“EFFECT OF SILICA FUME AND RECYCLED COARSE AGGREGATE IN CONCRETE”

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Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the project **"EFFECT OF SILICA FUME AND RECYCLED COARSE AGGREGATE IN CONCRETE"** in partial fulfillment of the requirements for the award of the degree of Masters of Technology in Civil Engineering with specialization in **Structural Engineering** and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **PRATEEK SONKHLA** during a period from July 2015 to June 2016 under the supervision of **Mr. CHANDRA PAL GAUTAM** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

Natural aggregate is being used faster than it is being made available creating a foreseeable shortage in the future. Despite this trend, the availability of demolished concrete for use as recycled concrete aggregate (RCA) is increasing. Using this waste concrete as RCA conserves natural aggregate, reduces the impact on landfills, decreases energy consumption and can provide cost savings. However, there are still many unanswered questions on the beneficial use of RCA in concrete pavements .This report aims to find the possibility of the structural usage of recycled aggregate concrete in lieu or mixed with natural aggregates, based on better understanding of behavior of recycled aggregate in concrete structures experimenting fresh and hardened concrete, mixtures containing recycled aggregates. The literature review provides an overview of sustainability and key performance indicators, the material properties of RCA both as an aggregate and in concrete, concrete mixture and proportioning designs with RCA, performance of existing RCA pavements, and the implementation of RCA highlighting some examples where RCA has been used successfully. Use of recycled aggregate (RA) in concrete can be useful for environmental protection and economical terms. Recycled aggregates are the materials for the future. It is well known fact that it is giving little lower strength than natural aggregate concrete. Though, if it is used up to 20% of replacement by weight, than it can give almost similar strength to that of natural aggregate concrete. Hence it was necessary to improve strength of recycled aggregate concrete for higher recycled aggregate content. Hence silica fume used for strength improvement.

Keywords: Recycled Aggregate Concrete, Recycled Aggregate, Silica fume

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LIST OF ABBREVIATIONS

ACV	Aggregate Crushing Value
C&DW	Construction and Demolition Waste
CA	Coarse Aggregate
CTM	Compression Testing Machine
f**'ck**	Target average Compressive Strength in N/mm2
f**ck**	Characteristic Compressive Strength in N/mm2
f**'st**	Split Tensile Strength in N/mm2
FA	Fine Aggregate
FCM	Fresh Concrete Mix
FM	Fineness Modulus
HSC	High Strength Concrete
IS	Indian Standard Specifications
NA	Natural Aggregate
OPC	Ordinary Portland cement
RA	Recycled Aggregate
RCA	Recycled Aggregate Concrete
S	Standard Deviation
Sc	Specific Gravity of Cement
SG	Specific Gravity
SSD	Saturated Surface Dry Density
WCM	Waste Concrete Mix

CHAPTER 1 INTRODUCTION

1.1 GENERAL INTRODUCTION

Concrete is the premier construction material across the world and the most widely used in all types of civil engineering works, including infrastructure, low and high rise buildings, defense installations, environmental protection facilities . The use of recycled aggregates in concrete opens a whole new range of possibilities in the reuse of materials in the building industry. The utilization of recycled aggregates is a good solution to the problem of an excess of waste material, provided that the desired final product will fit the standards. The studies on the use of recycled aggregates have been going on for 50 years. In fact, none of the results showed that recycled aggregates are unsuitable for structural use. Recently the use of recycled concrete as a structural fill material, in lieu of natural aggregate, has recently been increasing. In some regions, recycled concrete aggregate may cost 20 % to 30 % less than natural aggregate. The construction of infrastructures related to bridges, highways, water systems, and buildings has been increasing from the beginning of the past century, especially in areas where population density is high. Infrastructures need to be repaired with the pass of the time. In some cases, constructions need to be replaced, because their service life is reached or their original design no longer satisfies the new requirements (population, traffic, or weather). These facts have generated two important issues:

- a growing demand for construction aggregates, and second an increasing production of construction material waste.
- The construction waste only, on the other hand, produced from building demolition is estimated to be 123 million tons per year.

Historically, the most common method of managing this material has been through disposal in landfills. It is estimated that 50 percent of concrete debris and 20 percent of all asphalt pavements end up in landfills. As cost, environmental regulations, and land policies of landfill arise, the concern to seek alternative uses of the waste material also increases. This situation has led the aggregate industry to begin reclaiming construction waste as an alternative aggregate especially for pavement uses. Additionally, government entities have started promoting this recycling process as an option to natural aggregate, helping extend the life of natural resources, reducing the environmental disturbance around construction Site, and reducing the volume of waste to landfill areas.

1.2 BACKGROUND

Concrete has been proved to be a leading construction material for more than a century. It is estimated that the global production of concrete is at an annual rate of 1 m^3 per capita. The global consumption of natural aggregate will be in the range of 48.3 billion metric tons after 2015. Over 1 billion tons of construction and demolition waste (C&DW) is generated every year worldwide. At the same time, large quantities of natural aggregates are extracted for construction every year leading to the large scale depletion of natural aggregate and the increased amounts of C&DW. The construction and demolition waste are primarily used for landfill sites which are causing significant damage to the environment and developing serious problems. The use of the recycled aggregates created from processing of construction and demolition waste in new construction has become more important over the last two decades as it conserve the nonrenewable natural resource of virgin aggregates. Though the use of recycled concrete aggregate (RCA) can lead to reduction of up to 40% in compressive strength, for economical and environmental reasons and because of the increased amount of recycled aggregates production, there has been a growing global interest in maximizing the use of recycled aggregates in construction. In view of the increased volumes of construction, demolition waste, and industrial byproducts such as fly ash (FA) and the advantages offered by the use of admixtures in modern concrete, it is considered very beneficial from different prospects with similar performance characteristics to natural aggregate concrete. When proved successful, recycled aggregate concrete (RCA) can be substituted for natural aggregate concrete in many concrete applications. It is believed that impurities, particularly old cement paste clinging to recycled aggregate (RCA), have a significant influence on the strength of RAC. The authors have reviewed many studies that concluded that adhered mortar from the original concrete plays an important role in determining the performance with respect to permeability and strength. This was considered to be one of the most significant differences between RAC and natural aggregate (NA) concrete (NAC). Many other researchers have also done studies on the effect of fly ash with recycled aggregate on strength characteristics of normal and high strength concrete (HSC), concrete with lightweight aggregate, replacement of sand with fly ash, and influence of pozzolonic material from various industrial by-products on mechanical properties of high strength concrete. The behavior of the recycled aggregate concrete strength characteristics with full replacement of the recycled coarse aggregate in place of natural coarse aggregate are the significant findings of the earlier researchers. The partial to full replacement of the recycled coarse aggregate to the natural coarse aggregate is also essential to understand the mechanical behavior of the concrete in general.

1.3 AIM AND OBJECTIVE

This research aims to reduce the environmental problems generated from dumping the construction and demolition wastes. This aim can be achieved by recycling the construction and demolition wastes to produce concrete mixes for structural elements with high performance as natural aggregate.

OBJECTIVES:

1. Studying the physical and mechanical performance of recycled aggregate used in concrete mixtures in lieu of natural aggregate.

2. To examine the possibility of using recycled aggregate in concrete mixes.

3. To reduce the impact of waste materials on environment.

4. To investigate the percentage variation of silica fume.

5. To optimize the ratio of recycled aggregate to natural aggregate to produce better concrete mix.

The purpose of this research is to study the behavior of RAC aggregates when it is included in Portland cement concrete or in embankments. For the first case, slump tests were performed on freshly mixed concrete, and compression tests were performed on hardened concrete. Several batches of concrete were prepared with RAC and natural aggregate, changing their mixture design parameters, including aggregate sieve distribution (gradation) and water cement ratio.

1.4 THE USE OF RECYCLED AGGREGATE IN CONCRETE

The use of crushed aggregate from either demolition concrete or from hardened leftover concrete can be regarded as an alternative coarse aggregate, typically blended with natural coarse aggregate for use in new concrete. The use of 100% recycled coarse aggregate in concrete, unless carefully managed and controlled, is likely to have a negative influence on most concrete properties – compressive strength, modulus of elasticity, shrinkage and creep, particularly for higher strength concrete. Also the use of fine recycled aggregate below 2 mm is uncommon in recycled aggregate concrete because of the high water demand of the fine material smaller than 150 μm, which lowers the strength and increases the concrete shrinkage significantly. Many overseas guidelines or specifications limit the percentage replacement of natural aggregate by recycled aggregate. In general leftover concrete aggregate can be used at higher replacement rates than demolition concrete aggregate. With leftover concrete aggregate, information will 4 generally be known about the parent concrete – strength range and aggregate source etc., whereas for demolition concrete very little information may be known about the parent concrete, and the resulting aggregate may be contaminated with chlorides or sulphates and contain small quantities of brick, masonry or timber which may adversely affect the recycled aggregate concrete. Often the sources of material from which a recycled aggregate came (and there could be more than one source), are unknown and the variability and strength of the recycled aggregate concrete could be adversely affected in comparison with a recycled aggregate concrete where the recycled aggregate came from one source with a known history of use and known strength. It is therefore necessary to distinguish between the properties of recycled aggregate concrete made using demolition concrete aggregate and that using leftover concrete aggregate.

1.5 COST

The cost of quality aggregate has increased above the inflation rate and it is projected that, this trend will continue as further restrictions are placed on this resource in the future. Concrete C&D waste will be recycled if it is less expensive than disposing of it in a landfill and recycled concrete aggregate (RCA) will be used if it is less expensive than natural aggregate of similar quality. RCA use is based on economics, including the cost of transporting C&D waste and virgin aggregate, the cost of C&D disposal, and government intervention on tipping fees and mandatory usage through legislation. Approximately 60% of aggregate cost is due to transportation. The economics are starting to make recycled materials more attractive.

1.6 ACHIEVING SUSTAINABILITY WITH RECYCLED AGGREGATE CONCRETE

Sustainability is defined as “Meeting the needs of the present without compromising the ability of the future generations to meet their own needs”. The current usage of aggregate is not sustainable as demonstrated by the growing shortage of natural aggregates in urban area. Recycling concrete, from deteriorated concrete structures, would reduce the negative impact on the environment and increase sustainability of aggregate resources. Using RCA conserves virgin aggregate, reduces the impact on landfills and decreases energy consumption. Using RCA creates cost savings in the transportation of aggregate and waste products, and in waste disposal. Finding ways to reuse C&D waste and minimize things that are not suitable for reuse will increase sustainability.

1.7 SOURCES OF RECYCLED AGGREGATE

The aggregates that can be produced from the breakup and crushing of existing Portland cement concrete pavement and structural elements is called recycled aggregate .There are two sources of demolished concrete all over the world:

a). **Rigid concrete pavement**: where an asphalt concrete surface is present on an existing rigid pavement, the asphalt concrete must be removed before the old Portland cement concrete pavement is broken up.

b). **Concrete structures**: It is the intention of this operation to produce the maximum amount of Portland cement concrete that can be crushed, stockpiled, and accepted as aggregate in new Portland cement concrete. All reinforcing steel should be removed from the concrete either prior to or during the crushing operation.

1.8 CONCRETE RECYCLING

When structures made of concrete are demolished or renovated, concrete recycling is an increasingly common method of utilizing the rubble. Concrete was once routinely trucked to landfills for disposal, but recycling has a number of benefits that have made it a more attractive option in this age of greater environmental awareness, more environmental laws, and the desire to keep construction costs down. Concrete, it has been claimed, is not an environmentally friendly material due to its destructive resource-consumption nature and severe environmental impact after its use. Nevertheless, it will remain one of the major construction materials being utilized worldwide. Taking the concept of sustainable development into consideration, the concrete industry has to implement a variety of strategies with regards to future concrete use, for instance, improvements in the durability of concrete and the better use of recycled materials. In general, aggregates occupy 55-80% of concrete volume. Without proper, alternative aggregates being utilized in the near future, the concrete industry globally will consume 8-12 billion tonnes annually of natural aggregates after the year 2010. For a variety of reasons, reuse of construction and demolition (C&D) materials by the construction industry has become more significant. In addition to environmental protection, conservation of natural aggregate resources, shortage of waste disposal land, and increasing cost of waste treatment prior to disposal are the main reasons for the growing interest in recycling C&D materials.

