Sudan University of Science and Technology

College of Graduate Studies

Use of Recycled Concrete as Coarse Aggregate for High Strength Concrete

إستخدام الخرسانة المعاد تدويرها كركام خشن للخرسانة عالية المقاومة

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master in Civil Engineering (Structural Engineering**)**

Submitted by**:**

Samah Elhadi Hussein Ahmed

Supervised by:

Dr. Aliya Osman Mohamed

1440-2018

الآيـــــــة

قال تعالى :

(وَمِنَ النَّاسِ وَالدَّوَابِّ وَالْأَنْعامِ مُخْتَلِفٌ أَلْوانُهُ كَذلِكَ إِنَّما يَخْشَى ٱللّه مِنْ عِبادِهِ الْعُلَماءُ إِنَّ ٱللّه عَزِيزٌ غَفُورٌ)

صدق الله العظيم

[سورة فاطر : 28]

Dedication

I dedicate this research to the pure spirit of my beloved Dad, you had been greater support of me in life, and Allah grants him mercy and forgiveness.

ACKNOWLEGEMENT

We thanks to Allah the creator the maker the most merciful everything in the heavens and the earth glorify him.

Firstly, I would like to thank **Dr. Aliya Osman Mohamed** for her advice, support, assistance and patient guidance, throughout the period of this study.

I also want to thanks **Eng. Salah eldeen. A. Yousif**, for his valuable assistance, by giving me a permission to use his own laboratory for all tests during the testing phase of the study.

Then, to my family and friends, thanks for all the time, patience and undying support provided until this work was completed.

Finally, I would like to thank all the people who contributed in some way to the work described in this thesis.

ABSTRACT

This study is concerned with the production of high strength concrete using recycled concrete aggregates as alternative to natural aggregates. The study includes also the determination of the proportions, characteristics and components of concrete mixes required for production and use in multiple applications at suitable prices.

The basic materials used in this research (ordinary Portland cement, natural aggregates, recycled concrete aggregates, natural valley sand, local tap water as well as super plasticizer additive). The proportions of these materials were carefully selected to improve the strength concrete, also conduct various laboratory tests of the materials to ensure their quality. Then the design of concrete mixes with different proportions of recycled concrete aggregate was carried out in order to achieve the high strength concrete.

The selected materials, techniques and steps of mixing designs and mixing proportions were discussed for high strength concrete using four types of mixes, with mix proportions(1:1.57:2.73) for mix A, and, mix proportions(1:1.3:2.3) for mix B,C, and D.

Mix (A) NAC; ordinary Portland cement 450 kg/m³ were used with natural uncrushed aggregates 1040 kg/ m³, and natural sand with fineness modulus 3.23.

Mix (B); ordinary portland cement 450 kg/m³ was used with 30% recycled concrete aggregate 1040 kg/m³ by adding different levels of super plasticizer (0,3, 5, 8) litters per cubic meter, natural sand, with fineness modulus 3.23.

Mix (C); ordinary portland cement 450 kg/m³ was used with 50% recycled concrete aggregate 1040 kg/m³ by adding different levels of super plasticizer (0,3, 5, 8) litters per cubic meter, natural sand, with fineness modulus 3.23.

Mix (D); ordinary portland cement 450 kg/m³ was used with 100% recycled concrete aggregate 1040 kg/m³ by adding different levels of super plasticizer (0,3, 5, 8) litters per cubic meter, natural sand, with fineness modulus 3.23.

These mixtures were tested to evaluate the mechanical properties to have high strength concrete .Then discussed the results obtained from the tests according to the results obtained, for mix B the highest strength concrete in 28 days obtained was 42.3N/mm². for the mix containing 3 liters per cubic meter of super plasticizer with a water ratio of 0.40. Then mix C found that the highest strength of concrete in 28 days was obtained 43 N / mm ² for the mix containing 5 liters per cubic meter of super plasticizer with a water ratio of 0.34. For mix D the highest strength concrete in 28 days obtained was 43 N/mm² for the mix containing 8 liters per cubic meter of super plasticizer with a water ratio of 0.35.

The results of the mechanical tests of concrete in this study found that the recycled concrete can be a complete replacement for aggregates in the works that require a concrete strength of 40 N/ mm². Recycled aggregate cannot be applied in the high strength structure. But can be applied in the normal strength structure under the condition that does not involve a lot of handling works the ingredients must be selected and processed very carefully with the use of the additive.

مستخلص

تختص هذه الدراسة بإنتاج خرسانة عالية المقاومة بإستخدام الخرسانة المعاد تدويرها كبديل للركام الخشن. الدراسة تشمل ايضا تحديد نسب وخصائص ومكونات الخلطة الخرسانية المطلوبة لإنتاجها واستخدامها في تطبيقات متعددة بأسعار مناسبة، وذلك يمكن تحقيقه بالاستفادة القصوى من النفايات و الموارد المهدرة و الحفاظ علي البيئة.

المواد الأساسية المستخدمة في هذا البحث (الأسمنت البورتلاندي العادي، الركام الطبيعي،الخرسانة المعاد تدويرها، رمل الوديان الطبيعي، ماء الشرب بلإضافة إلى مضاف السوبر بلاستيسيزر). وقد تم إختيار نسب هذه المواد بعناية من أجل تحسين مقاومة الخرسانة، وإجراء اختبارات معملية مختلفة للمواد للتاكد من جودتها.ومن ثم تصميم خلطات خرسانية من الخرسانة المعاد تدويرها بنسبة مختلفة وذلك لتحقيق أعلى مقاومة للخرسانة. حيث تم مناقشة المواد المختارة وتقنيات وخطوات التصاميم الخلطة ونسب الخلط، للخرسانة عالية المقاومة .وذلك باستخدام نوعين من الخلطات بنسب هي:

خلطة باستخدام الركام الطبيعي (A): تم استخدام 450 كج/م^3 من الأسمنت البورتلاندي العادي، مع 1040كج/م^3 من الركام الطبيعي، مع رمل طبيعي ذو معامل نعومة 3.23.

الخلطة (B): تم استخدام 450 كج/م^3 الأسمنت البورتلاندي العادي مع1040كج/م^3 من الخرسانة معادة التدوير بنسبة 30%، باضافة نسب مختلفة من مضاف السوبر بلاستيسيزر(8،5،3،0) لتر للمتر المكعب، مع رمل طبيعي ذو معامل نعومة 3.23.

الخلطة (C): تم استخدام 450 كج/م^3 الأسمنت البورتلاندي العادي، مع1040كج/م^3 من الخرسانة معادة التدوير بنسبة 50%، باضافة نسب مختلفة من مضاف السوبر بلاستيسيزر (8،5،3،0)لتر للمتر المكعب، مع رمل طبيعي ذو معامل نعومة 3.23.

الخلطة (D): تم استخدام 450 كج/م^3 الأسمنت البورتلاندي العادي، مع1040كج/م^3 من الخرسانة معادة التدوير بنسبة 100%، باضافة نسب مختلفة من مضاف السوبر بلاستيسيزر(8،5،3،0) لتر للمتر المكعب، مع رمل طبيعي ذو معامل نعومة 3.23.

هذه الخلطات تم اختبارها لتقييم الخواص الميكانيكية للحصول علي خرسانة عالية المقاومة. ثم نوقشت هذه النتائج التي تم الحصول عليها من الاختبارات وتبين أن:-

وفقا للنتائج المتحصل عليها للخلطة B وجد ان أعلى مقاومة للخرسانة في 28 يوم كانت 42.3 نيوتن/مم^2 للخلطة التي تحتوي على 3 لتر للمتر المكعب من السوبر بلاستيسيزر مع نسبة ماء للأسمنت 0.4. اما الخلطة C وجد ان أعلى مقاومة للخرسانة في 28 يوم كانت 43 نيوتن/مم^2 للخلطة التي تحتوي على 5 لتر للمتر المكعب من السوبر بلاستيسيزر مع نسبة ماء للأسمنت0.34 . و الخلطة D وجد ان أعلى مقاومة للخرسانة في 28 يوم كانت 43 نيوتن/مم^2 للخلطة التي تحتوي على 8 لتر للمتر المكعب من السوبر بلاستيسيزر مع نسبة ماء للأسمنت0.35

من خلال نتائج الاختبار الميكانيكي للخرسانة في هذه الدراسة، وجد ان الخرسانة المعاد تدويرها تصلح ان تكون بديل جزئي او كامل للركام في الاعمال التي تطلب مقاومة خرسانة 40 نيوتن/مم^2، يمكن تطبيق الخرسانة المعاد تدويرها للحصول علي مقاومة عالية تحت الشرط الذي لا ينطوي على الكثير من أعمال الخرسانة والصب يدويا ويجب اختيار وتجهيز المكونات بعناية فائقة مع استخدام المضاف.

List of Symbols and Abbreviations

Symbol	Definition
ACI	American Concrete Institute
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS EN	British Standard European Norm
CDW	Construction and Demolition Waste
DVR	Direct Volume Replacement
DWR	Direct Weight Replacement
E	Elastic Modulus
Ec	Elastic Modulus of Concrete
EMV	Equivalent Mortar Volume
FC	Characteristic Strength
Fm	Mean Strength
f_{cu}	Ultimate Strength
HSC	High Strength Concrete
ITZ	Interfacial Transition Zone
K	Constant
L	Litter
NA	Natural Aggregate
NAC	Natural Aggregate Concrete
OPC	Ordinary Portland Cement
PCC	Plain Cement Concrete
RCA	Recycled Concrete Aggregates

RCC	Reinforce Cement Concrete
RA	Recycled aggregates
RM	Residual Mortar
S	Standard Deviation
SP	Super Plasticizer
Wc	Unit Weight of Concrete
W_f	Water content of fine aggregate
W_c	Water content of coarse aggregate
W/C	Water Cement Ratio
σ	Compressive Stress

List of Contents

List of Tables

List of Figures

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Any construction activity requires several materials such as concrete, steel, brick, stone, glass, clay, mud, wood, and so on. However, the cement concrete remains the main construction material used in construction industries. For its suitability and adaptability with respect to the changing environment, the concrete must be such that it can conserve resources, protect the environment, economize and lead to proper utilization of energy. To achieve this, major emphasis must be laid on the use of wastes and byproducts in cement and concrete used for new constructions.

The utilization of recycled concrete aggregate is particularly very promising as 75 per cent of concrete is made of aggregates. The use of recycled concrete aggregates from construction and demolition wastes is showing prospective application in construction as alternative to primary (natural) aggregates. Research on the usage of waste construction materials is very important since the materials waste is gradually increasing with the increase of population and increasing of urban development. The reasons that many investigations and analysis had been made on recycled aggregate are because recycled aggregate is easy to obtain and the cost is cheaper than virgin aggregate.

The use of concrete in structures consumes millions of tons of aggregates. Since earth is the source of the aggregates (either natural or crushed), then obtaining these amounts would have an adverse effect on the environment. Furthermore, demolishing concrete structures and dumping the concrete rubbles would aggravate the problem. Therefore, it becomes necessary to recycle the crushed concrete and use it as coarse aggregate in new concrete mixes.

By using the recycled crushed concrete aggregate, the consumption of natural aggregate can be reduced. Construction industry today is amongst the five largest in the world and at the current rate of growth, it is slated to be amongst the top two in the next century. The effect of using Recycled Concrete Aggregate (RCA) on the basic properties of normal concrete is studied. First, recycled concrete properties have been determined and compared to those of normal aggregates. Except for absorption, there was not a significant difference between the two. Later, recycled concrete were introduced in concrete mixes. In these mixes, natural coarse aggregate was partly or totally replaced by recycled concrete.

Results showed that the use of recycled concrete has an adverse effect on the workability of concrete. Such an effect can be easily retained by using plasticizers. In addition, concrete strength has been reduced by 5% to 25% depending on the percent of the normal aggregate replaced by recycled concrete and the water-cement ratio. With respect to the tensile strength, recycled concrete was slightly lower.

In this rapid industrialized world, recycling construction material plays an important role to preserve the natural resources. Recycling of concrete is important because it helps to promote sustainable development in the protection of natural resources, and reduces the disposal of demolition waste from old concrete.

Recycling concrete wastes is important in getting rid of demolished concrete, which increases with time and use. For example, the amounts of demolished buildings in Europe amount to around 180 million tons per year.

1.2 Problem Statement

As we know that concrete is the main construction material across the world and the mostly used in all types of civil engineering works. As aggregate represents about 70-80% of concrete components so it will be beneficial to recycle concrete for construction works and to solve the environmental problems, To minimize the problem of excess of waste material it is a good step to utilize the recycled concrete provide that the desired final product will meet the standards. The cost of recycled concrete may be less than 20 to 30 % less than natural aggregate in some regions.

1.3 Significance of the Study

The significant of this exploration are as follow:

1. Recycled concrete can reduce the amount of using natural aggregate
2. The researches will help towards the application of the use of recycled concrete as coarse aggregate.
3. Re-use the recycled concrete and give more economical sources for raw materials and apply the environment friendly concept.

1.4 Research Hypotheses

1. What is the goal of recycling solid waste and reconstruction?
2. Is it expected to target high strength by using recycled concrete aggregates?

3. How we can produce high strength concrete mixes with recycled concrete aggregates?

1.5 Research Objectives

The important aim for this on-going study is to determine the high strength characteristic of recycled concrete as aggregate for application in high strength structural concrete, which will give a better understanding on the properties of concrete with recycled aggregate, where can be an alternative material to coarse aggregate in structural concrete. The objectives of this research program can be listed as follows:

(1) To review existing research and established scientific knowledge in using of recycled concrete aggregate.

(2) To specify the most economical and practical combination of recycling materials.

(3) To produce concrete using RCA as a 100% replacement for natural aggregates and assess wide ranges of properties in fresh and hardened states and establish concrete performance.

(4) To have an adequate knowledge about HSC special materials and their mechanism of work using RCA, properties of HSC and its mix design procedures and proportions.

(5) To demonstrate through full scale construction demonstrations that quality recycled concrete aggregates can be produced at commercial level and be suitable for use in a range of concrete applications.

1.6 Research Methodology

These studies support the possibilities of applying RCA in the production of new mixes of high strength concrete. The method been followed of this is figure (1.1) shown the Flow chart of Research:

1. Review and search of recycled aggregates.

2. Construction of concrete samples using recycled aggregates by two tests (use of chemical additive - replacing cement type).

3. Investigation and laboratory testing on high strength concrete with recycled aggregate.

4. Analyze results, include conclusion drawn from study and recommendation for future work.

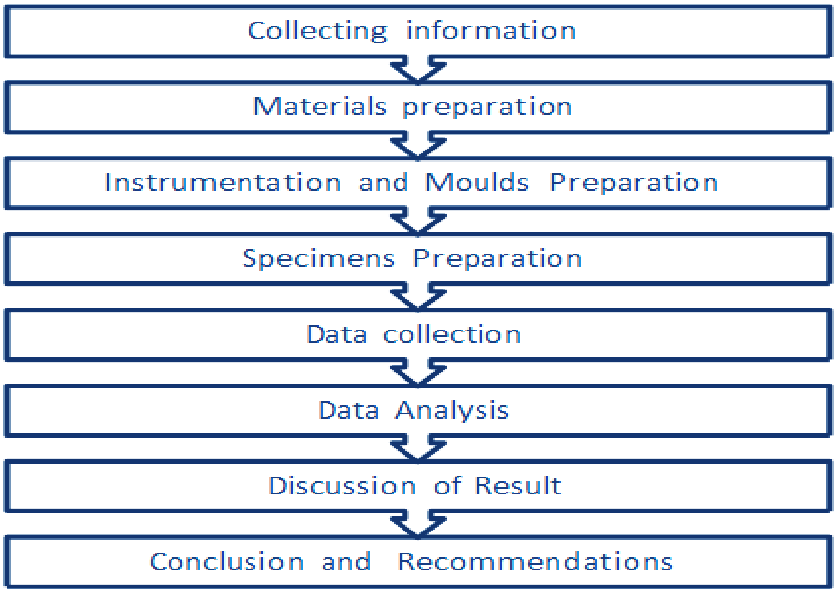


Figure (1.1): Flow chart of research

1.7 Thesis Layout

This thesis is structured in the following format:

Chapter One: Contains a general introduction, problem statement, signification of the study, research hypotheses, research objectives, and research methodology.

Chapter Two: Provides a review of relevant literature review on sustainability, and overview of recycling process, as well as comparison of recycled aggregate and natural aggregate. This chapter also discussed the previous investigation and testing done with recycled aggregate**.**

Chapter Three: Includes the preliminary information on concrete components and proprieties, sources and manufacturing of cement, qualities and affections of compressive strength of concrete and materials selection and mix design procedures and proportions.

Chapter Four: Describes the experimental tests according to American method ACI carried out in order to obtain the required data, included testing material procedure and steps (cement testing, coarse aggregate testing; fine aggregate testing and mix design steps).

Chapter Five: Results and discussions of all experimental results obtained from the testing procedures.

Chapter Six: Contains the conclusions of the research and recommendations on further work

CHAPTER TWO

Review on Sustainability and Recycled Materials

CHAPTER TWO

Review on Sustainability and Recycled Materials

Building and construction industry worldwide use natural resources and the disposal of construction and demolition debris to a landfill in very large quantities, Each of these practices harmful to the environment is no longer considered sustainable at current levels. And many governments around the world are policies that promote actively aims to reduce the use of primary resources and increased reuse and recycling (Angelos Koulouris 2005).

2.1 Sustainable development:

The definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet them", .Involving sustainable development and quality assurance of a better life for everyone either now or in the future, which is the basic principle, Planning underpinning, all local development documents, it must ensure that they are in accordance with the principles set out in the sustainable development strategy in the united nation as shown in figure (2.1) (Harlem 1987)

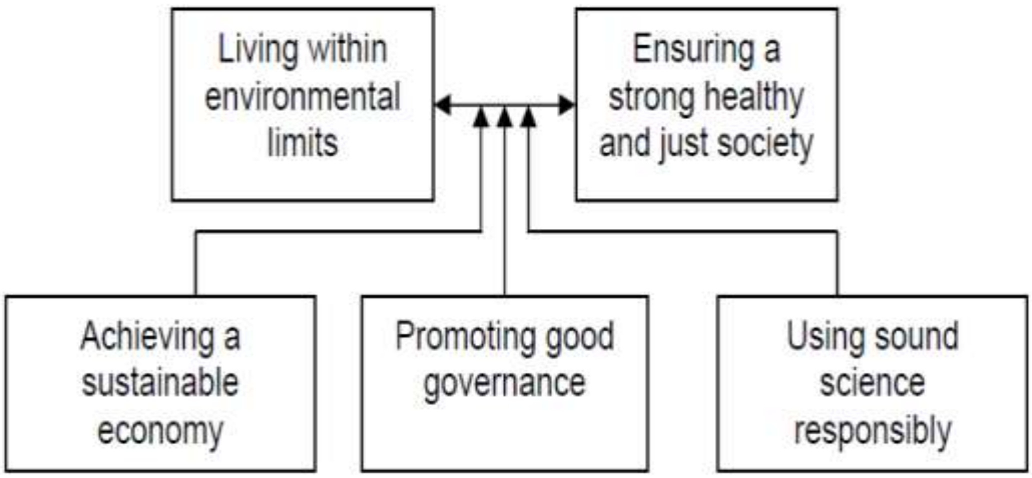


Figure (2.1): UN Sustainable development Strategy.

