“EXPERIMENTAL STUDY OF FLEXURAL STRENGTH AND DURABILITY ANALYSIS OF CONCRETE INCORPORATING ULTRAFINE SLAG”

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Under the supervision of

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By

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To

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Certificate

This is to certify that the work which is being presented in the project title ***"EXPERIMENTAL STUDY OF FLEXURAL STRENGTH AND DURABILITY ANALYSIS OF CONCRETE INCORPORATING ULTRAFINE SLAG"*** in partial fulfillment of the requirements for the award of the degree of Master of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Pratyush Malaviya** during a period from August 2014 to May 2015 under the supervision of **Mr. Saurav and Mr. Abhilash Shukla**, Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat (H.P.).

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DECLARATION

I hereby declare that the research work presented in this Project entitled "***EXPERIMENTAL STUDY OF FLEXURAL STRENGTH AND DURABILITY ANALYSIS OF CONCRETE INCORPORATING ULTRAFINE SLAG***" submitted for the award of the degree of Master of technology in the Department of Civil Engineering, Jaypee University of Information and Technology, Wakhnaghat, is original and my own account of research. This research work is independent and its main content work has not previously been submitted for degree at any university in India or Abroad.

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ABSTRACT

In the last millennium concrete had demanding requirements both in technical performance wise and economy wise and yet greatly varied in application from architectural masterpieces to the simplest of utilities. This study presents the results of an experimental investigation carried out to evaluate the flexural strength of Concrete incorporated with ultrafine slag (alccofine) by studying the effects of different proportions of ultrafine slag in the mix and to find optimum range of ultrafine Slag content in the mix.. High Strength Concrete is made by partial replacement of cement by alccofine by 0, 8, 10, 12, and 14% by weight of cement. The concrete specimens were cured on normal moist curing under elevated atmospheric temperature for better heat of hydration. The flexural strength was determined at 7 ,14 and 28 days and comparisons were made for both plain concrete and R.C.C. Effect of steel fibers upon concrete with ultrafine slag has also been evaluated along with fire resistance of the ultrafine slag up on concrete. The addition of alccofine shows an early strength gaining property. The combination of Ordinary Portland cement-alccofine was found to increase the compressive strength of concrete on all ages when compared to concrete made with ordinary Portland cement alone and has showed excellent durability characteristic with hydrochloric acid. Alccofine matches the dimensional realms of silica fume as it is more fine than GGBS. Silica fume is hard to get hold of as it is imported from outside of India. Based upon the results of this research alccofine - 1203 can be proposed as the substitute for silica fume in partial replacement of concrete.

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CHAPTER 1: INTRODUCTION

It is important to note the high-strength and highperformance concrete are not synonymous. Concrete is defined as high-strength concrete solely on the basis of its compressive strength measured at a given age. In the 1970’s, any concrete mixtures that showed 40 Mpa. or more compressive strength at 28-days were designed as high-strength concrete. Later, 60-100 MPa concrete mixtures were commercially developed and used in the construction of high-rise buildings and long-span bridges in many parts of the world. The definition of high-performance concrete is more controversial. The term, highperformance concrete (HPC) was used for the first time for concrete mixtures possessing high workability, high durability and high ultimate strength. ACI defined high-performance concrete as a concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practice.

Normal strength -- 20Mpa to 50Mpa
High strength -- 50Mpa to 100 Mpa
Ultra High strength 100 Mpa to 150Mpa
Especial – greater than150 Mpa

From the general principles behind the design of high-strength concrete mixtures, it is apparent that high strengths are made possible by reducing porosity, In homogeneity, and microcracks in the hydrated cement paste and the transition zone . The utilization of fine pozzolanic materials in high strength concrete leads to a reduction of the size of the crystalline compounds, particularly, calcium hydroxide.Consequently, there is a reduction of the thickness of the interfacial transition zone in high-strength concrete. The densification of the interfacial transition zone allows for efficient load transfer between the cement mortar and the coarse aggregate, contributing to the strength of the concrete. For very high-strength concrete where the matrix is extremely dense, a weak aggregate may become the weak link in concrete strength. Almost any ASTM portland cement type can be used to obtain concrete with adequate rheology and with compressive strength up to 60 MPa. In order to obtain higher strength mixtures while maintaining good workability, it is necessary to study carefully the cement composition and finenesses and its compatibility with the chemical admixtures. Experience has shown that low-C_3A cements generally produce concrete with improved rheology. In high-strength concrete, the aggregate plays an important role on the strength of concrete. The low-water to cement ratio used in high strength concrete causes densification in both the matrix and interfacial transition zone, and theaggregate may become the weak link in the development of the mechanical strength. Extreme care is necessary, therefore, in the selection of aggregate to be used in very high strength concrete. The particle size distribution of fine aggregate that meets the ASTM specifications is adequate for high-strength concrete mixtures. If possible, using of fine aggregates with higher fineness modulus is advisable because high-strength concrete mixtures already have large amounts of small particles of cement and pozzolan, therefore fine particles of aggregate will not improve the workability of the mix.The use of coarser fine aggregates requires less water to obtain the same workability; and during the mixing process, the coarser fine aggregates will generate higher shearing stresses that can help prevent flocculation of the cement paste.The higher the targeted compressive strength, the smaller the maximum size of coarse aggregate. Up to 70 MPa compressive strength can be produced with a good coarse aggregate of a maximum size ranging from 20 to 28 mm. To produce 100 MPa compressive strength aggregate with a maximum size of 10 to 20 mm should be used. To date, concretes with compressive strengths of over 125 MPa have been produced, with 10 to 14 mm maximum size coarse aggregate.Using supplementary cementitious materials, such as blastfurnace slag, fly ash and natural pozzolans, not only reduces the production cost of concrete, but also addresses the slump loss problem. The optimum substitution level is often determined by the loss in 12hr or 24-hr strength that is considered acceptable, given climatic conditions or the minimum strength required. While silica fume is usually not really necessary for compressive strengths under 70 MPa, most concrete mixtures contain it when higher strengths are specified.

1.1 BACKGROUND OF ULTRAFINE SLAG

Ultra fine slag in concrete has a 60 year history,development of the use in concrete has been a long story.A main hurdle were the needs for official recognition and acceptance of the technology - in the form of standards and related specifications. This section gives a brief summary of history, and of the standards developments leading up to the present day when international standards are in place. Ultrafine slag entails Silica Fume, Microsilica, condensed silica fume , GGBS etc. It was first mentioned in a US patent from 1944. The patent mainly touched upon its use in mortar, and little is known of commercial use of the process. Silica fume is an inherent co-product of silicon and ferrosilicon. Silicon is not found in nature, and is normally produced from silica (SiO_2) and carbon (C). Ideally, the following reaction is intended:

$$SiO_2 + 2C = Si + 2CO;$$

where; SiO_2 is normally quartz, C is a mix of coal, coke and wood chips and for ferrosilicon an iron source is added, e.g iron oxide.The production take place in large electric smelting furnaces at temperatures greater than 2000 ^{0}C .However, the chemistry is much more complex, and a number of side-reactions are involved. Silicon carbide (SiC) and the (unstable) gas SiO are important intermediate products. In practise, some of the SiO-gas escapes from the furnace and reacts with air given by the reaction.

$$SiO + \frac{1}{2}O_2 = SiO_2$$

The first published works on silica fume in concrete was by James William Sharp (1944) Under whom the patent on silica modified cement was assigned to Permanente Cement Company. He focused on plastic cements, 3%--5% silica fume it was noted that bleeding was substantially reduced and a 40% increase in 90-days strength for concrete was observed. Carl Johan Bernhardt (1952) worked with cement replacement – up to 30% and reported a significant increase in compressive strength in reasonable mixes he documented improvements in sulphate- and freeze-thaw resistance in mixes with 10-15% cement replacement. First known published technical paper on silica fume-concrete was in april 1952, Immediately before 1950, the first trial production was underway in Norway, using very improvised techniques to collect the silica fume. Then investigations were initiated at the Norwegian Technical University in Trondheim and in the tunnels of the Oslo subway. The tests involved lab tests and marine field exposure in Trondheim and exposure in extremely aggressive environment in the subway tunnel dug through alun shale, adjacent to the Norwegian Parliament in Oslo. In the late 1960s the world showed renewed interest in silica fume-concrete. Although Prof. Bernhardt`s result were well known amongst concrete academics in Scandinavia ; silica fume was not available in significantquantities, and little follow-up work was done in the next decade. However, in the mid 1960s the first industrial filters were installed in Scandinavia and North America. The increased availability of industrial quantities of silica fume initiated a new wave of research of silica fume in concrete. Prof. A. Markestad at the Norwegian Institute of Technology started a research programme, which included a number of student projects. They compared silica fume-concrete with OPC reference resulting in several properties. His results were published in a Nordic seminar in1968, where he concluded that well cured samples (14-28 days at 20^0C) exhibit partly remarkable improvements. This applies largely to all properties investigated such as bending – and compressive strength, permeability, water absorption, sulphate resistance and frost resistance. In the 1970 early commercial sales and increasing R&D encouraged test with silica fume in concrete which were basically conducted in Norway in a joint project between a cement producer and the ferro-alloys industries. The purpose was to study if there was a basis for joint commercialization. However a possible conflict area also became apparent that silica fume could be used for cement replacement in RMC. Sales to the concrete industry started in Norway in the early 1970s. Main use was as cement replacement in concrete products. Existing standards had limited use in structural concrete. The first known documented use in structural concrete was a silo roof slab cast in 1971 at the Fiskaa plant in an environment with corrosive gases. Half with OPC (320 kg/m^3), half with silica fume, 10% cement replacement. Evaluation after 7 years by the Norwegian Building Research Institute was done in comparing the OPC concrete with the silica fume-reference showed 10-15 mm reduction in cover thickness, double carbonation depth.

GGBS is not a new product. It has already proven itself reliably in its use all over the world since the mid 1800s.Thirty-eight years after the patent for Portland cement was first lodged by John Aspdin in 1824, Emil Langin discovered GGBS cement. By 1865, commercial production of lime activated GGBS had commenced in Germany and by 1880 GGBS was being used with Portland cement as the activator. In1889 it was used for construction of the Paris Metro. The United States commenced production of slag cements in 1896.Since then Europe, with its many blast furnaces and steel industries has used GGBS extensively in all manner of structures. By 1914, GGBS was being manufactured in Scotland. BS 146 was published in1923 followed by BS 6699 in 1986 for GGBS In Britain, over 2 million tonnes of GGBS is used every year. GGBS is also widely used by the cement and concrete industries in continental Europe, with some 17.7 million tonnes now being used annually. GGBS is specified for its many technical advantages and as a means of reducing the environmental impact of the production of Portland cement. GGBS reacts like Portland cement when in contact with water. But as the rate of reaction is slower, an activator is necessary. The calcium hydroxide released when Portland cement reacts with water serves to activate GGBS, hence GGBS is normally combined with Portland cement. When GGBS is used in concrete, the resulting hardened cement paste has more, smaller gel pores and fewer larger capillary pores than is the case with concrete made with normal Portland cement. This finer pore structure gives GGBS concrete a much lower permeability, and makes an important contribution to the greater durability of this concrete. The resulting hardened cement paste using GGBS is also more chemically stable. It contains much less free lime, which in concrete made with Portland cement leads to the formation of further reaction products such as ettringite or efflorescence. In addition, GGBS contains C3A, making GGBS concrete much less reactive to sulphates.

1.2 NEED FOR THIS RESEARCH

Concrete is a commonly used construction material formed by mixing cement (binder), aggregate, water and admixtures in different ratios depending on the function and strengths required. The oldest known surviving concrete is found in the former Yugoslavia and is thought to have been laid in 5600 BC using red lime as the cement. The first major concrete users were the Egyptians around 2500 BC; Egyptians used mud mixed with straw to bind dried bricks. Later the Romans since 300 BC made many developments in concrete technology including the use slaked lime a volcanic ash called pozzuolana; animal fat, milk, and blood were used as admixtures; and even built the Pantheon in 200 AD with lightweight aggregates in the roof. Even today this 43.3 m diameter dome is still the world’s largest non-reinforced concrete dome. After 400 AD the art of Concrete was lost with the fall of the Roman Empire. It was only in 1824 that modern concrete was developed by Joseph Aspdin. He patented what he called Portland cement which till date remains as the key ingredient in concrete. The work presented here aims at increasing the knowledge on the effect of ultrafine particles in concrete. In the context of this work, ultrafine particles are particles with a grain size finer than cement. These particles may be inert and improve the packing density of the fines in concrete, or they may be pozzolanic and react with hydration products of the cement.The hypothesis of this work is that substantial amounts of cement can be replaced by suitable very fine grained materials without affecting mechanical properties or durability negatively. Cement itself is considered as a fraction of the complete particle mix that builds up the concrete. By application of suitable particle packing models to the entire concrete mix, the particle size distribution (PSD) of the entire mix can be adjusted in order to achieve mobility in the fresh state and adequate properties when hardened. Due to the fact that the ingredients of a concrete mix are particles with continuous size distributions, a model should be based on packing of continuous size distributions. A modification of concrete mixes with ultrafine particles affects the fresh and hardened properties of the concrete. The workability, hardening, mechanical properties and durability may be influenced in different ways. Reactive particles like silica fume may have different effects compared to inert particles. Synergy effects from combination of reactive and inert particles can be expected. Therefore, this investigation is done in several steps. First, a literature review on particle packing, cement hydration, load independent deformation and mechanical strength of concrete is done. These issues are considered to be of primary interest for the subject of the work. Particle packing is directly related to the introduction of other fine particles than cement into concrete. It may be used to provide knowledge on how to utilise ultrafine particles in the best way. The hydration of cement is known to be influenced by the presence of other particles. Load-independent deformations of concrete are known to be influenced by the content of fines, the cement content and reactive additives. The mechanical strength of concrete is strongly related to the porosity which in turn is influenced by hydration, particle packing and additives. The experimental section of this work concentrates on concrete experiments. In addition, the influence of the ultrafines on the hydration is examined on paste samples with the help of isothermal calorimetry. In the concrete experiments, different measures are taken in order to isolate the influence of inert and reactive ultrafine particles. First, different inert ultrafine particles are used to replace cement at constant water content and variable water content. Then, mix compositions are optimised towards low cement content with the help of inert ultrafines. The effect of high contents of reactive ultrafine particles on concrete properties is tested, also in combination with inert ultrafines. Then, concrete compositions are optimised towards low binder content. The effect of different ultrafine particles on concrete properties is quantified by tests on compressive strength and calculation of shrinkage, and characterization of the microstructure by microscopy, mercury intrusion Porosimetry (MIP) and capillary suction as well as test of frost resistance. The results of this work shall contribute to an increased understanding of the effects of different very fine particles on concrete properties. Recommendations are given on how to include ultrafine particles in mix design. This work does not concentrate on concrete mixes that comply with recent concrete standards in which concrete properties are mainly related to the water-cement ratio. The results of this work are expected to be more useful for performance based design of concrete or in special applications. Further, it is not primarily the fresh concrete properties that are investigated. Workability of fresh concrete is of course an important issue but within the limitations of this work, super plasticizers were used to achieve workable mixes when necessary. The fine aggregate (0-8 mm) used in this work is of natural origin with well rounded particle shape. Crushed fine aggregate is not tested but it is likely that some adjustments are necessary when using this type of fine aggregate. There are other properties of hardened concrete, e.g. creep, E-modulus, chloride diffusion and carbonation which can be influenced by ultrafine particles but it is not possible to test all of them within this work. Neither is cost efficiency of the resulting mixes considered, at present time the cost of the used ultrafines may exceed the cost of the replaced cement. Additionally, many concrete plants may have problems handling ultrafines. However, the findings of this work can contribute to increased use of ultrafines in concrete and intensified research on suitable byproducts. In that way, cost efficiency can be achieved in the future.

1.2.1 Particle packing

Particle packing is fundamental to concrete. The better the packing of the particle system, the less binder is required in the concrete. The problem with concrete is, however, that concrete must flow and be compactable in the fresh state which stands in conflict with optimal packing. Introduction of large amounts of fine particles, in size of cement and below, into a concrete mix can solve this problem. Then, the particle size distribution of the whole mix composition, including cement, pozzolanas and/or fillers, should be taken into account when calculating the packing density.

1.2.2 Particle packing theory

Particle packing is an important issue not only for concrete materials. Ceramics, geotechology , food processing industry and others do benefit from densely packed systems. The first investigations concerning particle packing were done more than 200 years ago. One of the most important properties of a particle system is its packing density; the volume percentage of solids for each volume unit. Looking into a certain system, the particle packing of this system is a function of particle size distribution, particle shape, and particle surface, ratio between system size and maximum grain size and presence of liquids, if any. In order to understand the existing theories and models for systems with multiple grain sizes, one ought to look into systems with only one grain size first. Systems consisting of only one grain size are called mono-dispersions; they are useful for modelling but rarely seen in reality. If perfect spherical particles of only one size are assumed, the packing density of the system depends on which structure is formed by the spheres. The cubic packing structure results in a packing density of 0.52 while pyramidal or tetrahedral structures can give 0.74. Orthorhombic and double stagger packing result in packing densities of 0.60 and 0.70, respectively. The concept is based on the belief that the performance of a concrete mix can be optimized by maximizing the packing densities of the aggregate particles and the cementitious materials .In this section, the concept of packing density, i.e. the ratio of the volume of solids to the bulk volume of the solid particles, is introduced. This concept is playing a more and more important role in modern concrete mix design because of the increasing awareness that maximization of packing density by adjusting the grading of the whole range of solid particles, including the coarse aggregate, the fine aggregate and the cementitious materials, can improve the overall performance of the concrete mix. A preliminary mix design method called "three-tier system design" based on the concept of packing density is also proposed. Let us consider a concrete mix composed of a single-sized aggregate and cement paste only. In order to fill up all the gaps between the aggregate particles so as to drive away the air voids in the concrete mix, the volume of cement paste must be larger than the volume of gaps within the aggregate skeleton. If, instead of a single-sized aggregate, a multi-sized aggregate is used, the smaller size aggregate particles would fill up the gaps between the larger size aggregate particles, leading to a smaller volume of gaps within the aggregate skeleton. This has two implications. Firstly, with a multi-sized aggregate used, the volume of cement paste needed to fill up the gaps within the aggregate skeleton would be reduced. Secondly, if the volume of cement paste is kept the same, the use of a multi-sized aggregate would increase the volume of the excess paste (the portion of paste in excess of that needed to fill up the gaps within the aggregate skeleton), which disperses the aggregate particles, provides a coating of paste for each aggregate particle and renders workability to the concrete mix. Hence, the size distribution, or grading, of the aggregate has an important bearing on the paste demand and the workability of a concrete mix. That the grading of the aggregate can have a great influence on the performance of the concrete mix is actually well known long time ago. It is only that many parameters (the various size fractions of the aggregate) are needed to describe the grading and the effects of the various parameters are often blurred by the interaction between the various parameters involved. Nevertheless, it is nowadays very clear that the single most important parameter influencing the performance of concrete is the packing density of the aggregate. The packing density of a given aggregate or a given lump of solid particles is the ratio of the volume of solids to the bulk volume of the solid particles. Since the bulk volume is equal to the volume of solids plus the volume of voids, a higher packing density means a smaller volume of voids to be filled and vice versa. The single-sized aggregate can be packed together to occupy only limited space, i.e. can achieve only a relatively low packing density. The multi-sized aggregate can be packed together much more effectively to achieve a much higher packing density. With the paste volume fixed, the increase in packing density of the aggregate could be employed to increase the workability of the concrete at the same water/cementitious ratio or increase the strength of the concrete by reducing the water/cementitious ratio while maintaining the same workability. Apart from increasing the excess paste at a given paste volume to improve the workability and/or strength of the concrete, the increase in packing density of the aggregate could also be employed to improve the dimensional stability of the concrete. In a concrete mix, it is the cement paste that generates heat of hydration causing thermal expansion/contraction during the early age and shrinks when subjected to drying in the longer term. Hence, the larger the paste volume is, the larger would be the changes in dimension of the hardened concrete due to early thermal expansion/contraction and long term drying shrinkage. The heat of hydration and drying shrinkage of the concrete are dependent also on the water/cementitious ratio, both being larger at higher water/cementitious ratio. The reduction in paste demand due to a higher packing density of the aggregate would for the same workability allow the use of a smaller paste volume at a fixed water/cementitious ratio or a lower water/cementitious ratio at the same paste volume, either of which would significantly improve the dimensional stability of the concrete. The concept of packing density can be extended to apply also to the cementitious materials, which may include cement and other supplementary cementitious materials, such as pulverized fuel ash (PFA), ground granulated blast-furnace slag (GGBS) and condensed silica fume (CSF) etc. Drawing analogy to the previous case of packing aggregate particles, the packing density of the cementitious materials should have similar effect on the water demand and the flowability of the cement paste. The different types of cementitious materials are generally of different sizes. By mixing appropriate proportions of different cementitious materials together, the medium size particles would fill up the gaps between the larger size particles and the smaller size particles would fill up the gaps between the medium size particles and so forth. Hence, blending cementitious materials of different sizes together could increase the packing density of the cementitious materials and reduce the water demand.

