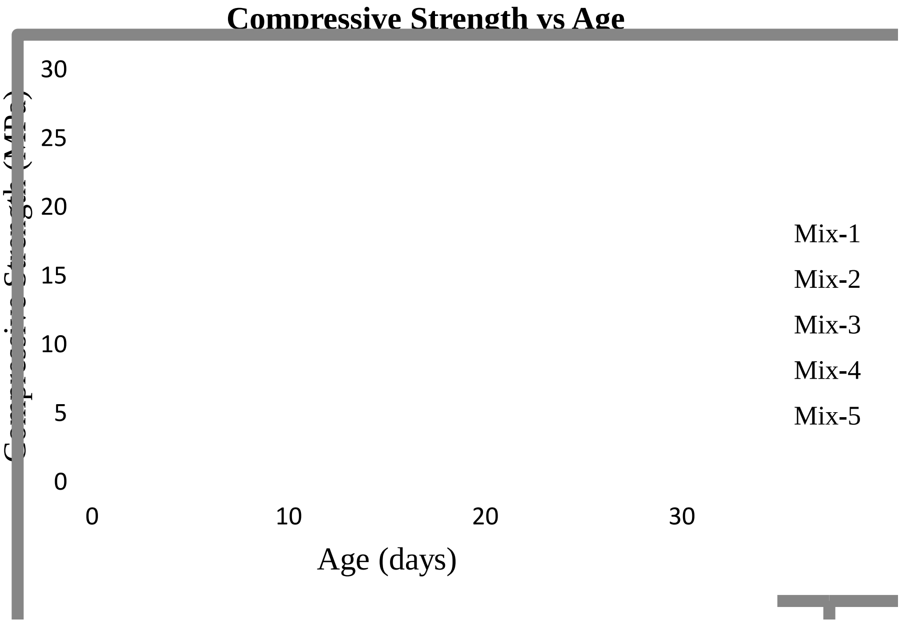

Figure 4.3: Compressive Strength of Concrete Made With Different Replacement Levels

On the other hand, 28 days' compressive strength of Mix-4 (75%NA+25%RA) was higher than Mix-1 (control). Mix-4 compressive strength was 28.1 MPa at 28 days which was 4.5% higher than the compressive strength of Mix-1 at the same age. This was due to the rough texture and higher absorption capacity of RCA. Presence of adhered mortar increases the absorption capacity of RCA and crushing of demolished concrete makes the aggregate surface rough. Both of these properties of RCA lead to better interlocking and bonding between the RCA and cement paste as compared to natural aggregate concrete [34].

Within the considered period the highest compressive strength was gained by Mix-4 (28.1 MPa) and the lowest was found for Mix-2 (20.6 MPa). The strength gaining pattern of Mix-3 and Mix-5 were almost similar except at the age of 7 days the compressive strength of Mix-5 was 9.2% lower than that of Mix-3. Table 4.6 below shows the results of compressive strength at different test days and their percent difference in strength gain concerning NAC (Mix-1) at the same respective age. The percent difference in compressive strength between the Mix-1 (control mix) and Mix-2 (0%NA+100%RA) at 28 days was 23.4%. This illustrated the true loss in strength as a result of replacing RCA with NA. As the replacement level of natural aggregate by RCA increases, the percent difference also increases.

Table 4.6: Summery of Mean Compressive Strength Results of Different Concrete Mixes

Mix-no.	Coarse Aggregate Replacement Levels	Age					
		7 day Strength		14 day Strength		28 day Strength	
Mix-1	100%NA+0%RA	15.4	Control	21.2	Control	26.9	Control
Mix-2	0%NA+100%RA	11.3	-26.6%	14.4	-32.1%	20.6	-23.4%
Mix-3	50%NA+50%RA	13.0	-15.6%	18.0	-15.1%	23.7	-11.9%
Mix-4	75%NA+25%RA	14.9	-3.2%	21.5	+1.4%	28.1	+4.5%
Mix-5	25%NA+75%RA	11.8	-23.4%	15.8	-25.5%	21.5	-20.1%

Note: the values in percent represent the difference in strength gain concerning Mix-1.

In comparing, the percent difference of different concrete mixes decreased at the 28th day which indicates that the RCA aggregate concrete is more favorable than NAC while considering its long term strength development. Besides, it may be attributed to the absorbed water of RAC that may work as a source of water to complete the hydration process [65].

4.5. Economic Aspects

It can be formulated that natural aggregate production in Ethiopia has been and will continue to be a local business based on easily accessible natural deposits. Most of the aggregate quarries are owned by the farmers on a private land, and they sell their product or lease the quarry to contractors for different works.

Due to the booming of construction activities in our country, natural resources and are increasingly depleted, and its cost is becoming increasingly high. Also as can be seen from the experience of aggregate manufacturing in Ethiopia, the true cost of aggregate material is influenced by various factors, yet production and transportation costs play the major role.

The benefits to the environment of using RAC include economic aspects, a reduction in environmental impacts and a saving of resources [13, 14]. The production of recycled concrete aggregate (RCA) is similar to the production of virgin aggregates. One of the primary differences occurs in the elimination of contaminants. Currently, in our country, demolished materials are dumped on land and not used for any purpose, but using of recycled aggregates from demolished wastes has significant economic advantages:-

- **Reduction in transportation costs:** Crushing the material on site, this process eliminates the transportation costs to import virgin aggregates.
- **Reduction in disposal costs:** Disposal of concrete and other waste construction materials by dumping or burial is a less attractive and more expensive option.
- **Save environment:** There is no excavation of natural resources and less transportation. Also less emission of carbon due to less crushing.
- **Save time:** There is no waiting for material availability.

Most importantly, it will reduce the use of limited natural aggregate, and it can provide a cost-effective solution regarding present and future concerns [11].

There may be overall considerable projects savings by using less virgin aggregate. Savings are induced from decreased hauling and disposal costs. An additional benefit is the recovery of the steel from the recycling process. There is also a potential for cost savings in many areas where aggregates are not locally available and have to be hauled long distances.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. General

Every year a huge amount of waste is generated due the construction and demolition of aging concrete structures, consequently increasing the environmental loads. Green concrete (recycled coarse aggregate concrete) produced using C&D waste offers a sustainable construction material that can reduce the overall impact of concrete production throughout its life cycle.