1.9 RCA PRODUCTION

Recycled aggregates to be produced from aged concrete that has been demolished and removed from foundations, pavements, bridges or buildings, is crushed and processed into various size fractions. Reinforcing steel and other embedded items, if any, are removed and care is taken to prevent contamination by dirt or other waste building materials such as plaster or gypsum. It is prudent to store old concrete separately to other demolition materials to help avoid contamination. Records of the history of the demolition concrete – strength, mix designs etc. – would seldom be available, but if available these are useful in determining the potential of the recycled aggregate concrete. The processes for the production of recycled aggregates are carried out in plants of treatment which are similar to the plants of crushing of natural aggregates. These include mainly five stages in the recycling process of construction and demolition waste and they are done in the following ways.

1. Coarse separation
2. Crushing
3. Separation of ferrous elements
4. Screening
5. Removal of impurities by air separation

During the coarse separation the debris is chopped smaller so as to go smoothly into the crusher inlet. The crushing can be also performed by squeezing, impacting and grinding. To obtain a decreasingly sized product three different crushing stages, take place primary crushing, secondary crushing and milling. Particle size distribution classes are determined during the screening operation. If necessary, impurities like wood, plastic and paper can be removed. Air separation technique is more convenient than the washing separation which is more expensive. The process ends with the storage of the products.

1.9.1 CURRENT APPLICATION OF RCA

The new J-Cube Capital Mall in Singapore (completed in 2011) is an example of the use of recycled coarse aggregate concrete in a structural application. Built on the site of the demolished Jurong Entertainment Centre, the new mall utilized the reclaimed concrete as aggregate in 50% of the new concrete structural elements that comprise the superstructure. Figure (1.1) illustrates the mall.

Figure (1.1) J-cube capital Mall, Singapore

A case study from North America was the demolition of the former Stapleton Airport in Denver, Colorado in which 2.1 million kilograms (2100 tonnes) of recycled concrete were utilized from old runway, office and warehouse structures in the construction of the New Enterprise Park at Stapleton (Figure 1.3). In total, 4300 m3 of recycled concrete incorporating approximately 1400 tonnes of RCA was used in the construction of the tilt up wall panels, making it the largest application of recycled concrete in a tilt-up application *(Etkin-Johnson, 2012)*.

1.10 SILICA FUME

Silica fume was first discovered in Norway in 1947 when the environmental controls started the filtering of the exhaust gases from furnaces. The main portion of these fumes was a finely composed of a high percentage of silicon dioxide. Silica fume consists of the fine particles with specific surface about six times of cement because its particles are very finer than cement particles. Hence, it has been found that when silica fume mixes with concrete the minute pore spaces decreases. Silica fume is pozzolanic, because it is reactive, like volcanic ash.

Figure (1.2) Silica Fume

Its effects are related to the strength, modulus, ductility, sound absorption, vibration damping capacity, abrasion resistance, air void content, bonding strength with reinforcing steel, shrinkage, permeability, chemical attack resistance, alkali-silica reactivity reduction, creep rate, corrosion resistance of embedded steel reinforcement, freeze-thaw durability, coefficient of thermal expansion (CTE), specific heat, defect dynamics, thermal conductivity, dielectric constant, and degree of fiber dispersion in mixes containing short microfibers. Also, addition of silica fume decreases the workability of the mix. Silica fume can solve problems, because of its very loose bulk density and fine particles. However, it causes other problem such as stickiness, bridging in storage silos, and clogging of the pneumatic transport equipment. Vibration reduction is useful for structural stability, hazard mitigation, and structural performance improvement. Effective vibration reduction requires both stiffness and damping capacity. Silica fume is effective for increasing both damping capacity and stiffness. Sound or noise absorption is helpful for numerous structures, such as noise barriers and pavement overlays. The addition of silica fume to the concrete increases the sound absorption ability.

1.10.1 SILICA FUME SOURCE

It is very fine no crystalline silica manufactured by electric arc furnaces as a byproduct of the production of metallic silicon or ferrosilicon alloys. The raw materials are coal, quartz, and woodchips. The smoke that produced from furnace operation is stored and sold as silica fume rather than being land filled. As the silica fume powder particles are hundred times finer than ordinary Portland cement, there might be problems arise when deals with silica fume, such as dispensing consideration, transportation, and storage that must be taken into account. To overcome some of these difficulties, the material is commercially divided in various forms. The difference between these forms is the size of the particle which do not significantly affect the chemical make-up or reaction of material. This difference has effect on the different purposes of use. Thus, careful consideration is needed when choosing the type of silica fume for specific application.

1.10.2 STRENGTH

High compressive is normally the first property associated with silica fume concrete. Many experiments have shown that the addition of silica fume to concrete mix increases the strength of mix by between 30% and 100% depending on the type of cement, type of mix, use of plasticizers, amount of silica fume, aggregates type, and curing regimes . The relationship between tensile, flexural and compressive strengths in silica fume concrete is the same as those for ordinary strength concrete. Increase in compressive strength by using silica fume also results an increase in the tensile and flexural strength. This plays an important role when silica fume concrete is used in bridging, flooring, and roadway projects. Increased tensile strength causes a possible reduction in slab thickness while maintaining high compressive strengths. Hence, it reduces the overall slab weight and cost. The stronger concrete is more brittle and silica fume concrete is no exception to this rule. Modulus of elasticity does not follow the pattern of tensile strength, but only displays slight increase compared to the compressive strength. Thus, high and ultrahigh strength concrete can be used for tall structures without loss of ductility.

Silica fume aids in achieving the following properties in concrete:-

1. Increased strength and density in concrete.

2. Prevents bleeding and segregation in fresh concrete.

3. Low permeability and water tightness.

4. Resistance to Chlorides and Sulphates.

5. Resistance to chemical attack.

6. Better flexural strength.

7. Excellent freeze/ thaw resistance.

8. Abrasion and Erosion resistance.

9. Corrosion protection.

1.11 PROPERTIES OF RECYCLED COARSE AGGREGATES

RCA often contains a large amount of attached mortar and cement paste. The volume percentage of old mortar may range from 20% to 30%, depending on the properties of parent concrete and the production process. The attached mortar and cement paste on recycled coarse aggregate are the principal cause of the difference between recycled coarse aggregate (RCA) and natural coarse aggregates. Test results indicated that recycled coarse aggregate has the following technical properties [Xu and Shi (2006), Xiao, (2008)].

1) Low bulk and saturated-surface-dry (SSD) density. The bulk density of recycled coarse aggregate is about 1290–1470 kg/m^3.The SSD density of recycled coarse aggregate is about 2310–2620 kg/m^3.

2) High water absorption. The absorptions of recycled coarse aggregate are approximately 8.34% (10 min), 8.82 (30 min) and 9.25% (24 h), which is much larger than that of natural coarse aggregates and might be regarded as the most important characteristic.

3) High porosity. The porosity of RCA is approximately 23.3%, due to high mortar/ cement paste content.

4) High crushing index. The crushing index of RCA is approximately 9.2% to 23.1%.

5) High clay content. The clay content of RCA is approximately 4.08%.

1.12 IMPURITIES IN RECYCLED COARSE AGGREGATE

Although, RCA are normally used as direct replacement of coarse aggregate. However, certain points must be kept in mind while using recycled coarse aggregate in concrete.

Absorption and Surface Moisture

Aggregates are porous materials and water can be absorbed onto the body of the aggregates. The absorption capacity is generally defined as the total amount of water required to bring the aggregate to a saturated surface dry (SSD) condition. Aggregates may exist in various moisture states: oven dry, air-dry, saturated surface dry or moist state. Figure (1.6) illustrates the various moisture states of aggregates.

A difference must be made between the moisture that is absorbed by the aggregate and the additional water that is observes on the aggregate surface. In concrete mix proportions, it is surface or free moisture that is used to balance the required mixing water. Only free water is available for mixing in concrete and it is this moisture which contributes to the water cement ratio. It is the size and number of internal pores that are responsible for absorption of water in aggregate and it is seen that recycled coarse aggregates have a higher water requirement than natural aggregates due to the higher water absorption value of adhered mortar.

The rate of absorption also plays a significant role in concrete mix proportioning including recycled coarse aggregates. In general, recycled coarse aggregates take longer time to absorb moisture than natural aggregates and, as a result, it may not reach full saturation during the mixing period. Therefore, it has been recommended to pre-soak the coarse aggregates to compensate for the slower absorption rate.

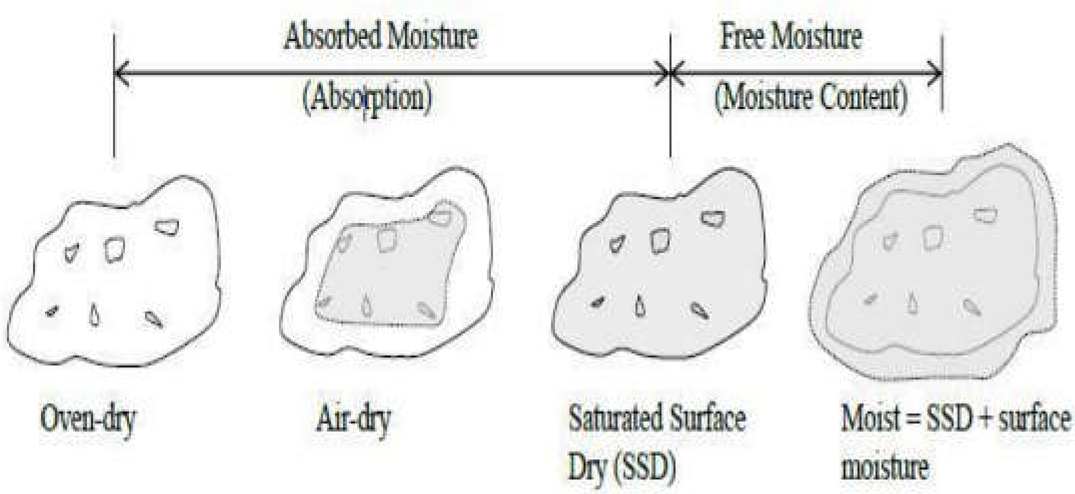

Figure (1.3) Several Moisture States of Aggregates (*Neville, 1995*)

1.12.1 Adhered Mortar Content

After crushing of concrete, the resultant recycled coarse aggregate concrete contains both natural stone and old mortar. This old adhered mortar can account for, about 25 to 60percent by volume of the aggregate itself. It was noted that the finer the aggregate, the more the adhered mortar content. The residual mortar content can have negative impacts also on such concrete properties as absorption, density, abrasion resistance etc. The amount of residual mortar present on recycled coarse aggregate depends largely on the crushing process by which the aggregates are produced. As the number of crushing of the aggregates increases, the amount of adhered mortar is reduced. It was also observed that use of impact crusher produces higher percentage of recycled coarse aggregate with less amount of residual mortar and it is also suggests that the adhered mortar in recycled coarse aggregate give lower strength then the fresh mortar produced in new concrete. As result, it concluded that the adhered mortar in recycled coarse aggregates is the weakest point in concrete produced with coarse recycled coarse aggregates.

Several methods have been investigated to determine the percent of residual mortar in recycled coarse aggregate. The most general and commonly used method is taking as sample of oven dried recycled coarse aggregate weighing 100 grams in a plastic container.

In this container add 1:3 HCL solutions such that the HCL solution surface was 15 mm above the aggregates. And when the level of the HCL falls down after some hours add more HCL in order to maintain the level. After 2 days the constituents of recycled coarse aggregate split up. Transfer the recycled coarse aggregate particles to a new container and additional water that is observes on the aggregate surface. In concrete mix proportions, it is surface or free moisture that is used to balance the required mixing water. Only free water is available for mixing in concrete and it is this moisture which contributes to the water cement ratio. It is the size and number of internal pores that are responsible for absorption of water in aggregate and it is seen that recycled coarse aggregates have a higher water requirement than natural aggregates due to the higher water absorption value of adhered mortar.