Recent research findings have provided positive support to the above theory. Further in the presence of a super plasticizer, the addition of GGBS, which has a higher fineness than cement, has shown improvement in the fluidity of cement paste through its filling effect. Reaserch shows that during the development of high strength self-consolidating concrete that at a ratio lower than 0.28, the addition of CSF, which has a mean particle size of about 0.1 μm, could substantially increase the workability of the concrete mix, despite large increase in surface area of the cementitious materials. Such increase in workability may be explained by the ultra-high fineness of the CSF, which allowed the CSF particles to fill up the gaps between the cement grains thereby freeing more mixing water to lubricate the concrete mix. Study has showed that blending cement with an ultra-fine PFA, which has a mean particle size of about 3 μm, would reduce the water demand of the cementitious system, due most probably to the increase in packing density after adding the ultra-fine PFA. More recently, many authors have directly measured the packing density of blended cementitious materials and confirmed that the addition of CSF could significantly increase the packing density of the cementitious system. They have also demonstrated that at a water/cementitious ratio of 0.2, the increase in flow ability of the cement paste after addition of CSF could be quite dramatic. The packing density of the cementitious materials has great impact on the strength of the concrete produced. First of all, the reduction in water demand due to a higher packing density would allow the use of a lower water/cementitious ratio for achieving higher strength. Secondly, better packing would reduce the permeability of the bulk of cementitious materials and thus bleeding of the fresh cement paste. Thirdly, better packing would reduce the porosity of the transition zone by filling up the voids formed as a result of the wall effect of the aggregate with very fine particles. Both the reduced bleeding of the cement paste and the reduced porosity of the transition zone would substantially improve the quality of the transition zone, which, as the weakest link in concrete, has dominant effect on the strength of concrete. This phenomenon is often manifested by having transgranular failure (failure with fracture planes cutting through the aggregate particles) instead of transition zone failure (deboning failure at the transition zone) in high strength concrete made with densely packed cementitious materials containing CSF . More recent research has demonstrated that due to improved packing, blending cement with a rice husk ash can lead to an increase in strength of the concrete and that because of the more significant improvement in packing density, the increase in strength is larger when the cement is gap-graded. Apart from strength, an increase in packing density of the cementitious materials would also improve the overall performance of the concrete. For instance, at the same water/cementitious ratio, the flow ability of the cement paste and the workability of the concrete mix would be improved. Furthermore, with increased packing density, the cement paste would be more cohesive and the concrete mix would be less likely to segregate during placing. With the water demand reduced, the water content of the concrete mix might also be adjusted downwards to limit the drying shrinkage and improve the dimensional stability of the concrete. Lastly, with better packing, the permeability of the bulk of cementitious materials, both in fresh state and in hardened state, would be dramatically reduced leading to a much higher durability of the concrete . Summing up the above discussions, many authors are of the view that the packing density of the solid particles in the concrete mix is the key concept in the design of HPC mixes. Both the packing of the aggregate and the packing of the cementitious materials need to be considered. In fact, it is the grading or packing of the whole range of particles from the coarse aggregate to fine aggregate, to cement grains, and to fine and ultra-fine cementitious materials that determines the overall performance of a concrete mix.

1.2.3 Packing of Cementitious Materials

The packing of the cementitious materials has greater effects than the packing of the aggregate on the performance of the concrete produced and therefore should be considered even more carefully in the mix design. In fact, HPC has nowadays developed to such stage that any further improvement in performance is very difficult to achieve Nevertheless, the packing density maximization of the cementitious materials should provide room for the continuous advancement of HPC. For e.g. blending different types of cementitious materials together to maximize the packing density of the cementitious materials, produced self-consolidating concrete of grade up to 100. However, recent progress in the prediction and maximization of the packing density of cementitious materials has slowed down dramatically. There are two main hurdles. Firstly, the packing behaviour of the cementitious materials and that of the aggregate are actually quite different and the usual practice of applying the theoretical models and experimental methods originally developed for aggregate particles to cementitious materials often yield erroneous results. Secondly, it is up to now not yet possible to measure directly the packing density of cementitious materials. It is a common belief that the packing density of cementitious materials can be determined using the method of measuring the dry bulk density of the particles, which has been successfully applied to aggregate for many years. It has been found, however, that when this method is applied to cementitious materials, the packing density results obtained are often unrealistically low and too sensitive to the type and level of compaction applied. The most probably cause was the presence of electrostatic and van der Waals forces at the particle surfaces, which caused flocculation and thus loose packing of the fine particles . Hence, such dry packing method of packing dry particles together for direct measurement of packing density is not really applicable to cementitious materials. Actually, in a concrete mix, the cementitious materials are always mixed with water to form a cement paste and therefore should be wet. Hence, the packing density of cementitious materials should be measured under wet instead of dry condition. In fact, because of the wetness, which lubricates the fine particles, and the capillary forces, which holds the fine particles together, the effectiveness of the compaction applied is higher under wet condition. The packing densities of pure cement under both dry and wet conditions have been measured and found that the packing density of cement under wet condition is substantially higher than that under dry condition. It is therefore suggested that a wet packing method (measurement of packing density under wet condition) should be used instead of the conventional dry packing method. Apart from water, super plasticizer should also be added when measuring the packing density of cementitious materials. Super plasticizer is an essential component of HPC. It disperses the flocculated particles, improves the packing density and thereby reduces the water demand of the cementitious materials. With super plasticizer added, the packing density measured by the wet packing method would be higher. After many unsuccessful trials with the dry packing method, the authors have recently turned to the possibility of measuring the packing density of cementitious materials by wet packing. Based on wet packing, the authors have developed a new method for the measurement of the packing density of cementitious materials. The main features of this new method are:

(1) The cementitious materials are first added and mixed with water to form a paste before packing density measurement;

(2) a saturated dosage of super plasticizer is added to the paste in order to disperse the cementitious materials as uniformly as possible; and

(3) the packing density is measured repeatedly at different water/cementitious ratios and the maximum packing density obtained is taken as the packing density of the cementitious materials.

This newly developed wet packing method has been successfully applied to measure the packing densities of different mix proportions of cement, PFA and CSF. Within the limit of the available literature in this field of research, this is the first time that the packing density of cementitious materials is directly measured. In order to incorporate the concept of packing density into the concrete mix design method, it is necessary to establish the relationships between the packing densities of cementitious and aggregate particles and the properties of cement paste and concrete mix. At The University of Hong Kong, researches are being carried out to establish the relationships between the packing density of cementitious materials and the rheology of cement paste. The preliminary results obtained so far show that maximizing the packing density of the cementitious materials can increase very substantially the flow ability of the cement paste formed, especially at low water/cementitious ratio. It should be noted that in this figure the mix proportions and water/cementitious ratios are all by volume. Also, the flow value is expressed as the increase in spread of the cement paste after the mini slump cone with upper and lower diameters of 60mm and 100mm and a height of 70mm was lifted. Tests are also being planned to correlate the properties of concrete to the packing density of the cementitious materials and the packing density of the aggregate so that hopefully a new generation mix design method for HPC based on the packing theory could be developed.

1.3 CONSTRUCTIONAL NEEDS

Cement based materials are the most abundant of all manmade materials and are among the most important construction materials and it is most likely that they will continue to have the same importance in future . However these construction and engineering materials must meet new and higher demands. When facing issues of productivity, economy, quality and environment they have to compete with other construction materials such as plastic , steel and wood. However, the development of a sustainable concrete is urgently needed for environmental reasons. It is clear that cement, the key binder ingredient in concrete has a high environmental impact. Presently about 10% of the total anthropogenic CO_2 is due to the cement production solely. Today innovation is leadingly being inspired by nature as a sustainable alternative. The main concern is that concrete is unsustainable due to the painful carbon footprint associated to it. It has been clear that cement, the key binder ingredient in concrete has a high environmental impact. The thumb rule for cement production goes as for every tonne of cement made, a tonne of CO_2 is produced . After the Kyoto Protocol, several commitments have been made to reduce this through a series of frameworks-

(i) Production efficiency,
(ii) Energy efficiency, especially in calcination phase as it accounts for the majority of the Energy consumption ; and
(iii) Innovation in CO_2 capture and storage (CCS) technologies.

1.4 Minimization of the Environmental Impacts

Presently to reach optimal levels of sustainability, several investigations are being made to reduce the environmental impact of concrete. Such as :

(i) Obtaining optimal strengths
(ii) Replacing Portland clinker with alternative cements; and
(iii) Increasing concrete durability.

Another reason for concrete having such an impactful carbon footprint is due to the huge quantities being used . Hence by obtaining optimal strengths the amount of concrete consumed to do the same job can be reduced. To achieve high strengths of concrete the water-cement ratio can be reduced to 0.16, as complete hydration is not needed if admixtures are added and as such attaining higher strengths than completely hydrated concrete. And in terms of threshold of workability due to lowered water amounts can be achieved using additives called plasticisers. However, the workability of the concrete is the only thing preventing from going below this ratio. Replacing Portland clinker, either partially or entirely, with alternative cements is also being investigated as an approach to tackling concrete's CO_2 emissions. Waste materials, such as slag (from blast furnaces) and fly ash (from coal-fired power stations), are already being used as supplementary cementitious materials (SCMs) and have been for some decades. However, with 50 % clinker replacement with fly ash, the early strength drops dramatically . Or even if the clinker were to be replaced entirely by slag, an alkali can be added to activate it. However, Alkali-Silica reactions is a more and more of a problem because as time goes by, it is being discovered that more and more aggregates are reactive. Concrete as a material is liable to crack formation and degradation. It has been observed that if 20 % of cement content is reduced the durability improves because it is the cement paste that is most porous. So it is the cement that provides a route by which elements of exposure can go in and out, hence the less cement used the better the concrete . Pores in the material allow corrosive materials such as chlorides and sulphates to penetrate the structure and attack the metal reinforcement – the cause of over 90 percent of problems of reinforced concrete durability . However, ultimate strength of concrete is more important than short term CO_2 savings.

1.5 **INTERNATIONAL STATUS**

Although much of the early (documented) development work was done in Norway, from the mid 1970-ies projects and R&D started in many countries such as :

1. Sweden (1975) : Lars Johansson documented basic properties of silica fume-concrete.

2. Gothenburg (1976 – 1978): Two wharves were constructed with different concrete compositions, with and without silica fume and were exposed to chlorides. The follow up report after 23 years exposure concluded with a dramatic effect of silica fume on the resistance to chloride penetration .

3. Denmark : Hans Henrik Bache of Aalborg Portland invented his DSP material i.e. Densified Systems containing homogeneously arrange, ultrafine Particles. Utilization of particle packing concept with silica fume as the finest particles was done. This demonstrated mortar strengthing the order of 250-300 Mpa. A comprehensive documentation of microstructure of silica fume cement pastes was performed after this .

4. Iceland (1970) : Severe ASR problems due to high-alkali cement combined with reactive aggregates were being encountered which gave birth to a comprehensive study with different pozzolanas . 5% silica fume replacement in all cements was started from 1979 . A follow-up study by Gudmundsson and Olafsson was done in 1999 and they concluded that after 20 years of service there were no signs of ASR in Iceland.

5. USA and Canada: Both countries have significant ferroalloys industry, and developed filtration technology and installed filters in parallel with Scandinavia. Several universities and institutes started studying silica fume in concrete in the late 1970s (e.g. Sherbrooke, Purdue, and Berkeley). Before 1980 there were very less publications.The silica fume results from the production of ferro-silicon and Silicon. Greater than 99% of the silica fume volume would not be produced unless the metal market was viable. In 70’s and early 80’s the industry developed metal production. It started mainly in Norway, France, USA and Canada with furnaces and also in many other countries such as, South Africa, Russia etc.

6. China : A quite large ferroalloys industry had been established in China but Most furnaces were small and not equipped with filters. In 1976, a semi-closed furnace with baghouse filter was installed in the Hunan province for the first time. It is not known if the silica fume from this furnace was used for concrete but basically it was the first in the last decade that significant silica fume had been used in concete in China.

7. Japan: Japan had a noticeable production of ferrosilicon and silicon in the period of 1970 to 1980. Silica fume was filtered and offered commercially by companies such as JMC, Osaka Special Alloy, Toyo Denka and Yakushima Denko. The quantity was

limited, probably lesser than 20,000 tpy. The research on silica fume was going on in this period all over the world. Shimazaki filed in 1971 a patent for a waterproofing of concrete based on fume from ferrosilicon production. It is still in application in Japan today.

The commercial use facilitated after the development of bag filter systems that allowed industrial scale collection and near 100% removal of particles from the furnace exhaust gases. This happened in the 70's and already around 1980 the Norwegian silica fume consumption was 50-60 000 tons. Global use increased, with focus on (Scandinavia), USA, Canada and France. Intense and widespread research was performed, by today there are several thousand of literature references.

From 1980 and onwards there was virtually an exponential growth of research, published reports and papers related to silica fume in concrete. By 1985 we had registered about 500 reports and papers in journals. The number of publications today are probably approaching 10,000 .Number of publications reached greater than 5000 papers with more than 3000 in review. Silica fume has come in common use in a majority of industrial countries and many developing countries. Silica fume has since long been an international tradeable product. It has been estimated that over 10 million m^3 silica fume-containing concrete is casted every year. Whereas the early years had a focus on silica fume as cement replacement, the overwhelming use today is to improve durability and strength. Heavy investment in new ferroalloys capacity in China should warrant for a good supply situation in the coming years. Solar quality silicon production can also have effect on supply.

Much of the technical knowledge of silica fume in concrete has been summarized in reports, ACI and fib are key documents. The ACI report is fairly well updated and a new version was released in the summer of 2006. The fib-report is 20 years of age, and an update is in the works. Today, an estimate gives more than 15 million m^3/year silica fume concrete produced globally, and the accumulated volume must by now have exceeded 200 million or more m^3.

Currently metal production is moving to China and other localities of inexpensive energy and cheap labor. And due to following points :

- Status metal industry:
- Alloy consumption increasing
- Shift in production locale
- In particular for bulk ferro-silicon
- Silicon alloys
- Increasing amounts for specialist applications, Electronics, Chemistry and solar power

8. Norway : In Norway commercialized up to 8% (later 10 replacement by weight of cement in structural concrete already from late 70's. In several countries the "typical" chemical composition of a "well-known" silica fume was used as material specification. The turn-around came with the introduction of the Canadian Standard in 1987. This year also ACI published its first attempt at a report on silica fume. A number of countries including Japan, Australia, France, Brazil etc. have developed standards that a very important for the local use of silica fume. Standard Norge which is the Norwegian body for standards called a committee to commence work a Norwegian Standard in 1989. The purpose was to have a National document to propose as the draft of a future European (CEN) standard. NS 3045 was published in 1992, and submitted to CEN (Comité Européen de Normalisation/European Committee for Standardization) for development into a European Standard.

9. Canada : Canada deserves a special mention upon this . CANMET interest in supplementary cementing materials meant that Canada pioneered the development of standards. CAN/CSA A23.5-M86 Supplementary Cementitious Materials, was the first comprehensive national standard that also covered silica fume. The standard gives clear evidence of its parentage – the fly ash standard was inspiration to the structure and content of the silica fume standard. This made the standard a mixed blessing, particularly to suppliers. On one hand the standard opened for a broader use of silica fume and on the other hand a number of requirements present then, some of them still, are more suited to

fly ash material than to silica fume. Being first, the Canadian standard gained popularity on a global scale, and several major projects in Asia used this standard, at least until ASTM or national standards were available. The current revision of the requirements to silica fume is found in A300103 cementitious materials for Use in Concrete. Today, outside Canada, only Hong Kong is a regular user of CSA when specifying silica fume. There they will probably move to EN shortly.

10. Europe : in Europe the standards for development for the European construction industry is governed by the Construction Products Directive (89/106/EEC) from the Commission. In short, products used in structures shall be covered by a harmonized standard or by a European Technical approval. For silica fume, a Working Group (WG9) was established under the committee for Concrete and Related Products (TC 104), the group that is responsible for EN 206, “Concrete - Part 1: Specification performance, production and conformity”. For various reasons, not of technical nature, the development of the standard took a very long time and EN 13263. Silica Fume in concrete was only published in 2005.

1.6 APPLICATION OF ULTRAFINE SLAG

As a result of growth in advance technology in concrete, high performance concrete (HPC) has gained worldwide popularity in the construction industry since 1990. In practice, high performance concrete, are generally characterized by high cement factors and very low W/C ratios. Such concrete suffer from two major weaknesses. It is extremely difficult to obtained proper workability, and to retain the workability for sufficiently long period of time with such concrete mixes. High dosage of high range water reducing agents(HRWR) then become a necessity, and resulting cohesive and thixotropic, sticky mixes are equally difficult to place and compact fully and efficiently. These problem indicate that there is probably a critical limit for the water content below which high HRWR dosage become not only essential but also unhelpful and undesirable, and often even harmful from a durability point of view. In high performance concrete applications, Silica Fume is generally proposed as the appropriate cement extender where high strength, low permeability are the prime requirements. Though silica fume is known to improve durability, its addition in concrete is often negated by the increase water and/or admixture dosage required to improve the workability and handling properties of the fresh concrete. Alccofine 1203 is a specially processed product based on slag of high glass content with high reactivity obtained through the process of controlled granulation. The raw materials are composed primary of low calcium silicates. The processing with other select ingredients results in controlled particle size distribution (PSD). The computed blain value based on PSD is around 12000cm^2/gm and is truly ultra fine. Due to its unique chemistry and ultra fine particle size, ALCCOFINE 1203 provides reduced water demand for a given workability, even up to 70% replacement level as per requirement. The quality and impermeability of high performance concrete are determined by the amount of water utilized in mix design i.e. the water/binder ratio. High range water reducers (HRWR) are extensively used to ensure placement with low water contents. The presence of extremely fine particles decreases the permeability and improves durability. In order to measure the effect of ALCCOFINE 1203 on the workability, water requirement and HRWR dosages, three sequences of concrete mixes were prepared, based on the following mix design methodology.

- Workability : Maintaining the water/binder ratio, admixture dosage constant and measuring the slump and compressive strength.

- Water demand: Maintaining the admixture quantity constant and varying the water/binder ratio and measuring the slump and compressive strength.

- Admixture requirement : Maintaining the water/binder ratio constant and varying the admixture content and measuring slump and compressive strength.

The quality feature of ALCCOFINE 1203 is the optimized particle size distribution and unique chemical composition, which reduces the water demand to achieve a specific slump value. In this methodology, the binder content and admixture content were kept constant and the outcome on water requirement, workability and compressive strength were measured. Finer particle size results in rendering more surface area for pozzolanic reaction, allowing concrete achieving higher strength very easily. Due to optimized particle size of ALCCOFINE 1203 workable concrete can be made using less admixture content. The mix deigns containing ALCCOFINE 1203 are prepared to give optimum advantages in terms of technical as well as economical benefits. The obtained comparative results clearly confirm the superior performance of ALCCOFINE 1203 over Silica Fume. As per the methodologies carried out, in first case with equal amount of water/binder ratio and HRWR in concrete specimen the comparative results of ALCCOFINE 1203 is better than the silica fume. The results are similar even in other two methodologies. Increase in strength & workability and decreased HRWR ratio is mainly due to the optimized Particle Size Distribution and proper chemical composition of ALCCOFINE 1203. ALCCOFINE 1203 facilitate to reduce water content and/or HRWR dosage to provide superior performance of concrete in terms of workability and compressive strength over Silica Fume. Long term pozzolanic activity of ALCCOFINE 1203 can be observed as a function of its particle size distribution and chemical composition. ALCCOFINE 1203 results in to formation of dense pore structure and inbuilt CaO provides increased secondary hydrated products because of which improved strength gain at early as well as later ages are observed. Secondary hydrated products formed due to pozzolanic and Cementitious hydration reaction fills the pores. This reduces the permeability of hydrated products to great extent and protects concrete from chemical attack.

1.7 ADVANTAGES & DISADVANTAGES

Till now we have conducted many trials have been conducted by various R and D, at various organization to assess the properties of ALCCOFINE 1203 and its performance in concrete. These trials results shown following benefits:

Fresh State

- Improves workability retention
- Improves flow ability
- Improves rheology
- Reduces segregation
- Reduces heat of hydration

Hardened state	• Improves durability • Improves resistance to ASR • Improves strength at all ages • Improves resistance to chemical attack / corrosion • Imparts light color • Lowers permeability

1.8 SUPPLEMENTARY CEMENTING MATERIALS

These are materials generated from either the industrial wastes or are a by product of some industrial production activities. Theses are being extensively used and are being researched upon in replacement of cement in concrete.

Table 1 comparision of particle size of various materials

Material	Particle size
Cement	35µ to 90µ
Flyash	10µ to 35µ
GGBS	5µ to 10µ
Silica fume	0.2µ to 25µ
Ultra fine slag	0.2µ to 4µ

1.8.1 FLYASH

Fly ash is commonly used in blended cements, and is a by-product of coal-fired electric power plants. The two general classes of fly ash can be defined: low-calcium fly ash (LCFA: ASTM Class F) produced by burning anthracite or bituminous coal; and high-calcium fly ash (HCFA: ASTM Class C) produced by burning lignite or sub bituminous coal. Utilization of waste materials such as fly ash in construction industry reduces the technical and environmental problems of plants and decreases electricity costs besides reducing the amount of solid waste, greenhouse gas emissions associated with Portland clinker production, and conserves existing natural resources. Despite the benefits of fly ash, practical problems remain in field application. At early stages of aging, the strength of concrete containing a high volume of fly ash as a partial cement replacement is much lower than that of control concrete, due to the slow pozzolanic reactivity of fly ash.

Fly ash is a waste by-product from thermal power plants, which use coal as fuel. It is estimated that about 125 million tonnes of fly ash is being produced from different thermal power plants in India. It consumes thousands of hectares of agriculture land for its disposal. It causes serious health and environmental problems. In spite of continuous efforts made and incentives offered by the government, hardly very few percentage of the produced ash is being used for gainful purposes like brick making, cement manufacture, soil stabilization and fill material. In order to utilize fly ash in bulk quantities, ways and means are being explored all over the world to use it for the construction of embankments and roads. Paper mill sludge is a major economic and environmental problem for the paper and board industry. The material is a by-product of the de-inking and re-pulping of paper. The total quantity of paper mill sludge produced in the world is many million tonnes. The main recycling and disposal routes for paper sludge are land-spreading as agricultural fertiliser, producing paper sludge ash, or disposal to landfill. In functional terms, paper sludge consists of cellulose fibres, fillers such as calcium carbonate and china clay and residual chemicals bound up with water. The moisture content is typically upto 40%. The material is viscous, sticky and hard to dry and can vary in viscosity and lumpiness. It has an energy content that makes it a useful candidate as an alternative fuel for the manufacture of Portland cement. As it is happening in most major areas, the waste management problem has already become severe in the world. The problem is compounded by the rapidly increasing amounts of industrial wastes of complex nature and composition. Energy plays a crucial role in growth of developing countries like India. In the context of low availability of non-renewable energy resources coupled with the requirements of large quantities of energy for Building Materials like cement, the importance of using industrial waste cannot be underestimated. Many research organizations are doing extensive work on waste materials concerning the viability and environmental suitability.