In 1987 by the world commission of the United Nations conference on environment and sustainable development means to achieve several conditions: to maintain the overall balance, and respect for the environment, and to prevent the depletion of natural resources.

2.2 Recycling of solid waste and reconstruction

Over the past few years, the environment has become a major concern all over the world puts more pressure on the need to increase recycling and reduce disposal to landfill sites. The investigation on recycling of concrete waste was initiated by Glushge in Russia in 1946, and in the following years, a number of experimental investigations have been carried out (Xiao et al 2006) Under the Kyoto Protocol, 85% of waste recycled by 2013.

The main reason for concern about the environmental impacts that total extraction of natural is having. The loss of the usual rural landscape, visual disturbance, noise and dust, increased traffic and blasting sound and vibration are the main problems associated with aggregate extraction. To minimize these problems while causing the least possible hindrance to operate and meet the total demand, many researchers suggested that more use should be made of waste and recycled materials (Sherwood 1995).

It must also pay attention to the state of the climate in the place where recycling will be in it, such as humidity, wind speed and direction, because it affects the working machinery on the one hand and on environmental safety on the other hand, the sounds and dust resulting from the recycling process may create a new environmental problem if the operation near residential areas unoccupied or that the wind can be transferred to some waste even if it is also not close to housing.

2.3 Construction and demolition waste

As the population grows and improves its lifestyle, a proportional increase of the consumption of natural resources and energy occurs. Therefore, and due to the inevitable consequences of this increase, a change of mentality towards the environment has been witnessed. One of the sectors with greater responsibility in the consumption of natural resources and generation of waste is the construction industry, (EEA 2009). The Construction and Demolition Waste (CDW) is undoubtedly one of the main focuses of attention in the search for a sustainable construction.

One of the ways or recovering CDW is turning them into aggregates, which are capable of various applications. Aggregates European Association estimates an annual production of 3000 million ton of aggregates in the European Union, out of which the recycled aggregates (RA) generated represent around 5%.

Since concrete is one of the main constituents of CDW (Oikonomou 2005), an important part of RA corresponds to crushed concrete. These RA can result from the demolition of concrete structures or the crushing of precast elements or lab specimens. Presently there are diverse applications of the recycled concrete aggregates (RCA), in foundations, pavements, soils stabilization, and reinforced concrete, among others (Hansen1992).

In this rapid industrialized world, recycling construction material plays an important role to preserve the natural resources. Recycling of concrete is important because it helps to promote sustainable development in the protection of natural resources, and reduces the disposal of demolition waste from old concrete .Old concrete and masonry that have “reached the end of the road” can be recycled and used not only as aggregate for new concrete, but also for a number of other applications in construction .For example, since 1982 the ASTM definition of coarse aggregate has included crushed hydraulic cement concrete, and the definition of manufactured sand includes crushed concrete fines similarly, the U.S. army corps of engineers and the Federal Highway Administration encourage the use of recycled concrete as aggregate in their specifications and guides.

CDW can be considered a renewable material. This leads to a simple four-step closed loop life cycle of the materials used in construction, as shown in figure (2.2) (Tushar et al).

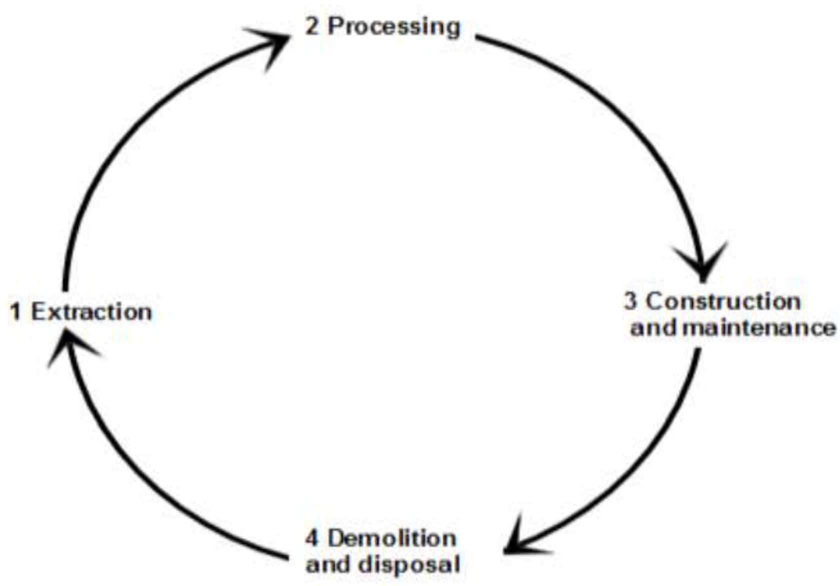


Figure (2.2) Life cycles of construction materials

2.4 Using of recycled concrete as aggregate

Construction industry today is amongst the largest industries in the world and at the current rate of growth, it is slated to be amongst the top two in the next century. Aggregates supply has also emerged as a problem in some of the metropolis. With the shortage as likely seen today the future seems to be in dark for the construction sector. The requirements of natural aggregates are not only required to fulfill the demand for the upcoming projects, but also are the needs of the extensive repairs or replacements required for the existing infrastructure and dilapidated buildings built few decades back (Nelson and Shing Chai 2004).

The use of recycled concrete aggregates in concrete can be useful to protect the environment. The construction of roads, bridges and buildings has been increasing since the beginning of the last century, especially in densely populated areas. Recycling is the act of processing the used material for use in creating new product. The usage of natural aggregate is getting more and more intense with the advanced development in infrastructure area. In order to reduce the usage of natural aggregate, recycled concrete aggregate produced from recycled concrete can be used as the replacement materials.

Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris, these materials are generally from buildings, roads, bridges, and sometimes even from catastrophes, such as wars and earthquakes figure (2.3) show the recycled concrete materials (Nelson and Shing Chai 2004).

Figure (2.3) Recycled concrete materials

Recycled concrete aggregate is used to fill multiple purposes as: concrete kerb and gutter mix, granular base course materials, embankment fill materials, paving blocks, backfill materials, and building blocks etc.

There are many advantages through using the recycled aggregate. The advantages that occur through usage of recycled aggregate are listed below:

1. Environmental considerations

the environmental impact of construction and sustainable development: Portland cement concrete has much to offer resource efficient minimizing depletion of our natural resources, fresh concrete is used on basis (whatever is left over can be reused or reclaimed as aggregate), and old hardened concrete can be recycled and used as aggregate in new concrete or as fill and pavement base material.

2. Economic factors

Aggregates are important components for all the construction activities, most municipalities impose tight environmental controls over opening of new aggregate sources; increase of the cost of starting new quarries is increased. For demolition contractors, landfill space is limited and can be far away, Hence, the disposal of old concrete and masonry is costly. Also, dumping fees will most likely rise as construction debris increases and the number of accessible landfills decreases. Furthermore, the cost and transport distances of conventional aggregates could continue to increase as sources grow scarce (Nelson and Shing Chai, 2004).

3. Job Opportunities

Unemployment is one of the problems experienced by many countries. There will be many people involved in this new technology, such as specialized and skilled persons, general workers, drivers and etc.

4. Sustainability

The amount of waste materials used for landfill will be reducing through usage of recycled aggregate.

5. Market is wide

According to Environmental Council of Concrete Organization, The markets for recycled concrete aggregate are wide; can be used for sidewalk, curbs, bridge substructures and superstructures, concrete shoulders, residential driveways, general and structural fills. It also mentioned that recycled concrete aggregate can be used in sub bases and support layers such as un stabilized base and permeable bases, (Nelson and Shing Chai 2004).

2.5 Procedures to produce the recycled concrete aggregates

Processing procedure of the demolition waste and consequent sorting during the demolition of buildings, are getting the waste with a different configuration, so basically it depends on the strategy used for demolition. Waste must go through the initial phase separation that key it is separated components. And it consists of the remaining part of the demolition waste by waste concrete, bricks, And it similar like (stone). This represents the bulk of the demolition waste (over 80%) and that It controls the recycling process.

Two categories of plants are available for treating CDW and processing them into recycled aggregates: stationary and mobile ones. Stationary facilities are recycling plants located in an enclosed site authorized to recycle CDW, through the use of fixed equipment and conducting no off-site operations. Mobile recycling machinery and equipment are instead sent to worksites to recycle waste at the source. Modules that allow recycling operations directly on the site furnish the same equipment (screens, crushers, magnetic separators, etc.) (EEA 2011).

The raw materials used in the production of recycled aggregates come from demolition of pavements and buildings. This material is broken into large pieces and transported to the processing plant. It must be clean, free of contaminants like steel reinforcing bars, wood and soil. Then it passes through three main phases crushing, sizing and blending. The processes of recycling of construction and demolition wastes are similar to those producing natural aggregate both have the same equipment, crushers, screens, removal impurities and transportation facilities.

Fixed plants may have the disadvantage of being far from the site where demolition takes place, but generally, the system is more productive than the mobile one (and therefore the burden associated to the increased transport is compensated by the better quality of the product and the higher capacity of the plant). Stationary plants generally process also natural aggregates and have higher capacity than mobile ones, allowing limit the processing cost of the recycled aggregate (economies of scale). Plants can accept different types of CDW, depending essentially, based on how clean it is and the materials it contains. The standard classification of the input material is clean, mixed and dirty. Preliminary cleaning can be performed through separation (typically in dry conditions), to eliminate impurity e.g. wood, plastic and paper. Magnetic separation is also useful to remove steel and iron from the input material.

The same processes take place in both the plants, aiming to separate the contaminants from the bulk stony material, and to obtain a useful grading: separation, crushing, and separation of ferrous elements, screening, and decontamination and removal of impurity (i.e. wood, paper, plastics…) (EEA 2011).

The first operation to be done aims to reduce the debris dimensions, which have to be used to feed easily the crusher. Then, several operations, mainly mechanical actions, are conducted to reduce again the size of the material, being grinding, squeezing and impacting. Primary and secondary crushing could be performed, with milling operations, to achieve the required grading. At the end of the productive chain, washing could also be done, even though this procedure is not very common due to the difficulties in the produced mud disposal (both in terms of costs and administrative procedures). A simplified scheme of a CDW treatment plant is represented in figure (2.4).

Figure (2.4): Scheme of a CDW treatment plant

2.6 Compressive strength to be achieved using recycled concrete as aggregates

Recycled concrete to occupy a role in high strength concrete it is necessary that the composition in the first place provides the necessary compressive strength. Various research works carried out on recycled aggregates have pointed the following parameters to be addressed to achieve the required strength according to ACI.

1. Adhered mortar.
2. Water absorption.
3. Size of aggregates.
4. Strength of parent concrete.
5. Age of curing.
6. Interfacial transition zone.
7. Ratio of replacement.
8. Moisture state in which used.
9. Impurities present.
10. Controlled environmental condition.

2.7 Previous studies about recycled concrete aggregates

The applications of recycled aggregate in the construction area are very extensive. Various research based on recycled concrete has been carried out in the past to investigate the possibility of replacing the natural with the total equivalent recycled, especially coarse aggregate in new concrete mixes in different proportions.

The data in this chapter were considered a prerequisite for all those who contributed to the recycling of concrete wastes. Much may be known here on a large scale. This briefing will be presented here to set the scene.

Ahmad S Subaih et al (2005) concrete results showed that 25MP and 30MP strength can be reached using recycled aggregate as a coarse material. Using more than 35% of fine recycled aggregate causes an obvious weakness in the concrete strength.

Jianzhang Xiao et al (2006) stated that the compressive strength of recycled concrete as aggregate generally decrease with increasing recycled concrete aggregate contents. For a recycled concrete aggregate replacement percentage equals 100%, the elastic modulus is reduced by 45%.

Nelson and Shing Chai (2004) stated that the workability was good and can be satisfactorily handled for 0% recycled concrete aggregate to 80% recycled concrete and with more percentage replacement of recycled concrete used in the concrete specimen, the percentage of tensile strength remained are gradually decreasing.

Ramadan y.al Khatib et al (1999) concrete made with recycled aggregates has a compressive strength about 22%-32% less than the strength of the concrete made with natural aggregates.

Rifat Rustom et al (2007) concrete made with recycled aggregate produced from construction and demolition waste has a compressive strength (28 days) about 27% - 30% less than the strength of the concrete made with natural aggregates.

CHAPTER THREE

CONCRETE COMPONENTS AND PROPERTIES

CHAPTER THREE

CONCRETE COMPONENTS AND PROPERTIES

3.1 Introduction

For more than 200 years, concrete has been accepted for its long lasting and dependable nature. In addition to durability and dependability, concrete also has superior energy performance, is flexible in design, is affordable, and is relatively environmentally friendly It can be expected that concrete will be needed to increase industrialization and urbanization while protecting the environment (Cement Association of Canada 2004). To do this; the concrete industry should consider recycling industrial by-products such as fly ash safely and economically. When industrial by-products replace cement, even up to 70%, in concrete, the environmental impact improves along With the energy efficiency and durability of concrete (Naik and Kraus 1999).

This chapter presents the Theoretical Studies of the materials used to procedure associated with this research work. And summarizes the properties of all the components used in the various concrete mixes. Concrete mix is comprised of coarse aggregates usually gravel, fine aggregates usually sand, cement, water, and any necessary additives.

3.2 Concrete components:

Concrete is basically a mixture of three components:

(i) Cement paste→ consisted Portland cement and water (admixtures).

(ii) Mortar→ is fine aggregate

(iii) Concrete →is coarse aggregate

The paste, usually comprised of Portland cement and water, binds the aggregates,

(Sand and gravel or crushed stone) into a rocklike mass as the paste hardness, because; of the chemical reaction of the cement and water. Figure (3.1) show the components of concrete.

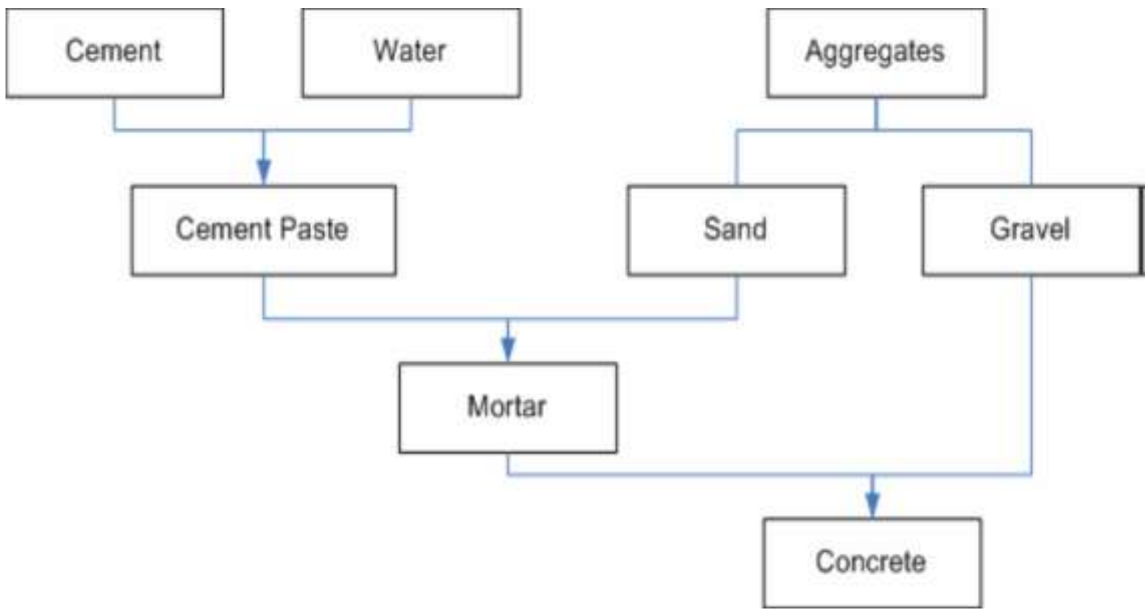


Figure (3.1): Concrete components

The most widely used construction material is concrete, commonly made by mixing Portland cement with sand, crushed rock, and water. Concrete is a mixture of sand, gravel, crushed rock, and/or other aggregates that are held together by a hardened paste of cement and water. The properties of concrete vary depending on the ingredients used and their proportions in the mix. Generally, concrete mix consists of 25-to 40 % cement paste, 25 to 40 % aggregate, and 7 to 15 % concrete. When cement and water are combined, hydration (liberation of heat) occurs. The strength of concrete begins with hydration and increases as long as hydration continues. After 28 days, the relative strength increase levels off.

3.3 Materials of the concrete component

3.3.1 Cement

Cement can be described as a material with adhesive and cohesive properties that makes it capable of binding entire metal fragments. This definition includes a wide variety of sedimentation materials.

For constructive purposes, the term "cement" is limited to interconnections used in stones, sand, bricks, blocks, etc. The main components of this type of cement are lime compounds, and cement that are important in the manufacture of concrete from the property of the development and hardening under the water by virtue of chemical reaction with it, and thus, called hydraulic cement.

The hydraulic cement is mainly composed of silicate and lime limestone and can be widely distributed as natural cement, Portland cement and alumina cement. This chapter deals with the manufacture, structure and properties of Portland cement when it is ungraded and hardened. There are different types of Portland and other cement (Brooks and Neville 2011).

I. Portland cement:

Ordinary Portland Cement (OPC) is the most important type of cement, is necessary in order to provide the concrete mix with strength, and to have the basic physical properties such it is used in general construction OPC is made by heating limestone (a source of calcium) with clay, and grinding with a source of sulphate as shown in table (3.1) (Brooks and Neville 2008). The OPC was classified into three grades, namely 33 grade, 43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988 (Shetty 2005).One of the most important benefits is the faster rate of development of strength. In the modern construction activities, higher grade cements have become so popular 43 grade cement is almost finding in the market here in Sudan.

