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# An Experimental Investigation on the Properties of Concrete with Partial Replacement of Cement by Silica Fume and Coarse Aggregate by Recycled Aggregate

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**ABSTRACT:** Concrete is a construction material which is extremely used worldwide in most of constructions. Preparation of concrete involves the use of natural resources like sand, natural aggregates, water etc. The present boom in day by day growing constructions is leading to excessive use of concrete, thereby resulting in depletion of natural resources such as sand and natural aggregates. In fact, there is acute shortage of natural aggregates and this problem is faced by many countries in the world. On the other hand, due to demolition of old structures, many times it is very difficult to find a dumping place for such a huge amount of waste concrete. To overcome such kind of situation it may be a better approach to retrieve aggregates from the demolished waste and use it again in the preparation of concrete in any possible manner. This process may also help to preserve the natural aggregates to some extent and also in the reduction of cost of material.

Practically, the quality of recycled aggregate concrete is not comparable due to the low density, high water absorption resulting low strength concrete. But this issue can be resolved using various kinds of admixtures which may improve the microstructure of concrete and hence will lead to improved quality of recycled aggregate concrete

The aim of this experimental investigation is to find the influence of silica fume on the properties of recycled coarse aggregate concrete. The main purpose of this investigation is that using the recycled coarse aggregate is to minimize the waste disposal and to preserve natural resources. In this investigation natural coarse aggregate is replaced with recycled coarse aggregate (RCA) by 20%, 30%, 40%, 50%, 60%, 75% and 100%. Preliminary investigation is carried out to know the optimum replacement of silica fume by replacing the cement with 6%, 8%, 10%, 12% and 14%. From the 28 days compressive strength results it was found that optimum replacement of silica fume is 10%. The influence of combined application of silica fume and recycled coarse aggregate on compressive strength, split tensile strength, flexural strength and permeability of M25 grade of concrete is investigated. The test results of concrete prepared using the different proportions of recycled coarse aggregate with the combination of 10% silica fume are compared with that of controlled concrete. The experimental investigation reveals that at 40% replacement of RCA in Coarse Aggregate gives highest compressive strength of 38.07 Mpa. For the same mix the values of Flexural Strength and Split Tensile Strength are 5.38 and 4.15 Mpa respectively.

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## I. INTRODUCTION

### 1.1 INTRODUCTION

The construction industry worldwide is using natural resources and disposing construction and demolition debris in landfills in very large quantities. These practices are not only damaging the environment but are considered unsustainable. The excessive utilization of aggregates for concrete production leads to excessive exploitation of natural aggregates and environmental degradation from quarrying activities. This has resulted in renewed interest in recycled aggregates as a viable source of structural material. Recycled aggregates, obtained from local construction and demolition waste directly, not only reduces the consumption of primary natural resources but also improves the sustainability by reducing the consumption of valuable landfill space. Several countries around the globe have been facing problems related to disposal of these waste materials owing to lack of sufficient space for dumping of these materials. Therefore, recycling of these construction and demolition waste for the production of aggregates is a solution to a number of problems faced by human civilization.

Construction and demolition waste (C&D waste) is increasingly seen as a valuable source of engineering materials for the construction industry. However, the percentage of use of these materials is not at all at a desired or sustainable level. There is also little knowledge of the technically realistic ways to reuse C&D waste. On the other hand in several countries the use of Recycled Aggregates (RAs) in concrete in practice some extent, and this use is also regulated by their national specifications. Many countries have also introduced legislation and policy measures to encourage the use of recycled aggregates in concrete. The use of recycled aggregates in earth and road construction is more common, though also this use could be essentially wider based on the technical and sustainable benefits it can offer. This report is concentrated on the use of recycled aggregates in concrete. The main emphasis is on the ways to widen the use. Quality of the produced recycled aggregates, as well as specified ways for the use is important factors deciding the potential for economical, sustainable and technically acceptable use.

Recycled aggregate is used as coarse aggregate in concrete production in order to conserve the original aggregate sources, reduce waste from demolition, and reduce disposal landfills. Although, recovery waste from demolition is beneficial to the environment, it is important to study the properties of recycled aggregates before using them as coarse aggregate in concrete.

Recycled aggregates is known to have low density, low specific gravity, high water absorption, and high porosity. The mortar attached to the original aggregate results in lower density, higher water absorption, and higher porosity than those of natural aggregate. Many researchers have found that use of recycled aggregate to partially and fully replace natural aggregate in concrete not only decreases the density, compressive strength, and modulus of elasticity of the concrete but also decreases the durability of concrete, including chloride resistance. The properties of recycled aggregate concrete could be improved by use of pozzolanic materials has been found to improve strength and durability of recycled aggregate concrete. Therefore, this research aimed to use silica fume as pozzolanic material to improve the properties of recycled aggregate concrete, i.e., compressive strength, flexural strength, split tensile strength and permeability.

### 1.2 RECYCLED AGGREGATE (RA) TYPES

Recycled aggregate (RA) is aggregate resulting from the processing of inorganic material previously used in construction. According to the European Standards for concrete there is a full possibility for the use of RA in concrete. The acceptable ways for the use must be determined nationally, i.e. according to the national specifications. As RA can include all kind of inorganic materials from the C&D waste, i.e. concrete, concrete masonry units, mortars, aerated concrete and also clay masonry units (bricks and tiles), it is not as good a material for concrete production as recycled concrete aggregate (RCA). RCA is made of solely crushed concrete. Separation of concrete material already during the demolition phase is essential to make it easier to produce good quality RCA. RCA (also RA) is typically classified

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according to the grain size. Typically coarse RCA (>4mm) is much easier to use in concrete production than fine RCA (< 4 mm). This is because after normal concrete crushing and sieving operations the proportion of good natural aggregates is much higher in the coarse portion than in the fine portion. After advanced RCA production methods, coarse RCA can basically consist of solely natural aggregate. Instead fine RCA typically contains more cement paste which absorbs water and makes the concrete production more challenging. Cement paste may also include harmful substances for concrete such as chlorides and sulphates. Especially fine RCA quality is dependent on the C&D waste quality, as also coarse graded RCA quality if the cement paste content that is adhered on the aggregate surfaces after the crushing and other processing operations remains high. By forceful C&D waste sorting and processing it is possible to produce high quality recycled aggregates for concrete production.

### 1.3 EFFECTS OF RECYCLED AGGREGATE (RA) ON RECYCLED AGGREGATE CONCRETE (RAC) PROPERTIES

The effect of recycled aggregate (RA) on fresh and hardened concrete properties are in optimal cases low or can also be positive. The effect of RA/RCA is dependent on several factors and must be considered closely. It is also possible to improve e.g. crushing and processing methods to enhance RA quality or to use additional materials, such as silica fume or other mineral admixtures to improve mechanical properties. Clean graded RA may contain foreign materials that alter fresh and hardened concrete performance together with chemical impurities. Fine aggregates are generally more susceptible to contaminants than the coarse fraction.

The main or typical effects of RA/RCA on concrete properties are

- RC/RCA water absorption is high compared with natural aggregate.
- Concrete mix water demand is higher and thus the amount of plasticizer required without losing workability is higher.
- Especially high amount of RA may cause problems with concrete workability.
- The effect of moisture content of RA on fresh and hardened concrete is not similar as the effect of moisture content of natural aggregate.
- It may be difficult to maintain steady RA moisture content during concrete production.
- Typically RA will decrease elastic modulus and increase creep and shrinkage but this is very case-specific - high amount of fine RA is unfavorable.
- Water absorption is usually increased by RA, but with small amount of RA it can also be smaller.
- With the same water-cement ratio (w/c) chloride penetration and carbonation are normally higher when RA is introduced.

### 1.4 CHALLENGES IN USING RECYCLED AGGREGATE

Recycled aggregate (RA) is well acknowledged as having a poorer quality due to its higher porosity resulted from cement mortar remains attaching to its surface that hampers the recycling rate of concrete waste. The RCA may contain as much as 35 to 40% of mortar, which would accordingly affect such deformation properties of RCAs as elasticity, creep, and shrinkage. Many researchers have recorded reduction in strength for concrete made with RA. As a result, the use of RA is mainly confined to low-grade applications. Based on a large number of experimental results published worldwide in literature it was found that the interrelationships between the mechanical properties of RAC could be different from those of normal concrete. The differences found are not at all absolutely any obstacle for the use of RCA, but it means, that the conditions of recycled aggregate and the mix proportion adopted are complicated and more knowledge and experience is needed. A single statistical regression analysis was not considered to be fully sufficient and further studies were recommended. Although it may be sustainable to use RA, the current legislation and experience, however, are not sufficient to support and encourage recycling of demolished concrete waste.

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## 1.5 ADVANTAGES OF RECYCLING OF CONSTRUCTION MATERIALS:

- Used for construction of precast & cast in situ gutters & kerbs.
- Cost saving: There are no detrimental effects on concrete & it is expected that the increase in the cost of cement could be offset by the lower cost of Recycled Aggregate (RA).
- Save environment: There is no excavation of natural resources & less transportation. Also less land is required.
- Save time: There is no waiting for material availability.
- Less emission of carbon due to less crushing.

## 1.6 DISADVANTAGES OF RECYCLING OF CONSTRUCTION MATERIAL

- Less quality (e.g. crushing strength reduces by 10 - 30%).
- Uniformity in possessing the properties.
- Land, special equipments machineries are required (more cost).
- High water absorption (up to 6%).
- It has higher drying shrinkage & creep.

