USE OF COPPER SLAG AS A REPLACEMENT MATERIAL OF FINE AGGREGATE IN FIBRE REINFORCED CONCRETE

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DECLARATION

The author hereby declare that this dissertation entitled ***"USE OF COPPER SLAG AS A REPLACEMENT MATERIAL OF FINE AGGREGATE IN FIBRE REINFORCED CONCRETE"***, in whole or part had not been used to obtain any degree in this, or any other institute, except where references have been given in text, it is entirely the author's own work. The author confirms that the library may lend or copy this upon request for academic purpose.

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CERTIFICATE

This is to certify that the work presented in dissertation entitled ***"USE OF COPPER SLAG AS A REPLACEMENT MATERIAL OF FINE AGGREGATE IN FIBRE REINFORCED CONCRETE"*, submitted** by **Mr. Mohit Jain** in partial fulfillment of the requirements for the award of degree of **Master in Engineering** in Structural Engineering at **Thapar Institute of Engineering and Technology, Patiala,** is a bonafide work carried carried out by student under our supervision and guidance. The matter embodied in this report has not been submitted anywhere for reward of any other degree.

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ABSTRACT

Concrete is one of the most used materials in the construction industry and is being used all over the world because of the longer service life provided by the concrete structures as compared to other construction materials being used in the construction industry. However, the durability properties of the concrete need to be checked before using it under different weather conditions exposed to severe atmospheric conditions. There have been a lot of researches done on principle of replacing cement or fine-aggregates or coarse-aggregates in the concrete using different materials for investigating the different properties of concrete. The aim of replacing the basic constituents of concrete can be any either to utilize some waste material thereby decreasing its impact on the environment or to use some properties of the replacement materials which possess the properties alike to the basic constituents of concrete or it can be any other purpose of replacement. Most of the researches had been done on partial substitution of cement or fine-aggregates. The replacement to be done depends upon the properties of the materials to be replaced and the replacing material. Sometimes the materials are used as an addition to the basic constituents of concrete for improving some of the properties of concrete. For example, addition of fibres into the concrete is done for increasing the tensile strength and crack resistance of concrete. Depending upon the materials replaced or the extra materials added or the characteristics of concrete improved, the nomenclature of concrete is changed.

The significant amount of work done in this research work involved assessing the different properties of concrete made with the replacement of fine-aggregate with copper slag up-to full replacement level with a constant level of steel fibres present in it. The different tests were conducted at different curing periods of 7, 28 & 56 days of curing period. It was found that the workability, durability and strength of concrete increases with the increase in the copper slag content. Also, the microstructure investigation of the concrete samples was carried out using SEM.

Keywords: Hybrid concrete, Fine aggregate, Copper Slag, steel fibers, strength and durability properties.

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LIST OF ABBREVIATIONS

CS	Copper Slag
FA	Fine Aggregate
OPC	Ordinary Portland Cement
PCC	Plain Cement Concrete
CA	Coarse Aggregate
FRC	Fibre Reinforced Concrete
UHPC	Ultra-High Performance Concrete
BFS	Blasted Furnace Slag
HSC	High Strength Concrete
PP	Polypropylene
BF	Basalt Fibre
BIS	Bureau of Indian Standards
w/c	Water/cement
IS	Indian Standard
RCPT	Rapid Chloride Permeability Test
ASTM	American Standard Testing Manual
SEM	Scanning Electron Microscope
CTM	Compression Testing Machine
UTM	Universal Testing Machine
NaOH	Sodium Hydroxide
NaCl	Sodium Chloride
kV	Kilo Volt
DC	Direct Current
V	Volt
V_f	Volume fraction
T. Strength	Tensile Strength

CHAPTER 1

INTRODUCTION

1.1. GENERAL

The use of concrete as a building material in the construction activities is increasing rapidly. The main constituent materials of concrete like OPC, aggregates and water form nearly the 60-85 % of the concrete volume. The aggregates used in the concrete can be classified as the FA (having size of particle smaller than 4.75 mm) and CA (having size of particle more than 4.75 mm). These aggregates used are obtained either from the rock cutting or from some natural sources. The function of each of the constituent materials of concrete is different as coarse-aggregates bounded together with the OPC paste forms the OPC concrete whereas the FA are responsible for filling up the gaps between the particles of coarse-aggregate. Since the demand of concrete in different construction activities is increasing rapidly thereby the demand for the FA and coarse aggregate is also increasing day by day due to which there is depletion of the natural resources from which we are obtaining these aggregates which is imparting a drastic impact on the environment ultimately leading to the environmental-imbalance. So, it is of prime importance and there is an urgent need of finding the substitute materials for FA and coarse aggregate so that we can utilize those substitutes effectively into the concrete to improve the different properties of concrete and make the sustainable and eco-friendly concrete.

There have been a lot of researches done on principle of replacing OPC or FAs or coarse aggregates in the concrete using different materials for investigating the different properties of concrete. The aim of replacing the basic constituents of concrete can be any either to utilize some waste material thereby decreasing its impact on the environment or to use some properties of the substitute materials which possess the properties alike to the basic constituents of concrete or it can be any other purpose of substitute. Most of the researches had been done on partial substitution of OPC or FA's. The substitute to be done depends upon the properties of the materials to be replaced and the replacing material. Sometimes the materials are used as an addition to the basic constituents of concrete for improving some of the properties of concrete. For example, addition of fibres into the concrete is done for increasing the T. strength and crack resistance of concrete. Depending upon the materials replaced or the extra materials added or the characteristics of concrete improved, the nomenclature of concrete is changed. Following are the some of the broader categories of concretes named after the type of substitution done:

- Fibre-Reinforced concrete
- Self-Compacting concrete
- Self-Healing concrete
- Polymer concrete
- Light Weight concrte
- High Performance concret or UHPC
- Flyash concrete and Silica-Fume concrte
- Hybrid concrete

1.2 HYBRID CONCRETE

A hybrid concrete is a form of concrete in which more than one material is to be replaced or added in order to improve the properties of concrete. It is a concept based on the idea of improving more than one property of concrete by compromising negligible or a little on the properties improved by the first substitute material. Normally, a hybrid concrete is made by replacing one of the constituents of concrete with some waste material and adding some extra material as an addition to improve certain property. For example, substitution of FA using pozzolanic material in steel fibre reinforced concrete. In such case, FA is replaced with pozzolanic material to improve the strength properties and fibres are added to improve the crack resistance.

1.2.1 Benefits of Making a Hybrid Concrete

We can improve more than one property of concrete at a single time of modifying the basic structure of concrete composition. Also, we can make the concrete more economical and eco-friendlier by replacing or adding one of the materials to be cheaper than the conventional components and more environments friendly. One more benefit is that we can improve two different categories of properties to be improved at the same time which else otherwise can't be improved by replacing or adding one kind of material in concrete.

1.2.2 Different Categories of Hybrid Concrete

- FA + Fibres
- Coarse Aggregate + Fibres
- Fibres + Fibres
- Coase Aggregate + FA

1.3 SLAG

Slag is a very big term. All the products obtained from the smelting of metal from its ore is termed as the slag. Mostly, the slag is a non-metallic compound obtained after smelting of metal. The characteristics of the slag such as chemical and morphological characteristics depend upon from which metal it is extracted and what type of solidification process is being employed in it. The slag in broader terms can be categorized into two categories depending upon the fact that from which industry we are obtaining the slag i.e. whether it is a iron/steel industry (Ferrous slag) or it is a copper/lead/zinc industry (Non-ferrous slag). The schematic diagram given below gives the production process of slag obtained from the non-ferrous elements like copper, nickel or zinc. Major portion of slag produced in the industries is of ferrous type and this slag is obtained from the iron and hence termed as the iron blast furnace slag (BFS). It's a type of by-product obtained from the smelting of iron ore. Almost 12% of the slag which is produced worldwide is of non-ferrous type i.e. slag obtained from smelting of copper/zinc or lead.

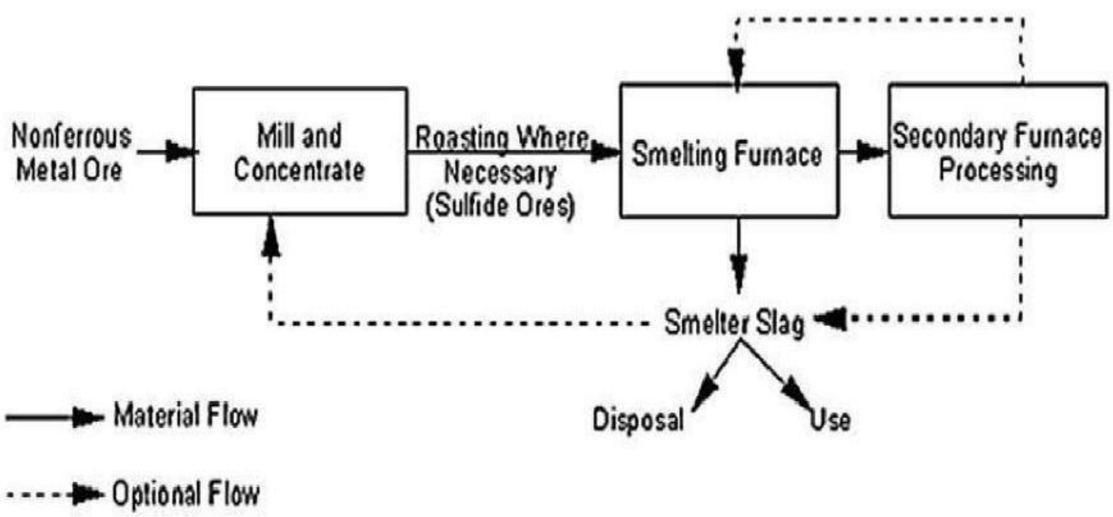


Figure 1.1: Slag Production Process

1.3.1 Slag Production Process

The process of production of slag involves a series of steps. The main process involved in the production of CS is the cooling down of the molten slag to from crystalline rock which will become a light grey color vesicular type of rock also known as cooled in air blast furnace slag.

This slag is used for many purposes and some of them are as described below:

(a) Uncrushed form – used as a filling material in areas subjected to very large loadings such as in rail systems, for working platform on construction sites, subgrade of pavement where the slag can fill the voids of the subgrade material.

(b) Base in graded roads – used as such or can be combined with some other slag forms or natural rocks or sand.

(c) Crushed Form – as an aggregate in concrete as a substitution or as an addition for sand and CA, as a filler material for insulation and for using as a filler material in platforms.

When the molten slag is passed under high volume and high-water pressure sprays, a material with a glossy surface and sand type material is obtained which is known as granulated BFS which is having color alike normal beach sand.

Except from the above listed uses of molten slag, the principal uses of this slag in construction industry are as summarized below:

(a) It is used as a substitute material for OPC when grounded to very fine form having capability of replacing OPC by 50-70 % in special concrete as an application in marine environment.

(b) Uses in making of glass, tracing element in agricultural industry, manufacturing of concrete blocks, as a supporting base material in sub-base of drainage works, in reinforced embankments etc.