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1.13 ADVANTAGES AND DISADVANTAGES OF RCA CONCRETE

The following are advantages of recycled coarse aggregate:-

1. Recycled coarse aggregate provides sustainability.
2. Recycled coarse aggregate reduces the amount of material that would be delivered to a landfill.
3. Recycled coarse aggregate reduces the need of virgin aggregates to be created.
4. RCA uses 90% less energy in production than the production of Portland cement.
5. Absorbs large amount of carbon dioxide while being crushed into smaller sizes, reduces the amount of CO2 in the atmosphere.
6. Use of high fineness of fly ash in recycled aggregate concrete yielded greater compressive strength.

The following are disadvantages of RCA.

1. Recycling plant can cause an increase in noise levels.
2. Adhered mortar content has negative impact on absorption and density.
3. Lack of Specification and Guidelines.

1.14 PROBLEM STATEMENT

In recent years, in a drive to increase environmental sustainability, better ways to manage Construction and Demolition Wastes (CDW) have been explored. Recycled aggregates (RA) are inert materials mostly originated from CDW. In broad terms, the CDW can be anything ranging from broken concrete and bricks from demolition sites, excavated materials from foundation work sites to broken up road surfaces resulting from the road maintenance, etc. CDW use is increasing over time, proportionate with the development of the towns and the countries. From here, it is clear the need to find an appropriate destination for these wastes. Reducing, reusing and recycling appear to be the best option, thus, also increasing the lifetime of landfills and reduce exploitation of the natural resources The construction of infrastructures related to bridges, highways, water systems, and buildings has been increasing from the beginning of the past century, especially in areas where population density is high. Infrastructures need to be repaired with the pass of the time. In some cases, constructions need to be replaced, because their service life is reached or their original design no longer satisfies the new requirements (population, traffic, or weather). These facts have generated two important issues: first, a growing demand for construction aggregates, and second an increasing production of construction material waste.

1.15 AIM AND OBJECTIVE

This research aims to reduce the environmental problems generated from dumping the construction and demolition wastes. This aim can be achieved by recycling the construction and demolition wastes to produce concrete mixes for structural elements with high performance as natural aggregate.

OBJECTIVES:

1. Studying the physical and mechanical performance of recycled aggregate used in concrete mixtures in lieu of natural aggregate.
2. To examine the possibility of using recycled aggregate in concrete mixes.
3. To reduce the impact of waste materials on environment.
4. To investigate the percentage variation of silica fume.
5. To optimize the ratio of recycled aggregate to natural aggregate to produce better concrete.

The purpose of this research is to study the behavior of RAC aggregates when it is included in Portland cement concrete or in embankments. For the first case, slump tests were performed on freshly mixed concrete, and compression tests were performed on hardened concrete. Several batches of concrete were prepared with RAC and natural aggregate, changing their mixture design parameters, including aggregate sieve distribution (gradation) and water cement ratio. For the second case, shear tests were performed on RAC aggregate with the objective of obtaining the failure envelope and the friction angle, and evaluating the shear capacity of this material.

1.16 SIGNIFICANCE

Leaving aside the current economical crisis, the concrete production is very important. This fact means that the aggregates, the main component of concrete, are much demanded. Because of the fact that, in some countries, the natural aggregates are a scarce resource, and also because the surface extractions destroy the landscape and upset the biological balance, it is necessary to find a new source of aggregates to guarantee the concrete production. The new source has accomplished two main goals: on the one hand, to maintain the price of concrete, which until now was the cheapest construction material; and on the other, to preserve the environment, without creating piles of waste over the world. Because it is necessary a new source of aggregates I hope that this research will be a small contribution in the advance of the utilization of the recycled aggregates as construction material in the future.

1.17 ORGANISATION OF THE THESIS

This thesis has been organized in five chapters as follows:

Chapter 1 - Introduction-

It presents various aspects of RCA concrete. This chapter also discusses objective, scope, and the methodology adopted for this investigation.

Chapter 2 - Literature Review-

A review of recent literature on behavior of NCA and RCA concrete has been discussed on the basis of which the need of the present investigation.

Chapter 3 - Materials and Methodology-

It describes the properties of the materials used in the test specimens, the sizes and the number of specimens, testing methods and the associated instrumentation.

Chapter 4- Test Results and Analysis-

The analyses of the results, the related discussion and salient observations from the testing have been included in a sequential manner. Results and discussion pertaining to material tests have been presented first and those of the strength tests have been presented later.

Chapter-5.Conclusion-

The significant conclusions obtained from experimental investigations of this study have been integrated and presented in a logical sequence and recommendations for further research made.

At the end, references used in this document are present.

2.1 Introduction

The quality of concrete made from recycled aggregate is generally lower than that of concrete made from natural aggregate. The main reason for this is that recycled aggregate with its higher water absorption capacity has a porous mortar matrix around the natural aggregate and hence develops an inferior bond. Undoubtedly, suitable quality recycled aggregates may be used successfully in higher grade applications such as structural concrete. The applications of recycled aggregate in the construction area are very wide. There are many testing based on the recycled aggregate have been carried out all around the world.

Some of the literature reviews on recycled aggregate are shown as below:-

- **G.RAMESH & NAGESH R IYER (2014)** studied about the use of field demolished waste concrete as coarse aggregate. They found a decrease in the compressive strength & split tensile strength ,increase in the water absorption in recycled aggregate concrete then, a total of 42 cubes & 63 cylinders were cast with addition of silica fume and fly ash to determine the property of recycled aggregate concrete. on addition of the admixtures the compressive strength and the split tensile strength increased.

- **Xiao et al. (2012)** observed that as increase recycled coarse aggregate amount, tensile strength decreases and tensile strength of recycled coarse aggregate concrete is lower as compare to those conventional concrete.

- ***Poon (2002)*** reported that when the percentage of recycled aggregate replacement increased, the compressive strength of the specimens was reducing. There is no effect on the concrete strength with the replacement of 30% of recycled aggregate. But the compressive strength was gradually decreasing when the amount replacement of recycled increased. He concluded that the properties and the strength characteristic of recycled aggregate concrete were having deficiency when compared to the specimens that made by the natural aggregate.

- **Topcu & Guncan, (1995)** produces complete stress–strain curves for RAC with replacement percentages of 0, 30, 50, 70 and 100%. It was concluded that with the increased amount of RA, values of compressive strength, toughness, elastic energy, plastic energy and the elastic modulus were decreased. Research indicates that the elastic modulus of RAC is about 30% less than NAC concrete attaining equal compressive strength.

- **Rak buranasing (2012)** showed that the use of high fineness of fly ash improved the properties of recycled aggregate concrete .Mix proportions of rac was prepared by 100 % recycled coarse aggregate and rivers sand was replaced by fine aggregate , result showed that use of fly ash improve slump loss and compressive strength of RAC.
- **Chenet al. (2003)** study, washed RA is used as coarse aggregate. He found that washed RA comprised higher strength than that of unwashed RA. Greater bond effects were produced when impurities, powder and harmful materials on aggregate surface in RA are washed away. He also identified that at low w/c ratio, the compressive strength ratio of recycled concretes to normal concretes are decreased. Main factor which lead to this result is strength of the paste increase at low w/c ratio. Based on composite material theory, he revealed that RA will become a weak material and its bearing capacity become smaller which influenced to decrease in strength.
- **Ahmed (2014)** studied the Existence of Dividing Strength in Concrete Containing Recycled Coarse Aggregate. Recycled coarse aggregates are highly porous and often contain micro cracks and weak interfacial transition zone (ITZ). Therefore, the recycled aggregates are weaker than natural coarse aggregate and their modulus of elasticity (E) is expected to be lower than that of natural coarse aggregate. This paper examines and presents the existence of dividing strength in concrete containing recycled coarse aggregate. In this study 192 concrete cylinders (100mm × 200 mm) and 192 mortar cubes (150 ×150 × 150 mm) were cast and tested at 28 days for compressive strengths of natural aggregate concretes (NAC) and recycled aggregate concretes (RAC). In the case of NAC, the linear relationship between the compressive strength of concrete and that of mortar is observed. However, in the case of RAC, a distinct two-stage relationship between concrete strength and mortar strength is observed indicating the existence of the dividing strength of recycled aggregate concrete. Based on the limited experimental study, the following conclusions can be drawn:

  1. Both the normal aggregate concrete and mortar had a similar strength development pattern.

2.The strength development of RAC exhibited a distinct two stage relationship between concrete strength and mortar strength. This indicates the existence of dividing strength in recycled aggregate concrete.

- **Chaudari et al. (2014)** studied the effect of fly ash on Recycled Coarse Aggregate concrete. In this experimental study the natural coarse aggregate is replaced with recycled coarse aggregate at different percentage and the mechanical strength of concrete is tested. In addition the fly ash is introduced as replacement of Cement to improve the quality of concrete. The mix designing is done for water cement ratios 0.38. Cylinders and cubes are casted using virgin coarse aggregate and replacing virgin aggregate with 20%, 30%, 40%, 50% and 100% recycle coarse aggregate, total sixteen batches are made. Results shows that recycle aggregate up to 40% can be used with 10% fly ash for making concrete. From the study he concluded that the strength of concrete decrease with increase in the percentage of recycled aggregate, this may be due to the loose mortar around the recycled aggregate which do not allow the proper bonding between the cement paste and aggregate. RAC based concrete with 10 % fly ash gives higher compressive strength than normal RAC based concrete in 90 days. This may due to bonding between the old mortar and fly ash. From the study it can be concluded that the Natural aggregate can be replaced by recycled aggregate up-to 40% with 10% fly ash.

2.2 Research gap

After analyzing these research papers I have concluded that the optimum silica fume content for replacing with cement is 20% in case of M20 and 15% in case of M30, using 40% replacement of natural aggregate with recycled aggregate for both cases gives optimum result. Now I will investigate the concrete properties by replacing cement with silica fume and natural aggregate with recycled aggregate for M40.

CHAPTER 3 MATERIAL AND METHODOLOGY

The details of experiment program in terms of material properties, test set-up for measuring different parameters are discussed in this chapter.

3.1 CONCRETE

Concrete is a material composed of cement and water combined with sand, gravel, crushed stone, or other inert material such as expanded slag or vermiculite. A strong stone-like mass is formed from chemical reaction of the cement and water. The concrete paste can be easily molded into any form or trowelled to produce a smooth surface. Hardening starts immediately after mixing, but precautions are taken, usually by covering, to avoid rapid loss of moisture since the presence of water is necessary to continue the chemical reaction and increase the strength. Too much of water, however, produces a concrete that is more porous and weaker. The quality of the paste formed by the cement and water largely determines the character of the concrete.

3.2 MATERIAL PROPERTIES

Cement, fine aggregates, coarse aggregates, recycled coarse aggregate, silica fume and water are used for present investigation. The properties of these materials are discussed in the following sections.

3.2.1 CEMENT

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials, clay predominates and in calcareous materials calcium carbonate predominates. Portland cement is manufactured by grinding together calcareous (limestone, chalk, marl, etc.) and argillaceous (shale or clay) materials in approximate proportion of 2:1 and other silica, alumina or iron oxide bearing materials. Portland cement referred as (Ordinary Portland Cement) is the most important type of cement. The OPC is classified into three grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. The grade indicates the compressive strength of cement at 28 days tested according to IS: 4031- part IV (Methods of physical tests for hydraulic cement).

Figure (3.1)   OPC 53 grade

3.2.2 FINE AGGREGATES

The material which passes through 4.75 mm sieve is termed as fine aggregate. Usually natural sand is used as a fine aggregate at places where natural sand is not available crushed stone is used as a fine aggregate.