Turkel and altuntas[1] studied the effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars and concluded that combinations of fly ash , silica fume and limestone powder can improve the workability of Self-compacting repair mortars more than fly ash , silica fume and limestone powder lone individually . Limestoane Powder has showed to have a encouraging influence on the mechanical performance at early strength development ,whereas silica fume has improved aggregate-matrix bond due to formation of a lesser porous transition zone in mortar. Silica fume can is helpful in reduction of water absorption while flyash and limestone powder does not have the have the same effect, at 28 days.

C Freeda Christy and D. Tensing[2] explored fly ash was in replacement of cement in mix of proportions of 1:3 , 1:4.5 and 1:6 . the cement was replaced in 10%,20%,25%,30% by weight of cement. Higher compressive strength was observed with increase in the richness of the mix. Study was concluded in improvement in the strength of the mortar containing fly ash as partial replacement replaced of fine aggregate and cement in the cement mortar 1:6.

Pitroda et al. [3] investigated on partial replacement of cement with fly ash in design mix concrete .Their work explores the feasibility of using the fly ash which is a thermal industry waste in concrete production as partial replacement of cement. The cement was been replaced by fly ash in variations of 0%,10%,20%,30% and 40% by weight of cement for M-25 and M-40 mix. Comparisons were made in terms of compressive and split strength with the conventional concretes so as to evaluate the mechanical properties for the test results for compressive strength of aging upto 28 days and split strength for 56 days are taken. The authors concluded that compressive strength was reduced when cement was replaced by fly ash and as fly ash percentage was increased the compressive and split tensile strength decreased. Utilization of fly ash in concrete will save the coal & thermal industry disposal costs and shall produce a ‘greener’ concrete for construction. The cost analysis indicated that cement reduction by flyash decreased the cost of concrete, but at the same time strength was also decreases..

Md. Moinul Islam and Md. Saiful Islam [4] studied the Strength behaviour of mortar using fly Ash as partial replacement of cement . Cement was partially varied in six percentages (10%, 20%, 30%, 40%, 50% and 60%) of class F fly ash by weight. Ordinary Portland cement mortar was also prepared as referral mortar. Compressive as well as tensile strengths of the mortar specimens were determined at 3, 7, 14, 28, 60 and 90 days. Test results exhibited that strength increases with the increase of fly ash up to an optimum value, beyond which, strength values started decreasing with further addition of fly ash. Among the six fly ash mortars, the optimum amount of cement replacement in mortar is about 40%, which provides 14% higher compressive strength and 8% higher tensile strength as compared to OPC mortar.

Solanki and Pitroda [5] studied the flexural strength of beams by partial replacement of cement with fly ash and hypo sludge in concrete . Two test groups were constituted with the replacement percentages of 0%, 10%, 20%and 30%.The results showed the effect of fly ash and hypo sludge on concrete beams has a considerable amount of increase of the flexural strength characteristics. Flexural strength of the concrete was found to be increased when the 20% replacement of cement by fly ash was increased up to 11.08 %. Flexural strength of the concrete was also increased when the 10% replacement of cement by hypo sludge is increased up to 8.91%.

Madhavi et al. [6] explored partial replacement of cement and fine aggregate by using fly ash and glass aggregate In their investigation they used fly ash as cement replacement material and glass aggregate as fine aggregate material partially in concrete. Natural sand was partially replaced (10% 20% 30%) with sheet glass aggregate. Compressive strength of cubes at 3 days, 7days and 28 days of duration were studied. Fineness modulus, specific gravity, moisture content, water absorption was also studied. Based on the test results, the ideal percentage of mix which shows maximum compressive strength was identified.

Jamnu et al.[7] presents the Compressive strength of high performance concrete with the replacement of cement with alccofine and Fly ash, and also with natural sand to manufactured sand. The concrete specimens were cured on normal moist curing under normal atmospheric temperature. The compressive strength was determined at 3, 7 and 28 days. The addition of alccofine shows an early strength gaining property and that of Fly-ash shows long term strength. The ternary system that is Ordinary Portland cement-fly ash-alccofine concrete was found to increase the compressive strength of concrete on all ages when compared to concrete made with fly ash and alccofine.

1.8.2 SILICA FUME

SF improves the above properties by pozzolanic reaction and by reactive filler effect SF contains a very high percentage of amorphous silicon dioxide which reacts with large quantity of $Ca(OH)_2$ produced during hydration of cement to form calcium-silicate-hydrate (C-S-H) gel. This gives strength as well as improves impermeability. This is known as pozzolanic reaction (chemical mechanism). Another action, a physical mechanism called "filler effect" in which the small spherical shaped SF particles disperse in the presence of a super plasticizer to fill the voids between cement particles and accelerates the hydration of C3S, since SF is fine reactive filler. These results in well packed, dense, strong and durable concrete mix. Due to pozzolanic reaction between SF and $Ca(OH)_2$. the larger size crystals of $Ca(OH)_2$ converts to crystal of C-S-H gel which is leading to reduction of pore size. This effect along with improved particle distribution results in reduction of the thickness of transition zone and leads to densely packed stronger and less permeable concrete. The incorporation of silica fume into the normal concrete is a routine one in the present days to produce the tailor made high strength and high performance concrete. The design parameters are increasing with the incorporation of silica fume in conventional concrete and the mix proportioning is becoming complex

Roy[8] studied the effect of partial replacement of cement by silica fume on hardened concrete. The properties of hardened concrete such as ultimate compressive strength, flexural strength, splitting tensile strength was determined for different mix combinations of materials and these values were compared with the corresponding values of conventional concrete. The maximum 7 days and 28 days cylindrical compressive strength are found to be 4.32% higher and 16.82% higher respectively when cement was replaced by silica fume .As the percentage of silica fume is increased, there was improvement in packing action of it as a filler material resulting in improvement of the interfacial bond between the aggregate and cement matrix resulting in a sharp increase in tensile strength. The maximum 28 days flexural strength of SF concrete is found to be 21.13% higher with respect to that of the normal concrete for 10% cement replaced by silica fume . This value is far more than the value calculated from the expression $0.7\sqrt{} f_{ck}$ (where f_{ck} is the characteristic strength of concrete) as specified by IS: 456-2002.

Perumal[9] evaluted the performance of high performance concrete trial mixes having different replacement levels of cement with silica fume. The strength and durability characteristics of these mixes were compared with the mixes without silica fume. Compressive strengths of 60 MPa, 70 MPa and 110 MPa at 28days were obtained by using only 10 percent replacement of cement with Silica fume. The use of SF and low w/c ratio resulted in practically impermeable concrete. The compression failure pattern of concrete was due to the crushing of coarse aggregate and was not due to bond failure.• Concrete mixes containing silica fume showed higher values of acid resistance, sea water resistance, abrasion resistance and impact resistance. The results of the strength and durability related tests demonstrated superior strength and durability characteristics of high performance mixes containing Silica fumes. This is due to the improvement in the microstructure due to pozzolanic action and filler effects of SF, resulting in fine and discontinuous pore structure.

Magudeaswaran P. [10] investigated the mechanical properties on silica fume and fly ash as partial cement replacement of high performance concrete and concluded that the density of the concrete decreased with increased in percentage of micro silica and Fly ash replacement up to 15%. Increase in the level of micro silica fume and Fly ash replacement between 30% to 45% led to a reduction in the compressive strength of hardened concrete. This study has shown that between 15 to 22.5% replacement levels, concrete will develop strength sufficient for construction purposes. Its use will lead to a reduction in cement quantity required for construction purposes and hence sustainability in the construction industry as well as aid economic construction.

Pradhan [11] explored the influence of silica fume on normal concrete these experiments were carried out by the authors by replacing cement with different percentages of silica fume at a single constant water-cementitious materials ratio while keeping other mix design variables constant. The silica fume was replaced by 0%, 5%, 10%, 15% and 20% for water-cementitious materials w/c ratio for 0.40. For all mixes compressive strengths were determined at 24 hours, 7 and 28 days for 100 mm and 150 mm cubes. Other properties like compacting factor and slump were also determined for five mixes of concrete. The compressive strength is increased by13.9 % for the replacement of cement by 10%fly ash and 5% silica fume mix. Split tensile strength is increased by 12.15% for the replacement of cement by 15% fly ash and 7.5% silica fume mix. Flexural strength increased by 16% for the replacement of cement by 15% fly ash and 7.5% silica fume mix.

Amudhavall[12] studied the effect of silica fume on strength and durability parameters of concrete and inferred 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%. In his investigations he performed a detailed experimental study on compressive strength, split tensile strength, flexural strength at age of 7 and 28 day. Durability study on acid attack was also studied and percentage of weight loss was compared with normal concrete. Test results indicate that use of Silica fume in concrete has improved the performance of concrete in strength as well as in durability aspect.

Mohamadien[13] investigated the effect of marble powder and silica fume as partial replacement for cement on mortar which resulted in the compressive strength increased by 31.4%, 48.3% at 7, and 28 days respectively at 15% replacement ratio of silica fume with cement content and in case of replacement marble powder with cement content the compressive strength increased by 22.7%, 27.8% at 7, and 28 days at 15% replacement ratio of marble powder with cement content respectively.

Elsayed[14] performed the effect of mineral admixtures on water permeability and compressive strength of concretes containing silica fume , fly ash and super pozz. The main objective of this research was to determine the water permeability and compressive strength of concrete containing silica fume, fly ash, super pozz and high slag cement to achieve the best concrete mixture having lowest permeability. The results were compared to those of the control concrete; ordinary Portland cement concrete without admixtures. The optimum cement replacement by fly ash, super pozz and Silica fume in this experiment was 10% super pozz. The knowledge on the strength and permeability of concrete containing silica fume, fly ash , super pozz and high slag cement could be beneficial in the utilization of these waste materials in concrete work , especially on the topic of durability.

1.8.3 ULTRAFINE SLAG

In recent past, more concern is being given on usage of micro materials in concrete for sustainability and durability. The main efficacy behind this approach is to have a perfect particle packing of materials in concrete so that high performance concrete (HPC) can be achieved. The effective particle packing of coarse and fine aggregates can be achieved by following proper grading whereas for below 90 microns proper blending of fine and micro fine materials is a must. In the present study, Particles with Blaine < 800 m^2/kg ,$d95 < 20$ μm and $d\ 95 < 15$ μm are considered as fine, micro fine and ultrafine materials respectively as per the references cited. Buffering capacity determines the long-term chemical conditioning provided by the cement in its ability to buffer the pH of invading ground waters to values ≥ 12.5. Most radio nuclides have a very low solubility under these high pH conditions. Microbial activity will also be suppressed. Mechanical strength affects the ability of the cement to prevent structural collapse of excavated cavities Permeability affects the rate of groundwater flow into and out of the repository, lower permeability favoring the slowing of any potential release of the radionuclide inventory. Sorption on CSH gel phases which are the major components of hydrated cements will retard the migration of radio-nuclides. Cement will therefore be used as the material for walls and floors, for encapsulating the waste, to backfill gaps between waste packages, and as a sealant for tunnels and shafts The two innovative micro products developed for specific application in concrete/soil and other formations are described in the present study. They are specially formulated composite materials with raw material Portland cement or granulated blast furnace slag (GGBS) .The respective raw material with value added material/s is ground in a mill attached with high efficiency classifier which classifies the material and ensures that only the required micro size particle enters the final product. Alccofine 1203 is a specially processed product based on slag of high glass content with high reactivity obtained through the process of controlled granulation. Owing to its unique chemistry and ultra fine particle size, alccofine1203 provides reduced water demand for a given workability, even up to 70% replacement level as per requirement of concrete performance. alccofine 1203 can also be utilized as a high range water reducer to improve compressive strength or as a super workability aid to improve flow.alccofine1203 is known to produce a high-strength concrete and is used in two different ways as a cement replacement, in order to reduce the cement content (usually for economic reasons) and as an additive to improve concrete properties (in both fresh and hardened states). Therefore, utilization of Alccofine1203 together with fly ash provides an interesting alternative and can be termed as high strength and high performance concrete. alccofine 1203 performs in superior manner than all other mineral admixtures used in concrete within India. Due to its inbuilt CaO content, alccofine 1203 triggers two way reactions during hydration :

- Primary reaction of cement hydration.
- Pozzolanic reaction

Alccofine also consumes by product calcium hydroxide from the hydration of cement to form additional C-S-H gel, similar to pozzolans. This results in denser pore structure and ultimately higher strength gain.

Study $^{\text{Counto microfine products pvt. Ltd.}}$ was conducted by Ambuja cements in india which presented the results of examination carried out on Alccofine 1203 in comparison with

Silica Fume in concrete, and the effect it has on workability, water requirement, admixture requirement, strength and durability. Thus, obtained results confirm that properly designed mixes with judicious use of Alccofine 1203 exhibits superior properties than Silica Fume. The mix deigns containing alccofine 1203 were prepared to give optimum advantages in terms of technical as well as economical benefits. The obtained comparative results clearly confirm the superior performance of alccofine 1203 over Silica Fume. As per the methodologies carried out, in first case with equal amount of water/binder ratio and HRWR in concrete specimen the comparative results of alccofine 1203 was better than the silica fume. The results are similar even in other two methodologies. Increase in strength & workability and decreased HRWR ratio is mainly due to the optimized Particle Size Distribution and proper chemical composition of alccofine 1203. It facilitates to reduce water content and/or HRWR dosage to provide superior performance of concrete in terms of workability and compressive strength over Silica Fume. Long term pozzolanic activity of alccofine 1203 can be observed as a function of its particle size distribution and chemical composition. alccofine 1203 results in to formation of dense pore structure and inbuilt CaO provides increased secondary hydrated products because of which improved strength gain at early as well as later ages are observed. Secondary hydrated products formed due to pozzolanic and cementitious hydration reaction fills the pores. This reduces the permeability of hydrated products to great extent and protects concrete from chemical attack .

Upadhyay[16] Investigated Effect on Compressive strength of High Performance Concrete Incorporating Alccofine and Fly Ash and concluded that the addition of Alccofine shows an early strength gaining property and that of Fly ash shows long term strength. The combination of Ordinary Portland cement-fly ash-Alccofine concrete was found to increase the compressive strength of concrete on all ages when compared to concrete made with fly ash and Alccofine alone.

Soni[17] investigated the Strength of concrete of grade M80 with locally available ingredients and then to study the effects of different proportions of Alccofine and fly ash in the mix and to find optimum range of Alccofine and fly ash content in the mix. The

Alccofine and fly ash is added by weight of cement as a replacement. The Concrete specimens were tested at different age level for mechanical properties of concrete, namely, cube compressive strength, flexural Strength. Perfect proportion of replacing cement material as Alccofine and flyash was obtained without losing its strength. Alccofine performed better as compare to other slag materials and microsilica. It helps to make concrete workable. Perfect dosages of Alccofine and fly ash proportion was concluded as 8% of Alccofine and 16% of flyash. Alccofine helps to increase strength in both compressive and flexural strength upto certain limit.

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Suthar[18] studied the strength development of high strength concrete containing alccofine and fly-Ash in which the compressive strength was determined at 56 days. The results indicated the concrete made with varying proportions generally show excellent fresh and hardened properties since the combination is somewhat synergistic. The addition of Alccofine shows an early strength gaining property and that of fly ash shows long term strength. The ternary system that is ordinary Portland cement-fly ash-alccofine concrete was found to increase the compressive strength of concrete on all age when compared to concrete made with fly ash and Alccofine alone.

Patel [19] studied the durability of high performance concrete incorporating alccofine and flyash.The study investigates the performance of concrete mixture in terms of Compressive strength, Chloride Attack tests, Sea water test and Accelerated corrosion test at age of 28 and 56 days. In addition the optimum dosage of Alccofine and fly ash from given mix proportion was determined. Result showed that concrete incorporating Alccofine and fly ash has higher compressive strength and Alccofine enhanced the durability of concretes and reduced the chloride diffusion. An exponential relationship between chloride permeability and compressive strength of concrete was exhibited.

Pawar [20] studied the effect of alccofine on self compacting concrete the study explores the use of the Alccofine powder to increase the amount of the fines and hence achieve self compatibility. The study focuses on comparison of the properties of SCC with flyash and Alccofine to that of standard one with flyash. Properties of SCC with flyash and

Alccofine were evaluated and compared with those of SCC with flyash .From the experimental investigations, following conclusions were established that the addition of Alccofine in SCC mixes increases the self compatibility characteristic like filling ability , passing ability and resistance to segregation and the fresh properties and harden properties of SCCs with 10% Alccofine are superior than SCCs with 5% and 15% of Alccofine.

Jamnu[21] studied the effect of alccofine And fly Ash upon the compressive strength of high performance concrete . The maximum compressive strength of concrete is achieved by using Alccofine 10% at Fly Ash 30%. The addition of Alccofine increases the self compatibility characteristics like filling ability, passing ability and resistance to segregation. The relative cost of Alccofine is cheaper then cement hence it proves to be economic with higher strength .Due to Changes in w/c ratio 0.45 to 0.5 higher compressive strength was achieved in a minor difference. At 3 days higher w/c ratio depicted higher strength compared to lower w/c ratio. Average compressive strength at 28 days for 0.5 w/c ratio gave 73.8 Mpa & 0.45 w/c gives 71.0 Mpa. compressive strength increment was not that much marginal.

Kulkarni[22] investigated the effect of elevated temperatures on mechanical properties of microcement based high performance concrete. After 28 day of curing, specimen were exposed to 150^0C, 300^0C, 450^0C, 600^0C, 750^0C and 900^0C temperature and retained for two hours in an electric furnace. No visible cracks and spalling were found up to 4500^0C seen to be appeared found up to 4500^0C for ordinary mix, but normal visible cracks were seen to be appeared on microfine mixes, and these cracks were more pronounced in the case of specimen subjected to 600^0C, 750^0C and 900^0C. Above 750 ^{0}C, small amount of spalling was observed, corners were damaged and very sensitive to handle. At 900^0C, specimens of both types of mixes were found to be heavily damaged and cracks were found to closer.

Saurav[23] investigated study of strength relationship of concrete cube and concrete cylinder using ultrafine slag alccofine and concluded that the hardened properties of concrete with alccofine were enhanced at the optimum alccofine percentage . After 12% replacement of alccofine there was very nominal change in the strength of conventional concrete. The cylindrical strength of concrete increased after addition of alccofine but was always less than its cubical counterpart.

Parmar[24] utilized pond fly ash as a partial replacement in fine aggregate with using fine fly ash and alccofine in high strength concrete (hardened concrete properties)highest compressive strength strength was at 6% alccofine as a cement replacement and 10% pond ash a replacement in fine aggregates. Highest compressive strength was obtained at 56th day. Maximum flexural strength was obtained at 28th day at using 6% Alccofine and 10% pond ash usage . The maximum split tensile strength of cylinder was observed at 56th day upon using 6% Alccofine and 10% pond fly ash.

Patel et al.[25] studied the effect of coarse aggregate characteristics on strength properties of high performance concrete using mineral and chemical admixtures For the purpose of this work, two types of coarse aggregates were used. The fine aggregate is normal sand obtained from a locally available preliminary laboratory investigation was conducted to ascertain the suitability of using the aggregates for construction work. Tests conducted included sieve analysis, bulk density, and specific gravity. IS mix design was adopted for this work and mix compositions were calculated by absolute volume method. For each type of coarse aggregate 25 cubes (150mm x150mmx150mm) were casted to allow the compressive strength to be monitored at 56 days. Three types of coarse aggregates were mixed in four different proportions for concrete production. Plasticizers and Super plasticizers were used in some mixes to reduce the water to cement ratio. The outcome of the work showed that the mixture with a ternary combination of granular fraction with a maximum size of 25mm, without admixtures showed the highest compressive strength. At a lower water to cement ratio, the binary granular system produced the highest compressive strength. This research was undertaken to investigate the effect of two different types of coarse aggregate on the compressive strength of normal concrete. Test result show that concrete made from A- type aggregate has higher compressive strength. The aggregate type had significant effect on the compressive strength of normal concrete.

Jamnu et al.[26] studied the mechanical properties of rubber crumb concrete using pretreated rubber crumbs and alccofine. From the past studies, the use of rubber in concrete shows poor strength with increasing amount of rubber. To come over this drawback and enhance the strength, rubber was pre-treated using NaOH and adding of silane coupling agent incorporating the use of alccofine (GGBS) to improve bonding with cement paste in this study. A total number of 21 numbers of mixes were casted with 0% of replacement of rubber crumbs with fine aggregate as control then followed by 5%, 10%, 20% and 30% separately for each replacement of cement with Alccofine (GGBS) percentage of 4%, 6%, 8% and 10%. All of the mixes are tested with the compressive strength test, split tensile test and flexural strength test. The results from all of the tests are to be compared with control concrete mix , this concluded in establishing that use of rubber in the concrete decreases the all type of strengths. Poor bonding between the rubber and cement slurry is the reason for the decrease in strength, if some bonding material is used and pretreatment of rubber is specified then both can provide improvement in the strength. This study aimed at using of alccofine as bonding material and giving pretreatment to rubber crumbs with NaOH and Silane Coupling agent. Concentration was done upon the performance of a single gradation of crumb rubber which is nearly similar to gradation of natural fine aggregate in normal concrete. The Rubber Crumbs were collected from local markets and manually blending of tyre pieces.

The influence of different gradations of the rubber aggregate on concrete properties was not been evaluated in this study. There was replacement of natural fine aggregate with 5%, 10%, 20% and 30% of rubber crumbs . Replacement of cement by 4%, 6%, 8% and 10% of alccofine and pretreatment to rubber crumbs was the prime reason in achieving the reduced compressive strength due to addition Rubber Crumbs.

Mo.Tofik[27] studied the on effect of high performance concrete with Alccofine and waste glass powder. The compressive and flexural strength was determined at 7, 14 and 28 days. The addition of alccofine showed an early strength gaining property and that of waste glass powder depicted long term strength. The ternary system of ordinary portland cement-alccofine-waste glass powder concrete was found to increase the compressive and flexural strength of concrete on all ages when compared to concrete made with alccofine and waste glass powder alone.

CHAPTER 2 : LITERATURE REVIEW

2.1 GENERAL

This chapter discusses the past research conducted by various researchers to study the applications & different methodology used in understanding of tests and finding due to the above said along with behavior of Alccofine 1203 as an admixture to concrete. This chapter gives a comprehensive review of the findings along with directions for future explorations.

