DURABILITY CHARACTERISTICS

OF

ULTRA HIGH PERFORMANCE CONCRETE

A Thesis submitted in partial fulfillment of the requirement for the award of degree of

MASTER OF ENGINEERING

in Structural Engineering

Submitted By

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DECLARATION

I, Shubham Chauhan hereby declare that the work presented in this thesis entitled **(Durability Characteristics of Ultra High Performance Concrete)** in partial fulfillments of the requirements for the award of degree of Master of Engineering in Structural Engineering submitted to Civil Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of Dr. Maneek Kumar (Professor, Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala from January to July,2018. The matter presented in this thesis has not been submitted either in part or full to any other university or institute for the award of any other degree.

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ABSTRACT

There is an increasing demand of development of new type of concretes which have high strength, durability, improved serviceability and better economy for a larger span of time.

Ultra High Performance Concrete (UHPC) also known as Reactive Powder Concrete (RPC), is a cementitious composite material with low water-binder ratios of less than 0.25 and an optimized gradation of granular constituents which provides an excellent alternative to this increased demand for high strength concrete. The characteristic compressive strength of UHPC should be greater than 120 MPa. UHPC shows irregular pore structure which helps in reducing the liquid permeability and thus, increases the durability when compared with other types of concrete. The advent of UHPC has led to development of new technologies and solutions which enables to create customized applications like lightweight structures, ultra-thin panels, multiplex shapes and curvatures which are difficult to create with the normal reinforced concrete. UHPC has great plastic and hardening properties which does not requires the use of reinforcement which further helps pre-casters to create structures with complex shapes with having high durability and overall less economy, and also little preservation is required in these types of structures.

The aim of this study was to evaluate the compressive strength and durability properties like sulphate attack resistance and Rapid Chloride Penetration Test (RCPT) values of concrete mixtures incorporating supplementary cementitious materials like silica fume, nano silica and ground granulated blast slag (GGBS) or alccofine as a partial replacement of cement, along with three different percentages of steel fibers (i.e. 0.5%, 1% and 1.5%) with a water-binder ratio of 0.18. To understand the various properties of UHPC a comprehensive literature review is carried out which is assembled from various references representing many development, deployment efforts and research around the world. This investigation reveals that it is possible to achieve UHPC mixes with optimal usage of supplementary cementitious materials like silica fume, nano-silica and GGBS. Also, the mixes so developed provide excellent resistance to sulphate attack. In addition resistance to chloride penetration is found out to be very good, with all the mixes so developed falling under the 'Very Low' to 'Negligible' category as per ASTM C 1202.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is the most widely used construction material for building any kind of a load bearing structure. The researchers worldwide have always been searching for construction materials since long time which provide higher performance to build longer, taller and sounder structures. The cementitious materials usage can be traced back thousands of years ago in Italy, ancient Egypt, Greece and the Middle East. In 1756 the development of modern Portland cement began when John Smeaton while performing an experiment combined limestone sand additives including pozzolans in various combinations for a lighthouse construction. In modern sense the production of Portland cement was done by Joseph Aspdin, an Englishman, in 1824 which was further initiated by Isaac C. Johnson in 1840's after which the demand and cost of concrete increased to make much stronger and durable materials. In 1950's the compressive strength of 34 MPa of concrete was termed as high strength. In the 1960's with the further advancement in the development of concrete the higher compressive strength was achieved, and 41 to 52 MPa was termed as high strength concrete which was also used commercially. In mid-60's the concrete compressive strength ranging from 40 to 80 MPa was termed as High Performance Concrete (HPC). Some of the ancient structures which have stood the test of time are shown in Fig.1.1 and Fig.1.2.

Fig.1.1: The Roman Pantheon (Source: www.wikipedia.org)

Fig.1.2: The Colosseum, Rome (Source: www.wikipedia.org)

In the early 1970's, the concrete with compressive strength of 62 MPa were being produced and used in many applications such as prestressed concrete bridges and high rise buildings. Now days, concrete having compressive strength of more than 120 MPa is considered as Ultra High Performance Concrete (UHPC) which is being used for constructing many mega structures like bridges and high rise towers. With the help of these high performance concrete technologies new innovations are developing these days which allows us to build lighter structures and longer spans without using much steel reinforcements thus providing reduction in the dead weight and cost of the structures.

1.2 ULTRA HIGH PERFORMANCE CONCRETE

Ultra High Performance Concrete (UHPC) is also known as performance enhanced concrete, which fall under the category of special series of concrete, produced to provide benefits in concrete constructions which is not achieved by conventional ingredients, curing practices and normal mixing. Therefore, Ultra High Performance Concrete (UHPC) is developed for a particular type of environment and special types of applications so that it will withstand the design loads and provide very good performance in the structure in which it will be placed. In other words, we can say that Ultra High Performance Concrete (UHPC) is a superior quality concrete having higher strength, better durability and long term stability as compared to normal concrete. It may also include concrete, which sufficiently reduces the time of construction without compromising on the long term serviceability.

1.2.1 Definition

Ultra High Performance Fiber-Reinforced Concrete (UHPFRC) is a very high strength, new generation fiber reinforced concrete having fine powders ideally graded and low water to binder ratios. Its composition includes an optimal amount of cement (ordinary Portland cement), coarse aggregates, fine aggregates, ground granulated blast furnace slag (GGBS) or alccofine, silica fume, nano-silica, very low amount of water and high tensile steel fibers.

These materials help to create UHPC mixes which have dense microstructure. Silica fume provides the most beneficial use as its physical and chemical properties, makes it to act as a very reactive pozzolan, which increases the strength and durability of concrete. Due to very low water-binder ratio of fresh concrete the workability becomes less so, to achieve the adequate workability superplasticizers are used in the formation of UHPC. The concrete properties such as mechanical, durability and ductility, are very different for UHPC as compared to ordinary concrete as well as high performance concrete because of the high-packing density. This family of concrete which has high compressive strength varying between 120 MPa to 150 MPa, improved ductile behaviour, and a high flexural strength of 14 MPa to 50 MPa. These enhanced strength values are because of dense and improved microstructure properties and discontinuous pore structure. The toughness index of Ultra High Performance Concrete (UHPC) is also very high as compared to ordinary concretes.

This type of material is very useful for applications in prefabricated and prestressed structures as it shows no creep or shrinkage. Also, the abrasion resistance is very high. However, the major issue of UHPC is its brittle nature which restricts its use in many applications.

1.2.2 Properties of UHPC

UHPC has following properties:

1. Compressive strength upto 200MPa.
2. Modulus of elasticity between 45 GPa to 50 GPa
3. Flexural strength upto 50MPa.
4. It has high tensile strength.
5. It is strong, durable and ductile.
6. It shows increased resistance to erosion, corrosion and abrasion.
7. UHPC is brittle in nature.

1.3 SELECTION OF MATERIALS

The materials which are used to produce Ultra High Performance Concrete (UHPC) are called its ingredients. The ingredients should be carefully selected and inspected for producing UHPC. With proper proportioning and controlling of basic ingredients a much stronger, durable and uniform concrete mix can be achieved.

There are two types of subgroups in ingredients, one which are active and the other are termed as inactive. The active group includes water and cement and the inactive group includes coarse aggregates and fine aggregates. The various ingredients with their specific requirements which are used to make UHPC are discussed below:

1.3.1 Portland Cement

There are two types of materials required in manufacturing of Portland cement which are argillaceous materials and calcareous materials. The argillaceous materials include clay or shale and calcareous materials includes chalk or limestone. The manufacturing units of Portland cement are set up in a place where availability of these materials is in abundance. In the process of manufacturing cement, the raw materials are properly mixed and grinded according to their purity and composition after which the kiln is set up to a temperature of 1300ºC to 1500ºC to burn these raw materials. After this process clinker is formed which is nodular in shape as the material partially fuses, then these clinkers are cooled down to a certain temperature and gypsum of quantity 3 to 5% is added to it. This process results into the production of Portland cement.

There are two process of mixing and grinding of raw materials which are dry process and wet process. In earlier days wet process is used for mixing of the raw materials as no technique was available back then which mixes the raw materials in powder form. But with help of research and development in the field of construction dry process is introduced by using compressed air method which gained momentum in the industry because it is much accurate method and requires less fuel then the wet process.

The physical properties which are required for the cement to be used in UHPC are as follows:

Minimum 7 days mortar cube strength	: 28.95 MPa.
Mortar air content	: 7 to 10 %
Maximum Blaine fineness	: 4000 cm^2/gm.

1.3.2 Supplementary cementitious materials

For obtaining UHPC, several materials are required which have special qualities and are different from basic concrete materials, and these are termed as supplementary cementitious materials. This includes Ground Granulated Blast Furnace Slag (GGBS), Silica fume, etc. These materials have high pozzolanic nature which helps to produce very dense microstructure and reduces the pores and their patterns in the concrete to a great extent which results in better strength and very low permeability.

1.3.3 Water-Cement ratio

The Water-Cement ratio is defined as the ratio of weight of water to the weight of binder/cement used in concrete mix. In the concrete mix the aggregates absorb some water which is not included in the weight of water.

For mixing of UHPC potable water is considered satisfactory. According to the researches it has been proven that with low w/c ratio we can achieve better strength of concrete, so to produce UHPC very low water-binder ratio is used ranging from 0.15 to 0.30 and to overcome the workability issues special quality of superplasticizers was used. In the present study one w/c ratio of 0.18 has been considered.

1.3.4 Aggregates

Aggregates are a very essential ingredient in the raw materials of the UHPC. The aggregates include gravel, sand, sag saw dust, crushed stone, broken bricks, etc. They are called inert materials as they do not take part in any type of chemical reaction occurring during setting and hardening of concrete. The volume of the concrete is increased with the help of aggregates as they occupy 85% of the total volume of concrete. Aggregates reduce the economy of concrete as they are cheaper than other materials and they also increase the durability and stability of concrete.

They are further divided into two sub-categories:

a) **Coarse aggregates:** These aggregates are formed due to artificial crushing of gravel or rock or by natural degradation of rocks. These aggregates clearly pass through IS sieve of 75 mm and leaves a very minimum residue in IS sieve of 4.75 mm, so in other words we can say that the coarse aggregates are the one which have maximum particle size of 75mm and minimum particle size of 4.75 mm. The study shows that in case of ordinary concrete the strength of aggregates is high as compare to the other components of concrete but in the case of UHPC aggregates with higher strength are not suitable because if the modulus of elasticity of aggregates is higher than the modulus of elasticity of concrete then it can cause contrary stress concentrations, thus damaging the concrete mechanically.

With the increase in maximum size of coarse aggregates the strength of concrete is known to be reduced so the maximum size is kept at the rate of 9.5 mm or 12.5 mm of coarse aggregates for development of UHPC. In the present study two types of coarse aggregates of size 10 mm and 20 mm is used to suitably produce UHPC.

b) Fine aggregates: Aggregates passing through IS sieve of 4.75 mm are considered as fine aggregates. As per the specification of size of fine aggregates they are further classified as clay and silt. The particles having size of less than 0.02 mm is recognized as clay, whereas the particle size range lying between 0.06 to 0.02 mm is termed as silt. Whereas, particle size greater than 0.07 mm is known as sand. Fine aggregates consist of crushed sand stone, crushed gravel stone and natural sand. Fine aggregates help in reducing the cost of concrete as it is much cheaper than other components of concrete, and it also reduces the voids in the concrete because of its fine particle size. Fine aggregates also contribute in in increasing the workability and volume of the concrete. The fineness modulus of fine aggregates lies between 2.2 to 3.2. The sand is considered to be fine when the range of fineness modulus lies between 2.2 to 2.6. The medium sand is considered when the range of fineness modulus lies between 2.6 to 2.9 and the coarse sand is considered when the range of fineness modulus lies between 2.9 to 3.2. The fine aggregates having fineness modulus in the range between 2.5 to 3.2 is best suited for developing UHPC.

1.3.5 Admixture

Admixtures are the natural or manufactured chemical materials which are added to the cement, water and aggregates in specific proportions just before or during concrete mixing. Admixtures help in modifying one or more properties of concrete and help in getting the desired results. In other words, the material other than cement, aggregate and water in the concrete which are used as an ingredient to reduce workability, controlling early hardening, setting time and providing strength to the concrete are called as admixture.

Admixtures are classified into two categories 'Mineral admixtures' and 'chemical admixtures'

a) Mineral admixtures: Mineral admixtures are basically obtained as an industrial residue or they occur naturally. They increase strength of concrete whereas, decreases the porosity or change in other properties of concrete. Mineral admixtures used in concrete are silica fume, metakolin, rice husk, fly ash and ground granulated blast furnace slag.
b) Chemical admixtures: These include superplasticizers, air entraining agents, plasticizers, accelerators, retarders, water-reducing agents, etc.

Following are the advantages of Admixtures:

1. It can increase the workability of concrete without addition of extra amount of water.
2. Help in easy pumping of the concrete, admixtures increase the flowability of concrete.
3. The freezing and thawing resistance of concrete is increased.
4. They restrain the corrosion of reinforcement in concrete.
5. They help in increasing the bond between concrete and steel and also new and old concrete surfaces.
6. Help in reducing the porosity of concrete which decreases the permeability of concrete and thus making concrete water tight.
7. they help in reducing bleeding and segregation of concrete mix.
8. By reducing the content of water, they help in densification of concrete making it much stronger and durable.

In the present thesis various admixtures that are used to develop UHPC include superplasticizers, Granulated Blast Furnace Slag (GGBS), Silica Fume and nano-silica which are further discussed below:

a) Superplasticizers: It is a type of admixture which helps in attaining the required workability for the concrete without adding extra amount of water. An adequate workability of concrete can also be achieved by adding more water to the concrete but with increase in water content strength and durability of concrete decreases. Superplasticizer is a more enhanced and modified type of plasticizer and it is also called as High Range Water Reducer (HRWR). Superplasticizers are much more chemically inert and powerful than the ordinary plasticizers and are suitable for developing high strength concrete. They are also termed as organic substances which when added to concrete during its mixing tend to change its properties to decrease water content for a certain workability of concrete. For development of UHPC Polycarboxylic Ether based Superplasticizers (PCEs) are used during the process of mixing.

The application instructions for the chemical admixtures are as follows:

1. Dosage: The site trials should be implemented to know the ideal dosage of superplasticizer in mix preparation of UHPC. In the trial, effect on workability and strength gain of concrete is to be measured. As per study, the rate of addition of superplasticizer lies between the ranges of 0.6 to 2% by weight of cement.
2. Over dosing: An over dose above the certain level of superplasticizer can result in high workability, retardation of setting time and air entrainment. The over dosing of superplasticizer should only be done if it is necessary, by ascertaining the lab trials performance before using in actual site conditions.

b) **Ground Granulated Blast Furnace Slag (GGBS):** It is a non-metallic by-product of the iron manufacturing industry which consists of aluminates and silicates of mainly calcium and various bases. The GGBS is formed in the blast furnace where iron is manufactured. The temperature of around 1500ºC is being set up in the blast furnace where the mixture of iron ore, limestone and coke is present. In this process iron is separated from the iron ore and the leftover material in form of slag floats on the top of extracted iron. The slag is further tapped off periodically as a molten liquid, thus for producing GGBS the molten ash is to be quickly quenched (chilled) with help of large quantity of water. After this process the slag forms into small granular particles which are similar to sand. The granulated slag is further dried and converted into the fine powder. The hardening of GGBS is very slow and with combining it by Portland cement it gets activated for its use in concrete. A combination of 50 percent Portland cement and 50 percent GGBS is typically considered. The GGBS percentage for use in concrete development, ranges from 20 percent to 80 percent.

In the production process of iron, the chemical composition of the raw material is not the same at all times due to which the slag composition varies accordingly. The viscosity of slag gets lower because of the impurities from iron ore and coke such as aluminate and silicate combined in the furnace with a flux. The method of slag production is also explained in Fig.1.3.

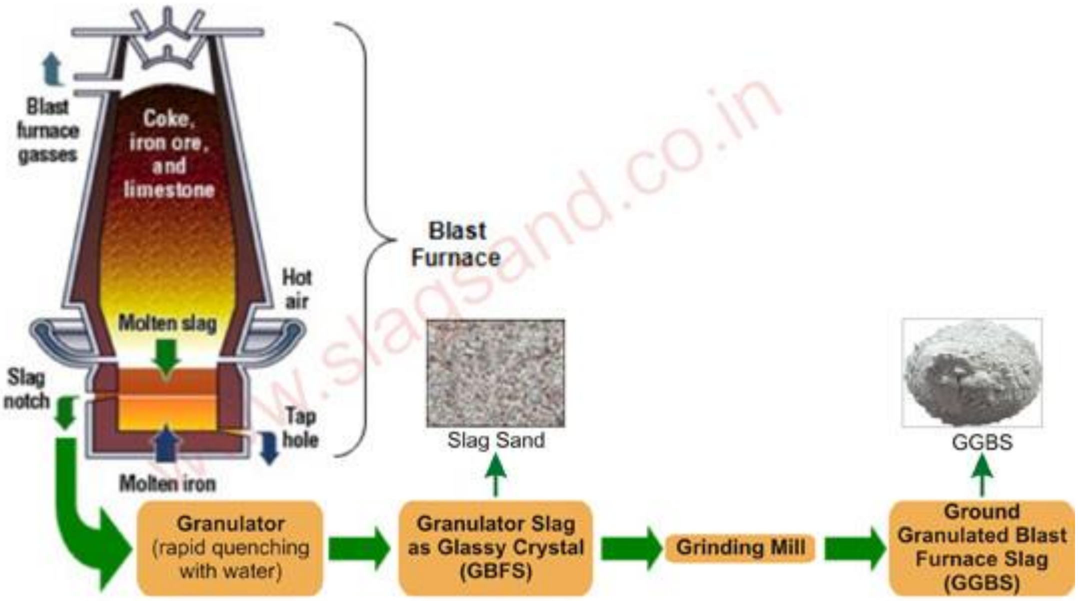


Fig.1.3: Method of production of GGBS (Source: www.slagsand.co.in)

The chemical composition of GGBS are as follows:

- Calcium oxide (CaO) = 40%
- Silica (SiO_2) = 35%
- Alumina (Al_2O_3) = 13%
- Magnesia (MgO) = 8%

The Physical properties are as follows:

- Colour: Off white.
- Bulk density: 1200 Kg/m^3.
- Specific gravity: 2.9.
- Fineness: 350 m^2/Kg.

Following are the advantages of GGBS:

1. Its usage can increase compressive strength of concrete.
2. The workability of the concrete improves, and it also helps in making the compaction process easier.
3. Its helps to provide higher resistance to sulphate attack and other chemicals.
4. The risk of thermal cracking in concrete is prevented by GGBS as it reduces the early age rise in temperature.
5. Improved resistance against the attack by chloride ions, then also preventing corrosion of reinforcement in concrete.

c) **Silica Fume:** Silica fume is also known as micro silica which is by-product of manufacturing silicon metal or ferrosilicon alloys. It is produced when high purity quartz is reduced with coal in an electric furnace during the process of manufacturing silicon. These oxidized vapours are further cooled and condensed. The condensed form of silica fume contains around 90% of silicon dioxide. In early 1970's there was no use of the silica fume which was considered as a waste to environment and it was either used as landfill or discharged in the air but due to strict environmental laws the researchers had to find an adequate application for silica fume. Therefore, it was observed that with addition of silica fume to concrete can increase both the strength and durability due to its small particle size as it works as a pore filler in the concrete.

The amorphous silica is the most commonly used silica fume in the cementitious systems which has 10 times smaller average particle size than cement. Since 1950's 10 to 25% of silica fume of the weight of cement is being used in the concrete. Silica fume possesses pozzolanic properties when combined with calcium hydroxide results into formation of much more C-S-H gel (Calcium-Silicate-Hydrate gel) at the final stages of the process and in fresh and partially hydrated cement paste the remaining voids get filled by addition of silica fume which helps to increase the density and making the concrete much more durable and stronger. Many researchers have agreed that silica fume can be used as a suitable supplementary cementitious material in the concrete as it reduces the cost and moreover provide environmental sustainability.

It has been observed that with addition of silica fume in the concrete many properties of concrete like compressive strength, flexural strength and split tensile strength get increased when compared with normal concrete specimen. Moreover, at 10% replacement of silica fume the maximum compressive strength, flexural strength and split tensile strength are observed. Beyond 10% replacement the strengths start decreasing. [Wilson and Navaneetha, 2016].

The optimum dosage of silica fume is considered around 7 to 10% by weight of cement in concrete but it has been used upto 15% by weight of cement for specific applications. With the addition of 15% of silica fume, the concrete gets much stronger and brittle which increases the demand of water in the mix of concrete.

Thus, High Range Water Reducers (HRWR) are required for such high replacement rates. Moreover, water reducer is not required for less than 5 percent dosage rates of silica fume in concrete.

Properties of silica fume:

- SiO_2 content is at least 85%.
- Mean particle size ranges between 0.1 to 0.2 micron.
- Surface area of silica fume is 20,000 m^2/kg.
- The particle shape of silica fume is spherical.