Table 3.1 Sieve analysis of fine aggregate

Sr no	Sieve no	Weight retained(gm)	Cumulative wt. retained	Cumulative % Retained	cumulative% passing
1	4.75	1	1	0.1	99.9
2	2.36	22	23	2.3	97.7
3	1.18	77	100	10	90
4	600µ	153	253	25.3	74.3
5	300µ	264	517	51.7	48.3
6	150µ	425	942	94.2	5.8
7	Pan	58	1000	100	0
8	TOTAL			Σ283.6	

Fineness Modulus of fine aggregate = ΣF/100 = 283.6/100=2.836

3.2.3 COARSE AGGREGATE

Generally, aggregates occupy 70% to 80% of the volume of concrete and have an important influence on its properties. They are granular materials, derived for the most part from natural rock (crushed stone, or natural gravels) and sands. In order to obtain a good concrete quality, aggregates should be hard and strong, free of undesirable impurities, and chemically stable. Soft and porous rock can limit strength and wear resistance, and sometimes it may also break down during mixing and adversely affect workability by increasing the amount of fines. The broken stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in the present work

Table 3.2 Sieve analysis of coarse aggregate

Sr no	Is sieve (mm)	Weight retained (gm)	Cumulative weight retained	Cumulative % Retained	Cumulative % passing Through
1	40	0	0	0	100
2	20	145	145	7.25	92.75
3	10	1829	1974	98.7	0.3
4	4.75	124	1998	99.9	0.1
5	2.36	0	1998	99.9	0.1
6	1.18	0	1998	99.9	0.1
7	600µ	0	1998	99.9	0.1
8	300µ	0	1998	99.9	0.1
9	150µ	0	1998	99.9	0.1
10	Pan	2	2000	100	0
	TOTAL			Σ805.35	

FM of Coarse aggregate = 805.35 / 100 = 8.0535

3.2.4 RECYCLED COARSE AGGREGATE

Recycled aggregates comprise of crushed, graded inorganic particles processed from the materials that have been used in the construction and demolition concrete debris. Locally available recycled coarse aggregate having the maximum size of 20 mm was used in the present work. These materials were obtained from a building which was 20-25 years old. The density of RA is found lower than the NA because of the porous and less dense residual mortar lumps that is adhering to its surfaces. The aggregates were properly graded according to the Indian standard codes and then mixed with the respective natural aggregate in appropriate percentages. The use of fine recycled aggregate below 2 mm is uncommon in recycled aggregate use age because of the high water demand of the fine material smaller than 150 µm, which lowers the strength and increases the shrinkage significantly.

COMPARISON BETWEEN COARSE RECYCLED AND COARSE NATURAL AGGREGATE:

1. Recycled aggregate has rough – textured, angular and elongated particles where natural aggregate is smooth and rounded compact aggregate.

2. Recycled aggregate is well graded as natural aggregate.

3. The water absorption capacity of coarse recycled aggregate is 5.0% which is about two times more than natural coarse aggregates.

4. The dry density of coarse recycled aggregate is lower than dry density of natural aggregate.

The difference is due to cement paste adhered to aggregate and some kinds of impurities in recycled aggregate .The rough – texture, angular and elongated particles require more water than the smooth surface which increase the capacity of water.

3.2.5 SILICA FUME

Silica Fume was brought from Rockfit Corporation Yamunanagar, Haryana. It is very fine, and manufactured by electric arc furnaces as a by-product of the production of metallic silicon or ferrosilicon alloys. The raw materials are coal, quartz, and woodchips. The smoke that produced from furnace operation is stored and sold as silica fume rather than being land filled. As the silica fume powder particles are hundred times finer than ordinary Portland cement, there might be problems arise when deals with silica fume, such as dispensing consideration, transportation, and storage that must be taken into account. To overcome some of these difficulties, the material is commercially divided in various forms. The difference between these forms is the size of the particle which do not significantly affect the chemical make-up or reaction of material. This difference has effect on the different purposes of use.

Thus, careful consideration is needed when choosing the type of silica fume for specific application.

Figure (3.2) Silica fume

3.2.5.1 PHYSICAL PROPERTIES

The properties of silica fume depend on the type of producing and the process used for its manufacture. It is in form of spherical particle shape. It is a powder with particles having diameters 100 times smaller than Portland cement particles. Silica fume comes in three forms of powder, condensed, and slurry. Its color varies from light to dark grey which depends on the process in the manufacturing and is influenced by some parameters such as wood chip composition, furnace temperature, ratio of wood chip to the coal used, exhaust temperature, and type of metal produced. For undensified silica fume, bulk density is in range of 200-350 kg/m. Due to the low bulk density, this form is considered impractical to be utilised in normal concrete production. Undensified silica fume is commonly used in refractory products and formulated bagged material such as mortars, grouts, protective coatings, and concrete repairs system. For this type of silica fume, bulk density is in range of 500 -650 kg/m. In the densification process the ultra fine particles become loosely agglomerated which makes the size of particles larger. Hence, the powder becomes easier to be used, with less dust compared to the intensified forms. This material is commonly used in those processes that utilize high shear mixing facilities such as concrete roof tile works, precast works, and ready mixed concrete plants with wet mixing units.

3.2.5.2 CHEMICAL PROPERTIES

Silica fume is produced during a high-temperature reduction of quartz in an electric arc furnace when the main product is silicon or ferrosilicon. Due to the large amount of electricity needed, theses arc furnaces are located in countries with well-provided electrical capacity including Scandinavia, Europe, Canada, USA, South Africa, and Australia. As the concrete hardens, the pozzolonic action of the silica fume starts from the physical effects. The silica fume reacts with the calcium hydroxide to produce calcium silicate and aluminates hydrates. Calcium silicate and aluminates hydrates, increase the strength and decrease the permeability by densifying the matrix of the concrete.

3.2.6 SPECIFIC GRAVITY OF SILICA FUME

Take 50 grams of silica fume

W1 = weight of empty bottle = 24.5g

W2 = weight of bottle + water = 75.5g

W3 = weight of bottle + oil = 64.8g

W4 = weight of bottle + oil + silica fume = 88.2g

W5 = weight of silica fume = 35.9g

W5 = (weight of silica fume + weight of bottle) – (weight of empty bottle)

Therefore,

W5 = 60.4 – 24.5 = 35.9g

Specific gravity of silica fume = W5 (W3-W1) / (W5+W3-W4) (W2-W1)

= 35.9(64.8-24.5) / (35.9+64.8-88.2)(75.5-24.5)

= 1446.77 / 637.5

= 2.26

Hence specific gravity of silica fume is = 2.2

3.2.7 WATER

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water is used for both mixing and curing purposes.

3.2.8 Mix proportion (M40)–

Mix Design – M 40 Design procedure

Conditions –

- Max. Size of aggregates – 20 mm
- Min content of cement – 320 kg/m^3
- Slump – 120 mm
- Exposure – severe and for pumping purpose
- Max content of cement – 450 kg/m^3
- Max water cement ratio – 0.45
- Specific gravity of cement – 3.15
- Specific gravity of coarse aggregates – 2.74
- Specific gravity of fine aggregates – 2.74

Design –

Target mean strength – Ft = Fck + 1.65* S

Ft – target mean strength

Fck - characteristic compressive strength at 28-day

S – standard deviation

Ft = 40+1.65*5 (S from table 1 of IS 10262:2009)

= 48.75 N/m^2

Max water content = 186 lit (for 120 mm slump from table 2 of IS 10262:2009)

Estimated water content for 120mm slump = 186 + (6/10)*18 = 197 lit

Calculation of cement –

w/c = 0.40

c= w/0.40

c= 197/.40 = 492.50 kg/m^3 (more than 450 kg/m3 hence we take 450 kg/m^3)

Calculation of coarse and fine aggregates –

Proportion of volume of coarse and fine aggregate content

From Table 3 -volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (zone 3) for water-cement ratio of 0.50 =0.62. (from table 3 of IS10262:2009)

In the present case water-cement ratio is 0.40. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10. The proportion of volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in water-cement ratio).

Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.40 = 0.64. For pumpable concrete these values should be reduced by 10 percent.

Therefore, volume of coarse aggregate = 0.64 x 0.9 = 0.576.

Volume of fine aggregate content = 1 - 0.576 =0.424.

MIX CALCULATIONS –

Volume of concrete = 1 m^3

Volume of cement = (mass of cement / specific gravity of cement)* (1/1000)

= 450/3.15 * 1/1000

= 0.142 m^3

Volume of water = mass of water/ s.g. of water * 1/1000 =197/1 *1/1000=0.197m^3

Volume of all in aggregates = (a-(b+c)) = (1- (0.142+0.197)) = 0.66

Mass of coarse aggregates = e * volume of coarse aggregates * specific gravity of coarse aggregates *1000

= 0.66*0.576*2.74*1000 =1046kg

Mass of fine aggregates = e * volume of coarse aggregates * specific gravity of fine aggreagates *1000

= 0.66*0.424*2.74*1000 =766.76kg

Mix proportion (M40)–

Cement = 450 kg/m^3

Water = 197 lit

Fine aggregates = 766.76 kg/m^3

Coarse aggregates = 1046 kg/m^3

Water-cement ratio = 0.4

- **M40 with partial replacement of 20 % NA with RA**

  Cement = 450 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 836.8 kg/m^3

  Recycled coarse aggregates = 209.2 kg/m^3

  Water-cement ratio = 0.4

- **M40 with partial replacement of 40 % NA with RA**

  Cement = 450 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 627.6 kg/m^3

Recycled coarse aggregates =418.4 kg/m^3

Water-cement ratio = 0.4

- **M40 with partial replacement of 50 % NA with RA**

  Cement = 450 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 523 kg/m^3

  Recycled coarse aggregates = 523 kg/m^3

  Water-cement ratio = 0.4

- **M40 with partial replacement of 10 % silica fume with cement using 100% NA**

  Cement = 405 kg/m^3

  Silica fume = 45 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Coarse aggregates = 1046 kg/m^3

  Water-cement ratio = 0.4

- **M40 with partial replacement of 10 % silica fume with cement and replacing 20% NA with RA**

  Cement = 405 kg/m^3

  Silica fume = 45 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 836.8 kg/m^3

  Recycled coarse aggregates = 209.2 kg/m^3

Water-cement ratio = 0.4

- **M40 with partial replacement of 10 % silica fume with cement and replacing 40% NA with RA**

  Cement = 405 kg/m^3

  Silica fume = 45 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 627.6 kg/m^3

  Recycled coarse aggregates = 418.4 kg/m^3

  Water-cement ratio = 0.4

- **M40 with partial replacement of 10 % silica fume with cement and replacing 50% NA with RA**

  Cement = 405 kg/m^3

  Silica fume = 45 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 523 kg/m^3

  Recycled coarse aggregates = 523 kg/m^3

  Water-cement ratio = 0.4

- **M40 with partial replacement of 15 % silica fume with cement using 100% NA**

  Cement = 382.5 kg/m^3

  Silica fume = 67.5 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

Natural Coarse aggregates = 1140 kg/m^3

Water-cement ratio = 0.4

- **M40 with partial replacement of 15 % silica fume with cement and replacing 20% NA with RA**

  Cement = 382.5 kg/m^3

  Silica fume = 67.5 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 836.8 kg/m^3

  Recycled coarse aggregates = 209.2 kg/m^3

  Water-cement ratio = 0.4

- **M40 with partial replacement of 15 % silica fume with cement and replacing 40% NA with RA**

  Cement = 382.5 kg/m^3

  Silica fume = 67.5 kg/m^3

  Water = 197 lit

  Fine aggregates = 766.76 kg/m^3

  Natural Coarse aggregates = 627.6 kg/m^3

  Recycled coarse aggregates = 418.4 kg/m^3

  Water-cement ratio = 0.4

- **M40 with partial replacement of 15 % silica fume with cement and replacing 50% NA with RA**

  Cement = 382.5 kg/m^3

  Silica fume = 67.5 kg/m^3

  Water = 197 lit

Fine aggregates = 766.76 kg/m^3

Natural Coarse aggregates = 523 kg/m^3

Recycled coarse aggregates = 523 kg/m^3

Water-cement ratio = 0.4

3.3 CASTING OF SPECIMENS

In this section casting procedure for compressive strength test Before casting, the entire moulds were cleaned and oiled properly. These were tightened properly before casting. The coarse aggregates, fine aggregates, cement and other ingredients (Silica fume) were weighed first with accuracy. The concrete mix was done by hand mixing on a non-absorbing platform. Firstly done the dry mix properly. Then made a space in the center of dry mix and 70 to 80% water was added, mix uniformly and rest was sprinkled on the mix. Cubes (150 x 150 x 150mm) were casted for compressive strength at 7and 28days, cylinders (200 × 100) for splitting tensile strength at 7and 28 days.