## 1.7 SILICA FUME IN CONCRETE

Silica Fume is also known as micro silica, condensed Silica Fume, volatilized silica or silica dust. Silica Fume (SF) is a by-product of the smelting process in the silicon and ferrosilicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2,000°C produces SiO<sub>2</sub> vapours, which oxidizes and condense in the low-temperature zone to tiny particles consisting of non-crystalline silica. By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85–95% non-crystalline silica. The by-product of the production of ferrosilicon alloy having 50% silicon has much lower silica content and is less pozzolanic. Therefore, SiO<sub>2</sub> content of the Silica Fume is related to the type of alloy being produced. The American concrete institute (ACI) defines Silica Fume as a “very fine noncrystalline silica produced in electric arc furnaces as a by-product of production of elemental silicon or alloys containing silicon”. It is usually a grey coloured powder, somewhat similar to Portland cement or some fly ashes. It can exhibit both pozzolanic and cementitious properties. Silica Fume has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties to a great extent. By using Silica Fume along with super plasticizers, it is relatively easier to obtain compressive strengths of order of 100–150 MPa in laboratory. Addition of Silica Fume to concrete improves the durability of concrete through reduction in the permeability, refined pore structure, leading to a reduction in the diffusion of harmful ions, reduces calcium hydroxide content which results in a higher resistance to sulphate attack. Improvement in durability will also improve the ability of Silica Fume concrete in protecting the embedded steel from corrosion. The Silica Fume is collected in very large filters in the baghouse and then made available for use in concrete.

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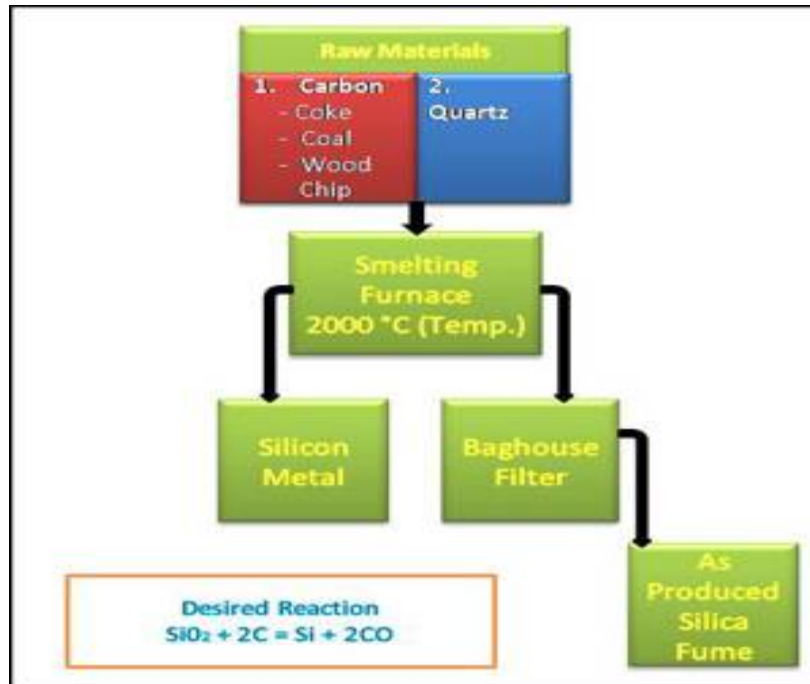


Fig.1.1 Production Process of Silica Fume

### 1.7.1 Availability and Handling

Silica Fume is available in two forms: dry and wet. Dry silica can be provided as produced or densified with or without dry admixtures and can be stored in silos and hoppers. Silica Fume slurry with low dosages of chemical admixtures are available. Slurried products are stored in tanks.

### 1.7.2 Reaction Mechanism

Because of its extreme fineness and very high amorphous silicon dioxide content, Silica Fume is a very reactive pozzolanic material. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide. The Silica Fume reacts with this calcium hydroxide to form additional binder material called calcium silicate hydrate (CSH) which is very similar to the that formed from Portland cement. It is an additional binder that gives silica-fume concrete its improved properties.

Mechanism of Silica Fume in concrete can be studied basically under three roles:

- (i) **Pore-size Refinement and Matrix Densification:** The presence of Silica Fume in the Portland cement concrete mixes causes considerable reduction in the volume of large pores at all ages. It basically acts as filler due to its fineness and because of which it fits into spaces between grains in the same way that sand fills the spaces between particles of coarse aggregates and cement grains fill the spaces between fine aggregates grains.
- (ii) **Reaction with Free-Lime (From Hydration of Cement) CH crystals** in Portland cement pastes are a source of weakness because cracks can easily propagate through or within these crystals without any significant resistance affecting the strength, durability and other properties of concrete. Silica Fume which is siliceous and aluminous material reacts with CH resulting reduction in CH content in addition to forming strength contributing cementitious products which in other words can be termed as ‘‘Pozzolanic Reaction’’.
- (iii) **Cement Paste–Aggregate Interfacial Refinement** In concrete the characteristics of the transition zone between the aggregate particles and cement paste plays a significant role in the cement-aggregate

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bond. Silica Fume addition influences the thickness of transition phase in mortars and the degree of the orientation of the CH crystals in it. The thickness compared with mortar containing only Ordinary Portland cement decreases and reduction in degree of orientation of CH crystals in transition phase with the addition of Silica Fume. Hence mechanical properties and durability is improved because of the enhancement in interfacial or bond strength. Mechanism behind is not only connected to chemical formation of C-S-H (i.e. pozzolanic reaction) at interface, but also to the microstructure modification (i.e. CH) orientation, porosity and transition zone thickness as well.

### 1.7.3 Heat of Hydration

Silica Fume is amorphous in nature and may contain some crystalline silica in the form of quartz or cristobalite. The higher surface area and amorphous nature of Silica Fume make it highly reactive. The hydration of C3S, C2S, and C4AF are accelerated in the presence of Silica Fume. Grutzeck *et al.* concluded that Silica Fume experiences rapid dissolution in the presence of Ca(OH)<sub>2</sub> and a super saturation of silica with respect to a silica-rich phase. This unstable silica-rich phase forms a layer on the surface of the Silica Fume particles. The layer is then partly dissolved and the remainder acts as a substitute on which conventional C-S-H is formed.

### 1.7.4 Effect of Silica Fume on Fresh Properties of Concrete

Rheological properties of a fresh cement paste play an important role in determining the workability of concrete. The water requirement for flow, hydration behaviour, and properties of the hardened state largely depends upon the degree of dispersion of cement in water. Properties such as fineness, particle size distribution, and mixing intensity are important in determining the rheological properties of cement paste. Due to the charges that develop on the surface, cement particles tend to agglomerate in the paste and form flocs that trap some of the mixing water. Factors such as water content, early hydration, water reducing admixtures and mineral admixtures like Silica Fume determine the degree of flocculation in a cement paste. Fresh concrete containing Silica Fume is more cohesive and less prone to segregation than concrete without Silica Fume. Concrete containing Silica Fume shows substantial reduced bleeding. Additionally Silica Fume reduces bleeding by physically blocking the pores in the fresh concrete. Use of Silica Fume does not significantly change the unit weight of concrete.

### 1.7.5 Applications of Silica Fume

- High Performance Concrete (HPC) containing Silica Fume—for highway bridges, parking decks, marine structures and bridge deck overlays which are subjected to constant deterioration caused by rebar corrosion current, abrasion and chemical attack. Silica Fume will protect concrete against deicing salts, seawater, road traffic and freeze/thaw cycles. Rebar corrosion activity and concrete deterioration are virtually eliminated, which minimizes maintenance expense.
- High-strength concrete enhanced with Silica Fume—provides architects and engineers with greater design flexibility. Traditionally used in high-rise buildings for the benefit of smaller columns (increasing the usable space) high strength concrete containing Silica Fume is often used in precast and pre-stressed girders allowing longer spans in structural bridge designs.
- Silica-fume Shotcrete—delivers greater economy, greater time savings and more efficient use of sprayed concrete. Silica Fume produces superior shotcrete for use in rock stabilization; mine tunnel linings, and rehabilitation of deteriorating bridge and marine columns and piles. Greater bonding strength assures outstanding performance of both wet and dry process shotcreting with less rebound loss and thicker applications with each pass of the shotcrete nozzle.
- Oil Well Grouting—whether used for primary (placement of grout as a hydraulic seal in the well-bore) or secondary applications (remedial operations including leak repairs, splits, closing of depleted zones); the addition of Silica Fume enables a well to achieve full production potential. Besides producing a blocking effect in the oil well grout that prevents gas migration, it provides these advantages such as (i) Improved flow,

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for easier, more effective application; (ii) dramatically decrease permeability, for better control of gas leakage; and (iii) lightweight

- Repair Products—Silica Fume is used in a variety of cementitious repair products. Mortars or grouts modified with Silica Fume can be tailored to perform in many different applications, overhead and vertical mortars benefit from Silica Fume's ability to increase surface adhesion. Silica Fume significantly improves cohesiveness making it ideal for use in underwater grouts, decreases permeability in grouts used for post-tensioning applications and increases the resistance to aggressive chemicals
- Refractory and Ceramics—the use of Silica Fume in refractory castables provides better particle packing. It allows for less water to be used while maintaining the same flow characteristics. It also promotes low temperature sintering and the formation of mullet in the matrix of the castable. This produces a castable that has a low permeability to avoid gas, slag and metal penetration. Castables incorporating Silica Fume are stronger than non-Silica Fume containing castables especially at high temperatures with higher density they attain lower porosity and are more volume stable

## 1.8 OBJECTIVE

The aim of the experimental investigation is to obtain the compressive strength, split tensile strength, flexural strength and chloride permeability of RCA concrete. In the first part of the study, cement is replaced with silica fume to know the optimum replacement level in varying percentages i.e. 6%, 8%, 10%, 12% and 14%. From the results optimum replacement is found to be 10%. In the second phase of study, natural coarse aggregate is replaced with recycled coarse aggregate by 20%, 30%, 40%, 50%, 60%, 75% and 100% with addition of 10% silica fume as a partial replacement to the cement. M25 grade of concrete was designed as per the Indian Standard code of practice.