Following are the uses of silica fume:

1. It reduces the segregation and bleeding of concrete.
2. It lowers the permeability of concrete.
3. Increases the modulus of elasticity.
4. The chemical resistance of concrete also increases.

d) Nano Silica: The nano particles of silica or silicon dioxide is known as nano silica. Nano silica particle size is about 1000 times smaller than particle size of cement and thus, it induces the high pozzolanic effect when added to concrete. It is basically a type of admixture which increases the strength and durability of concrete because of its smaller particle size and high pozzolanic behaviour. In a study it is observed that with the addition of nano silica the setting time of concrete reduces and further the flexural as well as compressive strength of the concrete increases when compared to other silica components [Roddy et al., 2008]. The crystallization of quartz which has nano sized crystals or by direct synthesis of silica solution forms the nano silica. With the replacement of nano silica upto 3% with cement it was observed that the compressive strength of concrete significantly increases. However, when we increase the dosage of nano silica upto 4% as a replacement of cement the compressive strength of concrete slightly decreases so, we can conclude that with higher replacement rate of nano silica with concrete the does not improve the compressive strength of concrete this is because of the improper dispersion of nano silica particles in the concrete mixture which results into no improvement in strength of concrete. Performance of the product is significantly governed by the dispersion rate of nano silica particles in the paste of cement. The nano silica particles have high surface energy which lead to the agglomeration. When higher dosage of nano silica is added to the concrete mix the particles of nano silica does not dispersed uniformly in the paste of cement which results in formation of weak areas because of the agglomeration. Therefore, to achieve desired properties and composite materials the process of disagglomeration of nano silica particles is required. In the present study to develop UHPC and achieve the desired properties a replacement of 2% of nano silica with binder material is done

1.3.6 Steel Fibers

Steel fibers are used as reinforcing material in the concrete with uniform distribution of steel fibers in the concrete mix the ductility and strength of concrete enhances also it is very helpful in controlling long term dry shrinkage cracks in concrete and therefore increases the durability. Steel fibers are produced by cutting down metal wires and in to increase the mechanical bond in concrete special types of fibers with different shapes, indentations and crimps are also produced like Duoform. From low carbon rolled steel coils the steel fibers are being produced with lower tensile strength for example Fibercon. The first crack flexural strength is being influenced very less by the steel tensile strength, however ultimate flexural strength is greatly influenced by it when the composite failure take place by failure of fiber rather than by fiber pull out. The fibers are distributed uniformly concrete mix to get the desired results and their efficiency depends on the content of fiber, geometry of fibers, the shape and size of aggregates, mix proportions of concrete and the mixing and compaction technique.

There are many types of steel fibers available which are used in different applications with various commercial names. According to the manufacturing process there are four groups of steel fibers present which are mill cut, melt extract, cut wire, (cold drawn) and slit sheet. According to the shape steel fibers are also categorised such as crimped steel fibers (Fig.1.4), straight steel fibers (Fig.1.5) and hooked steel fibers (Fig.1.6).

To segregate the various types of steel fibers different notations are used which are as follows:

- (h x w x l) is used for nomination of straight rectangular section of steel fibers. In which section depth is denoted by letter “h”, width is denoted by letter “w” and fiber length is denoted by letter “l”.
- (d x l) is used for nomination of circular or semi-circular section wher letter “d” stands for diameter and letter “l’ stands for length.
- Aspect ratio is generally used for the nomination of hooked end steel fibers.

Steel fibers can improve these characteristics in concrete:

1. Impact, crack and fatigue resistance.
2. Reduction in shrinkage.
3. Toughness as steel fibers delays the propagation of cracks.

Advantages of Fiber Reinforced Concrete are:

1. The resistance to freezing and thawing increases.
2. The toughness, resistance to impact and tensile strength increases.
3. The durability and strength of concrete is increased.
4. It reduces the permeability as well as dusting in concrete.
5. The surface becomes tough and durable.
6. Use of steel fibers reduces cost as they are much cheaper than the other components of concrete.
7. The localized stresses are distributed properly.
8. It also reduces the repair and maintenance cost of concrete.

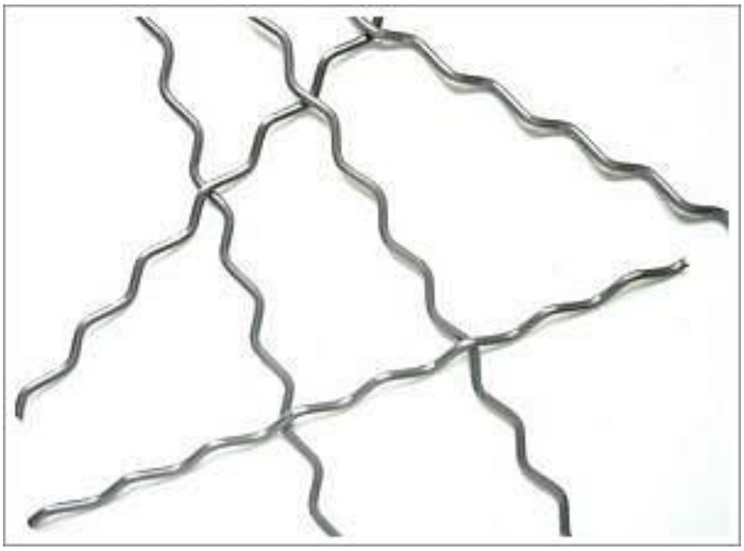


Fig.1.4: Crimped steel fibers (Source: www.steelfiber.org)

Fig.1.5: Straight steel fibers (Source: www.steelfiber.org)

Fig.1.6: Hooked steel fibers (Source: www.steelfiber.org)

In this proposed work, to develop Ultra High Performance Fiber Reinforced Concrete we have used crimped steel fibers (Fig.1.4) with three different percentages which are 0.5%, 1% and 1.5% by the weight of cement.

1.4 THE PERFORMANCE CRITERIA FOR UHPC STRUCTURES

In today's scenario, we seek into materials which have these different properties strength, durability, affordability and workability. The improvement of these following properties are the major factor to produce Ultra High Performance Concrete (UHPC). Sometimes, these properties do not correlate with each other one increases and other decreases. But, with time improvement of these properties occurs. These four properties are discussed below:

1.4.1 Strength

The strength is one of the major aspect in reducing the cost of the structure. In case of UHPC with having a strength range between 120 MPa to 150 MPa it acts very strongly as similar to steel as well as the flexural strength is also greater than normal concrete which is around 50 MPa due to which it requires less material to construct and also the dead weight gets lowered hence, reducing the cost of concrete. We can conclude that with increasing the strength of concrete two advantages can be counted which are less weight and less material.

1.4.2 Durability

Durability of concrete is basically defined as the capacity of concrete to withstand weathering action, abrasion, wear and tear and chemical attacks without affecting its desired engineering properties. When we look towards the old structures from Rome and Byzantine eras which are still present and standing makes us wonder the work of engineering and precision used at that time, the level of excellence in the construction was unmatchable at that time. Nowadays we construct a structure which has an average life span for example a life of ordinary bridge is around 100 to 150 years. In order to increase the life span of the structure better material with higher durability should be used. Therefore, UHPC has shown a good potential to be durable material and last for longer amount of time as proven in the studies and researches performed in the laboratories.

1.4.3 Workability

The ease of placing the concrete is known as workability. The cost and manufacturing time is majorly dependent on workability as cost and time are the two fundamental determinants on which the construction of certain type of structure will depend. The consistency and reliability of a material is indicated by workability. In case of production of UHPC it is observed that workability achieved by the old construction method is not satisfactory so to implement these types of materials in the structures we must develop better equipment's and methods to achieve better workability.

1.4.4 Affordability

Cost of the structure often determines whether the structure will built or not. There are many good quality construction materials available in the market but are not used because of their high cost but the cost of these materials can have reduced by their mass production and can be widespread in various applications. As we take an example of stainless steel which is very good quality material and can be used in many applications but due to its high cost its use is restrained.

1.5 APPLICATIONS OF UHPC

Following are the applications of Ultra High Performance Concrete (UHPC):

1.5.1 Bridge

The UHPC is widely used in the various applications of highway infrastructure. Its high compressive strength and tensile strength allows the designers to optimize and redesign the elements of structure. UHPC also has enhanced durability properties which allows to increase the life of structure and can be potentially used for construction of shells, claddings and overlays. In the United States of America UHPC has been used in simple-span bridges, precast concrete girder, precast concrete deck panels. Fig.1.7 shows the first highway bridge constructed using UHPC in United States.

Fig.1.7: Mars Hill Bridge, Wapelo County, USA (Source: www.ductal.com)

1.5.2 Cable-stayed bridge in South Korea

The following bridge shown in Fig.1.8 shows the cable–stayed pedestrian bridge in South Korea. In the front two girders of the bridge UHPC is used while in the rear girder of the bridge ordinary concrete is used. The company named KICT had constructed this bridge, with the help of this real life example we can understand the current design methods limitations and can notice the behaviour of UHPC in real world application especially in bridges of super-long span.

Fig.1.8: UHPC Girder Pedestrian Cable-Stayed Bridge (Source: www.researchgate.net)

The following constraints are determined to design and construct the bridge:

- The girder thickness should be less than 750 mm.
- Hybrid structure which includes UHPC and OPC is to be used.
- Underground obstacles should be avoided.
- The self weight of the bridge should not be transferred to the existing buildings
- There should be proper connection between new and existing buildings.

1.5.3 Sherbrooke footbridge

Sherbrook footbridge was the first engineering structure in the world in which UHPC was used. It was built in 1997 in Sherbrook, Quebec, Canada. The prestressed pedestrian bridge of span 60 meters is precasted, the bridge is post-tensioned and it is open-web space RPC truss as shown in the Fig.1.9. The Ultra High Performance Concrete (UHPC) is used in the four major access spans. Six 10 metres prefabricated match-cast segments are assembled to form main span. The cross section of the bridge is made up of a 30 mm thick ribbed slab in which transverse prestressing is done and it is made up of greased-sheathed monostrands. In the bridge the truss webs are made up of stainless steel tube confined with RPC, shown in Fig.1.9.

Fig.1.9: Sherbrooke footbridge [Karmout, M; 2009]

1.6 THE LIMITATIONS OF UHPC

There are many limitations in implementing UHPC in the construction area of developing as well as developed countries like Russia and US because of the following reasons:

1. The initial cost of UHPC is very high.
2. Design codes for UHPC is limited.
3. Risk perception and less familiarity with UHPC.
4. The brittleness of UHPC is high.

The ductility of concrete decreases when the compressive strength increases because of this matter the use of UHPC is limited in the structures. Due to lack of design codes for Ultra High Performance Concrete creates a major challenge for precast producers to use it in various applications. In fact, this class of concrete is much stronger and durable than other ordinary classes of concrete. To implement the use of UHPC and to provide adequate database for design of structure continued research is required in advance properties of UHPC. Even the officials of federal level where the major researches on UHPC are done and the highway engineers hesitates in using it as a suitable construction for the highways and bridges because UHPC do not have any significant history of proven performance in adequate content as responsibility of transportation safety for public is their first preference. Due to sense of risk in using UHPC, its production is limited due to which its cost increases significantly. Whenever a new technology is regarded as risky, whether due to history of use, producer comfort level or lack of knowledge, the cost of using that technology significantly increases.

1.7 PREVIOUS WORK

Significant results are derived from the previous work done to develop UHPC. The mineral admixtures like Ground Granulated Blast Furnace Slag (GGBS) or alccofine, nano silica and silica fume were used in varying proportions. The crimped steel fibers were used in this research. The two trial mixes were used with replacing alccofine by 10% and 15% of the weight of the binder material with three different water-cement ratios of 0.18, 0.20 and 0.22. The remaining admixtures having similar quantities in both mixes such as silica fume 8% and nano silica 2% replacement of the weight of binder material. The steel fibers are added in the mixes 1% and 2% by the weight of cement. The mix containing 10% alccofine, 8% silica fume, 2% nano silica with 2% steel fibers got the maximum compressive strength of 141.5 MPa after 28 days. The objective of the proposed work was to achieve a compressive strength of range between 120 MPa to 150 MPa after 28 days.

1.8 PROPOSED WORK OBJECTIVE

The present study is the continuation of earlier work done as mentioned above. The main objective of the study is to investigate the durability properties of UHPC with three different trial mixes. The alccofine is varied as 10%, 15% and 20% to the replacement of binder material, with 2% nano silica and 8% silica fume present in each mix. The crimped steel fibers is added in three different percentages which are 0.5%, 1% and 1.5% by the weight of cement were added to each mix. After getting the desired strength, tests of durability were performed on these three mixes.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

With improved ductility and high compressive strength of more than 120 MPa the Ultra High Performance Concrete (UHPC) marks a quantum leap in construction industry. Various captivating applications are offered by this high performance material. Very slim design structures are being offered by use of UHPC which are sustainable as well as economical. With the help of its high compressive and flexural strengths makes very good construction material e.g. for thin-wall shell structures, storage halls, bridge decks and highly loaded columns.

The literature review of work done by various researches has been showcased in this chapter on the strength and durability properties of Ultra High Performance Concrete (UHPC). The use of supplementary cementations materials like GGBS and silica fume in the concrete enhances its performance and used in many applications are being studied. However, the use of supplementary cementitious materials in concrete was done in past few years buts its advantageous properties was well realised after its extensive research was done. In the period of 1970’s to 1980’s the tower of new Tijorn cable-bridge in Sweden was constructed in which silica fume was used. To decrease the thermal stresses and cracking and to maintain the strength of concrete silica fume was replaced as part of cement.

The production and sale of the silica fume started picking up in Quebec, Canada in 1982 as the product demand was increased. In 1983, the silica fume concrete was firstly used in rehabilitation of Kinzua Dam stilling basin in the U.S., the quantities of materials were specified as concrete containing 386 Kg/m^3 of cement and 70 Kg/m^3 of silica fume. The compressive strength achieved at 7 days was 70 MPa and 28 days was 86 MPa. [Graybeal et al., 2003]

The other applications of supplementary cementitious materials in concrete worldwide are high pressure concrete pipes, light weight concrete construction, stilling basins and under water repairs, repair overlays for bridge decks, parking garages, spillways, cement grouts to fill post tensioning ducts, offshore platform construction and more recently high strength concrete in mega structures.

Due to enhanced durability properties of concrete incorporated by supplementary cementitious materials it is widely in making magnesium and aluminium plants, paper mill plants and waste water treatment plants.

2.2 STRENGTH CHARCTERISTICS OF UHPC

Al-Azzawl et al. (2011) studied the performance of Ultra High Performance Concrete members incorporated with steel fibers. Total six mixes were developed in which two different kind of admixtures were used separately (namely, silica fume and metakolin) and three different kinds of steel fibers ratios were used separately i.e. 1.0%, 1.5% and 2.0%. The three cube specimens were casted of a size 50 mm x 50 mm x 50 mm for each trial mix of UHPC and compression test was conducted for 3,7 and 28 days under uniaxial compression.

Lower water-cement ratio is used in cement to develop Ultra High Performance Concrete, the less amount of C_3A content helps in reducing the water-cement ratio in concrete so they used sulphate resisting Portland cement which contains lower amount of C_3A content as compared to ordinary cement. Very fine grade of sand is used which was properly separated by sieving and its grading is specified by the B.S specification No. 882/1992, the 600 µm is the maximum particle size of sand which was used. The straight brass coated steel fibers with diameter of 0.18 mm and length of 13 mm with an aspect ratio of 72 were used in their investigation. High performance polycarboxylate ether superplasticizer also known as High Range Water Reducing Agent was used along mineral admixtures like Silica fume (SF) and High Reactivity Metakaolin (HRM).

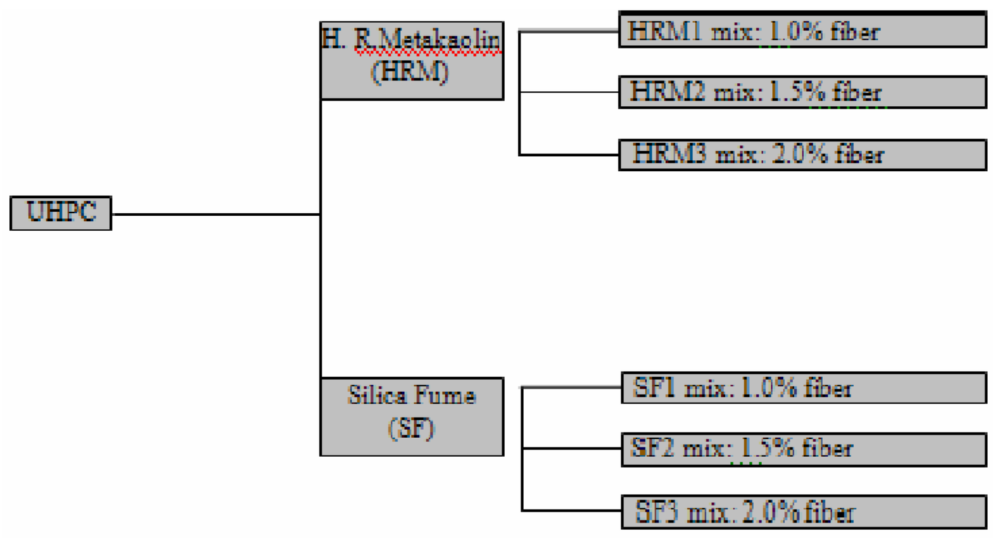


Fig.2.1: Mixes examined in the investigation [Al-Azzawi et al., 2011]

The influence on the mechanical properties of UHPC by the different mix ratios was investigated in this study in which the following aspects were considered:

- The Silica fume (SF) and (HRM) are two types of pozzolanic admixtures which were used.
- Three percentages of steel fibers for each type of admixture was used i.e. 1.0%, 1.5% and 2.0%.

This results into six types of mixes which was studied in this investigation which is shown in Fig.2.1.

The compression test was done after 3, 7 and 28 days of curing of cubes with standard size 50 mm x 50 mm x 50 mm. The compressive test was done with the Averey-Dension 2000 kN compressive testing machine with adopting the average of 3 cubes for each age. The compressive strength test results after 3, 7 and 28 days of curing of various mixes of UHPC were investigated and summarized in Table 2.1.

Table 2.1: Compressive strength results [Al-Azzawi et al. 2011]

MIX	**Compressive Strength (MPa)**							
	Cement (Kg/m^3)	**H.R. Metakaolin (HRM) %**	**Silica fume (SF) %**	**Steel fibers %**	**w/c ratio**	**3 days**	**7 days**	**28 days**
HRM1	850	15 %	-	1.0%	0.174	88	103	151
HRM2	850	15 %	-	1.5%	0.178	90	106	155
HRM3	850	15 %	-	2.0%	0.179	91	109	159
SF1	900	-	10%	1.0%	0.186	98	122	191
SF2	900	-	10%	1.5%	0.189	99	124	195
SF3	900	-	10%	2.0%	0.19	102	127	198

The mix having maximum compressive strength of 198 MPa after 28 days of curing was SF3 which was incorporated with 2.0% of steel fibers and 10% of silica fume with a water-cement ratio of 0.19. While, mix containing High Reactivity Metakaolin having the maximum compressive strength of 159 MPa was HRM3 which was incorporated with 2.0% steel fibers and 15% Metakaolin with a water-cement ratio of 0.179. The main reason behind the increase in compressive strength is due to high pozzolanic behaviour of mineral admixtures i.e. silica fume and metakaolin in the concrete. These pozzolanic materials reacts chemically in concrete at early ages of 3 and 7 days and significantly increases till 28 days. The process can be explained as the calcium hydroxide is released from hydration of cement which reacts with particles of high pozzolanic materials which leads to the reduction in porosity and refinement in grain size which further results into strengthen of concrete and reduction in microcracking.

Graybeal et al. (2003) studied the effect of four different types of curing regimes on compressive strength of Ultra High Performance Concrete (UHPC). They altered the proportions of constituent materials used in ordinary concrete to develop UHPC. They identified that cementious materials and superplasticizer are present in large quantity, but the water is present in low quantity in the concrete. The water and cementitious material ratio was kept as 0.15. The steel fibers used were 13 mm long with diameter of 0.2 mm and were added to volume of concrete at a ratio of 2%. The composition of materials used to develop UHPC in this research is shown in Table 2.2 (a).

Table 2.2 (a): UHPC composition [Graybeal et al. (2003)]

Material	Amount (lb/yd^3)	Weight (%)
Portland Cement	1200	28.5
Fine Sand	1720	40.8
Silica Fume	390	9.3
Ground Quartz	355	8.4
Superplasticizer	51.8	1.2
Accelerator	50.5	1.2
Steel Fibers	263	6.2
Water	184	4.4

The four curing regimes on the specimens of cylinders of size 3 x 6 inch was performed. The first regime was Steam curing which was recommended by manufacturer in which after stripping of the moulds the samples are cured with steam for 48 hours. Second regime was Ambient Air curing in which the samples are left in open air environment of laboratory after the casting process is over till the date of testing. The third regime was Tempered Steam curing in which the temperature of steam is lowered to 140ºF which was 194ºF earlier in first regime and specimens are cured with steam for 48 hours. The final regime was Delayed Steam curing, the process is identical to the first regime but the process is delayed for 15 days after the casting.

After applying the various curing regimes the researchers have noticed that they have considerable effect on the compressive strength of UHPC. Table 2.2 (b) shows the compressive test results for the different specimens under various conditions of curing. The maximum strength achieved was 28 ksi of steam cured specimens and the rate of reduction for delayed steam and tempered steam cured specimens was 10% of steam cured specimens strength. The ambient air cured specimens achieved approximately 65% strength of the steam cured specimens.

Table 2.2 (b): Compressive Strength of 3 x 6 inch Cylinders [Graybeal et al. (2003)]

Method	Samples	Compressive Strength (ksi)
Steam	96	28.0
Ambient Air	44	18.0
Tempered Steam	18	25.2
Delayed Steam	18	24.9

Yang et al. (2009) studied the possibilities of replacing expensive silica fume with two types of natural sands and recycled glass cullet in the mix composition of materials used to produce UHPC to reduce cost of producing UHPFRC so that it can be implemented as a regular construction material in the construction field. Two curing temperatures were set in this study on the basis of which difference between both ductility and mechanical properties were investigated. The cubes and prisms of UHPFRC were casted and cured at two temperatures of 20ºC and 90ºC. The SF, GGBS and cement were used in this study and their physical and chemical properties are shown in Table 2.3 (a).

Table 2.3 (a): Physical, chemical and mechanical properties of cement, silica fume (SF), ground granulated blast-furnace slag (GGBS) [Yang et al. (2009)]

Chemical composition (%)	Materials		
	Cement	SF	GGBS
SiO2	18.7	93.1	35
Al2O3	6.3	0.9	12

Fe2O3	3.2	2.0	0.2
CaO	64.7	0.4	40
MgO	0.7	1.2	10
Na2O	0.13	0.3	-
SO3	3.1	0.3	-
Cl-	0.025	0.09	-
Physical property			
Bulk Density (Kg/m^3)	1200	321.3	1050
Specific Surface (m^2/Kg)	460	20,000	470
Mechanical Property			
Age (days)	2	7	28
Compressive strength (MPa)	37	52	63

Table 2.3 (b): Density and water absorption of aggregate sand [Yang et al. (2009)]

Aggregate	SS	FOS-I	FOS-II	RGC
Oven dry density (kg/m3)	2.652	2.645	2.643	2.678
Bulk density (kg/m3)	1.634	1.555	1.537	1.443
Void content	38.4%	41.2%	41.9%	46.1%
Water absorption (%)	0.80	1.17	0.84	0.21

The UHPFRC mix design proportions are listed below in Table 2.3 (c).