Table (3.1): Main compounds of Portland cement

Name of compound	Oxide composition	Abbreviation
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Teicalcium aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

II. Cement properties and tests:

- **Fineness of cement:**

The fineness of Portland cement is an important quality index. It represents the average size of the cement grains. The fineness of Portland cement can be measured by different methods, fineness of cement is tested in two ways: (a) by sieving. (b) By determination of specific surface (total surface area of all the particles in one gram of cement) by air-permeability apparatus, expressed as cm^2/gm or m^2/kg. Generally, Blaine air permeability apparatus is used.

• **Hydration of Portland cement:**

The reaction of cement with water liberates considerable quantity of heat is called heat of hydration. The heat of hydration is usually defined as the amount of heat released during the setting and hardening at a given temperature, measured in J/g. The experiment is called the heat of solution method, basically, the heat of solution of dry cement is compared to the heats of solution of separate portions of the cement that have been partially hydrated for 7and 28 days, when mixing cement with water, a rapid heat evolution, lasting a few minutes, occurs. This heat evolution is probably due to the reaction of solution of aluminates and sulphates. This initial heat evolution ceases quickly when the solubility of aluminate is depressed by gypsum. Next heat evolution is on account of formation of ettringite and also may be due to the reaction of C3S refer different compounds hydrate at different rates and liberate different quantities of heat.

In the presence of water, the silicates and aluminates silicates (C3S and C2S) are the main cementitious compounds in cement, Table 3.1 form products of hydration, which in time produce a firm and hard mass (the hardened cement paste).

In commercial cements, the calcium silicates contain small impurities from some of the oxides present in the clinker; these impurities have a strong effect on the properties of the hydrated silicates. The calcium silicate hydrates are described as C-S-H, the approximate hydration reactions being written as follows: (Brooks and Neville 2008).

For C3S:

2C3S + 6H --7 C3S2H3 + 3Ca (OH) 2 **(3.1)**

[100] [24] [75] [49]

For C2S:

2C2S + 4H --7 C3S2H3 + Ca (OH) 2 **(3.2)**

[100] [21] [99] [22]

the heat of hydration depends on the chemical composition of the cement, and is approximately equal to the sum of the heats of hydration of the individual pure compounds when their respective proportions by mass are hydrated separately; typical values are given in table (3.2) and figure(3.2).

Table (3.2): Heat of hydration of pure compounds

Compound	Heat of hydration	
	J/g	**Cal/g**
C3S	502	120
C2S	260	62
C3A	867	207
C4AF	419	100

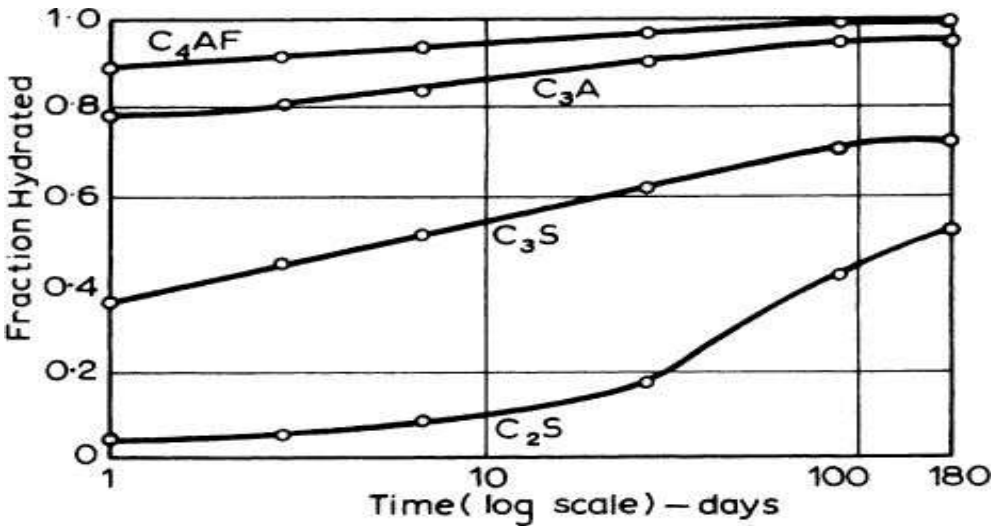


Figure (3.2) typical development of hydration of pure compounds

• **Consistence of standard paste:** The standard consistency of a cement paste is defined as that consistency which will permit a vicat plunger, this apparatus is used to determine the percentage of water required to produce a cement paste plasticity state required by the setting and soundness test for portland cement. The normal consistency test is regulated in ASTM C187. The standard consistency of the cement paste is some time called normal consistency.

• **Setting time test:** Setting time undertaken to determine the time required the cement paste to harden. The initial set cannot be too early due to the requirements of mixing, conveying, placing, and casting. Final setting cannot be too late owing to the requirement of strength development. Time of setting is measured by the Vicat apparatus with a 1mm diameter needle.

The initial setting time is defined as the time at which the needle penetrates 25 mm into the cement paste. The final setting time is the time at which the needle does not sink visibly into the cement paste. The flash group has already been mentioned and is characterized by heat-free, to determine the initial group, the Vicat device used again (Brooks and Neville 2008).

• **Soundness**: Unsoundness in cement is due to the presence of excess of lime than that could be combined with acidic oxide at the kiln. This is also due to inadequate burning or insufficiency in fineness of grinding or thorough mixing of raw materials. It is also likely that too high a proportion of magnesium content or calcium sulphate content may cause unsoundness in cement. This excess of gypsum leads to an expansion and consequent disruption of the set cement paste. Unsoundness in cement is due to excess of lime, excess of magnesia or excessive proportion of sulphates. Therefore, accelerated tests are required to detect it. There are number of such tests in common use (Brooks and Neville 2008).

• **Strength:** The strength of mortar or concrete depends on the cohesion of the cement paste, on its adhesion to the aggregate particles, and to a certain extent on the strength of the aggregate itself. The strength of cement is measured on mortar specimens made of cement and standard sand (silica). Compression testing is carried out on a 50-mm cube with an S/C ratio of 2.75:1 and W/C ratio of 0.485, for Portland cements. There are several forms of strength tests: direct tension, direct compression, and flexure. The latter determines in reality the tensile strength in bending because; as is well-known, hydrated cement, paste is considerably stronger in compression than in tension. (Brooks and Neville 2008).

3.3.2 Aggregate

Aggregate constitute a skeleton of concrete. Three-quarters of the volume of concrete is occupied by aggregate, it is not surprising that its quality is of considerable importance. However, economy is not the only reason for using aggregate: it confers considerable technical advantages on concrete, which has a higher volume stability and better durability than hydrated cement paste alone.

It is inevitable that a constituent occupying such a large percentage of the mass should contribute important properties to both the fresh and hardened product. Aggregate is usually viewed as an inert dispersion in the cement paste. However, strictly speaking, aggregate is not truly inert because physical, thermal, and, sometimes, chemical properties can influence the performance of concrete (Brooks and Neville 2009).

1) General classification of aggregates

Aggregates can be divided into several groups of rocks having common characteristics. The group classification does not imply suitability of any aggregate for concrete making, it should also be remembered that many trade and customary names of aggregates are in use, and these often do not correspond to the correct petrographic classification.

In addition to reducing the cost, aggregate in concrete can reduce the shrinkage and creep of cement paste. Moreover, aggregates have a big influence on stiffness, unit weight, strength, thermal properties, bond, and wear resistance of concrete.

Aggregates can be divided into several categories according to different criteria, Such as size, source, and weight unit.

❖ **According to the size, can be divided to**

I. Coarse aggregate: generally, the size of coarse aggregate ranges from 5 to 150 mm.

II. Fine aggregate (sand): aggregates passing through a No. 4 (4.75 mm) Sieve and predominately retained on a No. 200 (75 μm) sieve are Classified as fine aggregate

❖ **According to the source, can be divided into**

I. Natural aggregates: This kind of aggregate such as sand and gravel is taken from natural deposits without changing the nature during production.

II. Manufactured (synthetic) aggregates: These kinds of aggregate are manmade materials, resulting from products or by-products of industry. Some examples are blast furnace slag and lightweight aggregate.

❖ **According to the unit weight, can be divided to**

I. Ultra-lightweight aggregate: The unit weight of such aggregates is less Than 500 kg/m^3 including expanded perlite and foam plastic.

II. Lightweight aggregate: The unit weight of such aggregates is between 500 and 1120 kg/m^3, Examples of lightweight aggregates include cinder, blast furnace slag, volcanic pumice, and expanded clay.

III. Normal-weight aggregate: An aggregate with a unit weight of 1520-1680 kg/m^3 is classified as normal-weight aggregate. Sand, gravel, and crushed rock belong to this category and are most widely used.

IV. Heavy-weight aggregate: If the unit weight of aggregate is greater than 2100 kg/m³, it is classified as heavy-weight aggregate. Materials used as heavy-weight aggregate are iron ore, crashed steel pieces, and magnetite limonite.

2) Fine aggregate

According to ASTM C33-03, fine aggregate shall consist of natural sand figure (3.3), river sand and sea sand. The fine aggregate used has a density, relative density (specific gravity), absorption and fineness modulus value of 2620.8 kg/m³, 2.78, 2.04 % and 3.21 respectively. The fine aggregate was dried in an oven at 110°C ± 5°C for 1 day before being used to ensure that the water content for the mix is not affected.

Figure (3.3): Fine aggregate (sand)

3) Coarse aggregate

The type and source of aggregate does have a certain influence on the compressive strength of concrete. Generally, an un-crushed coarse aggregate (generally smooth and rounded) produces a concrete with a lower strength than one with crushed coarse aggregate.

Crushed granite of 20 mm size were used as coarse aggregate which has a density, relative density (specific gravity), and absorption value of 2590.95kg/m³, 2.632 and 0.5% respectively . The coarse aggregate was dried in an oven at 110°C ± 5°C for 1 day before being used to ensure that that the water content for the mix is not affected.

Crushed granite with a maximum size of 10 mm, specific gravity of 2.595, and water absorption of 0.50% was used as coarse aggregate. In this thesis, we will use recycled concrete as coarse aggregates.

3.3.3 Finding aggregate properties

• Properties of recycled concrete

Works on recycled concrete have emphasized that the basic material properties, such as shape, texture, specific gravity, absorption, moisture content, permeability, strength characteristics, deleterious substance, resistance to freeze–thaw, etc., need to be thoroughly evaluated before it is used to produce concrete. Aggregate's properties greatly affect the properties of a concrete. It would also be necessary to assess the effect of recycled material on final concrete and work out optimum composition of recycled aggregate to produce concrete of desirable quality.

The properties of RCA differ greatly from those of virgin aggregates primarily due to the existence of mortar attached to the aggregate. RCA composed of recycled members, due to the quality of these broken materials, such as water cement ratio, type of mixtures and total assets, gradient, as well as to differentiate between its properties through the performance period, it is not clear, in the interview the physical properties of historical and mechanical data characteristics, environmental characteristics a necessity in this case (Oikonomou 2005).

• Grading, shape and texture

The gradation of the RCA should be considered, as the amount of fines in the aggregate can contribute to the clogging potential of the drainage system. Finer particles will lead to a reduction in draining capacity and longer saturation time if these aggregates are used as a filler material in drainage systems, RCA particles at the finer end of a gradation specification may meet the standard, but will result in a concrete with a high water demand from the aggregates due to the hydrated cement paste (Hiller et al, 2011).

• Particle density and water absorption

Appropriate grades aggregates are essential to produce good compaction and dense concrete. Aggregate density recycled less than the original density totals due to relatively low from the old mortar density which is attached to originally the college particles. The particle density of aggregate is generally affected by the amount of moisture present and the physical properties of aggregate.

NA is known to exhibit poor water absorption from its lower porosity; however, the adhered mortar on RCA is more porous, thus increasing the water retention capabilities of the aggregates as opposed to NA. (Shamim Hashim 2013). Water absorption is defined as corresponding ratio of increased mass; this rate can be calculated using the increase of mass from an oven-dried sample when it has been immersed in water for 24 hours. (Brooks and Neville 2008) The absorption rates affect both bond formations and specific gravity. Table (3.3) properties of natural gravel and recycled aggregates according to This can be explained by the fact that the recycling process cause a lot of prevalent Small cracks in the cement paste old, In addition, the difference in the proportions w/c of the original mortar shells give a different Strength between the cement paste and the original aggregate (Brooks and Neville 2008).

Table (3.3): Differences in properties, between recycled concrete aggregates and natural aggregates

Property	**Natural Aggregate**	**RCA**
Shape and Texture	Well rounded, smooth (gravels) to angular and rough (crushed rock).	Angular with Rough surface.
Size fraction in mm	4-32	4-32
Absorption Capacity	0.8 – 3.7 %	3.7 – 8.7%
Specific Gravity	2.4 – 2.9 %	2.1 – 2.4
L.A. Abrasion Test Mass Loss	15 – 30 %	20 – 45 %
Sodium Sulphate Soundness test mass loss	7 – 21 %	18 – 59 %
Magnesium Sulphate Soundness Mass Loss	4 – 7 %	1 – 9 %
Chloride Content	0 – 1.2 kg/m3	0.6 – 7.1 kg/m3

- ## Specific Gravity

Specific gravity is a measure of the density of the aggregate. It is less specific gravity of the RCA due to present a mortar and crush in on all the particles, so the specific gravity of RCA is highly dependent on the mortar content, making it less dense than virgin aggregates because of the porosity of structure of the air and entrained. Smaller particles tend to be less specific gravity of the largest particles, thus limiting the amount of fine aggregate recycled into the mix can increase specific gravity. (Anderson et al 2009).

- ## Strength

A concrete strength and performance is very dependent on the aggregates used to produce the concrete table (3.4). RCA had significantly lower resistance to mechanical action such as crushing and impact. As shown in table (3.4) RCA concrete had lower crushing resistance compared to NA. The ACV for NA was found to be 28.23% while for RCA it was 32.08%. Furthermore, it was reported that the impact resistance of RCA was half that of NA when assessed using the AIV test (Anderson et al 2009).

Table (3.4): Mechanical properties of RCA

Property	**NA**	**RCA**
Aggregate Impact Value (%)	11.93	19.78
Aggregate Crushing Value (%)	28.23	32.08
LA abrasion value (%)	8.35	9.55

3.3.4 Admixtures:

Additives are substances non-aggregates, cement and water, added to the concrete mix during the process mixing very small quantities for the purpose of fresh concrete or concrete hardened giving properties certain required. The reason for this dramatic growth in the use of mixture is that they are able to give physical and economic benefits with large terms of concrete, Such as:

-Improve the ability to run fresh concrete without increasing the mixing water.

- Accelerate or delay in doubt.
- Reduce the rate of decline of concrete.
- Improved ability to pump concrete.
- Reduce the incidence of separation particle board.
- Increase the early resistance of concrete.
- Get high concrete resistance.
- Improve the properties of hardened concrete, such as road resistance.
- Get concrete is impervious to water or cellular concrete or concrete with special qualities.

I. Types of admixtures:

There are common types of many chemical additives that are used with concrete and can be divided into the following groups as in table (3.5).

Table (3.5): Concrete admixtures by classification

Type of admixture	Desired effect	Category of Admixture
Water reducers Air-entraining agents Inert mineral powder Pozzolans Polymer latexes	Workability	Chemical Air entraining Mineral Mineral Miscellaneous
Set accelerators Set retarders	Set control	Chemical Chemical
Pozzolans Polymer latexes	Strength	Mineral Miscellaneous
Air-entraining agents Pozzolans Water reducers Corrosion inhibitors Shrinkage reducer	Durability	Air entraining Mineral Chemical Miscellaneous Miscellaneous
Polymer latexes Silica fume Expansive admixtures Color pigments Gas-forming admixtures	Special concrete	Miscellaneous Mineral Miscellaneous Miscellaneous Miscellaneous

• Superplasticizers

Super plasticizers are admixtures, which are, water reducing but significantly and distinctly more so than the water-reducing admixtures. Superplasticizers are usually highly distinctive in their nature, and they make possible the production of concrete which, in its fresh or hardened state, super plasticizers are classified separately by ASTM C 494-10, and it refers to super plasticizers as “water-reducing, high range admixtures”.

The majority of super plasticizers are in the form of sodium salts but calcium salts are also produced; the latter, however, have a lower solubility. A consequence of the use of sodium salts is the introduction of additional alkalis into the concrete, which may be relevant to the reactions of hydration of the cement and to a potential alkali–silica reaction.

The manufacturer recommended SP dosage, usually, works properly with the materials used on a particular job (Agarwal et al. 2000). However, due to the variability of material and regional differences, the suitability of a given SP and its dosage should be based on trial mixes of the materials at hand.

Past experience with superplasticizers has clearly established their influence on the workability of concrete. When an SP is introduced to a concrete mixture, slump will increase, depending on the amount of SP. Water reducing superplasticizers are used to maintain the workability of concrete at low w/c ratios, and therefore water should be reduced when cement is kept constant to reduce the w/c ratio. There should be a limit to which water can be reduced as the SP dose is increased. (Agarwal et al 2000).

In this study, the type of SP was selected, i.e. SP type B; at this stage the appropriate dose should therefore be selected. Now, the question arises is what are the best combinations of SP dose for the materials at hand? The trials presented here are an attempt to answer this question.

3.3.5 Mixing water

Water is an important ingredient of concrete, and a properly designed concrete mixture, typically with 15 to 25% water by volume, will possess the desired workability for fresh concrete and the required durability and strength for hardened concrete, quality of water is covered by a clause saying in many specifications water should be fit for drinking. The criterion of portability of water is not absolute; drinking water may be unsuitable as mixing water when the water has a high concentration of sodium or potassium and there is a danger of alkali-aggregate reactions. The total amount of water in concrete and the water-to cement ratio may be the most critical factors in the production of good-quality concrete. Too much water reduces concrete strength, while too little makes the concrete unworkable. Because concrete must be both strong and workable, a careful selection of the cement-to-water ratio and total amount of water are required when making concrete (Brooks and Neville 2008).

3.4 Grades of concrete:

Cement concrete large scale is being used since the last about 70 years. In the early days the following nominal ratio by volume for concrete were specified. concrete which is designated as the M15, M20 etc. letter M, which refers to a combination of concrete and the number 15.20 indicates the pressure specified strength (fcu) of cubic 150 MM in 28 days, expressed in N/MM^2. Thus, it is known for its strength concrete pressure. M20 and M25 is the most common form of concrete stairs, and you must use the highest grades of concrete for harsh environments, very stiff and extreme. IS: 456-2000 has recommended that minimum grade of concrete shall be not less than M-20 in reinforced concrete work, design mix concrete is preferred to nominal mix, If design mix concrete cannot be used for any reason on the work for grades of M-20 or lower, nominal mixes may be used with the permission of engineer-in-charge, which however is likely to involve higher cement content. Accordingly, all concrete of above M-20 Grade for RCC work must be of design mixes.