## II. LITERATURE REVIEW

### 2.1 GENERAL

In recent years certain countries have considered the reutilization of construction and demolition waste as a new construction material as being one of the main objectives with respect to sustainable construction activities.

The literature review presents the current state of knowledge and examples of successful uses of alternative materials in concrete technology and in particular the use of Recycled Concrete aggregate as a coarse aggregate fraction in concrete. Many researchers have dedicated their work to describe the properties of these kinds of aggregate, the minimum requirements for their utilisation in concrete and the properties of concrete made with recycle aggregate.

In this chapter a review of literature on physical, mechanical and durability properties of recycled aggregate concrete with the addition of silica fume is presented.

### 2.2 REVIEW OF LITERATURE

**Tavakoli M. (1996)** studied the compressive; splitting tensile and flexural strengths of 100% recycled coarse aggregate concrete compare them with normal concrete. The test result shows the compressive, tensile and flexural strengths of RCA are little higher than the natural aggregate at 28-day specimen. This indicates that if the compressive strength of the original concrete that is being recycled is higher than that of the control concrete, then the recycled aggregate concrete can also be made to achieve higher compressive strength than the control concrete. The results also indicates that increase water absorption capacity of recycled aggregates, which partly reflect the increased amount of water, adhering to the original stone aggregate, generally lead to reduced compressive strength of recycled aggregate concrete.

**Ravindrarajah R. Sri, (1996)** discusses results of a series of investigations into the properties of recycled concrete aggregate and the effects of using them on the properties of concrete. Recycled concrete aggregate is differ from the natural aggregate due to the presence of considerable portion of mortar attached to the natural aggregate and consequently affects the properties and performance of concrete. The results show that for recycled aggregate concrete,

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compressive, tensile and modulus are reduced. The strength of recycled aggregate concrete can be recovered by making suitable mix adjustments by adding the pozzolanic materials like fly ash, silica fume etc.

**Dhir *et al.* (1998)** studied the effect of the cleanliness and percentage of the replacement of RCA. They found out that the degree of cleanliness of aggregate has significantly affected on the results of the properties of both the plastic and hardened concrete. The workability and compressive strengths both were lower than the quarried aggregate depending on the percentage of replacement of RCA.

**Sanchez de Juan *et al.* (2000)** studied the variation of RCA, from 20% to 100%, as replacement of natural coarse aggregate on the properties of concrete. The results showed that the compressive strength of recycled concrete is lower than that of a control concrete with equal water/cement ratio and same cement content. Recycled concrete with a percentage of recycled coarse aggregate lower than 50% show decreases in the range 5-10%, while for concretes with 100% recycled aggregates, decreases ranged from 10-15%. Experimental results also indicated that properties of conventional concretes and recycled concretes with same compressive strength when less than 20% of recycled coarse aggregate are used. The exception being modulus of elasticity was decreased until 10% can be found in recycled concretes. When the percentage of recycled aggregate is lower than 50%, tensile strength of recycled concrete is similar to conventional concrete with same compressive strength. As a result of the testing, all properties of concrete with a 100% of recycled coarse aggregate are affected

**Sharma *et al.* (2001)** has reported that the compressive strength and tensile strength are 15% lower for recycled aggregate concrete. The modulus of elasticity of recycled aggregate is lower and fatigue behavior is closer to normal concrete. The shrinkage and creep of the recycled concrete is higher than conventional concrete. The study also reports addition of flyash results in reduction of permeability of recycled aggregate concrete.

**Pawar *et al.* (2003)** has reported the study and review of literature in recycled aggregate concrete. It is reported that the shape of RCA is angular and texture and is more porous and rough. Specific gravity decreases and water absorption is high for the recycled aggregates. Compressive, tensile and flexural strength are lower. It is suggested to use fillers like silica fume and judicious dose of plasticizers if required to overcome increased water absorption of recycled aggregate concrete and low workability.

**JianzhuangXiao (2004)** studied the mechanical properties of recycled aggregate concrete under uniaxial loading. He concluded that the compressive strength of concrete containing recycled concrete aggregates decrease with increasing recycled concrete aggregates content. For 100% replacement of natural coarse aggregates with recycled concrete aggregates, the elastic modulus is reduced by 45%.

**Limbachiya (2004)** studied the properties of recycled aggregate compared with natural aggregates and found out the density of RCA is typically 4-8% lower and water absorption 2-6 times higher. The results showed that a reduction in slump value with increasing RCA concrete mix. The results also showed that up to 30% coarse RCA has no effect on the standard concrete cube strength but thereafter a gradual reduction with increasing RCA content occurs. This means that some adjustment is necessary of the water/cement ratio to achieve the equivalent strength with high proportions of RCA.

**Katz (2004)** stated two methods to improve the quality of the recycled aggregates. The superplasticizer (1% weight of silica fume) was added to the solution of 10L of water and 1 kg raw silica fume to ensure proper dispersion of silica fume particles. After the silica fume impregnation, the SF treatment seems to improve significantly the compressive strength up to 51MPa at ranged from 23% to 33% at 7 days of the recycled aggregate concrete. Ultrasonic cleaning of the recycled aggregate to remove the loose particles and improve the bond between the new cement paste and the recycled aggregate, which, in turn, increased 7% of strength.



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**M Etxeberria et al. (2006)** specified recycled coarse aggregates obtained by crushed concrete were used for concrete production. Four different recycled aggregate concretes were produced; made with 0%, 25%, 50% and 100% of recycled coarse aggregates, respectively. The mix proportions of the four concretes were designed in order to achieve the same compressive strength. In general the workability of recycled aggregate concretes is affected by the absorption capacity of the recycled aggregates. The shape and texture of the aggregates can also affect the workability of the concrete. Concrete crushed by an impact crusher achieves a high percentage of recycled coarse aggregates without adhered mortar. Concrete made with 100% of coarse recycled aggregate requires high amount of cement to achieve a high compressive strength and consequently is not an economic proposition as it is not cost effective. Concrete made with 100% of recycled coarse aggregates has 20–25% less compression strength than conventional concrete at 28 days, with the same effective w/c ratio and cement quantity.

**Khaldoun rahal et al. (2007)** compared the mechanical properties of recycled aggregate concrete (RAC) and conventional normal aggregate concrete (NAC). Ten mixes of concrete with target compressive cube strength ranging from 20 to 50MPa were cast using normal or recycled coarse aggregates. The development of the cube compressive strength and the indirect shear strength at ages of 1, 3, 7, 14, 28 and 56 days, the compressive strength, the strains at maximum compressive stress and the modulus of elasticity tested by using concrete cylinders at 28 days are reported. RAC where the observed strength was slightly lower than the target strength. On the average, the 56-day cube strength was 5% and 3% higher than the 28-day strength for RAC and NAC respectively.

**Suraya Hani Adnan (2009)** stated that compressive strength is the basic mechanical properties and one of the indicators to determine the performance of a concrete. The effects of various percentages (0%, 25%, 50%, 75% and 100%) of Recycled Aggregate (RA) on compressive strength of Recycled Aggregate Concrete (RAC) were investigated. RA is used to replace Natural Aggregate (NA) as coarse aggregate in concrete mixes. This research also covered RAC mixtures at different w/c ratio (0.4, 0.5, and 0.6). It was found that RAC had lower compressive strength compared to natural aggregate concrete at the age of 28 days. RAC with w/c 0.4 had the highest strength. And the results found that with the same w/c ratio, the slump value decreases if percentage of RA is increased. The compressive strength of Recycled Aggregate Concrete was lower than that of Natural aggregate concrete. Lower w/c ratio of RAC lead to higher in compressive strength. RAC could increase its compressive strength by reducing the w/c ratio of concrete. The relationship of w/c ratio and compressive strength of RAC is inversely proportional.

**Padmini A.K. et al. (2009)** studied about the influence of parent concrete on the properties of recycled aggregate concrete. Some of the salient observations of these studies are the method of crushing of parent concrete, particle shape, water cement ratio those which has significant effect on recycled aggregates. As per the results the water absorption capacity of recycled aggregates increased with increase in strength of parent concrete from which recycled aggregates was derived. The resistance against mechanical actions was lower than fresh crushed granite aggregate. In order to achieve a design compressive strength, recycled aggregate concrete requires lower water-cement ratio and higher cement content with respect to fresh granite aggregate.

**Mathews M.S. et al. (2009)** investigated the water absorption of recycled aggregate increases with an increase in strength of parent concrete from which the recycled aggregate is derived, while it decreases with an increase in maximum size of aggregate. Higher water absorption of recycled aggregate necessitates adjustment in mix water content to obtain the desired workability. For achieving a design compressive strength, recycled aggregate concrete requires lower water–cement ratio and higher cement content to be maintained as compared to concrete with fresh granite aggregate. For a given target mean strength, the achieved strength increases with an increase in maximum size of recycled aggregate used. For a given compressive strength of concrete, the split tensile and flexural strengths are lower for RAC than parent concrete.

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**R. Kumutha and K. Vijai (2010)** In APRN Journal of Engineering and Applied Sciences done an experimental investigation and found that the recycled aggregate will influence much in hardened properties of concrete. As the percentage of crushed concrete coarse aggregate and crushed brick fine aggregate is increased, the strength of concrete gets decreased. From the obtain results, it is clear that there is a possibility to use a 100% crushed concrete coarse aggregate and 60% crushed brick fine aggregate in compression elements like concrete blocks and concrete pavements since the target strength can be achieved. As there is considerable reduction in flexural strength with recycled aggregate.

**Ishtiyag Gull (2011)** investigated the testing of strength of recycled waste concrete and its applicability and found that the differences in strengths between fresh concrete material and strengthened concrete are less than 10% for cubes and cylinders and less than 5% for flexural beams at 28 days of testing. Such differences in compressive strength are very small and will not have a considerable effect on concrete applications. Hence, this study recommends the recycling of waste concrete as an aggregate material in production of new concrete, provided the labor cost incurred in the extraction of waste aggregate from demolished buildings and also the cost incurred in using admixture to increase the strength of waste aggregate do not exceed the cost of fresh aggregate. The recycling of waste concrete helps us to conserve the natural aggregate and use them for more important constructional works. Also, the waste aggregate obtained from demolition of buildings and destruction of buildings by earthquakes creates disposal problems.