2.2 HARDENED CONCRETE PROPERTIES

2.2.1 Flexural strength

Sangeetha et al.[28] studied the flexural Behaviour of Reinforced Concrete Beams with Partial Replacement of GGBS their study focused on the structural behavior of reinforced concrete beam with Ground Granulated Blast furnace Slag (GGBS).It is an inexpensive replacement of Ordinary Portland Cement (OPC) used in concrete, and it improves fresh and hardened properties of concrete. Experimental investigation included testing of eight reinforced concrete beams with and without GGBS. Portland cement was replaced with 40% GGBS and Glenium B-233 was used as superplastisizer for the casting of beams. The results of laboratory investigation on the structural behavior of reinforced concrete beams with GGBS are presented. Data presented include the load-deflection characteristics, cracking behavior, strain characteristics and moment- curvature of the reinforced concrete beams with and without GGBS when tested at 28 days and 56 days. The investigation revealed that the flexural behaviour of reinforced GGBS concrete beams is comparable to that of reinforced concrete beams.

Sveinsdóttir[29] investigated the strenghthening of concrete beams by the use of epoxy adhesive and cement based bonding materials and concluded that .By means of externally bonded BFRP shear reinforcement the shear load carrying capacity of the beams can be increased. The shear capacities of the shear strengthened beams were improved by more than 60% by applying the BFRP as externally reinforcement. The orientation of the fibres was found to have an important effect, especially where 3 layers were applied in 45° fibre orientation. There was a greater strengthening effect and better control off the shear crack propagations. There was inconsistency for the strengthened beams in failure mechanism, in terms of concrete crushing, fibre ruptures or fibres de-bonding. Increased efficiency was obtained when BFRP bond failure is avoided or delayed. This method, is relatively easy for construction and handling, can be used effectively for strengthening RC beams that require increased shear capacity or confinement. The shear strength of concrete beams according to the theory is limited by the many types of failure modes, it does not fully describe the complex behaviour of concrete in shear, although good predictions were seen for the 345° stripps strengthening layout.

Soni [30] studied the experimental study on high-performance concrete,with mixing of alccofine and flyash aim of this research was to evaluate the performance of high performance concretes(HPC) Containing supplementary cementitious materials. In the last millennium concrete had demanding requirements both in terms technical performance and economy and yet greatly varied from architectural masterpieces to the simplest of utilities. The main aim of the investigation program is first to prepare the Strength of concrete of grade M80 with locally available ingredients and then to study the effects different proportions of Alccofine and fly ash in the mix and to find optimum range of Alccofine and fly ash content in the mix. The Alccofine and fly ash is added by weight of cement as a replacement. The Concrete specimens were tested at different age level for Mechanical Properties of concrete, namely, Cube Compressive Strength, Flexural Strength.

2.2.2 Split tensile test

The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibres in the mixture. Different types of fibers, such as those used in traditional composite materials can be introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibres help to transfer loads at the internal micro cracks. Such a concrete is called fibre-reinforced concrete (FRC). One of the important properties of Steel Fibre Reinforced Concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particularly under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fibre composite pronounced post cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading. The real contribution of the fibres is to increase the toughness of the concrete. The fibres tend to increase the strain at peak load, and provide a great deal of energy absorption in post-peak portion of the load-deflection curve.

Neeraja et al.[33] did investigations on strength characteristics of steel fibre reinforced concrete. Tests were conducted by adding Ground Granulated Blast furnace Slag (GGBS) and steel fibres to concrete in an amount equivalent to approximately 0%, 20%, 40%, 60% and 80% to the weight of cement content and that for steel fibres from 0 to 2% with an increment of 0.5%. The test results proved that the compressive strength of concrete increased with per cent increase in GGBS up to 40%. Beyond 40%, there was marginal decrease in strength of concrete. In addition, tests were conducted, taking the combinations of GGBS and steel fibres. From the test results, it was found that there is improvement in the strength of concrete by addition of GGBS and steel fibres.

Rana[34] investigated to find out the optimum quantity of steel fibres required to achieve the maximum flexural strength for M25 grade concrete. From the exhaustive and extensive experimental work it was found that with increase in steel fibre content in concrete there was a tremendous increase in flexural strength. Even at 1 % steel fibre content flexural strength of 6.46 N/mm^2 was observed against flexural strength 5.36 N/mm^2 at 0% hence increase of 1.1% flexural strength was obtained.

Deotale[35] performed a detailed experimental investigation to study the effect of partial replacement of cement by flyash, rice husk ash with using steel fiber in concrete. Proportion were varied from 30% flyash and 0% rice husk ash mix together in concrete by replacement of cement last proportion taken 15% flyash and 15% rice husk ash, with gradual increase of rice husk ash by 2.5% and simultaneously gradual decrease of flyash by 2.5% and to improve the strength of concrete steel fibers were added and fiber volume fraction was 0%, 0.25%, 0.5%, 0.75% and 1.0% in volume basis in the proportion of 10% rice husk ash and 20% flyash The purpose of this research was to study the effects of steel fibers on the workability, compressive strength, flexural tensile strength, splitting tensile strengths, Acid resistant test , durability study of fly ash and rice husk ash in concrete.

Shende[36] performed critical investigation for M-40 grade of concrete having mix proportion 1:1.43:3.04 with water cement ratio 0.35 to study the compressive strength, flexural strength, Split tensile strength of steel fibre reinforced concrete containing fibers of 0%, 1%, 2% and 3% volume fraction of hook tain. Steel fibers of 50, 60 and 67 aspect ratio were used. A result data obtained has been analyzed and compared with a control specimen (0% fiber). A relationship between aspect ratio vs. Compressive strength, aspect ratio vs. flexural strength, aspect ratio vs. Split tensile strength represented graphically. Result data clearly shows percentage increase in 28 days Compressive strength, Flexural strength and Split Tensile strength for M-40 Grade of Concrete.

Shukla [37] evaluated the compressive and split tensile strength of steel fibre reinforced concrete made using portland pozzolona cement, and 1% of steel fibre. The PPC replacement (with metakaolin) level was varied between 10-16% by weight of cement at an interval of 1%. M-25 referral mix at 0.46 water cement ratio was used. The cube specimen and cylinder specimen were cast and tested for determination of compressive and split tensile strength of concrete at different replacement levels. It was observed that at 12% replacement level, compressive and split tensile strength increased substantially as compared to the referral concrete.

Faisal [38] studied the properties and applications of fiber reinforced concrete describing the different types of fibers and the application of fiber reinforced concrete in different areas. No workability problem was encountered for the use of hooked fibers up to 1.5 percent in the concrete mix. The straight fibers produce balling at high fiber content and require special handling procedure. Use of fiber produces more closely spaced cracks and reduces crack width. Fibers bridge cracks to resist deformation. Fiber addition improves ductility of concrete and its post-cracking load carrying capacity. The mechanical properties of fiber reinforced concrete are much improved by the use of hooked fibers than straight fibers, the optimum volume content being 1.5 percent. While fibers addition does not increase the compressive strength, the use of 1.5 percent fiber increase the flexure strength by 67 percent, the splitting tensile strength by 57 percent, and the impact strength 25 times. The toughness index of FRC is increased up to 20 folds (for 1.5 percent hooked fiber content) indicating excellent energy absorbing capacity. Fiber reinforced concrete controls cracking and deformation under impact load much better than plain concrete and increased the impact strength 25 times.

2.2.3 Resistance to fire

Concrete is a construction material with a relatively low thermal conductivity coefficient, thus heat in this material spreads slowly, and a significant thermal gradient may occur within the concrete element. Moreover, due to the difference of temperature between the exposed surface and the inside of the element, it should be assumed that a damage gradient may occur in concrete element. The assessment of the residual capacity of concrete structures seems to be a complex task, its complexity mainly attributable to the heterogeneity of concrete and the irregular distribution of damage induced by fire. Concrete has an excellent intrinsic behaviour when exposed to fire, especially when compared to other building materials. However, its fire resistance should not be taken for granted and a proper structural fire design is certainly necessary. Its design should be based on the understanding of both the material and the structural behaviour of concrete exposed to fire. A number of complex physicochemical reactions occur when concrete is heated, causing mechanical properties as strength and stiffness to deteriorate.

Furthermore, the phenomenon of spalling causes pieces of concrete to break off from the surface, reducing the cross-section of an element and possibly exposing the reinforcing to the high temperatures. Spalling can be highly dangerous and is most common in high strength concrete. However, its mechanism is still not fully understood.

Hossain[39] checked the fire resistance of cement mortar containing high volume fly ash. During which he casted 2 inch cubes of cement mortar (1:2.75) with the inclusion of different percentage of fly ash are prepared, cured for 28 days, heated at different elevated temperatures, cooled down at room temperature and finally tested in the laboratory. The test resulted that the mortar containing 50% fly ash as a replacement of cement exhibits greater resistance to high temperature. Also, compressive and bond strengths of mortar containing different percentage of fly ash initially increase with the increase of temperature but after 200 ^{0}C they decrease with the further increase of temperature.

Sreenivasulu[41] studied the mechanical properties Of heated concrete of M100 grade. He investigated the effect of elevated temperatures ranging from 50^{0}C to 2500^{0}C on the compressive and splitting tensile strengths of ultra strength concrete of M100 grade. Tests were conducted on 150 mm cubes, 150 mm diameter and 300 mm height cylindrical specimens. The specimens were heated to different temperatures of 50^{0}C, 100^{0}C, 150^{0}C, 200^{0}C and 250^{0}C for different durations of 1, 2, 3 and 4 hours at each temperature. After the heat treatment, the specimens were tested for both compressive and splitting tensile strengths. The compressive and split tensile strengths of M100 concrete were increased initially upto a temperature of 50^{0}C - 100^{0}C and beyond that they got reduced rapidly with increasing the temperature. It was observed that major part of loss in split tensile strength took place in the first 1 hour exposure. The compressive and split tensile strength was lost very much when they are heated at 250^{0}C.

Bilow[42] studied the complex behavior of structures in fire and the simplified techniques which have been used successfully for many years to design concrete structures to resist the effects of severe fires. They concluded that concrete’s excellent fire resistance has been proven by many tests performed for over 60 years. The American Concrete Institute and various building codes have developed prescriptive and analytical methods based on the fire tests on concrete components of structures. These methods provide architects and engineer a relatively easy way to select member proportions and reinforcement requirements for all but the very unusual structures. For the very unusual structures, alternate methods are available to adequately model or to test the complex behavior of reinforced concrete components subject to fire.

Awoyera[43] investigated the significance of concrete cover to reinforcement in structural element at varying temperatures in his study he casted sixty samples of 320 mm x 150 mm x 100 mm concrete beams reinforced with 10 mm main bars and 6 mm nominal reinforcement in the laboratory in four batches. Each batch contained fifteen samples with concrete cover for reinforcement varied at 10 mm, 15 mm, 20 mm and 25 mm respectively. After 28 days of curing, the beam samples were subjected to simulated fire in the laboratory furnace at temperatures ranging from 50 ºC (122 ºF) – 700º C (1292 ºF) in steps of 50 ºC. Thereafter, the samples were allowed to cool to room temperature. Subsequently, samples of reinforcement were removed from the beam samples and tested with the universal material testing machine. Results of tensile tests on reinforcements showed that ultimate tensile strength of steel decreased with increasing temperatures. The greatest loss in strengths of steel reinforcements was recorded for beams with 10 mm concrete cover, which reduced from a value of 592.0 N/mm^2 at room temperature to 224.50 N/mm^2 at a terminal temperature of 700ºC (1292 ºF), which represented a 62% reduction in strength.

2.2.4 Durability Analysis

Durability of concrete is a well-known term that expresses the ability of this material to keep its original properties unchanged over time. The term service life has a wider meaning since it defines the time throughout which the whole structure will keep its serviceability, i.e. the service that will be rendered above an acceptable level over an anticipated period. The term service life has become popular in relatively recent time when the research studies carried out on several structures suffering severe damage until failure evidenced that concrete had not deteriorated. This fact, along with the existence of 100-year-old buildings and bridges that are still in service, is the best proof that structure stability does not depend only on concrete durability. In other terms, durability of concrete affects the service life of a structure but must not be confused with it. Nowadays, it is generally acknowledged that the service life of a structure essentially depends on the optimization of four principal factors as follows:

- Materials durability,
- Structural and mix design,
- Construction process,
- Maintenance.

Czuban [44] studied the repair durability of reinforced concrete structures affected by steel corrosion. Special reinforced concrete samples were designed to investigate all aspects of this complex problem. Natural conditions leading to chloride contamination and corrosion initiation were reproduced in the laboratory by subjecting specimens to numerous wetting and drying cycles in a controlled environmental chamber for more than 14 months. The initiation of the corrosion reaction was monitored using three different electrochemical techniques. Samples were then repaired using different techniques and the corrosion behaviour of the repaired specimens was investigated for several months. Test variables included the characteristics of the repair concrete. Results shed a new light on the basic mechanisms affecting the durability of repairs. Data indicate that improper removal of chloride contaminated concrete and inappropriate selection of the repair concrete can have a detrimental influence of the durability of the repaired element.

Qiaoet al .[45] investigated the accelerated degradation and durability of Concrete in Cold Climates and concluded that the damage and degradation in the concrete samples can be effectively accumulated (accelerated) by using the F/T conditioning protocol (ASTM C666). Both the dynamic modulus of elasticity and fracture energy tests were capable of probing the material degradation by the F/T cycles. Fracture energy test method was more sensitive to screen material degradation and better associated with degradation of aggregate, since the degraded aggregate is prone to fracture. After 1500 F/T cycles, the material showed more than 63.8% of fracture energy reduction; while there is only about 25.3% of dynamic modulus reduction after 1500 F/T cycles. The Vickers indentation test can be an effective test method to discern the degradation rate of intra-grannular (like aggregate and cement paste) and inter-grannular (e.g., aggregate-paste interface)

Massazza [46] studied about the durability of concrete and through his research he concluded that concrete is a durable material and that serious deterioration of concrete structures is due either to exceptional events or to exquisitely human factors like the lack of knowledge or negligence. This opinion was strengthened by the fact that over the last fifty years science and technology of materials have developed gradually so that cement and concrete performance has appreciably increased. Therefore, a longer service life of concrete structures does not generally depend on concrete durability but upon accurate structural and mix design, careful construction process, and diligent maintenance. These factors are related to human behavior and their improvement requires that engineers and their staff were better educated in relation to the materials properties, with more attention being devoted to surveillance of construction steps and maintenance.

Magudeaswaran[47] studied the durability characteristics of high performance concrete. His study was mainly concentrated on the durability characteristics of HPC with partial replacement of cement by fly ash (F) and silica fume (SF). The cement was replaced with 25% F & 12.5% SF, 30% F & 15% SF, 35% F & 17.5% SF. Water cement ratio was kept constant for all mixtures. The main properties that were observed are water absorption capacity, the alkalinity to test and the durability. It was observed that for the increase in the percentage of fly ash and silica fume there was steady increase in the water absorption and alkalinity which significantly indicates the markable change in strength and durability characteristics of concrete.

QCL group [48] investigated the sulphate attack and chloride ion penetration and their role in concrete durability and concluded that Resistance to sulphate attack and chloride ion penetration are two of the latest areas of durability concern to specifiers and users of concrete. Traditionally they were addressed by specifying cements of particular chemical composition, which were not always compatible (e.g. low C_3A for sulphate resistance, a higher C_3A for marine chloride resistance). The advent of quality assured SCMs capable of being evaluated using a range of performance tests is providing a sound base for revisiting the specification of concrete to achieve these particular durability objectives. While economic constraints may place some limits on the range of SCMs available in different areas of Queensland, data is being obtained which indicate that there is great potential for the use of SCMs to address these and other challenges in achieving durable concrete structures. Based on data reported from the CSIRO research project above, it would appear that in specifying concrete to resist sulphate attack or chloride ion penetration, a suitable approach would be incorporation of at least 20% fly ash or 60% slag ; either of which would also be beneficial in reducing any tendency for alkali silica reaction.

Reddy [49] explored the effect of hydrochloric acid on fly ash based blended cement and silica fume blended cement and their concretes. the blended cement and silica fume blended cement and their concretes blended cement concrete and silica fume blended cement concrete produced with HCL dosage of 100, 150, 300, 500 and 900 mg/l added in de-ionised water. in addition to this control specimens were prepared with de-ionised water (without HCL) for comparison. The setting times and compressive strength were evaluated for 28 and 90 days apart from studying rapid chloride ion permeability. the results show that, as HCL concentration increases, there is retardation in initial and final setting of cements both blended cement and silica fume blended . The compressive strength of both blended cement concreter and silica fume blended cement has come down with an increase in the concentration of HCL at both 28 and 90 days. compressive strengths of blended cement concrete concrete and silica fume blended cement have decreased in the range of 2 to 19%, at 28 and 90 day age respectively, with an increase in hcl concentration, when compared with the control specimens. It was also observed that chloride ion permeability has increased with an increase in the concentration of the acid. x-ray diffraction analysis has been carried out for both blended cement concrete and silica fume blended cement specimens at hcl concentration of 500 mg/l in de-ionised water.

Swaroop et al .[50] explored the durability studies on concrete with fly ash & ggbs mainly confined upon evaluation of changes in both compressive strength and weight reduction in five different mixes of M30 Grade namely conventional aggregate concrete (CAC), concrete made by replacing 20% of cement by Fly Ash (FAC1), concrete made by replacing 40% of cement by Fly Ash (FAC2), concrete made by replacing 20% replacement of cement by GGBS (GAC1) and concrete made by replacing 40% replacement of cement by GGBS (GAC2). The effect of 1% of H_2SO_4 and sea water on these concrete mixes was determined by immersing these cubes for 7days, 28days, 60days in above solutions and the respective changes in both compressive strength and weight reduction were observed and up to a major extent it can be concluded that concretes made by Fly Ash and GGBS had good strength and durable properties comparison to conventional aggregate in severe environment.

Dhinakaran et al.[51] investigated to improve the performance of concrete in terms of strength and resistance to chloride-ion-penetration by incorporating metakaolin as mineral admixture in concrete. Parametric study was carried out by considering w/cm ratio, various percentage of metakaoline and age of concrete as parameters to understand the effect of each parameter. The study was conducted for different water-to-cement metakaolin ratio (w/cm) ratios of 0.32, 0.35, 0.4 and 0.5. The metakaolin proportion was varied from 0 to 15% with an increment of 5% and ages of concrete from 3 to 90 days were considered and experiments performed accordingly. The effects of above said parameters on the various properties of concrete such as workability, compressive strength, chloride penetrability (Rapid chloride permeability test as per ASTM C 1202), pH of concrete and depth of penetration of chloride ions were investigated, and the results of metakaolin concrete were compared with the conventional concrete. From the results, it was observed that metakaolin concrete showed greater strength for higher w/cm ratios (0.4 and 0.5) and its resistance to chloride ion penetration was more or less consistent for all w/cm ratios and the optimal amount of metakaolin resulted significant reduction in chloride ion penetration. A Multiple non-linear regression analysis was used to develop a statistical model to predict the strength and found to have good correlation between the observed and predicted values. It was concluded that the concrete developed in this study have significant potential for use on real time projects.

Deotale [51] studied the acid resistant and chloride attack test on partially replaced cement by fly ash, rice husk ash with using steel fiber in concrete. Their study concluded upon the compressive strength being increased with the increase in the percentage of Fly ash and Rice Husk Ash up to replacement (22.5%FA and 7.5% RHA) of Cement in Concrete for different mix proportions. The maximum 28 days split tensile strength was obtained with 22.5% fly ash 7.5% rice husk ash mix and maximum 28 days flexural strength was obtained again with 22.5% fly ash and 7.5% rice husk ash mix. The percentage of water cement ratio is reliant on quantity of RHA used in concrete. Because RHA is a highly porous material . The workability of concrete had been found to be decreased with increase RHA in concrete . As the rice husk is burned out at 600º to 800º c. It was observed that the 80 % silica was produced due to this it gives a excellent thermal insulation. Through Rice husk ash is harmful for human being and the cost of rice husk ash is zero and thus they preferred RHA use in concrete as compare to silica fumes and it is also economical. The workability of RHA concrete was found to decreased but the FA increases the workability of concrete. Rice Husk Ash can be used with admixtures, plasticizers, and super plasticizers, for increasing the workability and strength of concrete with partial replacement of cement. The mechanical properties in terms of flexural and tensile strength have been significantly improved with the addition of RHA. The unit weight of concrete increased uniformly with the increase in fiber content and decreased with the increase of rice husk ash content. The inclusion of steel fiber reduces the workability with increasing fiber content. 1t is found that the addition of steel fibers into concrete the small increase in compressive strength with increase in fiber content after7,14 ,28,56 and 90 days of curing. It is observed that the addition of steel fibers did not improve the compressive strength in concrete. Steel fibers have showed more significant effects on flexural and tensile strength at 0.75% by volume fractions. Durability studies carried out in the investigation through acid attack test and chloride test with 1% H_2SO_4 and 3% NaCl revealed that 22.5%FA+7.5%RHA concrete is more durable in terms of durability factors than control concrete. It was observed that rice husk ash concrete will have higher life compared to control concrete.

Perumal et al .[52] studied the effect of partial replacement of cement with silica fume on the strength and durability characteristics of high performance concrete. In order to make a quantitative assessment of different cement replacement levels with SF on the 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 SF, investigations were taken .This study reported on the performance of HPC trial mixes having different replacement levels of cement with SF. The strength and durability characteristics of these mixes were compared with the mixes without SF. Compressive strengths of 60 MPa, 70 MPa and 110 MPa at 28days were obtained by using 10 percent replacement of cement with SF. The results also show that the SF concretes possess superior durability properties.

Amudhavalli et al.[53] explored the effect of silica fume on strength and durability parameters of concrete main parameter investigated were s M35 grade concrete with partial replacement of cement by silica fume by 0, 5, 10,15and by 20%. This paper presents a detailed experimental study on Compressive strength, split tensile strength, flexural strength at age of 7 and 28 day. Durability study on acid attack was also studied and percentage of weight loss is compared with normal concrete. Test results indicate that use of Silica fume in concrete has improved the performance of concrete in strength as well as in durability aspect.