3.3.1 CASTING FOR COMPRESSIVE STRENGTH TEST

The compressive strength of concrete is defined as the load which causes the failure of a standard specimen divided by the area of cross- section in uniaxial compressive under a given rate of loading. The test for compressive strength should be made on 150 mm size cube. Sometimes the test is made on cylinder of size 200 mm diameter X 100mm height. In India, the concrete grade is based on cube strength and if the cylinder is tested, the strength should be modified into equivalent cube strength. (150 x 150 x 150mm) cube was used to study the compressive strength of various mixes. The cubes were filled with fresh concrete in three equal layers. Each layer was compacted for 35 times with a 16mm diameter rod, 600mm long and bullet pointed at lower end. Three cubes were casted for each parameter. The compressive strength test was carried out for 7 days and 28days.

Figure (3.3) Casting of cubes

3.3.2 CASTING FOR SPLIT TENSILE STRENGTH

Tensile strength of concrete greatly affects the extent and size of cracking of concrete. It is of a great importance while designing liquid retaining structure and prestressed concrete structures. Tensile strength of concrete ranges from 10 -15 percent of the compressive strength. Unlike the steel, the concrete strength in tension is very less than that in compression. In concrete, there exist numerous fine cracks which lower the tensile strength. Whenever a compressive load is applied, the compressive stress can push up any cracks in concrete and can be transferred through the cracks. On the other hand, when a tensile load is applied, the tensile stress pulls up the concrete and can be transferred only through the uncracked concrete. The average tensile stress may be small; the actual stress in uncracked is much larger. This further causes the cracks to lengthen reducing the uncracked concrete area. Thus the tensile strength of concrete is much lower than its compressive strength. 200mmX100mm cylinder was used to study the compressive strength of various mixes. The cylinders are filled with fresh concrete in three equal layers. Immediately after casting, the specimens are covered with gunny bags to prevent water evaporation. Three cylinders are casted for each parameter. The split tensile strength test is carried out for 7 days and 28 days. Therefore, six identical specimens are casted for each concrete mix. The cylinders after casting are shown in Figure (3.4).

Figure (3.4) casting of cylinder

3.4 WORKABILITY

It consists of a frustum of cone and is hollow at top and bottom. Slump test was conducted to assess the workability of fresh control concrete and concrete containing recycled aggregate. For each mix in the test program, a sample of freshly mixed concrete is placed and compacted by rod in a frustum of cone mold. The slump value is equal to vertical distance between the Original and displaced position of the center of the top surface of the concrete after raising a mold.

Procedure

- The internal surface of the mould shall be thoroughly cleaned and freed from moisture and any set concrete before commencing the test.
- The mould shall be placed on a smooth, horizontal, rigid and non-absorbent surface, such as a carefully leveled metal plate, the mould being firmly held in place while it is being filled. The mould shall be filled in four layers, each approximately one-quarter of the height of the mould.
- Each layer shall be tamped with twenty-five strokes of the rounded end of the tamping rod.
- The strokes shall be distributed in a uniform manner over the cross-section of the mould and for the second and subsequent layers shall penetrate in the underlying layer.
- After the top layer has been rounded, the concrete shall be struck off level with a trowel or the tamping rod, so that the mould is exact filled
- Any mortar which may have leaked out between the mould and the base plate shall be cleaned away. The mould shall be removed from the concrete immediately by raising it slowly and carefully in a vertical direction.
- This allows the concrete to subside and the slump shall be measured immediately by determining the difference between the height of the mould and that of the highest point of the specimen being tested.

Apparatus

Frustum of a cone, tamping rod

Figure (3.5) Slump cone

3.5 TEST SETUP FOR COMPRESSIVE STRENGTH TEST

As shown in Fig 3.6, specimens were crushed at 7days and 28 days. The compressive strength was calculated by dividing the failure load by average cross sectional area. The load should be provided on the opposite sides of the cube as cast and not at the top and bottom, so as to obtain parallel faces. To states the compressive strength, average of strengths of all cubes made from the same concrete provided the results of individual cube does not differ by ±15 percent of the average.

Specimens:-

The compressive strength testing machine of capacity 1000 KN was used for determining the maximum compressive loads carried by concrete cubes. At the test age the specimens are taken out of the curing tank and kept outside for 10 minutes. Then one specimen is placed on the steel platen of the machine such that the specimen is tested perpendicular to the casting position. Then the test is carried out at the loading rate of 5 KN/s specified IS: 516– 1959.

Procedure:

- Specimens stored in water shall be tested immediately on removal from the water and while are still in the wet condition, surface water and grit shall be wiped off the specimen.
- If the specimen received dry shall be kept in water for 24 hours before they are taken for testing.
- Before placing the specimen in the testing machine the bearing surface of the testing machine shall be wiped clean and any loose sand or other material should be removed from the surface of the specimen, which are to be in contact with the compression platens.
- In case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, i.e. not to the top and bottom. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platens.
- No packing shall be used between the faces of the specimen and the steel platen of the testing machine.
- The load shall be applied without shock and increased continuously, until the resistance of the specimen to the increasing load breaks down and any unusual features in the type of failure

shall be noted. Calculation of compressive strength: Divide the maximum load applied to the specimen during the test by the cross sectional area of the specimen.

F

Figure (3.6) Testing of cubes

3.6 TEST SETUP FOR SPLIT TENSILE STRENGTH

As shown in Figure (3.7), three identical specimens are crushed at 7days and three identical specimens are crushed at 28 days. A concrete cylinder of sizes 200mm height X 100mm diameter is subjected to the action of compressive forces along two opposite edges. By applying the force in this manner, the cylinder is subjected to compression near the loaded region and the length of cylinder is subjected to uniform tensile stress.

The split tensile strength = $2p/\pi dl$

Where,

P= the compressive load on cylinder

l= Length of cylinder

d= Diameter of cylinder

Procedure:

- Draw diametric lines on each end of the specimen so that they are in the same axial plane.
- Centre one of the plywood strips along the centre of the lower bearing block.
- Place the specimen on the plywood strip and align so that the lines marked on the ends are vertical and centered over the plywood strip.
- Place the second plywood strip and the bearing bar so that they are lengthwise on the cylinder, centered on the previously marked lines on the ends
- Apply the load continuously at a constant rate of 100 to 200 psi/minute of splitting tensile stress until failure occurs.
- Record the maximum load at failure.

Calculate the splitting tensile strength as follows**:**

$$f'_{st} = \frac{2P}{\pi ld}$$

Where;

P is the maximum load at failure in pounds,

l is the length of the cylindrical specimen, and *d* is the diameter of the cylindrical specimen, in inches

Figure (3.7) Testing of cylinder

3.7 COMPACTION

The compaction was done by hand using tamping bar. The concrete was filled in the moulds in four layers and each layer was approximately one quarter of the height of mould. Each layer was tamped with 25 strokes of the round end of the tamping bar. The strokes should be distributed over the entire area of the mould. Finally the surface of concrete was levelled and finished and smoothened by metal trowel.

3.8 CURING CONDITIONS

All concrete samples were placed in curing basin after 24 hours from casting. The samples were remained in curing basin until tested at the specified age. The Figure (3.8) illustrates the appearance of curing basin which used in this study.

Figure (3.8) Curing basin

CHAPTER 4 TEST RESULTS AND ANALYSIS

This chapter describes the results of the test program designed to study the properties of the various recycled aggregate concrete mixes as described in the test program. The slump test of fresh concrete (workability), compressive strength, and split tensile strength test of concrete specimens were discussed to investigate the influence of recycled aggregate on concrete properties

4.1 DISCUSSION OF TEST RESULTS

Tables (4.1, 4.2 and 4.3) show the average results of the tests in this experimental program, workability, compressive strength, and split tensile strength respectively. Workability is measured for fresh concrete but compressive strength and split tensile strength results are at 7 day age and at 28 day age. In this study concrete mixes were prepared with various percentage replacements for natural aggregate (coarse) namely, 0% (NA), 20% (RCA 20), 40% (RCA 40) and 50% (RCA 50).Again, cement is replaced with silica fume in 10% and 15 % respectively. Mould sizing 150mm X 150mm X 150mm were used for compression test and cylinder of 100mm dia. 200mm long is used for splitting tensile test. After casting, the cubes are cured at ambient temperature for 7 days and 28 days respectively. The test procedure is according to the method mentioned in IS: 516:1989. After the analysis of practically obtained results the relationship between various parameter of concrete mix and strength is obtained. The selected parameters are percentage of silica fume, percentage of recycles aggregate, age of concrete.

4.2 EXPERIMENTAL RESULTS

To study the properties of recycled aggregate in fresh and harden state, standard tests were conducted for both RAC and NAC to correlate between them. The test conducted includes workability and strength tests. For this concrete cubes and cylinders were cast. For each mix, 150 mm size cubes were cast and kept moist for 7days and 28 days to determine the compressive strength. To determine the splitting tensile strength 100 x 200 mm cylinders were cast. Specimens, cured in water, were tested after removal from water and while they were still in wet and surface dry condition. The testing methods of cement concrete as per IS guidelines has been used for testing recycled concrete specimens.

4.2.1 SLUMP TEST (WORKABILITY)

MIX	0% SF	10% SF	15% SF
NA	95 mm	85 mm	75mm
RCA 20	85 mm	70 mm	60 mm
RCA 40	55 mm	30 mm	20 mm
RCA 50	40 mm	10 mm	10 mm

TABLE 4.1 Slump values

The slump test was conducted in order to determine the degree of workability obtained for RAC in comparison with the conventional concrete. The slump value was used as indication of mix workability and all the mixes was designed for 80-100mm slump value. Table (4.1), shows a decreasing of workability when the percentage of recycled aggregate and silica fume increases, which would give a harsh mix. Hence it's advisable to use admixtures which can improve its workability to be used for structural purpose.

Figure (4.1) Slump value determination

4.2.2 COMPRESSIVE STRENGTH RESULTS

The compressive strength of concrete is affected by both the aggregate properties, and the characteristics of the new cement paste that is developed during the maturing of concrete. The potential strength of concrete is partially a function of aspects related to mix proportioning such as cement content, water/cement ratio and choice of suitable aggregate but also a function of proper curing when chemical bonding develops. The w/c ratio, proper compaction and adequate curing, affect the development of concrete microstructure, and also affect the amount, distribution and size of pores. The bond that is developed when concrete hardens is the aggregate-paste bond, which is both physical and chemical. The presumption is that recycled aggregate concrete might develop an even weaker chemical bond with cement paste, as the chemical composition of the aggregate is different from those of commonly used natural aggregates and the re-bonding of some elements in cement paste residue can take place. The most important parameters of the aggregate affecting compressive strength are its shape, texture, maximum size and the strength of coarse aggregate which is one of the dominant factors in classification of concrete aggregate.

The decrease of compressive strength due to increase of recycled aggregate percentage can be explained as follows:

- The recycled aggregate is covered with hardened cement paste, which is very weak layer, so the compressive strength of recycled aggregate itself is weak.
- The hardened cement paste on recycled aggregate is high in water absorption consequently no enough residual water is present to complete all the quantity cement reaction. This leads to poor compaction, consequently not well compacted concrete.
- There were some impurities in the recycled aggregate like wood, glass, bricks, etc. which could not be removed completely which affected the bond in general adversely.
  (For the entire chart table compressive strength in N/mm2 and concrete age in days)

Table 4.2 shows the influence of recycled aggregate in concrete mixes, optimum results was gained in zero recycled aggregate, the strength of recycled aggregate concrete was lower than the natural aggregate concrete for the same targeted compressive strength concrete.

MIX	CURING PERIOD	0% SF	10%SF	15%SF
NA	7 DAYS	23.1	23.7	24.4
	28 DAYS	34.4	35.1	35.3
RCA 20	7 DAYS	22.2	23.1	23.3
	28 DAYS	33.3	33.7	34.4
RCA 40	7 DAYS	21.1	22.8	22.4
	28 DAYS	30.4	33.5	32.8
RCA 50	7 DAYS	22.1	22	22.2
	28 DAYS	25.5	26	26.6

TABLE (4.2) compressive strength values

The experimental results obtained after the curing of 7 days and 28 days are shown below in the graph.