This study was carried out to investigate the effect of recycled aggregate from concrete waste on compressive strength of 25 MPa concrete. The target strength was considered along with different patterns of recycled aggregate utilizations (recycled concrete made with different RCA replacement levels). The performance of this concrete was compared with the control concrete mix. In this chapter, the conclusions and recommendations of this current study are discussed. Also, proposed for future study directions are also outlined here.

5.2. Conclusions

The specific gravity and absorption capacity of recycled coarse aggregate was 18.21% lower and 5.21 times higher than that of natural coarse aggregate, respectively.

The slump value of different concrete mixes remained unaffected due to the utilization of various replacement levels of RCA. However, as the percentage of RCA replacement level increases the compressive strength decreases.

The compressive strength of Mix-4 (75%NA+25%RA) achieved 4.5% higher strength than that of Mix-1 (control) at 28th day. This can be attributed to the rough texture and better interlocking properties RCA. Therefore, up to 25% RCA replacement level, it is possible to achieve similar or higher compressive strength than the natural coarse aggregate concrete.

The percent difference of different concrete mixes decreased at the 28th day which indicates that the long-term strength development of recycled coarse aggregate concrete is more favorable than natural aggregate concrete.

The use of recycled aggregate in the construction industry offers important economic advantages and helps to prevent unnecessary damages to the environment and provide optimum exploitation of the resources.

5.3. Recommendations

Detailed specifications for recycled aggregates including material properties and their appropriate applications should be provided and developed by local governments or councils to promote their use. Recycled materials should be promoted as secondary materials in structural constructions.

Since different supply sources will cause variation in quality, quality controls of recycled aggregates are required. The local authority should be established for controlling the quality and production of these materials.

The limited applications of recycled aggregates are attributable to their inferior quality. To enhance confidence for their use, existing techniques need to be further developed to improve its quality.

Introduction of financial incentives should be introduced to encourage the diversion of waste from landfill. A charge reflecting the environmental and social costs of landfilling could be placed on waste disposed in landfill. The proceeds from this charge could be spent to improve construction and demolition waste management and waste minimization initiatives.

Deliver long-term quality goals of recycling at the initial stage of the project; that is, at site planning, the waste sorting and recycling materials on-site.

5.7. Future Research Directions

1) Waste management and recycling situations in Addis Ababa.
2) Use of recycled aggregate for high-strength concrete.
3) Development of design guidelines and mixing approach for all classes of RA.

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APPENDIX-A: EXPERIMENTAL RESULTS

1. Properties of Coarse Aggregate

1.1. Gradation test

Table A.1.1: Sieve Analysis for Coarse Aggregate (Replacement level: 100%NA+0%RA)

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	ASTM Limit		ES Limit	
					Min	Max	Min	Max
37.5				100	100	100	95	100
25	437	8.64	8.64	91.37	90	100	-	-
19	1936.4	38.27	46.91	53.1	35	70	30	70
12.5	2026.4	40.05	86.96	13.05	25	55	-	-
9.5	489.5	9.67	96.63	3.38	10	40	10	35
4.75	157.5	3.11	99.74	0.27	0	10	0	5
Pan	13.3	0.27	100	0				
Total	5060.1							

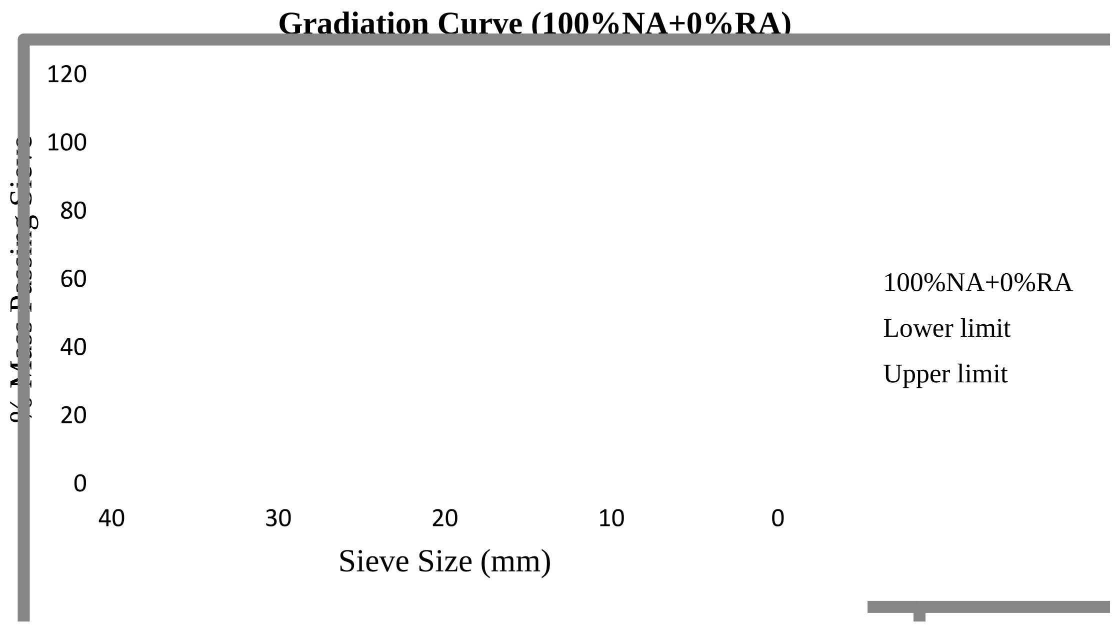

Figure A.1.1: Gradation Curve for Coarse Aggregate (Replacement level: 100%NA+0%RA)

Table A.1.2: Sieve Analysis for Coarse Aggregate (Replacement level: 0%NA+100%RA)

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	ASTM Limit		ES Limit	
					Min	Max	Min	Max
37.5				100	100	100	95	100
25	599.36	9.56	9.56	90.44	90	100	-	-
19	2522.22	40.23	49.79	50.21	35	70	30	70
12.5	2420.65	38.61	88.40	11.6	25	55	-	-
9.5	524.13	8.36	96.76	3.24	10	40	10	35
4.75	130.40	2.08	98.84	1.16	0	10	0	5
Pan	72.72	1.16	100	0				
Total	6269.48							