3.5 RCA concrete mixture proportioning

Mix proportions greatly influence the final performance of concrete. In particular, the design RCA is usually carried out by simply replacing the Natural Aggregate NA with recycled material, differences in physical properties among aggregates, such as surface texture and water absorption, when designing RCA is taken as NA, through two possible methods: Direct Volume Replacement (DVR) and Direct Weight Replacement (DWR) substituting NA with an equivalent amount of RCA in volume or weight percentage respectively This is the main cause of the poor mechanical performance often reported when different kinds of RAC mixes were tested principally in the test conditions above reported (high replacement ratio, high strength target, severe exposure conditions). A novel method, recently (Fathifazl et al 2009), called Equivalent Mortar Volume (EMV), has been used to prevent the strength losses often reported in literature. The method basically considers RCA as a two-phase material, composed of NA and the mortar attached to it (here denoted as RM, Residual Mortar), which must be quantified and counted in the proportion of the mix. Since the physical properties of RCA are affected by the RM quantity and characteristics, this method can directly account for any deficiencies in low-quality aggregate, balancing the mix without affecting the mechanical and durability-related performance of the final concrete.

3.6 Concrete properties:

Properties of concrete are affected by many factors, and mainly due to the mixing ratio of cement, sand, gravel and water. The proportion of these substances controls the various specific characteristics, properties of concrete are:

3.6.1 Effects of RCA on fresh concrete

Fresh concrete made of the total recycled tend to be too harsh because of the shape of angular coarse surface of the aggregate, are more vulnerable to recession, loss and require water contents higher due to the absorption of higher pulp cement attached to the whole, and the contents of the air higher due to the greater porosity of recycled assemble themselves and entrained air in the original mortar of concrete made from virgin aggregates (Anderson et al 2009).

One study found that in order to produce similar workability as NA concrete 5% more mixing water was required when using just the coarse fraction of recycled concrete aggregates (coarse RCA) and up to 15% more mixing water when using both the coarse and fine fractions of RCA, in order to achieve an identical slump to NA concrete due to the angularity and rough surface of the RCA particles as opposed to the smooth and rounder NA particles (Hansen 1985).

3.6.2 Effects of RCA on hardened concrete

Hardened concrete must be strong enough to withstand the structural and service loads which will be applied to it and must be durable enough to withstand the environmental exposure for which it is designed. If concrete is made with high-quality materials and is properly proportioned, mixed, handled, placed and finished, it will be the strongest and durable building material.

Compressive strength of concrete containing RCA is dependent upon the strength of the original concrete from which the RCA was made. Concrete's compressive strength gradually decreases as the amount of fine aggregate increases (Frondistou-Yannas 1977).

3.6.3 RCA concrete mechanical properties

The quality of recycled concrete aggregate, in terms of mechanical properties, several factors affect the strength of recycled concrete aggregate the water content in the mix, admixture types and content, and the rate of loading also influences RCA quality and strength. water/cement ratio, which is particularly important because it directly affects concrete porosity and the quality of the Interfacial Transition Zone (ITZ). In addition, aggregate size, mineralogy and type (natural–limestone or siliceous aggregates, recycled, artificial, etc.) are also particularly relevant in influencing concrete strength. Typically, the full replacement of NA with RCA through both DVR and DWR concrete design methods leads to a reduction of 20–25 % in 28-days compressive strength, with respect to conventional mixtures. An increase of cement content may be useful to achieve the same strength of the control concretes, but it is considered nor cost- nor environmental-effective. A full replacement of NA with RCA has been used successfully in concretes with low-medium compressive strength, until 20–40 MPa (Fathifazl et al 2009).

3.6.4 RCA concrete durability

Durability of RCA can be evaluated through several experimental methods, depending on the deterioration process which should be represented at laboratory scale. Generally the lower properties of recycled aggregates, i.e. the lower density and mechanical strength, within the higher absorption and porosity, determine RCA to be less durable in terms of carbonation, chloride penetration, permeation, and freezing/thawing resistance. Another internal source of deterioration arises from the possible contamination of recycled concrete aggregates by gypsum.

The same may occur if recycled aggregate is contaminated by chlorides, which can lead to an internal source of chlorides inside the mix. In both the cases the addition of mineral admixtures, such as fly ash, can reduce the chloride penetration depth, in particular at low water/cement ratio (a factor which also, per se, improves RCA durability). It has to be recalled that also the mixture proportioning method may affect concrete durability. Durability-related properties in chlorides exposed environment are improved with respect to RCA (Rodríguez et al 2013).

3.6.5 Compressive strengths

Compressive strengths of concrete containing RCA usually a little less than concrete made from natural aggregates; however, there is little agreement on the size of the power cut. Some studies cited strengths of 2-10 percent less compression, the last report and a similar force is higher in some cases, depending on the proportions of water and cement to mingle. Higher air content typically found in mixtures containing RCA may also lead to less robust values. It was also confirmed that the angular configuration of the RA and its jagged surface increased the compressive strength of the RA concrete. Mostly due to the improved bonds within the internal structure of the concrete, this is especially poignant and of interest if the RA is oven-dried.

The compressive strength of RCA concrete is affected by water/cement (w/c) ratio, the percentage of coarse aggregate replaced with RCA, and the amount of adhered mortar on the RCA. It's a compression machine is capable of determining the quantitative value of compressive strength. (Anderson 2009).

3.7 High Strength Concrete (HSC)

High strength concrete refers to concrete which has a uniaxial compressive strength greater than that which is ordinarily obtained in a region. This definition has been widely accepted by practicing engineers because the maximum strength concrete which is currently being produced varies considerably from region to region in the word (Peterman and Carrasquillo 1986).

Concrete according to strength, is basically classified as:

Normal Strength Concrete 20-50 N/mm²

High Strength Concrete 50-100 N/mm²

Ultra High Strength Concrete 100-150 N/mm²

Especial Concrete > 150 N/mm²

3.7.1 Production

The key to successful production of HSC is maintaining a consistent and low water/cement ratio together with effective mixing. HSC has been produced successfully in both wet batch and dry batch plants but in all cases, stringent control of all sources of water in the mix is critical. These include:

1. Added mix water.
2. Water in liquid admixtures or silica fumes slurry.
3. Free moisture on fine and coarse aggregates. It should be noted that small changes in the moisture content of the fine aggregate have a proportionately greater effect on water/cement ratio and hence strength of HSC, than it does for normal strength concrete.

4. Other sources of water such as washout or cleaning water in mixers and transport vehicles.

Production of HSC requires particular attention to detail as factors causing only second- order effects in normal strength concrete can have major implications at very high strength levels. HSC is relatively a high-cost material, but it can produce overall savings when used in appropriate situations. Producers should be selected on the basis of proven experience with HSC specifically, rather than general experience or cost alone (Peterman and Carrasquillo 1986).

3.7.2 Use on-site

Properly proportioned HSC can be easily placed by skip and has been successfully pumped over large distances at only slightly higher pump pressures than normal ,The possibility of limited workability retention time must, however, also be kept in mind. The behavior of HSC is different in certain respects from conventional strength concrete (Peterman and Carrasquillo 1986).

2.8 Design of concrete mix

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in two states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability therefore becomes of vital importance (Brooks and Neville 2008).

3.9 Method of curing

For high durability, and should not be the only "strong" concrete but also impermeable, especially in the near-surface areas. In addition, low porosity and the most densely hardened cement paste, and high external resistance influences and pressures and the attack. To achieve this in the hardened concrete, have measures to be taken to protect the fresh concrete, especially than when, premature drying due to wind and sun, low humidity, and temperature extremes (cold, heat) and damage to the rapid changes in the degree of heat, and also the rain, heat and physical shock, chemical attack, stress. The placing of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening. Curing is the name given to procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete.

The curing process followed the method of normal curing of test specimens (20ºC method) ASTM C31/C31M - 18. Concrete properties improve with age as long as conditions were favorable to obtain the designed concrete strength. The curing period was seven, 28 days for all the cubes (Brooks and Neville 2008).

3.10 Summary

High strength concrete (HSC) by using RCA is made possible by the development of high strength cementing materials and super plasticizing admixtures ordinary cement type. The selection of constituent materials is critical in achieving a high compressive strength.

Maintaining a consistent low water/cement ratio is the most important factor for successful production. HSC can be used with most conventional construction techniques, but special attention must be given to avoiding delays during placing, finishing and curing. HSC is also characterized by an increased elastic modulus and tensile strength as well as lower drying shrinkage. Autogenously shrinkage, however, can be very high. The main applications of HSC have been in the columns of high-rise buildings, offshore structures and long-span bridges.

It is shown that the mix design depends on the variables of additives ratio, water absorption, particles density and proportioning of the aggregates. In addition of cement type, once the fresh concrete was mixed, the workability test of the fresh concrete will be conduct. Moreover, after required days of the concrete specimens were cured, the compression test was conducted on day 7, and 28. All the test procedures and methods on workability and hardened properties were discussed in chapter four.

CHAPTER FOUR

Experimental Tests According to American Method

CHAPTER FOUR

Experimental Tests According to American Method (ACI)

4.1 Introduction

The following chapter presents experimental program and the constituent materials used to produce high strength concrete using recycled concrete aggregates ,which this research concern with. It also includes information on preparation, and testing procedure, ACI standards were followed for the experimental work throughout this research. Tests were carried out to examine the properties of both fresh and hardened concrete.

4.2 Mixing Ingredients

HSC constituent materials used in this research include Ordinary Portland Cement, recycled concrete aggregates (uncrushed), fine aggregates, local tap water, and additives superplastisizer. Proportions of these materials have been chosen carefully in order to optimize the packing density of the mixture.

4.2.1 Cement

- **Ordinary Portland Cement:**

For ordinary Sudanese Portland cement type I, conforming to EN 197-1 (OPC 42.5N) manufactured by Barbr company figure (4.1) which is extensively used in Sudan. Was used in trail batches production the chemical composition of the cement used throughout the tests is presented in table (4.1) were used in this study.

Figure (4.1): Portland cement used in mixes preparation

Table (4.1) Chemical composition of ordinary Portland cement

Oxide	Determined as (%)	EN197-1 Limits
CaO	64.92	-
SiO2	17.703	-
Al2O3	4.377	-
Fe2O3	3.440	-
MgO	0.748	-
SO3	3.838	Max. 6.0%
Na2O	0.401	-
K2O	0.306	Max 3.5%
Sro	0.258	
LOI	2.200	Max 3.0%

• Testing of cement

a) **Fineness test:**

Objective: To determine the fineness of cement by dry sieving as Per IS: 4031 (Part 1) –1996 as shown in figure (4.2).

Figure (4.2): Sieve No 200

Procedure: 100g of dry cement tested by sieve index 0.09 ml for 20 minute manually, the sieve of the test was based upon a pot lid tightly, and taking into account the cleanliness of the sieve before testing. The percentage weight of residue over the total sample is reported. % weight of Residue = Wt. of sample retained on the sieve total weight of the sample. The percentage residue should not exceed 10%.

b) Consistency:

Objective: To determine the quantity of water required to produce cement paste of standard consistency as per IS: 4031 (Part 4) - 1988.

Procedure: Weigh approximately 400g of cement and mix it with a weighed quantity of water the time of gauging should be between 3 to 5 minutes, Fill the Vicat mold with paste and level it with a trowel, then lower the plunger gently till it touches the cement surface, release the plunger allowing it to sink into the paste, note the reading on the gauge, repeat the above procedure taking fresh samples of cement different quantities of water until the reading on the gauge is 5 to 7mm, now express the amount of water as a percentage of the weight of dry cement to the first place of decimal.

c) Setting time test:

Objective: To determine the initial and final setting times of cement, by Vicat apparatus conforming to ASTM. As shown in figure (4.3).

Figure (4.3): Vicat Apparatus

Procedure: Unless otherwise specified this test shall be conducted at a temperature of 27 +20C and 65 + 5% of relative humidity of the Laboratory.

Prepare 400g of cement added to the water to form standard paste with stop watch running while adding water to the cement 0.85 times the water required to a give a paste of standard consistency IS:4031 (Part 4) 1988. Cement mixed with water for four minutes and then placed cement paste in Vicat apparatus and adjustment surface of paste. Vicat apparatus putted over metal plate, which was under cylindrical side. The surface of needle dropping even touched the surface of the paste slowly, then descended to fall under the influence of the total weight of the cylindrical tip and took a reading gradient in front the mark on the drum and drooping after the needle tip from the bottom. The process of entry needle into cement paste was rebated more than once. The process was rebated several times until the needle far from the bottom of the mold the time was recorded and it was initial setting time. Needle of final setting time was installed in Vicat apparatus and it left to fall under gravity, and this method was rebated several times and final setting was recorded. Initial and final settings were shown in tables (4.2)

Table (4.2) Physical and mechanical properties of ordinary Portland cement

Sl. No	**Test according to ASTM**		**Result**	**Requirement of SSMO164-2002**
1	Normal consistency		26%	
2	Sitting time	Initial sitting time(min)	45	Not greater than 60 min
		Final sitting time(min)	276	Not greater than 390 min
3	fineness	impurities	3.99%	Not more than 10%
4	Compressive strength	2 days	27.5	Equal or greater than 10 (N/mm²)
		28 days	35.4	Equal or greater than 42.5 (N/mm²)

4.2.2 Fine Aggregate

Natural concrete fine aggregate of medium grading as per IS: 383-1987 locally available valleys sand having bulk density 1860 kg/m3, was washed used throughout all the experimental work.

4.2.3 Coarse Aggregates:

A. Natural aggregate: uncrushed natural aggregate NA of 20 mm size which was proven to produce excellent NA will be applied in this investigation. NA will be used as control mixes.

B. Recycled concrete aggregate: For coarse aggregate, in this study recycled concrete were be used from concrete with uncrushed natural aggregate, figure (4.4) shown RCA had been used in such study.

Figure (4.4): Recycled Concrete Aggregate

C. Aggregates Testing

a) Sieve Analysis

The aim of sieve analysis: To determine the particle size distribution of fine and coarse aggregates by sieving as per IS: 2386 (Part I) – 1963 as shown in figure (4.5).

Test procedure:

1. The test sample is dried to a constant weight at a temperature of 110 + 50 C and weighed.
2. The sample is sieved by using a set of IS sieves.
3. On completion of sieving, the material on each sieve is weighed.
4. Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.
5. Fineness modulus is obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

Reporting of results:

1. The results should be calculated and reported as:

2. The cumulative percentage by weight of the total sample.

3. The percentage by weight of the total sample passing through one sieves and retained on the next smaller sieve, to the nearest 0.1 per cent.

4. The results of the sieve analysis may be recorded graphically on a semi log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate.

Figure (4.5) Sieves Size

b) Specific Gravity and Water Absorption

The aim of test: The test covers the procedures for determining the specific gravity, apparent specific gravity and water absorption of aggregates.

Test procedure:

(1) The sample shall be screened on 10mm IS sieve, thoroughly washed to remove fine particles of dust.

(2) immersed the sample in distilled water in the glass vessel; it shall remain immersed at a temperature of 22 to 32°C for 24 f l/2 hours.

(3) Air entrapped in or bubbles on the surface of the aggregate shall be removed by gentle agitation, this may be achieved by rapid clockwise and anticlockwise rotation of the vessel between the operator’s hands.

(4) The vessel shall be overfilled by adding distilled water and the plane ground-glass disc slid over the mouth so as to ensure that no air is trapped in the vessel.

(5) The vessel shall be dried on the outside and weighed (weight A).

(6) The vessel shall be emptied and the aggregate allowed draining. Refill the vessel with distilled water.

(7) The vessel shall be dried on the outside and weighed (Weight B).

(8) The aggregate shall be placed on a dry cloth and gently surface dried with the cloth, transferring it a second dry cloth when the first will remove no further moisture.

(9) The aggregate shall then be weighed (weight C).

(10)The aggregate shall be placed in the oven in the shallow tray, at a temperature of 100 to 110°C for 24 f l/2 hours. It shall then be cooled in airtight container and weighed (weight D).

Calculations of Specific gravity, apparent specific gravity and water absorption shall be calculated as follows:

Specific gravity = $$(\left(\frac{D}{C-(A-B)}\right) * 100) \quad (4.1)$$

Apparent specific gravity = $$(\left(\frac{D}{D-(A-B)}\right) * 100) \quad (4.2)$$

Water absorption % = $$(\left(\frac{C}{B-(A-C)}\right) * 100) \quad (4.3)$$

Where:

A = weight in g of vessel containing sample and filled with distilled water,

B = weight in g of vessel filled with distilled water only,

C = weight in g of saturated surface-dry sample, and

D = weight in g of oven-dry sample.

c) Bulk density and voids

The aim of test: This method of test covers the procedure for determining unit weight or bulk density and void of aggregates.

Test procedure:

1. Measure the volume of the cylindrical metal measure by pouring water into the metal measure and record the volume (V) in liter.
2. Fill the cylindrical metal measure about one-third full with thoroughly mixed aggregate and tamp it 25 times using tamping bar.
3. Add another layer of one-third volume of aggregate in the metal measure and give another 25 strokes of tamping bar.
4. Finally fill aggregate in the metal measure to over-flowing and tamp it 25 times.
5. Remove the surplus aggregate using the tamping rod as a straightedge.
6. Determine weight of the aggregate in the measure and record that weight W in kg.

Compacted unit weight or bulk density = W/V.

Where,

W = Weight of compacted aggregate in cylindrical metal measure, kg.

V = Volume of cylindrical metal measure, liter

The percentage of voids is calculated as follows:

Percentage of voids = [(Gs – r)/ Gs]*100 (4.4)

Where:

G = Specific gravity of the aggregate

Y = Bulk density in kg/liter

- **Absorption**

Percentage of Void = $((G_s - r)/G_s)*100$

= 100*(2.371-1.69)/2.371

= 28.722%

- **Bulk Density**

Mold Volume (V) = 0.002120 m^3

Mold Weight (W) = 6.154 Kg

Weight of Loose Agg (W_1) = 9.193 Kg

Weight of compacted Agg (W_2) = 9.737 Kg

Bulk Density of Compacted = $(W_2-W)/V$

= 1690.3 Kg/m^3

Bulk Density of Loose = $(W_1-W)/V$

= 1430.3 Kg/m^3

Recycled concrete Aggregate was used as shown in figure (4.5) the properties of Coarse Aggregate are shown in table (4.3).