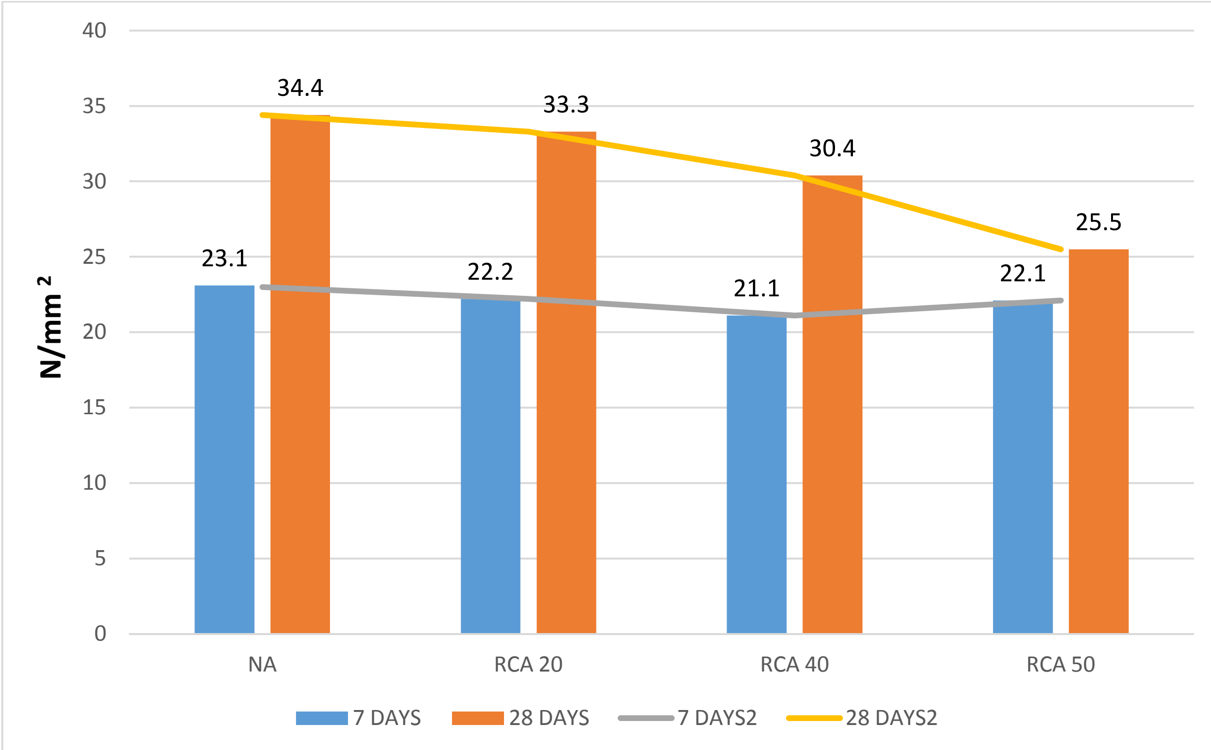

Figure (4.2) compressive strength vs age for 0% silica fume

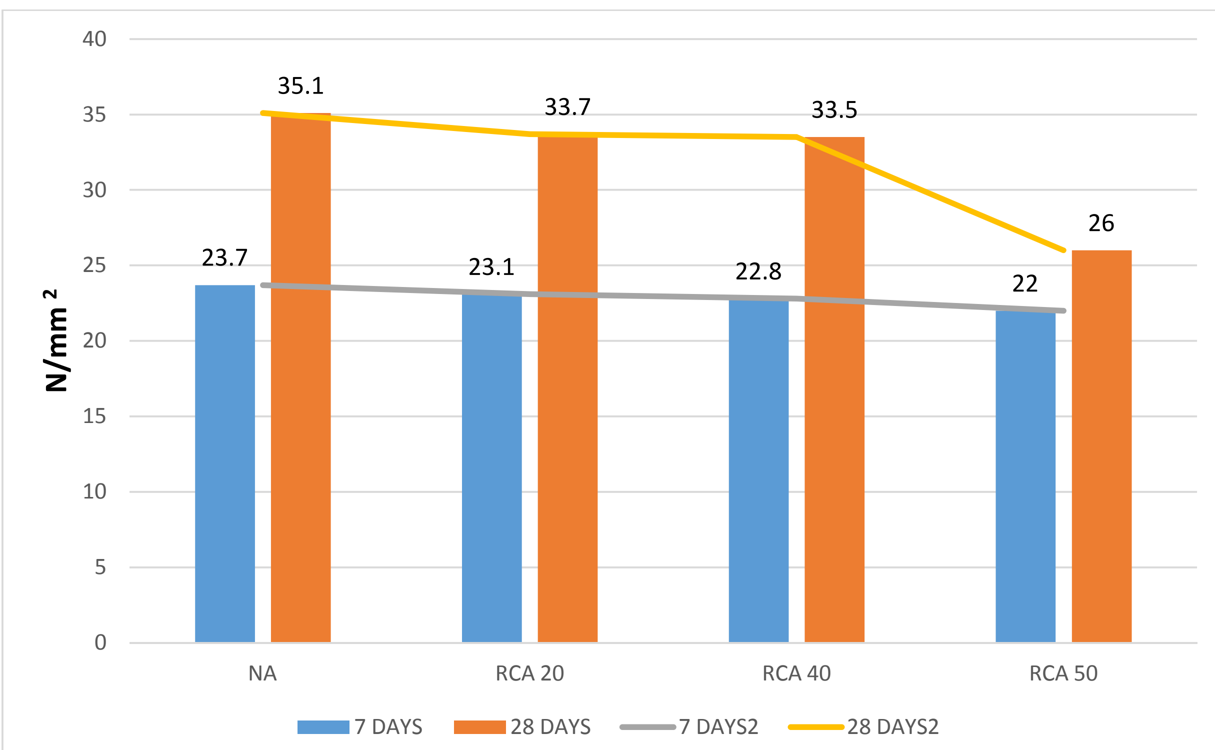

Figure (4.3) compressive strength vs age for 10 % silica fume

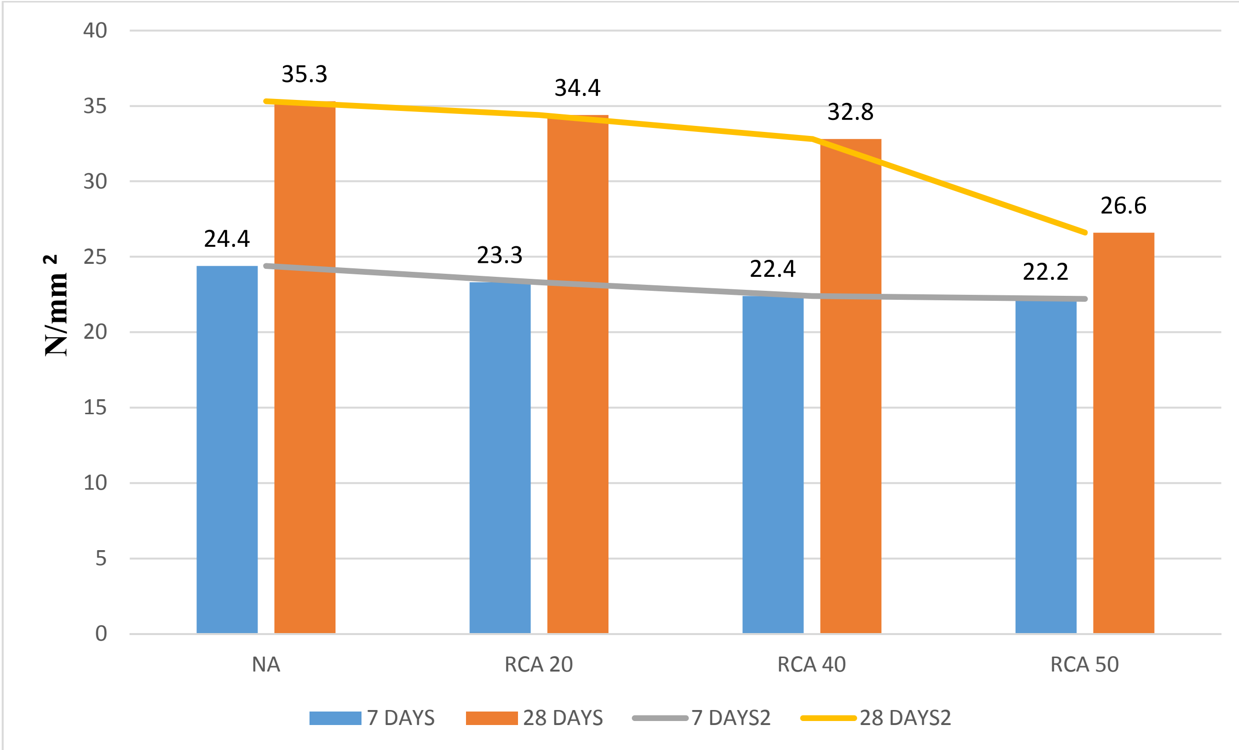

Figure (4.4) compressive strength vs age for 15 % silica fume

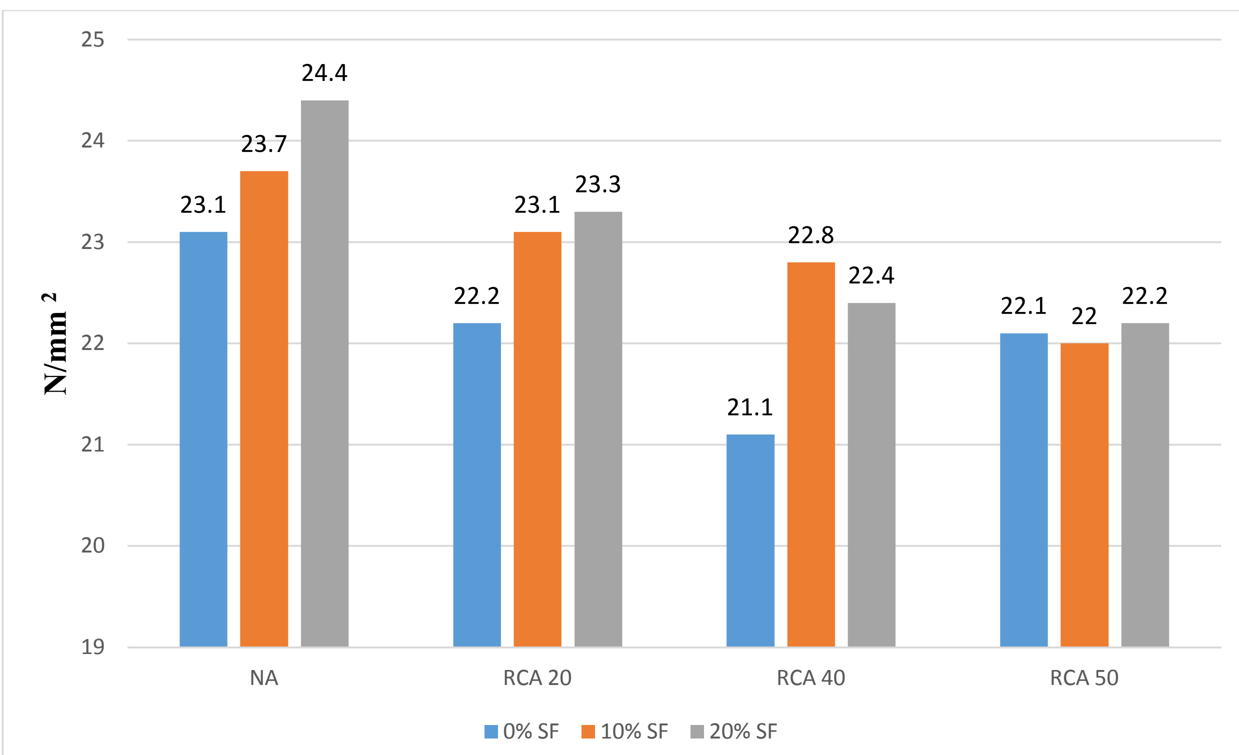

Figure (4.5) 7 days compressive strength for mix with different % of SF and RCA

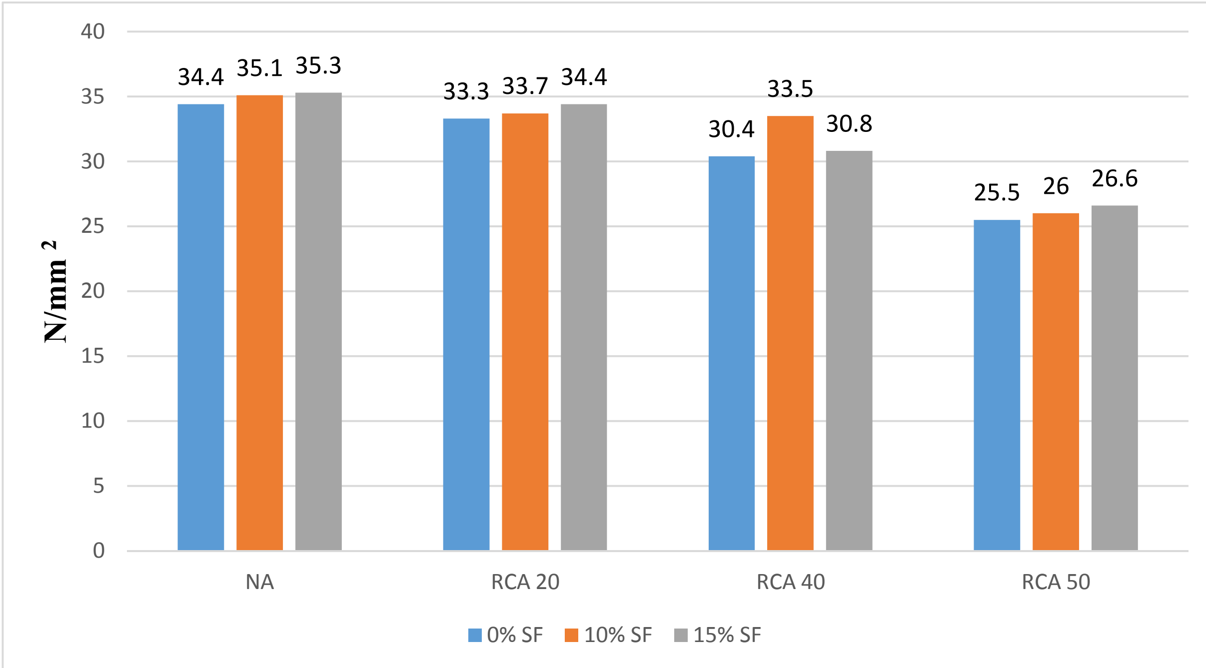

Figure (4.6) 28 days compressive strength for mix with different % of SF and RCA

4.2.3 SPLIT TENSILE STRENGTH RESULTS

The split tensile strength also shows the similar pattern of results as the compressive strength results are showing in graph. Tensile strength of concrete ranges from 10 to 15 percent of the compressive strength. The tensile strength results are shown in the Figure (4.7, 4.8, 4.9, 4.10 and 4.11) respectively. As per the results from Table 4.3 and graphs the split tensile strength of 5% and 10% replacement of cement with Silica fume has higher value than the control mix and 40% + 10% replacement has comparatively equal split tensile strength to Control Mix. For the 15% replacement of silica fume the split tensile strength decreases gradually. The decrease of compressive strength and spilt tensile strength due to increase of recycled aggregate percentage can be explained as follows:

• The recycled aggregate is covered with hardened cement paste, which is very weak layer, so the compressive strength of recycled aggregate itself is weak. The hardened cement paste on recycled aggregate is high in water absorption consequently no enough residual water is present to complete all the quantity cement reaction. This leads to poor compaction, consequently not well compacted concrete. The existence of cement paste layer on recycled aggregate prevent integration of all aggregate ,and prevent enough bond between recycled aggregate and new cement paste.

MIX	CURING PERIOD	0% SF	10%SF	15%SF
NA	7 DAYS	3.5	3.6	3.8
	28 DAYS	4.9	5.5	5.2
RCA 20	7 DAYS	3.0	3.1	3.6
	28 DAYS	4.2	5.0	4.9
RCA 40	7 DAYS	2.5	3.5	3.1
	28 DAYS	4.4	4.7	4.9
RCA 50	7 DAYS	2.0	2.5	2.7
	28 DAYS	3.9	4.2	4.1

Table (4.3) Split tensile strength values

The experimental results obtained after the curing of 7 days and 28 days are shown below in the graph.