1.4 COPPER SLAG

In the manufacturing of copper from its ore, a major by-product is obtained as a waste material. This product obtained during the manufacturing of copper in industry is termed as the Copper-slag. This by-product is produced in large quantities all over the world in terms of billion tons and hence its safe disposal is a also a major problem of concern. The three main industries producing this by-product are Sterlite, Birla and Hindustan which are producing near about 6-

6.7 tons of slag in different locations. Besides the CS being used in a number of industries or works such as in sand blasting in the manufacture of abrasive tools, the remaining amount of CS is disposed off without any more use or reclamation. The properties such as physical and chemical characteristics of CS make it capable of being used as a substitute or substitute material in the concrete. Despite from some main properties of CS it also has very good soundness characteristics, very good resistance to abrasion and stability. It also possesses pozzolanic characteristics as that of OPC due to the presence of CaO in it and other oxides of aluminium, silica and iron. Its use in concrete as a substitute or addition of FA or coarse-aggregate or OPC may result in the reducing the cost and making the concrete to be environment friendly. A lot of researches have been done and a number of researches are going on finding its suitability and use in the normal concrete and also in High Strength concrete. (HSC).

Plate 1.1: Copper Slag

s

1.4.1 Physical Characteristics of CS

The physical properties of CS include the surface, texture, color, hardness and specific gravity of the CS material etc. As per the previous researchers who used CS in their studies, the CS is a glossy type material having a black color to greyish type with a FM of around 3.5 which may vary from source to source of the CS material. Specific-gravity of CS also varies from the source of obtaining and the iron content of the ore from which it is obtained. It can have a specific gravity from as low as 2.8 to as high as 3.75. The unit weight is also higher than the natural aggregate conventionally used in concrete. Absorption of water by CS material is low as compared to natural aggregates due to its glossy nature. The water-absorption and specific gravity also varies according to type of CS i.e. whether it is air-cooled or granulated where granulated one having more absorption due to porous structure as compared to air-cooled one. The shape of granulated CS is regular with angular particles with size range of 4.75 mm – 0.075 mm. The molecules of the CS do not get locked into one another due to the sudden cooling of molten slag.

1.4.2 Chemical Characteristics of CS

Normally, the mix of CS with OPC possesses the similar chemical characteristics as that of the mix of OPC with fly ash and hence it can have pozzolanic properties also. CS being a waste material of the copper manufacturing industry may cause hazardous impact on the environment and practices opted for its safe disposal such as land filling is normally not the accepted one therefore its use as a substitute or addition material in OPC concrete is preferred one.

1.5 CONSEQUENCES OF CS

The consequences of using CS in concrete can be both positive and negative which may arise due to the properties that the CS material possess. The soaking up of water and ease of mixing of the concrete can be improved because of the glossy surface of the CS but at the same time the compressive-strength, T.-strength and flexural strength may be reduced due to the presence of excess water so an optimum amount of CS to be used in the concrete need to be worked out. Based upon the previous researches it is recommended to use CS up-to a maximum content of 40% and using beyond which it may result in the creation of more voids, cracks and damaging of the concrete microstructure ultimately leading to the negative effects on the concrete.

1.5.1 Advantages of Using Copper-Slag as FA

a. Using copper-slag as substitute material for FA is environment friendly as it will result in the reduction of the waste produced from the copper manufacturing industry.

b. The disposal method opted for the safe disposal of hazardous and no hazardous toxic material should be such that It should not affect the natural resources as given by the environment so finding methods of usage of such materials in concrete could be the best option available from environment point of view.

c. The ease of mixing of concrete will increase with the increase of CS as substitute of FAs in concrete mix.

d. Up to 40% there was little increase in strength or was having strength comparable to control mix.

1.5.2. Disadvantages of Using Copper-Slag as FA

a. Variations in chemical composition can change the properties of CS. So, chemical testing before using is important.

b. The glossy surface of CS particles imparts negative effect on the cohesion.

1.6 FIBRE REINFORCED CONCRETE

A concrete made with the addition of fibres in it is termed as the fibre reinforced concrete. The purpose of adding fibres into the concrete can be any like to prevent cracking due to shrinkage or to increase the impact resistance of the concrete or to make the concrete capable of absorbing energy created due to vibrations etc. The fibres sometimes also responsible for reducing the permeability of the concrete and prevent the propagation of the crack throughout so that the structural component can take more loads. The fibres normally help in reducing the compressive and split-T. strength of concrete and not the flexural strength of concrete so these fibres cannot be used as a substitute for the structural steel reinforcement. The content of fibres in the concrete is expressed as the percentage of volume of concrete. This percentage volume of fibres is termed as the volume fraction. So, the fibres are added into the concrete as volume fraction (V_f %) and typically the volume fraction of fibres in the concrete is very less in the range of 0.1 to 3% depending upon the type of fibres used in the concrete. The main parameter which asses the suitability of a fibre to be used in the concrete is the aspect ratio. The aspect-ratio of the fibre affects the ease of mixing and other properties of the concrete. So it is very important to decide a suitable aspect ratio of the fibre to be used in the concrete. There are number of factors which decides whether the load coming on the structure will be carried by the fibre only or matrix or the fibre-matrix both and what will be the mechanism occurring during this process. So different researches have been done and going on to ascertain the type, size of fibres to be used and their effects on the concrete. Some of the main type of fibres and the mechanism of fibres will be discussed in the later topics.

1.6.1 Different Kinds of Fibre-Reinforced Concrete

Depending upon the type of fibres used in concrete, the concrete is named accordingly. The use and suitability of a particular fibre depends upon the properties of the given fibre. Some of the most common types of fibres and their properties are as follows:

a) **Plastic or polymeric fibres:** The fibres namely nylon and polypropylene falls under this category of fibres. Such fibres have a T. strength of 561.0-867.0 N/mm^2. These fibres tend to elongate more on the application of load and hence make the material composite to absorb 1025% more energy as compared to unreinforced concrete. Due to this property of these fibres, these fibres find their use in the areas where high energy absorption rate is required. Also, these fibres are made of thermoplastic resin which becomes soft when heated to high temperature because of which theses fibres cannot be used in high temperature areas. As the type of fibres used is polypropylene, so such concrete is named as Polypropylene Fibre-Reinforced (PFR) OPC mortar & concrete.

b) **Glass fibres:** These fibres are available in three basic forms namely ravings, strands and woven or chopped strand mat. The filaments of these fibres are available in the range of 10 to 20 micron and coated with some material to protect them from surface absorption and to make them bind to the strands. The drawback faced in the using of these fibres in OPC concrete is that the surface of these glass fibres gets corroded due to the highly alkaline behavior of hydrated OPC paste. However nowadays, to prevent it glass fibres come with the protective coatings mostly of resins to make them resistant to chemical attacks. Also these fibres have fire resistant properties; these fibres find their use in the cladding or permanent shuttering in the structural concrete work. As the type of fibres used is glass, so such concrete are named as GFRC Glass Fibre Reinforced concrete.

c) **Steel fibres:** These are the fibres which are obtained from the cutting down of drawn wires, fibres with different crimps and indentations and shapes in order to enhance the mechanical bond strength. The main property of such fibres is the T.-strength which imparts the characteristic strength to the concrete in which these fibres are used. The low T. strength fibres can also be produced from low carbon steel coils. The shape, length and diameter are the main properties of steel fibres responsible for its T. strength. Also, the amount, distribution and mix proportions of the fibres in the mix design are major factors responsible for the strength of the concrete mix. Steel fibre finds their applications in the field of highway pavement, roads, airfields; bridge decks other industrial flooring especially those areas which are subjected to wear and tear of the material. The steel fibres used in the concrete can be straight, rounded, flat ended, crimped, hooked ended etc. The diameter of such fibres ranges from 0.25mm to 1.0 mm. As the type of fibres used is polypropylene, so such concrete are named as SFRC Steel Fibre Reinforced concrete.

d) **Carbon fibres:** These are the high T. strength fibres with a high young's modulus of elasticity value and also a high specific strength as compared to steel and glass fibres. These fibres have linear stress strain relationship and possess creep and fatigue resistance. These fibres show a 20 percent reduction in the strength over a period of one year on curing continuously at a temperature of 50 degree Celsius. At low volume of fibre fraction their fracture toughness is lower than that of the Glass fibre reinforced concrete (GFRC) but if such fibres are used in combination with some other fibres they show a substantial growth in the strength of the concrete. As the type of fibres used is carbon, so such concrete is named as CFRC Carbon Fibre Reinforced concrete.

e) **Natural Fibres:** These are the fibres which are obtained from the naturally occurring materials like stem fibres, leaf fibres, fruit fibres and wood fibres etc. These fibres are available in almost all the countries and cost of production of such fibres is very low as very less industrialization of such fibres is there. Further their usage in the concrete required less skilled labor which ultimately reduces the cost of the OPC concrete. These fibres find their use not only in concrete but also in the soil stabilization practices also. These fibres possess the drawbacks of their low T.-strength, lower elastic modulus and high soaking up of water values and high susceptibility of fungal and insect attacks. Depending upon the type of the fibres used and the source of obtaining these natural fibres, the concrete is named accordingly. Some names of the natural fibre-reinforced concrete are as follows:

- Jute fibre-reinforced concrete
- Coil fibre-reinforced concrete
- Sisal fibre-reinforced concrete
- Bagasse fibre-reinforced concrete
- Coconut fibre-reinforced concrete

1.6.2 Phenomena of Fibre Reinforced Concrete

To understand how the fibres tend to affect the properties of the concrete i.e. to increase or to decrease some specific parameter or property of the concrete, different concepts had been given by different authors and researchers which are described as below:

a)Fracture Mechanics Concept: As per this concept, as the concrete is subjected to T. load the fibres tend to prevent the enlargement of the cracks that appears in the concrete. The width of the crack is studied with the concrete without fibres and with fibres and it was observed that as the fibres are used in the concrete the widening of the crack decreases. The mechanics of the fibre in the concrete relates to first crack strength and the ultimate strength. The first crack strength is related to the spacing of the fibres and the ultimate strength is related to the amount of the fibres and the orientation of the fibres. The propagation of the crack will take place if the release of the strain energy is at least equal to the increase in the surface energy due to the formation of new surface area. Also, by increasing fibre content up to certain amount in the concrete, the width of the cracks reduces.

b)Crack Arrest Mechanism: As per this mechanism, whenever the concrete specimen reinforced with fibres is subjected to the loads, the fibres provide a crack arrest mechanism by producing pinching forces which tend to close a crack. This arresting of the cracks by the fibres depends upon the first crack strength which in turn depends upon

The spacing of the fibres in the concrete hence using the small fibres in large amount will decrease the spacing between the fibres and hence enhances the crack strength of the concrete.

1.6.3 Factors Affecting the Properties of Fibre Reinforced Concrete

There are some factors which are responsible for affecting the properties of the fibre-reinforced concrete and they are explained as below:

a) **Relative Fibre Matrix Stiffness:** The relative stiffness among the fibre and matrix plays a major role in the efficient transfer of stress. For efficient transfer of stress from fibre to matrix, the modulus of flexibility of the matrix should be lower than that of the fibre. Higher is the modulus of the fibres used, higher will be the imparted characteristic strength and stiffness to the whole section. However, if the modulus of flexibility of the fibre used is lower, even then such kinds of fibres can help in the absorbing large amount of energy and provide resistance to impact and explosive loading.

b) **Fibre Matrix Interfacial Bond:** For the efficient transfer of stresses from matrix to fibre, the interfacial bond between the fibre and matrix should be strong and continuous. The continuity of this interfacial bond plays a major role in deciding the optimum fibre length and aspect-ratio of the fibre for the improved strength of the fibre matrix. If the interfacial bond is such that the failure occurs due to the fibre pullout, then the matrix will become the chief load carrying element and very less increase in the strength can be obtained.

c) **Fibre-Matrix Strain Compatibility:** The strain compatibility between the fibre-matrix plays a major role in anticipating the mode of failure i.e. the failure occurred due to the breaking of fibre or due to the bond failure in the matrix. As the cracking strain of the most of

the OPC based matrix is of the order of 250 x 10^{-4} m/m whereas most of the fibres have higher extensibility as compared to this value of strain, the failure of the matrix occurs due to the bond failure within which implies the usage of the fibres in the concrete.

d) **Miscellaneous Factors:** Apart from the above factors discussed, the fractional volume of the fibres, orientation of the fibres, length, diameter and aspect ratio are the some of the other factors responsible for imparting strength to the concrete. As the fibre volume fraction in the concrete increases the strength improvement increases but the increase in the fibre volume may result in the cost of construction also so to make the use of fibres in the concrete economically viable, the percentage of volume fraction is limited to 2 to 3 percent. Also the orientation of the fibres in the concrete plays a major role in improving the strength of the concrete. A concrete with random orientated fibres is expected to take more loads as compared to the concrete with fibres aligned in one direction only.