CHAPTER 3 EXPERIMENTAL PROGRAMME

3.1 GENERAL

The aim of this experimental program is to compare the behavior of Alccofine 1203 in use as a supplementary cementing material when subjected to different tests. All the tests carried out on concrete are mentioned here in this chapter followed by a brief description about mix design & aggregates .

3.2 MATERIAL USED

3.2.1 Cement

Cement is a fine, grey powder. It is mixed with water and sand, gravel and crushed stone to generate concrete. Cement and water form a paste that binds the other materials together as concrete hardens . Ordinary cement contains two basic ingredients named as argillaceous and calcareous. In the argillaceous materials clay predominates and in calcareous materials calcium carbonate predominates.

Table 2 Composition limits of Portland cement

INGREDIENT	CONTENT
CaO (Lime)	60-67
SiO_2(Silica)	17-25
Al_2O_3 (Alumina)	3-8
Fe_2O_3 (Iron oxide)	0.5-6
MgO (Magnesia)	0.1-4
Alkalies	0.4-1.3
Sulphur	1-3

Grade 43 Ultra tech cement was used for experimental purposes while casting of beams, cylinders, cubes for all concrete mixes. It was of a uniform grey colour with a slight greenish shade & was without any lumps. Various basic tests have been summarized as follows:

Table 3 properties of cement

S.No.	Characteristics	Values Obtained	Standard Values
1.	Normal Consistency	33%	-
2.	Initial Setting time	48 minutes	Not less than 30 minutes
3.	Final Setting time	240 minutes	Not greater than 600 minutes
4.	Fineness	4.8%	Less than 10
5.	Specific Gravity	3.09	-

3.2.2 Fine Aggregates

Sand used was locally procured and was found to be conforming to Indian Standard specifications IS 383-1970 . The sand was first sieved through 4.75 mm sieve to remove any particles larger than 4.75 mm and then was washed to remove the dust.

Table 3 Physical Properties of Fine Aggregated

Sr. No.	Chracteristics	Value
1.	Specific gravity	2.46
2.	Bulk density	1.4
3.	Finess modulus	2.56
4.	Water absorption	0.85
5.	Grading Zone (Based on percentage passing 0.60 mm)	Zone Ⅲ

Properties of fine aggregates used have been presented in following table .the aggregates were sieved through a set of sieves to obtain sieve analysis presented in table 4. The aggregates was found to belong to zone Ⅲ.

Table 4 Sieve analysis of fine aggregates

Sr. No	Sieve Size	Mass Retained	Percentage Retained	Cumulative Percentage Retained	Percentage Passing
1.	4.75 mm	4.0 g	0.4	0.4	99.6
2.	2.36 mm	75.0 g	7.50	7.90	92.1
3.	1.18 mm	178.0 g	178.0	25.70	74.3
4.	600 µ	220.0 g	220.0	47.70	52.3
5.	300 µ	274.0 g	27.4	75.10	24.9
6.	150 µ	246.5 g	24.65	99.75	0.25
7.				$\sum = 256.55$	

Total weight taken = 1000 gm

Fineness Modulus of Sand = 2.56

3.2.3 Coarse Aggregate

Coarse aggregate can be defined as any material Retained on IS no. 4.75 . The crushed stone is generally used as a coarse aggregate .The size of work decides the maximum size of coarse aggregate. 10 mm aggregate was used for this work which was locally available. The aggregate was washed to remove dust and dirt and were dried to surface dry condition . The aggregate were tested as per IS : 383-1970. The results of various tests conducted on coarse aggregate are mentioned in table 3.5 and table 3.6 shows the sieve analysis.

Table No. 05 :Physical Properties of coarse aggregates (10mm)

Sr. No.	**Characteristics**	**Value**
1.	Type	Crushed
2.	Specific Gravity	2.66
3.	Total Water Absorption	0.56
4.	Fineness Modulus	6.83

Table No. 06 Sieve analysis of coarse aggregates

Sr. No.	**Sieve Size**	**Mass Retained**	**Percentage Retained**	**Cumulative Percentage Retained**	**Percentage passing**
1	20 mm	0	0	0	100
2	10 mm	2516	83.39	83.87	16.13
3	4.75 mm	474	15.8	99.67	0.33
4	PAN	10	0.33	∑ =183.54	

Total weight taken = 3 Kg

FM of Coarse aggregate = [183.54 + 500] / 100 = 6.83

3.3.3 Water

Curing is a procedure that is adopted to promote the hardening of concrete under conditions of humidity and temperature which are conducive to the progressive and proper setting of the constituent cement. Curing has a major influence on the properties of hardened concrete such as durability, strength, water-tightness, wear resistance, volume stability, and resistance to freezing and thawing. Concrete that has been specified, batched, mixed, placed, and finished can still be a failure if improperly or inadequately cured. Curing is usually the last step in a concrete project and, unfortunately, is often neglected even by professionals. Water that is suitable for drinking should be used in concrete. Water from lakes and streams that contain marine life can also be used . No sampling is necessary when water is obtained from above mentioned source . If there is any suspicion that water may contain sewage, mine water or wastes from industrial plants or canneries , it should not be used until tests indicate them as satisfactory.

3.3.4 Supplementary cement materials

Supplementary cementing materials (SCM) also called Mineral admixtures contribute to thr properties of hardened concrete through hydraulic or pozzolanic activity. Typical examples are natural pozzolans, fly ash, ground granulated blast furnace slag and silica fume which can be used individually with Portland or blended cement or in different combinations. These materials react chemically with calcium hydroxide released from hydration of Portland cement to form cement compounds. These materials are often added to concrete to make concrete mixtures more economical, reduce permeability, increase or influence other concrete properties. Early SCMs consisted of natural, readily available materials such as volcanic ash or diatomaceous earth. More recently, strict air pollution controls and regulations have produced an abundance of industrial by products that can be used as supplementary cementitious materials such as fly ash, silica fume and blast furnace slag. The use of such by products in concrete construction not only prevents these products from being land filled but also enhances the properties of concrete in the fresh and hydrated states. SCMs can be used either as an addition to the cement or as a replacement for a portion of the cement. Most often SCM will be used to replace a portion of the cement. Most often SCM will be used to replace a portion of the cement content for economical or property enhancement reasons. Supplementary cementitious materials are often incorporated in the concrete mix to reduce cement contents, improve workability, increase strength and enhance durability. SCMs can be divided into two categories based on their type of reaction ; supplementary cementing materials or mineral admixtures. Hence theses have a potential to reduce the cost of concrete in addition to conferring the benefit of providing Supplementary cementitious properties. Thses admixtures play a reactive part in chemical reactions of the hydration system. Mineral admixture include for e.g. silca fume , fly ash , GGBS, rice husk ash, Natural Pozzolons,

3.3 Mixture Proportioning

For HPC there is no specific method of design mix. In the present investigation approximations form I.S method as per I.S.10262:2009 and also as per the available literatures on ultrafine slag are used. In order to achieve high strength lower w/b ratio is adopted and to achieve good workability Alccofine 1203 is used. The trial mix proportions of the concrete are shown in Table 3.7 . In the present investigation w/b ratio used is 0.29 .

Table No 07 Mix proportion for grade M60

Grade	**water**	**cement**	**Fine aggregate**	**Coarse aggregate**
M60	0.29	1	1.35	2.19

3.4 Batching, Mixing and Casting of Specimens

Cubical moulds of size 100mm x 100mm x 100mm were used to prepare the concrete specimens for the determination of compressive strength of concrete. Care was taken during casting and . The moulds were placed upon the compaction table for proper compaction. Cylindrical moulds of size 100 mm x 200 mm were used to prepare the concrete specimens for the determination of split tensile strength of steel reinforced concrete. Rectangular moulds of 100mm x 100mm x 500mm were used for flexural testing of beams. All the specimens were prepared in accordance with Indian Standard Specifications IS: 516-1959. All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. A careful procedure was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 grams. The concrete mixture was prepared by the concrete mixer. It was cleaned first by water and dried then , to ensure any impurities were not adhering to its surface form prior use .OPC having 43 grades was used in casting. Dry fine aggregates are introduced first in the mixer & are thoroughly mixed. After that coarse aggregates are added to it. Cement replaced by ultrafine slag (alccofine 1203) as per optimum percentage by weight was added . Then water was added carefully so that no water was lost during mixing. A total of 84 cubes, 117 beams and 45 cylinders were prepared which consists of cubes , beams , cylinders incorporated with alccofine 1203 along with steel fibers and steel reinforcements in required cases. Proposed checks were made at 7, 14 and 28 days . The compaction machine was stopped as soon as the cement slurry appeared on the top surface of the mould. All the specimens were left in the steel mould for the first 24 hours at ambient condition. After that they were de-moulded with care upon requirement of aging so that no edges were broken and were placed in the curing tank at the room temperature for curing. The room temperature for curing was 27 ± 20 (IS: 10262-1982).

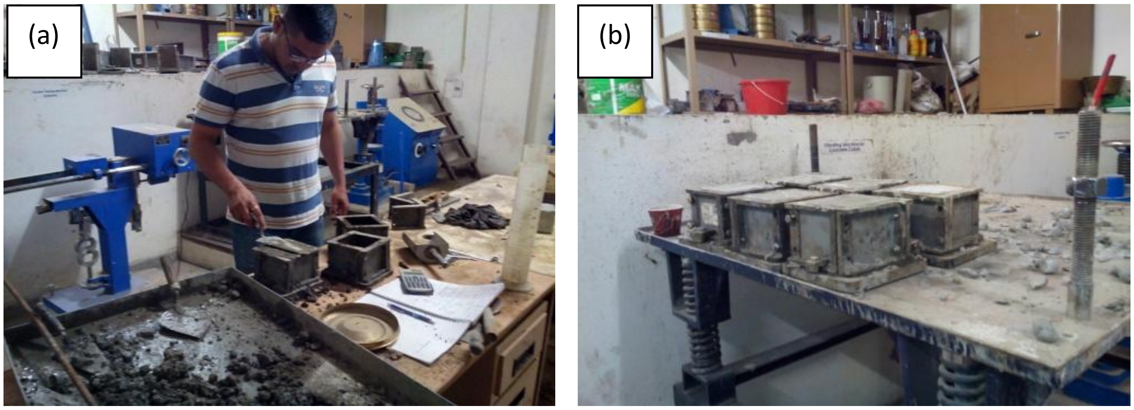

Figure No. 01 (a, b) Cubes being casted and on vibrating table.

3.5 Tests Conducted

3.5.1 Compression test (IS: 516 – 1959)

The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load a without shock and increased continuously at a rate of approximately 140 $kg/cm^2/min$ until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.The permissible error shall be not greater than ± 2 percent of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied. The bearing surface of the platens, when new, shall not depart from a plane by more than 0.01 mm at any point, and they shall be maintained with a permissible variation limit of 0.02 mm. The movable portion of the spherically seated compression platen shall be held on the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction. The measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area, calculated from the mean dimensions of the section and shall be expressed to the nearest kg per sq cm. Average of three values shall be taken as the representative of the batch provided the individual variation is not more than ± 15 percent of the average. Otherwise repeat tests shall be made.

3.5.2 Flexural Bending Test (IS: 516 – 1959)

The testing machine may be of any reliable type of sufficient capacity for the tests and capable of applying the load at the rate such that the extreme fibre stress increases at approximately 7 kg/cm^2/min, that is, at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens. The load shall be increased until the specimen fails, and the maximum load applied to the specimen during the test shall be recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure shall be noted. The permissible errors shall be not greater than ± 0.5 percent of the applied load where a high degree of accuracy is required and not greater than ± 1.5 percent of the applied load for commercial type of use. The bed of the testing machine shall be provided with two steel rollers, 38 mm in diameter, on which the specimen is to be supported and these rollers shall be so mounted that the distance from centre to centre is 60 cm for 15.0 cm specimens or 40 cm for 10.0 cm specimens. The load shall be applied through two similar rollers mounted at the third points of the supporting span, that is, spaced at 20 or 13.3 cm centre to centre. The load shall be divided equally between the two loading rollers, and all rollers shall be mounted in such a manner that the load is applied axially and without subjecting the specimen to any torsional stresses or restraints. One suitable arrangement which complies with these requirements is indicated in Fig. 03.

Calculation — The flexural strength of the specimen shall be expressed as the modulus of rupture f_b, which, if '*a*' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, shall be calculated to the nearest 0.5 kg/sq cm as follows :

$$f_b = \frac{p \times l}{b \times d^2};$$

when '*a*' is greater than 20.0 cm for 15.0 cm specimen, or greater than 13.3 cm for a 10.0 cm specimen, or

$$f_b = \frac{3p \times a}{b \times d^2}$$

Where If '*a*' is less than 17.0 cm for a 15.0 cm specimen, or less than 11.0 cm for a 10.0 cm specimen, the results of the test shall be discarded.

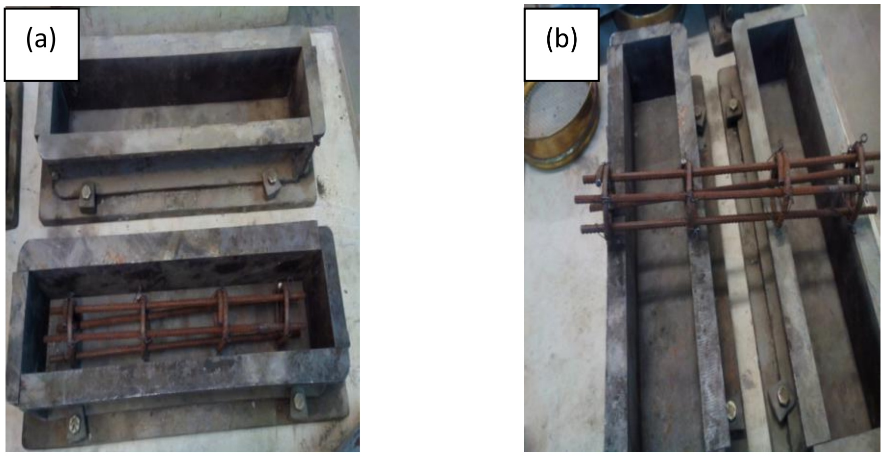

Figure 02 (a,b) Size Of Mould of beam – 500 mm x 100 mmx100mm
R/F -- 8 mm (Longitudinal) 480 mm
6 mm (Stirrups) @ 150 mm c/c

Figure No 03 Plain Concrete Beam placed in U.T.M

3.5.3 Split Tensile Test (IS 5816 : 1999)

Fibre reinforced concrete (FRC) is Portland cement concrete reinforced with more or less randomly distributed fibres. In FRC, thousands of small fibres are dispersed and distributed randomly in the concrete during mixing, and thus improve concrete properties in all directions. FRC is cement- based composite material that has been developed in recent years. It has been successfully used in construction with its excellent flexural-tensile strength resistance to spitting, impact resistance and excellent permeability and frost resistance. It is an effective way to increase toughness, shock resistance and resistance to plastic shrinkage cracking of the mortar. Fibre is a small piece of reinforcing material possessing certain characteristics properties. They can be circular, triangular or flat in cross-section. The fire is often described by a convenient parameter called aspect ratio. The aspect ratio of the fibre is the ratio of its length to its diameter. The principle reason for incorporating fibres into a cement matrix is to increase the toughness and tensile strength and improve the cracking deformation characteristics of the resultant composite. For FRC to be a viable construction material, it must be able to compete economically with existing reinforcing system. FRC composite properties, such as crack resistance, reinforcement and increase in toughness are dependent on the mechanical properties of the fibre, bonding properties of the fibre and matrix, as well as the quantity and distribution within the matrix of the fibres.

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A compression machine of sufficient capacity & reliability shall be used for the tests an should be capable of applying the load without shock and accelerated continuously at a nominal rate within the range 1.2 N/(mm^2/min) to 2.4 N/ (mm^2/min) should be used. It shall comply with the requirements given in IS 516 as far as applicable except that the bearing faces of both platens shall provide a minimum loading area of 12 mm multiplied by the length of the cylinder or cube, as the case may be so that the load is applied over the entire length of the specimen. If necessary, a supplementary bearing bar or plate of machined steel may be used. A steel loading plate having minimum hardness value, when tested in accordance with IS 1500 shall be used between the platen of the machine and the hardboard packing strips. The piece shall not be shorter than the specimen. One such arrangement is shown in figure no. 04 . Tests shall be made at the required ages of the test specimens, that is at 7 , 14 and 28 days. The ages shall be calculated from the time of the casting of the moulds. The age at test shall be reported along with the results. At least three specimens are to be tested for each age of tests. Unless other conditions are required for specific laboratory investigation specimen shall be tested immediately on removal from the water whilst they are still wet . Surface water and grit shall be wiped off the specimens and any projecting fins removed from the surfaces if any. Central lines shall be drawn on the two opposite faces of the cube using any suitable procedure and a device that will ensure that they are in the same axial plane. The mass and dimensions of the specimen shall be noted before testing. The sides of the specimen, lying in the plane of the pre-marked lines, shall be measured near the ends and the middle of the specimen and the average taken to the nearest 0.2 mm. The length of the specimen shall be taken to the nearest 0.2 mm by averaging the two lengths measured in the plane containing the pre-marked lines. Before commencement of testing the bearing surfaces of the testing machine and of the loading strips have to be wiped clean and the test specimen shall be placed in the centering jig with packing strip and loading pieces carefully positioned along the top and bottom of the plane of loading of the specimen. The jig shall then be placed in the machine so as to locate the specimen centrally. For cylindrical specimen it shall be ensured that the upper platen is parallel with the lower platen. On manually controlled machines as failure is approached the loading rate decreases at this stage the controls shall be operated to follow possible the specified loading rate as far as. The maximum load applied shall then be recorded. The appearance of concrete and any unusual features in the pattern of failure are to also be noted. The rate of increase of load may be calculated from the formula:

$$(1.2 \text{ to } 2.4) \times \frac{\pi}{2} \times I \times d \quad \text{N/min.}$$

The measured splitting tensile strength f_{ct} , of the specimen shall be calculated to the nearest 0.05 N/mm^2 using the following formula:

$$f_{ct} = \frac{2P}{\pi \text{ld}}; \quad \text{where}$$

P = maximum load in Newtons applied to the noted before testing.

I = length of the specimen as shown in (in mm), and

d = cross sectional dimension of the specimen (in mm).

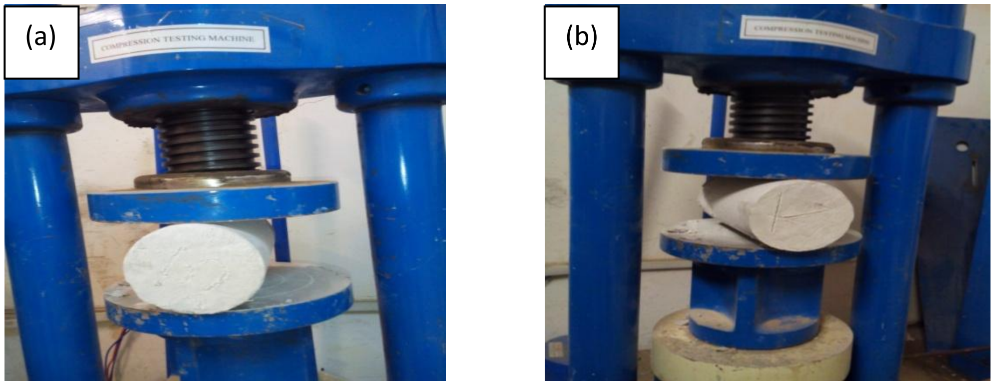

Figure No. 04 (a,b) Cylinders under compression testing machine

3.5.4 Fire Resistance Test

The 100mm x 100mm x 100mm size cubes were casted and mould was kept in wet place for 24 hours, then prepared cubes were removed from the mould and placed in water for 28 days at room temperature. Later those cubes were heated in the electric muffle furnace which is provided with a thermostat to maintain constant temperatures at different ranges. At a time 24 cubes i.e. 8 sets of 3 cubes each were prepared out of which half were submerged for 14 days & other half for 28 days. These sets were heated for 1, 2, 3 hours at 4 different temperatures (27 ^{0}C, 500 ^{0}C, 650 ^{0}C, 800^{0}C). After that these sets were left at room temperature for 24 hours for cooling. Compressive strength has been calculated as per BIS 516-1959. Each of the samples selected for testing should be exposed to the desired duration once it gas reached the desired temperature. After fire resistance test, compressive strength of the samples was determined to detect effect of fire on strength properties of concrete cubes.

The testing machine for compressive test should be reliable of sufficient capacity and capable of applying the load at the rate of approximately 140 kg/cm^{2}/min until the resistance of the specimen to the increasing load gives in and no greater load can be continued . The permissible error should be not greater than ± 2 percent of the maximum load. The testing machine must be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied. The bearing surface of the platens, when new, shall not depart from a plane by more than 0.01 mm at any point, and they shall be maintained with a permissible variation limit of 0.02 mm. The movable portion of the spherically seated compression platen shall be held on the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction. Three specimens, from different batches, were made for testing at each of the required age. Specimens that were stored in water were tested immediately on removal from the water while they were in the wet condition. Surface water and grit if any should be wiped off along with any projecting fins .The dimensions of the specimens should be checked to the nearest 0.2 mm and their weight before testing. 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 and not to the top and bottom. The axis of the specimen needs to be carefully aligned with the centre of thrust of the spherically seated platen. No packing should be used between the faces of the test specimen and the steel platen of the testing machine. As the spherically seated block is brought to bear on the specimen, the movable portion shall be rotated manually so that uniform seating may be obtained. The load shall be applied without shock and accelerated continuously at specified rate. The load at which the specimen fails is to be recorded along with the appearance of the concrete . If any unusual patterns are there in the type of failure , they shall be noted. The measurement of the compressive strength of the specimens are to be calculated by dividing the maximum load applied upon the specimen during testing divided by the cross-sectional area, calculated from the mean dimensions of the section and shall be expressed to the nearest kg /cm^2. Only the average of three values should be taken as the representative of the batch provided the individual variation is not more than ± 15 percent of the average value. If so , tests are to be revised. A correction factor according to the height/diameter ratio of specimen after capping shall be obtained from the curve for correction factor for height-diameter ratio of a core presented in IS 516-1959. The execution of this correction factor and the measured compressive strength is the corrected compressive strength, this being the equivalent strength of a cylinder having a height/diameter ratio of two. The equivalent cube strength of the concrete shall be determined by multiplying the corrected cylinder strength by $\frac{5}{4}$.