**Kou et al. (2012)** used commercial recycled aggregates at 0%, 25%, 50% and 100% replacement levels on natural aggregates. At 28 days the compressive strength of 100% recycled aggregate concrete was 12.2% lower than natural aggregate concrete. After 90 days the values of recycled aggregate concrete was better and even more at 20% replacement level of natural aggregate.

**Jeena Mathew (2012)** studied the effect of silica fume on strength and durability properties of M35 grade concrete with partial replacement of cement. The different percentages of silica fume are 0, 5, 10, 15 and 20%. The optimum 7 and 28 days compressive strength and flexural strength has also been obtained in range of 10-15% silica fume replacement level.

**PatilShreekedar (2013)** studied the effect of mineral admixture in mix proportioning of high performance concrete. The results show that the maximum replacement level of micro silica is 15% for M60 grade high performance concrete.

**Debabrata Pradhan (2013)** studied the properties of silica fume concrete such as compressive strength, compacting factor and workability. He replaced cement by silica fume at different levels to know what percentage of silica fume gives the optimum value of compressive strength and for all replacements water to cement ratio is kept constant.

**Hiren A Rathod (2013)** studied the recycled concrete aggregates as a substitute to natural aggregate for sustainable development in India. He concluded that when recycled concrete aggregates are added in concrete then results in increased water demand, reduction in workability, slump value as compared to concrete made with Natural coarse aggregates. He concluded that decrease in strength of concrete with increase in percentage of replacement ratio of recycled concrete aggregates

**S. BHANJA et al (2013)** The results of the present investigation indicates that, other mix design parameters remaining constant, silica fume incorporation in concrete results in significant improvement in the tensile strength of concrete, along with the compressive strength. The optimum silica fume replacement percentages for tensile strength have been found to be a function of w/c ratio of the mix. The optimum 28 days split tensile strength has been obtained in the range of 5-10% silica fume replacement level, whereas the value for flexural strength ranged from 15% to 25%.

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**Amudhavalli & Mathew (2012)** studied the Effect of silica fume on the strength and durability characteristics of concrete. The main parameter investigated in this study is M35 grade concrete with partial replacement of cement by silica fume by 0, 5, 10, 15 and by 20%. A detailed experimental study in Compressive strength, split tensile strength, flexural strength at age of 7 and 28 day was carried out. Results show that Silica fume in concrete has improved the performance of concrete in strength as well as in durability aspect.

**Perumal & Sundararajan (2004)** observe the Effect of partial replacement of cement with silica fume on the strength and durability properties of high grade concrete. Strength and durability properties for M60, M70 and M110 grades of HPC trial mixes and to arrive at the maximum levels of replacement of cement with Silica fume, investigations were taken. The strength and durability characteristics of these mixes are compared with the mixes without SF. Compressive strengths of 60 N/mm<sup>2</sup>, 70 N/mm<sup>2</sup> and 110 N/mm<sup>2</sup> at 28 days were obtained by using 10 percent replacement of cement with SF. The results also show that the SF concretes possess superior durability properties.

**Kumar & Dhaka (2016)** write a Review paper on partial replacement of cement with silica fume and its effects on concrete properties. The main parameter investigated in this study M35 concrete mix with partial replacement by silica fume with varying 0, 5, 9, 12 and 15% by weight of cement. The paper presents a detailed experimental study on compressive strength, flexural strength and split tensile strength for 7 days and 28 days respectively. The results of experimental investigation indicate that the use of silica fume in concrete has increased the strength and durability at all ages when compared to normal concrete.

**Ghutke & Bhandari (2014)** examine the Influence of silica fume on concrete. Results showed that the silica fume is a good replacement of cement. The rate of strength gain in silica fume concrete is high. Workability of concrete decreases as increase with % of silica fume. The optimum value of compressive strength can be achieved in 10% replacement of silica fume. As strength of 15% replacement of cement by silica fume is more than normal concrete. The optimum silica fume replacement percentage varies from 10 % to 15 % replacement level.

**Hanumesh, Varun & Harish (2015)** observe the Mechanical Properties of Concrete Incorporating Silica Fume as Partial Replacement of Cement. The main aim of this work is to study the mechanical properties of M20 grade control concrete and silica fume concrete with different percentages (5, 10, 15 and 20%) of silica fume as a partial replacement of cement. The result showed that the compressive strength of concrete is increased by the use of silica fume up to 10% replacement of cement. From 10% there is a decrease in compressive strength and The split tensile strength of concrete is increased by the use of silica fume up to 10% replacement of cement. From 10% there is a decrease in split tensile strength. The optimum percentage of replacement of cement by silica fume is 10% for M20 grade of concrete.

**Shanmugapriya & Uma (2013)** carried an Experimental Investigation on Silica Fume as a partial Replacement of Cement in High Performance Concrete. The concrete used in this investigation was proportioned to target a mean strength of 60 MPa and designed as per A The water cement ratio (W/C) adopted was 0.32 and the Super Plasticizer used was CONPLAST SP 430. Specimens such as cubes, beams and cylinders were cast for various mix proportions and tested at the age of 7, 14 and 28 days CI 211.4R-08. The investigation revealed that the partial replacement of cement by silica fume will develop sufficient compressive strength, flexure strength and split tensile strength for construction purposes. The optimum dosage of silica fume found to be 7.5% (by weight), when used as partial replacement of ordinary Portland cement.

**Alok (2016)** write A Research Paper on Partial Replacement of Cement in M30 Concrete from Silica Fume and Fly Ash. Replacement levels of OPC by Silica Fume were 0%, 2.5%, 5% and 7.5% where replacement levels of Ordinary Portland cement by Fly Ash were 0%, 5%, 10% and 15% by weight. 1% superplasticizer was used in all the test specimens for better workability at lower water cement ratio and to identify the sharp effects of Silica Fume and

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Fly Ash on the properties of concrete. Water-cement ratio was kept 0.43 in all cases. 43.1 N/mm<sup>2</sup> was the maximum compressive strength which was obtained at replacement level of 7.5% by weight of SF and 20% by weight of FA with cement. 6.47 N/mm<sup>2</sup> was the maximum flexural strength which was obtained at replacement level of 7.5% by weight of SF and 20% by weight of FA with cement. 2.573 N/mm<sup>2</sup> was the maximum split tensile strength which was obtained at replacement level of 7.5% by weight of SF and 20% by weight of FA with cement.

**Jain & Pawade (2015)** studied the Characteristics of Silica Fume Concrete. The physical properties of high strength silica fume concretes and their sensitivity to curing procedures were evaluated and compared with reference Portland cement concretes, having either the same concrete content as the silica fume concrete or the same water to cementitious materials ratio. The experimental program comprised six levels of silica fume contents (as partial replacement of cement by weight) at 0% (control mix), 5%, 10%, 15%, 20%, and 25%, with and without superplasticizer. It also included two mixes with 15% silica fume added to cement in normal concrete. Durability of silica fume mortar was tested in chemical environments of sulphate compounds, ammonium nitrate, calcium chloride, and various kinds of acids.

**Roy & Sil (2012)** Studied the Effect of Partial Replacement of Cement by Silica Fume on Hardened Concrete. From the study it has been observed that maximum compressive strength (both cube and cylinder) is noted for 10% replacement of cement with silica fume and the values are higher (by 19.6% and 16.82% respectively) than those of the normal concrete (for cube and cylinder) whereas split tensile strength and flexural strength of the SF concrete (3.61 N/mm<sup>2</sup> and 4.93 N/mm<sup>2</sup> respectively) are increased by about 38.58% and 21.13% respectively over those (2.6 N/mm<sup>2</sup> and 4.07 N/mm<sup>2</sup> respectively) of the normal concrete when 10% of cement is replaced by SF.

**Amarkhail (2015)** observed Effects of Silica Fume on Properties of High-Strength Concrete. He found that up to 10% cement may be replaced by silica fume without harming the concrete workability. Concrete containing 10% silica fume replacement achieved the highest compressive strength followed by 15% silica fume replacement with a small difference. Concrete with 15% silica fume content achieved the highest flexural strength. 10% and 15% silica fume content as replacement of cement were found to be the optimum amount for significantly enhancement of compressive strength and flexural strength respectively.

**Sasikumar & Tamilvanan (2016)** Performed an Experimental Investigation on Properties of Silica Fumes as a Partial Replacement of Cement. Main parameter investigated in this study is M30 grade concrete with partial replacement of cement by silica fume 0%, 25%, 30%, 40% and 50%. The normal consistency increases about 40% when silica fume percentage increases from 0% to 25%. The optimum 7 and 28 day compressive strength has been obtained in the 25% silica fume replacement level. Also the split tensile strength is high when using 25% silica fume replacement for cement.

## III. MATERIALS

### 3.1 GENERAL

In this chapter, materials properties of cement, fine aggregate, coarse aggregate, recycled coarse aggregate and silica fume are presented. The testing of the same is done by using appropriate IS codes.

### 3.2 MATERIALS

#### 3.2.1 Cement

Locally available 53 grade of Ordinary Portland Cement (Ultra Tech Brand.) conforming to IS: 12269-1987 was used in the investigations. Table 3.1 gives the physical properties of OPC used in the present investigation and they conform to IS specifications.

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**Table 3.1. Properties of Cement**

S. No	Property	Test results
1	Normal consistency	30%
2	Specific gravity	3.12
3	Initial setting time	105 minutes
4	Final setting time	290 minutes

### 3.2.2 Aggregate

The size, shape and gradation of the aggregate play an important role in achieving a proper concrete. Fine aggregate shall have free from silt content and possess low water absorption. The flaky and elongated particles of CA will lead to blocking problems in confined zones. The sizes of aggregates will depend upon the size of rebar spacing.