1.7 OBJECTIVE OF STUDY

The primary objectives of entitled report are:-

- To find the Optimum amount of CS as a partial substitution of FA in the concrete, as proposed by various researchers.
- Effect of copper-slag on fresh properties i.e. eases of mixing, when used as substitution of FA.
- Effect of copper-slag on the hardened properties of concrete such as on the compressive strength and T. strength of concrete.
- To find the effect of CS and fibres on the durability properties of concrete such as soaking up of water, penetration of water under pressure and chloride ion penetration etc.
- Studying the combined effect of copper-slag and steel fibres on the different properties of concrete.

CHAPTER 2

LITERATURE REVIEW OF COPPERSLAG AND FRC

2.1 EFFECT OF USING CS ON DIFFERENT CONCRETE PROPERTIES

Different studies had been done by many researchers on the CS as a substitute material for FA on different properties. Some of the major studies on the behavior of concrete with CS as substitute of FA are explained below:

2.1.1 Workability

Al-Jabri et al., (2009) found out the ease of mixing of the concrete mix, slump test was conducted, and the results of the slump tests indicated that the ease of mixing of the concrete mix increases with the increase in the substitution of CS content in the concrete mix. The increase in the ease of mixing of the concrete mix was basically attributed due to the reason that the CS particles have smooth, glassy surface due to which they absorb very less amount of water and there is availability of the huge amount of available water in the concrete mix which results in the increase of ease of mixing of concrete mix.

Al-Jabri et al., (2011) found out the ease of mixing of the concrete mix, slump test was conducted, and the observations of the slump tests indicated that the ease of mixing of the concrete mix increase with the increase in the substitution of CS content in the concrete mix. The increase in the ease of mixing of concrete mix was basically attributed due to the reason that the CS particles have smooth, glassy surface due to which they absorb very less amount of water and there is availability of the large amount of free water in the concrete mix which results in the increase in the ease of mixing of the concrete mix. Also, the compactness of the concrete mix with CS content was higher due to the high value of specific gravity of the CS as compared to the sand. The compactness of the mix was increased by almost 5%.

Wu et al., (2010) investigated and the results of the ease of mixing tests were same as that of the other researcher's studies i.e. increasing ease of mixing with the increase in the substitution of CS in the mix. The maximum value of slump was 245mm obtained at 100% substitution level as compared to the slump of the control mix which was 60mm. The reason of increased ease of mixing was attributed as the fine and glossy nonabsorbent surface of the CS as compared to sand which resulted in the reduced shear resistance between the concrete mix particles resulting in the high flow ability of the concrete mix.

Dos Anjos et al. (2017) reported that there was a remarkable increase in the cohesion and plasticity of the newly mix concrete and water reducing admixture were used in order to get the mix of the required consistency. The increase in the ease of mixing of the concrete mix was attributed to the spherical shape of the blasted CS particles, glassy texture and lower soaking up of water characteristics than natural FA. The increase in the ease of mixing was not only due to the non-absorbent surface of the CS particles but also due to its increased specific mass which contributed to the higher slump of the concrete mix.

2.1.2 Compressive Strength

Al-Jabri et al. (2009) reported the test results in which eight concrete mixtures with varying amount of copper-slag from 0 to 100% substitution level were made at a constant w/c ratio of 0.35 and six cubical specimens of size 150mm x150mm x 150mm and three cylindrical samples of size 150mm diameter x 300 mm length were casted and tested for the unconfined compression test. Three specimens were tested after a period of 7 Days and three were tested at the end of period of 28 days. The results obtained shows that the compressive strength of the cubical specimens was increased up-to 50% substitution level and afterwards it started decreasing. This decrease was observed due to presence of excess free water as requires for the hydration of OPC paste. The available free water causes the particles of the mix to separate and leave pores behind in the mix which ultimately resulted in the decay in the strength.

Al-Jabri et al., (2011) prepared specimens with the varying percentage of copper-slag from 0% to 100% at a constant w/c ratio = 0.40. The cubical specimens of size 150mm x150mm x 150mm for OPC concrete were prepared. Three specimens of each of the mix proportion were tested after a period of 3, 7, 28, 56 and 90 days of curing. The major concern was on 56- and 90-days testing of compressive strength to observe any major effect on the compressive strength after long duration.

Wu et al., (2010) performed the compressive strength tests on the casted specimens of size 150mm x150mm x 150mm at a constant w/c ratio = 0.30 and at the end of 7, 28 and 90 days of curing period and reported the results as the compressive strength the concrete mix replaced with CS shows a decay in the strength. This contradicts the previous studies where increase in strength as the CS content was increased. This opposite trend may be due to the difference in the physical and chemical properties of the CS used in the concrete mix as the slag may be obtained from the different ores of the copper. Further the decrease in the strength becomes more prominent after 40% substitution level. The presence of the high ferric oxide content might be the reason for the decay in the strength as with the increase in the CS content, the ferric oxide content increases which delays the hydration of the OPC and ultimately resulted in the decrease in the strength.

Dos Anjos et al., (2017) the testing was done for the samples were prepared at a constant w/c - 0.52 using blasted CS at substitution level ranging from 0% to 100%. The results reported showed a decay in the compressive strength nut the decrease was not severe. Up-to the substitution level of 20% there was 5.5% decay in the compressive strength compared to the control mix. This decay in strength can be attributed due to the presence of impurities such as residues, paint particles, anti-oxidants from the removed painting system and oxides and hydroxides from the eroded layer.

2.1.3 Split T. Strength

Al-Jabri et al., (2009) performed experiments using three cylindrical samples of size 150 mm diameter and 300 mm length at a constant w/c ratio of 0.35 were tested for the splitting T. strength. The T. strength results showed the similar trend as that of the compressive strength test results.

Al-Jabri et al., (2011) conducted the 28 Days T. Strength of concrete for specimens of size 150 mm diameter and 300 mm length at a constant w/c ratio of 0.40 and predicted this observation that average T.-strength or the change in the T. -strength was within the permissible limits as specified by the codal provisions i.e.45$\sqrt{F_{cu}}$.

Wu et al. (2010) conveyed results that 28 days splitting T. strength test was conducted on specimens of size 150 mm diameter and 300 mm length at a constant w/c ratio of 0.30 and the results showed a decreasing trend of strength. This can be attributed due to the increase in the pores in microstructure of the concrete induced by the trapped excess water. This porous structure of concrete makes the concrete more prone to T. cracking as weak bonds were formed in among the components of the concrete matrix. As the copper-slag content increased, the T.-strength of the concrete was dropped drastically due to available of excess surface water.

Dos Anjos et al., (2017) conveyed that the T. strength at w/c = 0.52 decreases with the increase in the CS content and maximum decrease was observed for the specimen with 80% CS content which was 33.5% as compared to control mix.

2.2 EFFECT OF STEEL FIBRES ON DIFFERENT CONCRETE PROPERTIES

2.2.1 Physical and Chemical Characteristics of Different Fibres in Fibre Reinforced Concrete

Depending upon the physical characteristics of the fibres like shape, size aspect ratio, the effect of these fibres on the properties of concrete changes so it is important to study the properties of the fibres before using them in the concrete. The physical and chemical characterization of fibres used by different researchers in their researches has been shown below:

Table 2.1 Properties of Hook ended steel fibre (Abbass et al., 2018

S.No.	Length (mm)	Diameter (mm)	Aspect Ratio (l/d)
1.	40	0.62	65
2.	50	0.62	80
3.	60	0.75	80

Table 2.2 Properties of Basalt fibre (Ayub et al., 2014

Fibre Type	Diameter (micro m)	Cut Length (mm)	T. Strength (MPa)	Elastic Modulus (GPa)	Specific Gravity	Elongation (%)
Filament Type	18	25	4100-4840	93.1-110	2.63-2.68	3.1

Table 2.3 Physical characteristics of Polypropylene fibres (Kakooei et al., 2012

Specific Gravity	$0.91 gr/cm^3$
Diameter	22 μm
Width Crossing	Circular
Melting point	160-170
Soaking up of water	0
Torsion Resistibility	350-450

2.2.2 Compressive Strength

Abbass et al. (2018) conducted the compressive strength tests on cylindrical specimens of size 100 x 200 mm at 7 and 28 days of curing. The steel fibres of different physical properties were used at different w/c ratios to make low, medium and high strength concrete. They reported that the compressive strength of the concrete increases with the increase in the fibre content from 0.5% to 1.5%. The increase in the compressive strength was less for the high strength concrete (w/c =0.25) as compared to the low and medium strength concrete (w/c =0.35 and 0.45). The increase in the strength was attributed due to the confining effect provided by the fibres. The increase in the strength was more for the fibres with higher aspect ratio. This is because the fibres provided the crack arrest i.e. prevented the growth of the cracks in the concrete.

Ayub et al. (2014) reported the compressive strength results of High Performance concrete cylindrical specimens of size 100 x 200 mm made with 10% substitution of OPC with Silica Fume and Met kaolin at a constant w/c ratio = 0.40 and at addition of 1%, 2% and 3% basalt fibres with respect to the control concrete. It was observed that there was only a slight increase in the compressive strength with the increase in the fibre content up-to 2% substitution level however the compressive strength decreases at 3% fibre volume. Further, it was noted that the increase in the strength was more for the concrete with OPC replaced with mat kaolin as compared to the silica fume.

Kakooei et al. (2012) investigated the results of the compressive strength on cylindrical specimens of size 100 x 200 mm at w/c ratio = 0.48 using two types of aggregates namely coral aggregates and siliceous aggregates along with the addition of polypropylene fibres in

the concrete mix. The fibres were added in amounts ranging from 0, 0.5, 1, 1.5 and 2 kg m^{-3} .

It was investigated that there was notable increase in the compressive strength at 1.5-2 kg m^{-3} fibre content. The increase in the strength is attributed due to Connection Bridge formed by the fibres to prevent the crack propagation.

Ahmed et al., (2016) investigated that use of CS in concrete will result into the increase in the strength but there was a decrease in the ease of mixing property on introducing glass wool fibre (GWF). The experiments were conducted using CS alone, GWF alone and then the combination of both a fixed CS level of 40% and varying GWF content at a constant w/c ratio of 0.40. An increase of 11.22% in compressive strength was observed in the mix using both CS and GWF as compared to control mix.

Sowjanya and Prasanna (2016) reported the results using CS in steel fibre reinforced concrete. The experimental results were conducted to study different properties at fixed steel fibre content of 1% with varying content of CS. From the results it can be cocluded that the optimum % of CS is 40-50% as maximum results were obtained at this substitution level. There was 34.2% increase in the compressive strength of mix with increase in the CS content as compared to the control mix.