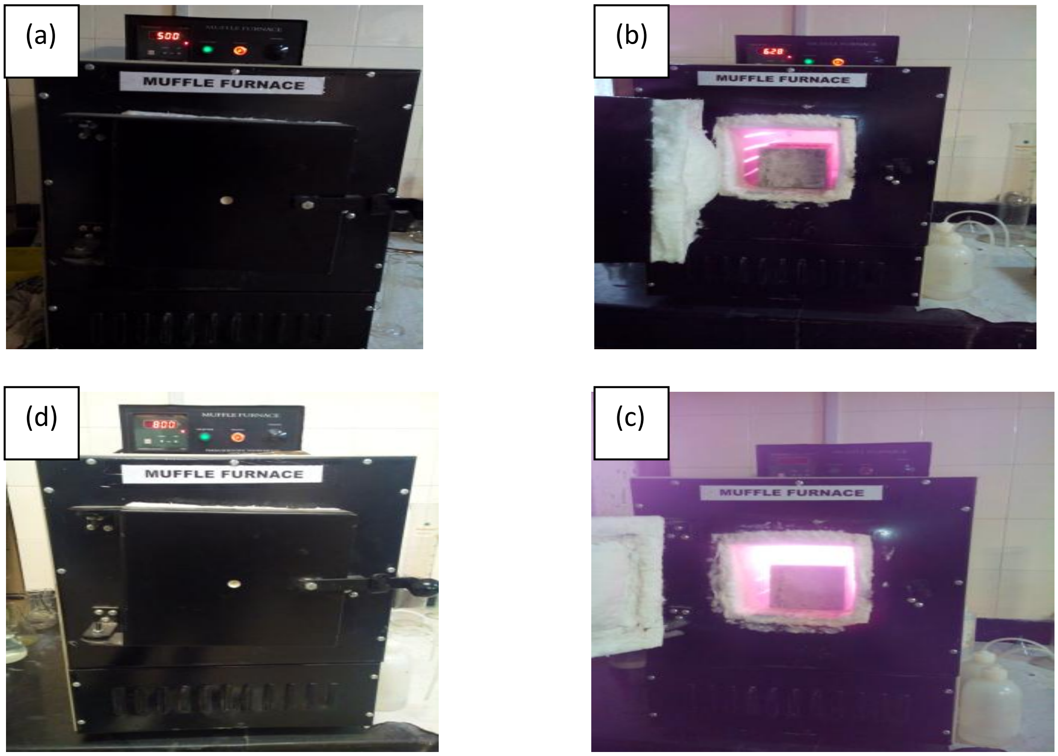

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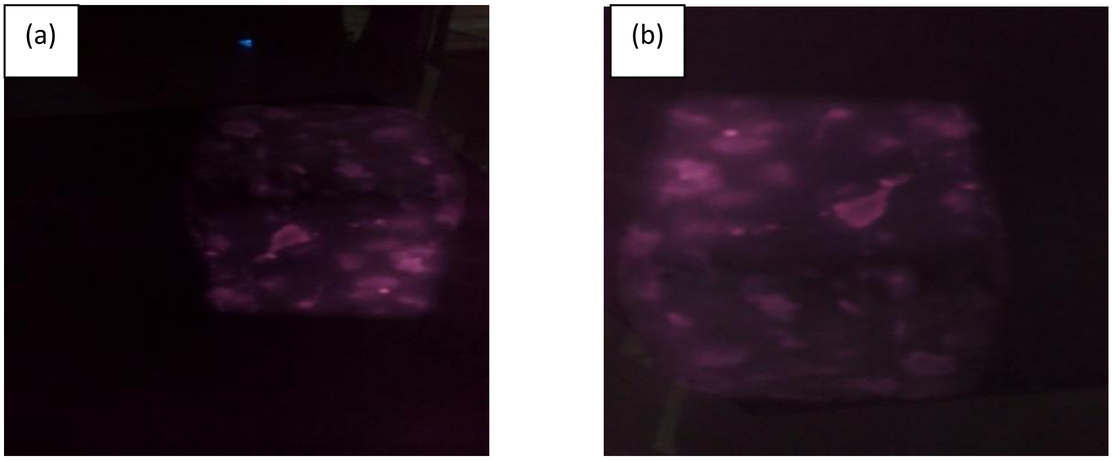
Figure No. 05 (a,b,c,d,) Cubes incorporating ultrafine slag at varying temperatures placed in muffle furnace.



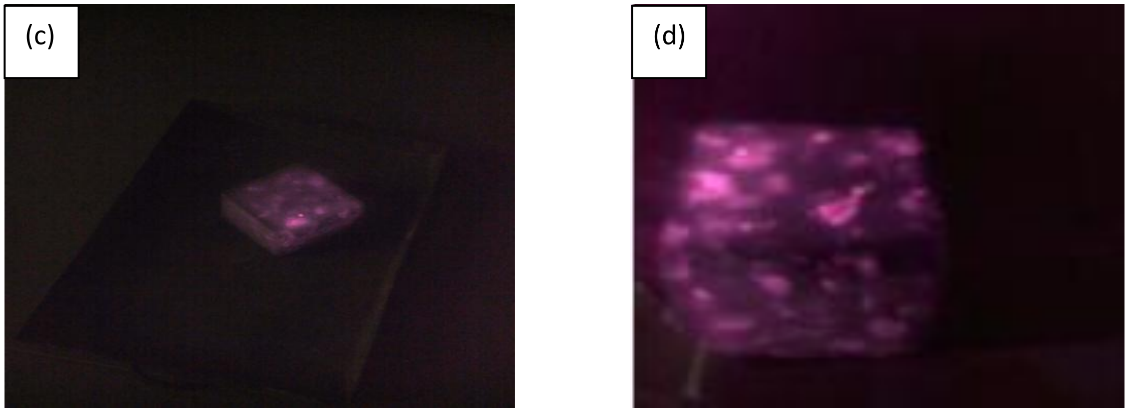


Figure No. 06 (a,b,c,d,) Cubes taken out from furnace after desired exposure duration

3.5.5 Durability tests

A long service life is considered synonymous with durability. Since durability under one set of conditions does not necessarily mean durability under another, it is customary to include a general reference to the environment when defining durability. According to ACI Committee 201, durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration; that is, durable concrete will retain its original form, quality, and serviceability when exposed to its environment. No material is inherently durable; as a result of environmental interactions the microstructure and, consequently, the properties of materials change with time. A material is assumed to reach the end of service life when its properties under given conditions of use have deteriorated to an extent that the continuing use of the material is ruled either unsafe or uneconomical.

3.5.5.1 Sulphate Attack

Most soils contain some sulphate in the form of calcium, sodium, potassium and magnesium. They occur in soil or ground water. Because of solubility of calcium sulphate is low, ground waters contain more of other sulphates and less of calcium sulphate. Ammonium sulphate is frequently present in agricultural soil and water from the use of fertilizers or from sewage and industrial effluents. Decay of organic matters in marshy land, shallow lakes often leads to the formation of H_2S, in which can be transformed in to sulphuric acid by bacterial action. Water used in concrete cooling towers can also be a potential source of sulphate attack on concrete. Therefore sulphate attack is a common occurrence in natural or industrial situations. Solid sulphates do not attack the concrete severely but when the chemicals are in solution, they find entry into porous concrete and react with the hydrated cement products. Of all the sulphates magnesium sulphate causes maximum damage to concrete. A Characteristic whitish appearance is the indication of sulphate attack. The term sulphate attack denote an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates. In the hardened concrete, calcium sulphoaluminate, forming within the framework of hydrated cement paste. Because of the increase in volume of the solid phase which can go up to 227 percent, a gradual disintegration of concrete takes place. Another factor influencing the rate of attack is the speed in which the sulphate gone into the reaction is replenished. For this it can be seen that when the concrete is subjected to the pressure of sulphate bearing water on one side the rate of attack is highest.

3.5.5.2 Chloride Attack

The free chloride content in concrete has been found to be one of the major causes for corrosion of steel and it is one of the critical issues being dealt today by civil engineers globally . In fact, in the marine environment, a large number of concrete bridges, dams, and other mega structures have suffered from safety and serviceability problems due to the deterioration of concrete, can be directly attributed to the chloride penetration into the concrete. It is also understandable from the reported literature that, most of the concrete structures failed in the past are not necessarily due to inadequate design but due to failure of concrete to protect reinforcing steel from aggressive elements like chlorides. The chlorides that are penetrated through concrete pores depend upon the pore structure of concrete and the improvement in pore structure is mainly achieved by the use of mineral admixtures like fly ash, silica fume, metakaolin. In addition, these admixtures reduce the mobility of chloride ions by changing the mineralogy of the cement hydrates. The chloride permeability depends on several factors like chemical composition of cement, water-to cement ratio, types and amounts of mineral admixtures etc. Therefore, in order to improve the resistance of concrete to chloride penetration, the mix proportions of concrete should be carefully selected considering the above parameters. Many studies have been carried out on the use of admixtures, however search for efficient alternative admixture is still continuing. Thus in the present work, studies were carried out on the compressive strength and chloride resistance of concrete, thereby reducing the corrosion susceptibility by adding alccofine as a partial replacement of cement.

3.5.5.3 Curing in acid solution

Curing is adopted to promote the hardening of concrete under conditions of humidity and temperature which are conducive to the progressive and proper setting of the constituent cement. Curing has a major influence on the properties of hardened concrete such as durability, strength, water-tightness, wear resistance, volume stability, and resistance to freezing and thawing. Concrete that has been specified, batched, mixed, placed, and finished can still be a failure if improperly or inadequately cured. Curing is usually the last step in a concrete project and, unfortunately, is often neglected even by professionals. 3 sets of five different mixes of M60 Grade namely referral concrete (AC_0), concrete made by replacing 12% of cement by Alccofine (AC12) & concrete made by replacing 14% of cement by Alccofine (AC14) were prepared & so on. The cubes were demoulded after 1 day of casting and then kept in respective solutions of 5% H_2SO_4 , 5 % HCL & in referral solution of 100 % H_2O for curing, at room temperature with a normal humidity.The cubes are taken out from curing after 30 days .The surface of specimen was cleaned and weights were measured. The mass loss and strength of specimen due to acid attack was determined at 30 days.

Chapter 4 RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter, Compressive strength, Flexural Strength , Tensile strength and Sulphate resistance & Chloride resistance of various concrete mixes incorporating ultrafine slag (Alccofine-1203) in varying percentages is discussed. All the tests conducted were in accordance with the methods described in chapter three. Results were compared and checked for compressive strength, split tensile strength, fire resistance, sulphate resistance and chloride resistance of concrete.

4.2 Ultrafine Slag

The effect of ultrafine slag upon concrete has been presented as follows upon the compressive strength, flexural strength, split tensile test, fire resistance, sulphate attack and chloride resistance.

4.2.1 Compressive Strength

Concrete was prepared under moderate exposure condition and quality control was good. It was poured into cubical moulds and placed on vibrating table to minimize air entrapped which would otherwise affect the compressive strength. After 24 hrs the moulds were removed and the specimens were kept for curing at room temperature until taken out for testing. Specimens were tested at different ages i.e. 3 days, 7 days and 28 days compressive strength. The load is applied at a constant rate thus ensuring progressive increase in stress as failure approached.

Table 08 Compressive strength of concrete mixes, incorporating varying percentages of alccofine 1203 at 7, 14 and 28 days

MIX	Compressive strength (N/mm^2)			Average Compressive strength (N/mm^2)		
	7 days	14 days	28 days	7 days	14 days	28 days
C 0	42.3	47.56	63.1	`42.1	48	63.5
	41.7	48.21	62.9			
	42.3	48.23	62.5			
C 8	42.89	61.45	69.10	43.32	62.6	71.20
	42.56	62.7	70.56			
	44.51	63.35	73.94			
C 10	44.23	79.00	81.63	45.32	79.44	82.40
	46.50	78.25	82.10			
	45.16	81.07	83.40			
C 12	44.57	82.21	89.20	47.32	83.13	88.60
	46.56	83.92	88.43			
	50.83	83.26	88.17			
C 14	45.61	70.56	88.96	45.12	71.33	87.83
	45.36	71.89	88.08			
	44.39	71.54	86.45			

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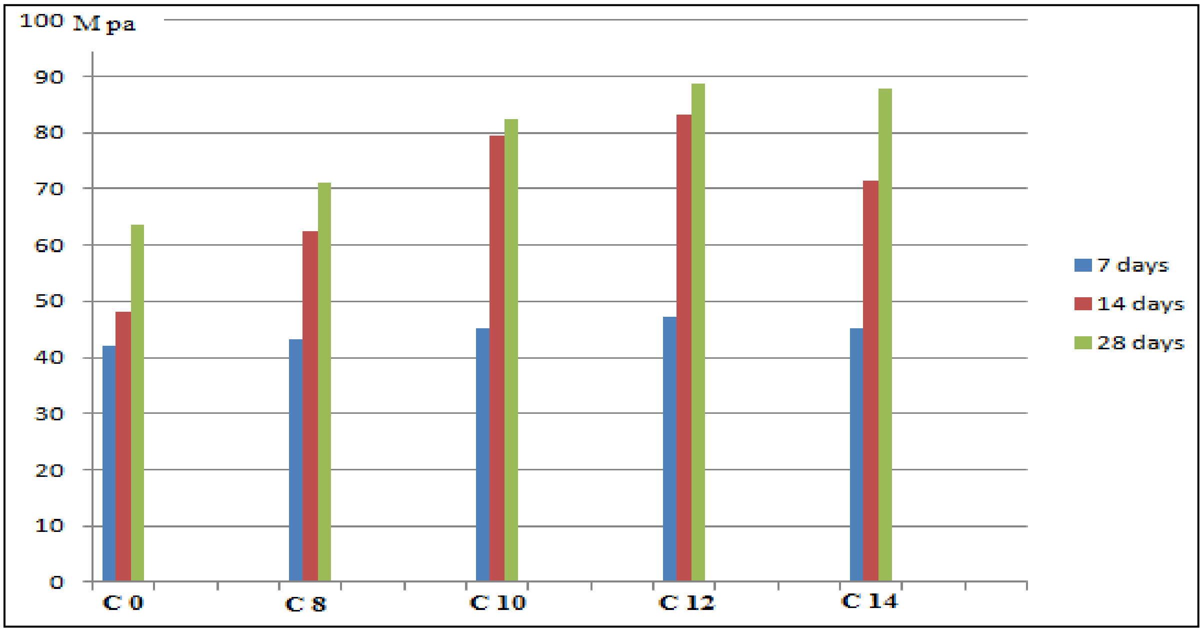


Figure No. 07 Comparison of compressive strength of concrete cubes at ages of 7 ,14 and 28 days..

4.2.2 Flexural strength

In order to study the effect on flexural strength, the beams containing different proportion of alccofine-1203 were prepared and kept for curing for 7, 14 and 28 days. The test was conducted on U.T.M as per I.S.516-1959.

Table 9 Nomenclature for beams

Plain concrete beams	**R/F concrete beams**
C 0 - 00% (00 gm)	R 0 - 00% (00 gm)
C 08 - 08% (240 gm)	R 08 - 08% (240 gm)
C 10 - 10% (300 gm)	R 10 - 10% (300 gm)
C 12 - 12% (360 gm)	R 12 - 12% (360 gm)
C 14 - 14 % (420 gm)	R 14 - 14% (420 gm)

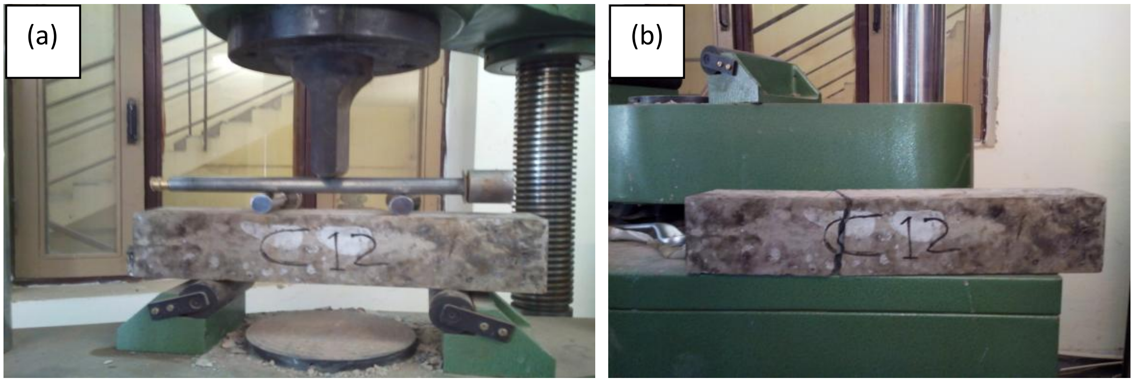


Figure 8   (a,b,c) Plain Concrete Beam placed in U.T.M

Figure No. 9 (a,b,c) Failure of reinforced concrete beams.

Table No. 10 Flexural strength of plain concrete beams, incorporating varying percentages of Alccofine 1203 at 7, 14 and 28 days.

MIX	**Flexural strength (N/mm^2)**			**Average Flexural strength (N/mm^2)**		
	7 days	14 days	28 days	7 days	14 days	28 days
C 8	1.51	3.40	5.8	1.58	3.40	6.1
	1.57	3.20	5.9			
	1.66	3.6	6.6			
C 10	1.59	3.40	6.5	1.65	3.52	6.8
	1.74	3.86	7.4			
	1.62	3.30	6.5			
C 12	1.70	3.80	6.80	1.68	3.79	6.92
	1.65	3.69	6.85			
	1.69	3.88	7.11			
C 14	1.9	3.5	6.45	1.89	3.45	6.50
	1.85	3.45	6.55			
	1.92	3.40	6.50			

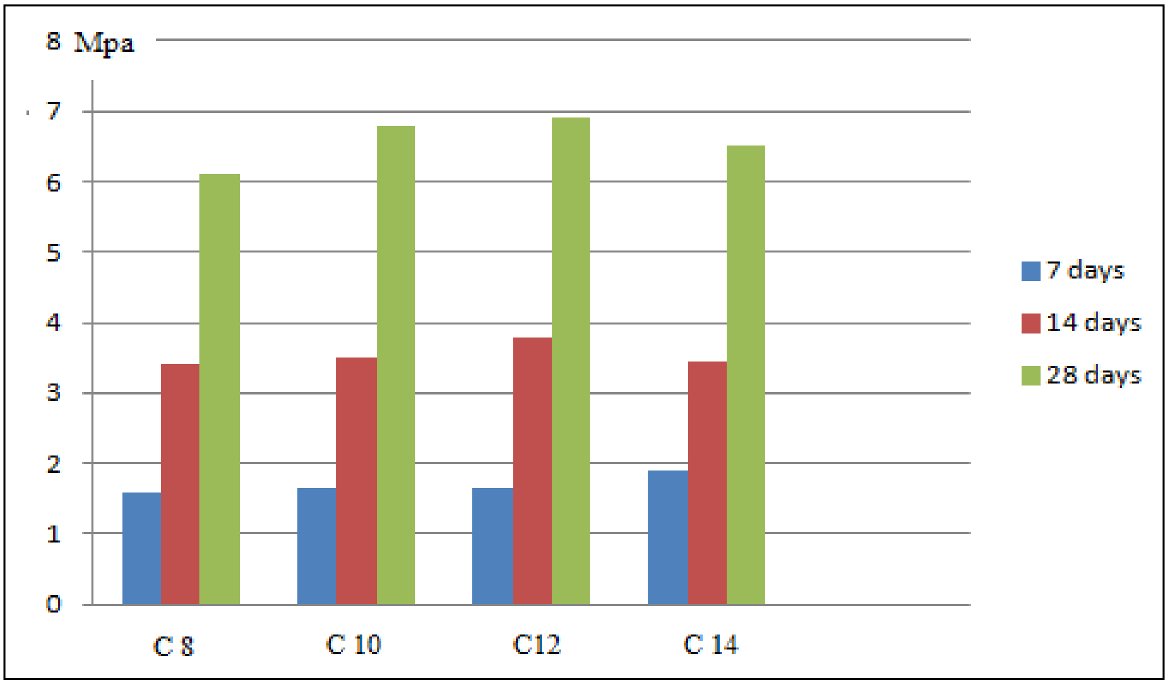


Figure No. 10 Comparison of flexural strength of plain concrete beams, incorporating varying percentages of Alccofine 1203 at 7, 14 and 28 days.

Table No. 11 Flexural strength of reinforced concrete beams, incorporating varying percentages of Alccofine 1203 at 7, 14 and 28 days.