Table 2.3 (c): Mix design of UHPFRC [Yang et al. (2009)]

Concrete mix proportion Cementitious component (level of cement replacement) (kg/m3)			Aggregate sand (kg/m3)	Water binder ratio	Superplasticizer (% solid by weight of binder)
Cement	GGBS	SF	1050	0.15	1.05
657	429.8 (35%)	119.4 (10%)			

The researchers had noted that little influence in the compressive strength is observed in the replacements of natural sand by SS, FOS-I and FOS-II while RGC replaced by natural sand showed faster early age strength gain but losses compressive strength after as compared to others. The compressive strength development using SS, FOS-I and FOS-II and RGC in UHPFRC cured under 20ºC and 90ºC is shown in Fig.2.2. At 91 days the compressive strength lies between the range of 160 to 180 MPa when the specimens of SS, FOS-I and FOS-II were used while the RGC specimens lies between the range of 140 to 160 MPa. No significant growth in compressive strength was observed after 7 days in any specimen when cured at 90ºC. After 7 days, the specimens of UHPFRC cured at 20ºC continued to increase the strength but at a slow rate as shown in Fig.2.2. At 91 days, the compressive strength difference between specimens cured at 20ºC and 90º is very high and it is observed that normal temperature of curing around 20ºC is suitable for developing UHPFRC and can be used in various applications.

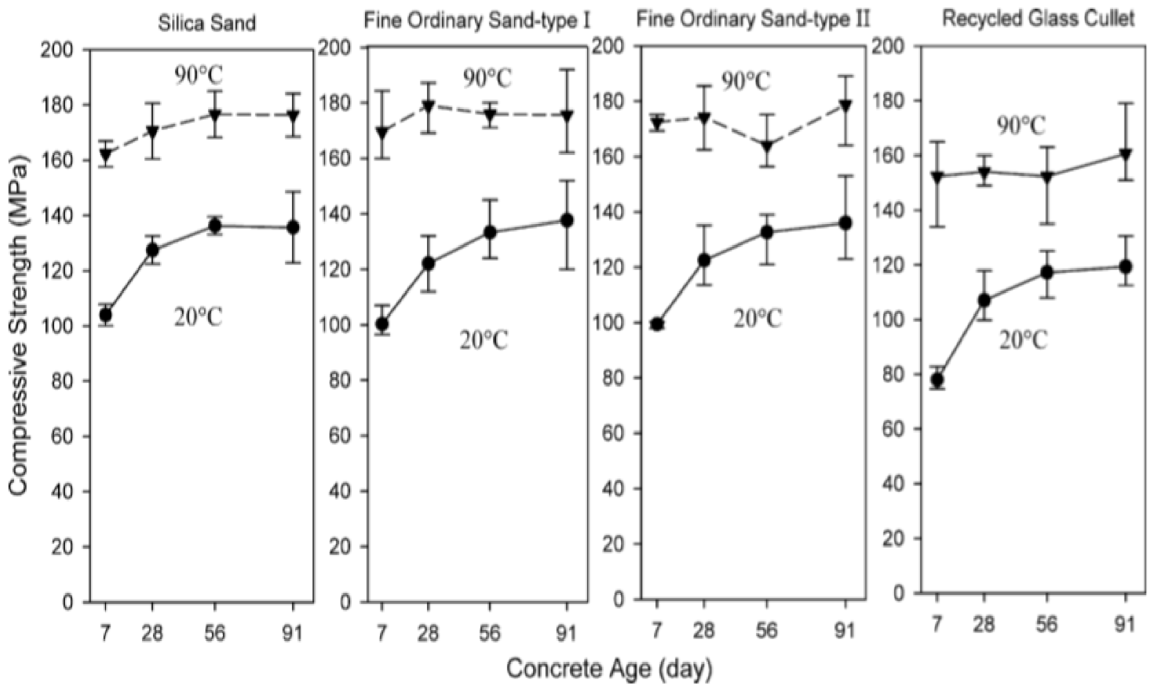


Fig.2.2: Compressive strength versus age of UHPFRC: effect of replacement of sand aggregate with SS, FOS-I, FOS-II and RGC [Yang et al. (2009)]

Tuan et al. (2011) studied the replacement of silica fume with a substitute material of similar properties in developing Ultra High Performance Concrete (UHPC), as silica fume is a high cost material and availability is also limited in a country like India. To eliminate these obstacles researchers have used Rice Husk Ash (RHA) in this study to produce UHPC.

To produce the RHA, the rice husk is burnt under uncontrolled combustion conditions in a drum by which ash is obtained. The ash is further ground for 90 minutes by using vibrating ball mill. They prepared a set of 15 mixtures to investigate the effect of replacement of RHA, synergic effect of RHA and silica fume and fineness of RHA. The mix compositions prepared are shown in Table 2.4.

Table 2.4: UHPC compositions used in this study [Tuan et al. (2011)]

Water to binder ratio (by weight)	Sand to binder ratio (by weight)	RHA (% by weight)	SF (% by weight)	The mean particle size of RHA (dRHAmean), µm
0.18	1	0–10–20		5.6
0.18	1		10–20–30	
0.18	1	10–20–30	10	5.6
0.18	1	20		9.0–6.3–5.6–3.6
0.18	1	5	15	5.6
0.18	1	15	5	5.6
0.15–0.18–0.20–0.23	1	10	10	5.6

The Hobart mixer of capacity 20 litres was used for mixing all materials with each batch of 3.5 litres in volume. The mixing procedure is shown in Fig.2.3 (a)

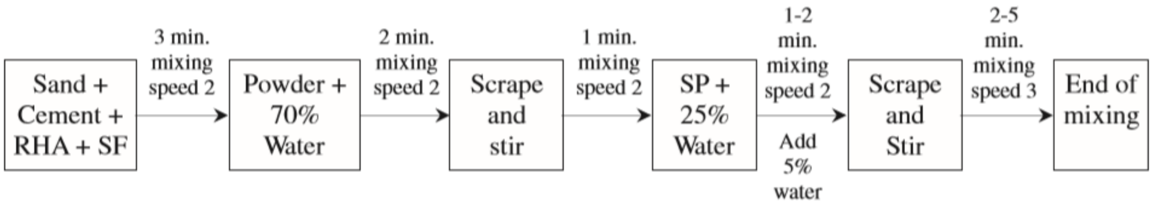


Fig.2.3 (a): Mixing procedure for UHPC [Tuan et al. (2011)]

The effect on compressive strength of UHPC due to various replacements of RHA and SF is shown in Fig.2.3 (b). It has been observed in the samples of silica fume, the maximum compressive strength is achieved when 10% of silica fume is replaced by cement. However, beyond the replacement of 20% silica fume with cement the strength starts decreasing. In the rich husk samples, the higher compressive strength is achieved by sample containing 10% RHA as a replacement of cement than sample containing 20% RHA at early ages of 3 and 7 days. However, at the ages of 28 and 91 days the trend changes and the sample containing 20% RHA as a replacement of cement possesses higher compressive strength than the samples with 10% RHA. Therefore, the RHA samples do not show more compressive strength than SF samples but at a replacement rate of less than 30%, Rice Husk Ash (RHA) can be used be used to produce Ultra High Performance Concrete (UHPC).

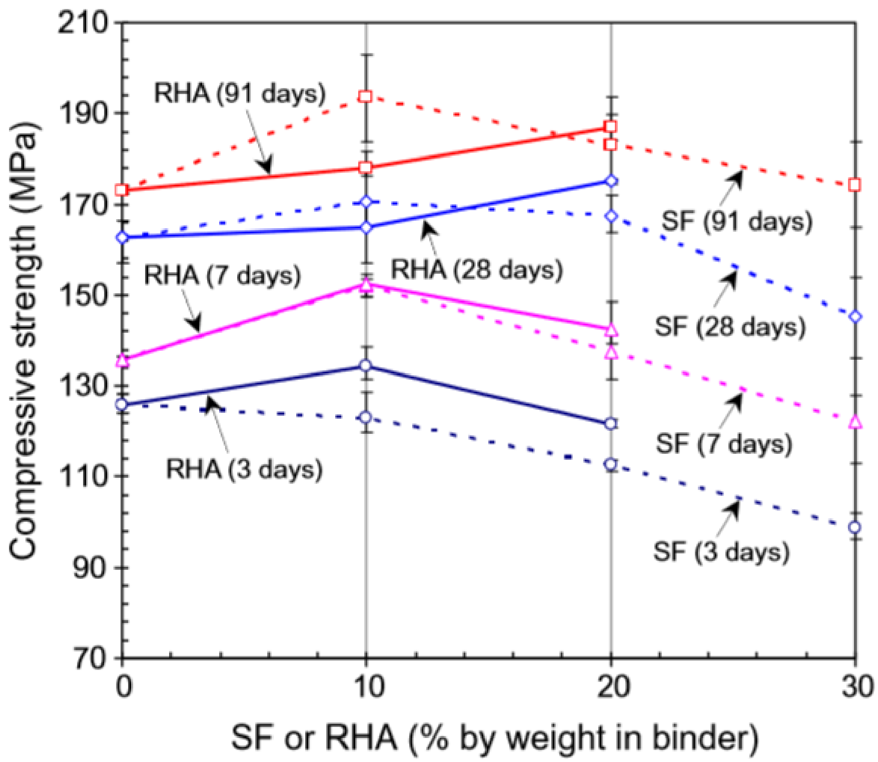


Fig.2.3 (b): Compressive strength of UHPC samples vs. % SF (dotted line) or % RHA (Solid line), w/b ratio = 0.18, dRHAmean = 5.6 µm. [Tuan et al. (2011)]

Wang et al. (2012) investigated the effect on the compressive strength and fluidity of UHPC when Ground Granulated Blast Furnace Slag (GGBS) is used as partial replacement of cement. During the investigation the technologies used to develop UHPC is very common which includes room temperature curing, normal forced mixer used for mixing fresh concrete, compaction by vibration and pouring.

The raw materials used in the study are ordinary and easily obtained. Mineral additives such as silica fume and limestone powder were used along with GGBS in large quantities to obtain the dense micro structure and also to reduce the heat of hydration in the concrete. The cementitious material properties are discussed in Table 2.5 (a).

Three mixes were prepared with various replacements of GGBS with cement and 10% of silica fume was replaced by cement in each mix. The mix proportions are listed in Table 2.5 (b). In the study it was observed that the mix 2-1 containing 0% content of GGBS had higher compressive strength and lower fluidity than the mix 2-2 which contains 20% GGBS at early ages (28 and 56 days) but at later ages (90, 180 and 365 days) achieves approximately equal strength. The mix 2-3 showed very low fluidity and compressive strength at all ages when compared with the control mix 2-3.

Table 2.5 (a): Chemical compositions and physical properties of binders [Wang et al. (2012)]

Binder	Chemical compositions (%)								Specific surface area (m2/kg)	Density (g/cm^3)
	CaO	SiO_2	AL_2O_3	MgO	Fe_2O_3	TiO_2	SO_3	LOI		
C	59.37	20.86	9.28	2.07	3.74	0.47	2.49	1.47	330	3.10
SF	-	95.19	-	0.80	0.13	-	-	2.81	20,000	2.23
GGBS	50.44	30.36	16.90	1.84	0.34	0.57	-	2.42	870	2.75
LP	52.12	3.45	1.47	0.77	0.24	-	-	40.22	600	2.75

The results of this experiment are shown in Fig.2.4.

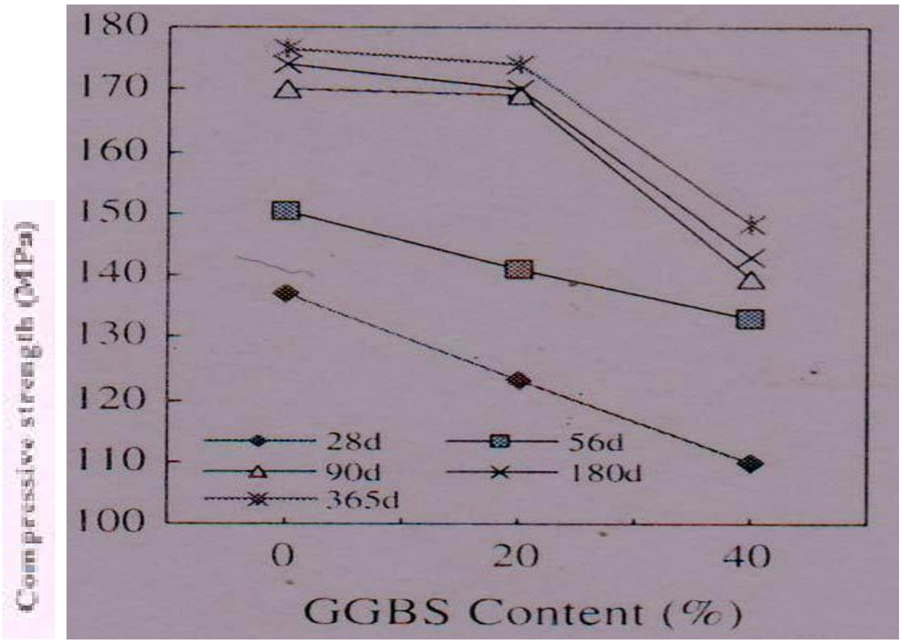


Fig.2.4 Influence of GGBS content on strength and fluidity of UHPC. [Wang et al. (2012)]

Table 2.5 (b): Mixture proportions for test of influence of GGBS replacement on strength and fluidity of UHPC. [Wang et al. (2012)]

Mix	Binder (kg/m^3)	Binder components (%)			W/B	Water (kg/m^3)	Superplasticizer (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
		C	SF	GGBS					
2-1	900	90	10	0	0.18	162	18	616	923
2-2	900	70	10	20	0.18	162	18	616	923
2-3	900	50	10	40	0.18	162	18	616	923

In this study it was concluded that the UHPC can be prepared with addition of mineral admixtures like GGBS, SF and LP, low water- cement ratio, superplasticizer and high cementitious content in normal conditions.

Long et al. (2002) investigated the properties of systems containing ultrafine powders such as ground granulated blast furnace slag (PS), pulverized fly ash (PFA) and silica fume (SF) such as fluidity and compactness. They systematically enhance the proportions of compositions, to produce Very High Performance Concrete (VHPC) the specimens were heated at a specific temperature to achieve a compressive strength of around 200 MPa. Various properties of these ultrafine materials are shown in Table 2.6 (a).

Table 2.6 (a): Chemical compositions and physical properties of PFA, PS and SF: [Long et al. (2002)]

Composition (%)							Ignition Loss (%)	Mean Diameter (µm)	Density (g/cm^3)
Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3			
PFA	21.7	25.8	9.7	3.7	1.2	0.2	1.16	5.8	2.47
PS	28.3	13.6	0.62	38.4	7.2	7.4	0	6.5	2.78
SF	88.2	3.45	0.80	0.00	2.08	0.3	2.52	0.2	2.14

The various materials used for production of VHPC were Quartz sand with a maximum particle size of less than 0.63 mm along with ultrafine powders such as PS, PFA and SF, the ordinary Portland cement with a maximum compressive strength of 56 MPa at the age of 28 days and two types of steel fibers with different L/D (length to diameter) ratio and with having cylindrical shape were added in the concrete. To attain the suitable workability superplasticizer were added as 2% weight of cement. The specimen size of 40 mm x 40 mm x 160 mm were casted and kept at a temperature of 20ºC in flog room. Then the moulds were opened after 24 hours and the specimens were bathed in water for 3 days (72 hours) at a temperature of 20ºC. After this process the specimens are then kept in a steam room for 72 hours at a temperature of 95ºC.

Table 2.6 (b): Experimental results of flowability and strength of mortars: [Long et al. (2002)]

No.	W/B	Proportions of raw materials (C/PFA/PS/SF)	Flowability (mm)	Flexural strength (MPa)	Compressive strength (MPa)
1	0.180	1:0:0:0.10	190	20.4	151.4
2	0.167	1:0:0:0.20	185	22.2	175.4
3	0.160	1:0:0:0.25	175	22.5	187.8
4	0.154	1:0:0:0.30	160	21.1	186.6
5	0.16	1:0:0.2:0.25	170	28.4	178.6
6		1:0:0.3:0.25	185	29.5	198.2
7		1:0:0.4:0.25	200	30.5	193.6
8		1:0:0.6:0.25	165	27.6	190.0
9		1:0:0.3:0.30	180	28.4	207.0
10		1:0:0.4:0.30	190	29.6	200.8
11	0.16	1:0.2:0:0.25	180	24.7	188.2
12		1:0.3:0:0.25	190	28.5	208.4
13		1:0.4:0:0.25	200	30.4	197.8
14		1:0.6:0:0.25	175	30.3	184.0
15		1:0.3:0:0.30	185	31.0	204.8
16		1:0.4:0:0.30	195	29.9	213.2

The researchers have showed that the ultrafine particles and water-cement ratio majorly effects the density of concrete. Thus, determines the effect on the hardened properties of cementitious materials. It had been observed that compressive and flexural strength of the concrete enhanced due inclusion of ultrafine materials which concentrates the microstructure of concrete and reduces micro cracking. Very low water-cement ratio of 0.16 was used in this study to achieve the desired strength. It has been noticed that with increase in the content of silica fume the strength of concrete increases, in the specimens containing SF only. The ideal range for SF content is 0.2 to 0.3 by the weight of cement. However, the samples containing only SF had lower compressive strength than samples containing SF and PS or SF and PFA. The compressive strength of samples containing SF and PFA had the highest compressive strength even higher than the samples containing SF and PS. The strength and flowability results of VHPC is shown in Table 2.6 (b).

Ehsan Ghafari et al. (2014) studied the effect on the properties of Ultra High Performance Concrete (UHPC) due to the addition of nano silica (nS). It has been observed in thermo gravimetric analysis results that in early ages, nano silica consumes more $Ca(OH)_2$ when compared with silica fume. The mercury intrusion porosimetry measurements was also studied in this experiment which showed that the capillary pores are being reduced by the addition of nano silica particles. The SEM (Scanning Electron Microscope) analysis shows the interfacial transition zone between the binding paste and the aggregates improves with the addition of nano silica in the concrete. It also improves the compressive strength and transportation properties of concrete.

The ideal measure is around 3 percent cement replacement of nano silica by cement to get the best results. However, with the higher rate of nano silica in the cement paste leads to the inadequate distribution of nano silica which is a very restraining factor to use in concrete.

Table 2.7: Composition of UHPC mixture (by weight (kg.m3)) [Ehsan Ghafari et al. (2014)]

Sample	Cement	SF	nS	Sand	Water	SP
M0 (Control)	950	255	-	873	189	31
M1	941.5	255	9.5	873	189	31
M2	932	255	19	873	189	31
M3	921.5	255	28.5	873	189	31
M4	912	255	38	873	189	31

At the age of 7 days it has been observed that the samples containing 3% of nano silica by weight of cement has resulted in increase in compressive strength by 24%, and 40% higher when compared with the reference mix. The reason of increase in compressive strength is due to the microstructure of the concrete became denser because of the rapid pozzolanic activity in the concrete in presence of $Ca(OH)_2$. Also, the addition of nano silica particles quickened the hydration procedure of C_3S clinker stage because of the huge and extremely reactive surface of the nanoparticles. In any case, the outcomes demonstrated that the use of nano silica had a modest impact at 28 days and 90 days of ages. It has been noted that M3 specimen had maximum compressive strength among all which was 144 MPa and 148 MPa i.e, 8% and 6% higher than M0 (Control) respectively. Thus, the pattern confirms that the pozzolanic reactions due to nano silica takes place at early ages and there was a decrement in the compressive strength of concrete when the replacement of nano silica exceeds up to 4%. In this manner, a higher substitution of concrete by nano silica did not prompt a change in compressive strength, which can be because of scattering of nano silica particles in the blend. The Fig … shows the compressive strengths of various nano silica added concrete mixes.

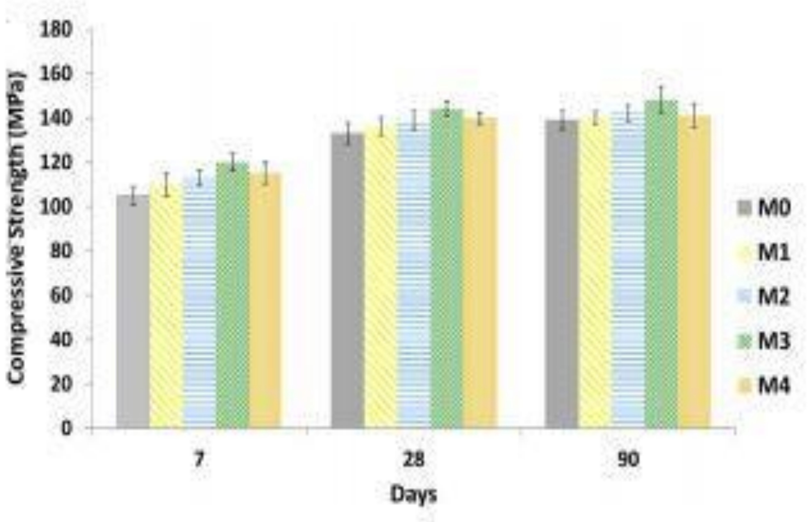


Fig.2.5: Compressive strength (MPa) of nS particle blended concrete [Ehsan Ghafari et. al. (2014)]

2.3 DURABILITY CHARACTERISTICS OF UHPC

Graybeal et al. (2003) investigated the durability properties of UHPC. They studied the resistance to effects on UHPC in external and internal environmental conditions. The experiments performed were chloride ion penetration, scaling resistant testing, freeze-thaw and abrasion resistance on the specimens to define the durability characteristics of UHPC. The material composition used for producing UHPC is shown in Table 2.8 (a).