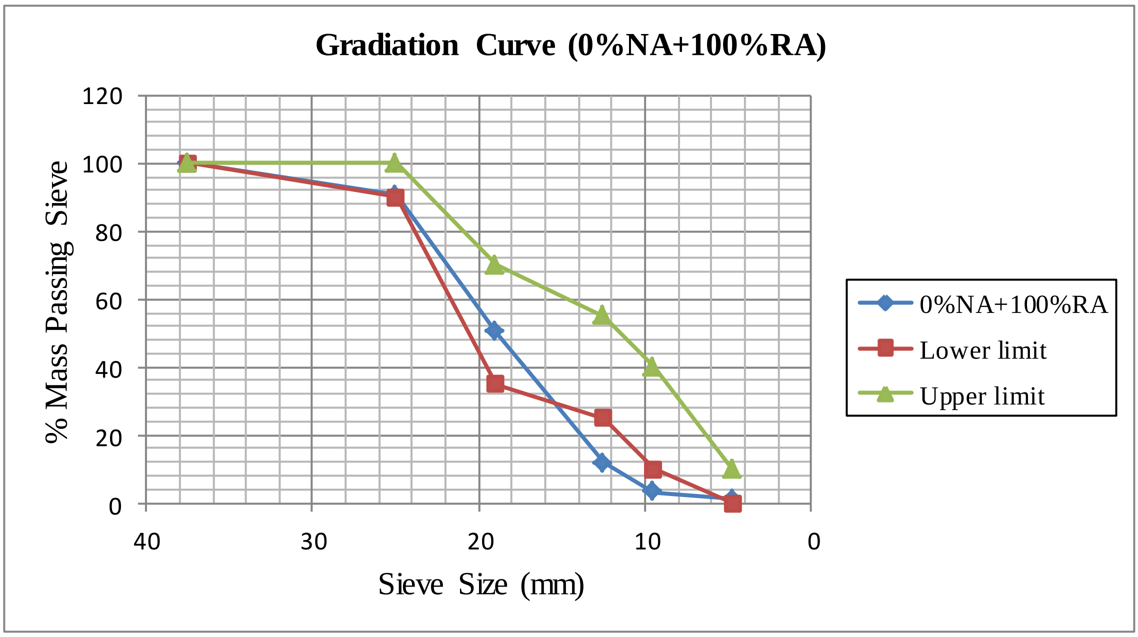

Figure A.1.2: Gradation Curve for Coarse Aggregate (Replacement level: 0%NA+100%RA)

Table A.1.3: Sieve Analysis for Coarse Aggregate (Replacement level: 50%NA+50%RA)

Sieve Size (mm)	**Weight Retained (gm)**	**Retained (%)**	**Cumulative Retained (%)**	**Cumulative Passing (%)**	**ASTM Limit**		**ES Limit**	
					Min	**Max**	**Min**	**Max**
37.5				100	100	100	95	100
25	337.70	9.10	9.10	90.90	90	100	-	-
19	1456.57	39.25	48.35	51.65	35	70	30	70
12.5	1459.53	39.33	87.68	12.32	25	55	-	-
9.5	279.07	7.52	95.20	4.80	10	40	10	35
4.75	133.22	3.59	98.79	1.21	0	10	0	5
Pan	44.90	1.21	100	0				
Total	3710.99							

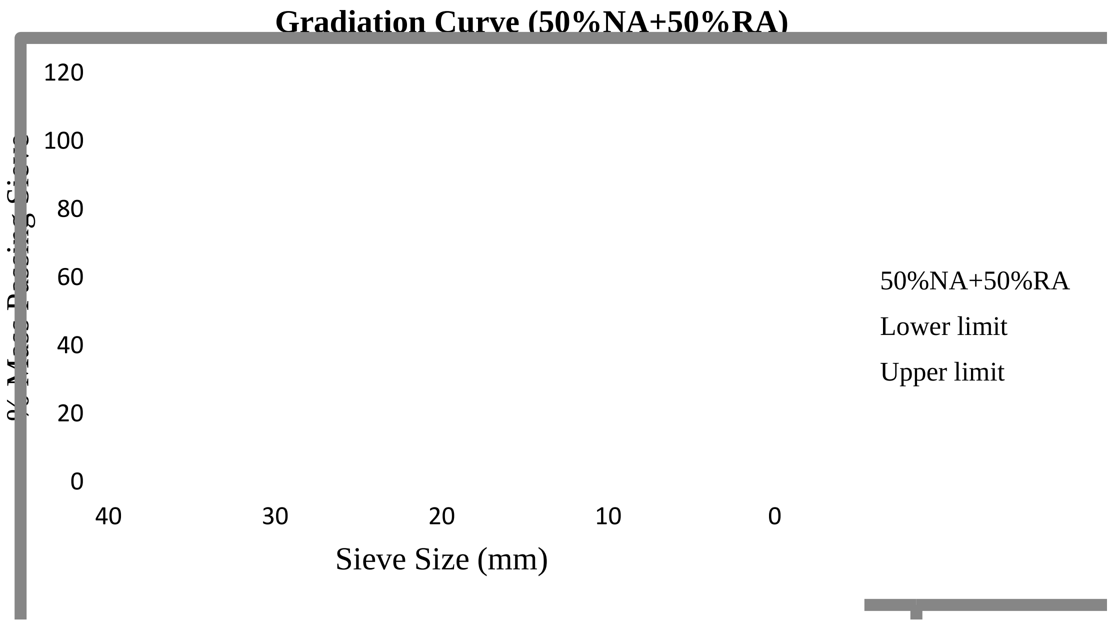

Figure A.1.3: Gradation Curve for Coarse Aggregate (Replacement level: 50%NA+50%RA)

Table A.1.4: Sieve Analysis for Coarse Aggregate (Replacement level: 75%NA+25%RA)

Sieve Size (mm)	**Weight Retained (gm)**	**Retained (%)**	**Cumulative Retained (%)**	**Cumulative Passing (%)**	**ASTM Limit**		**ES Limit**	
					Min	**Max**	**Min**	**Max**
37.5				100	100	100	95	100
25	339.61	8.61	8.61	91.39	90	100	-	-
19	1517.02	38.46	47.07	52.93	35	70	30	70
12.5	1578.94	40.03	87.10	12.9	25	55	-	-
9.5	354.21	8.98	96.08	3.92	10	40	10	35
4.75	121.49	3.08	99.16	0.84	0	10	0	5
Pan	33.13	0.84	100	0				
Total	3944.40							