Mix	**Flexural strength (N/mm^2)**			**Average Flexural strength (N/mm^2)**		
	7 days	14 days	28 days	7 days	14 days	28 days
R 8	4.50	9.40	18.75	4.52	9.44	19.63
	4.45	9.35				
	4.61	9.57	19.0			
R 10	6.26	13.10	25.45	6.13	12.87	26.64
	6.10	11.50	28.48			
	6.03	14.00	26.0			
R 12	6.80	14.40	29.58	6.92	14.46	30.076
	7.00	14.78	29.65			
	6.95	14.20	31.0			
R 14	6.0	12.75	27.30	6.15	13.16	28.25
	6.2	13.73	28.15			
	6.25	13.0	29.30			

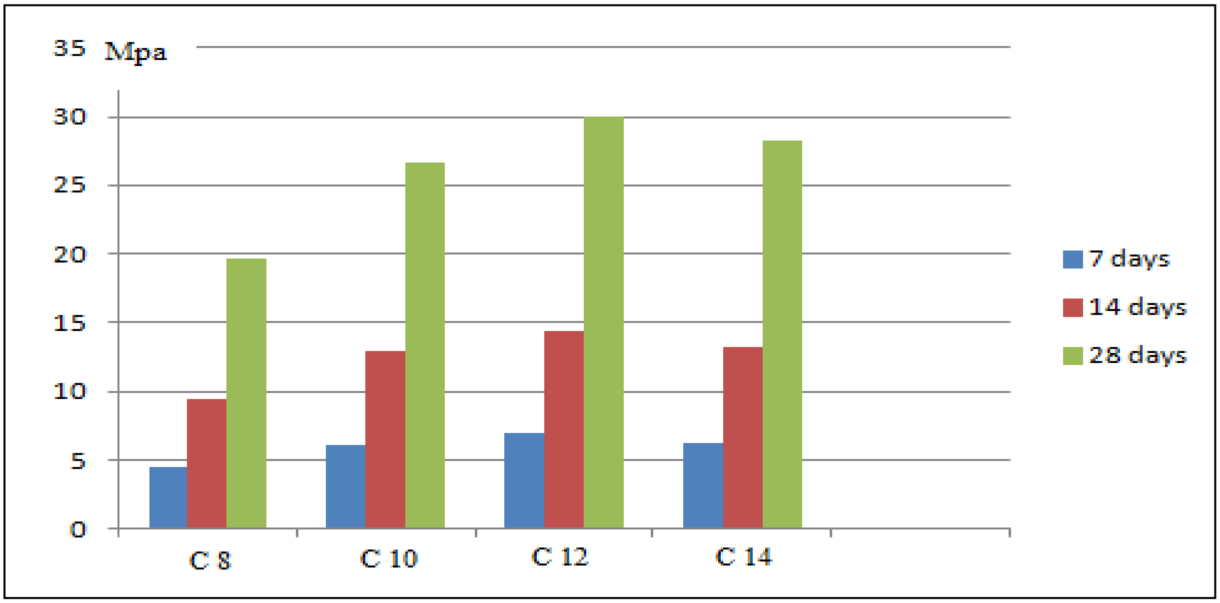


Figure No 11. Comparison of flexural strength of reinforced concrete beams, incorporating varying percentages of Alccofine 1203 at 7, 14 and 28 days.

4.2.3 Split tensile test

Steel fibres reduce steel reinforcement requirements, improve ductility, structural strength, reduce crack widths and control the crack widths tightly thus improve durability, improve impact & abrasion resistance, improve freeze- thaw resistance Steel fibres cut to size 50 mm are used in this investigation. Steel Fibres are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibres produced greater impact, abrasion and shatter resistance in concrete. Generally fibres do not increase the flexural strength of concrete and so cannot replace moment resisting or structural steel reinforcement. Indeed, some fibres actually reduce the strength of concrete. The amount of fibres added to the concrete mix is expressed as a percentage of total volume of the composite (concrete and fibres), termed volume fraction . It typically ranges from 0.1 to 2%. Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d) . Fibres with a non circular cross section use an equivalent diameter for the calculation of aspect ratio. If the modulus of elasticity of the fibre is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increase in the aspect ratio of the fibre usually segments the flexural strength and the toughness of the matrix. However, fibres which are too long tend to ball in the mix and create work ability problems. Some recent research indicated that using fibres in concrete have limited effect on the impact resistance of the materials. This finding is very important since traditionally, people think that the ductility increases when concrete is reinforced with fibres. The properties of steel fibre used are presented in Table 13 below.

Table No. 12 Properties of steel fibre

Length	50mm
Diameter	1mm
Appearance	clear and bright
Tensile strength	800-2500 mpa
Shape	Rectangular
Size	0.8mm x 0.35mm
Aspect ratio	43.75

Figure 12 Steel Fibers

4.2.3.1 Advantages of SFRC:

1. Fast and perfect mixable fibers and High performance and crack resistance
2. Optimize costs with lower fiber dosages
3. Steel fibres reinforced concrete against impact forces, thereby improving the toughness characteristics of hardened concrete.

4. Steel fibres reduce the permeability and water migration in concrete, which ensures Protection of concrete due to the ill effects of moisture.
5. Fibres are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage.

For the experimental work mix prepared was of M60 grade concrete. The cylinders were cast in steel moulds of 100mm×200mm (IS 5816 : 1999). The beams were also cast in steel moulds of 500mm x100 mmx100 mm (IS 10086:1982). Mix proportions for grade M60 has water cement ratio taken as 0.29 which is less than maximum w/c ratio as per IS 456 : 2000 for moderate exposure condition.

4.2.3.2 Mixing Procedure for Steel Fibres

For variation in concentrations of steel fibers in specimens, they were weighted in different quantities as per calculated conversions of volume in terms of weight this was done by means of an electronic weighing balance. Each of the small fibres are dispersed and distributed randomly in the concrete during mixing, and thus improve properties of concrete in different directions.

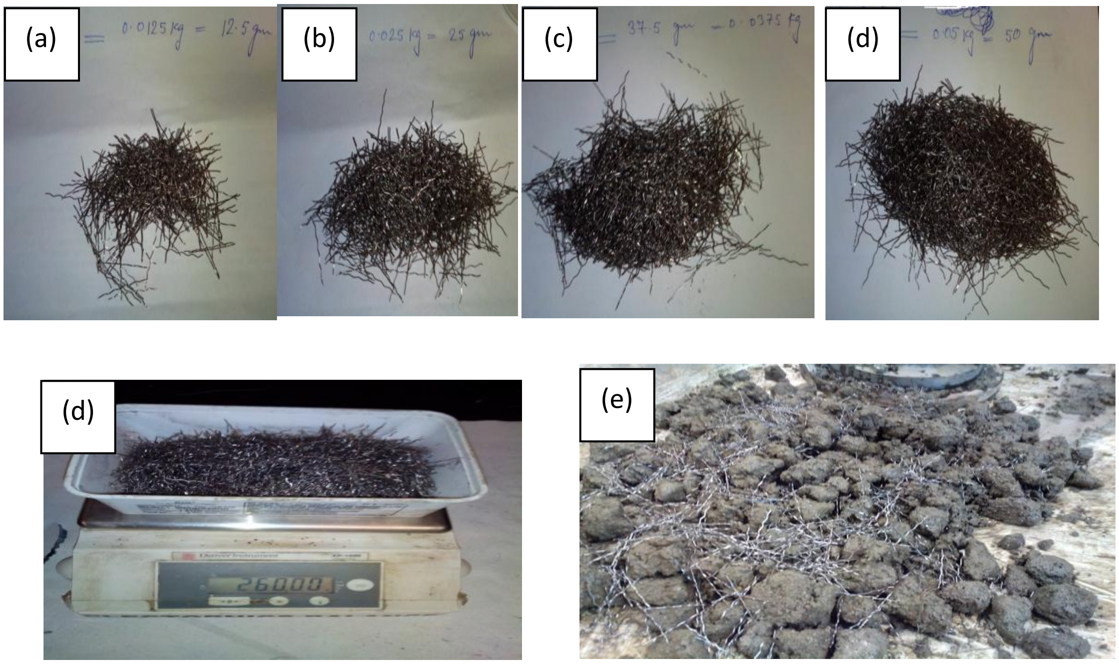


Figure No 13 (a , b , c , d , e) Steel fibres weighed & being mixed in concrete

Concrete mixed with steel fibers was prepared under moderate exposure condition and quality control was good. It was poured into cylindrical & rectangular moulds and was hand compacted by tamping rod to ensure homogenous distribution of steel fibers to minimize air entrapped which would otherwise affect the compressive strength. After 24 hrs the moulds were removed and the specimens were kept for curing at room temperature until taken out for testing. Specimens were tested at different ages i.e. 7 days, 14 days and 28 days for split tensile test & at 28 days for flexural strength. The load is applied at a constant rate thus ensuring progressive increase in stress as failure approached. For the cylinders the top surface of the cylinder was kept in contact with the platen of the existing machine (fig 4 a, b). For evolution of performance of concrete using ultra fine slag (Alccofine-1203) with varying steel fiber content different specimens were created. These are subdivided into eight as follows groups.

1. Control concrete without steel fibre. (0%)
2. Control concrete with 0.5% steel fibre. (0.5%)
3. Control concrete with 1.0% steel fibre. (1%)
4. Control concrete with 1.5% steel fibre. (1.5%)
5. Control concrete with 2.0% steel fibre. (2%)

Figure No.14 Set of cylinders in moulded conditions

Figure No. 15 Set of cylinders in demoulded state

Table No. 13 Split tensile strength of concrete cylinders, incorporating 12 % alccofine-1203 & varying percentages of steel fibers at 7, 14 and 28 days.

Mix	Tensile strength (N/mm^2)			Average Tensile strength (N/mm^2)		
	7 days	14 days	28 days	7 days	14 days	28 days
SC0	42.65	47.0	55.65	45.60	49.86	58.40
	40.90	49.65	58.23			
	53.25	52.93	61.32			
SC5	80	80.90	80.56	79.30	80.63	83.80
	74.5	78.42	83.47			
	73.80	78.15	78.74			
SC10	78.56	77.25	78.98	80.10	81.20	84.12
	73.7	77.61	85.50			
	75.0	81.56	81.32			
SC15	76.90	83.45	80	81	82.33	85
	77.9	83.12	82.25			
	82.0	82.0	87.25			
SC20	77.50	80.55	82.5	77.20	81.40	82.60
	79.78	81.15	78.55			
	79.48	82.0	78.45			

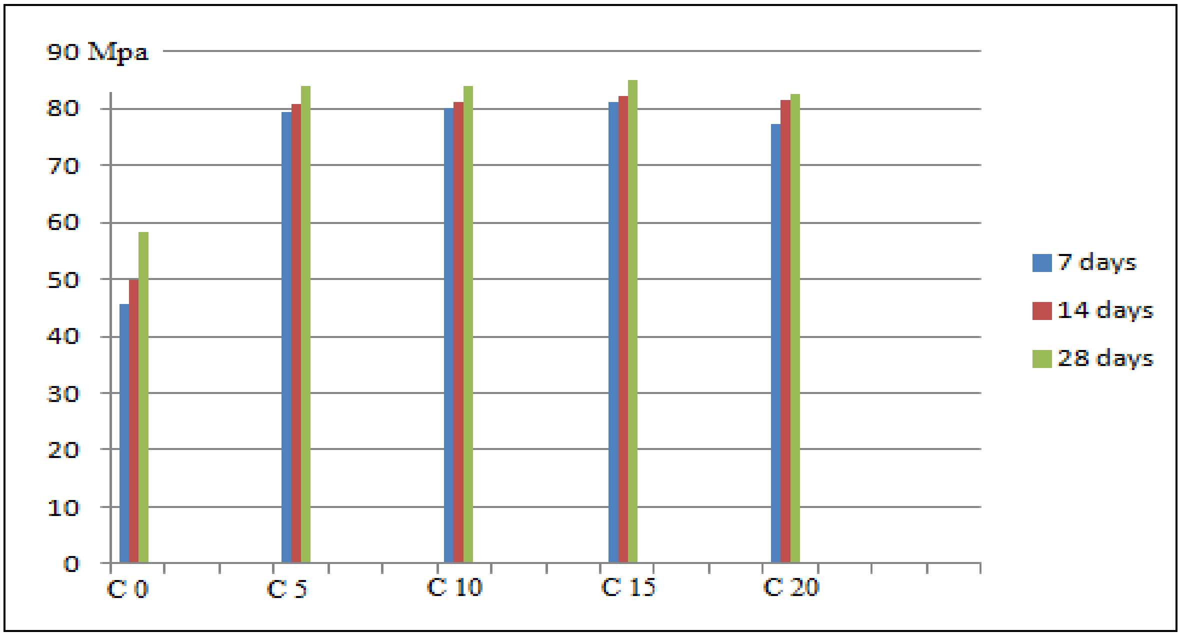


Figure 16 Comparision of split tensile strength of concrete cylinders, incorporating 12 % alccofine - 1203 & varying percentages of steel fibers at 7, 14 and 28 days.

4.3 Flexural testing of beams reinforced with steel fibers

The results of flexural testing are presented in Table 15 . The test was carried out conforming to IS 516-1959 to obtain flexural strength of concrete beams at the age of 7, 14 and 28 days under two point loading technique . The beams were tested using universal testing machine (U.T.M) as per I.S. 516- 1959.

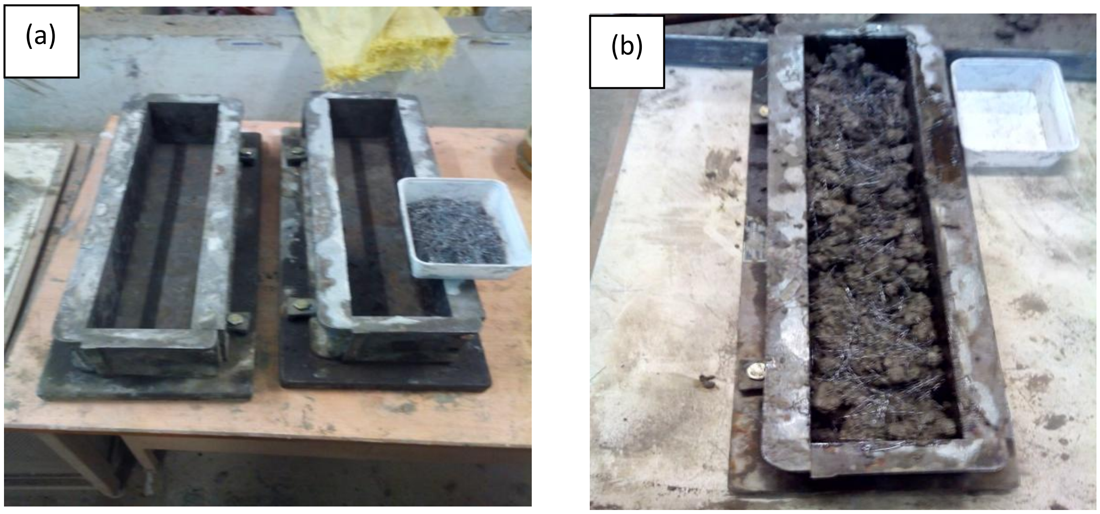


Figure No. 17 (a,b,c) Concrete beams incorporated with steel fibers

Table No. 14 Flexural strength of concrete beams, incorporating 12 % Alccofine- 1203 & varying percentages of steel fibers at 7, 14 and 28 days.

Mix	Flexural strength (N/mm^2)			Average Flexural strength (N/mm^2)		
	7 days	14 days	28 days	7 days	14 days	28 days
SB0	1.50	3.6	6.1	1.68	3.79	6.92
	1.55	3.4	5.8			
	1.99	4.37	8.86			
SB5	1.89	3.9	6.56	2.1	3.90	6.98
	1.7	2.8	6.0			
	2.71	2.9	8.40			
SB 10	2.0	4.0	6.55	2.23	4.21	7.2
	2.2	4.2	6.9			
	2.76	4.43	8.15			
SB15	2.0	4.10	7.5	2.29	4.28	7.7
	2.58	4.25	7.25			
	2.30	4.49	8.35			
SB20	1.50	4.0	7.15	2.0	4.19	7.24
	2.85	5.0	7.92			
	1.65	3.5	6.65			

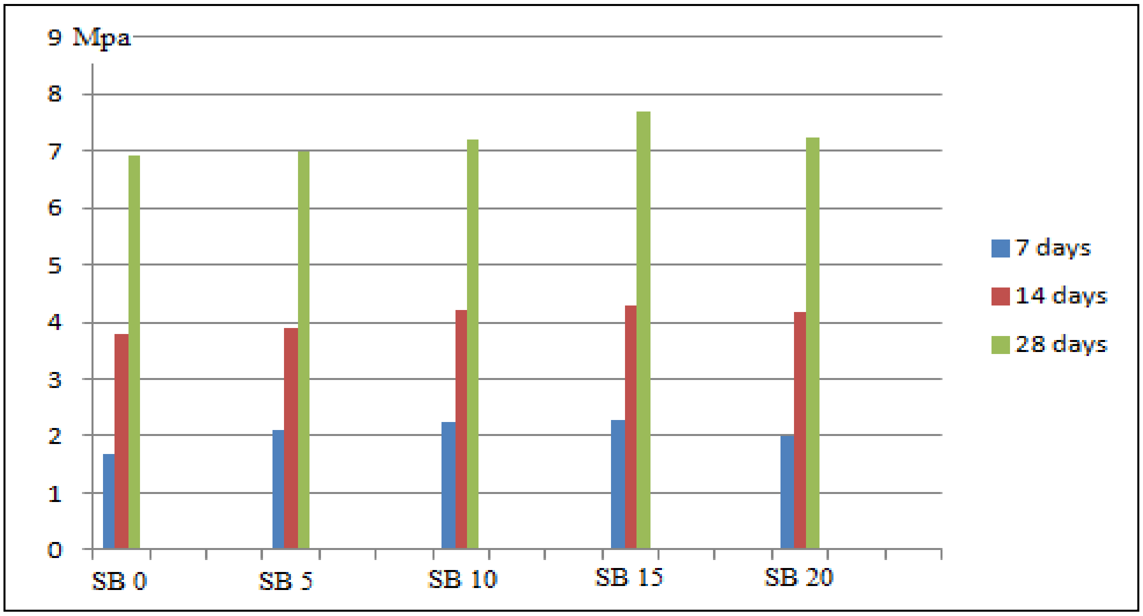


Figure No. 18 Comparison of flexural strength of concrete beams, incorporating 12 % Alccofine- 1203 & varying percentages of steel fibers at 7, 14 and 28 days.

4.4 Resistance to fire

The 100mm x 100mm x 100mm all with optimum percentage of (12 %) Alccofine - 1203 were casted , moulded then prepared cubes were removed from the mould . At a time 36 cubes i.e. 3 sets of 12 cubes each were prepared out of which the first set was submerged for 7 days & other two sets for 7 and 28 days . Later those cubes were heated in the electric muffle furnace which is provided with a thermostat to maintain constant temperatures at different ranges.. These sets were heated for 1, 2, 3 hours duration at 4 different temperatures (27^{0}C, 500^{0}C, 650^{0}C, 800^{0}C). After that these sets were left at room temperature for 24 hours for cooling. Compressive strength has been calculated as per BIS 516-1959 . Each of the samples selected for testing has been be exposed to the desired duration once it as reached the desired temperature. After fire resistance test, compressive strength of the samples was determined to detect effect of fire on strength properties of concrete cubes.

4.4.1 Development of cracks at elevated exposure temperature

Concrete on heating it expands & contracts on cooling. Restraint to contraction causes the development of tensile stresses. The temperature related contraction stress can cause cracking. Cracks may also be caused by differential temperatures in thick members. When the surface layer cools and contracts, movement is restrained by the core of the member which is still at a higher temperature, and hence cracks may form in the surface.

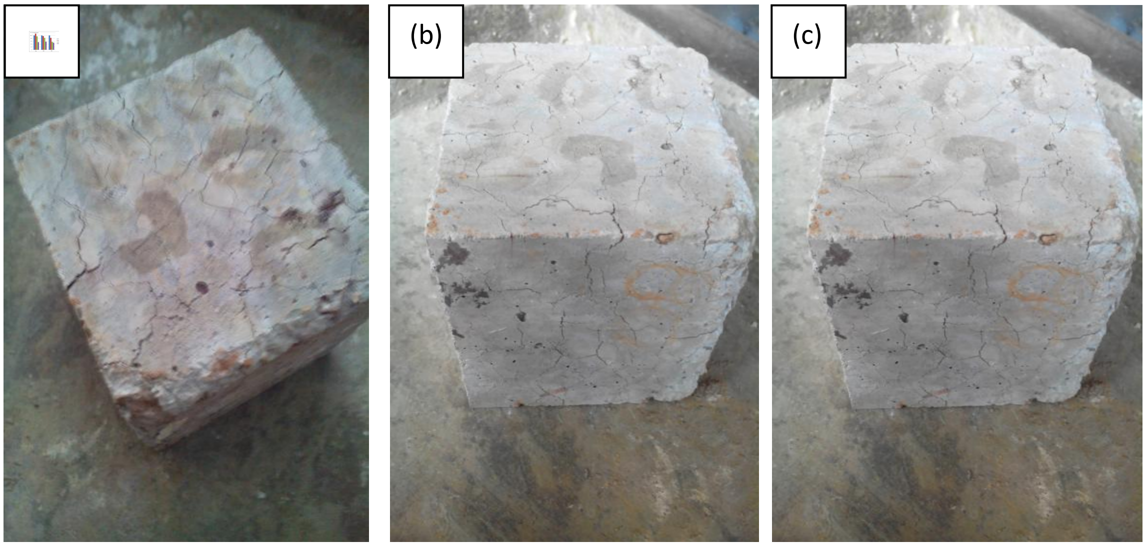


Figure No. 19 (a, b, c) Superficial cracks on cubes due to varying thermal gradient.

4.4.2 Inferences based upon appearance

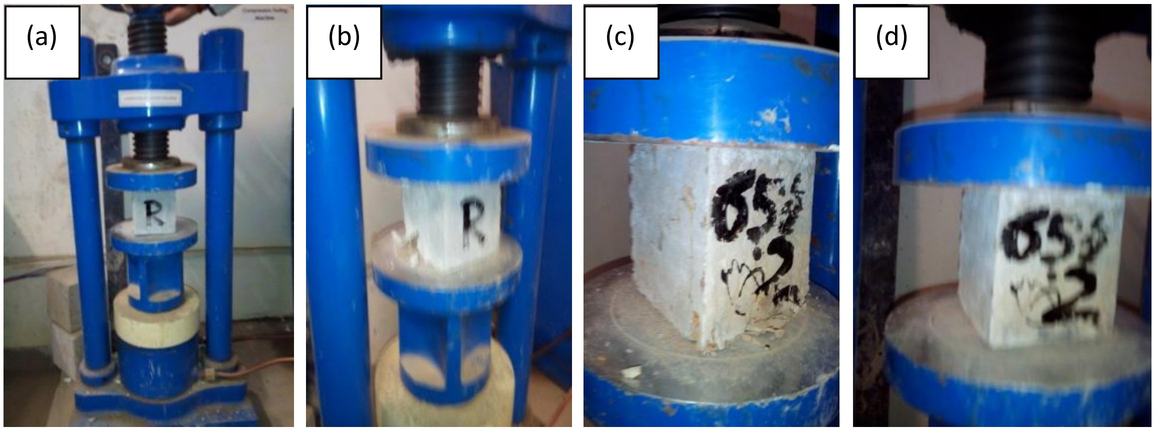
1. At 500 ^{0}C: Cubes experience minor cracks and dehydration of the cementitious paste with complete loss of free moisture and a reduction in paste volume.