Reddy and Chamanti (2017) reported the reults of properties of concrete using CS and basalt fibers. The experimental results were conducted to study different properties at fixed basalt fibre (BF) content of 1% with varying content of CS and also using CS alone. From the results it can be concluded that the optimum % of CS is 40-50% as maximum results were obtained at this substitution level. There was increase in the compressive strength and split T. strength of mix with increase in the CS content as compared to the control mix of M30 grade.

2.2.3 Spitting T. Strength

Abbass et al. (2018) investigated the results of the T. strength on the specimens of size 150 x 300 with the introduction of fibres in the concrete. It was noted that there was a linear increase in the T. strength with the increase in the fibre content from 0.5% to 1.5%. Further, the increase in the T. strength was more for the high strength concrete and lower w/c ratio which was about 47% as compared to the medium and low strength concrete (w/c ratio = 0.45) which was 31%.The increase in the strength was basically resulted due to the crack arrest mechanism and the fibre transferring energy.

Ayub et al. (2014) reported the results of splitting T. strength on cylindrical specimens of size 100 x 200 mm at a constant w./c ratio = 0.40 with 10% of OPC replaced with silica fume and met kaolin and basalt fibre addition at 1%, 2% and 3% substitution level. It was observed that the T. strength increase with the addition of fibres but the increase was much more prominent in case of silica fume concrete in comparison to metakaolin concrete.

Ahmed et al., (2016) reported that use of CS in concrete will result into the increase in the strength but there was a decrease in the ease of mixing property on introducing glass wool fibre (GWF). The experiments were conducted using CS alone, GWF alone and then the combination of both a fixed CS level of 40% and varying GWF content at a constant w/c ratio of 0.40. An increase of 8.73% in split T. strength was observed in the mix using both CS and GWF as compared to control mix.

Reddy and Chamanti (2017) reported the reults of properties of concrete using CS and basalt fibers. The experimental results were conducted to study different properties at fixed basalt fibre (BF) content of 1% with varying content of CS and also using CS alone. From the results it can be concluded that the optimum % of CS is 40-50% as maximum results were obtained at this substitution level. There was increase in the compressive strength and split T. strength of mix with increase in the CS content as compared to the control mix of M30 grade.

2.2.4 Flexural Strength

Abbass et al. (2018) reported that there was pronounced improvement in the flexural strength of the concrete with different length and different mixes. The size of the specimen used for the testing was 150 x 150 x 600 mm. It was noted that the flexural strength of the concrete mix increases from 3% to 124% with the increase in the percentage content of fibres from 0.5% to 1.5%. The increase in the strength was more for the fibres with larger aspect ratio as compares to fibres with the smaller aspect ratio. Also, for the fibres swith the smaller length, the increase in the flexural strength was almost negligible.

2.2.5 Elastic Modulus

Ayub et al. (2014) reported in their research that there was little increase in the elastic modulus of the concrete specimen over the different volumes of the fibre addition. Further, there was not notable variation of the elastic modulus with the addition of fibres.

2.2.6 Workability

Abbass et al. (2018), Ayub et al. (2014), Kakooei et al. (2012) reported in their studies that the ease of mixing of the concrete decreased with the increase in the fibre substitution in the concrete mix due to the difficulty in the mixing of the fibres in the concrete mix. Jiang et al. (2014) conducted the test on the concrete mixed with chopped basalt fibres and polypropylene fibres to find the ease of mixing of the concrete. The slump value of the concrete mix reduces from 142mm to 59mm on increasing the polypropylene fibre content from 0.05% to 0.3% (Mix ID- PP1 to PP3). Whereas when basalt fibres were added, the slump value drops from 172mm to 67mm on increasing the fibre substitution from 0.05% to 0.5% (Mix ID- BBI1 to BBI3).The reason for the decreased ease of mixing can be attributed as the fibres form a network structure which prevents the concrete mix from segregation and flow. Also, due to large surface area of the fibres more OPC paste wraps around the fibres resulting in the decreased viscosity of the mix and hence reduced ease of mixing. Moreover, when he added 22 mm BF fibre, the slump value was more instead in case when there was addition of 12 mm BF. The reason may be conveyed as for shorter fibres there are more fibres per unit volume and the fibre distribution compactness is larger.

Ahmed et al., (2016) reported that use of CS in concrete will result into the increase in the strength but there was a decrease in the ease of mixing property on introducing glass wool fibre (GWF). The experiments were conducted using CS alone, GWF alone and then the combination of both a fixed CS level of 40% and varying GWF content at a constant w/c ratio of 0.40. The decrease in the ease of mixing was reported to be 20 mm when compared to control mix.

Sowjanya and Prasanna (2016) reported the results using CS in steel fibre reinforced concrete. The experimental results were conducted to study different properties at fixed steel fibre content of 1% with varying content of CS. From the results it can be cocluded that the optimum % of CS is 40-50% as maximum results were obtained at this substitution level. There was an increase in the ease of mixing of mix with increase in the CS content.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 PRELIMINARY TESTING

The preliminary testing includes the testing of the materials to be used in casting of the specimens. This included the tests on OPC, FA, coarse aggregate, CS and investigating the properties of fibres used in the casting work.

3.1.1 Cement

OPC is the main binding material used in the concrete. The properties of the OPC investigated were specific gravity, initial setting time, consistency etc. The below table gives the results of the properties and their obtained value:

Table 3.1 Properties of the OPC used

Name of the Property	Result
Grade of OPC	OPC 43
Specific gravity	3.12
Initial setting time (min)	123
Consistency of standard OPC paste (%)	28
Final setting time (min)	270

3.1.2 Fine Aggregate

The natural sand with nominal maximum size of aggregate of 4.75 mm was used as a FA in the concrete. The FA was tested as per Indian Standard Specifications IS: 383-1970. The properties of the FA such as sieve size analysis are compared with those of standard recommendations as per IS: 383-1970. The physical properties and sieve analysis of the FA is given as below:

Table 3.2 Physical properties of FA

Name of Property	Observed Value
Maximum size of aggregate	4.75 mm
Specific gravity	2.63
Net soaking up of water	0.80
Fineness modulus	2.92
Grade of sand	Grade II

Plate 3.1: FA

Table 3.3 Sieve analysis of FA

Sieve No.	Mass retained (gm)	Percentage retained (%)	Passing (%)	% Retained cumulative
4.75	28	2.8	97.2	2.8
2.36	186.5	18.65	81.35	21.45
1.18	177.5	17.75	82.25	39.2
600	130	13.0	87.0	52.2
300	291	29.1	70.9	81.3
150	138	13.8	86.2	95.1
Pan	49	4.9	95.1	
				Σ% retained = 292.05

Weight of the sample taken = 1000 g

Fineness modulus = 292.05/100 = 2.92

3.1.3 Coarse Aggregate

Crushed stone aggregate with nominal maximum size of 20 mm (passing 20 mm and retained on 10 mm sieve) were used in this study. The physical properties and sieve size analysis results of the coarse aggregate is as given below:

Table 3.4 Physical properties of coarse aggregate

Name of property	**Observed value**
Maximum size of aggregate	20 mm
Specific gravity	2.69
Net soaking up of water	0.85
Fineness modulus	6.10
Bulk compactness	1550 kg/m^3

Plate 3.2: Coarse aggregate

Table 3.5 Sieve analysis of coarse aggregate (10 mm)

IS Sieve	Mass retained (gm)	Mass retained (%)	Cumulative % retained	% Passing
20 mm	0	0	0	100
10 mm	379	18.95	18.95	81.05
4.75 mm	1442.5	72.125	91.075	8.95
Pan	178.5	8.925	--	0
			Σ% Retained =110.025	

Weight of the sample taken = 2000 g

Fineness modulus = (110.025+500)/100 = 6.10

Table 3.6 Sieve analysis of coarse aggregate (20mm)

IS Sieve	Mass retained (gm)	Mass retained (%)	Cumulative % retained	% Passing
20 mm	160	3.2	3.2	96.8
10 mm	4410	88.2	91.4	8.6
4.75 mm	360	7.2	98.6	1.4
Pan	70	1.4	--	0
			Σ% Retained = 193.2	

Weight of the sample taken = 2000 g

Fineness modulus = (193.2+500)/100 = 6.93

3.1.4 Copper Slag

The CS is a waste material obtained from copper manufacturing industries. In this study, the CS is used as a substitution material for FA. Hence the properties investigated of this material were as similar to those of properties of the FA such as specific gravity, soaking up of water, sieve size analysis etc. The below table gives the physical properties of the CS and also the chemical composition analysis of the CS:

Table 3.7 Physical properties of copperslag (CS)

Name of property	**Observed value**
Maximum size of CS	4.75 mm
Specific gravity	3.51
Net soaking up of water	0.36
Fineness modulus	3.11

Table 3.8 Sieve analysis of CS

Sieve No.	**Mass retained (gm)**	**Percentage retained (%)**	**Passing (%)**	**% Retained cumulative**
4.75	Nil	---	100	--
2.36	14	1.4	98.6	1.4
1.18	334	33.4	65.2	34.8
600	456	45.6	19.6	80.4
300	147	14.7	4.9	95.1
150	41	4.1	0.8	99.2
Pan	8	0.8		
				Σ % retained = 310.9

Weight of the sample taken = 1000 g

Fineness modulus = 310.2/100 = 3.10

3.1.5 Steel Fibre

The steel fibres used in this work were obtained from the Kasturi Metal Composites Pvt. Ltd., Amravati, Maharashtra. The physical properties of these steel fibres used are as given blow:

Table 3.9 Properties of steel fibres

Name of property	Observed value
Type of steel fibre	Hooked ended
Length (mm)	60
Diameter (mm)	0.75
T. strength of steel fibre	1200 N/mm^2
Aspect ratio (L/D)	80

3.2 MIX DESIGN AS PER IS 10262:2009

The concrete mix design is carried out for a particular compressive strength of concrete to achieve adequate amount of ease of mixing so that the concrete can be easily transported, placed and compacted. The concrete mix design as per Indian Standards IS: 10262-2009 is done for the casting of the specimens for different tests to be performed. The mix design is done for M25 grade of concrete. The preliminary data of the constituent materials required for the mix design of concrete is found out as stated above. The quantities of the material required per cubic meter volume of concrete are found out and the quantities per batch of the concrete were calculated by multiplying the calculated data with the batch volume.

M25 MIX DESIGN DATA

Characteristic Compressive Strength at 28 Days = 25 N/mm^2

Maximum size of aggregate = 20 mm

Type of Exposure = Mild

Table 3.10 Mix proportion M25

Name of the material	Quantity (kg/m^3)
OPC	413
FA	765
Coarse aggregate	1032
Water	186
w/c ratio	0.45

The control mixes with constant amount of OPC content, fine and coarse aggregate content were made to achieve maximum 28 days compressive strength of 31.4 MPa. In the mix proportions of the different mixes, the content of FA was varied with CS (CS) in proportion of 0%,20%,40%,60%,80% and 100% substitution level. The amount of the steel fibre was kept constant at 1% volume fraction by volume of concrete mix. The composition of different mixes is as given below in the table. The concrete mix was designed to have the constant OPC content, coarse aggregate and water content with varying amount of C**S**.