Table 2.8 (a): UHPC Composition [Graybeal et al. (2003)]

Material	Amount (lb/yd^3)	Weight (%)
Portland Cement	1200	28.5
Fine Sand	1720	40.8
Silica Fume	390	9.3
Ground Quartz	355	8.4
Superplasticizer	51.8	1.2
Accelerator	50.5	1.2
Steel Fibers	263	6.2
Water	184	4.4

To check the chloride ion permeability of UHPC, Rapid Chloride Ion Permeability Test (RCPT) was performed on the specimens of UHPC. The specimens were specifically casted for four different curing conditions which were steam curing, ambient air curing, tempered steam curing and delayed curing. The specimens were tested at ages of 28 and 56 days. The charge is passed for 6 hours and reading of electric current was noted at every 1 minute of interval.

Table 2.8 (b): ASTM C1202 Rapid Chloride Ion Penetrability Results: [Graybeal et al. (2003)]

Curing Method	Tests	Days	Avg coulombs passed	Chloride Ion Penetrability
Steam	3	28	18	Negligible
Ambient Air	3	28	360	Very Low
Ambient Air	3	56	76	Negligible
Tempered Steam	3	28	39	Negligible
Tempered Steam	3	56	26	Negligible
Delayed Steam	3	28	18	Negligible

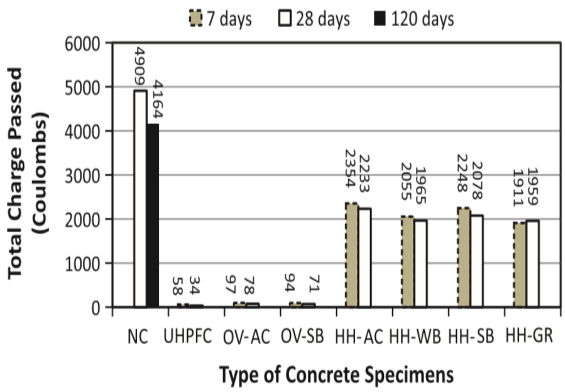
The results of this test shows that UHPC shows very less amount of chloride ion penetration in all curing conditions at both 28 and 56 days. However, it was noted in the experiment that there was a major decrement in the chloride ion penetration from 28 days to 56 days in the ambient air curing condition i.e. from very low to negligible. The least penetration of chloride ion was occurred in the samples of steam and delayed steam curing condition. The values of total charge passed is shown in Table 2.8 (b).

Tayeh et al. (2012) had to find an alternative repair material for the old structure which can survive in harsh environment and should be durable. They decided to use UHPFC as the repair material because of its excellent quality and normal concrete (NC) is considered as the old structure material and they examined the difference between both the materials by permeability characteristics. The tests performed in the study was rapid chloride permeability, gas permeability and water permeability. The two grades of specimens were used in this experiment, Grade-170 for UHPFC and Grade-40 for normal concrete. The composition of the mix used to produce NC and UHPFC is shown in Table 2.11.

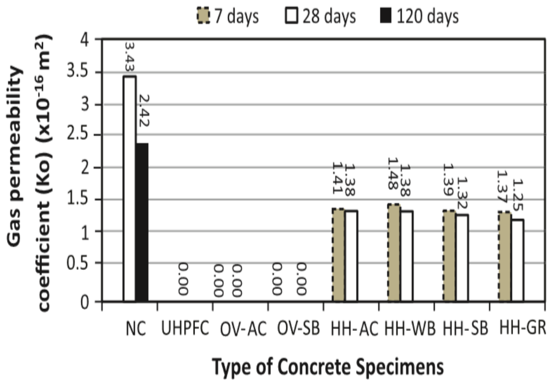
Table 2.9: Mix proportions for NC substrate and UHPFC [Tayeh et al. (2012)]

Concrete type (kg/m^3)	**NC substrate**	**UHPFC**
OPC (Type 1, 42.5R) Coarse aggregate (max. 12.5 mm)	400 930	768 -
River sand (F.M. = 2.4)	873	-
Mining sand (<1180 μm)	-	1140
Silica fume (23.7 m^2/g)	-	192
Steel fiber (Lf = 10 mm, df = 0.2 mm)	-	157
Superplasticizer (PCE-based)	4	40
Water	200	144
Total	2407	2441
W/B	0.5	0.15
Cube strength, fcc,28d	45 MPa	170 MPa
Split cylinder tension strength, fsp,28d	2.75 MPa	15.3 MPa

The RCPT test was conducted on both NC and UHPFC specimens of which results are demonstrated in Fig.2.6. The results were derived in terms of Total Charge Passed (TCP) in Coulombs, lesser the value of TCP, higher the resistance rate of chloride ion penetration. It has been observed that the specimens containing UHPFC exhibits the least TCP values which was 58 coulombs at the age of 28 days and 34 coulombs at the age of 28 days. Also the OV composite specimens shows the TCP values not more than 97 coulombs.



a)



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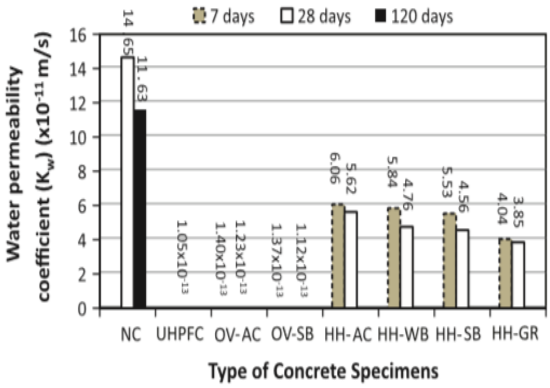


c)

Fig.2.6: Experimental test results on (a) Rapid chloride permeability, (b) Gas permeability and (c) Water permeability [Tayeh et al. (2012)]

According to ASTM C 1202, the specimens of UHPFC and OV composites lies in the category of ''Negligible Chloride Permeability''. With the help of this experiment it was proven that UHPFC can be used as a suitable material for repair and rehabilitation of an old structure where durability is a major factor. The specimens containing NC exhibits very high TCP values which was 4909 coulombs at 28 days of age and 4164 coulombs at 120 days of age. The TCP values of NC lies in the category of ''Negligible Chloride Permeability'', which proves that normal concrete cannot be used in building structures which are exposed to aggressive environment conditions. The same trends were observed in the gas permeability and water permeability tests as UHPFC specimens as well as OV composite specimens outperforms the results when compared with NC specimens making it a clear choice for using it as a repairing material for old structures in harsh environment such as marine zone.

Parant et al. (2007) created and filed patent for a new class of Ultra High Performance Fibre Reinforced Cement Composite (UHPFRCC) in which they have introduced three different sizes of steel fibers which leads it to Multiscale Fibre Reinforced Cement Composite (MSFRCC). The composition of Multiscale Fibre Reinforced Cement Composite (MSFRCC) is shown in Table 2.8.

The durability of the specimen was checked when the innovative corrosion test was conducted under loading. Thin slabs which were already pre-cracked were further damaged till fatigue under loading from 30 MPa of service load in the bending test, then retained under bending at the unchanged level. The process of 30 weekly wetting–drying cycles is undertaken by the part of these slabs in 5% sodium chloride solution at a temperature of 20ºC. The process is commenced from reloading to failure. Couple of series of eleven prismatic specimens were casted, in which one was tested by the heat treatment. It was observed from the study that in the aggressive environmental conditions there was no decrement in the mechanical properties of MSFRCC and in the case of corrosion, the fibers in the concrete does not get affected. It has been also investigated that the mechanical properties of the specimens which were pre-cracked by fatigue does not show any regression when kept in sodium chloride solution.

Table 2.10: Composition of MSFRCC [Parant et al. (2007)]

Raw materials		**Proportioning mixing**
OPC	CPA CEM I 52.5 R	1050 kg/m^3
Sand	Quartz 125–400 µm	514 kg/m^3
Silica fume	Zirconium	268 kg/m^3
Superplasticizer	Polyphosphonate - 30%	44 kg/m^3
Total water		211 L
Steel fibre content		858 kg/m^3
Silica fume/cement		0.225
Superplat/binder		1.02%
Sand/cement		0.49
Total water/binder		0.16

Since, the water flow which migrates towards the micro-cracks was not enough due to which autogenous healing was restrained in the experiment. The researchers concluded that in the above mentioned concrete very small widths was created, but it can easily have recovered by the self-healing property and thus making the concrete much durable in the aggressive environmental conditions and increases the life span of the concrete.

Abbas et al. (2016) studied the various mechanical and durability characteristics of Ultra High Performance Concrete (UHPC) in which different lengths and dosages of steel fibers were used. They used three different lengths of steel fibers 8 mm, 12 mm and 16 mm in the concrete, with the dosage of 1%, 3% and 6% by the volume of mixture for each type of steel fiber. The composition of materials used to produce UHPC is shown in Table 2.9 (a).

They had checked the chloride ion penetration in the concrete with the help of Rapid Chloride Ion Penetration Test (RCPT) according to ASTM C 1202, in which three different chloride exposure of 3%, 3.5% and 10%. The specimens of size 100 mm x 50 mm were casted for each mix condition for RCPT and checked at both ages of 28 and 56 days.

Table 2.11 (a): UHPC mixture proportions. [Abbas et al. (2016)]

Quantities	**Mass/cement mass**
Cement	1.00
Silica fume	0.20
Quartz powder	0.30
Quartz sand	1.20
Superplasticizer	3.50
Steel fibers length	8 mm. 12 mm and 16 mm
Steel fibers dosage	1%, 3% and 6%
Water	0.23

The test was conducted for 6 hours for each specimen and total number of coulombs passed was recorded in every 30 minutes of interval. The results of RCPT at 28 and 56 days of ages under various chloride ion exposures are shown in Table 2.9 (b). By the following results it has been noticed that various chloride ion exposure of 3%, 3.5% and 10% do not effect the total number of coulombs passed in the concrete very much. Also, length of the fibers does not impact on the results of RCPT. However, it has been observed that the dosage of steel fibers had a considerable effect on the values of coulombs. In specimens of UHPC containing 3%

and 6% of steel fibers of length 8 mm shows lesser number of coulombs passed when compared with control mix specimen having no steel fibers around 27 and 36 lesser respectively. This is happening because steel fibers decreases the permeability in concrete as they restrains the formation of drying shrinkage and plastic cracks. The MIP and SEM analysis shows the dense micro-structure due to the inclusion of steel fibers. Thus, steel fibers reduces the porosity in the concrete helping to increase the durability.

Table 2.11 (b): Rapid chloride ion penetrability of UHPC mixtures under various chloride ion exposures. [Abbas et al. (2016)]

Mixture	Steel fiber		Average coulombs passed					
	Length mm (in)	Dosage (%)	3.0%		3.5%		10.0%	
			28 days	56 days	28 days	56 days	28 days	56 days
1	-	-	71	70	72	71	80	78
2	8 (0.31)	1	60	60	59	60	65	63
3		3	45	43	47	44	50	49
4		6	36	35	38	33	42	40
5	12 (0.47)	1	60	58	59	60	67	65
6		3	47	48	49	48	52	53
7		6	38	39	40	40	40	40
8	16 (0.62)	1	65	54	66	65	72	70
9		3	52	53	54	52	56	54
10		6	43	40	45	42	48	46

Alkaysi et al. (2016) studied the effect on durability properties of UHPC when content of silica powder and type of cement is varied in the mix. The researchers varied three types of cements in the mix, the first one was Portland Type I white cement which has high content of C_3S. The second type is Portland type V cement which exhibits good sulphate resisting properties and also is less in cost.

The third choice was Portland Type I with GGBFS which was combined equally to form this type of cement. The silica powder was varied from 0% to 25% in each mix. Also, the two types of sand is used and varied in the mixes which were F12 sand (particle size less than 1000 µm) and F100 sand (particle size less than 300 µm). The water-cement ratio is kept very low and nine various types of blends were formed as shown in Table 2.10 (a).

The Rapid Chloride Ion Penetration Test was performed according to the ASTM C 1202 for which samples of size 100 mm x 50 mm were casted for each mix.

Table 2.12 (a): Mixes proportions for UHPCs tested. [Alkaysi et al. (2016)]

Name	White cement	Silica fume	Silica powder	Fiber (%)	F100	F12
W - 25	1.00	0.25	0.25	1.50%	0.26	1.06
W - 15	1.00	0.25	0.15	1.50%	0.29	1.14
W - 00	1.00	0.25	0.00	1.50%	0.31	
	Portland type V					
V - 25	1.00	0.25	0.25	1.50%	0.26	1.05
V - 15	1.00	0.25	0.15	1.50%	0.29	1.14
V - 00	1.00	0.25	0.00	1.50%	0.31	1.26
	Type I/GGBS cement					
IG - 25	1.00	0.25	0.25	1.50%	0.26	1.06
IG - 15	1.00	0.25	0.15	1.50%	0.29	1.14
IG - 00	1.00	0.25	0.00	1.50%	0.31	1.26

Table 2.12 (b): Summary of test results. [Alkaysi et al. (2016)]

UHPC	Rapid chloride penetration Total charge passed (coulombs)
W-25	89
W-15	295
W-00	637
V-25	939.5
V-15	488.5
V-00	57
IG-25	137.5
IG-15	229
IG-00	137.5

It was observed that all UHPC mixes showed very good resistance against the chloride ion penetration, the specimens of Portland Type I with GGBFS shows the maximum resistance to the chloride ion penetration, followed by specimens containing Portland Type I white cement. While Portland type V cement showed the maximum penetration among all. It is also observed that the content of silica fume increases the penetration of chloride ion, as 25% of silica fume containing concrete showed maximum penetration in the concrete, followed by 15% and 0% of silica fume containing concrete. The results of RCPT are shown in Table 2.10 (b).

Amr S. El-Dieb (2009) studied the possibility of developing Ultra High Strength Self-Compacting concrete (UHSC) using obtainable local ingredients with the addition of steel fibers. In this research the effect on durability properties of UHSC is being studied. Various mixes were prepared in which different volumes of local materials and steel fibers were used i.e. 0.08%, 0.12% and 0.52%. The compositions of various mixes are shown in Table 2.11.

Table 2.13: Variation of main mix composition and compressive strength. [Amr S. El-Dieb (2009)]

Mix composition	A	B	C	D	E
Total cementing materials (kg/m^3)	775	775	900	900	900
Silica fume (%)	15%	15%	17.5%	17.5%	17.5%
Water/Binder ratio	0.23	0.23	0.23	0.24	0.24
Fine aggregate (%)	0.27	0.27	0.27	0.28	0.28
– Coarse sand (%)	45%	60%	60%	50%	100%
– Dune sand (%)	76%	100%	70%	70%	70%
Coarse aggregate (%)	55%	40%	40%	50%	0%

The specimens of UHSC were casted on which durability test of sulphate attack was performed. The specimens were exposed to high concentration of sodium sulphate solution (5% by weight Na_2SO_4) and the test was set up at a high temperature of 50ºC which resembles the environment of Gulf states were the research was performed. The test was done after the 28 days of curing of the specimens and performed at different time intervals of 3, 6, 9 and 12 months in which their compressive strength is measured with the initial strength of concrete which was obtained after the age of 28 days. The change in compressive strength after immersion in sulphate solution with the 28 days strength is shown in Fig 2.7.

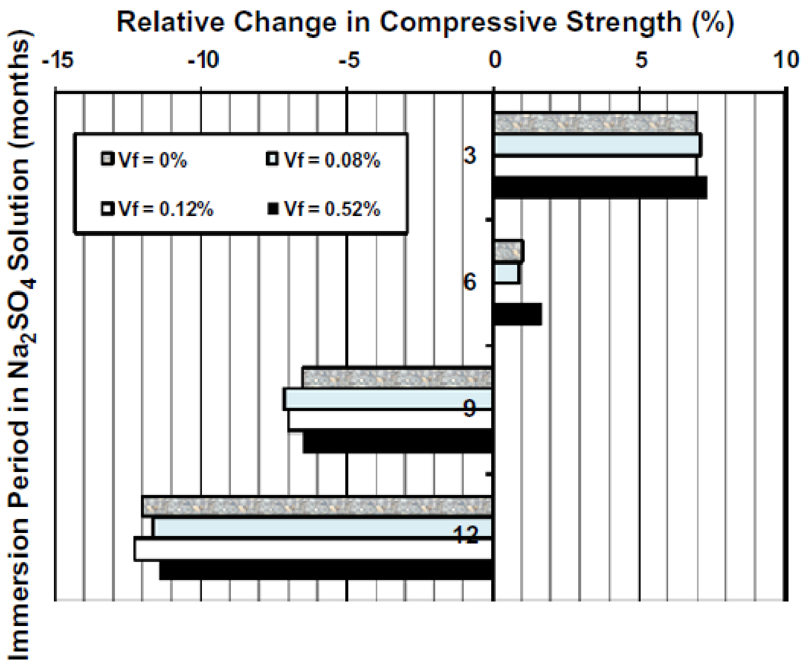


Fig.2.7: Effect of immersion in Na_2SO_4 solution for different time periods on compressive strength. [Amr S. El-Dieb (2009)]

In the investigation it has been observed that UHSC shows brilliant resistance towards sulphate attack, at the age of 3 months the specimens higher compressive strength than the control mix, this could be due to the high temperature of 50ºC which increases the pozzolanic reaction in the concrete. After the age of 12 months the compressive strength of various mixes were decreased by around 12% from the control specimens which specifies the effect of sulphate exposure on concrete. There was no noticeable effect on inclusion of different volumes of steel fibers. However, the inclusion of steel fibers varied the strength of concrete specimens according to the volume. They finally concluded with the help of SEM analysis that UHSC exhibits great resistance against sulphate attack as a dense microstructure is formed because of inclusion of various materials and steel fibers which decreases the permeability of concrete.

Xu et al. (2014) investigated the resistance of High Performance Concrete (HPC) to sulphate attack. The two types of water-cement ratios were used were 0.30 and 0.35. The total number of 5 groups with different water-cement ratio and stress ratio were made and 37 specimens of size 100 mm x 100 mm x 100 mm were casted for each group. The specimens were submerged in two different solutions of sodium sulphate i.e. 5% and 10% by weight of Na_2SO_4 under two different stress ratios of compressive loading of 0.3 and 0.6. The mix proportions used to produce HPC is shown in Table 2.12 (a). The different groups created to test the sulphate attack resistance of concrete is shown in Table 2.12 (b).

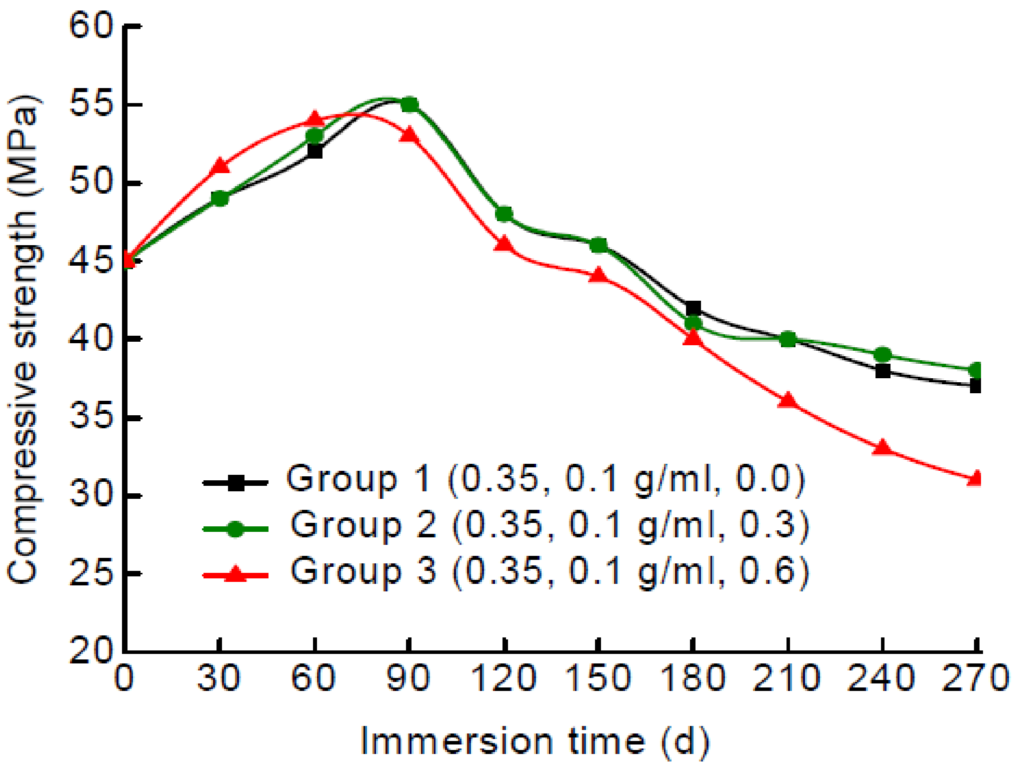
Table 2.14 (a): Proportions of concrete mixture prepared [Xu et al. (2014)]

w/b	Water	Binder			Fine aggregate (kg/m_3)	Coarse aggregate (kg/m3)	Superplasticizer (kg/m_3)	Cubic compressive strength (MPa)
		Cement	Fly ash	Silicon powder				
0.35	187	383	115	35	8.0	45	1057	45
0.30	172	412	124	37	8.6	62	1021	62

Table 2.14 (b): Specific combinations and groups [Xu et al. (2014)]

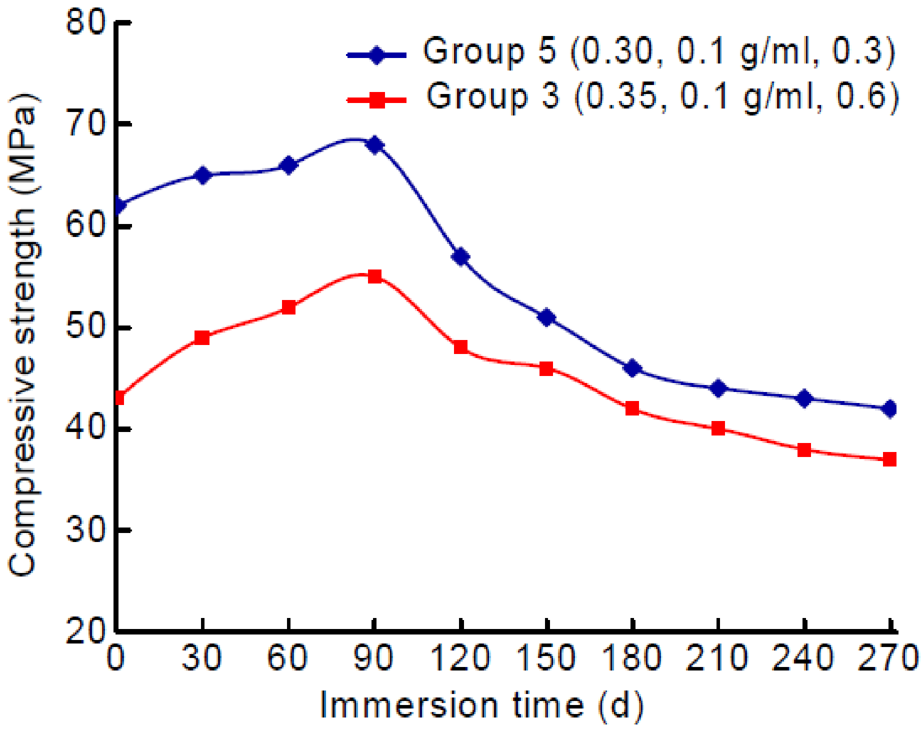
Group	w/b	Na_2SO_4 (g/ml)	Stress ratio
1	0.35	0.1	0.0
2	0.35	0.1	0.3
3	0.35	0.1	0.6
4	0.35	0.05	0.3
5	0.35	0.1	0.3

After the following experiment it was observed that HPC exhibits good resistance against the sulphate attack as under compressive loading the concrete structure gets densified. Thus, the initial resistance of concrete to sulphate attack increases. When the compressive loading at stress level of 0.3 is applied the improvement in resistance to sulphate attack is noticed while applying the compression loading at stress level of 0.6 the opposite effect occurs in which process of sulphate attack is accelerated and concrete starts to deteriot. It was also observed in the study that with decreasing the amount of water-cement ratio the resistance to sulphate attack also increases because due to less water-cement ratio the pore size in concrete gets reduced which helps in filling up and densified the concrete. Therefore, it was concluded that with increasing the amount of sodium sulphate concentration the resistance to sulphate attack of HPC decreases as well as with combine effect of sulphate attack and compression actions lead to deteriot the concrete. The results obtained after the study is shown in Fig.2.8.