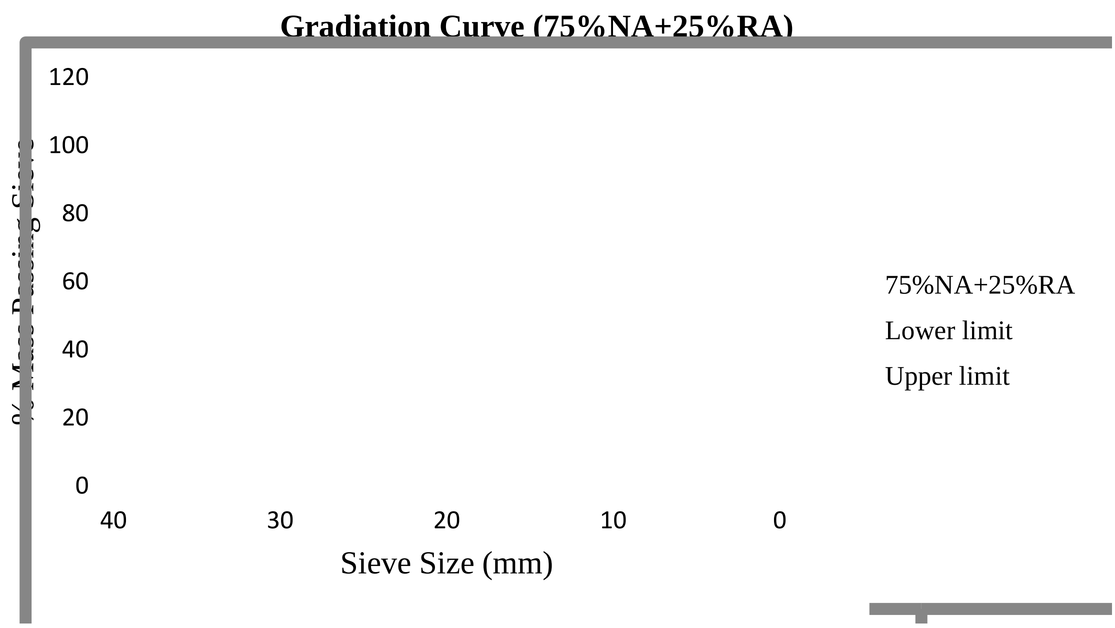

Figure A.1.4: Gradation Curve for Coarse Aggregate (Replacement level: 75%NA+25%RA)

Table A.1.5: Sieve Analysis for Coarse Aggregate (Replacement level: 25%NA+75%RA)

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	ASTM Limit		ES Limit	
					Min	Max	Min	Max
37.5				100	100	100	95	100
25	294.52	9.15	9.15	90.85	90	100	-	-
19	1286.87	39.98	49.13	50.87	35	70	30	70
12.5	1249.86	38.83	87.96	12.04	25	55	-	-
9.5	265.87	8.26	96.22	3.78	10	40	10	35
4.75	92.38	2.87	99.09	0.91	0	10	0	5
Pan	29.30	0.91	100	0				
Total	3218.80							

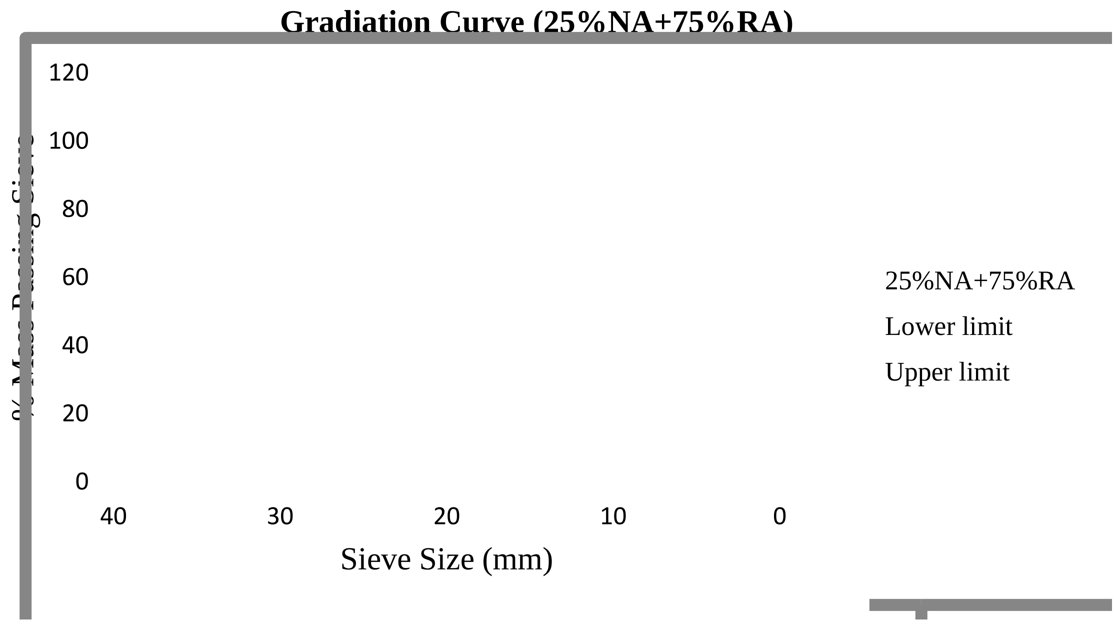

Figure A.1.5: Gradation Curve for Coarse Aggregate (Replacement level: 25%NA+75%RA)

1.2. Specific Gravity and Absorption test

For Replacement level: 100%NA+0%RA

- Weight of oven dry sample in air "A" (gm) = 992.2
- Weight of saturated surface dry specimen in air "B" (gm) = 993.6
- Weight of saturated surface dry specimen in water "C" (gm) = 652.7

Bulk Specific Gravity = A/(B-C) = 2.91

Bulk Specific Gravity (SSD) = B/(B-C) = 2.91

Apparent Specific Gravity = A/A-C = 2.92

Absorption Percent = (B-A/A)*100 = 0.14%

For Replacement level: 0%NA+100%RA

- Weight of oven dry sample in air "A" (gm) = 1316.5
- Weight of saturated surface dry specimen in air "B" (gm) = 1326.2
- Weight of saturated surface dry specimen in water "C" (gm) = 770.3