The coarse aggregate chosen for Concrete is typically angular in shape and is well graded.

#### 3.2.2.1 Fine Aggregate

The material which passes through 4.75 mm sieve is generally termed as fine aggregate. The sand used for the experimental works is locally procured and conformed to grading zone-II of IS 383-1970. The physical properties and sieve analysis of fine aggregate are presented in Table 3.2 and Table 3.3 respectively. The results of sieve analysis are shown in Fig.3.1

**Table 3.2. Physical Properties of Fine Aggregate**

S.No	Property	Values
1	Specific Gravity	2.56
2	Fineness Modulus	2.60
3	Grading of Sand	Zone – II

**Table 3.3. Sieve Analysis of Fine Aggregate**

IS Sieve Designation	Weight retained (gm)	Percentage weight retained (%)	Percentage passing by weight	Cumulative percentage wt. retained
10mm	0	0	100	0
4.75mm	5	0.5	99.5	0.5
2.36mm	45	4.5	95	5
1.18mm	130	13	82	18
600 micron	360	36	46	54
300 micron	350	35	11	89
150 micron	50	5	6	94

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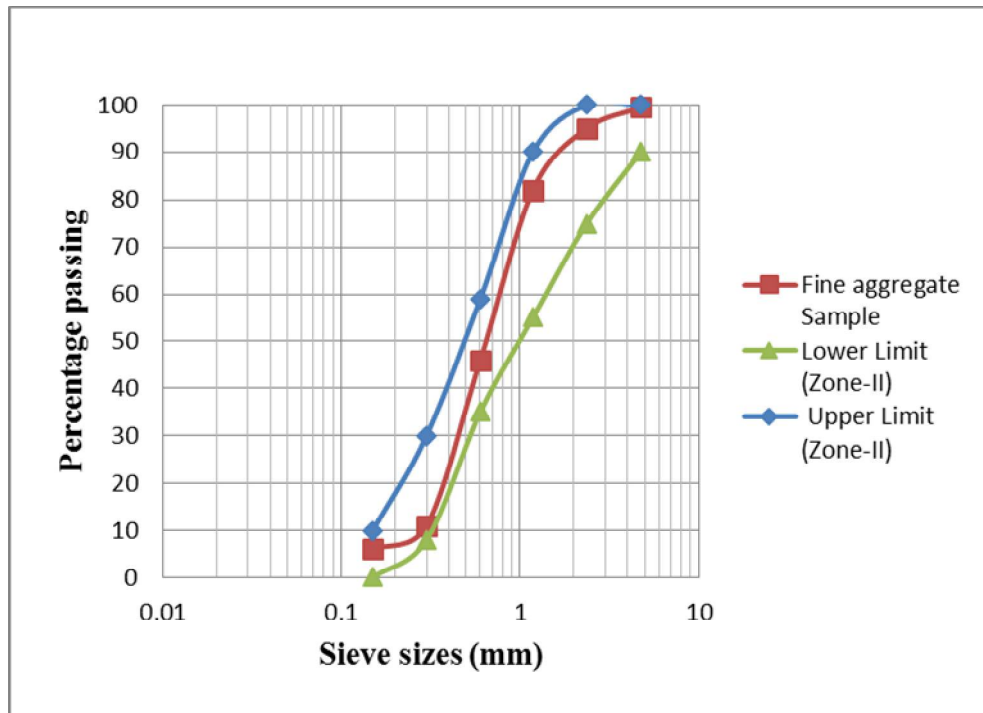


Fig.3.1. Results of Sieve Analysis of Fine Aggregate

### 3.2.2.2 Coarse Aggregate

The coarse aggregate is the strongest and the least porous component of concrete. It is also a chemically stable material. Presence of coarse aggregate reduces the drying shrinkage and other dimensional changes occurring on account of movement of moisture. Coarse aggregate contributes to concrete impermeability if it is properly graded and the mix is suitably designed.

The coarse aggregate used for this investigation is confirmed to IS specifications. The size of coarse aggregate was used in the ratio of 60:40 graded aggregates i.e. 60% of 20mm to and 40% of 12.5mm. The coarse aggregate was tested for its physical properties like specific gravity, fineness modulus, and water absorption. The tested results are presented in the following Table 3.4

Table 3.4. Properties of Coarse Aggregate

S.NO	PROPERTY	VALUES
1	Specific Gravity	2.66
2	Water Absorption	0.4%
3	Fineness Modulus	6.53

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### 3.2.2.3 Recycled Coarse Aggregate

The recycled coarse aggregate used in this investigation is obtained by crushing the tested laboratory concrete cubes. The properties of recycled coarse aggregate are shown in Table 3.5

Recycled aggregate is obtained by the following phases:

1. Crushing: Crushing is done by using hammers.
2. Sieving: The crushed aggregate is sieved through sieves of sizes 20mm, 12.5mm and 10mm

**Table 3.5. Properties of Recycled Coarse Aggregate**

S.NO	Property	Values
1	Specific Gravity	2.56
2	Water Absorption	1.75%

### 3.2.3 Silica Fume

Silica Fume is highly pozzolanic mineral admixture, which is mainly utilized to improve concrete strength and durability of concrete. Silica Fume reacts with calcium hydroxide formed during hydration of cement results in the increase in strength and also the Silica Fume fills the voids between cement particles leads to increase in the durability. Silica Fume is procured from ASTRRA CHEMICALS, Thousand Lights and Chennai. The properties of Silica Fume are shown in Table 3.6, 3.7 and fig. 3.2 shows the Silica Fume sample used for concrete preparation.

**Table 3.6 Physical Properties of Silica Fume**

S.No.	Properties	Results
1	Physical State	Micronised Powder
2	Odour	Odourless
3	Colour	White
4	Pack Density	0.76 Gm/Cc
5	Ph Of 5% Solution	6.90
6	Specific Gravity	2.63
7	Moisture	.058%
8	Oil Absorption	55 MI / 100 gms

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**Table 3.7 Chemical Properties of Silica Fume**

S.No.	Properties	Results
1	Silica (SiO <sub>2</sub> )	99.886%
2	Alumina (Al <sub>2</sub> O <sub>2</sub> )	0.043%
3	Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> )	0.040%
4	Titanium Oxide (TiO <sub>2</sub> )	0.001%
5	Calcium Oxide (CaO)	0.001%
6	Magnesium Oxide (MgO)	0.000%
7	Pottasium Oxide (K <sub>2</sub> O)	0.001%
8	Sodium Oxide (Na <sub>2</sub> O)	0.003%
9	Loss On Ignition	0.015%



**Fig.3.2 Silica Fume Sample**



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### 3.2.4 Water

The water used for the present investigation is that tap water available in the laboratory. The analysis of the is done in the laboratory and found that the limits of impurities are within the permissible range.

**Table 3.8: Properties of Water**

Water Parameters	As per Environmental Laboratory	As per Specifications
pH	6.8	≥6.0 (IS456 2000)
Chlorides	250mg/l	500mg/l (RCC) 2000mg/l (PCC)
Sulphates	150mg/l	400mg/l
Organic Matter	50mg/l	200mg/l
Inorganic Matter	1150mg/l	3000mg/l
Suspended Matter	500mg/l	2000mg/l

## IV. CONCRETE MIX DESIGN

### 4.1 GENERAL

Concrete mix design is the process of selecting suitable ingredients of concrete and determining their relative proportions 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 procedure for mix design is adopted as per Indian Standard Recommended Guidelines of IS 10262:2009 and IS 456:2000.

### 4.2 MIX DESIGN FOR M25 GRADE OF CONCRETE (Natural Coarse Aggregate)

**Table 4.1. Design Data**

Grade designation	M25
Type of cement	OPC 53 Grade
Maximum nominal size of aggregate	20mm
Cement content	350 kg/m <sup>3</sup>
Maximum water cement ratio	0.5
Specific gravity of cement	3.12
Specific gravity of coarse aggregate	2.67
Specific gravity of fine aggregate	2.56

#### Target Mean Strength:

$$\begin{aligned}
 f_{ck}^1 &= f_{ck} + 1.65 S \\
 &= 25 + 1.65 \times 4 \\
 &= 31.6 \text{ N/mm}^2
 \end{aligned}$$

Where,

$f_{ck}$  = characteristic compressive strength  
S = Standard deviation = 4

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**Calculation of cement content:**

$$\begin{aligned} \text{Water cement ratio} &= 0.46 \\ \text{Water content} &= 0.46 \times 350 \\ &= 161 \text{ Liters} \end{aligned}$$

From Table 3 (IS 10262:2009) volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate (zone-II), for water cement ratio of 0.46 = 0.63.

$$\begin{aligned} \text{Volume of coarse aggregate} &= 0.63 \\ \text{Volume of fine aggregate} &= 1 - 0.63 \\ &= 0.37 \end{aligned}$$

**Mix Calculations:**

$$\begin{aligned} \text{Volume of Concrete} &= 1\text{m}^3 \\ \text{Volume of Cement} &= \frac{\text{Mass of cement} \times 1}{\text{sp.gravity of cement} \times 1000} \\ &= \frac{350 \times 0.98}{3.12 \times 1000} \\ &= 0.114 \text{ m}^3 \\ \text{Volume of Water} &= \frac{\text{Mass of water} \times 1}{\text{sp.gravity of water} \times 1000} \\ &= \frac{161 \times 0.98}{1 \times 1000} \\ &= 0.16 \text{ m}^3 \\ \text{Volume of Aggregates} &= 0.98 - (0.114 + 0.16) \\ &= 0.706 \text{ m}^3 \\ \text{Mass of Coarse Aggregate} &= 0.706 \times 0.63 \times 2.67 \times 1000 \\ &= 1188 \text{ kg} \\ \text{Mass of Fine Aggregate} &= 0.706 \times 0.37 \times 2.56 \times 1000 \\ &= 668.72 \text{ kg} \end{aligned}$$