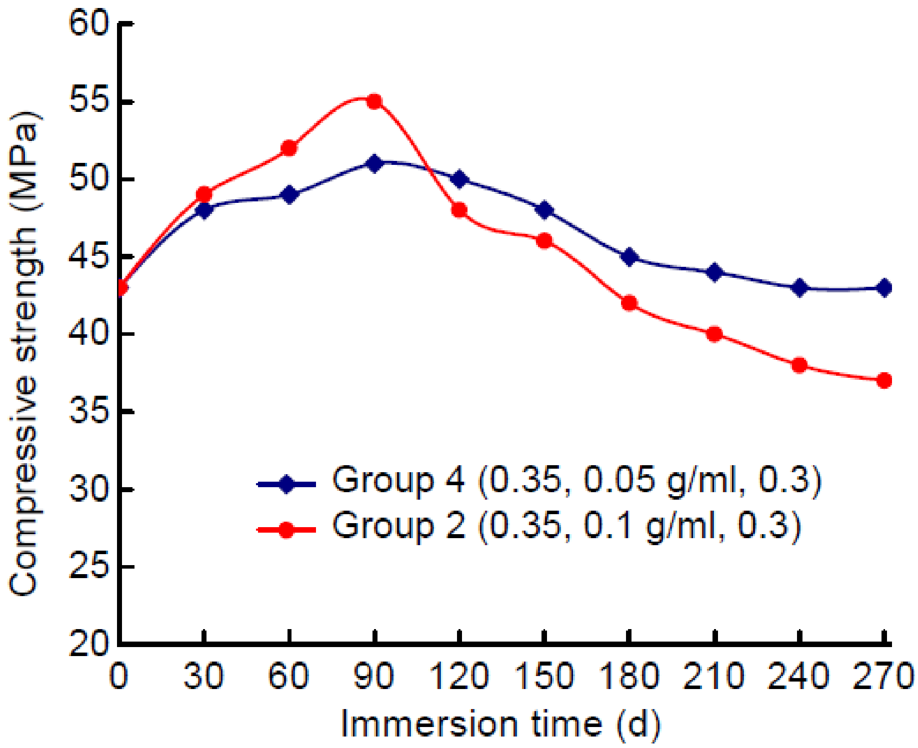
Compressive strength (MPa)
60
55
50
45
40
35
30
25
20
0
30
60
90
120
150
180
210
240
270
Immersion time (d)
Group 1 (0.35, 0.1 g/ml, 0.0)
Group 2 (0.35, 0.1 g/ml, 0.3)
Group 3 (0.35, 0.1 g/ml, 0.6)

(a)



Compressive strength (MPa)
80
70
60
50
40
30
20
0
30
60
90
120
150
180
210
240
270
Immersion time (d)
Group 5 (0.30, 0.1 g/ml, 0.3)
Group 3 (0.35, 0.1 g/ml, 0.6)

(b)



(c)

Fig.2.8: Relationship between compressive strength and immersion time of HPC under different a) stress ratios, b) water-binder ratios, c) solution concentrations [Xu et al. (2014)]

CHAPTER 3

MATERIALS AND DESIGN METHODOLOGY

3.1 GENERAL

In this chapter we will discuss about the properties of various materials used in developing Ultra High Performance Concrete (UHPC). The materials like cement, water, aggregates, GGBS, nano-silica, silica fume and steel fibers were used in the present study. The various properties and procedure for testing of these materials have been discussed in this chapter. The aim was to design UHPC with a desired strength of more than 120 MPa. The main aim was to determine the mix design with suitable quantity of materials in order to attain the desired properties. The experimental program was organized to determine the compressive strength and durability properties of UHPC concrete specimens.

3.2 CHARCTERISTICS OF MATERIALS USED

According to the relevant IS codes various physical and chemical properties of the materials were determined through the laboratory tests to produce Ultra High Performance Concrete (UHPC). As per the requirements of the codal provisions, the properties of the various materials are evaluated to examine their suitability in the concrete mix, which helped to obtain a mix design for the required strength of concrete. The details of different materials along with their examined properties which were used in this research are listed below:

3.2.1 Portland Cement

In the present study Ordinary Portland Cement of grade 53 from the manufacturer ACC Cement was used during the course of investigation as shown in Fig.3.1. OPC 53 cement has optimum distribution of particle size, balanced phase composition and enhanced quality crystalline structure which helps in increasing the strength and durability of the concrete. The cement was obtained from a single lot from ACC Cement manufacturing plant located in Barmana, Himachal Pradesh. OPC 53 grade cement specifications are provided by IS 12269:2013. According to IS 12269:2013 the different physical properties of the cement were determined and are listed in Table 3.1. The cement was properly stored and kept away from any kind of moisture and deterioration. The tests which were performed on the cement are specific gravity test, standard consistency, initial setting time and final setting time and also compressive strength. The following are results of the above tests performed.

Table 3.1: Properties of OPC 53 Grade Cement

Characteristics	Values Obtained Experimentally	Value Specified by IS 12269: 2013	Test Method Referred to
Specific Gravity	3.12	-	IS 4031 Part 11
Standard Consistency %	30	-	IS 4031 Part 4
Setting Time (minutes)			IS 4031 Part 5
Initial	120	30 (Minimum)	
Final	320	600 (Maximum)	
Compressive Strength (N/mm^2)			IS 4031 Part 6
3 Days	30.40	27	
7 Days	41.35	37	
28 Days	55.20	53	

Fig.3.1: OPC 53 grade cement

3.2.2 Water

Water is a major ingredient which binds the materials together in the concrete mix. For mixing and curing of the specimens of concrete potable water is generally considered. In the present study potable water which was available in the laboratory was used for making UHPC. The water used had no harmful contaminants.

3.2.3 Aggregates

Aggregates are the wide range of basic ingredients used in the concrete. They occupies a large quantity in the concrete which is about 85% of volume of concrete. They include sand, sag saw dust, gravel, broken bricks, crushed stone etc. In the present study two types of aggregates were used and the same are listed below:

- Coarse aggregates of size 10 mm and 20 mm.
- Fine aggregates having size of particle below 4.75mm.

a) **Coarse aggregates:** These aggregates are formed due to artificial crushing of gravel or rock or by natural degradation of rocks. These aggregates clearly pass through IS sieve of 75 mm and leave on very minimum residue on IS sieve of 4.75 mm, so in other words we can say that the coarse aggregates are one which has maximum particle size of 75mm and minimum particle size of 4.75 mm.

According to the IS: 383-1970 the aggregates quality should be dense, hard, clear, durable, free from veins, strong and adherent coating. The aggregates should be free from large quantities of broken pieces, organic matter, alkali and other harmful substances and also the shapes of aggregates like elongated, flaky and scoriaceous should be avoided. The aggregates used in the present study are of sizes 10 mm and 20 mm, they are the mixture of crushed stone which is found locally.

The aggregates available contained dirt which was removed by proper washing and then dried in oven for 24 hours to remove the excess content of moisture. After that they are kept in normal condition to cool down to room temperature so that they can be used in mix of concrete. The sieve analysis performed in the laboratory of coarse aggregates of size 20 mm is shown in Table 3.2(a) and for size of 10 mm is shown in Table 3.2 (b). The different physical properties and specific gravity of coarse aggregates are shown in Table 3.2 (c).

Table 3.2 (a): Sieve Analysis of Coarse Aggregates (20 mm)

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	363	3.63	96.37	3.63
4	10	8890	88.9	7.47	92.53
5	4.75	747	7.47	0.00	100
6	2.36	0	0.00	0.00	100
7	1.18	0	0.00	0.00	100
8	600 μ	0	0.00	0.00	100
9	300 μ	0	0.00	0.00	100
10	150 μ	0	0.00	0.00	100
11	Pan			Sum	696.16
Total		10000		FM = 6.96	

Table 3.2 (b): Sieve Analysis of Coarse Aggregates (10 mm)

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	0.00	0.00	100.00	0.00
4	10	3650	36.5	63.5	36.5
5	4.75	6350	63.5	0.00	100
6	2.36	0	0.00	0.00	100
7	1.18	0	0.00	0.00	100
8	600 μ	0	0.00	0.00	100
9	300 μ	0	0.00	0.00	100
10	150 μ	0	0.00	0.00	100
11	Pan			Sum	636.5
Total		10000		FM = 6.36	

Table 3.2 (c): Physical properties of coarse aggregates

Characteristics	Value	
Colour	Grey	
Shape	Angular	
Maximum size	10 mm	20 mm
Specific Gravity	2.80	2.828

b) Fine aggregates: The aggregates which pass through IS sieve of 4.75 mm are considered as fine aggregates. The fine aggregates are classified into four grading zones from Grade I to Grade IV with respect to fineness. The particle size grade of zone I of the aggregate is the coarser as compared to zone IV.

Table 3.3 (a): Physical properties of fine aggregates

Characteristics	Values
Type	Natural Sand
Grading Zone	II
Fineness Modulus	3.02
Specific Gravity	2.544

Table 3.3 (b): Sieve Analysis of Fine Aggregates

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	4.75	31	3.1	96.9	3.1
2	2.36	137	13.7	83.2	16.8
3	1.18	238	23.8	59.4	40.6
4	600 μ	168	16.8	42.6	57.4
5	300 μ	316	31.6	11	89
6	150 μ	65	6.5	4.5	95.5
7	Pan	45	4.5	0	
Total		1000		Sum	302.4
Zone II			FM = 3.02		

The grade of fine aggregate used was grading zone II which was obtained from the local dealer in Patiala, Punjab. The silt and clay are further removed by washing and dried in oven to remove the excess moisture content. The different physical properties of fine aggregates are shown in Table 3.3 (a). The values of sieve analysis obtained in laboratory tests are shown in Table 3.3 (b).

3.2.4 Ground Granulated Blast Furnace Slag (GGBS)/Alccofine

Alccofine is the industrial name of Ground Granulated Blast Furnace Slag (GGBS) and it is a very fine material having very small particle size as compared to other cementitious materials. The microfine admixture 'ALCCOFINE-1203' was used as a replacement of cement in developing UHPC in the present study. The Alccofine was obtained from the manufacturing plant of Ambuja Cement Ltd. (ALCCOFINE MICRO MATERIALS RANGE) in Mumbai. The Alccofine has low calcium content which is obtained through a controlled granulation process. It is a high pozzolanic material which increases the hydration process in the concrete thus, increasing the density of concrete. Thus, strength and durability properties of the concrete are also increased significantly. The Fig.3.2 shows 'ALCCOFINE-1203'. The characteristics of Alccofine are shown in Table 3.4 (a) and Table 3.4 (b).

Fig.3.2: Alccofine-1203 from Ambuja Cement Ltd.

Table 3.4 (a): Physical Properties of Alccofine-1203

Property	Unit	Content
Bulk Density	kg/m^3	680
Fineness	cm^2/gm	12000
Average Particle Size	Microns	4 to 6
Specific Gravity		3.1

Table 3.4 (b): Chemical composition of Alccofine -1203

CaO	33.8%
SiO_2	34.2%
Al_2O_3	22.7%
Fe_2O_3	1.8%
MgO	6.6%

3.2.5 Nano Silica

Nano silica used is in liquid solution form having very fine particle size. The high specific surface areas and high purity content (greater than 99%) helps nano silica particles to affect the mechanical and durability properties of concrete.

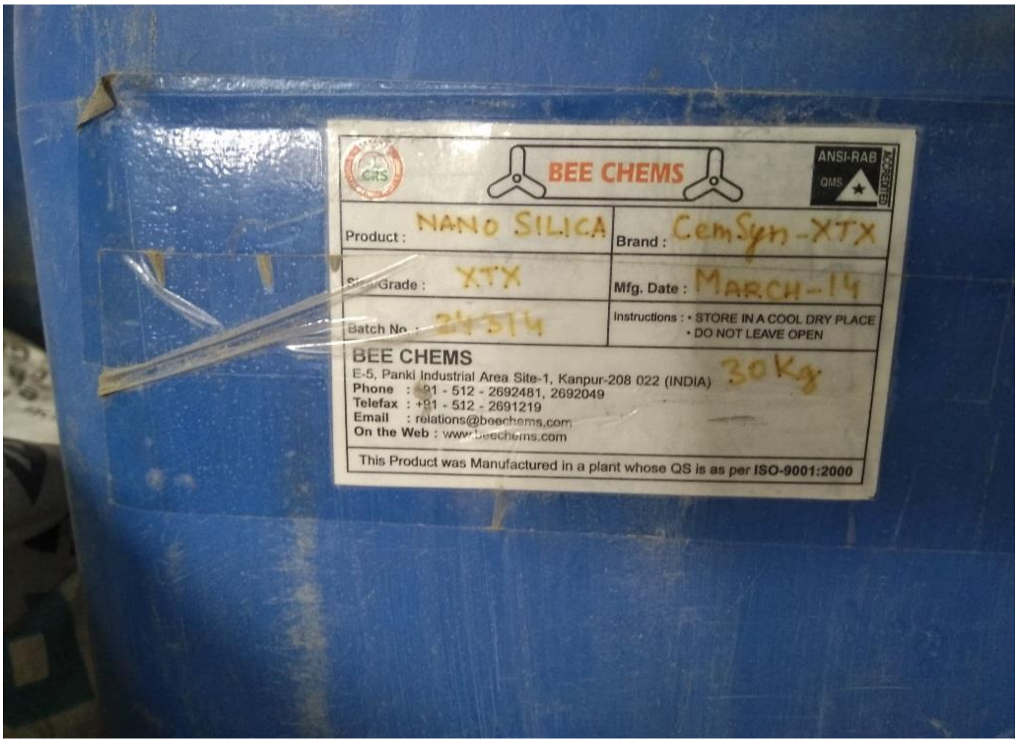


Fig.3.3: Nano silica

The particle size of nano silica is the finest among all admixtures used in this research, even smaller than alccofine and silica fume. In the present study the nano silica is obtained from BEECHEMS, Kanpur is shown in Fig.3.3.

Properties (Physical and Chemical): The size of particle is about 1-100 nm. The colour of nano silica is white, it is translucent in nature having complete solubility and has no odour. The specific gravity of nano silica lies between 1.20–1.22.

3.2.6 Silica Fume

Silica fume is a pozzolanic admixture which helps in reducing the pores size in concrete by filling up the void space in concrete because of its small particle size which helps in reducing the permeability of concrete. It is also known by other names as condensed silica fume and micro silica. The silica fume used in the present was manufactured in KGR Agro Fusions (P) Ltd., Ludhiana Punjab. The silica fume used is of quality as specified by codal provisions of AASHTO M 307 and ASTM C 1240 as it has very fine particle size of around 1/100th the particle size of cement and high SiO_2 content, which makes silica fume a good admixture for production of UHPC. The various physical and chemical properties of silica fume used, as provided by in KGR Agro Fusions (P) Ltd are listed below:

a) Physical properties: The significant physical properties are listed below in Table 3.5 (a)

Table 3.5 (a): Physical properties of silica fume

Colour	White
Specific gravity	2.20
Bulk Density	550-700 kg/m^3
Particle size (typical)	< 1µm
Specific surface	15,000 to 30,000 m^2/kg

b) Chemical Properties: The chemical compositions of silica fumes vary according to the furnace type used in manufacturing and also design of furnace plays an important role in determining the chemical composition of silica fume. The chemical composition received from the manufacturer is tabulated below in Table 3.5 (b):

Table 3.5 (b): Chemical Composition of silica fume

SiO_2	MgO	SO_3	H_2O	K_2O	Na_2O	CaO	Si	Cl	Fe_2O_3
92.25%	<1.5%	<1.1%	<0.4%	<2.25%	<1.4%	<0.35%	<0.5%	<0.06%	<2%

3.2.7 Superplasticizers

MASTERGLENIUM SKY 8233 is a modified polycarboxylic ether based superplasticiser, was used in this study. This high-performance superplasticiser was obtained from BASF solutions, Nalagarh.

The product is useful in development of high performance concrete where high strength and durability are required. It is suitable for use with nearly all types of cements.

The Fig.3.4 shows the product used in the study.

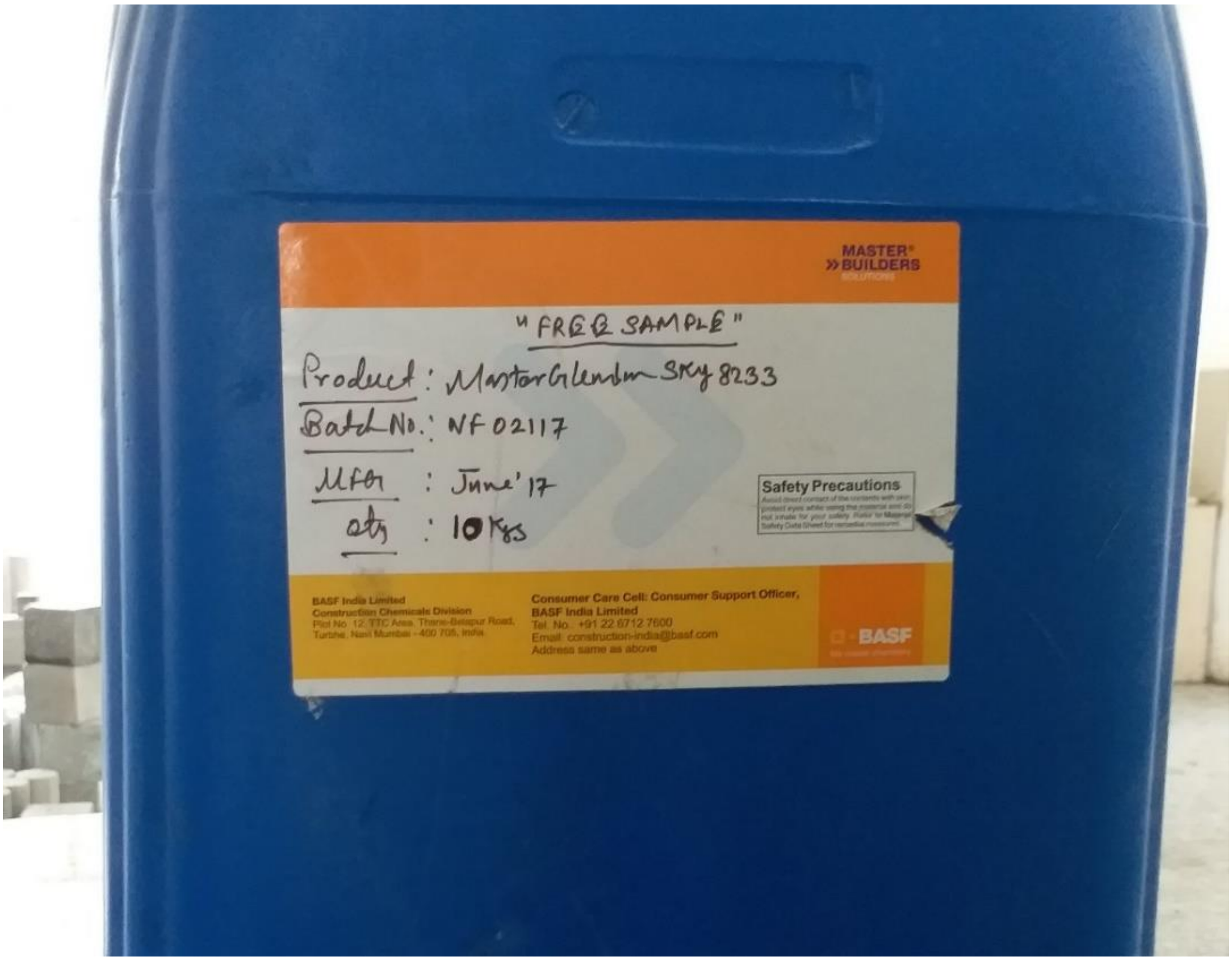


Fig.3.4: Masterglenium Sky 8233 Superplasticizer

The superplasticizer specified by the following codal provisions of:

- IS 9103: 1999,
- EN 934-2 T3.1/3.2 and
- ASTM C494 Type G

The physical properties of Masterglenium Sky 8866 are given in Table 3.6.