Bulk Specific Gravity = A/(B-C) = 2.36

Bulk Specific Gravity (SSD) = B/(B-C) = 2.38

Apparent Specific Gravity = A/A-C = 2.41

Absorption Percent = (B-A/A)*100 = 0.73%

For Replacement level: 50%NA+50%RA

- Weight of oven dry sample in air "A" (gm) = 1396.4
- Weight of saturated surface dry specimen in air "B" (gm) = 1403.7
- Weight of saturated surface dry specimen in water "C" (gm) = 871.2

Bulk Specific Gravity = A/(B-C) = 2.62

Bulk Specific Gravity (SSD) = B/(B-C) = 2.63

Apparent Specific Gravity = A/A-C = 2.65

Absorption Percent = (B-A/A)*100 = 0.58%

For Replacement level: 75%NA+25%RA

- Weight of oven dry sample in air "A" (gm) = 1234.2
- Weight of saturated surface dry specimen in air "B" (gm) = 1238.2
- Weight of saturated surface dry specimen in water "C" (gm) = 789

Bulk Specific Gravity = A/(B-C) = 2.74

Bulk Specific Gravity (SSD) = B/(B-C) = 2.75

Apparent Specific Gravity = A/A-C = 2.77

Absorption Percent = (B-A/A)*100 = 0.32%

For Replacement level: 25%NA+75%RA

- Weight of oven dry sample in air "A" (gm) = 1344
- Weight of saturated surface dry specimen in air "B" (gm) = 13522
- Weight of saturated surface dry specimen in water "C" (gm) = 831.2

Bulk Specific Gravity = A/(B-C) = 2.57

Bulk Specific Gravity (SSD) = B/(B-C) = 2.59

Apparent Specific Gravity = A/A-C = 2.62

Absorption Percent = (B-A/A)*100 = 0.61%

1.3. Unit Weight

For Replacement level: 100%NA+0%RA

- Weight of container "A" (kg) = 4.65
- Weight of container + sample "B" (kg) = 15.9……….. **Loosely Filled**
- Volume of container "C" (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1607

- Weight of container "A" (kg) = 4.65
- Weight of container + sample "B" (kg) = 16.7……….. **Compacted**
- Volume of container "C" (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1721

For Replacement level: 0%NA+100%RA

- Weight of container "A" (kg) = 4.65
- Weight of container + sample "B" (kg) = 15.2……….. **Loosely Filled**
- Volume of container "C" (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1507

- Weight of container "A" (kg) = 4.65
- Weight of container + sample "B" (kg) = 15.7……….. **Compacted**
- Volume of container "C" (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1579

For Replacement level: 50%NA+50%RA

- Weight of container "A" (kg) = 4.65
- Weight of container + sample "B" (kg) = 15.4……….. **Loosely Filled**
- Volume of container "C" (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1535

- Weight of container “A” (kg) = 4.65
- Weight of container + sample “B” (kg) = 16.2……….. **Compacted**
- Volume of container “C” (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1650

<u>For Replacement level: 75%NA+25%RA</u>

- Weight of container “A” (kg) = 4.65
- Weight of container + sample “B” (kg) = 15.6……….. **Loosely Filled**
- Volume of container “C” (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1564

- Weight of container “A” (kg) = 4.65
- Weight of container + sample “B” (kg) = 16.4……….. **Compacted**
- Volume of container “C” (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1683

<u>For Replacement level: 25%NA+75%RA</u>

- Weight of container “A” (kg) = 4.65
- Weight of container + sample “B” (kg) = 15.3……….. **Loosely Filled**
- Volume of container “C” (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1521

- Weight of container “A” (kg) = 4.65
- Weight of container + sample “B” (kg) = 15.9……….. **Compacted**
- Volume of container “C” (m^3) = 0.007

Unit Weight (kg/m^3) = B-A/C = 1607

1.4. Moisture Content

For Replacement level: 100%NA+0%RA

- Weight of original sample “A” (gm) = 2000
- Weight of oven dry sample “B” (gm) = 1974

Moisture Content (%) = (A-B/B)*100 = 1.3%

For Replacement level: 0%NA+100%RA

- Weight of original sample “A” (gm) = 2000
- Weight of oven dry sample “B” (gm) = 1968

Moisture Content (%) = (A-B/B)*100 = 1.6%

For Replacement level: 50%NA+50%RA

- Weight of original sample “A” (gm) = 2000
- Weight of oven dry sample “B” (gm) = 1970

Moisture Content (%) = (A-B/B)*100 = 1.5%

For Replacement level: 75%NA+25%RA

- Weight of original sample “A” (gm) = 2000
- Weight of oven dry sample “B” (gm) = 1972

Moisture Content (%) = (A-B/B)*100 = 1.4%

For Replacement level: 25%NA+75%RA

- Weight of original sample “A” (gm) = 2000
- Weight of oven dry sample “B” (gm) = 1971

Moisture Content (%) = (A-B/B)*100 = 1.45%

2. Properties of Coarse Aggregate

2.1. Gradation test

Table A.2.1: Sieve Analysis for Fine Aggregate

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	ASTM Limit		ES Limit	
					Min	Max	Min	Max
9.5				100	100	100	100	100
4.75	22.1	2.21	2.21	97.79	95	100	95	100
2.36	42.2	4.22	6.43	93.57	80	100	80	100
1.18	132.2	13.22	19.65	80.35	50	85	50	85
0.6	580	58	77.65	22.35	25	60	25	60
0.3	152.2	15.22	92.87	7.13	10	30	10	30
0.15	44.4	4.44	97.31	2.69	2	10	2	10
0.075	7.3	0.73	-	1.96	-	-	-	-
Pan	3.0	0.3	-	1.66				
Total	1000		296.12					