The ingredients of M25 grade of concrete for one cubic meter are,

$$\begin{aligned} \text{Cement} &= 350 \text{ kg/m}^3 \\ \text{Sand} &= 669 \text{ kg/m}^3 \\ \text{Coarse aggregate} &= 1188 \text{ kg/m}^3 \\ \text{Water content} &= 161 \text{ liters/m}^3 \end{aligned}$$

The mix proportions for M25 grade of concrete with Natural Coarse Aggregate is shown in Table 4.2

**Table 4.2. Mix Proportion for M25 Grade Concrete**

	Cement (Kg/m <sup>3</sup> )	Fine aggregate (Kg/m <sup>3</sup> )	Coarse aggregate (Kg/m <sup>3</sup> )	Water (Kg/m <sup>3</sup> )
Mix proportion	1	1.91	3.39	0.46
Quantity/m <sup>3</sup>	350	669	1188	161

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## V. EXPERIMENTAL METHODS

### 5.1 GENERAL

The experimental works was carried out based on the following two phases:-

1. Preparation of test specimens and
2. Tests on hardened concrete

### 5.2 PREPARATION OF TEST SPECIMENS

#### 5.2.1 Moulds

Cube, cylinder and prism specimens are cast to determine compressive strength, split tensile strength and flexural strength. Steel cubical moulds of size 150 X 150 X 150-mm are used to make specimens for finding the compressive strength. Cylindrical moulds of size 150 mm diameter and 300 mm length are used for determining split tensile strength and modulus of elasticity. Prism moulds of size 100 X 100 X 500-mm are used to find the flexural strength of concrete

**Table 5.1 Preparation of Specimens**

S.No	Type of test	Sample	No. of Samples				Total
			3 days	7 days	28 days	90 Days	
1	Compressive Strength	Cubes	39	39	39	24	141
2	Split Tensile Strength	Cylinders	---	---	24	---	24
3	Flexure Strength	Prisms	---	---	24	---	24
4	Permeability	Cylinders	---	---	24	---	24

#### 5.2.2 Mixing

The cementations materials are thoroughly blended and then the aggregate is added and mixed followed by gradual addition of water and mixing. Wet mixing is done until a mixture of uniform colour and consistency are achieved which is then ready for casting. Before casting the specimens, workability of different types of concrete mixes were found by slump cone test.

#### 5.2.3 Casting

After the completion of workability tests, the concrete has been placed in the standard metallic moulds in three layers and compacted each time by tamping rod. Before placing the concrete inner faces of the mould are coated with the machines oil for easy removal of test specimens. The concrete in the moulds has been vibrated for 30sec using the Table vibrator and the surface of the specimens have been finished smoothly.

#### 5.2.4 Curing

After the casting of cubes, cylinders and prisms the specimens are kept at room temperature for one day and the specimens are removed from the moulds after 24hours of casting of concrete specimens. Marking has been done on the specimens for identification. To maintain the constant moisture on the surface of the specimens, they are placed in water tank for curing. All the specimens have been cured for the desired age. Concrete specimens are cured for 3, 7, 28, 56 and 90days.

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### 5.3 TESTS ON HARDENED CONCRETE

#### 5.3.1 Compressive Strength Test

For compressive strength testing, the bearing surfaces of the testing machine were wiped clean and the cubes were placed in the machine in such a manner that the load is applied to opposite sides of the cubes as cast. The axis of the specimen was carefully aligned with the centre of thrust of the spherically seated plate. The spherically seated block was brought to bear on the specimen and the load was applied without shock and continuously at a rate approximately 140 kg/cm<sup>2</sup> / minute until failure of specimen. Fig.5.1. Shows test setup for compressive strength and crack pattern. The maximum load applied to the specimen until failure was recorded.

**Compressive stress = ultimate load/bearing area.**



**Fig.5.1. Compressive Strength Test**

#### 5.3.2 Split Tensile Strength Test

It is the standard test, to determine the tensile strength of concrete and this test could be performed in accordance with IS: 5816-1970. A standard test cylinder of concrete specimen of size 150mm diameter and 300mm height were placed horizontally between the loading surfaces of Compression testing machine as shown in Fig.5.2. Narrow strips of the steel plate are placed above and below the specimen cylinder, are subjected to compressive load. The compression load is applied diametrically and uniformly along the length of the cylinder until the failure of the cylinder along the vertical diameter. Concrete cylinder is then split into two halves along this vertical plan.

Load at which the specimen failed is recorded and splitting tensile stress is calculated from the formula as

$$f_t = \frac{2P}{L \cdot D}$$

Where

$f_t$	=	Split tensile stress
$P$	=	Compressive load on the failure
$L$	=	Length of the cylinder
$D$	=	Diameter of the cylinder

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**Fig.5.2. Split Tensile Strength Test**

### 5.3.3 Flexural Strength Test

For Flexural strength test, the specimen was placed in UTM, in such a manner that load shall be applied to the upper most surface, as cast in the mould, along two lines spaced  $L/3$  apart. The load was applied without shock and increased at rate such that, the extreme fibre stress increases at approximately  $7 \text{ kg/mm}^2/\text{min}$ , until failure occurs. Experimental setup is shown in Fig.5.3

The flexural strength of specimen expressed as the modulus of rupture ( $f_b$ )

$$f_b = \frac{3Pa}{bd^2}$$

If crack falls outside the load point

Where

$a$  = distance between the line of fracture and the nearer support.

$P$  = applied load.

$b$  = width of the specimen.

$d$  = depth of the specimen.

$$f_b = \frac{PL}{bd^2}$$

If crack falls within the load point

Where

$L$  = clear span of the specimen.

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**Fig.5.3. Flexural Strength Test**

### **5.3.4 Rapid Chloride Permeability Test (RCPT):**

Corrosion of reinforcing steel due to chloride ingress is one of the most common environmental attacks that lead to the deterioration of concrete structures. This durability problem has received wide-spread attention in recent years because of its frequent occurrence and the associated high cost of repairs. Chlorides penetrate crack-free concrete by a variety of mechanisms: capillary absorption, hydrostatic pressure, diffusion, and evaporative transport. Of these, diffusion is predominant. Diffusion occurs when the concentration of chloride on the outside of the concrete member is greater than on the inside. This results in chloride ions moving through the concrete to the level of the rebar. When this occurs in combination with wetting and drying cycles and in the presence of oxygen, conditions are right for reinforcement corrosion.

The rate of chloride ion ingress into concrete is primarily dependent on the internal pore structure. The pore structure in turn depends on other factors such as the mix design, degree of hydration, curing conditions, use of supplementary cementitious materials, and construction practices. Therefore, wherever there is a potential risk of chloride-induced corrosion, the concrete should be evaluated for chloride permeability.

This test method was originally developed by the Portland Cement Association, under a research program paid for by the Federal Highway Administration (FHWA). The original test method may be found in FHWA/RD-81/119, "Rapid Determination of the Chloride Permeability of Concrete." Since the test method was developed, it has been modified and adapted by various agencies and standard's organizations. These include:

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- AASHTO T277, “Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete”
- ASTM C1202, “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration”

Many concrete structures are built today with specifications calling for low-permeability concrete. The construction industry accepts this test procedure as a measurement for determining chloride permeability.

The test method involves obtaining a 100 mm diameter core or cylinder sample from the concrete being tested. A 50 mm specimen is cut from the sample. The side of the cylindrical specimen is coated with epoxy, and after the epoxy is dried, it is put in a vacuum chamber for 3 hours. The specimen is vacuum saturated for 1 hour and allowed to soak for 18 hours. It is then placed in the test device (see test method for schematic of device). The left-hand side (–) of the test cell is filled with a 3% NaCl solution. The right-hand side (+) of the test cell is filled with 0.3N NaOH solution. The system is then connected and a 60-volt potential is applied for 6 hours. Readings are taken every 30 minutes. At the end of 6 hours the sample is removed from the cell and the amount of coulombs passed through the specimen is calculated.

The test results are compared to the values in the chart below. This chart was originally referenced in FHWA/RD-81/119 and is also used in AASHTO T277-83 and ASTM C1202 specifications.

**Table 5.2 Relation between Charge Passed and the Chloride Permeability**

Charge passed (Coulombs)	Chloride Permeability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible



**Fig.5.4. Test setup for RCPT test**

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## VI. RESULTS AND DISCUSSIONS

### 6.1 GENERAL

The results of the experimental investigation are presented in this chapter. The following tests were conducted on M25 grade of concrete made with recycled aggregate as replacement of natural aggregate and silica fume as a partial replacement of cement and then the results were compared with the controlled concrete. Compressive strength

- Split tensile strength
- Flexural strength
- Rapid Chloride Permeability

### 6.2 Compressive Strength

Based on the mix design control concrete and other mixes were cast and tested at 3, 7 and 28 days as shown in the table 6.1. In the controlled mix SF is replaced in cement from 6, 8, 10, 12 and 14% by weight of the cement. The maximum value of compressive strength is obtained at 10% replacement of cement by SF as shown in the table 6.1.

Table.6.1. Compressive strength values for concrete mixes

Type of concrete mix	Compressive strength (MPa)		
	3 Days	7 Days	28 Days
Control mix	13.92	21.92	33.18
SF-6%	15.99	25.32	38.07
SF-8%	16.48	27.48	39.25
<b>SF-10%</b>	19.29	27.84	41.33
SF-12%	15.86	24.76	37.77
SF-14%	14.98	23.56	35.67

Table 6.2 shows the variation of compressive strength for all concrete mixes. It can be observed that the compressive strength is increased for recycled coarse aggregate concrete upto 40% replacement levels with the combination of 10% silica fume. An increment of 14.7% which is more compared to the other replacement levels was observed at 40% RCA and 10% silica fume replacement levels when compared to the controlled concrete. The change in compressive strength is observed as 7.8% between SF 10% and RCA 40 + SF 10% mixes. The probable reason for high compressive strength at 40% RCA and SF 10% may be due to higher density and adequate quantities of SF dosage. Table 6.2 shows the compressive strength values for all concrete mixes.