Table 3.11 Different concrete mix proportions

Mix no.	**OPC (kg/m^3)**	**FA (kg/m^3)**	**CS (kg/m^3)**	**Coarse aggregate (kg/m^3)**	**W/C ratio**	**Water (kg/m^3)**	**Steel fibre (%)**
CS0	413	765	0	1032	0.45	186	1
CS20	413	612	153	1032	0.45	186	1
CS40	413	459	306	1032	0.45	186	1
CS60	413	306	459	1032	0.45	186	1
CS80	413	153	612	1032	0.45	186	1
CS100	413	0	765	1032	0.45	186	1

*CS0/20/40/60/80/100 CS at 0%, 20%, 40%, 60%, 80%, 100% substitution with FA

3.3 CASTING AND CURING OF SPECIMENS

The specimens of different sizes were casted as per the requirements of the testing methodology. The casting of the specimens involved the weighing of the materials, dry mixing of the constituent materials i.e. OPC, FA, CA and CS and then water was added to the dry mix. Steel fibres were added simultaneously with the mixing process. The type of mixing adopted was the hand mixing as the machine mixing lead to the clogging of the steel fibres. The moulds were oiled properly before pouring the concrete mix into them. The top surface of the specimens was scraped off to obtain the smooth surface finishing. The samples were removed from the mould after 24 hrs. and were then placed into the curing tank for 7, 28, 56 days. The surface of the specimens taken out from the curing tank was wiped off with cloth before testing. The description of the type and size of the specimens is as given below:

Table 3.12 Specimens description

Name of the test	Type of specimen	Size of specimen (mm)
Compressive strength	Cube	150 x 150 x 150
Split T. strength	Cylinder	300 x 150 (L x D)
Permeability test	Cube	150 x 150 x 150
Sorptivity	Cylinder	50 x 100 (L x D)
RCPT	Cylinder	50 x 100 (L x D)

3.4 TESTING PROGRAM

The different tests performed on the casted specimens and standards followed for the testing procedure are as given below:

Table 3.13 Tests and Codes

TEST	CODE
Compressive strength	BIS 516-1959
Split T. strength	IS 5816-1999
Penetration Test	DIN 1048 Part- 5
Sorptivity	ASTM C1585-2004
RCPT	ASTM C1202-2012
Scanning electron microscope (SEM)	

The above tests were performed at different curing periods i.e. 7, 28, 56 days of curing. **3.4.1 Workability**

The ease by which the concrete can be mixed, transported and placed in the specimen is termed as the ease of mixing. Ease of mixing of the concrete is an important factor while selecting a suitable concrete for a particular work. The ease of mixing of the concrete is affected by the large number of factors such as the size of the aggregates, specific surface area, water content and water/OPC ratio etc. The amount of ease of mixing of concrete required depends upon the type of the concreting work undertaken. For example, for pumping of concrete at a height, larger amount of ease of mixing is required as compared to the concrete being poured into the foundation of the building. The ease of mixing required is initially taken into the account while designing the concrete mix and trial mixes are prepared to attain the desired ease of mixing. The ease of mixing of the concrete can be increased by increasing the w/c ratio which in turn may result in the decreased strength of the concrete. To increase the ease of mixing of the concrete without increasing the water content, certain chemical compounds or mineral admixtures are added into the concrete to attain the desired ease of mixing which are known as the superplasticizers. The study of ease of mixing at different amount of CS has been studied in this research report.

3.4.2 Compressive Strength

It is the strength of the concrete when the concrete specimen is subjected to compressive loads which will result in the compression of the concrete specimen. To test the compressive strength of the concrete mix, different concrete mixes were prepared and casted into the standard specimen size of cub of dimension 150 mm as per specifications given by Indian standard IS: 516-1969. After casting of the specimens, they were put for drying for 24 Hrs. and were taken out of the mould on the other day and were placed for curing for 7, 28- & 56-days period.

At the end of stipulated time of curing, the samples were taken out of the curing tank and were tested on the machine. The machine normally used for the compression test of the cubical specimen is the Compression Testing Machin (CTM). The cube specimen was placed into the machine and compressive load was applied at the speed of 5 KN/sec. The value of peak load as given the machine was noted and to obtain the value of compressive stress, this value of peak load when divided by cross-sectional area of the cube gave stress. Empirically, the formula is given by

$$\sigma = P/A$$

; σ = Compressive Strength (MPa)

P = Peak Load (KN)

A = x-sectional area of specimen (mm^2)

Plate 3.3: Cube compression test in Compression testing machine

3.4.3 Splitting T. Strength

The T. strength of the concrete is one of the important properties of concrete as the knowledge of the value of the T. strength of concrete is required in designing of the many of the concrete structural elements. The value of T. strength of concrete is used in the design of prestressed concrete, liquid retaining structures, roadways and runway slabs etc. It is difficult to determine the direct T. strength of concrete so the course of action taken is to determine the splitting T. strength of concrete and from there is to determine the direct T. strength of concrete. A splitting T. strength test of concrete is that in which a cylinder is splitted along the vertical height and across the diameter. It is an indirect method of testing.

Preparation of specimen

The specifications of the standard test specimen used for the splitting T. strength of concrete are 300 mm in length and 150 mm in diameter. The length of the specimen in not to be less than the diameter and not to be greater than the twice of the diameter. The base plate of the cylindrical mould should be oiled properly before pouring the concrete mix into the mould in order to prevent the adhesion of the concrete.

Computation and results

The following formula as per IS 516 is used for computing the splitting T. strength of the concrete specimen

$$T = (2P/\pi DL)$$

Where T = Splitting T. strength of concrete in MPa

P = Maximum applied load as indicated by the machine in KN

D = Diameter of the cylindrical specimen in 'm'

L = Length of the cylindrical specimen in 'm'

Plate 3.4: Splitting T. strength test of cylinder.

3.4.4 Penetration Test

The permeability test of concrete is the type of durability test which is conducted to determine the resistance of the concrete against the penetration of water of any other compound. The permeable concrete can make the concrete more prone to attack of different chlorides and salts present in the water when used in under water structures. The ingression of water into the concrete can also cause the corrosion of the reinforcement used in the concrete and hence ultimately leading to the decreased T. strength and making the structure less durable. Therefore the permeability of concrete is an important aspect to know the durability characteristics of the concrete. The permeability test of concrete determines the permeability under the application of the hydrostatic pressure.

Preparation of the specimen

The specimens required for the permeability test of concrete are the 150 x 150 mm cubical specimen cured at 28 days. The samples are fixed in the permeability apparatus after taking them out from the curing tank and wiping off the extra surface water. The hydrostatic pressure required is to be maintained at 5 kg/cm^2 and the same pressure is to be maintained continuously for 3 days.

Observation and reading

At the end of a period of three days, the samples are taken from the test apparatus and splitted into two parts by applying point load in the UTM and the depth of penetration of the water is measured using the measuring scale. Also the drop in the level of water in the water tube of the permeability apparatus is calculated.

Plate 3.5: Depth of penetration of splitted concrete specimen

3.4.5 Rapid Chloride Permeability Test (RCPT)

Durability of the concrete is an important aspect of civil engineering since it determines how the concrete is going to behave the action of environmental agencies and worst atmospheric effects during structure's service life. There are several tests conducted to assess the durability characteristics of the concrete and one of them is resistance to the penetration of different salts and chlorides and chemical into the concrete. Rapid chloride penetration test is on of these durability tests of concrete which is conducted to assess the penetration resistance of concrete to chlorides and salts. The penetrated ions of chlorides and salts may cause adverse effect on the performance of concrete under adverse environmental conditions. The basic principle on which this test is based upon is the electrical conductance of the concrete due to the presence of differently charged ions in the concrete.

The test method includes observing the conductance of the concrete specimen by bringing the specimen in contact with two oppositely charged ions and then conducting the current through it and observing the flow of current through the specimen for a period of 6h under a potential difference of 60 V DC supply. The total amount of current passed is expressed in terms of the charge passed in Coulombs which is then related to the resistance of the specimen to the chloride ion penetration depending upon the amount of charge passed.

Table 3.14 Standards of Chloride ion permeability as per ASTM C1202

Amount of charge passed (in Coulombs)	Permeability of chloride ion
> 4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

Preparation of samples

Cylindrical concrete disc of thickness (100×200 mm) with and without CS were casted and cured in water for 7, 28 and 56 days. concrete mixture was designed using M-25 grade. Then FA was partially replaced with 0, 20, 40, 60, 80 and 100 % CS.

Plate 3.6: concrete specimens placed in desiccator

Conditioning and testing of concrete specimen

The specimens to be used for the rapid chloride permeability test need to be conditioned and prepared before placing and testing them in the RCPT apparatus. The specimens are vacuum dried by placing the, in the desiccator for a period of 3 hrs. so that all the free entrapped air in the voids can be expelled out and there is no obstruction in the passage of the flow of ions through the specimen. After this the specimens were left for soaking in the container for another 18h period. Then removal of specimen from the desiccator and dried and placing into the gasket by applying grease at the joints so that no outflow of the solution is there. The solution of 3% NaCl and 0.3 NaOH solution were prepared and filled into the two cells of the gasket. A DC current of 60 V was allowed to pass through and the conductance of the current by the concrete specimen was recorded at the end of period of 6hrs.

3.4.6 Sorptivity

It is a type of durability test of concrete in which the concrete specimen is exposed to the water from only one surface. The concrete specimens are placed in the water up-to a depth of 2-3 mm from the top surface of the water and the rate of absorption of water with time under the hydraulic action is determined. The increase in the mass of the specimen with time is noted with time. This test is quite helpful to report the results for the use of concrete in the underwater retaining structures or the concrete structures subjected to the capillary suction of the water. The Sorptivity test of the concrete is a measure of the soaking up of water with respect to time when only one surface of the specimen is exposed to water attack.

Size and preparation of the specimens

The size of the specimens required for this test is of 50 mm length and 100 mm diameter with an allowable error of 2 mm. The specimens of the desired size can either be casted as such using the mould of the respective shape and size or can be cut out from the bigger specimens. In our case, cylindrical specimens of size 100 mm diameter and 200 lengths were casted and cured for a period of 28 days and then specimens of size 100 mm diameter and 50 mm length were cut out from the cylindrical specimens using a cutter. After taking the specimens from the curing tank, the specimens were oven dried for a period of 24 hrs.

After this, the test was performed as per the guidelines of ASTM C1585-04 and observation in the change in the mass of the specimens with respect to time was noted.

Plate 3.7: Sorptivity test of concrete specimen

3.4.7 SEM (Scanning Electron Microscope)

It is a type of microscopic level of testing of the concrete samples at a high magnification level using highly precise and magnification microscopic instruments. The technique involves projecting a focused beam of electrons on the concrete sample which will give the details of the concrete structure at a microscopic level and produce images of microstructure of concrete. The technique can provide the morphology and chemical composition of the concrete samples which may be helpful for interpreting the results obtained from different testing results on the concrete specimens and characterization of the heterogeneous materials. Sample used for the SEM testing are prepared by drying at room temperature and then examining at increasing voltage of 20 kV SEM.