2. At 650 ^{0}C: Prominent cracking of both the cementitious paste & aggregates due to expansion. Color of concrete turns somewhat pinkish.

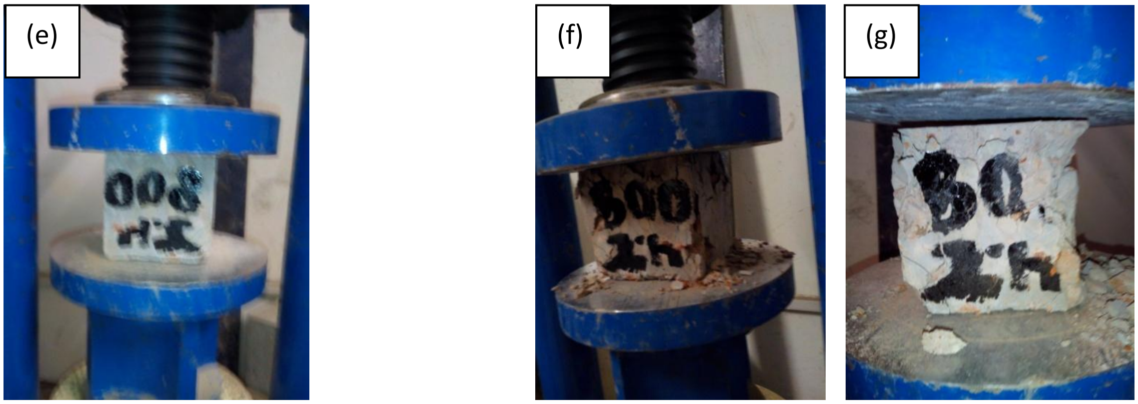
3. At 800 ^{0}C: Complete dehydration of the cementitious paste with considerable shrinkage cracking, was observed . Concrete becomes crispy and easily broken down upon contact. Colour of concrete changes to grey.

4.4.3 Specimens under CTM

The parameters that control the compressive strength of concrete when exposed to elevated temperatures are temperature range and duration of exposure. The test results are presented in following tables . The variation of % Residual Compressive strength with temperature for different exposure durations is shown in Fig No. 22,23,24 . The residual compressive strength at any temperature is expressed as the % of Compressive strength at room temperature. The evaluation of compressive strengths at 7, 14 & 28 days are as shown in Tables 16 ,17 and 18.



Before After Before After



Before After

Figure 20 (a, b, c, d, e, f, g) Random specimens before & after testing.

Table No. 15: Compressive and % Residual compressive strengths of cubes after exposing to elevated temperature cured for 7 days.

Temperature	Compressive strength (N/mm^2)			% Residual Compressive Strength (N/mm^2)		
	1 hour	2 hour	3 hour	1 hour	2 hour	3 hour
$27\ ^{0}$C	42	42	42	100	100	100
500^{0}C	48	40	29.09	114.28	95.238	69.26
650^{0}C	45	38	20.65	107.142	90.476	49.166
800^{0}C	19.7	21.11	17.75	46.904	50.261	42.0261

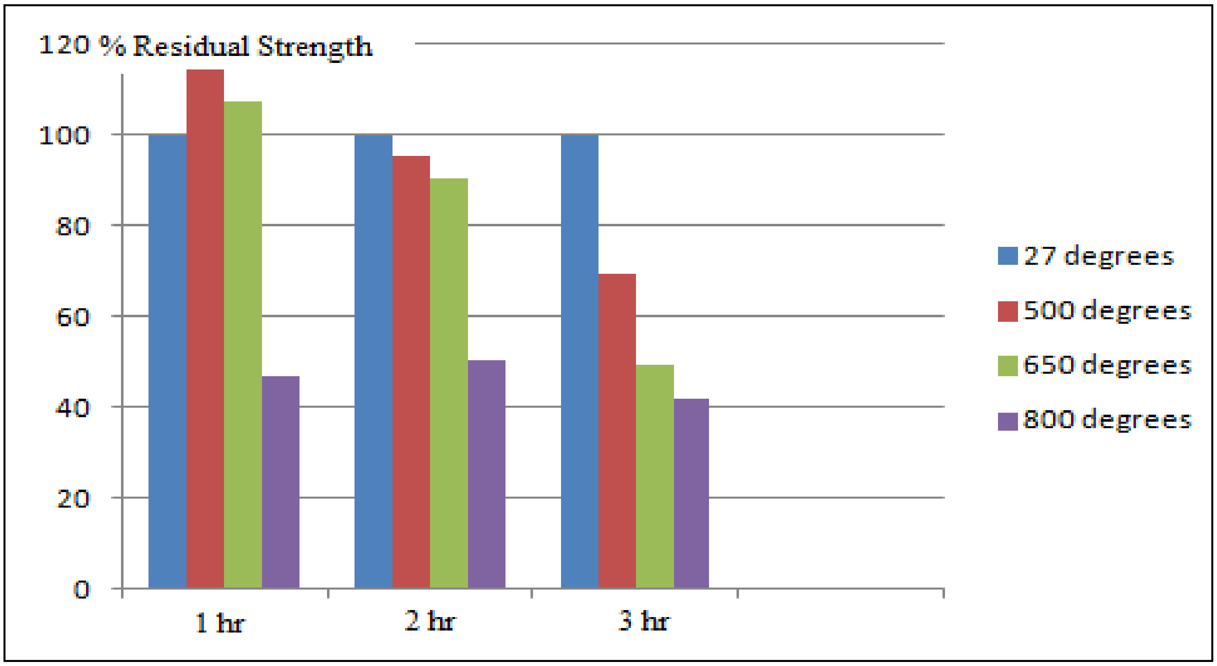


Figure No. 21 Variation of % Residual compressive strength with varying temperature at 7days of curing.

Table 16: Compressive and % Residual compressive strengths of cubes after exposing to elevated temperature cured for 14 days.

Temperature	Compressive strength (N/mm^2)			% Residual Compressive Strength (N/mm^2)		
	1 hour	2 hour	3 hour	1 hour	2 hour	3 hour
27 ^{0}C	48	48	48	100	100	100
500^{0}C	54	46	35.09	112.50	95.833	83.54
650^{0}C	45	40	26.65	93.75	83.33	55.520
800^{0}C	25.5	27.11	23.75	53.125	56.479	49.479

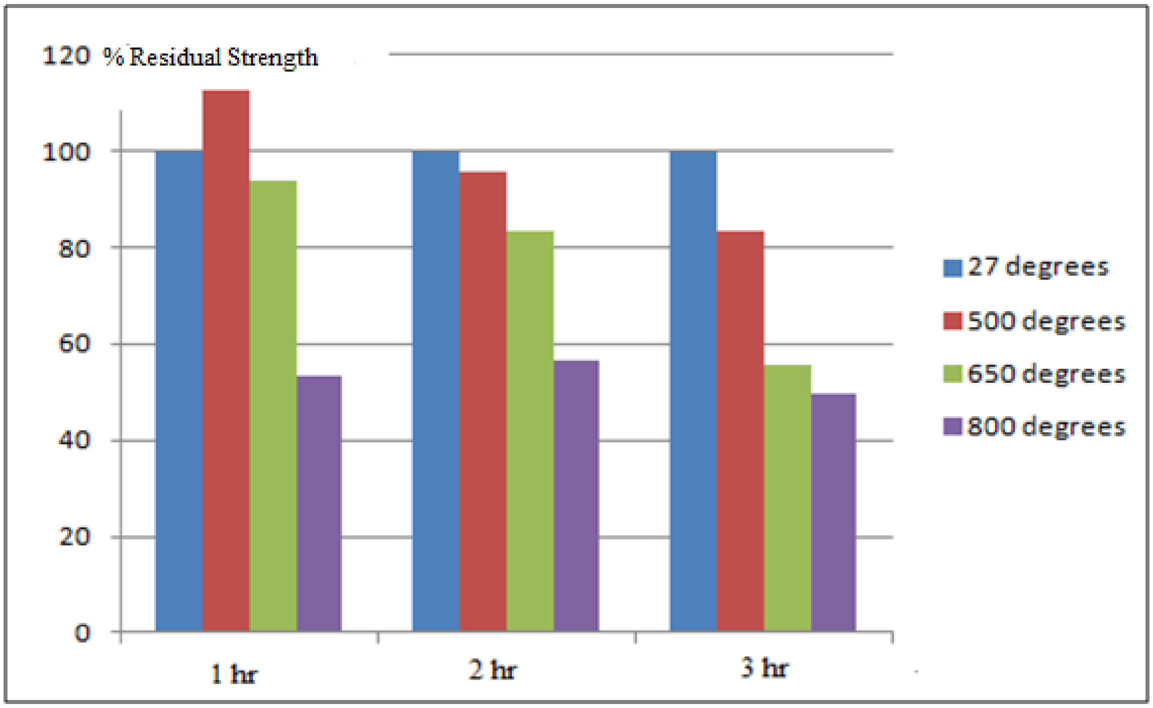


Figure No. 22 Variation of % Residual compressive strength with temperature at 14 days of curing.

Table No. 17: Compressive and % Residual compressive strengths of cubes after exposing to elevated temperature cured for 28 days.

Temperature	Compressive strength (N/mm^2)			% Residual Compressive Strength (N/mm^2)		
	1 hour	2 hour	3 hour	1 hour	2 hour	3 hour
27 ^{0}C	58.2	58.2	58.2	100	100	100
500^{0}C	67.51	57.42	41.31	116.006	98.65	70.97
650^{0}C	63.17	55.65	30.61	108.53	95.61	52.59
800^{0}C	26.29	27.252	28.60	45.17	46.82	49.14

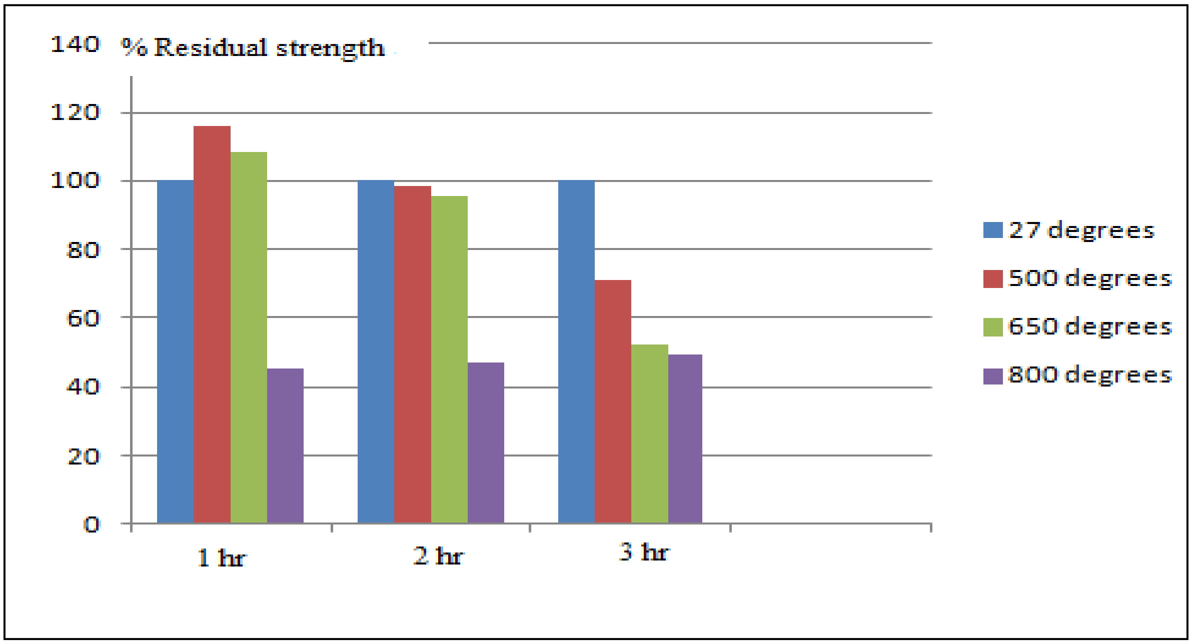


Figure 23 Variation of % Residual Compressive strength with temperature at 28 days of curing.

4.5 Durability Analysis

4.5.1 Casting

Initially the constituent materials were weighed and dry mixing was carried out for cement, sand and coarse aggregate and ultra fine slag. This was thoroughly mixed manually to get uniform colour of mix. The mixing duration was 2-5 minutes and then the water was added as per the mix proportion. The mixing was carried out for 3-5 minutes duration. Then the mix poured in to the cube moulds of size 100 x 100x 100 mm and then compacted by placing on compaction table. In this study we prepared 3 sets of five different mixes of M60 Grade namely referral concrete (AC_0), concrete made by replacing 12% of cement by Alccofine (AC12) & concrete made by replacing 14% of cement by Alccofine (AC14) & so on. The cubes were demoulded after 1 day of casting and then kept in respective solutions of 5% H_2SO_4 , 5 % HCL & in referral solution of 100 % H_2O for curing, at room temperature with a normal humidity.The cubes are taken out from curing after 30 days . The concentration is to be maintained throughout this period (in interval of 15 days). After 30 days the specimens were taken out from respective solution. The surface of specimen was cleaned and weights were measured. The mass loss and strength of specimen due to acid attack was determined and has been presented in table below.

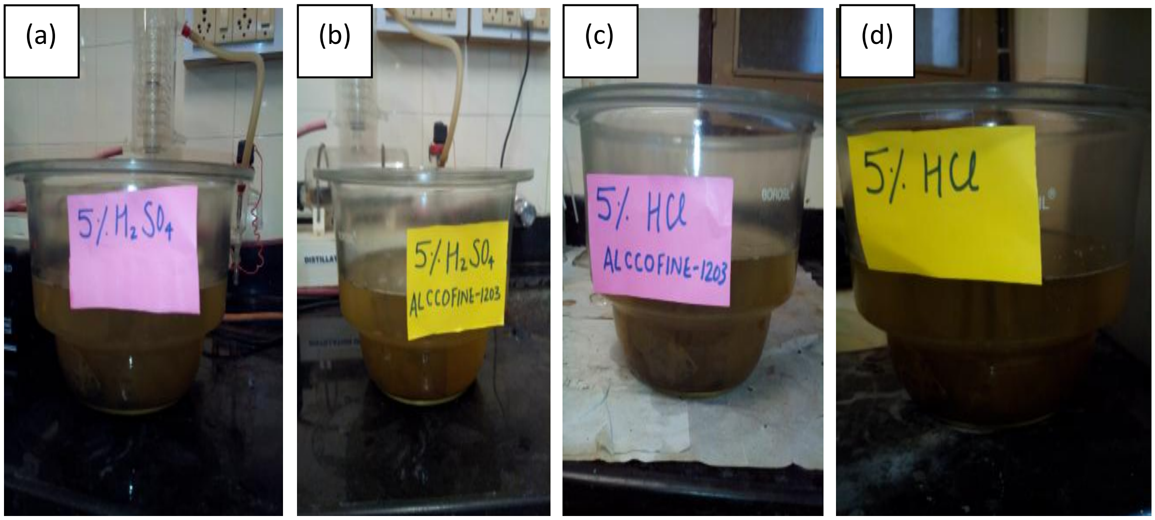


Figure No. 24 (a,b,c,d) Cubes immersed in respective solutions

Figure No. 25 Referral Concrete In 100% H_2O Solution

Table No. 18 Compressive strength reduction of referral concrete after curing in water.

Designation	% of Alccofine	Solution for curing	% Compressive strength(Mpa)	% Compressive strength reduction (Mpa)
AC_0	0	100% Water	63.5	00
AC_6	6	100% Water	69.25	00
AC_8	8	100% Water	71.20	00
AC_{10}	10	100% Water	82.40	00
AC_{12}	12	100% Water	88.60	00
AC_{14}	14	100% Water	87.83	00

Table No. 19 Compressive strength reduction of referral concrete after curing in HCL solution.

Designation	% of Alccofine	Solution for curing	% Compressive strength (Mpa)	% Compressive strength reduction (Mpa)
AC_0	0	5% HCL	61.5	3.14
AC_6	6	5% HCL	68.84	0.58
AC_8	8	5% HCL	78.96	0.57
AC_{10}	10	5% HCL	81.94	0.55
AC_{12}	12	5% HCL	88.14	0.52
AC_{14}	14	5% HCL	87.56	0.30

Table No. 20 Compressive strength reduction of referral concrete after curing in H_2SO_4 solution.

% of Alccofine	% of Alccofine	Solution for curing	% Compressive Strength (Mpa)	% Compressive strength reduction (Mpa)
AC_0	0	5% H_2SO_4	59.02	7.05
AC_6	6	5% H_2SO_4	64.23	7.25
AC_8	8	5% H_2SO_4	60.18	15.48
AC_{10}	10	5% H_2SO_4	58.65	26.13
AC_{12}	12	5% H_2SO_4	57.27	35.63
ACC_{14}	14	5% H_2SO_4	55.89	36.36

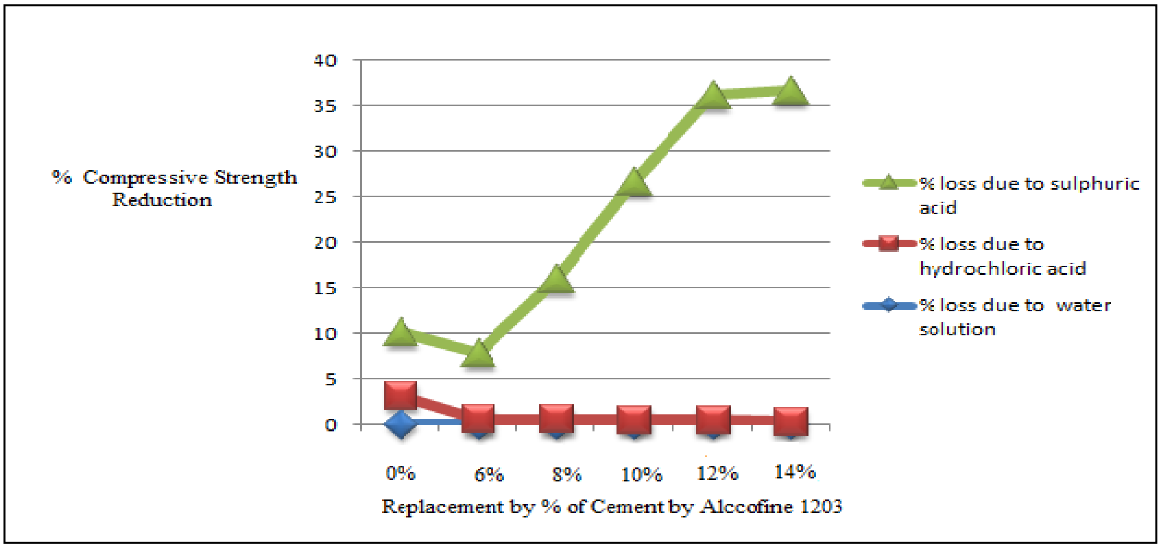


Figure No. 26 comparison of reduction in compressive strength between concrete cured in water , hydrochloric acid solution and sulphuric acid solution.

Chapter 5 CONCLUSIONS

Although the subject of this study seems as strength and durability of alccofine 1203 in general, as the title implies but this was rather a study on concrete in particular. A new method of generating HPC has been investigated by using ultrafine slag Alccofine1203. Following are observations made by this research.

5.1 Compressive Strength

The test results indicated that, when 8% to 12% by weight replacement of alccofine 1203 for cement is done, compressive strength increases. When 14% replacement of cement is done strength starts decreasing. Compressive strength of ultrafine slag concrete at 28 days compared to control mix was increased by 11% to 29 % on increasing the silica fume content from 8% to 14%. Also there is 10% to 27% increase in 28 days strength with 14 % replacement when compared to control specimen. decrease of compressive strength is noticed when compared to 12% replacement level. The results here establish that the optimum value for replacement of cement by alccofine 1203 is 12% .

5.2 Flexural Strength

From the results listed in Tables 11 and 12, it is obtainedthat in both cases of plain and reinforced concrete beams the 28 days strength of all the mixes is invariably higher than corresponding 7 days and 14 days strength . This is due to continuous hydration of cement with concrete and improved particle packing owing to the dimensions of alccofine particles. However a fall in strength was seen when replacement level exceeded 12 %.

5.3 Split Tensile Test

As compared to the referral SFRC, the split tensile strength is maximum at steel fibre with 1.5% (SB 15) addition by volume. Replacement of 12% Alccofine is common to all mixes and it is nearly 43.7%, 39.43% and 31.29% more than that of referral SFRC at 7, 14 and 28 d respectively. Split tensile strength of referral concrete as well as SFRC at 7 , 14 and 28 d are given in Table 14 and the variation of split tensile strength of specimens at different replacement level of steel fibers is shown in Fig. 17.

5.3.1 Steel fiber reinforced concrete beams

The beams were casted with 12% replacement of alccofine & cured for 28 days. All were incorporated with varying percentage of steel fibers by its volume and were compared with beams containing no steel fiber. Beams were tested under two point loading as per BIS 516-19. As compared to the beam without any steel fibers , the steel fibre beams showed increased resistance of 26.63%, 11.43%, 10.12%, at 7 , 14 and 28 days respectively . Elevated strength was shown at 28 days by all specimens as compared to that at 7 days. The maximum being at 1.5 % replacement of steel fibers.

5.4 Fire Resistance

The variation of Compressive strength with the increase in temperature is studied in terms of the percentage residual compressive strength for different durations of 1, 2 & 3 hours. Initially, the strength increased with temperature 27^0C to 500^0C for different durations and beyond that it was reduced. The maximum Compressive strength was noticed when the cube was heated at 500 ^{0}C for 1 hour duration .The compressive strengths are increased up to 27^0C -500^0C & beyond that it was rapidly reduced with increasing temperature. The compressive strength was lost very much when they are heated to temperatures greater than 800 degrees.

5.5 Durability Analysis

The conversion of calcium compounds into calcium salts of the attacking acid. These reactions destroy the concrete structure. The percentage of loss in compressive strength was %, %, respectively. Thus replacement of Alccofine is found to have increased the durability against hydrochloric acid attack. This is due to the silica present in alccofine which combines with calcium hydroxide and reduces the amount susceptible to acid attack. Sulphate attack denote an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates. Alccofine concrete suffers a rapid loss of compressive strength as soon as it is exposed to sulphuric acid.

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