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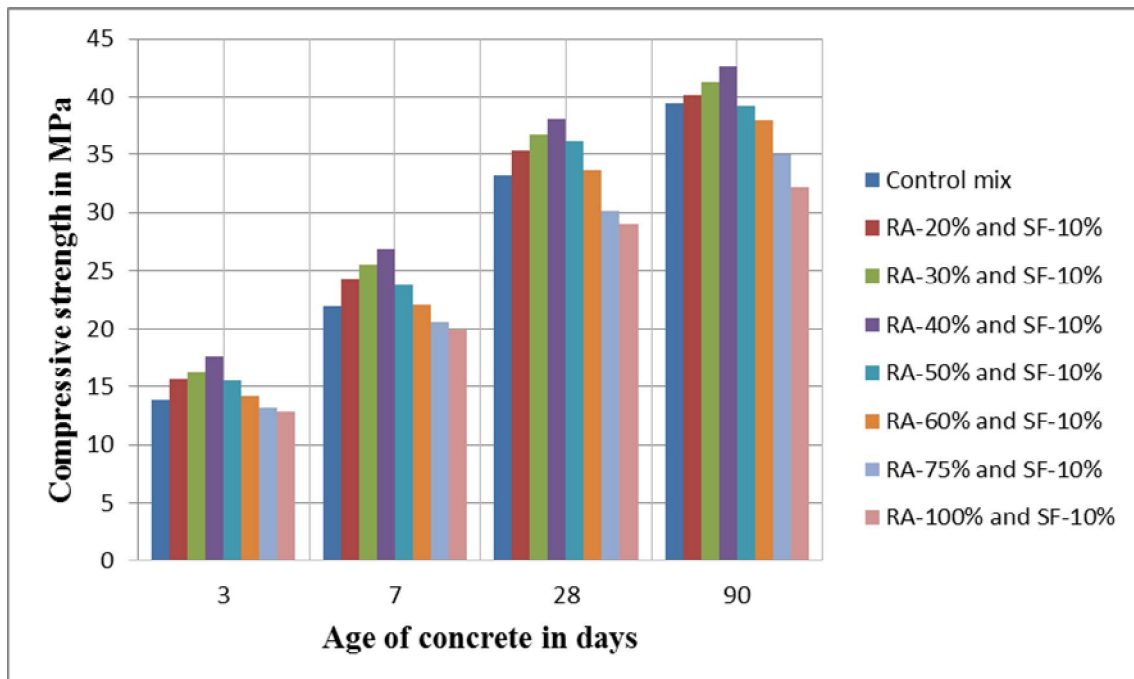
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**Table.6.2. Compressive strength values for all concrete mixes**

Type of concrete mix	Compressive strength (MPa)			
	3 Days	7 Days	28 Days	90 Days
Control mix	13.92	21.92	33.18	39.43
RCA-20% & SF-10%	15.70	24.29	35.26	40.12
RCA-30% & SF-10%	16.26	25.48	36.74	41.27
<b>RCA-40% &amp; SF-10%</b>	<b>17.62</b>	<b>26.82</b>	<b>38.07</b>	<b>42.61</b>
RCA-50% & SF-10%	15.55	23.70	36.16	39.19
RCA-60% & SF-10%	14.22	22.06	33.63	37.98
RCA-75% & SF-10%	13.18	20.59	30.07	34.95
RCA-100% & SF-10%	12.88	19.99	29.03	32.16



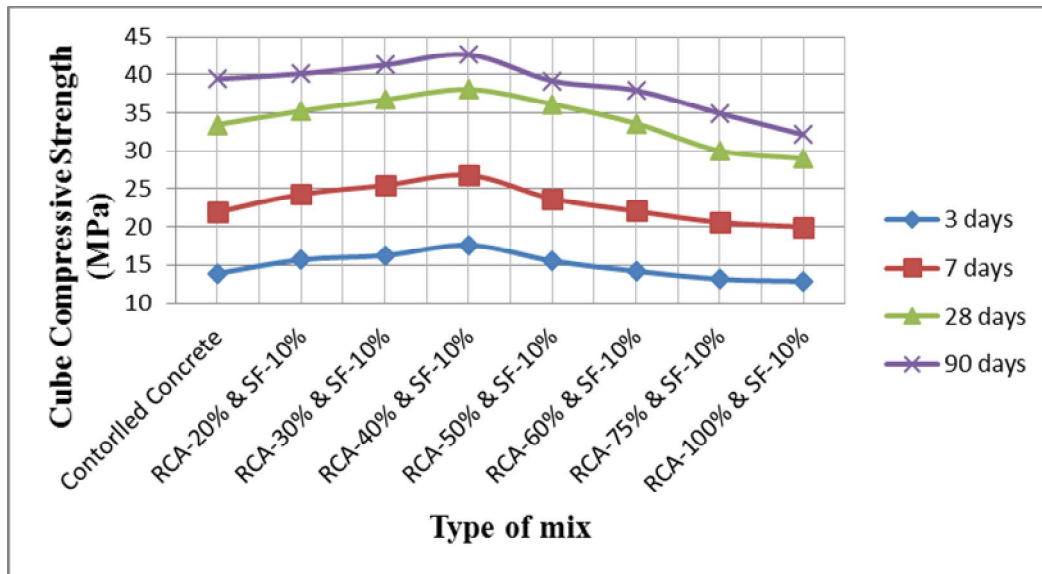
**Fig.6.1. Variation of compressive strength for all concrete mixes.**

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**Fig.6.2. Variation of compressive strength for all concrete mixes.**

Fig 6.1 and Fig 6.2 indicates the significance of variation of compressive strength with respect to age and with respect to type of mixes. Deviation is considered as significant if the difference in compressive strength is more than 10%, otherwise it is considered as insignificant. In the present study significant deviations are observed for RCA 30%+SF 10% and RCA 40%+SF 10%, for other mixes it is insignificant.

### 6.3 Split Tensile Strength

Fig.6.3 shows the variation of split tensile strength for all concrete mixes. From the figure it can be observed that the split tensile strength of recycled coarse aggregate concrete upto 40% replacement levels is increased with the combination of 10% silica fume. An increment of 20.6% which is more compared to the other replacement levels was observed at 40% RCA and 10% silica fume replacement levels compared to the controlled concrete. Table 6.3 shows the split tensile strength values for all concrete mixes.

**Table.6.3. Split tensile strength values for all concrete mixes**

S.No	Concrete type	Split tensile strength (MPa)
1	Controlled concrete	3.44
2	RA-20% and SF-10%	3.58

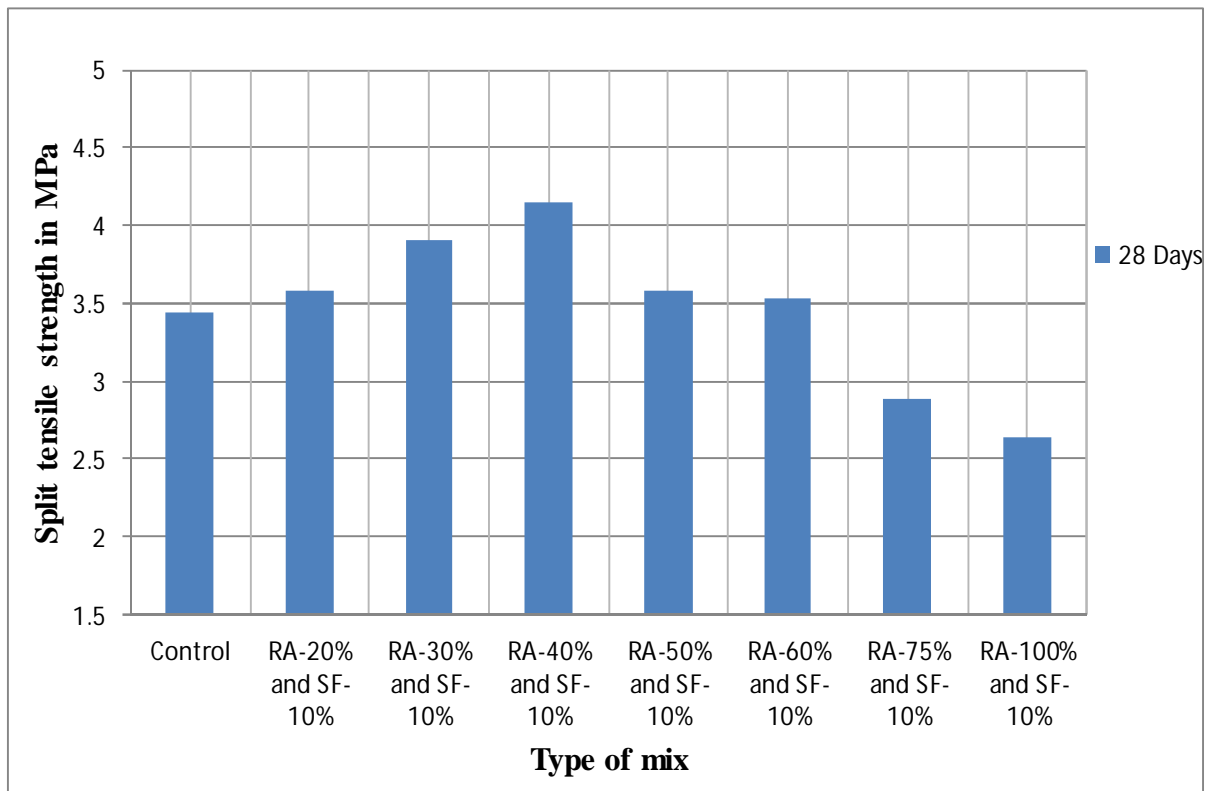
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3	RA-30% and SF-10%	3.91
<b>4</b>	<b>RA-40% and SF-10%</b>	<b>4.15</b>
5	RA-50% and SF-10%	3.58
6	RA-60% and SF-10%	3.53
7	RA-75% and SF-10%	2.88
8	RA-100% and SF-10%	2.64



**Fig.6.3. Variation of split tensile strength for all concrete mixes**

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Fig 6.3 indicates the significance of variation of split tensile strength with respect to type of mixes. Deviation is considered as significant if the difference in % at 28 days age of split tensile strength is more than 10%, otherwise it is considered as insignificant. In the present study significant deviation are observed for RCA 30%+SF 10% and RCA 40%+SF 10%, for other mixes it is insignificant.