CHAPTER 4

RESULTS AND DISCUSSIONS

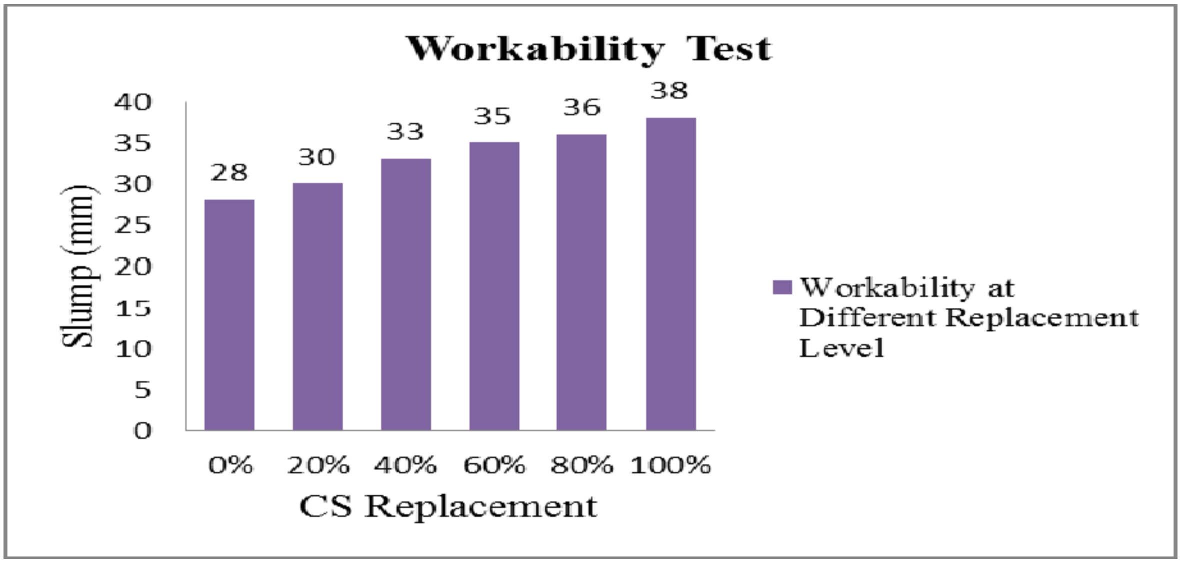
This chapter deals with the results of the different tests conducted on the concrete specimens namely tests on the fresh properties, hardened properties and durability properties of concrete and also the discussions on the results obtained from different tests.

4.1 FRESH PROPERTIES

Under fresh properties of concrete, the tests that fall are the tests which are conducted with the paste of the concrete mix before the setting of the concrete mix. The test conducted is the ease of mixing of concrete. The ease of mixing of the different concrete mixes at different levels of FA substitution with the CS was determined and the results obtained are put into a table and a bar chart of the same results is obtained.

Table 4.1: Slump values for different CS content concrete mixes.

Sample ID	Slump value (mm)
CS0	28
CS20	30
CS40	33
CS60	35
CS80	36
CS100	38



*CS – CS, steel fibre – 1% Volume fraction

Fig 4.1: Ease of mixing test results of different concrete specimen.

Discussion: It was observed that there was increase in the ease of mixing of concrete with the increase in the percentage substitution of FA with CS. This increase was mainly due to the crystalline, glassy surface of the CS particles due to which the soaking up of water of the CS particles was less as compared to the FA particles which resulted in the availability of more free water in the mixture and hence ultimately the increased slump value or ease of mixing.

4.2 HARDENED PROPERTIES

In the hardened properties of concrete, the tests which are conducted are those tests which are conducted after the setting of the concrete mix and after curing of the specimens after a particular time period like 7, 28 & 56 days. The tests such as compressive strength and split T. strength test are conducted on the hardened concrete specimens at period of 7, 28 & 56 days of curing.

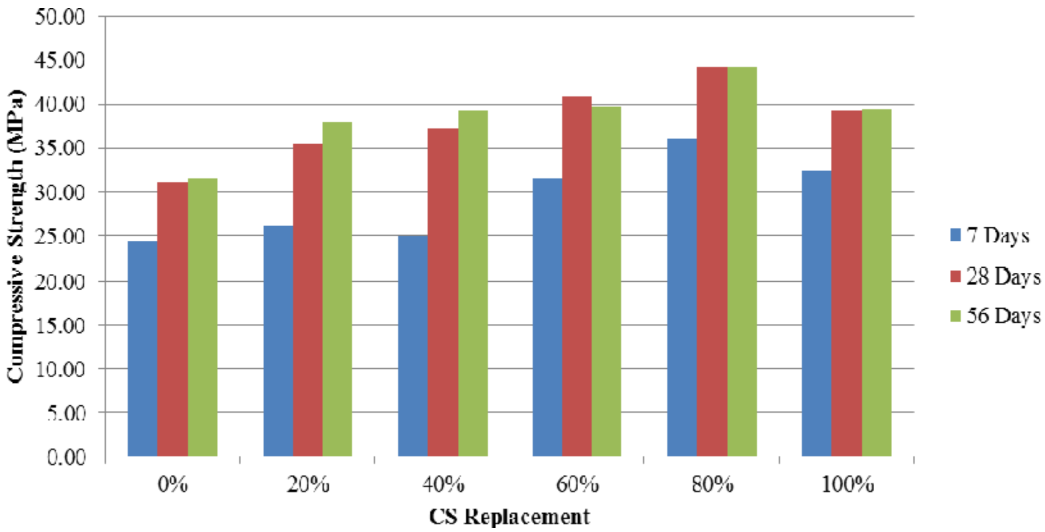
4.2.1 Compressive Strength

The average compressive strength of the concrete specimens at different levels of CS with steel fibres and at different stages of curing period were studied and it was found that the strength increases with the increase in the curing period. The detailed values of the results obtained, and the discussion of the results is as explained below:

Table 4.2: Average compressive strength at 7, 28 & 56 days.

Sample ID	7 Days	28 Days	56 Days
CS0	24.39	31.04	31.57
CS20	26.16	35.50	38.04
CS40	24.92	37.19	39.23
CS60	31.66	40.84	39.76
CS80	36.15	44.25	44.35
CS100	32.35	39.33	39.37

*CS – Copper Slag



*CS – Copperslag, Steel fibre – 1% Volume fraction

Fig 4.2: Average compressive strength at 7, 28 & 56 days.

Discussion: It has been observed that the effect of substitution of FA with CS on compressive strength of the concrete showed different trends at 7,28 & 56 days of curing. The compressive strength of the concrete at 7 Days of curing increases up-to 20% CS substitution and then it decreases at 40% CS substitution but the decrease in the strength is not much and it might happen due to some experimental error because afterwards it again started increasing with the increase in the CS substitution up-to 80% and then decreases at 100% CS substitution. The reason for the increase in the strength is that the fibres provide the arresting mechanism to the concrete by preventing cracks from propagating through the sample. Also the particle size distribution curve of CS is more uniform as compared to natural sand which resulted in the reduction in the voids and making the interface between the mortar and the aggregate stronger and failing of concrete occurring by the crushing of coarse aggregate.

The compressive strength of concrete at 28 days of curing increases with the increase in the substitution of FA with the CS up-to 80% and then it starts decreasing at 100% CS substitution.

The compressive strength of concrete at 56 days of curing also increases with the CS substitution. Also the compressive strength along the different curing periods i.e. 7, 28 & 56 days also increases with the increase in the CS substitution except for the case 60% CS substitution where the 28 days compressive strength is more than the 56 days compressive strength but the difference in the two strengths is very less.

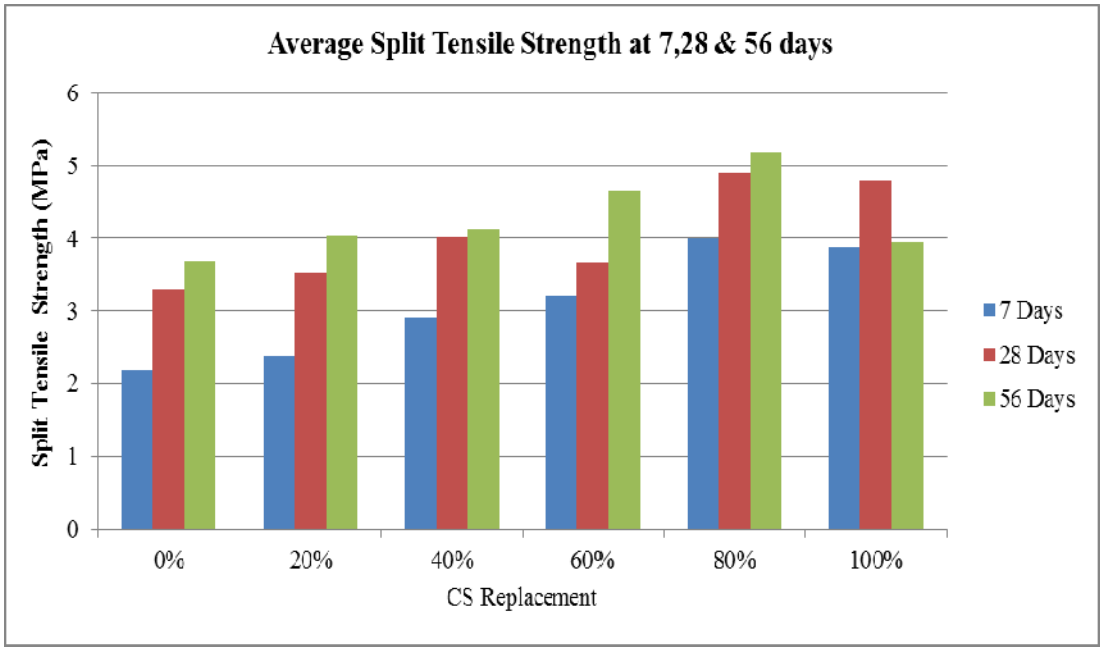
4.2.2 Split T. Strength

The average split T. strength of the concrete specimens at different levels of CS with steel fibres and at different stages of curing period were studied and it was found that the strength increases with the increase in the curing period. The detailed values of the results obtained and the discussion of the results is as explained below:

Table 4.3: Average split T. strength at 7, 28 & 56 days.

Sample ID	7 Days	28 Days	56 Days
CS0	2.18	3.31	3.70
CS20	2.39	3.53	4.03
CS40	2.91	4.02	4.13
CS60	3.23	3.66	4.65
CS80	3.99	4.90	5.19
CS100	3.88	4.79	3.95

*CS – Copperslag



*CS – Copperslag, Steel fibre – 1% Volume fraction

Fig4.3: Average split T. strength at 7, 28 & 56 days.

Discussion: It has been observed that the effect of substitution of FA with CS on split T. strength of the concrete showed different trends at 7,28 & 56 days of curing. The split T. strength of concrete at 7 days of curing increases linearly with the increase in the substitution of FA with the CS up-to 60% and there was a rapid increase in the strength from 60% to 80 % CS substitution and then it starts decreasing at 100% CS substitution.

The split T. strength of the concrete at 28 Days of curing increases up-to 40% CS substitution and then it decreases at 60% CS substitution but the decrease in the strength is not much and it might happened due to some experimental error because afterwards it increases rapidly from 60% to 80% CS substitution and then decreases slightly at 100% CS substitution. The reason for the increase in the strength is that the fibres provide the breaking resistance to the concrete by preventing cracks from propagating through the sample.

The split T. strength of concrete at 56 days of curing also increases with the CS substitution up-to 80% CS substitution and then decrease at 100% CS substitution.

Also the split T. strength along the different curing periods i.e. 7, 28 & 56 days also increases with the increase in the CS substitution except for the case 100% CS substitution where the 28 days split T. strength is more than the 56 days split T. strength.

4.3 DURABILITY PROPERTIES

The durability tests on concrete are conducted to assess the performance of the concrete subjected to different atmospheric conditions and attack of different alkalis and acids or any other chemical compounds. The different tests are conducted to assess the durability of the concrete.