Table 3.6: Physical Properties of Superplasticizer

Specific Gravity	1.08
Relative Density	1.08± 0.01 at 25ºC
Aspect	Reddish Brown Liquid
Chloride ion content	< 0.2%
pH	≥ 6
Type	Polycarboxylic Ether Polymer

The trials mixes were performed in the laboratory to determine the optimum dosage of *Masterglenium Sky 8233*. The recommended rate of addition of superplasticizer is in the range of 0.6 – 2% by the weight of cement.

3.2.8 Steel Fibers

Steel fibers are used to increase the compressive and tensile strengths of the concrete as they capture the propagation of cracks and delays its process which results into slow cracking of concrete. Therefore, due to slow cracking process under flexural loading concrete shows high tensile and extensibility strength, at first as well as ultimate crack and even after extensive cracking in concrete the fibers holds the matrix together.

The main objective of the steel fibers are to convert a material, which is brittle in nature, to a material which is ductile which definitely also helps to enhance the energy absorption rate of concrete which is further helpful in withstanding frequently applied shock or impact loading. In this present investigation crimped type steel fibers were used which were obtained from Kasturi metal composite Pvt. Ltd., Maharashtra, India as shown in Fig.3.5. The general specifications of used steel fibers are presented in Table 3.7.

Table 3.7: Specification of steel fibers

Ultimate Strength as per ASTM A820M	> 1100 MPa
Length	30 mm
Diameter	0.60 mm
Aspect Ratio	50

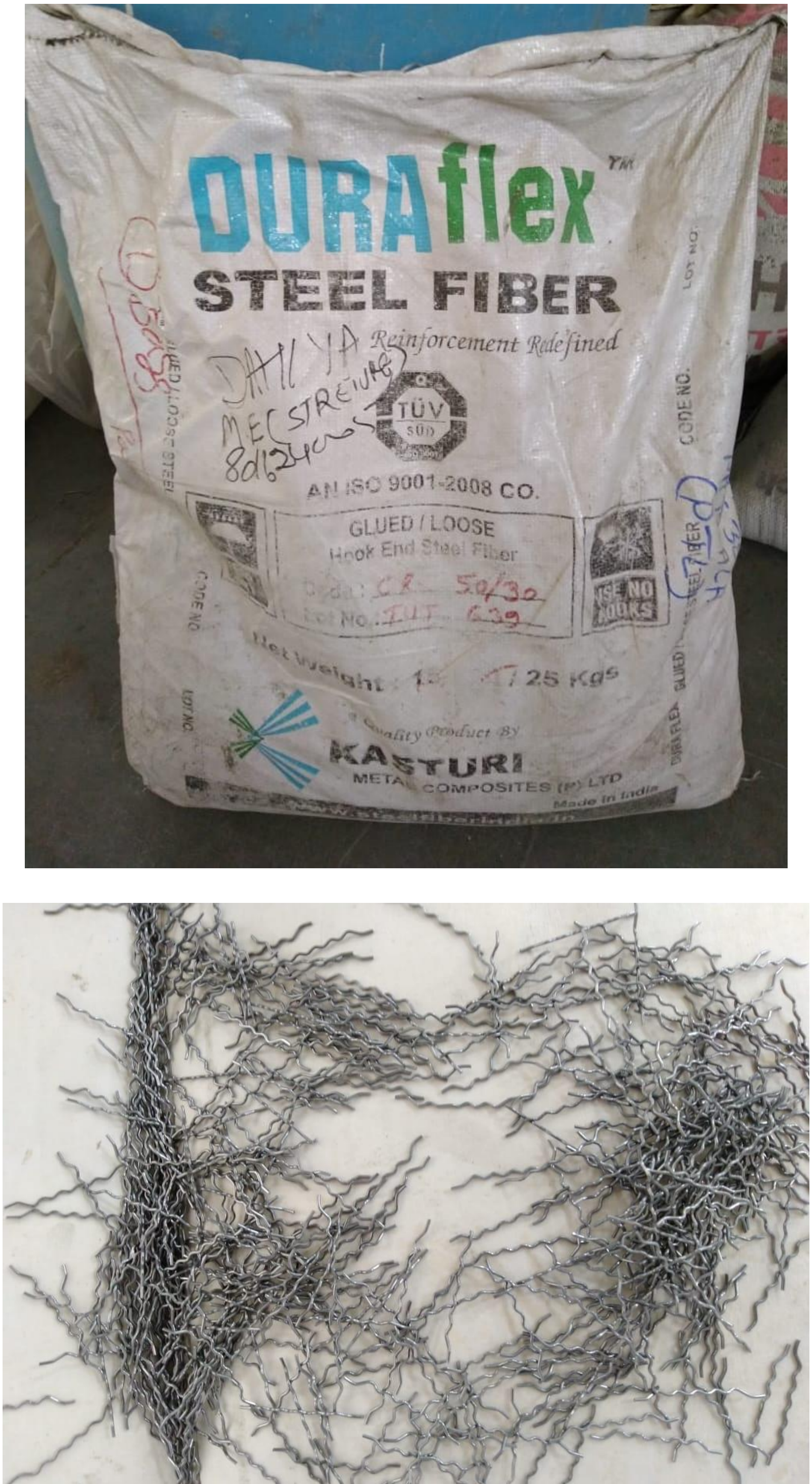


Fig.3.5: Crimped steel fibers used in the study

3.3 TEST METHODS

In this unit the test methods or procedure applied to determine the properties of cement, fine and coarse aggregates, compressive strength of concrete and durability tests like *Sulphate attack* and *Rapid Chloride Penetration Test (RCPT)* on the UHPC is discussed.

3.3.1 Specific gravity

Specific gravity is generally defined as the ratio between the density of the material to the density of the water. The IS: 2720-(Part 3): 1980 specifies the method to calculate specific gravity of cement and IS: 2386 (Part 3): 1983 specifies the method to calculate the specific gravity of aggregates. The specific gravity of various ingredients of UHPC is obtained in this study.

3.3.2 Sieve analysis for coarse and fine aggregates

Gradation test is also known as sieve analysis which is implemented to achieve the mean size of particles and fineness modulus. As per IS: 2386 (Part-1): 1963 specifies the procedure to perform sieve analysis in which various sets of sieves are used to evaluate grading of aggregates and fineness modulus.

3.3.3 Compressive Strength of Concrete

For determining the compressive strength of Ultra High Performance Concrete (UHPC), the cubes of size 150 mm x 150 mm x 150 mm were cast and tested after curing ages of 7 and 28 days under standard laboratory conditions. Three cubical specimens of each UHPC mix and each percentage of steel fibers were casted. The time period is noted after the dry materials are mixed with water which starts forming binding material. The Automatic Compression Testing Machine (ACTM) with a capacity of 5000 KN was used for testing the specimens.

Before the testing of sample, the surface water is removed by wiping using a clean cloth. After it is removed from curing tank and specimens are further kept at room temperature for 30 minutes to remove the excess moisture content. According to the IS: 516-1959 the rate of loading of 5 MPa per second should be continuously applied on the concrete specimens until the failure occurs and placing the cubes in such a way in testing machine that the load was supplied at the right angle to the faces of cube rotating them at 90º. The Fig.3.6 shows cube specimen testing under ACTM.

Fig.3.6: Cube after compression test in Automatic Compression Testing Machine (ACTM)

3.3.4 Sulphate attack

The sulphate attack tests on the specimen is carried out to check the durability characteristics of the concrete. In the present study sodium sulphate solution is used in which a total number of 48 cube specimens were cast of which three specimens of each mix and each varying percentage of steel fibers were cast of size 150 mm x 150 mm x 150 mm and cured for the age of 28 days. After the specified curing period which these specimens are kept in sodium sulphate solution (5% by weight of Na_2SO_4) for 28 days.

The compressive strength of these specimens was tested after the completion of 28 days and compared with the compressive strength of water cured specimens of same mix. The rate of change in the compressive test is analysed and thus, giving an indication of the durability of the specific type of concrete. In the experiment conducted the sodium sulphate powder was obtained from Avarice Pvt. Ltd., Delhi shown in Fig.3.7.

Fig.3.7: Sodium Sulphate (Na_2SO_4)

3.3.5 Rapid Chloride Permeability Test (RCPT)

In order to determine the chloride ingress resistance of UHPC the Rapid Chloride Penetration Test (RCPT) is performed. The samples of diameter of 100 mm and width 50 mm were cast and tested at the age of 28 days. The test procedure of RCPT was followed as specified in ASTM C 1202 in which the sample is kept in a measuring cell. The one part of filled with solution of sodium chloride (3% by weight of NaCl) at the negatively charged terminal and another part is filled with solution of NaOH (0.3 M NaOH) at the positively charged terminal. A regular current is passed through a specific voltage of 60V for a standard time period of 6 hours. The results of this test are evaluated in TCP (total charge passed) which is measured in coulombs. As per ASTM C 1202 the values of TCP denote the qualitative values, with the help of which we can denote the chloride ion permeability of concrete as presented in Table 3.8. The results of this test are mainly affected by duration and method of curing and type of ingredient used in the concrete specimen.

Before conducting the test, vacuum desiccators' bowl was used in which the specimens are kept for 3 hours in vaccum as shown in Fig.3.8. The vacuum desiccators' bowl contains the desiccators with stopcock, vacuum pump, valve, vacuum gauge and distilled water. After the specimens are removed from the vacuum desiccators' bowl they are dried and placed in a gasket. The specimens are then placed in the test setup as shown in Fig.3.9.

Table 3.8: Qualitative relationship between chloride ion penetrability of concrete and results of the test

S. No.	Charge Passed (in coulombs)	Chloride ion Penetrability
1.	>4000	High
2.	2000-4000	Moderate
3.	1000-2000	Low
4.	100-1000	Very Low
5.	<100	Negligible

Fig.3.8: Vacuum desiccators' bowl

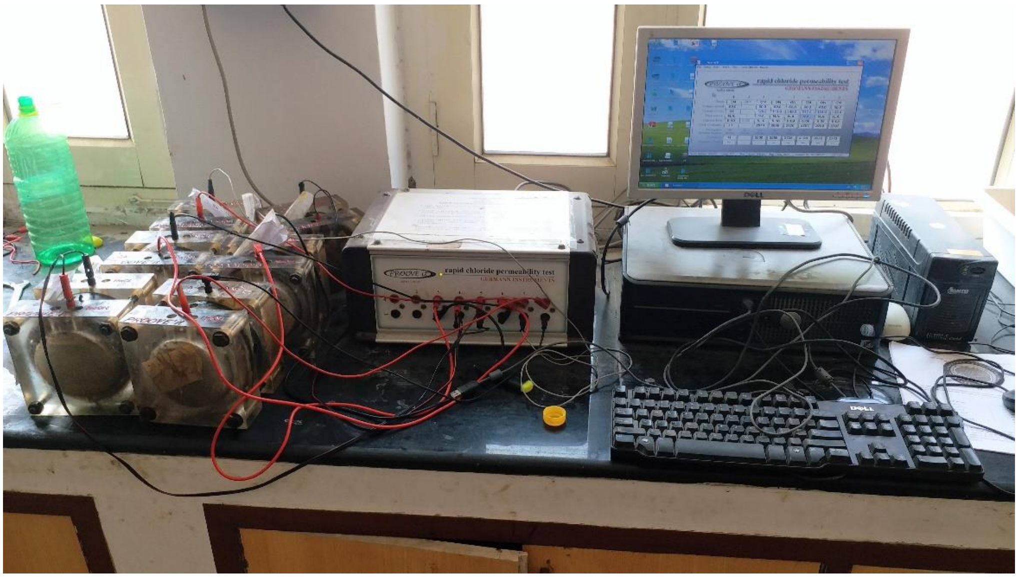


Fig.3.9: Rapid Chloride Permeability Test (RCPT) setup

3.4 CONCRETE MIX PROPORTIONING

The test data for materials used in proportioning of concrete mixes is presented in Table 3.8.

Table 3.9: Test Data for materials

1	Cement Used	OPC-53
2	Specific Gravity of Cement	3.12
3	Specific Gravity of Coarse Aggregate (20 mm)	2.828
4	Specific Gravity of Coarse Aggregate (10 mm)	2.80
5	Specific gravity of Fine Aggregate	2.544
6	Specific gravity of Alccofine	3.10
7	Specific gravity of Silica Fume	2.20
8	Specific gravity of Nano Silica	1.22
9	Specific gravity of Superplasticizer	1.08
10	Free Surface Moisture of Coarse Aggregate (20mm &10mm)	Nil
11	Sieve Analysis of Fine Aggregate	Conforming to Zone II (IS: 383-1970)
12	Sieve Analysis of Coarse Aggregate	Conforming to Table 4 (IS: 383-1970)

3.4.1 Mix proportions used in the present study

In the present study four different kinds of mixes were prepared (M1, M2, M3, and M4) in which percentage of Alccofine is replaced by 0%, 10%. 15%, 20% by the weight of cement. The water-binder ratio taken in each mix was 0.18 which is very low and helps to develop Ultra High Performance Concrete (UHPC). In addition to this, four different percentages (0%, 0.5%, 1.0% and 1.5%) of steel fibers were added to each mix to study the compressive strength and durability properties of UHPC.

Six cubes of each mix and each percentage of steel fibers were casted for checking compressive strength on 7 and 28 days also three cubes of each mix and each percentage and each percentage of steel fibers were casted to check the sulphate attack on UHPC. To check the chloride ion penetration three cylindrical specimens were casted.

The following are the materials used in making UHPC and their varying percentages are listed below in Table 3.11 (a).

Table 3.10 (a): Percentage of ingredients in various trial mixes

Trial Mix	Alccofine (%)	Steel fibers (%)	Silica fume (%)	Nano Silica (%)
M10	0	0	8	2
M11	0	0.5	8	2
M12	0	1.0	8	2
M13	0	1.5	8	2
M20	10	0	8	2
M21	10	0.5	8	2
M22	10	1.0	8	2
M23	10	1.5	8	2
M30	15	0	8	2
M31	15	0.5	8	2
M32	15	1.0	8	2
M34	15	1.5	8	2
M40	20	0	8	2
M41	20	0.5	8	2
M42	20	1.0	8	2
M43	20	1.5	8	2

A slump of around 50-75 mm was maintained for a suitable workability in the experiment for which superplasticizer is varied between 1.5-2.0%. The final mix design quantities are shown in Table 3.11 (b).

Table 3.10 (b): Mix Proportions

Materials	Trial 1	Trial 2	Trial 3	Trial 4
Water (kg/m3)	150	150	150	150
Cement (kg/m3)	750	666.67	625	677.01
FA (kg/m3)	490.19	490.04	489.96	489.88
CA(20mm) (kg/m3)	677.43	677.22	677.11	677.01
CA (10mm) (kg/m3)	330.35	330.25	330.20	330.15
SF (kg/m3)	66.67	66.67	66.67	66.67

NS (kg/m3)	16.67	16.67	16.67	16.67
AF (kg/m3)	0	83.33	125	166.67
Superplasticizer (kg/m3)	16.67	16.67	16.67	16.67
Water-Binder ratio	0.18	0.18	0.18	0.18
Steel Fibers (kg/m3)	0	0	0	0
	3.75	3.33	3.12	2.91
	7.50	6.66	6.25	5.83
	11.25	9.99	9.37	8.74

CHAPTER 4
RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter, the results and discussions on compressive strength and durability tests conducted on the Ultra High Performance Concrete (UHPC) mixes are presented. In order to enhance the properties, the proportion of materials of mix in varying percentages of alccofine, nano silica and silica fume were incorporated in the mix along with cement (OPC 53 Grade) and different sizes of aggregates. The investigation on properties of UHPC specimens were conducted after 28 days of curing. The following consist of experimental program list:

1. To develop UHPC, different physical and chemical properties of the materials were tested.
2. Various trial design mixes were made for UHPC to check for optimum superplasticizer dosage for desired workability.
3. The specimens of concrete were cast and cured for 28 days.
4. To check compressive strength and sulphate resistance of concrete, the size of 150 mm x 150 mm x 150 mm cubical specimens were cast.
5. The cylindrical specimens of 100 mm x 50 mm were casted for checking chloride ion penetration by Rapid Chloride Permeability Test (RCPT).

4.2 COMPRESSIVE STRENGTH TEST RESULTS

4.2.1 Compressive strength

Compressive strength is the maximum stress that concrete can resist without any failure when the load is gradually applied on it. The compressive forces are the main component to be resisted by the concrete structures. The lateral tensile strain is the main reason for the vertical cracks in the concrete which in RCC, is overcome by providing steel reinforcement. The failure in the concrete specimen mainly occurs diagonally in the vertical plane.

4.2.2 Test Procedure and Results

In order to test the compressive strength of controlled as well as steel fibers incorporated concrete mix, specimens of size 150 mm x 150 mm x 150 mm were prepared. The modified mix specimens were made by partial replacement of cement with GGBS, silica fume and nano silica and using different percentage of steel fibers. These were tested after the curing age of 7 and 28 days. In the experimental procedure the standard pan mixer was used for preparing mix in the laboratory. Firstly, the proper hand mixing is done of cementitious materials like cement, silica fume and GGBS until a uniform colour is obtained and the coarse and fine aggregates were put into the mixer separately with steel fibers and properly mixed for several minutes. After which the cementitious materials blend is added to the aggregates in the pan mixer and dry mixing is done for around 5 minutes. Then 50% of water is added in the mix to form a saturated mix, while mixing the ingredients together the nano silica and superplasticizer is added to the remaining water and gradually added to the mix and mixer was rotated for 5–7 minutes to obtain a proper blend of mix. The superplasticizer is varied in each mix to attain a constant workability i.e. slump of around 50 to 75 mm. The time period is noted after the dry materials are mixed with water which starts forming binding material. The ACTM with a capacity of 5000 KN was used to test the specimens. The results of compression test are shown in Table 4.1.

Table 4.1: Compression strength results

Mix	Steel fibers (%) by weight of cement	Compressive strength at 7 days (MPa)	Compressive strength at 28 days (MPa)
M10	0	65.8	99.2
M11	0.5	73.8	104.0
M12	1	78.1	113.7
M13	1.5	83.0	118.2
M20	0	84.3	122.6
M21	0.5	88.6	126.8
M22	1	90.8	130.0
M23	1.5	97.8	139.8
M30	0	77.4	116.4
M31	0.5	89.4	124.5
M32	1	89.7	134.0
M33	1.5	96.6	136.5
M40	0	76.0	111.8
M41	0.5	84.2	120.3
M42	1	88.7	127.6
M43	1.5	92.4	133.4

4.3 DISCUSSION OF COMPRESSIVE STRENGTH TEST RESULTS

4.3.1 Effect of variation in percentage of steel fibers on compressive strength of concrete for Trial 1 (Alccofine 0%)

The concrete mix M10 having no steel fibers with the water-binder ratio of 0.18 (containing 0% alccofine, 8% silica fume and 2% nano silica) resulted in a compressive strength of 65.8 MPa and 99.2 MPa at 7 and 28 days of curing respectively. When 0.5% of steel fibers by weight of cement were added in the same mix which is denoted as M11, it was observed that the compressive strength was 73.8 MPa and 104.0 MPa at the ages of 7 and 28 days respectively, indicating an increase in strength in both the ages. Subsequently, in M12 when the percentage of steel fibers were increased to 1.0% by the weight of cement the compressive strength is noticed as 78.1 MPa and 113.7 MPa at the curing ages of 7 and 28 days, again a noticeable increase in strength is observed at both the ages. At last, in M13 when the percentage of steel fibers were increased to 1.50% by the weight of cement the compressive strength at 7 and 28 days were observed to be 83.0 MPa and 118.2 MPa showing an obvious trend of increasing compressive strength with increasing the percentage of steel fibers in Trial 1. Fig.4.2 shows the effect of variation in compressive strength of concrete mixes with varying percentage of steel fibers.

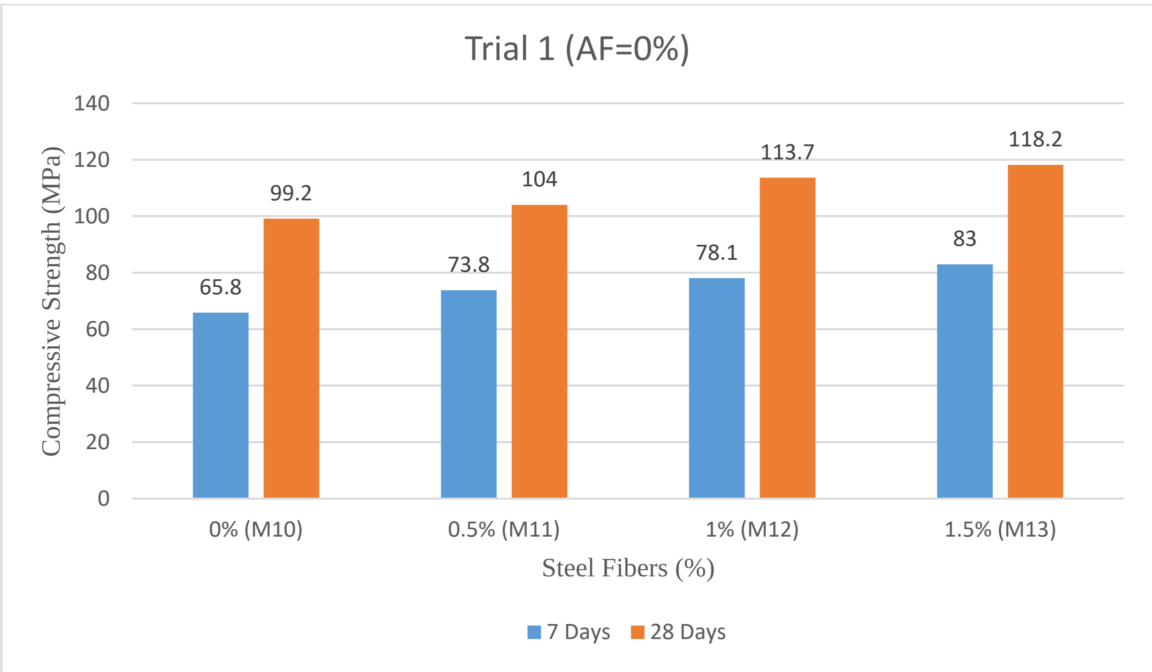


Fig.4.1: Variation of compressive strength for Trial 1 with AF=0%

From the above discussed values of the compressive strengths, it is observed that in Trial 1 with increase in content of steel fibers the strength of concrete gradually increases at both the curing ages. The maximum increment in the strength at 7 days of curing was observed with M11 with 0.5% of steel fibers which was 12.15% and maximum increment in the strength at 28 days of curing was observed in M12 containing 1.0% of steel fibers from the mix containing 0.5% of steel fibers which was 9.32%. The overall increase in strength of Trial1 concrete specimens were noted to be around 26.13% at 7 days and 19.15% at 28 days of curing.