Table (4.3): Properties of coarse aggregate

SI. No	Property	Result
1	Specific Gravity	2.66
2	Apparent Specific Gravity	2.69
3	Absorption	0.71
4	Total moisture content	1.82
5	Bulk density (kg/m3)	1690.3

Natural sand as per IS: 383-1987 was used. Locally available valleys sand having bulk density 1692 kg/m3 was washed and used the properties of fine aggregate are shown in Table (4.4).

Table (4.4): Properties of fine aggregate

SI. No	Property	Result
1	Specific Gravity	2.61
2	Apparent Specific Gravity	2.65
3	Absorption	0.91
4	Total moisture content	2.61
5	Bulk density (kg/m3)	1692

4.2.4 Water

In concrete production standard drinkable water, was used. For all the purposes of tests .Table (4.5) shows chemical composition of water.

Table (4.5): Chemical composition of the water

P.P.M	Determined as (%)
Na	31.98
Mg	19.18
Cl	l 0.0716
PH	7.0
K	5.773
Pb	0.126
Zn	0.089
Fe	0.051
Cd	0.018
SO4	0.0014

4.2.5 Superplasticizer

The chemical admixture used ASTM C494-Type F mix is superplasticizer, which it shows a strong self-compacting behaviour therefore suitable for the production of self-compacting concrete and improves the properties of fresh and hardened concrete. The type of super plasticizer used in this research are conplast SP 432 from Mamcom activities co, LTD, SP901 (SepraPlast) and Super plasticizer type B as shown in figure (4.6).

The SP dosage will be determined on the basis of trial concrete mixes. Results will help to obtain the appropriate dosage of SP which should be proportioned in concrete mixes which will be produced for further research on these materials.

Figure (4.6): Super plasticizer type B

4.3 Concrete mix design by American method ACI:

initially NA concrete mix proportions were established following steps described in the conventional ACI 211.1 method for concrete mix design and casting Using 100% coarse RCA was designed to give high strength concrete, proportions were established by using a blend of natural sand.

1. The American Concrete Institute ACI 211.1-91 recommends a method of mix design, considering the most economical use of available materials to produce concrete of a desirable workability, durability and strength. The following design criteria are assumed in formulating the design tables:
2. Type I, non-air entraining cement with a specific gravity of 3.15 is used.
3. The coarse and fine aggregates are of satisfactory quality and are graded within limits generally accepted specifications.

4. The coarse aggregate has maximum Size 20mm, bulk dry specific gravity 2.65, bulk density 1690.3 Kg/m3, total moisture content 1.82, and absorption 0.71.

5. The fine aggregate has a bulk dry specific gravity of 2.6, absorption 0.91 percent and fineness modulus of 3.23, and total moisture content 2.61.

6. The method consists of a sequence of logical, straight forward steps which take into described:

Step (1): Calculating the mean compressive strength (fm)

From the previous experience of making concrete with specified main strength of 30 MPa for high strength concrete with similar material to those proposed, the standard deviation of 20 standard cylindrical test results is 4 MPa from Eq (4.6a). The probabilty factor usually takes it 1.64, the required average strength *fm* can be estimated from Eq (4.5).

$$fm=(fmin+(k*s*m)) \tag{4.5}$$

Use:

(s = 4 MPa 4 MPa (for *fmin* >= 20 MPA)) (4.6a)

(s = 0.2 *fmin* 6 MPa (for *fmin* <= 20 MPA)) (4.6b)

fmin = 30 MPa.

n= Number of test specimen is 20.

k = Probabilty factor usually takes it 1.64.

s = Standard deviation is 4 MPa.

m = Modification factor is 1.08 given from table (4.6).

Then fm = (30+ (1.64*4*1.08)) = 37.1 MPa

Table (4.6): Modification factor for standard deviation

Number of tests	Factors for standard deviation
15	1.16
20	1.08
25	1.03
30 or more	1

Step (2): Choice of slump

If slump is not specified, a value appropriate for the work can be selected from table (4.7) which is reproduced from the text book below*, depending upon the type of constructions, the required slump and maximum size of aggregate the slump was chosen in range (25-100) mm, selected from table (4.7).

Table (4.7): Recommended slumps for various types of construction

Type of Construction	**Slump (mm)**	
	mm	**in.**
Reinforced foundation walls and footings	25-75	1-3
plain footings, caissions and substructure walls	25-75	1-3
Beams and reinforced walls	25-100	1-4
Building columns	25-100	1-4
Pavements and slabs	25-75	1-3
Mass concrete	25-50	1-2

*(note that the table numbers are given from the text book rather than the ACI standard).

Step (3): The type of exposure

The type of exposure will help in deciding air entrained or non-air entrained concrete is to be used and the recommendations contained in table (4.13) are useful in this regard. There is no special exposure condition ordinary Portland (Type I) cement without air entrainment.

Step (4): Choice of maximum aggregate size

Large maximum sizes of aggregates produce fewer voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete, and of course it is the mortar which contains the most expensive ingredient, cement. Thus the ACI method is based on the principle that the maximum size of aggregate should be the largest available so long it is consistent with the dimensions of the structure, in practice the dimensions of the forms or the spacing of the rebar’s controls the maximum Coarse Aggregate (CA) size. ACI 211.1 states that the maximum CA size should not exceed:

1. 1/5th of the narrowest dimension between sides of forms,
2. 1/3rd the depth of slabs.

3. 3/4ths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pre-tensioning strands.

Special Note: When high strength concrete is desired, best results may be obtained with reduced maximum sizes of aggregate since these produce higher strengths at a given w/c ratio. From table (4.8) maximum aggregate size was be chosen is 20 mm.

Table (4.8): Maximum size of aggregate recommended for various types of construction.

Min Dimension of section (mm)	**Max, Size of Aggregate (mm)**			
	Reinforced Walls, Beams and Columns	**Un reinforced Walls**	**Heavily Reinforced Slab**	**Lightly Reinforced or Un-reinforced slab**
62.5-125	12.5-20	20	20-25	20-40
150-275	0-0	40	40	40-80
300-275	40-80	80	40-80	80
750 or more	40-80	160	40-80	80-160

Step (5): Estimation of mixing water and air content.

The approximate mixing water required selected from table (4.9) for the desired workability and maximum size of aggregate. The ACI method uses past experience to give a first estimate for the quantity of water per unit volume of concrete required to produce a given slump. In general the quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum CA size, the shape and grading of both CA and FA, as well as the amount of entrained air. Approximate mixing water and air content requirements for different slumps and maximum aggregate sizes.

From table (4.9) the mixing water content for non-air entrained concrete with Slump 100 mm and maximum aggregate size 20 mm then the maximum.

Water content is 200 Kg/m^3.

Approximate entrapped air is 2%.

Step (6): Selection of water cement ratio.

The water cement ratio is selected based on the dual criterion of durability and strength using table (4.10) and table (4.11) the minimum of the two values is adopted for the trial mix where water cement ratio equals to 0.446 according to table (4.10).

Step (7): Calculation of cement content.

The cement content is calculated from the water content and water cement ratio required for durability or strength. The water content divided by the water cement ratio, where the weight of cement equals to 448.14 kg according to equation (4.7) bellow:

$$Weight\ of\ cement\ = \frac{Weight\ of\ water}{\mathrm{w/c}} \qquad \textbf{(4.7)}$$

Table (4.9): Approximate mixing water (kg/m³ of concrete) requirements for different slumps and maximum sizes of aggregates

Slump (mm)	Maximum size of aggregates (mm)							
	10	12.5	20	25	40	50	70	150
Non Air Entrained Concrete								
20-50	205	200	185	180	160	155	145	125
80-100	225	215	200	195	175	170	160	140
150-180	240	20	210	205	185	180	170	-
Approximate amount of entrapped air in non-air entrained air in non-air entrained concrete (per cent)	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2
Air Entrained Concrete								
30-50	180	175	165	160	145	40	15	120
80-100	200	190	180	175	60	155	150	135
150-180	215	205	190	185	170	165	160	-
Recommended average total air content (per cent)	8.0	7.0	6.0	5.0	4.5	4.0	3.5	3.0

Table (4.10): Relationship between water/cement ratio and compressive strength of concrete

Cylinder compressive at 28 days (kg/cm2)	Water/Cement Ratio by Weight	
	Non Air entrained concrete	Air entrained concrete
450	0.38	-
400	0.43	-
350	0.48	0.40
300	0.55	0.46
250	0.62	0.53
200	0.70	0.61
150	0.80	0.71

Table (4.11): Maximum permissible water cement ratio for different types of structures and degree of exposure

Types of Structures	Exposure Condition					
	Severe wide range in temp. or frequent alternation of freezing and thawing (air			Mild temp. rarely below freezing or rainy or aid		
	In air	At the water line or within the range of fluctuating water level		In air	At the water line or within the range of fluctuating water level	
		In fresh water	At the water line or within the range of fluctuating water level		In fresh water	At the water line or within the range of fluctuating water level
Thin sections, such as railing , curbs , sills , ledges , ornamental or architectural concrete reinforced piles , pipe and all sections with less than 25 mm concrete cover reinforcing	0.48	0.44	0.39	0.48	0.48	0.39
Moderate sections, such as retaining wall, abutments, piers, girders, beams.	0.53	0.48	0.44	-	0.53	0.44
Exterior portion of heavy (mass) section.	0.57	0.48	0.44	-	0.53	0.44
Concrete deposited by termite under water	-	0.44	0.44	-	0.44	0.44

Concrete slab laid on the ground	0.53	-	-	-	-	-
Concrete protected from weather, interiors of buildings , concrete below ground	-	-	-	-	-	-
Concrete which will later be protected by enclosure or beck fill what which may be exposed to freezing and thawing for several years before such protection is offered	0.53	-	-	-	-	-

Step (8) Estimation of coarse aggregate content

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA. The coarse aggregate content is estimated from table (4.12) for maximum size of aggregate 20 mm and the fineness modulus of fine aggregate 3.23 the dry bulk volume of coarse aggregate is 0.58.

Quantity of coarse aggregate = (dry bulk volume of coarse aggregate * bulk density of coarse aggregate).

= 0.58*1690.3 = 980.37 Kg/m³.

Quantity of coarse aggregate on SSD basis = (quantity of coarse aggregate * absorption).

=980.37 *((0.7/100) +1) = 987.23 Kg/m³.

Surface moisture content = Total moisture content - absorption

=1.82-0.71=1.11%.

Coarse aggregate concerning the moisture content = (quantity of coarse aggregate on SSD basis * Surface moisture content) = 1040 Kg/m³.

(SSD) = Saturated Surface Dry

Table (4.12): Volume of dry rodded coarse aggregate per unit volume of concrete

Max. Size of aggregate (mm)	**Fineness Modulus of Sand**			
	2.40	**2.60**	**2.80**	**3.00**
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.56
40	0.76	0.74	0.72	0.70
50	0.78	0.76	0.74	0.72
70	0.81	0.79	0.77	0.75
150	0.87	0.85	0.83	0.81

Step (9): Estimation of fine aggregate content

The fine aggregate content is determined by subtracting the sum of the volumes of coarse aggregate, cement, water and air content from the unit volume of concrete. For each ingredient, the absolute volume is equal to the mass divided by the absolute density of fresh concrete is 2355 kg/m³ given from table (4.13); the absolute density is the specific gravity of the material divided by the density of water (100% kg/m³).
Fine aggregate SSD Basis can be estimated from Eq (4.8) bellow:

$$Af = \gamma f(1000 - \left(W - \left(\frac{C}{\gamma}\right) + \left(\frac{Ac}{\gamma c}\right) + 10A\right)) \quad (4.8)$$

Where:

A*f*= Fine aggregates content, Kg/M³

Ac= Coarse aggregates content 1040 Kg/M³.

C = Cement content, 450 Kg/M³.

γ = Specific gravity of cement 3.15.

γc = Bulk specific gravity of coarse aggregate 2.66.

γf = Bulk specific gravity of fine aggregate 2.61.

W = Water content requirement 200 Kg/M³.

A = Air content, 2% per cent;

A*f*=2.61(1000-(200-(450/3.15)+(1040/2.66)+10*2))

Fine aggregate SSD, A*f* = 580 Kg/M³

Table (4.13) First estimate of density (unit weight) of fresh concrete

Maximum size of aggregate		**First estimate of density (unit weight) of fresh concrete**			
		Non-air-entrained		**Air- entrained**	
mm	**in**	**KG/M3**	**IB/YD3**	**KG/M3**	**IB/YD3**
10	(3/8)	2285	3840	2190	3690
12.5	(1/2)	2315	3890	2235	3760
20	(3/4)	2355	3960	2280	3840
25	1	2380	4010	2285	3850
40	(11/2)	2415	4070	2320	3910
50	2	2445	4120	2345	3950
70	3	2495	4200	2400	4040
150	6	2530	4260	2440	4110

Remarks:

In this research is used ACI method above steps but because it has problem for calculation of W/C ratio it's modified the results of content of materials to nears quantities as trail and trying to decreased w/c ratio and increased CA/FA ratio to achieve HCS and good workability.

4.4 Mixing Preparation

After selecting all necessary constituents and amounts to be used (mixes design); from the preceding discussions on information found from literature, all materials are weighted properly. Then mixing with a driven power-driven rotary tilting revolving drum mixer began to ensure that all particles are surrounded with cement paste and all materials must be distributed homogenously in a concrete mass. The necessary requirement of different ingredient materials required for producing HSC can be summarized as:

- Component of mix materials (for cubic meter).
- Water content =200 kg/m³.
- Portland cement content = 450 kg/m³.
- Fine aggregate = 580 kg/m³.
- Coarse aggregate = 1040 kg/m³.
- Super plasticizer = 3L, 5L, 8L.
- The temperature of climate ranged in (32-38.5) ºC.
- The temperature of water used in mixes ranged in (6-8.5)ºC.
- The temperature of mixes ranged in (22-24) ºC.
- The density of fresh concrete was used in design as 2400 kg/m3.
- The aggregate dry density used was 1690.3 kg/m3, and the maximum aggregate size use of all mixes was 20 mm using standard cube (100*100*100) mm and cube (150*150*150) mm, cubes representing each ratio, were casted and tested at age 7 and 28 days.

4.5 Mixing procedure

The mixing procedure for all concrete mixes not containing admixtures was to first mix 50 percent of the water with the aggregates followed by the addition of the cement using drum mixer as shown in figure (4.7), and then the remainder of the water was added as required to reach the desired slump. Batches containing super plasticizer were mixed similarly to the mixes without admixture, but super plasticizer was mixed with water before added. After final mixing, the mixer is stopped, turned up with its end right down and the fresh homogeneous concrete is poured into a clean steel pan. The casting of all specimens used in this research completed within 20 minutes after being mixed. All specimens were cast and covered to prevent evaporation.

i. By using ACI method, by using data given, calculate the w/c ratio, water content, cement content, fine aggregate content, and coarse aggregate content.

ii. The weight of the empty container is taken before placing the ingredients of concrete.

iii. The mix design quantity of ingredients for the concrete is determined.

iv. From the mix design of the concrete, weigh every ingredient separately like coarse aggregate, fine aggregates, clean water and cement before mixing.

v. The ingredients like coarse aggregates, fine aggregates and cement are placed step by step at a flat plate and make the hole at the center.

vi. The clean water will be the last where added slowly to let it applies the hydration process between the water and cement.

vii. The coarse aggregates, fine aggregates, water and cement are mixed together with the scoop equally.

viii. After the mix design, the fresh hardened concrete is placed in water container for 7 and 28 days

ix. Hardening.

Figure (4.7): Drum mixer used for the mixing process

4.6 Test of fresh concrete

- ## Slump flow test

Concrete slump test is to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. Concrete slump test is carried out from batch to batch to check the uniform quality of concrete during construction

The slump test is the most simple workability test for concrete, involves low cost and provides immediate results. Due to this fact, it has been widely used for workability tests since 1922. The slump is carried out as per procedures mentioned in ASTM C143 in the United States.

a) **Equipment required for concrete slump test:**

Mold for slump test, non-porous base plate, measuring scale, temping rod. The mold for the test is in the form of the frustum of a cone having height 30 cm, bottom diameter 20 cm and top diameter 10 cm. The tamping rod is of steel 16 mm diameter and 60cm long and rounded at one end. Slump test apparatus shown in figure (4.8) bellow:

Figure (4.8): Slump test apparatus

b) Procedure for concrete slump test:

1. Clean the internal surface of the mold and apply oil.
2. Place the mold on a smooth horizontal non- porous base plate.
3. Fill the mold with the prepared concrete mix in 3 approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mold. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mold and the base plate.
7. Raise the mold from the concrete immediately and slowly in vertical direction.
8. Measure the slump as the difference between the height of the mold and that of height point of the specimen being tested.

c) Result of concrete slump test: When the slump test is carried out, following are the shape of the concrete slump that can be observed:

i.True Slump – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown in figure (4.9).

ii.Zero Slump – Zero slumps is the indication of very low water-cement ratio, which results in dry mixes. This type of concrete is generally used for road construction.

iii.Collapsed Slump – This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.

iv.Shear Slump – The shear slump indicates that the result is incomplete, and concrete to be retested.

Figure (4.9): Slump test after mixing process

4.7 Test of Hardened concrete

- ## Compressive strength test

A significant portion of this research focused on the behaviors of cube specimens under compressive loading. The compressive tests discussed in this section were all completed standard test method for cubes. Total numbers of 40 cubes were manufactured. For all mix, 150×150×150 and 100×100×100 mm cube specimens were prepared, as shown in figure (4.10).