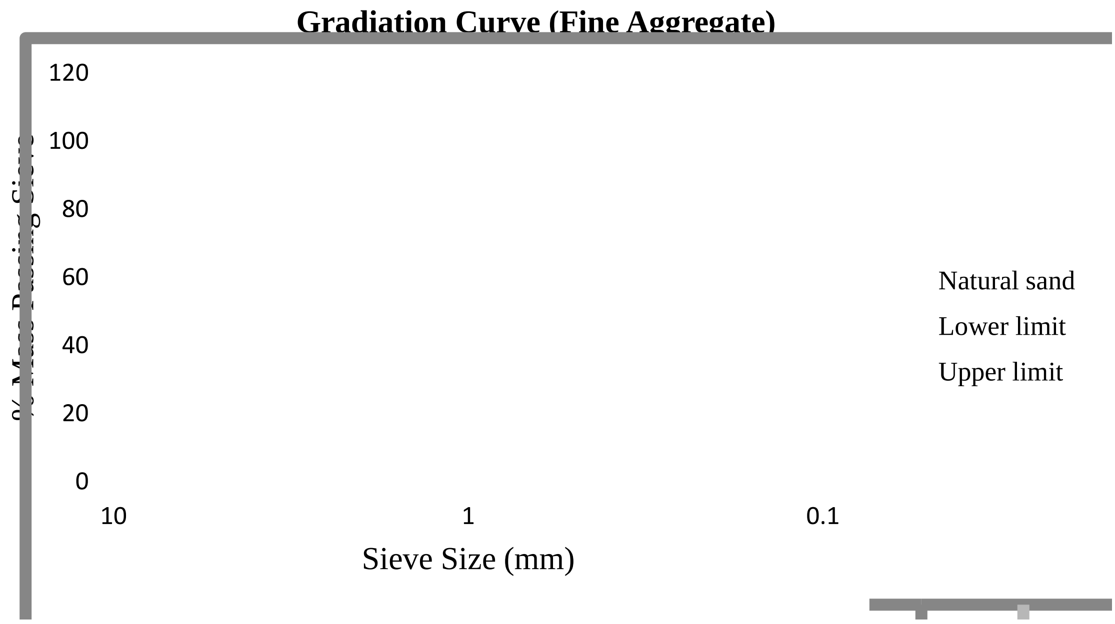

Figure A.2.1: Gradation Curve for Fine Aggregate

2.2. Fineness Modulus

$$FM = \frac{\sum \% \text{ Cumulative Coarser}}{100}$$

FM = 296.12/100 = 2.96

2.3. Silt Content

$$\text{Silt Content (\%)} = \frac{\text{Original Dry Mass (Total Wt) - Dry Mass after Washing}}{\text{Dry Mass after Washing}} * 100$$

Silt Content (%) = (1000 – 983.4)/1000 * 100 = 1.66%

2.4. Specific Gravity and Absorption

- Weight of oven dry sample in air "A" (gm) = 493.6
- Weight of pycnometer filled with water "B" (gm) = 1652
- Weight of pycnometer + sample + water "C" (gm) = 1938.5

Bulk Specific Gravity = A/(B+500-C) = 2.3

Bulk Specific Gravity (SSD) = 500/(B+500-C) = 2.34

Apparent Specific Gravity = A/(A+B-C) = 2.38

Absorption Percent = (500-A/A)*100 = 1.3%

2.5. Unit Weight

- Weight of container "A" (kg) = 3.01
- Weight of container + sample "B" (kg) = 6.85……….. **Loosely Filled**
- Volume of container "C" (m^3) = 0.003

Unit Weight (kg/m^3) = B-A/C = 1280

- Weight of container "A" (kg) = 3.01
- Weight of container + sample "B" (kg) = 7.03……….. **Compacted**
- Volume of container "C" (m^3) = 0.003

Unit Weight (kg/m^3) = B-A/C = 1340

2.6. Moisture Content

- Weight of original sample “A” (gm) = 500
- Weight of oven dry sample “B” (gm) = 490

Moisture Content (%) = (A-B/B)*100 = 2%

APPENDIX-B: MIX DESIGN

1. Mix Design-1 (For Replacement level: 100%NA+0%RA)

Table B.1.1: Required Material Information for Mix-1

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1721 kg/m^3	1340 kg/m^3
2	Fineness Modulus	-	2.96
3	Specific Gravity	2.91	2.34
4	Absorption	0.14%	1.3%
5	Moisture Content	1.3%	2%

- **Assuming Non-Air-Entrained Concrete**

Step 1.1: Choice of Slump

Based on the recommended values of slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding and segregation of concrete.

Step 1.2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 1.3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 1.4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- Effective water/cement ratio for specific compressive strength of 25 MPa is 0.50.

Step 1.5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.50 = 358 kg/m^3

Step 1.6: Estimation of Course Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- Volume of coarse aggregate for maximum nominal aggregate size of 25mm and finesse modulus of 2.96 is 0.66 m^3 (using linear interpolation).
- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1721*0.66 = 1135.86 kg/m^3

Step 1.7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3
- Cement = 358/(3.15*1000) = 0.11 m^3
- Coarse Aggregate = 1135.86/(2.91*1000) = 0.39 m^3
- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.39 m^3)*2.34*1000 = 751.14 kg/m^3

Step 1.8: Adjustment for Moisture Content

- Water = 179-[751.14*(0.02-0.013)]-[1135*(0.013-0.0014)] = 160.57 kg
- Coarse Aggregate = 1135.86*(1+0.013) = 1151 kg
- Fine Aggregate = 751.14*(1+0.02) = 766.16 kg

Step 1.9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Table B.1.2: Mix Proportions for Mix-1

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*160.57	5.46
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1151	39.13
Fine Aggregate	0.034*766.16	26.05

Step 1.10: Compressive Strength Test

Table B.1.3: Summery of Compressive Strength Results for Mix-1

No	Test Age (days)	Dimensions (m)			Weight (kg)	Volume (m^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (kg/m^3)
		L	W	H					
1	7	0.15	0.15	0.15	8.7	$(0.15)^3$	360	16.0	2577.8
2		0.15	0.15	0.15	8.5	$(0.15)^3$	354	15.7	2518.5
3		0.15	0.15	0.15	8.5	$(0.15)^3$	326	14.5	2518.5
Mean							347	15.4	
1	14	0.15	0.15	0.15	8.4	$(0.15)^3$	478	21.2	2488.9
2		0.15	0.15	0.15	8.4	$(0.15)^3$	490	21.8	2488.9
3		0.15	0.15	0.15	8.4	$(0.15)^3$	463	20.6	2488.9
Mean							477	21.2	
1	28	0.15	0.15	0.15	8.5	$(0.15)^3$	616	27.4	2518.5
2		0.15	0.15	0.15	8.5	$(0.15)^3$	605	26.9	2518.5
3		0.15	0.15	0.15	8.6	$(0.15)^3$	598	26.6	2548.1
Mean							606	26.9	

2. **Mix Design-2 (For Replacement level: 0%NA+100%RA)**

Table B.2.1: Required Material Information for Mix-2

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1579 kg/m^3	1340 kg/m^3
2	Fineness Modulus	-	2.96
3	Specific Gravity	2.38	2.34
4	Absorption	0.73%	1.3%
5	Moisture Content	1.6%	2%

- **Assuming Non-Air-Entrained Concrete**

Step 2.1: Choice of Slump

Based on the recommended values of slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 2.2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 2.3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 2.4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- Effective water/cement ratio for specific compressive strength of 25 MPa is 0.50.