It was observed in Trial 1 that in addition of the steel fibers the strength of concrete gradually increases, but the various strength obtained from the Trial 1 was not satisfactory to produce Ultra High Performance Concrete (UHPC) because the maximum strength observed in Trial 1 was 118.2 MPa at 28 days of curing which does not lie between the range of 120 MPa-150 MPa. So, it is concluded that for developing UHPC, supplementary cementitious materials like GGBS, silica fume and nano silica with adequate percentage of steel fibers is necessary.

4.3.2 Effect of variation in percentage of steel fibers on compressive strength of concrete for Trial 2 (Alccofine 10%)

In the concrete, the Trial 20 containing 0% steel fibers with the water-binder ratio of (containing 10% alccofine, 8% silica fume and 2% nano silica) resulted the compressive strength of 84.3 MPa and 122.6 MPa at 7 and 28 days of curing respectively.

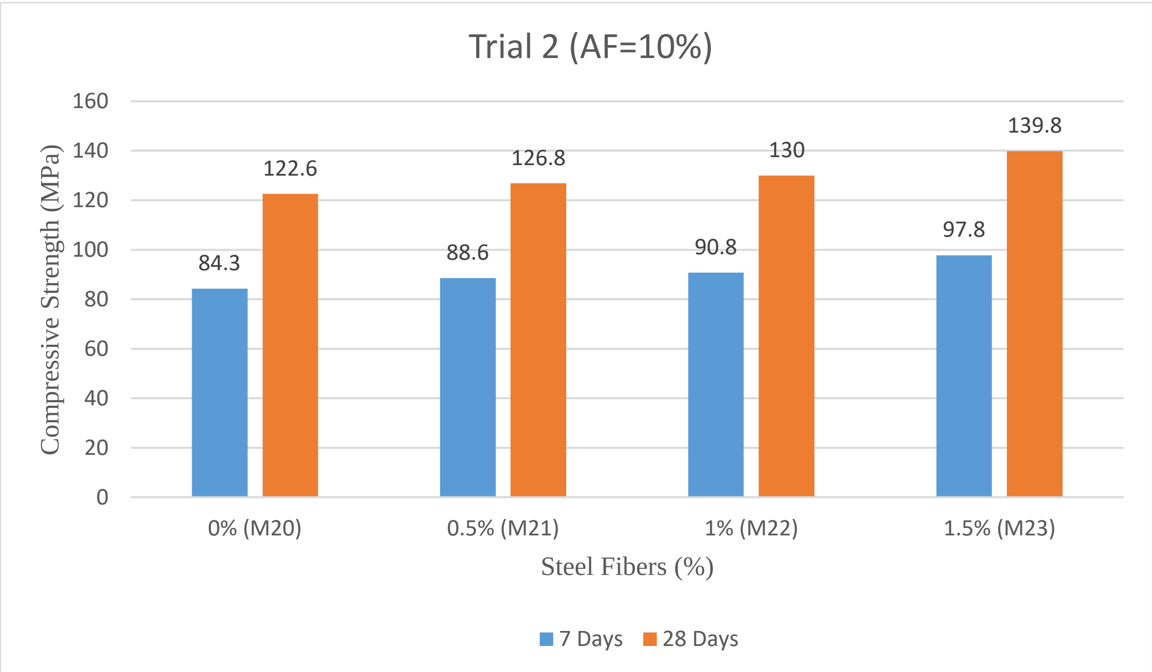


Fig.4.2: Variation of compressive strength for Trial 2 with AF=10%

When 0.5% of steel fibers were added by weight of cement in the same mix which is denoted as M21, it was observed that the compressive strength was 88.6 MPa and 126.8 MPa at the ages of 7 and 28 days respectively, indicating an increase of strength in both the ages. Subsequently, In M22, when the percentage of steel fibers was increased to 1.0% by the weight of cement the compressive strength is noticed as 90.8 MPa and 130.0 MPa at the curing ages of 7 and 28 days, a marginal increase in strength is observed in the both ages. At last, in M23 when the percentage of steel fibers was increased to 1.50% by the weight of cement the compressive strength at 7 and 28 days were observed to be 97.8 MPa and 139.8 MPa respectively, showing an obvious trend of increasing compressive strength with increasing the percentage of steel fibers in Trial 2. The strength observed in Trial 2 with including 1.5% steel fibers were the maximum compressive strength observed in the experiment.

It is further noticed in the experiment that with the inclusion of steel fibers in the mix gradually increases the compressive strength of concrete and the major observation was that the replacement of cement by the 10% alccofine enhanced the compressive strength of the concrete. The maximum increment of strength in Trial 2 was observed in M23 with 1.5% of steel fibers at 7 days as well as 28 days of curing which was 7.70% and 7.01% respectively. The overall increase in strength of Trial 2 concrete specimens were noted to be around 16.01% at 7 days and 13.86% at 28 days of curing. Fig.4.2 shows the effect of variation in compressive strength of concrete mixes with varying percentage of steel fibers.

It was concluded for Trial 2 that with replacement of cement by of 10% GGBS, 8% silica fume and 2% nano silica with addition of steel fibers we can achieve the suitable strength for producing Ultra High Performance Concrete (UHPC), as all the four mixes in Trial 2 with varying percentage of steel fibers i.e. M20, M21, M22, M23 possesses a strength of more than 120 MPa at 28 days of curing and lies in the UHPC range of 120 MPa-150 MPa. The Trial 2 containing 10% GGBS, 8% silica fume and 2% nano silica with 1.5% steel fibers with a water-binder ratio of 0.18 shows the maximum compressive strength at both 7 and 28 days of ages among all other mixes in the experiment and we can say that it is the best mix to develop maximum strength UHPC.

4.3.3 Effect of variation in percentage of steel fibers on compressive strength of concrete for Trial 3 (Alccofine 15%)

In the concrete, the Trial 30 containing 0% steel fibers with the water-binder ratio of (containing 15% alccofine, 8% silica fume and 2% nano silica) resulted in compressive strength of 84.3 MPa and 116.4 MPa at 7 and 28 days of curing, respectively. When the percentage of steel fibers were added at 0.5% of the weight of cement in the same mix which is denoted as M31, it was observed that the compressive strength was 88.8 MPa and 124.5 MPa at the ages of 7 and 28 days respectively, indicating an increase of strength in both the ages. Subsequently, in M32 when the percentage of steel fibers was increased to 1.0% by the weight of cement the compressive strength is noticed as 89.7 MPa and 134.0 MPa at the curing ages of 7 and 28 days, an increase in strength is observed at both ages. At last, in M33 when the percentage of steel fibers were increased to 1.50% by the weight of cement the compressive strength at 7 and 28 days were observed to be 96.6 MPa and 136.5 MPa respectively, showing an obvious trend of increasing compressive strength with increasing the percentage of steel fibers in Trial 3.

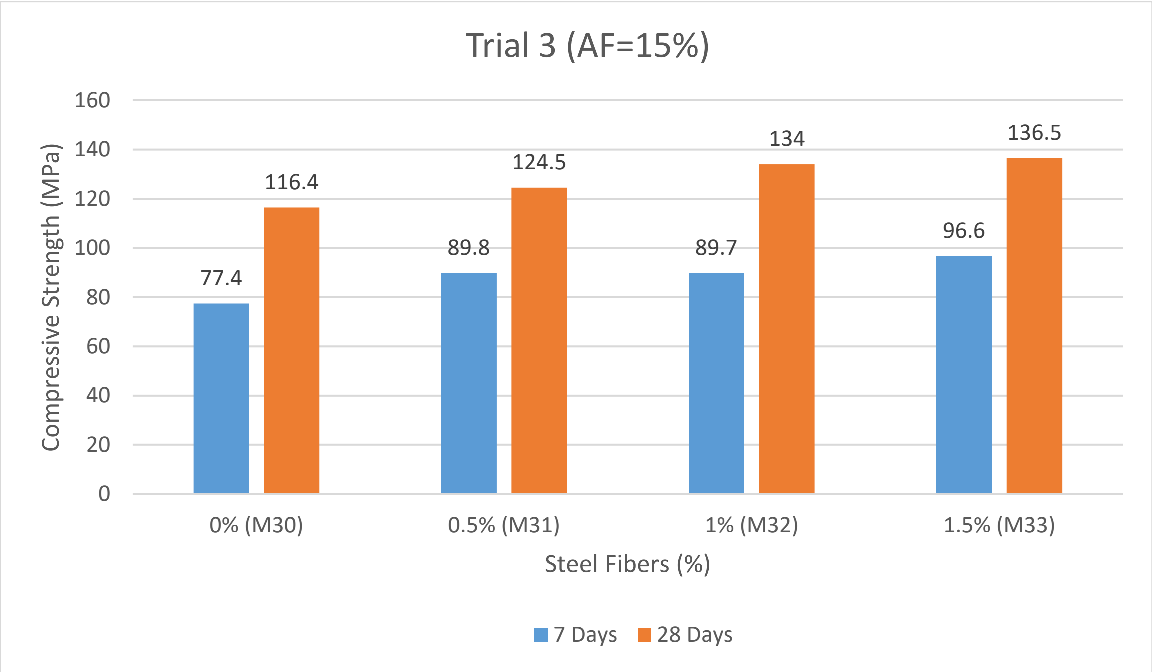


Fig.4.3: Variation of compressive strength for Trial 3 with AF=15%

It was also observed in Trial 3 that with replacing the content of cement with the alccofine in the concrete mix by 15% the compressive strength required for developing UHPC can be obtained a similar trend is noticed in Trial 3 as seen in Trial 2 that with inclusion of varying percentages of steel fibers strength of the concrete increases gradually. However, the Trial 3 shows the marginal loss in compressive strength at both 7 and 28 days when compared with the Trial 2 which contains 10% of alccofine, as the maximum strength observed at 28 days of curing was 136.5 MPa which was about 2.36% less than the maximum compressive strength of Trial 2.

The maximum increment in the strength at 7 days of curing was observed in M31 with 0.5% of steel fibers which was 16.02% and maximum increment in the strength at 28 days of curing was observed in M32 containing 1.0% of steel fibers which was 7.63%. The overall increase in strength of Trial 3 concrete specimens were noted to be around 17.26% at 7 days and 24.80% at 28 days of curing.

It can be concluded for Trial 3 that with replacement of cement by of 15% GGBS, 8% silica fume and 2% nano silica with addition of steel fibers we can achieve the suitable strength for producing Ultra High Performance Concrete (UHPC), as three out of four mixes in Trial 3 with varying percentage of steel fibers i.e. M31, M32, M33 possesses a strength of more than 120 MPa at 28 days of curing and lies in the UHPC range of 120 MPa-150 MPa.

4.3.4 Effect of variation in percentage of steel fibers on compressive strength of concrete for Trial 4 (Alccofine 20%)

In the concrete, the Trial 40 containing 0% steel fibers with the water-binder ratio of (containing 20% alccofine, 8% silica fume and 2% nano silica) resulted in compressive strength of 76 MPa and 111.8 MPa at 7 and 28 days of curing, respectively. When the percentage of steel fibers were added at 0.5% of the weight of cement in the same mix which is denoted as M41, it was observed that the compressive strength was 84.2 MPa and 120.3 MPa at the ages of 7 and 28 days respectively, indicating an increase of strength in both the ages. Subsequently, in M42 when the percentage of steel fibers was increased to 1.0% by the weight of cement the compressive strength is noticed as 88.7 MPa and 127.6 MPa at the curing ages of 7 and 28 days, an increase in strength is observed at both ages. At last, in M43 when the percentage of steel fibers was increased to 1.50% by the weight of cement the compressive strength at 7 and 28 days were observed to be 92.4 MPa and 133.4 MPa respectively, showing an obvious trend of increasing compressive strength with increasing the percentage of steel fibers in Trial 4.

It is further noticed in the experiment that with the inclusion of steel fibers in the mix gradually increases the compressive strength of concrete and the major thing noticed was with replacement of cement by the 20% alccofine enhanced the compressive strength of the concrete. However, the maximum strength obtained in Trial 4 is decreased about 5.52% and 4.34% from the Trial 2 and Trial 3 respectively at the 7 days of curing and the maximum strength obtained in Trial 4 is decreased about 4.57% and 2.27% from the Trial 2 and Trial 3 respectively at the 28 days of curing. Whereas, at 7 days and 28 days of curing the maximum strength of concrete increased about 11.32% and 12.85% from the Trial 1 which contains 0% of alccofine.

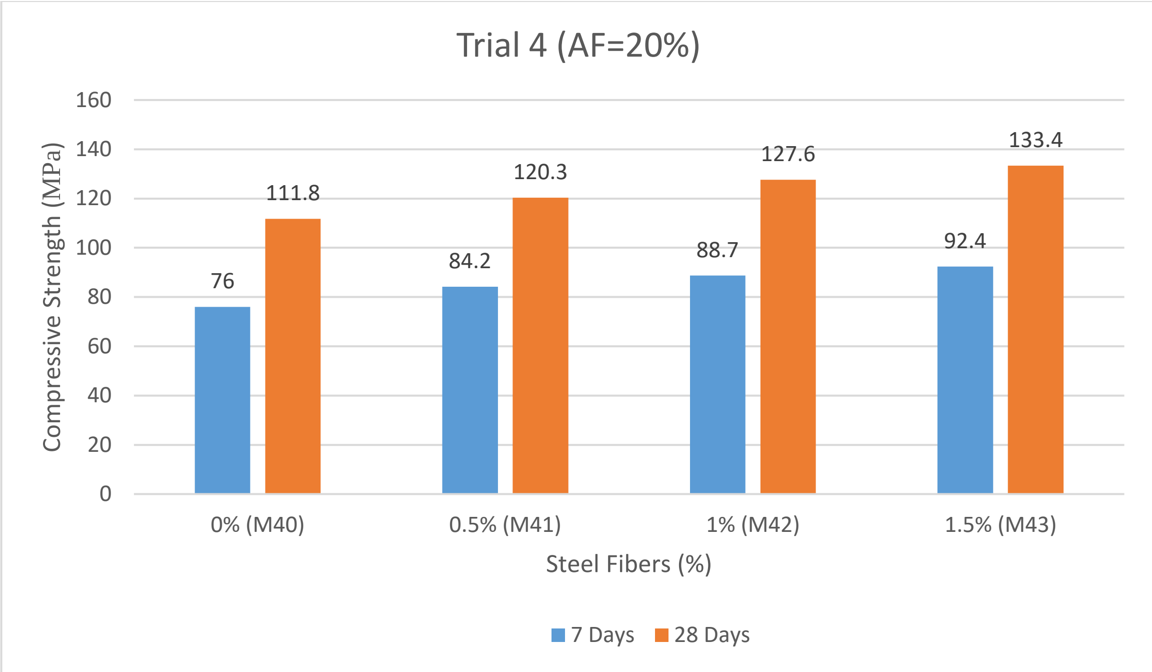


Fig.4.4: Variation of compressive strength for Trial 4 with AF=20%.

The maximum increment of strength in Trial 4 at 7 days of curing was observed in M41 with 0.5% of steel fibers which was 10.78% and maximum increment in the strength at 28 days of curing was also observed in M42 containing 1.0% of steel fibers which was 7.60%. The overall increase in strength of Trial 4 concrete specimens were noted to be around 21.57% at 7 days and 19.32% at 28 days of curing.

It can be concluded for Trial 4 that with replacement of cement by of 20% GGBS, 8% silica fume and 2% nano silica with addition of steel fibers we can achieve the suitable strength for producing Ultra High Performance Concrete (UHPC), as three out of four mixes in Trial 4 with varying percentage of steel fibers i.e. M41, M42, M43 possesses a strength of more than 120 MPa at 28 days of curing and lies in the UHPC range of 120 MPa-150 MPa.

4.3.5 Effect of variation of percentage of alccofine on compressive strength of different mixes

In the present study, we have observed a general trend that with the variation in percentage of alccofine as the replacement of cement the strength of concrete varies irrespective of steel fibers. In Fig.4.5 shows the effect of increasing the amount of alccofine on compressive strength of mixes. It is observed that at the replacement of cement by 10% alccofine, 2% Nano silica and 8% silica fume with the water-binder ratio of 0.18 and with addition of 1.5% shows the maximum compressive strength in every mix at both 7 and 28 days.

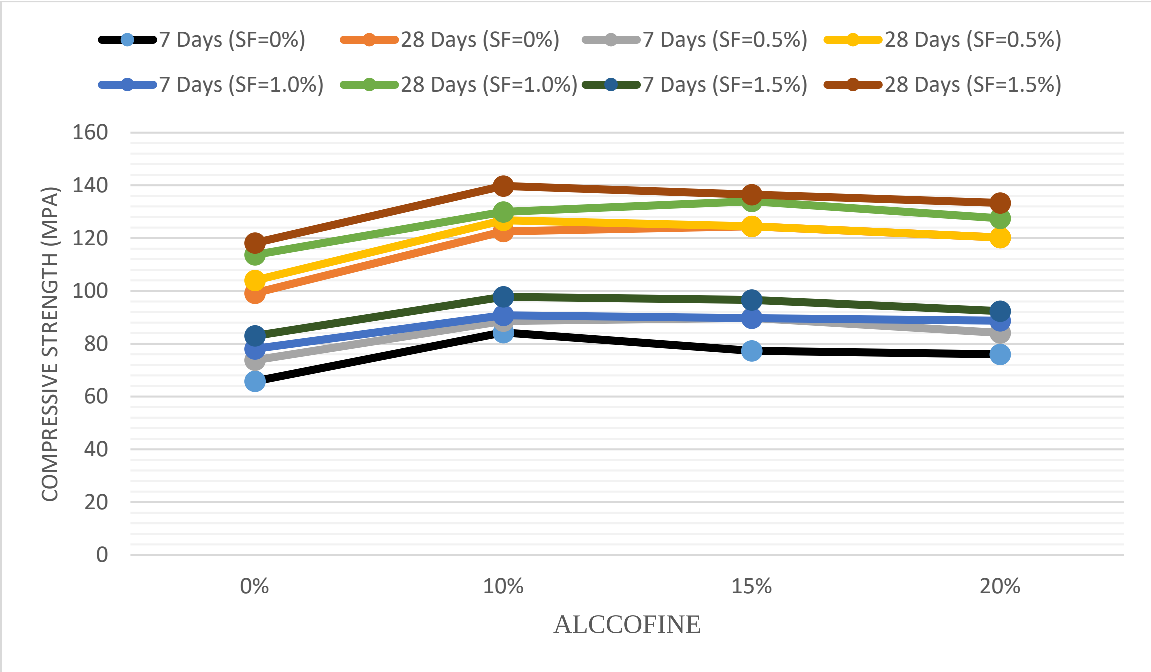
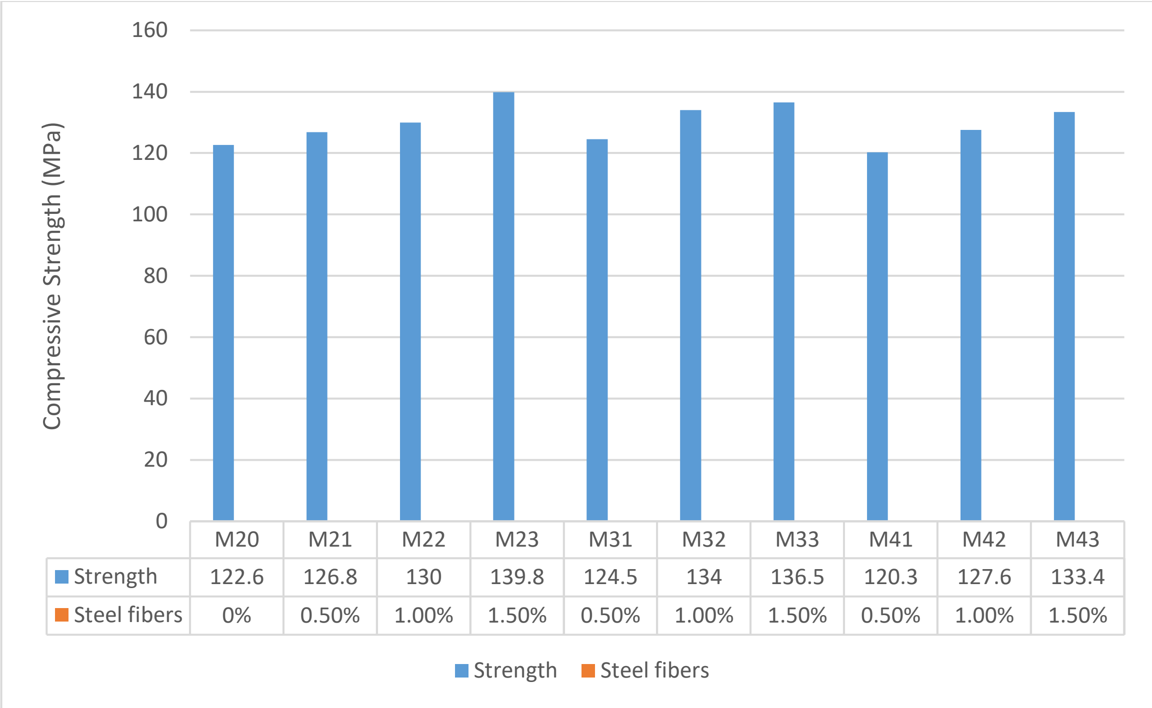


Fig.4.5: Effect on compressive strength by varying amount of alccofine

The graph shows the trend that maximum compressive strength of concrete mixes can be optimally achieved at 10% alccofine this further declines with increasing amount of alccofine i.e. 15% and 20%. The mixes containing 15% alccofine shows lesser compressive strength when compared with the mixes containing 10% alccofine. However, it shows better results than 0% alccofine and 20% alccofine. The least compressive strength is shown by the mixes containing 0 % alccofine as they are not able to achieve the compressive strength above 120 MPa by which we can say that in order to develop required compressive strength for UHPC we need to add various supplementary cementitious materials like GGBS, silica fume and nano silica with a suitable amount of steel fibers.