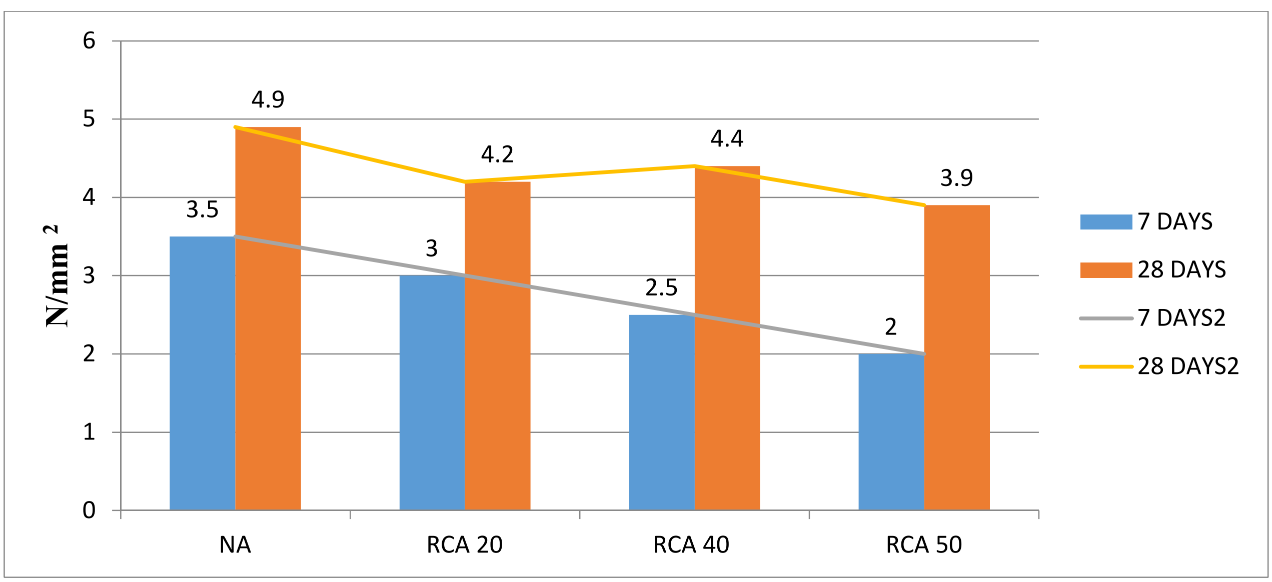

Figure (4.7) Split tensile strength vs age for 0% silica fume

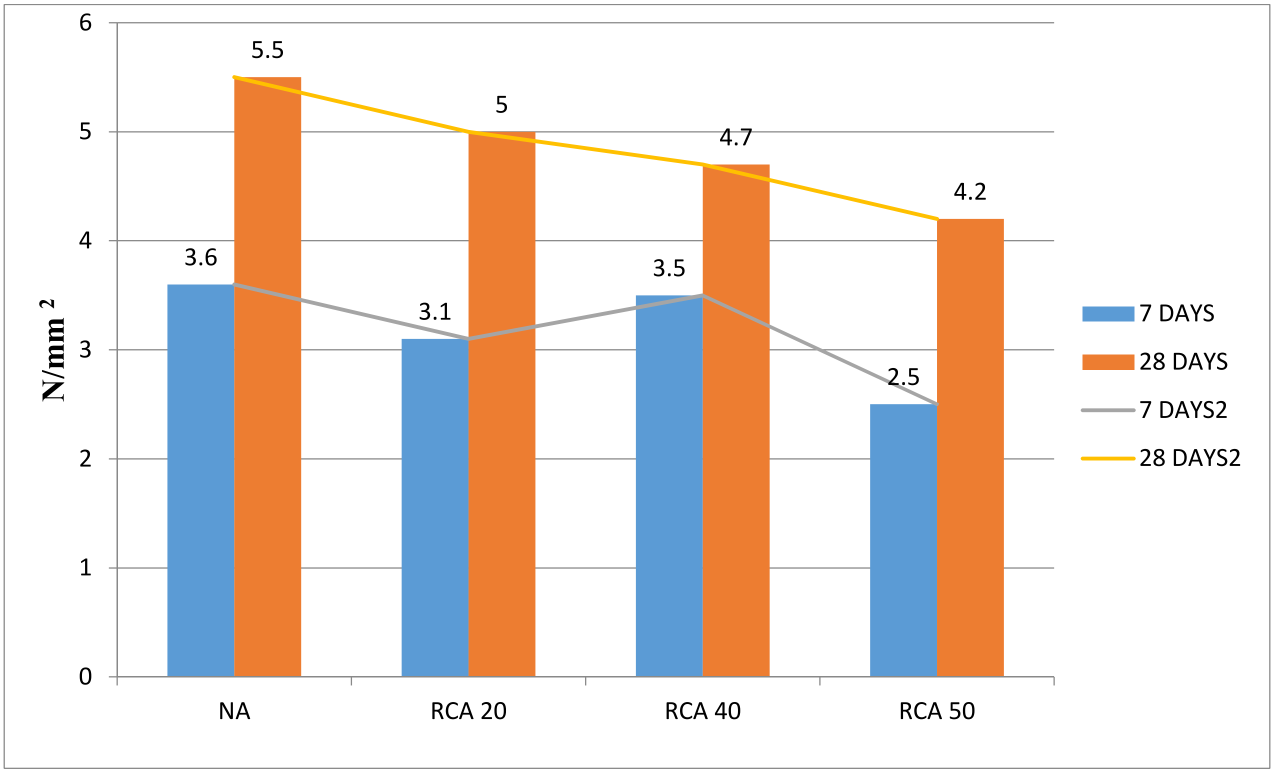

Figure (4.8) Split tensile strength vs age for 10% silica fume

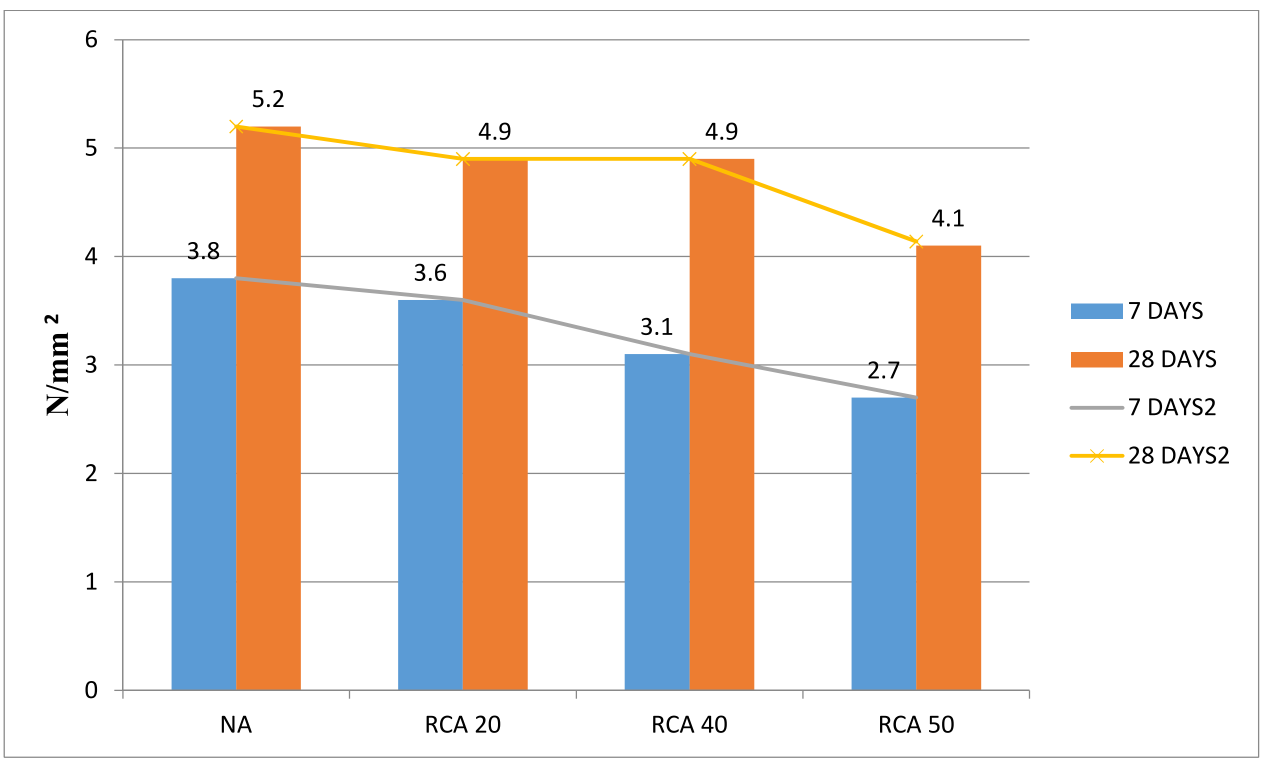

Figure (4.9) Split tensile strength vs age for 15% silica fume

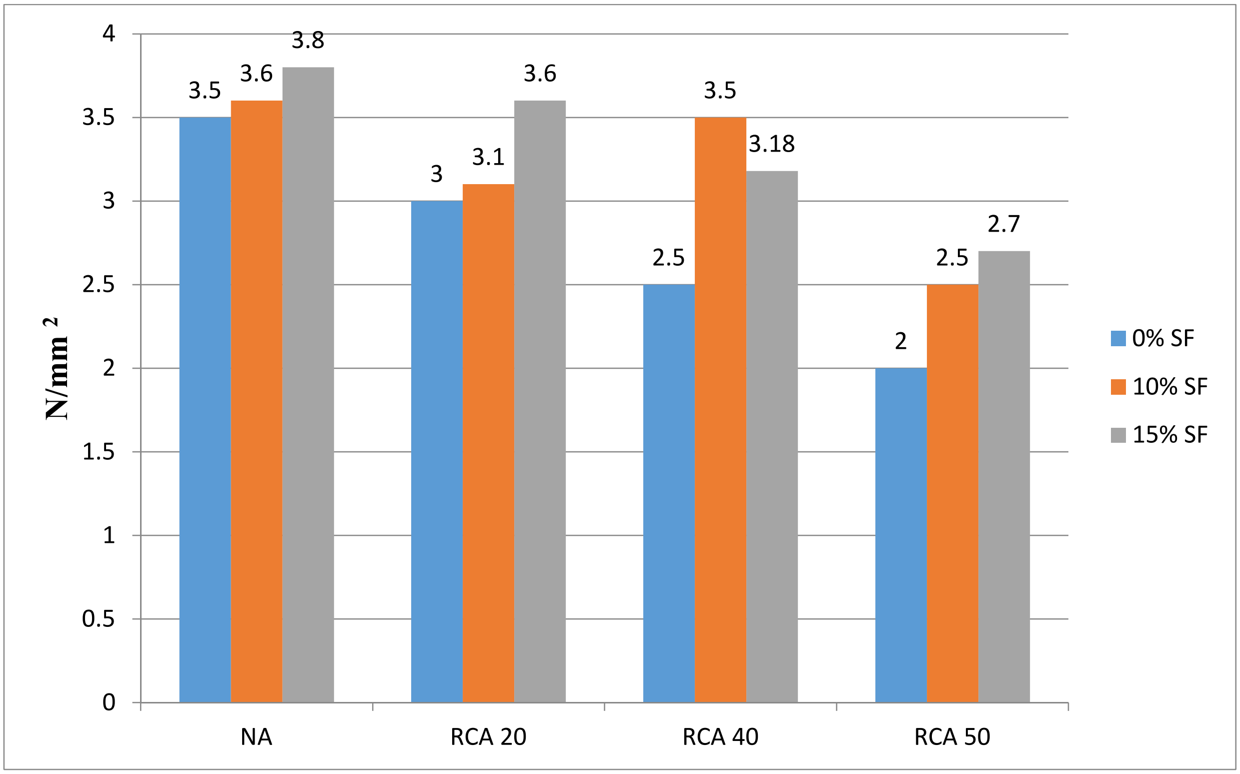

Figure (4.10) 7 days split tensile strength for mix with different % of SF and RCA

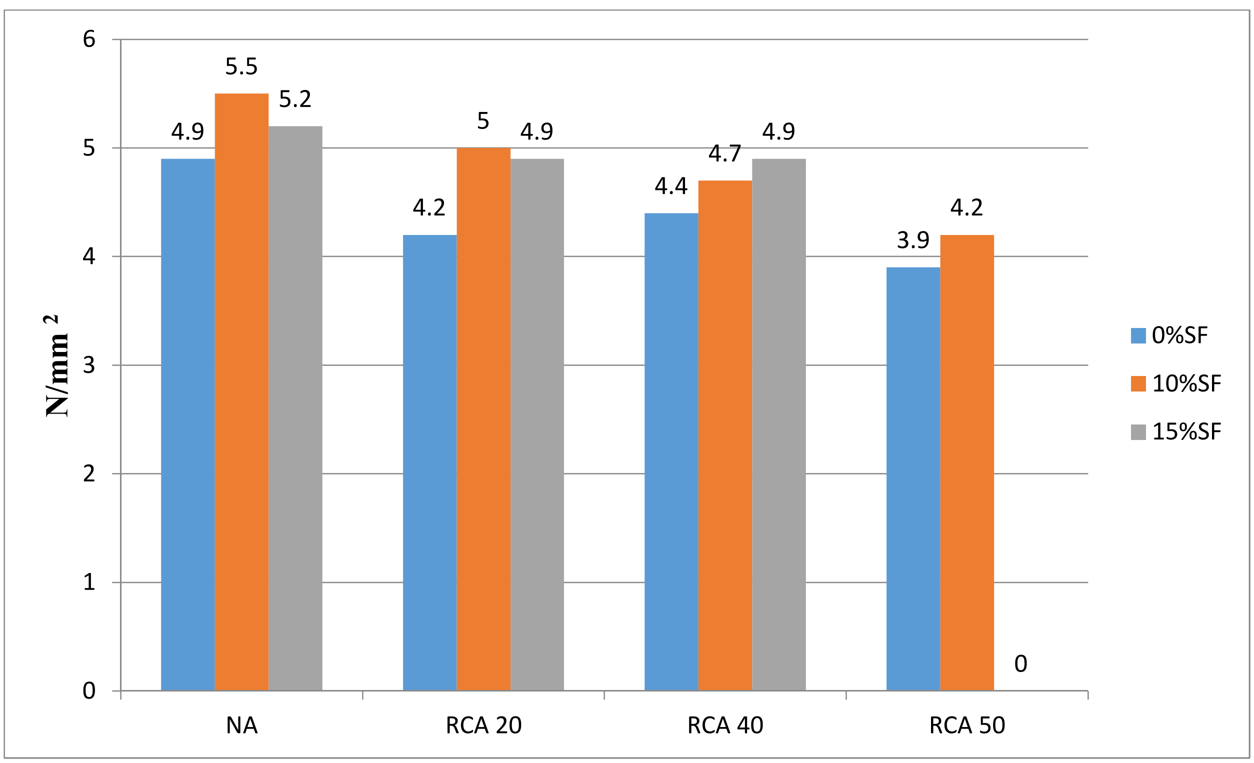

Figure (4.11) 28 days split tensile strength for mix with different % of SF and RCA

The decrease of compressive strength and spilt tensile strength due to increase of recycled aggregate percentage can be explained as follows:

• The recycled aggregate is covered with hardened cement paste, which is very weak layer, so the compressive strength of recycled aggregate itself is weak.

• The hardened cement paste on recycled aggregate is high in water absorption consequently no enough residual water is present to complete all the quantity cement reaction. This leads to poor compaction, consequently not well compacted concrete.

• The existence of cement paste layer on recycled aggregate prevent integration of all aggregate ,and prevent enough bond between recycled aggregate and new cement paste.

• There were some impurities in the recycled aggregate like wood, glass, bricks, etc. which could not be removed completely which affected the bond in general adversely.

4.3 RESULT

- Water absorption of RCA was 5 to 9 times higher and specific gravity of is 15% to 20% lower than the NCA. Attached cement mortar and voids in that are the basic reason behind such behavior.
- The workability of recycled aggregate concrete mix is lower than natural aggregate concrete.
- The strength of concrete decrease with increase in the percentage of recycled aggregate, this may be due to the loose mortar around the recycle aggregate which do not allow the proper bonding between the cement paste and aggregate.
- RAC based concrete with 10% silica fume gives higher compressive strength than normal RAC. This may due to bonding between the old mortar and Silica fume.
- 15% silica fume is giving lower result than required as the strength should have increased but it decreases.

4.4 SUMMARY

The workability of recycled concrete is reduced because the mortar from the original concrete makes the recycled aggregate more porous and absorptive than its natural counterpart; the absorption capacity of recycled aggregate is more than two times of natural aggregates absorption capacity. The additional absorption requires more water be added to the recycled aggregate stockpile, to reach saturation before it can be added to the concrete mix. The results of tests of recycled aggregate showed, the recycled aggregate concrete can provide strength almost equivalent to a corresponding concrete with natural aggregates for the same quantity of cement. The use of recycled aggregate does not seriously affect the compressive strength of the concrete when only the coarse aggregates were replaced by coarse fragments of demolition debris.

CHAPTER 5 CONCLUSION

5.1 CONCLUSION OF THE STUDY

Experimental works on the use of recycled aggregates have proven that good quality concrete could be produced with recycled aggregates. The use of aggregates produced from recycled construction and demolition waste should be further promoted. Silica fume is the one of he most popular pozzolanas, whose addition to concrete mixtures results in lower porosity, permeability and bleeding because their oxides (SiO2) react with and consume calcium hydroxides which is produced by the hydration of ordinary Portland cement. The main results of pozzolanic reactions are: lower heat liberation and strength development; lime- consuming activity; smaller pore size distribution.