### 6.4 Flexural Strength

Fig.6.4 shows the variation of flexural strength for all concrete mixes. From the figure it can be observed that the flexural strength of recycled coarse aggregate concrete upto 40% replacement levels is increased with the combination of 10% silica fume. An increment of 14.2% which is more compared to the other replacement levels was observed at 40% RCA and 10% silica fume replacement levels compared to the controlled concrete. Table 6.3 shows the flexural strength values for all concrete mixes.

**Table.6.4. Flexural strength values for all concrete mixes**

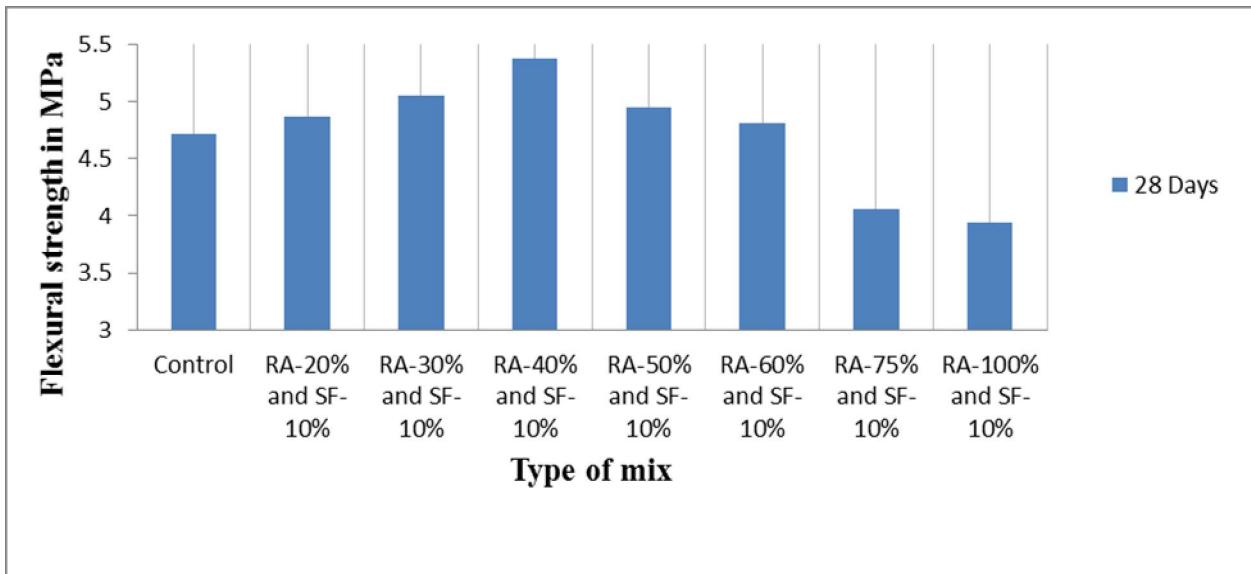
S.No	Concrete type	Flexural strength (MPa)
1	Controlled concrete	4.71
2	RA-20% and SF-10%	4.87
3	RA-30% and SF-10%	5.05
<b>4</b>	<b>RA-40% and SF-10%</b>	<b>5.38</b>
5	RA-50% and SF-10%	4.95
6	RA-60% and SF-10%	4.81
7	RA-75% and SF-10%	4.06
8	RA-100% and SF-10%	3.94

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**Fig.6.4. Variation of flexural strength for all concrete mixes**

Fig 6.4 indicates the significance of variation of flexural strength with respect to type of mixes. Deviation is considered as significant if the difference in % at 28 days age of flexural strength is more than 10%, otherwise it is considered as insignificant. In the present study significant deviation are observed for RCA 40%+SF 10%, for other mixes it is insignificant.

### 6.5 Rapid Chloride Permeability Test

This test determines concrete's chloride permeability by measuring the charge passed through the specimen. AASHTO standard provided the relation between the charge passed in coulombs in 6 hours for concrete specimen and the level of chloride permeability is shown in the Table 6.5.

**Table 6.5 Results of the Chloride Permeability**

S.No	Type of Mix	Charge passed (Coulombs)	Chloride Permeability
1	Controlled concrete	2394	Moderate
2	RA-20% and SF-10%	2319	Moderate
3	RA-30% and SF-10%	2284	Moderate
4	<b>RA-40% and SF-10%</b>	2168	Moderate
5	RA-50% and SF-10%	2246	Moderate
6	RA-60% and SF-10%	2341	Moderate
7	RA-75% and SF-10%	2465	Moderate
8	RA-100% and SF-10%	2516	Moderate

Fig.6.5 shows the results of rapid chloride permeability test. Rapid chloride permeability test was conducted at the age of 28 days on concrete specimens. It can be observed that the tested concrete specimens show moderate permeability in the range of 2000 – 4000 Coulombs at the age of 28 days. Concrete made with 10% silica fume and 40% recycled coarse aggregate has better permeability resistance than controlled concrete.

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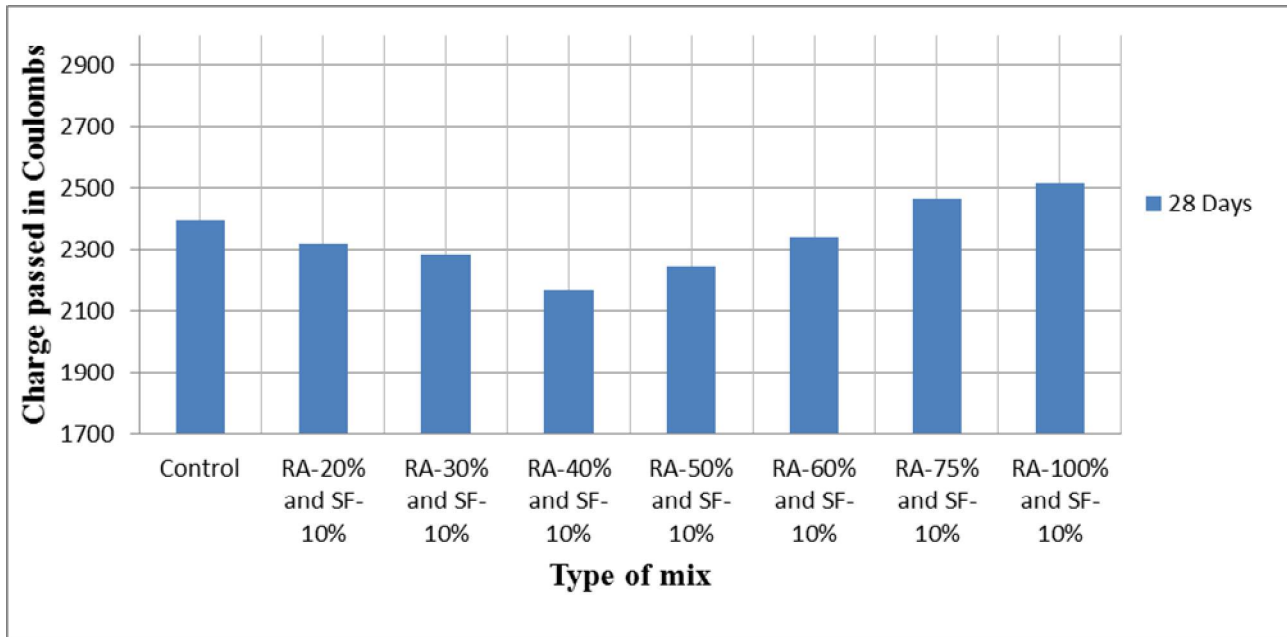


Fig.6.5. Rapid Chloride Permeability Test Results for all Concrete Mixes

## VII. CONCLUSIONS

### 7.1 GENERAL CONCLUSIONS

The following conclusions were drawn from this experimental investigation:

- Trail mixes were carried out to find the optimum percentage replacement of silica fume by 6%, 8%, 10%, 12% and 14%.
- The compressive strength of silica fume concrete is found to be more than normal concrete.
- 10% replacement of silica fume shows higher strength than other replacement levels..
- It is shown that addition of recycled aggregate shows decrease in strength.
- But up to 40% replacement of recycled aggregates with 10% silica fume shows higher strength properties than the controlled mix.
- The percentage increase in compressive strength, split tensile strength and flexural strength of concrete with combination of RCA-40% and SF-10% replacement levels is 14.7%, 20.6% and 14.2% which is more when compared to normal concrete.
- Concrete made with 10% silica fume and 40% recycled coarse aggregate has better permeability resistance than controlled concrete.

### 7.2 SCOPE FOR THE FUTURE WORK

Further studies on the Recycled Coarse Aggregates with Silica Fume can be carried out on the following areas.

- The durability, creep, shrinkage and elastic properties of concrete using recycled coarse aggregate concrete with silica fume

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- Use of RCA and SF as admixture in concrete with various applications in high strength concrete and also in high performance concrete application.

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