Step 2.5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.50 = 358 kg/m^3

Step 2.6: Estimation of Course Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- The volume of coarse aggregate for a maximum nominal aggregate size of 25mm and finesse modulus of 2.96 is 0.66 m^3 (using linear interpolation).

- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1579*0.66 = 1042.14 kg/m^3

Step 2.7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3

- Cement = 358/(3.15*1000) = 0.11 m^3

- Coarse Aggregate = 1042.14/(2.38*1000) = 0.438 m^3

- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.438 m^3)*2.34*1000 = 638.82 kg/m^3

Step 2.8: Adjustment for Moisture Content

- Water = 179-[638.82*(0.02-0.013)]-[1042.14*(0.016-0.0073)] = 165.46 kg

- Coarse Aggregate = 1042.14*(1+0.016) = 1059 kg

- Fine Aggregate = 638.82*(1+0.02) = 651.59 kg

Step 2.9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Table B.2.2: Mix Proportions for Mix-2

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*165.46	5.62
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1059	36.01
Fine Aggregate	0.034*651.59	22.15

Step 2.10: Compressive Strength Test

Table B.2.3: Summery of Compressive Strength Results for Mix-2

No	Test Age (days)	Dimensions (m)			Weight (kg)	Volume (m^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (kg/m^3)
		L	W	H					
1	7	0.15	0.15	0.15	8.3	$(0.15)^3$	270	12.0	2459.3
2		0.15	0.15	0.15	7.9	$(0.15)^3$	239	10.6	2340.7
3		0.15	0.15	0.15	7.9	$(0.15)^3$	252	11.2	2340.7
						Mean	254	11.3	
1	14	0.15	0.15	0.15	8.0	$(0.15)^3$	336	14.9	2370.4
2		0.15	0.15	0.15	8.0	$(0.15)^3$	322	14.3	2370.4
3		0.15	0.15	0.15	8.0	$(0.15)^3$	317	14.1	2370.4
						Mean	325	14.4	
1	28	0.15	0.15	0.15	7.9	$(0.15)^3$	466	20.7	2340.7
2		0.15	0.15	0.15	7.9	$(0.15)^3$	452	20.1	2340.7
3		0.15	0.15	0.15	8.0	$(0.15)^3$	473	21.0	2370.4
						Mean	464	20.6	

3. **Mix Design-3 (For Replacement level: 50%NA+50%RA)**

Table B.3.1: Required Material Information for Mix-3

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1650 kg/m^3	1340 kg/m^3
2	Fineness Modulus	-	2.96
3	Specific Gravity	2.63	2.34
4	Absorption	0.58%	1.3%
5	Moisture Content	1.5%	2%

- **Assuming Non-Air-Entrained Concrete**

Step 3.1: Choice of Slump

Based on the recommended values of slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 3.2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 3.3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 3.4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- Effective water/cement ratio for specific compressive strength of 25 MPa is 0.50.

Step 3.5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.50 = 358 kg/m^3

Step 3.6: Estimation of Course Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- Volume of coarse aggregate for maximum nominal aggregate size of 25mm and finesse modulus of 2.96 is 0.66 m^3 (using linear interpolation).

- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1650*0.66 = 1089 kg/m^3

Step 3.7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3
- Cement = 358/(3.15*1000) = 0.11 m^3
- Coarse Aggregate = 1089/(2.63*1000) = 0.414 m^3
- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.414 m^3)*2.34*1000 = 694.98 kg/m$^{\mathbf{3}}$

Step 3.8: Adjustment for Moisture Content

- Water = 179-[694.98*(0.02-0.013)]-[1089*(0.015-0.0058)] = 164.12 kg
- Coarse Aggregate = 1089*(1+0.015) = 1105 kg
- Fine Aggregate = 694.98*(1+0.02) = 708.88 kg

Step 3.9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Table B.3.2: Mix Proportions for Mix-3

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*164.12	5.58
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1105	37.57
Fine Aggregate	0.034*708.88	24.10

Step 3.10: Compressive Strength Test

Table B.3.3: Summery of Compressive Strength Results for Mix-3

No	Test Age (days)	Dimensions (m)			Weight (kg)	Volume (m^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (kg/m^3)
		L	W	H					
1	7	0.15	0.15	0.15	8.4	$(0.15)^3$	299	13.3	2488.9
2		0.15	0.15	0.15	8.5	$(0.15)^3$	305	13.6	2518.5
3		0.15	0.15	0.15	8.5	$(0.15)^3$	273	12.1	2518.5
						Mean	292	13.0	
1	14	0.15	0.15	0.15	8.2	$(0.15)^3$	391	17.4	2429.6
2		0.15	0.15	0.15	8.4	$(0.15)^3$	415	18.4	2488.9
3		0.15	0.15	0.15	8.5	$(0.15)^3$	409	18.2	2518.5
						Mean	405	18.0	
1	28	0.15	0.15	0.15	8.4	$(0.15)^3$	551	24.5	2488.9
2		0.15	0.15	0.15	8.4	$(0.15)^3$	508	22.6	2488.9
3		0.15	0.15	0.15	8.4	$(0.15)^3$	539	24.0	2488.9
						Mean	533	23.7	

4. **Mix Design-4 (For Replacement level: 75%NA+25%RA)**

Table B.4.1: Required Material Information for Mix-4

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1683 kg/m^3	1340 kg/m^3
2	Fineness Modulus	-	2.96
3	Specific Gravity	2.75	2.34
4	Absorption	0.32%	1.3%
5	Moisture Content	1.4%	2%

- **Assuming Non-Air-Entrained Concrete**

Step 4.1: Choice of Slump

Based on the recommended values of slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 4.2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 4.3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 4.4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- Effective water/cement ratio for specific compressive strength of 25 MPa is 0.50.