4.3.1 Sorptivity

It is a type of durability test of concrete in which the rate of soaking up of water of the concrete specimens expressed in terms of the gain in weight of the specimen with respect to time under the hydraulic action is calculated. Two specimens of each of the percentage substitution level were taken and immersed in the water and the readings of the increase in the weight of the specimens with time are taken which are as given below:

Table 4.4: Increase in the mass of the specimens with time.

		Mass of the specimens					
Sample ID		**CS0**	**CS20**	**CS40**	**CS60**	**CS80**	**CS100**
Time (in sec)	**√Time**						
0	0	985.52	1028.45	1058.66	1073	1055	1077.5
60	8	986.47	1029.32	1058.75	1073.22	1055.55	1077.69
300	17	987.50	1029.42	1058.95	1073.38	1055.69	1077.85
600	24	987.88	1029.5	1059.35	1073.55	1055.93	1077.9
1200	35	987.93	1029.85	1059.65	1073.69	1056.15	1077.99
1800	42	987.95	1029.96	1059.85	1073.95	1056.4	1078.25
3600	60	988.00	1030.15	1060.15	1074.25	1056.4	1078.23
7200	85	988.00	1030.36	1060.49	1074.65	1056.4	1078.35
10800	104	988.00	1030.48	1060.74	1074.95	1056.65	1078.65
14400	120	988.00	1030.55	1060.95	1075.15	1056.8	1078.85

18000	134	988.00	1030.65	1061.35	1075.33	1056.8	1078.95
21600	147	988.00	1030.86	1061.45	1075.44	1056.8	1079
92220	304	988.15	1031	1061.59	1075.46	1056.9	1079.5
193200	440	988.65	1031.45	1061.6	1075.5	1056.9	1079.5
268500	518	989.05	1031.65	1061.6	1075.6	1057.2	1079.6
432000	657	989.35	1031.77	1061.75	1075.6	1057.2	1079.6
527580	726	989.55	1031.83	1061.76	1075.65	1057.2	1079.6
622200	789	989.75	1031.95	1061.8	1075.7	1057.3	1079.85
691200	831	989.88	1031.99	1061.85	1075.7	1057.5	1079.85
Net gain in mass (in g)		4.36	3.54	3.19	2.7	2.5	2.35

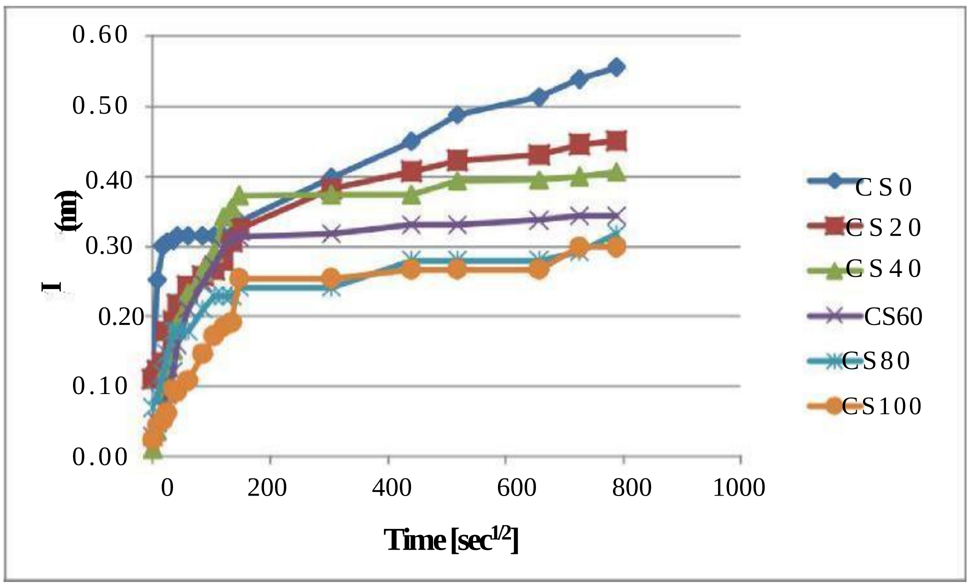


Fig 4.4 Rate of absorption with square root of time

Discussion: It has been observed from the above values that the increase in the mass of the specimen is highest for the control specimen i.e. the specimen with 0% CS content and least increase in the mass of the specimen is observed for the specimen with 100% CS content which implies that the specimens with the 100% FA substitution with CS showed the least capillary rise of water with time while the specimen with 0% FA substitution showed the highest soaking up of water due to capillary rise. Because of this, the curve between ***I (in mm)*** and square root of **time (in sec)** becomes flatter with the increase in the CS content in the concrete specimen. The reason for the above behavior of the specimen is that as the CS has the glossy, crystalline nonabsorbent surface and hence absorbs less amount of water as compared to the natural FA and as the CS content in the specimen increases the content of this nonabsorbent material increases and hence the gain in the mass of the specimen decreases with time.

4.3.2 Penetration Test

It is also a type of durability test of concrete which is conducted to determine the penetration resistance of concrete to water. The more is the permeability of concrete the higher will be the chances of ingress of water into the concrete. The test is conducted for a period of three days and the water is subjected to penetrate into the concrete specimen at a pressure of 5 kg/cm^2. The initial and the final readings of the water level in the tube are noted and also the depth of penetration is calculated by splitting the specimen into two parts from the middle. The different observations taken for the specimens with different percentage of CS content at a fixed amount of steel fibre content are as shown below in the table:

Table 4.5: Observations of water penetration test apparatus.

Sample ID	**CS0**	**CS20**	**CS40**	**CS60**	**CS80**	**CS100**
Initial reading	37.6	35.6	37.4	35.2	33.8	33.4
Final reading	32.9	31.6	33.7	31.6	31.4	30.5
Difference in the water level	4.7	4	3.7	3.6	2.4	2.9
Depth of penetration (mm)	20.2	19.6	16.7	16.2	14.9	14.55

Plate 4.1: Penetration test apparatus

Discussion: It has been observed from the above values that the penetration of the water into the concrete decreases with the increase in the CS content. The drop in the water level reading in the water tube also decreased with the increase in the CS content in the concrete specimen. The reason for the decrease in the penetration of the water in the concrete can be interpreted as due to the glossy texture and non-absorbent surface of the CS which resulted in the less penetration of the water.

4.3.3 Rapid Chloride Permeability Test (RCPT)

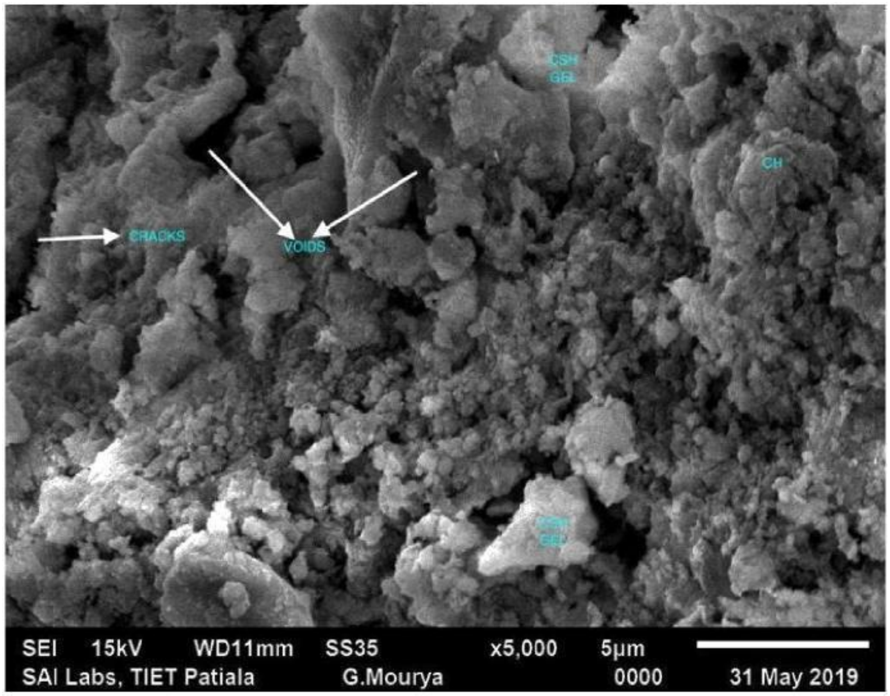
It is a type of durability test which is conducted to determine the chloride ion penetration of the concrete specimens when subjected to attack of the chlorides in under water retaining structures or sea water or in the structures where the concrete is subjected to some chemicals etc. The test was conducted on all the concrete specimens containing varying CS content and a fixed amount of steel fibres and the observations of the amount of current passed.

Plate 4.2: Rapid chloride permeability test apparatus and observation screen.

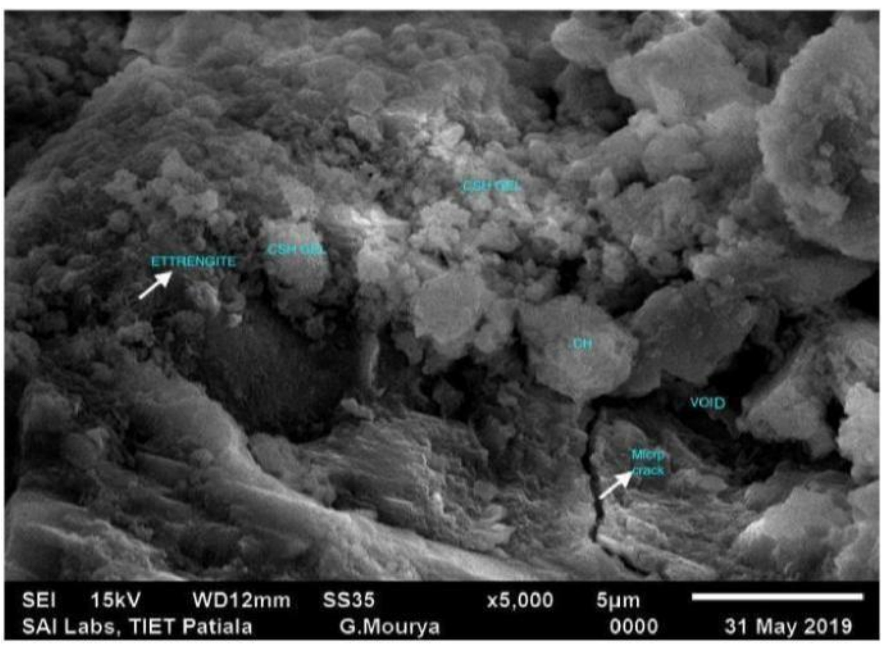
Discussion: It has been observed on conducting the test that the current passed through the sample resulted in the overflow of the current from the concrete specimens which resulted in the failure of the test specimen. The reason for the overflow of the current can be predicted as due to the presence of steel fibres in the concrete specimens, the current directly get passed through the concrete specimen instead of the conductance of the current due to the movement of ions from NaCl and NaOH solutions. Hence the test didn't give any result of the current conductance