Based on the experimental investigation reported in the work, the following conclusions are drawn:

- Water absorption of RCA was higher and specific gravity of is lower than the NCA. Attached cement mortar and voids in that are the basic reason behind such behavior.
- The workability of recycled aggregate concrete mix is lower than natural aggregate concrete because recycled aggregate has more surface area.
- The strength of concrete decrease with increase in the percentage of recycled aggregate, this can be due to the loose mortar around the recycle aggregate which do not allow the proper bonding between the cement paste and aggregate.
- RAC based concrete with silica fume gives higher compressive strength than normal RAC. This may due to bonding between the old mortar and Silica fume.
- It was observed that the presence of recycled aggregates seemed to produce lower performance.

5.2 RECOMMENDATIONS FOR FURTHER STUDIES

While studies have shown that recycled concrete aggregate can be used as aggregate for new concrete, there is a need to obtain long-term in-service performance and life cycle cost data for concrete made with recycled aggregate concrete to assess its durability and performance. If additional research supports the use of concrete buildings then existing specification should be revised to permit and encourage the use of recycled concrete as aggregate. Using recycled aggregate in concrete mixes leads to conserve existing supplies of natural aggregates and to reduce the amount of solid waste that must be disposed of in landfills. Further testing and studies on the recycled aggregate concrete is highly recommended to indicate the strength characteristics of recycled aggregates for application in high strength concrete. Below are some of the recommendations for further studies:

An important step in maintaining and encouraging the recyclability of concrete is the ability to separate other building materials like wood, bricks, polyethylene products, minerals etc. from the concrete construction that would either be incompatible in a common preparation process, or would at least restrict the recycling.

- Although by decreasing the water/cement ratio, recycled aggregate can achieve higher compressive strength concrete. But the workability will be very low. Therefore, it is recommended that adding admixtures such as super plasticizer and silica fume into the mixing so that the workability will be improved.
- More investigations and laboratory tests should be done on the strength characteristics of recycled aggregate. It is recommended that testing can be done on concrete slabs, beams and walls. Some mechanical properties such as creeping and abrasion were also recommended.
- More trials with different particle sizes of recycled aggregate and percentage of replacement of recycled aggregate are recommended to get higher strength characteristics in the recycled aggregate concrete.
- More investigations and laboratory tests should be done on the durability of recycled aggregate concrete in new concrete, and its creep and shrinkage characteristics.
- Further studies on the long-term feasibility of recycling.
- The fire-resistant property of recycled aggregates should be carefully studied.
- More studies on the economic aspect of concrete processing and recycling.
- More investigations and laboratory tests should be done on the use of fine recycled aggregates

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