Step 4.5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.50 = 358 kg/m^3

Step 4.6: Estimation of Course Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- The volume of coarse aggregate for a maximum nominal aggregate size of 25mm and finesse modulus of 2.96 is 0.66 m^3 (using linear interpolation).

- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1683*0.66 = 1110.78 kg/m^3

Step 4.7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3
- Cement = 358/(3.15*1000) = 0.11 m^3
- Coarse Aggregate = 1110.78/(2.75*1000) = 0.403 m^3
- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.403 m^3)*2.34*1000 = 720.72 kg/m^3

Step 4.8: Adjustment for Moisture Content

- Water = 179-[720.72*(0.02-0.013)]-[1110.78*(0.014-0.0032)] = 161.96 kg
- Coarse Aggregate = 1110.78*(1+0.014) = 1126 kg
- Fine Aggregate = 720.72*(1+0.02) = 735.13 kg

Step 4.9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Table B.4.2: Mix Proportions for Mix-4

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*161.96	5.51
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1126	38.28
Fine Aggregate	0.034*735.13	24.99

Step 4.10: Compressive Strength Test

Table B.4.3: Summery of Compressive Strength Results for Mix-4

No	Test Age (days)	Dimensions (m)			Weight (kg)	Volume (m^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (kg/m^3)
		L	W	H					
1	7	0.15	0.15	0.15	8.4	$(0.15)^3$	348	15.5	2488.9
2		0.15	0.15	0.15	8.3	$(0.15)^3$	331	14.7	2459.3
3		0.15	0.15	0.15	8.4	$(0.15)^3$	326	14.5	2488.9
						Mean	335	14.9	
1	14	0.15	0.15	0.15	8.4	$(0.15)^3$	492	21.9	2488.9
2		0.15	0.15	0.15	8.4	$(0.15)^3$	469	20.8	2488.9
3		0.15	0.15	0.15	8.4	$(0.15)^3$	487	21.6	2488.9
						Mean	483	21.5	
1	28	0.15	0.15	0.15	8.7	$(0.15)^3$	617	27.4	2577.8
2		0.15	0.15	0.15	8.4	$(0.15)^3$	652	29.0	2488.9
3		0.15	0.15	0.15	8.3	$(0.15)^3$	629	28.0	2459.3
						Mean	633	28.1	

5. **Mix Design-5 (For Replacement level: 25%NA+75%RA)**

Table B.5.1: Required Material Information for Mix-5

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1607 kg/m^3	1340 kg/m^3
2	Fineness Modulus	-	2.96
3	Specific Gravity	2.59	2.34
4	Absorption	0.61%	1.3%
5	Moisture Content	1.45%	2%

- **Assuming Non-Air-Entrained Concrete**

Step 5.1: Choice of Slump

Based on the recommended values of slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 5.2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 5.3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for the slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 5.4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- Effective water/cement ratio for specific compressive strength of 25 MPa is 0.50.

Step 5.5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.50 = 358 kg/m^3

Step 5.6: Estimation of Course Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- Volume of coarse aggregate for maximum nominal aggregate size of 25mm and finesse modulus of 2.96 is 0.66 m^3 (using linear interpolation).

- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1607*0.66 = 1060.62 kg/m^3

Step 5.7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3

- Cement = 358/(3.15*1000) = 0.11 m^3

- Coarse Aggregate = 1060.62/(2.59*1000) = 0.409 m^3

- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.409 m^3)*2.34*1000 = 706.68 kg/m^3

Step 5.8: Adjustment for Moisture Content

- Water = 179-[706.68*(0.02-0.013)]-[1060.62*(0.015-0.0061)] = 164.61 kg

- Coarse Aggregate = 1060.62*(1+0.015) = 1077 kg

- Fine Aggregate = 706.68*(1+0.02) = 720.81 kg

Step 5.9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Table B.5.2: Mix Proportions for Mix-5

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*164.61	5.59
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1077	36.62
Fine Aggregate	0.034*720.81	24.51

Step 5.10: Compressive Strength Test

Table B.5.3: Summery of Compressive Strength Results for Mix-5

No	Test Age (days)	Dimensions (m)			Weight (kg)	Volume (m^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (kg/m^3)
		L	W	H					
1	7	0.15	0.15	0.15	8.0	$(0.15)^3$	268	11.9	2370.4
2		0.15	0.15	0.15	8.2	$(0.15)^3$	274	12.2	2429.6
3		0.15	0.15	0.15	8.1	$(0.15)^3$	253	11.2	2400.0
						Mean	265	11.8	
1	14	0.15	0.15	0.15	8.2	$(0.15)^3$	344	15.3	2429.6
2		0.15	0.15	0.15	8.2	$(0.15)^3$	366	16.3	2429.6
3		0.15	0.15	0.15	8.2	$(0.15)^3$	359	15.9	2429.6
						Mean	356	15.8	
1	28	0.15	0.15	0.15	8.0	$(0.15)^3$	492	21.7	2370.4
2		0.15	0.15	0.15	7.9	$(0.15)^3$	486	21.6	2340.7
3		0.15	0.15	0.15	7.9	$(0.15)^3$	477	21.2	2340.7
						Mean	485	21.5	

APPENDIX-C: SAMPLE PHOTOS

Figure C.1.1: Aggregate Crushing Machine

Figure C.1.2: RCA Production

Figure C.1.3: RAC Quartering

Figure C.1.4: NAC Quartering

Figure C.1.5: RAC Splitting and Quartering

Figure C.1.6: Sand Splitting and Quartering

Figure C.1.7: RAC Sieve Analysis

Figure C.1.8: Soaking for Specific Gravity

Figure C.1.9: RAC+NAC Unit Weight

Figure C.1.10: Oiling Empty Molds

Figure C.1.11: Concrete Mixing

Figure C.1.12: Concrete Production

Figure C.1.13: Measuring Slump

Figure C.1.14: Concrete Casting and Compacting

Figure C.1.15: Marking

Figure C.1.16: Curing

Figure C.1.17: Surface Drying and Weighing

Figure C.1.18: Compressive Strength Test