4.3.4 Scanning Electron Microscopy (SEM)

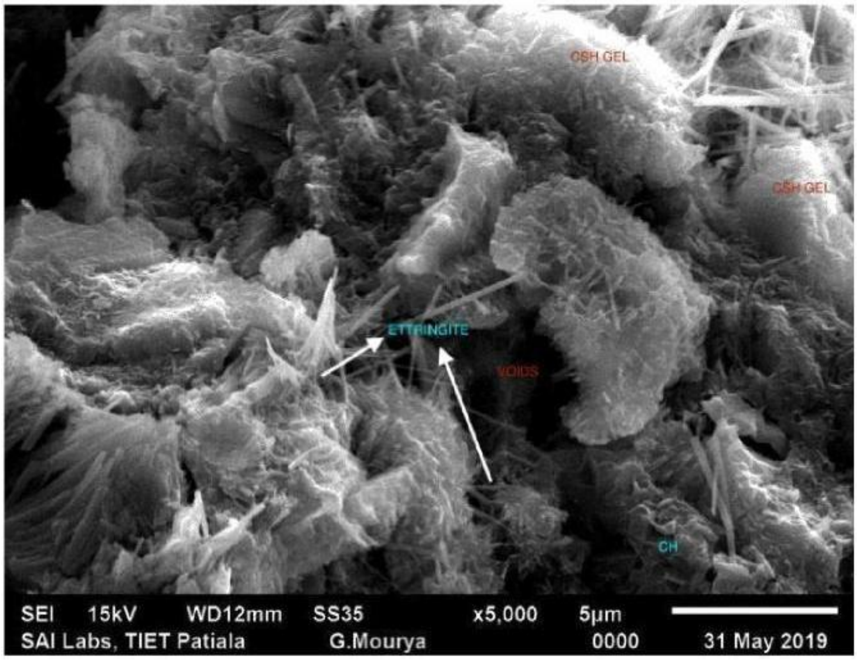
The scanning electron microscopy (SEM) of the different concrete samples at different levels of magnification was done to observe the microstructure of the concrete samples at different levels of copper-slag content. This analysis was done in order to see the reason for the variation in the increase or decrease in the strengths of different concrete specimens containing different percentage of CS. The SEM images obtained of the samples are as given below and discussion of relation of the obtained result in regard to the compressive strength and split T. strength is also as given below:



4.3 (a) CS 40



4.3 (b) CS 60



4.3 (c) CS 100

Plate 4.3 SEM analysis of concrete samples.

Discussion: From the SEM analysis of different concrete samples at different levels of magnification at the end of 28 days curing period it is observed that different compounds are formed in the concrete samples at different levels of CS in the mix. The compounds mainly formed are ettringite, CSH gel, CH compound etc. The early or late formation of such compounds is responsible for the strength and other characteristics of concrete. For example, as we have seen in the above results of compressive strength and split T. strength, for 100% CS these values are lesser as compared to the 80% CS level and from SEM analysis we came to know about the formation of large amount of ettringite in the concrete sample. These ettringite are needle like compounds which needs to be formed at early stage and if delayed will results in the formation of cracks and expansion of concrete. Also, the formation of CSH gel (which looks like a cotton) in the sample containing 60 % CS is more as compared to the 40% CS sample which resulted in the more strength in the later one. Another compound which is formed is CH (calcium hydroxide) which is most soluble compound of hydration reaction is a hexagonal or octagonal shaped compound is formed in almost all the samples which is not much responsible from strength point of view but is responsible for durability point of view.

CHAPTER 5

CONCLUSIONS

This chapter deals with the final conclusions of the present work done. The observations and results obtained from the different tests conducted on the concrete specimens lead to the conclusions which may be helpful in the further studies. The conclusions for the different tests are described as below:

5.1 COMPRESSIVE STRENGTH

The compressive strength test results of the concrete specimens revealed that with the increase in the substitution level of the FA with CS content at a fixed steel fibre fraction, the compressive strength of the concrete specimen goes on increasing up-to a substitution of 80% and then it started decreasing which concludes that the CS can be used as substitution material for FA up-to this percentage level only. The compressive strength of the concrete specimens also increase along the curing periods i.e. the compressive strength increases as the curing period of the specimens increases from 7 days to 56 days. The optimum content of CS to be used in the concrete based upon this research work can be suggested as 80%.

5.2 SPLIT T. STRENGTH

The split T. strength test results followed almost the similar trend as that of the compressive strength. The split T. strength test results of the concrete specimens revealed that with the increase in the substitution level of the FA with CS content at a fixed steel fibre fraction, the split T. strength of the concrete specimen goes on increasing up-to a substitution of 80% and then it started decreasing which concludes that the CS can be used as substitution material for FA up-to this percentage level only. The split T. strength of the concrete specimens also increase along the curing periods i.e. the split T. strength increases as the curing period of the specimens increases from 7 days to 56 days. The optimum content of CS to be used in the concrete based upon this research work can be suggested as 80%.

5.3 WORKABILITY

The ease of mixing test results of the concrete mix using CS as a substitution material for FA with a fixed steel fibre fraction revealed that although the ease of mixing of the concrete mix increases with the increase in the CS content yet the net slump value obtained is not much and hence the ease of mixing of the concrete mix falls under the category of low ease of mixing mix.

5.4 SORPTIVITY

The Sorptivity test results of the concrete specimens using CS as a substitute material for FA revealed that the rate of soaking up of water of the concrete specimen decreases with the increase in the CS content which concluded that the concrete mix made using CS can be used in the structures where less absorbing concreting material is required.

5.5 PENETRATION TEST

The permeability test results of the concrete specimens using CS as a substitute material for FA revealed that the penetration resistance of the concrete specimen increases with the increase in the CS content which concludes that such a concrete can be used at places where less permeable concrete is required such as under sea water retaining structures.

5.6 RCPT

The rapid chloride permeability test results of the concrete specimens using CS as a substitute material for FA revealed no conclusions as the fibres present in the concrete specimens resulted in the overflow of the current through the concrete specimen in a very short period of time and didn't predict the actual current passing due to the movement of ions through the concrete specimen.

5.7 SEM (SCANNING ELECTRON MICROSCOPE)

The results obtained from the SEM analysis revealed the microstructure of the concrete samples which proved to be helpful in identifying the reasons for the variations in the results obtained in terms of compressive strength and split T. strength. The SEM analysis also revealed the compounds formed due to hydration of cement paste.

5.8 SCOPE OF STUDY

As per the results obtained from different test results using varying amount of CS at fixed steel fibre content it can be concluded that the use of CS as a substitute for FA can be limited to some extent. Since there are some voids still available in the concrete as revealed by the SEM images, it is possible to use some finer materials to fill up these voids and hence some substitute to cement as a finer material or some other material (may be a waste product) as a substitute to fine aggregate can be used to make the structure of concrete more dense which will ultimately increase the strength of the concrete.

Also, the potential use of other fibres instead of steel fibres in combination with some substitute can be investigated.

REFERENCES

A.T. (2015) 'Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration',(C), pp. 1–8. doi: 10.1520/C1202-12.2.

Abbass, W., Khan, M. I., & Mourad, S. (2018). Evaluation of mechanical properties of steel fiber reinforced concrete with different strengths of concrete. Construction and Building Materials, 168, 556-569.

Al-Jabri, K. S., Al-Saidy, A. H., & Taha, R. (2011). Effect of copper slag as a fine aggregate on the properties of cement mortars and concrete. Construction and Building Materials, 25(2), 933-938.

Al-Jabri, K. S., Hisada, M., Al-Oraimi, S. K., & Al-Saidy, A. H. (2009). Copper slag as sand replacement for high performance concrete. Cement and Concrete Composites, 31(7), 483-488.

Ambily, P. S., Umarani, C., Ravisankar, K., Prem, P. R., Bharatkumar, B. H., & Iyer, N. R. (2015). Studies on ultra-high-performance concrete incorporating copper slag as fine aggregate. Construction and Building Materials, 77, 233-240.

Angadala Sowjanya, & P. Krishna Prasanna. (2016). Effect of Copper Slag on Steel Fiber Reinforced Concrete and Conventional Concrete. International Journal of Research in Engineering, IT and Social Sciences,06,9-15

Ayub, T., Shafiq, N., & Nuruddin, M. F. (2014). Mechanical properties of high-performance concrete reinforced with basalt fibers. Procedia Engineering, 77, 131-139.

Dos Anjos, M. A. G., Sales, A. T. C., & Andrade, N. (2017). Blasted copper slag as fine aggregate in Portland cement concrete. Journal of environmental management, 196, 607613.

IS:5816-1999, R. 2004 (2004) 'Splitting tensile strength of concrete', Bureau of Indian Standards,New Dehli.

IS:4031 (Part V) (1988) 'Methods of Physical Tests for Hydraulic Cement-Determination of Initial and Final Setting Times', Bureau of Indian Standards, New Delhi.

IS: 650 and IS 650 (1991) 'Specification for Standard Sand for Testing Cement', Bureau of Indian Standards, (May 1991).

IS:2386 (Part lll) (1963) 'Method of Test for aggregate for concrete.', Bureau of Indian Standards, New Delhi, p. (Reaffirmed 2002).

IS:8112-2013 (2013) 'IS 8112: 2013, Ordinary Portland Cement, 43 Grade - Specification, Bureau of Indian Standards, New Delhi', Bureau of Indian Standards,New Delhi, (March).

IS:10262 (2009) 'Guidelines for concrete mix design proportioning', Bureau of Indian Standards,New Delhi, pp. 1–21.

IS 4031(Part 6), I. S. (2005) 'Indian Standard Is: 4031 (Part 6) - 1988 (Reaffirmed 2005). Methods Of Physical Tests For Hydraulic Cement Part 6 Determination Of Compressive Strength Of Hydraulic Cement Other Than Masonry Cement (First Revision)', Bureau of Indian Standards,New Delhi, pp. 1–3.

IS 456:2000 (2006) 'Plain and reinforced concrete-Code of Practice (Fourth Revision)', Indian Standard, p. 114.

Jiang, C., Fan, K., Wu, F., & Chen, D. (2014). Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete. Materials & Design, 58, 187-193

Kakooei, S., Akil, H. M., Jamshidi, M., & Rouhi, J. (2012). The effects of polypropylene fibers on the properties of reinforced concrete structures. Construction and Building Materials, 27(1), 73-77.

Kisan, M. et al. (1963) 'Indian Standard 2386 (Part I): Method of Test for aggregate for concrete- Particle size and shape', Bureau of Indian Standards, New Delhi, p. (Reaffirmed 2002).

Kisan, M. et al. (1988) 'Indian Standard 4031 (Part IV): Methods of Physical Tests for Hydraulic Cement', Bureau of Indian Standards, New Delhi.

Murari, K., Siddique, R., & Jain, K. K. (2015). Use of waste copper slag, a sustainable material. Journal of Material Cycles and Waste Management, 17(1), 13-26.

Obili Maheshwar Reddy, P. Chamanti2,“ Effect of Copper Slag and Basalt Fibers on Various Properties of Concrete”, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 6, Issue 1, January 2017, ISSN (Print) : 2347-6710

Rajasekar, A., Arunachalam, K., & Kottaisamy, M. (2019). Assessment of strength and durability characteristics of copper slag incorporated ultra high strength concrete. Journal of Cleaner Production, 208, 402-414.

T. Ch.Madhavi, Arindam Mallick, Sohail M.B., Soumyadeep Nath, & Mohit Jain. Effect of Copper Slag on Strength of Polypropylene Fiber Reinforced Concrete. International Journal of Engineering and Technology.

Test, C. C. et al. (2004) ‘ASTM C 1585:2004 Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes’, American Society for Testing and Materials., pp. 1–6. doi: 10.1520/C1585-13.2.

Wu, W., Zhang, W., & Ma, G. (2010). Optimum content of copper slag as a fine aggregate in high strength concrete. Materials & Design, 31(6), 2878-2883.