The cubes were filled with fresh concrete without compacting, after preparing the specimens; It was placed for 24 hours until harden. The cubes were stored in water until the time of the test, as shown in figure (4.12) the cubes are placed in the testing machine so that the load is applied to opposite sides as cast and not to the top and bottom as cast. Therefore, the bearing faces of the specimen are sufficiently plane as to require no capping. If there is appreciable curvature, the face is grinded to plane surface because, much lower results than the true strength are obtained by loading faces of the cube specimens that are not truly plane surfaces. The compressive strength machine in figure (4.11) used for determining the maximum compressive loads carried by concrete specimen cubes, as shown in the figure the compressive strength of the specimen, σ comp (in N/mm^2), is calculated by dividing the maximum load carried by the specimen during the test by the cross sectional area of the specimen figure (4.10).

$$\sigma_{comp} = P/A$$

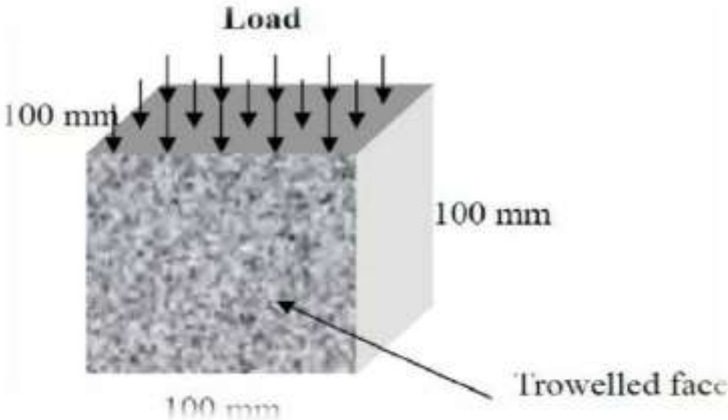


Figure (4.10) Force applied on the 100 mm cube

The compressive strength was determined at different ages 7, 14, and 28 days. At least three of these cubes were tested for each period the mean value of the specimens was considered as the compressive strength of the experiment.

Figure (4.11): Compressive testing machine used in this study.

4.8 Curing methods

Curing is very important to control the rate and extent of moisture loss from concrete during the hydration process. Therefore, it is important to provide sufficient time for the hydration process of the cement to occur during the period in which it is gaining strength, curing problems are exaggerated when concreting in hot weather, as a result of both higher concrete temperatures and increased rate of evaporation from the fresh mix. The compressive strength modulus of elasticity and other characteristics of concrete in hot atmosphere are thus dependable on its treatment during the first few weeks.

The curing period may depend on the properties required for the concrete, the purpose for which it is to be used, and the ambient conditions, i.e. the temperature and relative humidity. Curing must be undertaken considering duration of time needed for the concrete to achieve in complete curing would cause major defects. These defects will allow the presence of permeability and reduce the compressive strength and they will lead to weaken the durability of concrete. Although there were a lot of research work done on the effect of curing on the silica fume on concrete, but the effect of delay curing is not investigated. Consequently, this will specify the suitable curing method for concrete and will also help to improve the mechanical properties for concrete, as compressive strength, after the casting process was completed, the concrete should be prevented from premature drying, and exposing to the variations in temperature should be avoided. These precautions are necessary in order to protect the concrete from negative impact on methods of curing in this study; method of curing was used as shown in figure (4.12) bellows:

Figure (4.12): Cubes at curing basin

4.9 Summary

It shows that the mix design depends on the variables of additives ratio, water absorption, particles density and proportioning of the aggregates, in addition of cement type. Once the fresh concrete was mixed, the workability test of the fresh concrete will be conduct. Moreover, after required days of the concrete specimens were cured, the compression test was conducted on day 7, and 28. In addition to, all test. Procedures and methods on workability and hardened properties were discussed in chapter three.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 Introduction

Series ofexperimental tests were carried out on the components of concrete (mix).This chapter discusses the results obtained from the testing program. The results are the aggregate gradation, slump test, compression test;to evaluate how the quality of these components isby using recycled concrete aggregate and their influence on the compressive strength of concrete.

5.2 Presentation of resulttests

The materials intended to be used in this study were tested in compliance with the current relevant standards methods. Results showed their suitability for use in producing concrete mixes. The experimental results show the recycled concrete aggregate influence much in fresh and hardened properties of concrete.These results have been obtained from testas below:-

5.3 Tests for coarse aggregate

Tests for coarse aggregate RCA has been presented as shown in table (5.1) and. The maximum size of aggregates 20 mm, the gradation tests was carried for recycled concreteaggregate test and natural aggregateobtained were presented in table (5.1) and figure (5.1).

Table (5.1) A sample of coarse aggregate (RCA) with mass of 1000g ispassed through the sieves shown in the following and masses retained on each sieve:

BS Sieve size (mm)	Weight of retained(g)	Percentage retained%	Cumulative percentage retained%	Percentage passing%	Permissible percentage passing as per BS 882:1992
50	0	0.0	0.0	100.0	100
37.5	0	0.0	0.0	100.0	89-100
20	381	40.3	40.3	59.7	60-100
14	261.5	27.6	67.9	32.1	30-100
10	148	15.6	83.6	16.4	15-100
5	136	14.4	97.9	2.1	5-70
2.36	10.5	1.1	99.0	1.0	0-15
Pan	4	0.4	99.5	0.5	Overall limits
TOTAL	946				

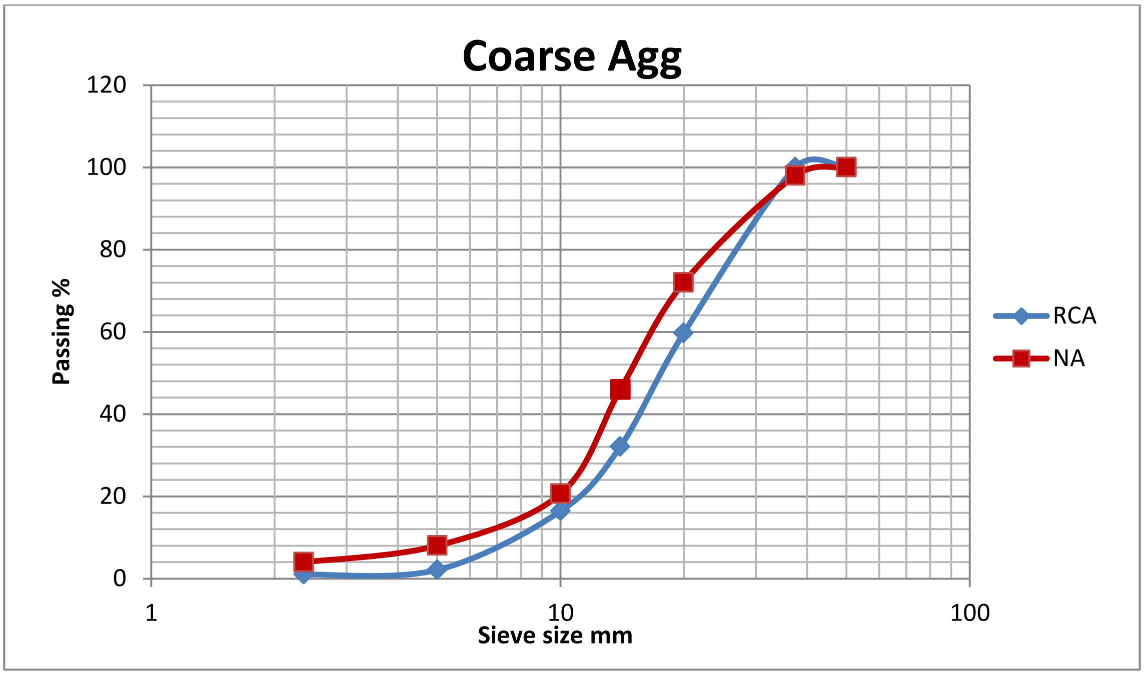


Figure (5.1) Logarithmic curve explain sieve analysis of coarse aggregate natural aggregate and RCA

5.4 Tests for fine aggregate

A calculation of sieve analysis of a sample of fine aggregate haspassed through the sieves as shown in table (5.2) and figure (5.2).

Table (5.2): Sieve analysis of fine aggregate:

BS Sieve Size	Weight of retained (g)	Percentage Retained (g)	Cumulative percentage retained %	Percentage passing %	Permissible Percentage passing as per BS 882:1992
10.0mm	14.6	1.50	1.50	98.50	100
4.75mm	34.3	3.52	5.02	94.98	89-100
2.36mm	42	4.33	9.35	90.65	60-100
1.18mm	294	30.31	39.66	60.34	30-90
600 µm	348.3	35.91	75.57	24.43	15-54
300 µm	180.3	18.59	94.15	5.85	5-40
150 µm	34.4	3.44	97.60	2.40	0-15
75 µm	21.51	2.22	99.81	0.19	-
Pan	0.733	0.08	99.89	0.00	Overall limits
TOTAL	970.2	99.89			
Fineness modulus= 323/100 =3.23					

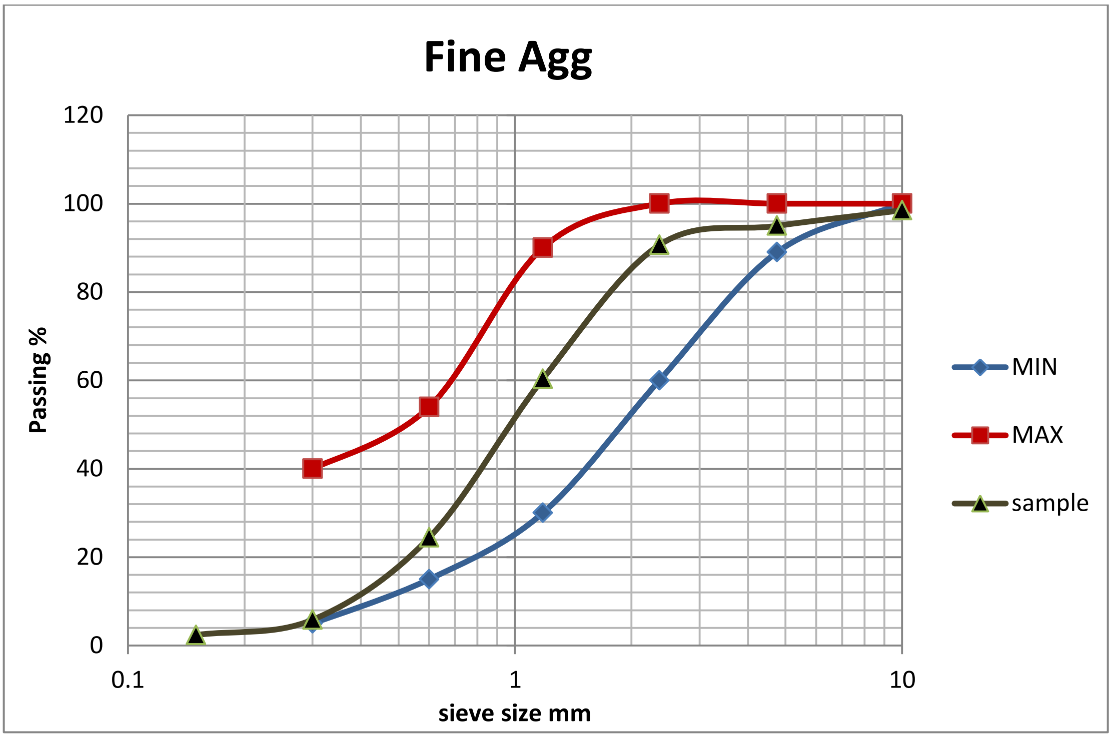


Figure (5.2) Logarithmic curve explain sieve analysis of fine aggregate

5.5 Tests for trail mixes

The experimental testing of RCA and similar NAC specimen as control mix produced with these materials, cast and tested under standard laboratory conditions in accordance with the current standards was undertaken to test this hypothesis.Tests were carried out for trail mixesmentioned as shown in table (5.3) below:

- Mix (A) NAC; Ordinary Portlandcement 450 kg/m³ were used with natural uncrushed aggregates 1040 kg/ m³, with natural sand with fineness modulus 3.23with mix proportions (1:1.57:2.3).
- Mix (B);OrdinaryPortlandcement 450 kg/m³ was used with 30% recycled concreteaggregate 1040 kg/m³ by adding different levels of super plasticizer (0,3, 5, 8) litters per cubic meter, natural sand, with fineness modulus 3.23 with mix proportions (1:1.3:2.3).
- Mix (C);Ordinary Portland cement 450 kg/m³ was used with 50% recycled concrete aggregate 1040 kg/m³ by adding different levels of super plasticizer (0,3, 5, 8) litters per cubic meter, natural sand, with fineness modulus 3.23 with mix proportions (1:1.3:2.3).

• Mix(D);Ordinary Portlandcement 450 kg/m³ was used with100%recycled concrete aggregate 1040kg/m³ by adding different levels of super plasticizer (0,3, 5,8) Litters per cubic meter, natural sand, with fineness modulus 3.23 with mix proportions (1:1.3:2.3).

The results obtained from the different mixes are summarized and discussed as follow:

1) Cement content in order to produce high strength concrete, higher cement contents than for normal strength concrete must be used. The cement content of concrete mixes made in this study is 450 kg/m³.

2) Lower water/cement ratios are required for producing high strength concrete than for producing normal strength concrete.

3) Coarse aggregate gradation RCA effect of the gradation of the coarse aggregate on the compressive strength of high strength concrete is directly related to the effect of the gradation on the mixing water requirement for a given slump.

Table (5.3): trail mixes design Proportions:

Mix type	RCA proportion	Admixture doses Superplasticizer (Litter)	W/C ratio	Cement (Kg/m³)	Fine aggregate (Kg/m³)	Course aggregate (Kg/m³)
A	0%	0	0.6	450	650	1040
B	30%	0	0.43	450	580	1040
		3	0.40			
		5	0.35			
		8	0.32			
C	50%	0	0.43	450	580	1040
		3	0.36			
		5	0.34			
		8	0.3			
D	100%	0	0.5	450	580	1040
		3	0.43			
		5	0.35			
		8	0.35			

5.5.1 Slump Test Result and Analysis

Table (5.4) shows workability results for all mixes:

Mix type	RCA proportion	Admixture doses Superplasticizer (Litter)	Slump (mm)
A	0%	0	95
B	30%	0	90
		3	135
		5	150
		8	190 (collapse)
C	50%	0	85
		3	120
		5	130
		8	150
D	100%	0	75
		3	95
		5	120
		8	140

4) The slump test indicates a decreasing trend of workability when the percentage of Recycled concrete aggregate increased. Table (5.5) below shows the average slump recorded during the test,figure(5.3) below shows a graphical representation of slump height.

Table (5.5) the slump result for each batch of mix concrete:

Percentage of RCA (%)	W/C ratio	Slump mm	Average of compressive strength in28 days N/mm²
0% recycled aggregate	0.6	95	32.3
30% recycled aggregate	0.43	90	31
50% recycled aggregate	0.43	85	31.6
100% recycled aggregate	0.5	75	33

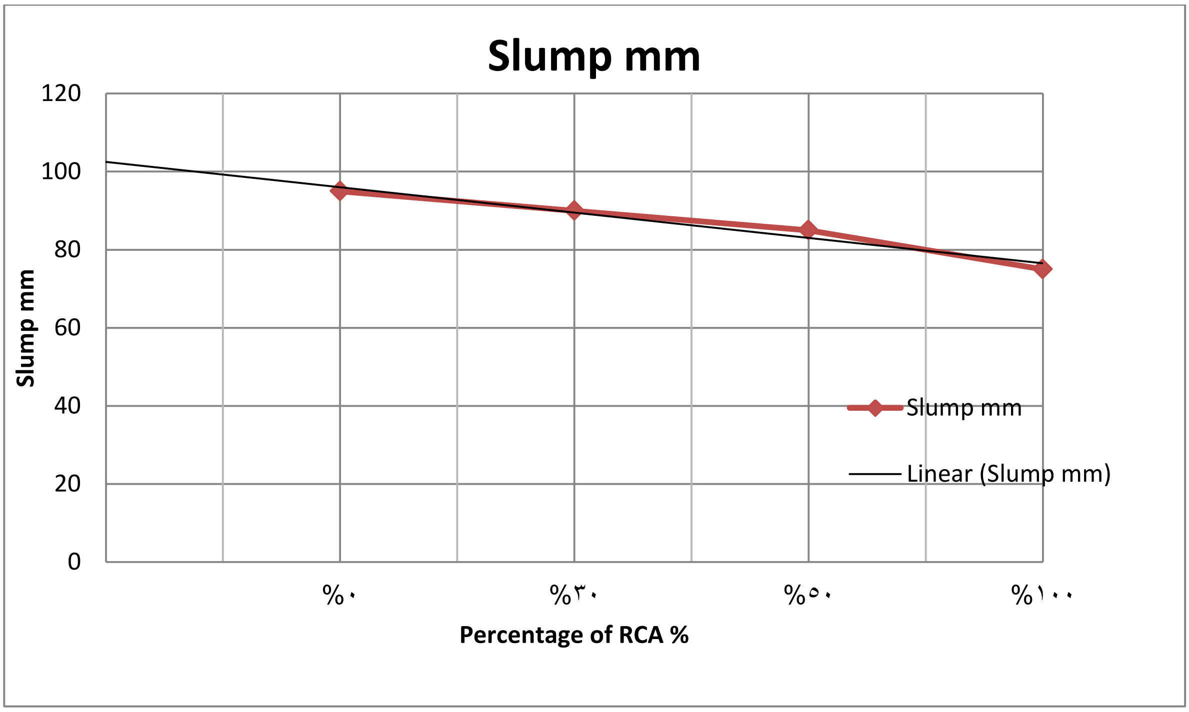


Figure (5.3) result of Slump Test for natural RCA in different proportions.

5) According to the result from figure (5.3), the highest slump obtained was 95mm and the lowest slump was 75mm. The average slump for each batch of mix was 85mm. Therefore, target slump hadbeen achieved, where the range is accordance to ACI mix design (25-100) mm.

6) The average slumps that obtained for 100% recycled aggregate (with 0.5 water cementratio) were 75mm. There was noproblem for the placement and compaction of fresh concrete in this batch. The workability was very low due to the slump was. The reasonwas because of the high absorption capacity of recycled concrete aggregate.

7) The result obtained, from figure (5.4), (5.5), and (5.6) it shows that the workability was getting higher when more admixture doses were used, so that the slump value is increased with increased of the admixture doses, for all mixes.

8) The procedure followed here is based on a practical trial and error approach; the observations made as the testing proceeds help to decrease the number of trials required. In these trials, water was reduced by percentages of 0, and 25% of the initial mix design water while SP is introduced incrementally and the standard slump measured for every increment.

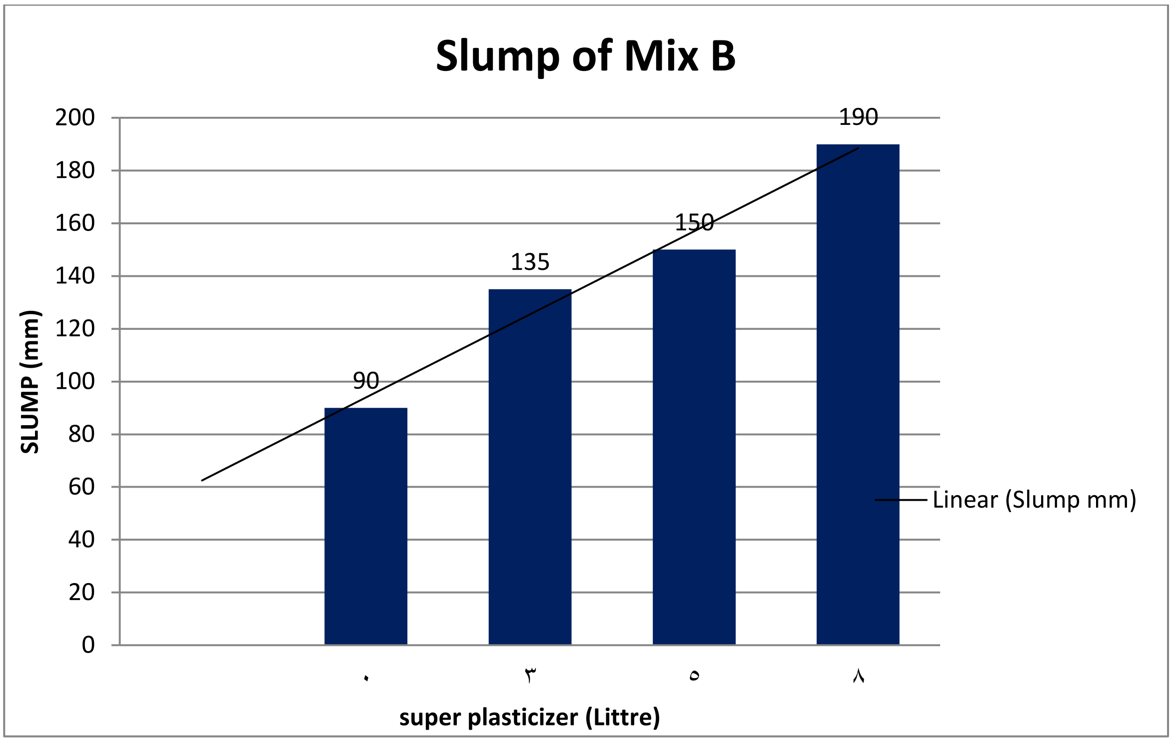


Figure (5.4) Slump for mix (B) with superplasticizer 30%

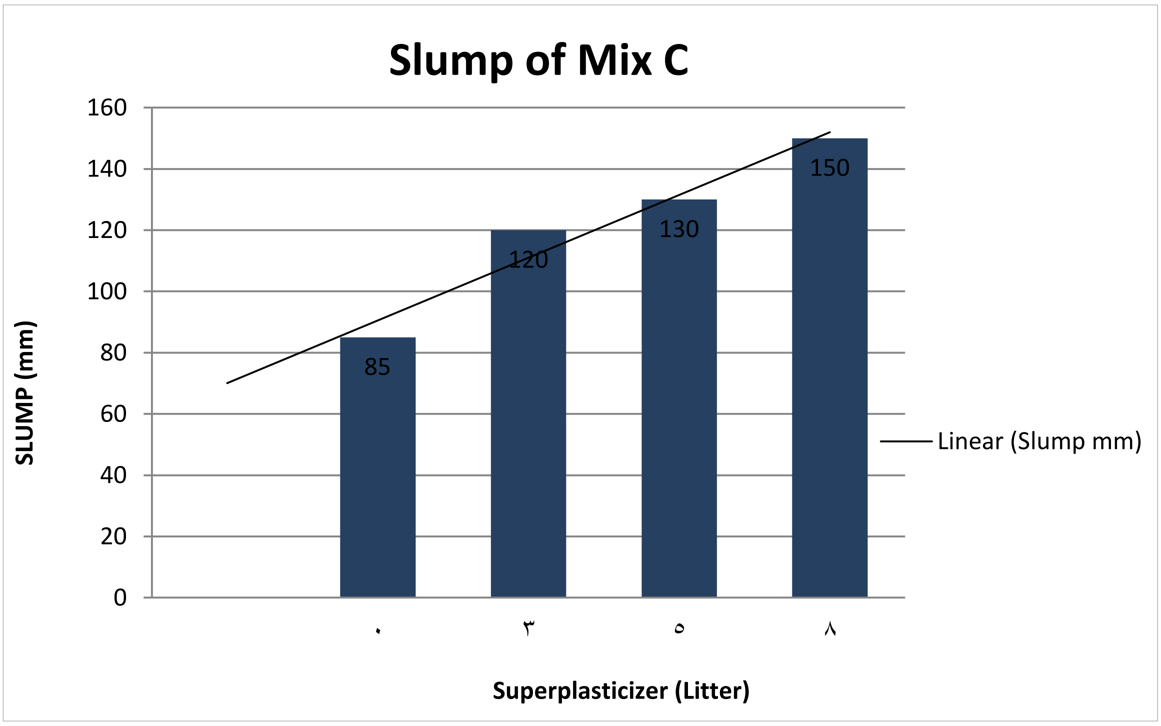


Figure (5.5) Slump for mix (C) with superplasticizer 50%

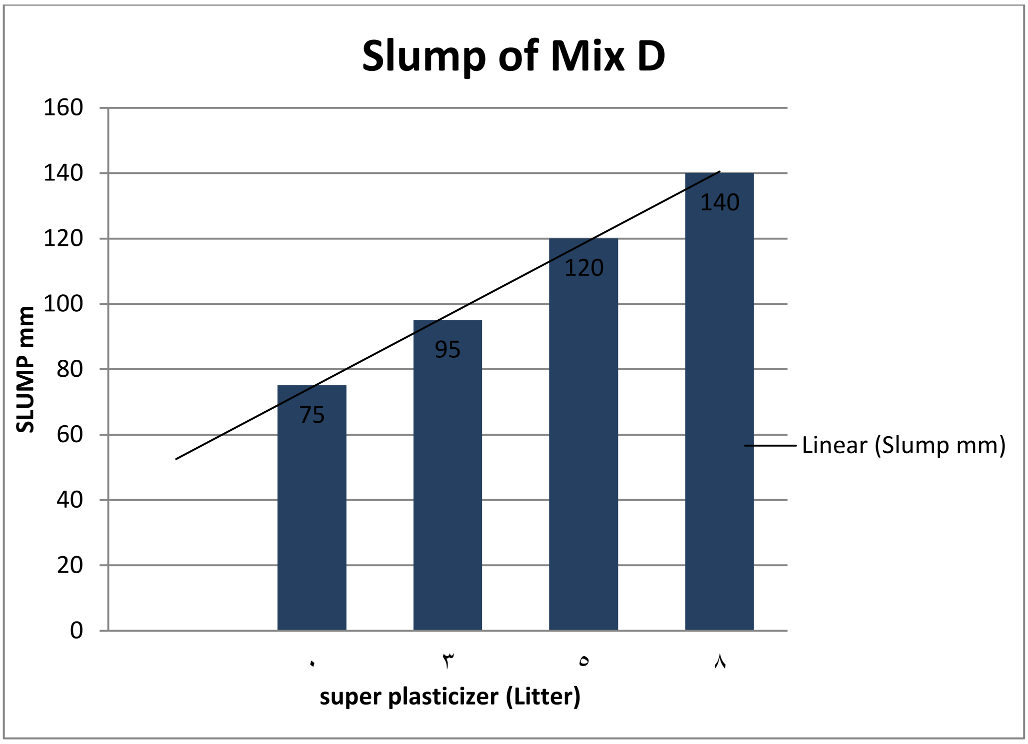


Figure (5.6) Slump for mix (D) with superplasticizer 100%

5.5.2 Compression Test Result and Analysis

The strength characteristics of each cube were tested in compression .Three cubes for every curing age will be crushed, and the average compressive strengths will be determined.

1) The compression test indicates that an increasing trend of compressive strength concrete, however, it shows that the strength of recycled concrete aggregate specimens are higher than natural aggregate concrete specimens. Table (5.6) below shows that the compressive strength with age recorded during the test.

Table (5.6) compressive strength results with age all for trail mixes:

Mix type	RCA proportion	Admixture doses Superplasticizer (Litter)	Average of compressive strength N/mm²	
			7DAYS	28DAYS
A	0%	0	24.3	32.3
B	30%	0	24	31
		3	34	42.3
		5	28	33.3
		8	28.6	36.6
C	50%	0	25.3	31.6
		3	31.3	34
		5	30.6	43
		8	32.2	34.5
D	100%	0	29.7	33
		3	31.3	34.5
		5	32	36.5
		8	33.6	43

2) Figure (5.7), shows the percentage of the compressive strength when percentage of recycled aggregate replacement increased. The compressive strength used from each batches were based on7-28 days strength.

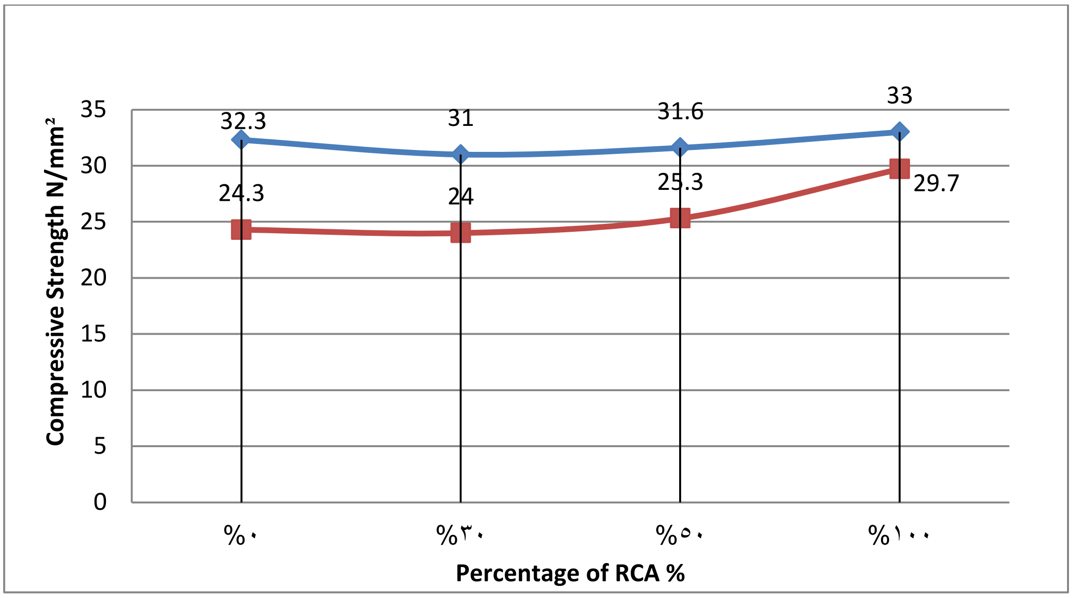


Figure (5.7): Compressive strength development showing the range of variationfor equivalent strength RCA and NA concrete.

3) The results also shows that the concrete specimens with more replacement of recycledaggregate will get the highest strength when compared to the concrete specimens with less recycled aggregate, and thatdue to the bond between the old mortar of RCA and the new one which it make good cohesion strength.

4) From figure(5.8),for mix B as the amount of the admixture increase,the compressive strength is developed in 7 and 28 days with additives (super plasticizer), the highest amount ofcompressive strength was recorded in admixturedoses 3 litters.

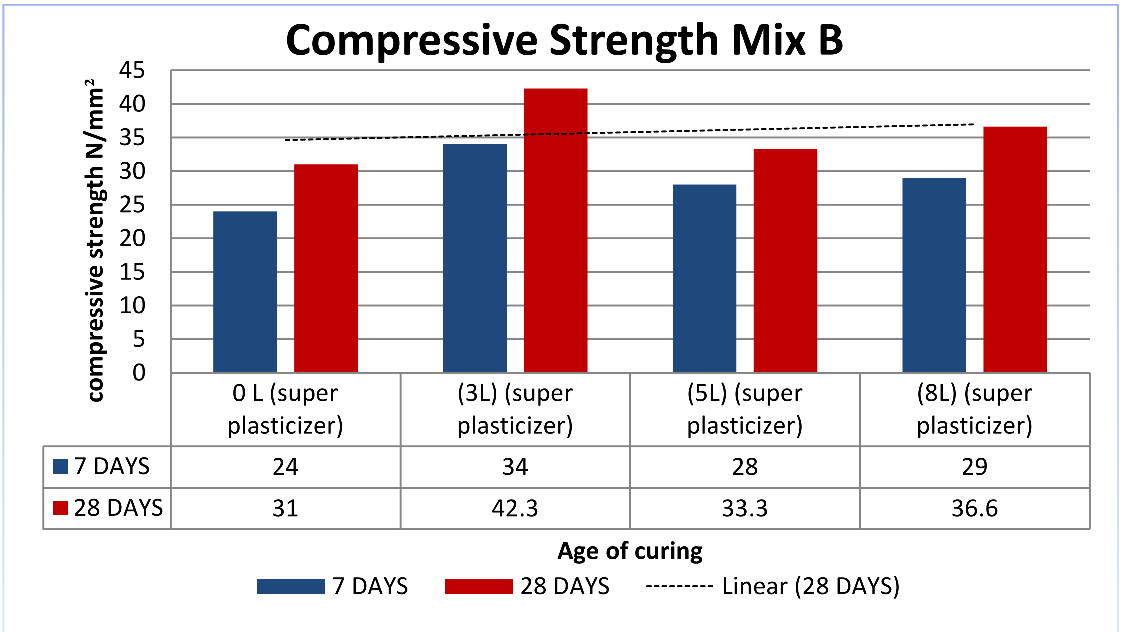


Figure (5.8): Variation of compressive strength throughout the ages(for mix B).

5) From figure (5.9),for mix C as the amount of the admixture increase, the compressive strength is developed in 7 and 28 days for this with additives (super plasticizer),the highest amount ofcompressive strength was recorded in admixturedoses 5 litters.

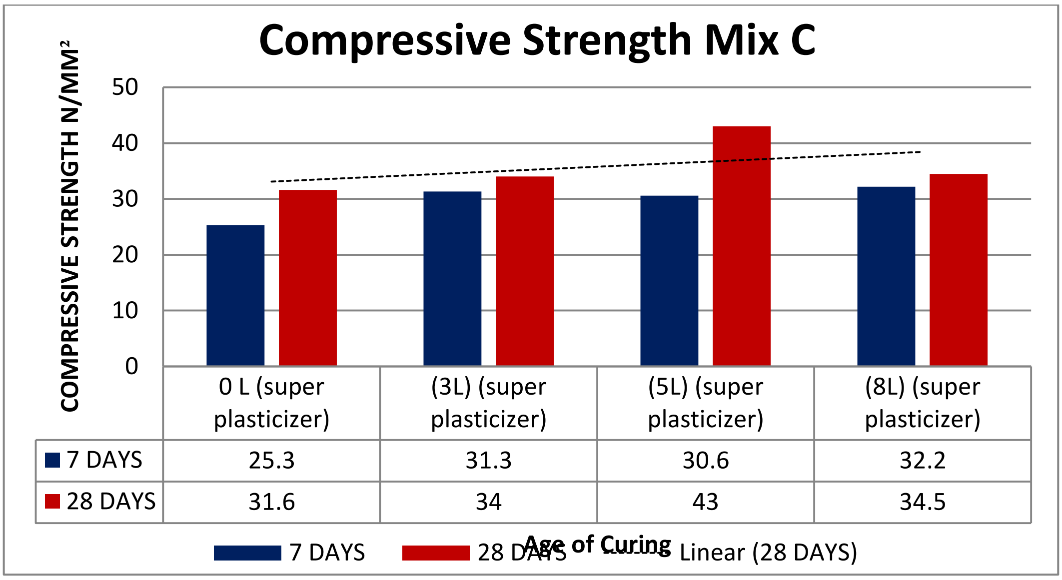


Figure (5.9): Variation of compressive strength throughout the ages (mix C).

6) From figure (5.10),for mix B as the amount of the admixture increase, the compressive strength is developed in 7 and 28 days for this with additives (super plasticizer),the highest amount of compressive strength was recorded in admixturedoses 8 litters.

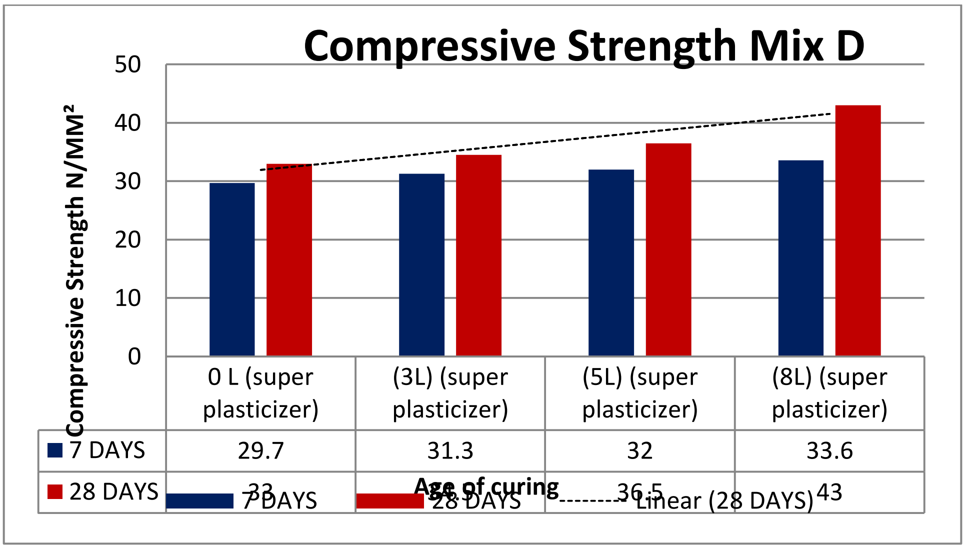


Figure (5.10): Variation of compressive strength throughout the ages (mix D).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion:

The main reason for this research is the best use of construction and demolition waste, given its importance with the gradual increase in physical waste due to population growth and urban and urban development, and the reasons that led to numerous investigations and analyzes on recycled concrete as aggregates because it is easy to obtain recycled concrete asaggregates And the cost is cheaper than the pristine aggregate. The virgin totals need to be mine but the assembly can be recycled ignoring the process.

1. This on-going research project is to determine the strength characteristics of recycled concrete aggregate for potential application in structural concrete. The study shows that when the water/cement ratio was decreased by using super plasticizer admixtures, the compressive strength can reach 43 MPa. This is classified as medium strength concrete and they can be applied in different structural work, which need compressive strength less than 40 MPa. Furthermore, with the cheaper price of RCA compared to natural aggregate, the builders can carry out the construction task with lesser material costs.

2. Chemical admixtures such as super plasticizer SP have been used to produce recycled aggregate concrete, particularly high strength concrete (HSC). The effect of these materials on the behavior of NAC is very well established. More specifically, it is believed that not enough has been done so far to increase the use of RCA to replace NA in concrete construction, particularly in higher-grade applications.

3. Although by decreasing the water/cement ratio, recycledconcrete aggregate can achievehigh strength concrete. But the workability will be very low. Therefore, it is adding admixtures SP into the mixing so that the workability will be improved.

4. The compressive strength of concrete by adding admixtures SP into the mixing so that the workability improved.

5. Although RCA can be applied in the high strength structure, but one issue must not be neglected as RCA with Adjust the amount of water content would have maintain Acceptable workability. Whenever RCA is applied, water content in the concrete mix has to be monitored carefully due to the water absorption capacity of recycled aggregate will vary. This type of concrete can only be used under the condition that does not involve a lot of handling works.

6. There was bleeding observed in some of the mixes which have increased of super plasticizeradmixture doses regardless the RCA content.

7. Strengths of RCA concrete achieved were promising and encouraging for further investigations.

6.2 Recommendations:

In this study the recycled concrete aggregate with highquality for basic material, was used to produce high compressive strength concrete indifferent ages. From the results obtained:

- Further testing and studies on the recycled concrete aggregate is highly recommended to indicate the strength characteristics ofRCA for application in high strength concrete.
- RCAmay achieve high strength concrete, the study uses super plasticizer, it is recommended that adding admixtures such as Silica Fume and another type of admixtures into the mixing so that the workability will be improved.
- More investigations and laboratory tests should be done on the othercharacteristics of RCA, some mechanical properties such as creeping, abrasion and durability were also recommended.
- More trials with different particle sizes of recycled aggregate and percentage of replacement of recycled aggregate are recommended to get different outcomesand higher strength characteristics in the recycled aggregate concrete.
- Further study of the use of RCA in high strength concrete as well as in reinforcedConcrete elements is recommended. This should involve the assessment of the bond between the reinforcement and the concrete and identify the effects of RCA through pull out testing on combinations of concrete strength and type of reinforcement bar.
- At 28 days, a concrete made with ordinary Portland cement and kept in normal curing conditions will develop about 75% of its strength, therefore it is recommended more compression tests at the age of 65 days.

References

ACI 211.1-911994, method for concrete mix designand casting,in ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete.

ACI 212.3R-911994,Chemical admixtures for concrete, in ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete.

Agarwalet al2000, Compatibility of superplasticizers with different cements. Construction and Building Materials

Anderson et al2009, Use of Recycled Concrete Aggregate in PCCP, WSDOT Research Report Office of Research and Library Services.

Angelos Koulouris 2005, Use of Coarse Recycled Aggregates in Designated Concrete Mixes

ASTM C31/C31M - 18 Standard Practices for Making and Curing Concrete Test Specimens in the Field, Standards Catalog 2016. .

ASTM C33-03,Standard Specification for Concrete Aggregates,Standards Catalog 2016.

ASTM C187,Standard Test Method for Normal Consistency of Hydraulic Cement, Standards Catalog 2016.

ASTM C 494,Standard Specifications for Chemical Admixtures for Concrete, Standards Catalog 2016.

ASTM C-1107,Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink), Standards Catalog 2016. .

Buck1973, recycled concrete Highway research record.

Brooksand Neville2009,Concrete Technology, second Edition, Licensing Agency Ltd.

Brooksand Neville2011, Concrete Technology, fifth Edition, Licensing Agency Ltd.

Cement Association of Canada,2004. “Concrete thinking for a sustainable future.” www.cement.ca /cement.nsf/e/ "25, oct, 2016".13:25.

Das2003,Development of Highways and Airports in India,Proceedings of the 6th National Conference on Construction, New Delhi, CDROM, Technical Session 1

EEA: European Environment Agency2009,EU as a recycling society: Present recycling levels of Munici -pal Waste and Construction & Demolition Waste in the EU. ETC/SCP working paper

EEA: European Environment Agency2011,Europe as a recycling society: European Recycling Policies in relation to the actual recycling achieved. ETC/SCP working paper

Fathifazl et al 2009, new mixtureproportioning method for concrete made with coarse recycled concrete aggregate. J MaterCivEng: 601–611

Frondistou 1977,Wasteconcrete as aggregate for new concrete, Journal of the American Concrete Institute.

Gilpin and David2004, recycling of construction debris as aggregate in the mid-Atlantic region.

Hansen 1985,Corporate Author Rilem Technical Committee D.R.C. Recycled aggregates and recycled aggregate concrete second state-of-the-art report developments Materials and Stru

Harlem 1987, by the World (Jnited Nations Conference on Environment and Development.

Hiller 2011,Efficient Use of Recycled Concrete in Transportation Infrastructure. Report RC-1544 to Michigan Department of Transportation.

Kou andEtxeberria2011, Influence of recycled aggregates on long termmechanical properties and pore size distribution of concrete

Naikand Kraus1999,the role of flow able slurry in sustainable developments in civil engineering.

Nelson and Shing Chai 2004,Highstrength Structural Concrete with Recycled Aggregates.

Oikonomou2005,Recycled concrete aggregates. cementandconcrete composites.

Peterman andCarrasquillo 1986, Production of high strength concrete USA.

Rodríguez et al 2013,Expansion ofmortars with gypsum contaminated fine recycled aggregates.

Shamim 2013, Display the Results of Some Researcher about the use of Recycled Aggregate in New Concrete, International Journal of Science and Research.

Sherwood1995, the use of waste and recycled materials in roads.

Shetty2005, concrete technology theory and practice, s. Chand and company ltd.

Tusharet al, Use of Recycled Aggregate Concrete, IOSR Journal of Mechanical and Civil EngineeringISSN: 2278-1684.

United States Army Engineer School Fort Leonard Wood1992.

Xiao et al 2006, an overview of study on relationship between the mechanical properties of recycled aggregate concrete.

Appendixes

Appendixes A: RCA preparation

A1 demolition of concrete

A2 Recycled Aggregate After preparation

Appendixes B: mix possessing

B1 concrete after mixing

B2 Compaction of cubes

B3 Measure of slump test

4 Cubes after casting

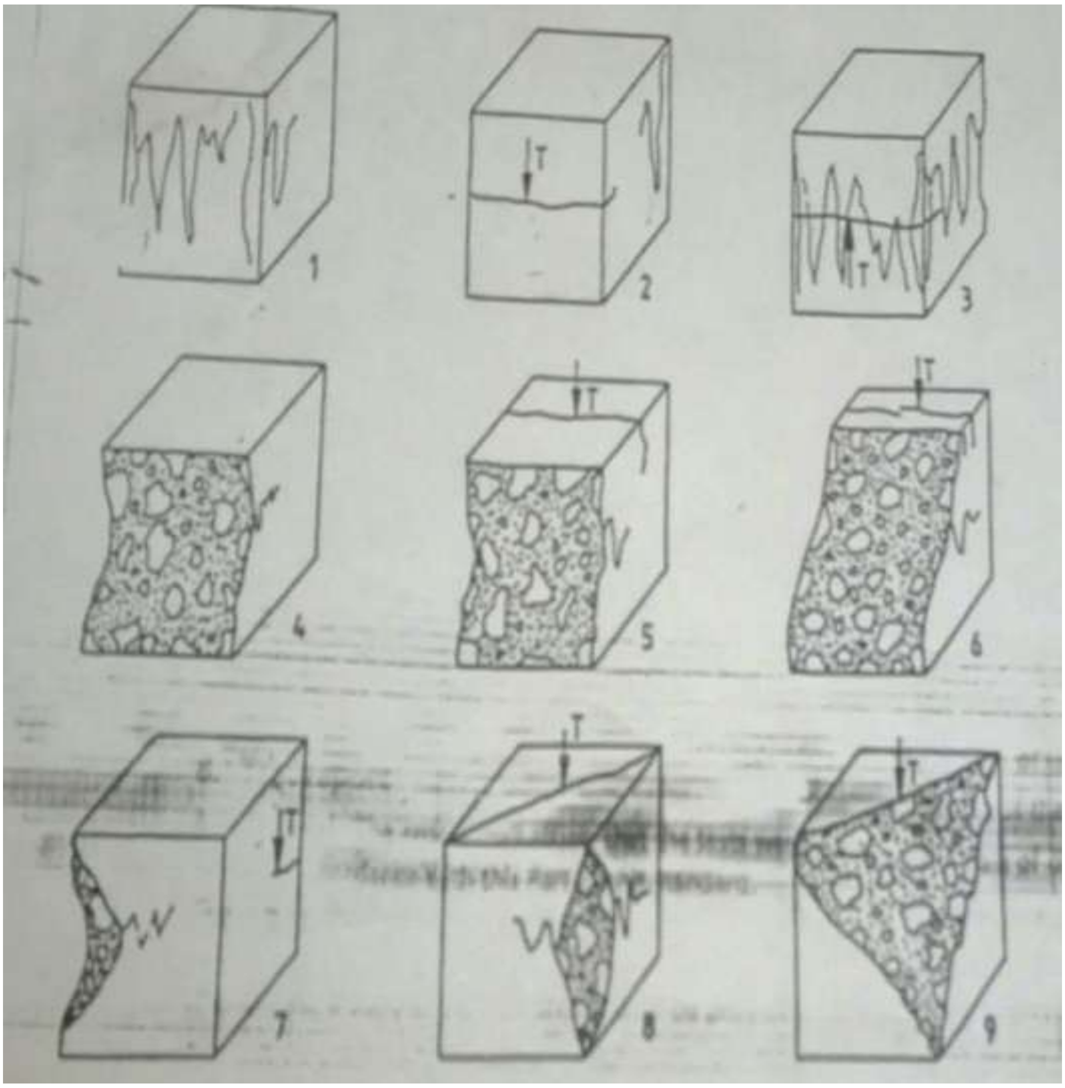
B5 Capping method

B6 curing method

Appendixes C: Compressive strength test

C1 Weight of the cube before crushing

C2 Compressive strength test machine



C3 Satisfactory failures

C4 Failure shape

C5 Failure shape

A. Result of experiment of Fresh and hardened tests of control mix FOR NAC :

Date of cast…**5/8/2017**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives
Weight(kg/m³)	4.5	3	6.5	13	0.6	22.3 ° c	non

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**25.3**	**10000**	**95**	**10^{-3}**	**2530**	**260**	**26**	**24.3**
2		**25.7**				**2570**	**240**	**24**	
3		**24.5**				**2450**	**230**	**23**	
4	**28 days**	**24.7**				**2470**	**310**	**31**	**32.3**
5		**24.8**				**2480**	**330**	**33**	
6		**24.8**				**2480**	**330**	**33**	

B. Result of experiment of Fresh and hardened tests of 30% RCA:

1. Result of experiment of tests without additives:

Date of cast…**30/6/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	2.175	6.4	12.8	0.43	22 º c	Non

Cube No.	Age of Curing days	Weight Kg	Area of load mm²	Slump mm	Volume of cube m³	Density Kg/m³	Failure Load KN	Fcu N/mm²	Average Compressive strength N/mm²
1	**7 days**	**26.4**	**10000**	**90**	**10^{-3}**	**2640**	**230**	**23**	**24**
2		**25.7**				**2570**	**250**	**25**	
3		**25.3**				**2530**	**240**	**24**	
4	**28 days**	**25.3**				**2530**	**260**	**26**	**31**
5		**25.5**				**2550**	**340**	**34**	
6		**25.9**				**2590**	**340**	**34**	

2. Result of experiment of tests with(**3L**)three Littre additives:

Date of cast…**4/7/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	2.0	6.4	12.8	0.40	23 ° c	0.34g

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**25.7**	**10000**	**135**	**10^{-3}**	**2570**	**380**	**38**	**34**
2		**25.6**				**2560**	**320**	**32**	
3		**26.6**				**2660**	**320**	**32**	
4	**28 days**	**25.6**				2560	**400**	**40**	**42.3**
5		**26.8**				2680	**410**	**41**	
6		**26.0**				2600	**460**	**46**	

3. Result of experiment of tests with(**5L**)three Littre additives:

Date of cast…**9/7/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	1.75	6.4	12.8	0.35	23 º c	0.57g

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**26.1**	**10000**	**150**	**10^{-3}**	**261**	**280**	**28**	**28**
2		**25.8**				**2580**	**310**	**31**	
3		**25.8**				**2580**	**280**	**28**	
4	**28 days**	**26.2**				2620	**330**	**33**	**33.3**
5		**25.9**				2590	**330**	**33**	
6		**25.4**				2540	**340**	**34**	

4. Result of experiment of tests with(**8L**)three Littre additives:

Date of cast…**11/7/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	1.60	6.4	12.8	0.32	27 º c	0.91g

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**26.3**	**10000**	**190**	**10^{-3}**	**2630**	**260**	**26**	**28.6**
2		**26.8**				**2680**	**300**	**30**	
3		**25.9**				**2590**	**300**	**30**	
4	**28 days**	**26.2**				**2620**	**370**	**37**	**36.6**
5		**26.5**				**2650**	**380**	**38**	
6		**25.8**				**2580**	**350**	**35**	

C. **Result of experiment of Fresh and hardened tests of 50% RCA:**

1. Result of experiment of tests without additives:

Date of cast…**13/7/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	2.15	6.4	12.8	0.43	22.5 º c	Non

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**25.7**	**10000**	**85**	**10^{-3}**	**2570**	**250**	**25**	**25.3**
2		**25.3**				**2530**	**250**	**25**	
3		**24.6**				**2460**	**260**	**26**	
4	**28 days**	**25.7**				**2570**	**310**	**31**	**31.6**
5		**24.5**				**2450**	**320**	**32**	
6		**24.7**				**2470**	**310**	**31**	

2. Result of experiment of tests with(**3L**)three Littre additives:

Date of cast…**14/7/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	1.8	6.4	12.8	0.36	25 º c	0.34g

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**25.2**	**10000**	**120**	**10^{-3}**	**2520**	**280**	**28**	**31.3**
2		**25.2**				**2520**	**340**	**34**	
3		**25.2**				**2520**	**320**	**32**	
4	**28 days**	**24.3**				2430	**330**	**33**	**34**
5		**24.4**				2440	**430**	**43**	
6		**24.5**				2450	**350**	**35**	

3. Result of experiment of tests with(**5L**)three Littre additives:

Date of cast…**16/7/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	1.70	6.4	12.8	0.34	27.5 º c	0.57g

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**25.6**	**10000**	**130**	**10^{-3}**	**2560**	**340**	**34**	**30.6**
2		**26.1**				**2610**	**330**	**33**	
3		**26.8**				**2680**	**250**	**25**	
4	**28 days**	**26.2**				2620	**320**	**32**	**43**
5		**26.5**				2650	**430**	**43**	
6		**26.8**				2680	**430**	**43**	

4. Result of experiment of tests with(**8L**)three Littre additives:

Date of cast…**23/7/2018**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	2.15	6.4	12.8	0.30	29 º c	0.91g

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**27.6**	**10000**	**150**	**10^{-3}**	**2760**	**330**	**33**	**32.2**
2		**26**				**2600**	**330**	**33**	
3		**26.8**				**2680**	**310**	**31**	
4	**28 days**	**26.6**				2660	**350**	**35**	**34.5**
5		**26.8**				2680	**340**	**34**	
6		**26.3**				2630	**510**	**51**	

D. Result of experiment of Fresh and hardened tests of 100% RCA:

1. Result of experiment of tests without additives:

Date of cast…**27/2/2017**……… Type of cement…**O.P.C**………

Cube Dim. …**150*150*150** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives
Weight(kg/m^3)	12	5.4	14.8	29.7	0.5	21.5 º c	non

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm^2**	**Slump mm**	**Volume of cube m^3**	**Density Kg/m^3**	**Failure Load KN**	**Fcu N/mm^2**	**Average Compressive strength N/mm^2**
1		**8.2**				**2430**	**540**	**24**	
2	**7 days**	**8.3**				**2459**	**675**	**30**	**29.7**
3		**8.6**				**2548**	**790**	**35.1**	
4		**8.46**	**22500**	**75**	**$3.375*10^{-3}$**	**2506**	**760**	**33.7**	
5	**28 days**	**8.43**				**2497**	**685**	**30.4**	**33**
6		**8.42**				**295**	**790**	**35**	

2. Result of experiment of tests with(**3L**)three Littre additives:

Date of cast…**28/2/2017**……… Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	2.15	6.4	12.8	0.43	23^{o} c	0.34

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**27.2**	**10000**	**95**	**10^{-3}**	**2720**	**330**	**33**	**31.3**
2		**27.3**				**27300**	**310**	**31**	
3		**26.9**				**26900**	**300**	**30**	
4	**28 days**	**27.9**				**2790**	**350**	**35**	**34.5**
5		**26.6**				**2660**	**340**	**34**	
6		**27.4**				**2740**	**440**	**44**	

3. Result of experiment of tests with(**5L**) additives:

Date of cast…**1/3/2017** Type of cement…**O.P.C**………

Cube Dim. …**100*100*100** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	5	1.75	6.4	12.8	0.35	23.6 ° c	0.57

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**27.7**	**10000**	**120**	**10^{-3}**	**27700**	**320**	**32**	**32**
2		**26.8**				**26800**	**300**	**30**	
3		**26.9**				**26800**	**340**	**34**	
4	**28 days**	**26**				**2600**	**470**	**47**	**36.5**
5		**26**				**2600**	**380**	**38**	
6		**26.3**				**2630**	**350**	**35**	

4. Result of experiment of tests with(**8L**) additives:

Date of cast…**12/3/2017**……… Type of cement…**O.P.C**………

Cube Dim. …**150*150*150** mm…

content	cement	water	Fine aggregate	Coarse aggregate	W/C	Heat of Mix	additives (super plasticizer) type B
Weight(kg/m³)	12	4.2	14.8	29.7	0.35	24 ° c	0.91

Cube No.	**Age of Curing days**	**Weight Kg**	**Area of load mm²**	**Slump mm**	**Volume of cube m³**	**Density Kg/m³**	**Failure Load KN**	**Fcu N/mm²**	**Average Compressive strength N/mm²**
1	**7 days**	**8.3**	**22500**	**140**	**3.375*10⁻³**	**2459**	**750**	**33.3**	**33.6**
2		**8.3**				**2459**	**800**	**35.5**	
3		**8.3**				**2459**	**720**	**32**	
4	**28 days**	**8.5**				**2518**	**1050**	**46**	**43**
5		**8.5**				**2528**	**890**	**40**	
6		**8.4**				**2489**	**590**	**26**	