4.3.6 Ultra High Performance Concrete Mixes

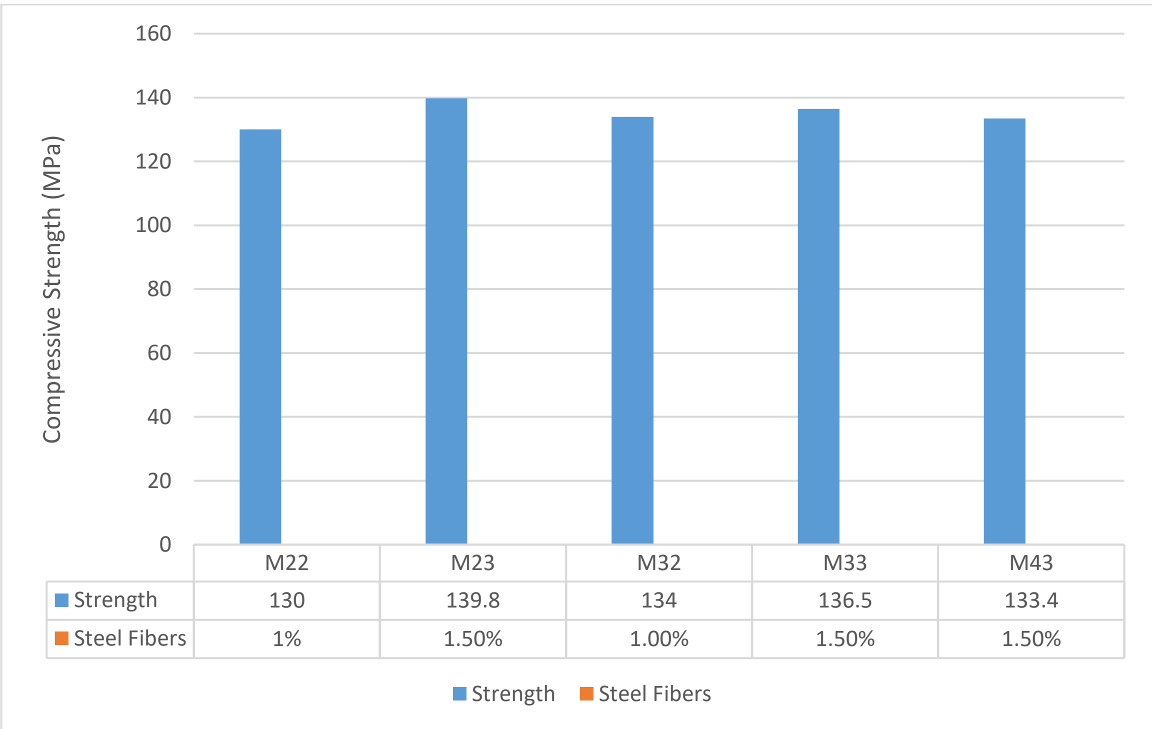
The mixes having a strength of more than 120 MPa at 28 days of curing are shown in Fig.4.6. As can be observed from the Fig.4.6, it is observed that in Trial 2 all the mixes with varying percentage of steel fibers i.e. M20, M21, M22, M23 shows strength above than 120 MPa as well as in Trial 3 and Trial 4 three out of four mixes with varying percentage of steel fibers i.e. M31, M32, M33, M41, M42, M43 shows strength above than 120 MPa. However, the no mix in Trial 1 shows the strength above 120 MPa as no alccofine was added to it. Therefore, all the mixes achieving strength of more than 120 MPa can be used to develop Ultra High Performance Concrete (UHPC) mixes.



	M20	M21	M22	M23	M31	M32	M33	M41	M42	M43
Strength	122.6	126.8	130	139.8	124.5	134	136.5	120.3	127.6	133.4
Steel fibers	0%	0.50%	1.00%	1.50%	0.50%	1.00%	1.50%	0.50%	1.00%	1.50%

Fig.4.6: Mixes achieving compressive strength above 120 MPa

The mixes achieving compressive strength above 130 MPa are shown in Fig.4.7.



	M22	M23	M32	M33	M43
Strength	130	139.8	134	136.5	133.4
Steel Fibers	1%	1.50%	1.00%	1.50%	1.50%

Fig.4.7: Mixes achieving compressive strength above 130 MPa

4.3.7 Cracks pattern observed after compression test

The cracks were observed in the various patterns with both macro and minor levels in every UHPC mix specimen tested under compression testing machine. In the Fig.4.8 shows the control mix with 0% Alccofine and 0% steel fibers. While in the Fig.4.9 presented below is specimen of M23 which showed the maximum compressive strength among all mixes, both of various mixes cracks patterns were different because of the presence of Alccofine and steel fibers.

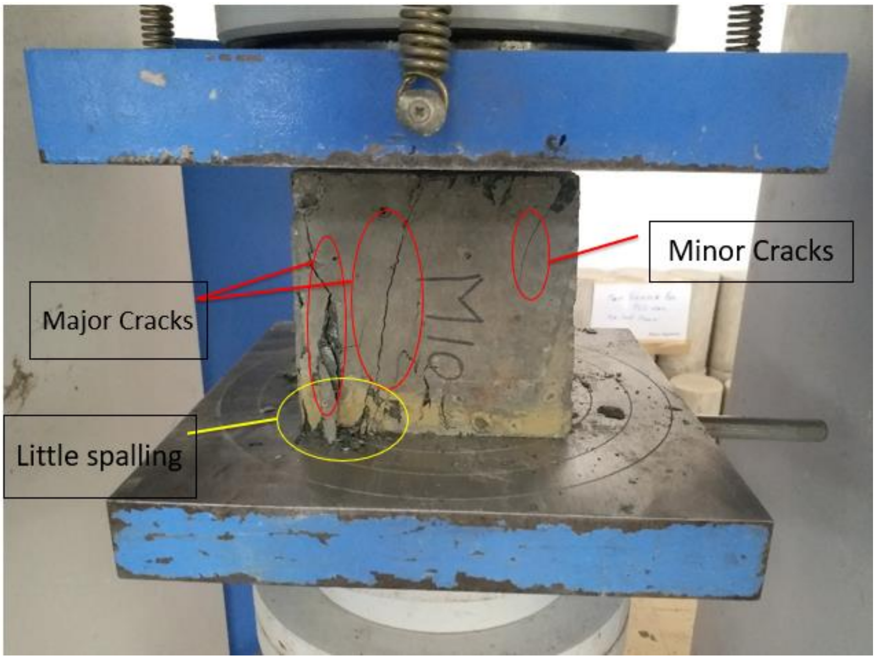


Fig.4.8: Crack patterns observed in control mix M10

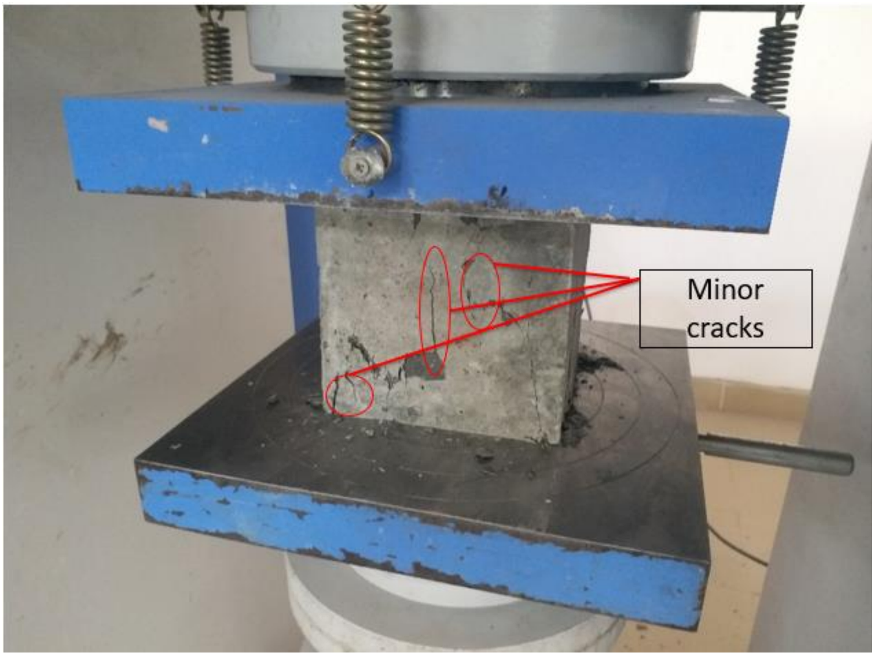


Fig.4.9: Cracks pattern observed in M23

4.4 SULPHATE ATTACK RESULTS

To check the durability characteristics of concrete resistance of UHPC mixes to sulphate attack is performed as per the standard laid down procedure. Sulphate attack is very prone in the areas of aggressive wastewater environment such as sewer systems and pipelines where different types of chemicals are present which damage the infrastructure and causes loss of economy. Sulphate is one such hazardous chemical for the concrete and can cause severe deterioration to it. The sulphate on reacting with concrete forms thaumasite or another type sulphate attack can lead to expansive ettringite and gypsum. Thaumasite forms in the presence of calcium silicate, carbonation ions and sulphate in the environment where humidity is in excess and temperature is low. The thaumasite formation includes the reaction of C-S-H with sulphate ions and carbonate. This reaction can take place in any kind of binder based on Portland cement and thus, damages the concrete structure. Therefore, it is very important to check the resistance to sulphate attack of concrete especially in case of UHPC which is largely used in making pipelines and other mega structures.

4.4.1 Test Procedure and Results

In the present study sodium sulphate solution is used in which the samples are submerged. A total number of 48 cube specimens were cast in which three specimens of each mix and each varying percentage of steel fibers were casted of size 150 mm x 150 mm x 150 mm and cured for the age of 28 days after which these specimens are kept in sodium sulphate solution (5% by weight of Na_2SO_4) for 28 days.

Fig.4.10: Specimen under sulphate attack in ACTM

The compressive strength of these specimens were tested after the completion of 28 days and compared with the compressive strength of water cured specimens of same mix. The rate of change in the compressive test is analysed and thus, determine the durability of the specific type of concrete is determined. The Fig.4.10 shows the sulphate attacked cubical specimen placed under compression testing machine. Whereas, Table 4.2 shows the compressive strength test results before and after sulphate attack.

Table 4.2: Sulphate attack results

Mix	Steel fibers (%) by weight of cement	Compression strength after 28 days of sulphate attack (MPa)	Compressive strength at 28 days (MPa)
M10	0	101.4	99.2
M11	0.5	106.6	104.0
M12	1	111.2	113.7
M13	1.5	121.8	118.2
M20	0	130.0	122.6
M21	0.5	129.6	126.8
M22	1	139.5	130.0
M23	1.5	146.8	139.8
M30	0	120.2	116.4
M31	0.5	132.7	124.5
M32	1	134.2	134.0
M33	1.5	140.4	136.5
M40	0	116.6	111.8
M41	0.5	125.4	120.3
M42	1	129.1	127.6
M43	1.5	137.2	133.4

4.5 DISCUSSION OF SULPHATE ATTACK TEST RESULTS

4.5.1 Effect of sodium sulphate attack on Trial 1

In Trial 1 (containing 0% alccofine, 8% silica fume and 2% nano silica), the control mix M10 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows the compressive strength of 101.4 MPa after 28 days of sulphate attack which was increased about 2.21% from the compressive strength of specimen of normal water curing for 28 days which was 99.2 MPa. When the percentage of steel fibers were added about 0.5% of the weight of cement in the same mix which is denoted as M11, it was observed that the compressive strength after sulphate attack was 106.6 MPa as it is marginally increased by 2.5% from the compressive strength of specimen of normal water curing for 28 days which was 104.0 MPa. Subsequently, in M12 when the percentage of steel fibers were increased to 1.0% by the weight of cement the compressive strength noticed was 111.2 MPa which is decreased to a marginal rate of 2.1% from the compressive strength of 28 days normal water cured specimen which was noted as 104.0 MPa. At last, in M13 when the percentage of steel fibers were increased to 1.50% by the weight of cement the compressive strength after 28 days of sulphate attack was observed to be 121.8 MPa which was increased about 3.0% from the normal water cured specimen which was noted as 118.2 MPa.

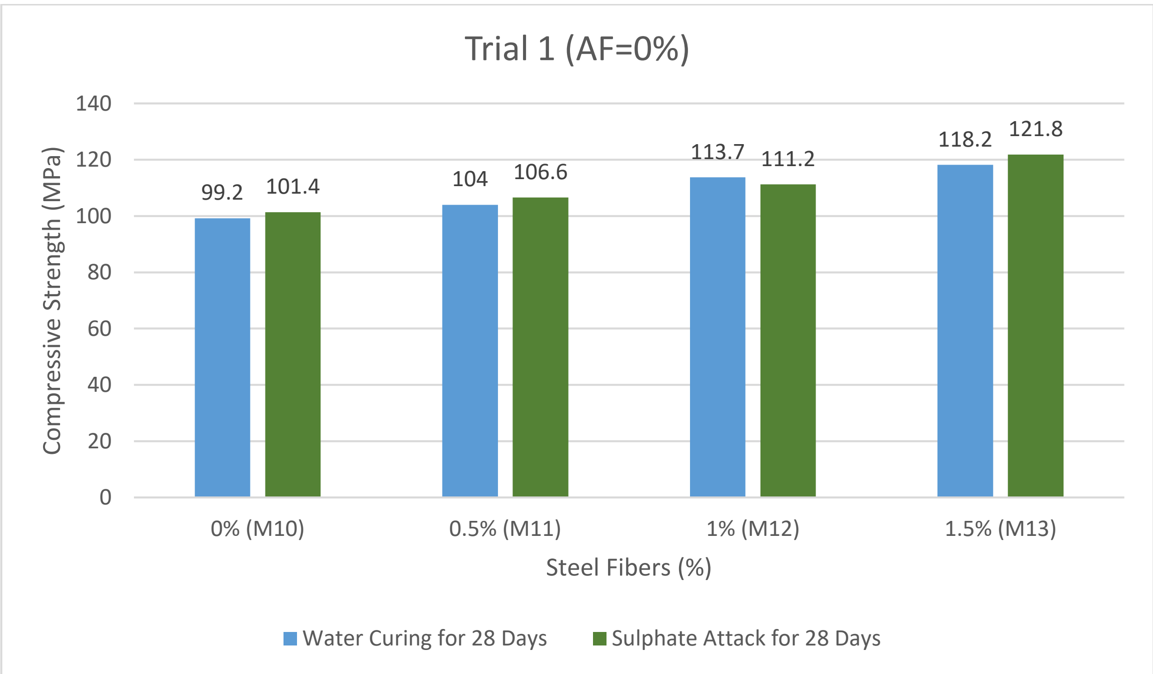


Fig.4.11: Comparison between compressive strengths of water cured and sulphate attacked specimens of Trial 1

As per the above graph shown we can say that the Trial 1 resists the sulphate attack at a good level because the strength of concrete it increases at 28 days of sulphate attack which was put after 28 days of water curing in which three out of four mixes with varying percentage of steel fibers i.e. M10, M11, M13. The maximum increment was observed in the M13 with 1.5% steel fibers which showed 3.0% or 3.6 MPa increase in compressive strength. However, the mix containing 1% steel fibers showed decrement of 2.5 MPa. The Trial 1 average increase in percentage of compressive strength after sulphate attack is 2.57%. Therefore, we can conclude that because of the presence of supplementary cementitious materials like silica fume and nano silica the resistance of Trial 1 towards sulphate attack increases.

4.5.2 Effect of sodium sulphate attack on Trial 2

In Trial 2 (containing 10% alccofine, 8% silica fume and 2% nano silica), the control M20 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows the compressive strength of 130.0 MPa after 28 days of sulphate attack which was increased about 6.03% from the compressive strength of specimen of normal water curing for 28 days which was 122.6 MPa. When the percentage of steel fibers were added about 0.5% of the weight of cement in the same mix which is denoted as M21, it was observed that the compressive strength after sulphate attack was 129.6 MPa as it is marginally increased by 2.20% from the compressive strength of specimen of normal water curing for 28 days which was 126.8 MPa. Subsequently, in M22 when the percentage of steel fibers were increased to 1.0% by the weight of cement the compressive strength noticed was 139.5 MPa which is increased to a rate of 7.30% from the compressive strength of 28 days normal water cured specimen which was noted as 130.0 MPa. At last, in M23 when the percentage of steel fibers were increased to 1.50% by the weight of cement the compressive strength after 28 days of sulphate attack was observed to be 146.8 MPa which was increased about 5.0% from the normal water cured specimen which was noted as 139.8 MPa.

In the following graph it is observed that Trial 2 resistance against the sulphate attack is maximum among all other mixes. The maximum increment in Trial 2 was noticed in M22 with 1% of steel fibers which shows 7.30% increase in the compressive strength of concrete when compared to compressive strength of normal water cured specimen. The average increment in the compressive strength after sulphate attack is about 5.13% which is much higher than the other trials (Trial 1, Trial 3 and Trial 4). Thus, we can conclude that replacing 10% of cement by alccofine in the UHPC mix we get the maximum resistance against the sulphate attack among all mixes studied in this investigation.

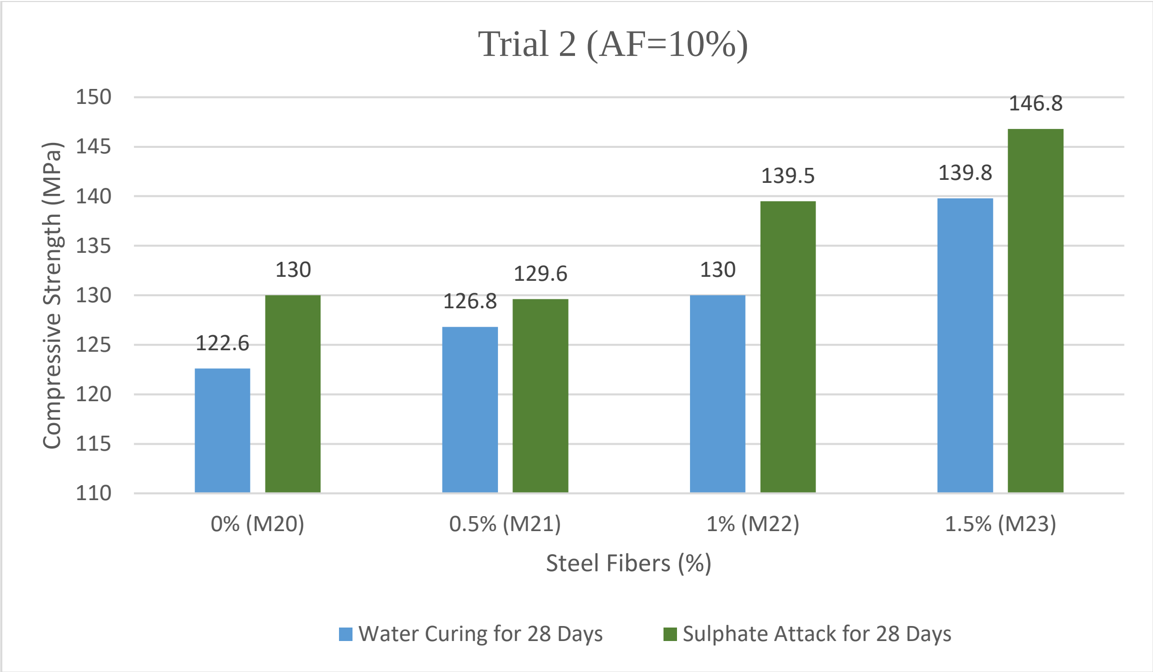


Fig.4.12: Comparison between compressive strengths of water cured and sulphate attacked specimens of Trial 2

4.5.3 Effect of sodium sulphate attack on Trial 3

In Trial 3 (containing 15% alccofine, 8% silica fume and 2% nano silica), the control M30 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows the compressive strength of 120.2 MPa after 28 days of sulphate attack which was increased about 3.26% from the compressive strength of specimen of normal water curing for 28 days which was 116.4 MPa. When the percentage of steel fibers were added about 0.5% of the weight of cement in the same mix which is denoted as M31, it was observed that the compressive strength after sulphate attack was 132.7 MPa as it is marginally increased by 6.58% from the compressive strength of specimen of normal water curing for 28 days which was 124.5 MPa. Subsequently, in M32 when the percentage of steel fibers were increased to 1.0% by the weight of cement the compressive strength noticed was 134.2 MPa which is increased negligibly to a rate of 0.14% from the compressive strength of 28 days normal water cured specimen which was noted as 134.0 MPa. At last, in M33 when the percentage of steel fibers were increased to 1.50% by the weight of cement the compressive strength after 28 days of sulphate attack was observed to be 140.4 MPa which was increased about 2.85% from the normal water cured specimen which was noted as 136.5 MPa.

As per the above graph shown we can say that the Trial 3 resists the sulphate attack at a decent level because the strength of concrete increases at 28 days of sulphate attack. All the four varying percentage of steel fibers mixes M30, M31, M32, M33 showed increase in compressive strength. Thus, the maximum increment in Trial 3 was noticed M31 with 0.5% of steel fibers which shows 6.58% increase in the compressive strength of concrete when compared to compressive strength of normal water cured specimen. The average increment in the compressive strength after sulphate attack is about 3.20% which is higher than Trial 1 and Trial 4. However, lower than Trial 2.

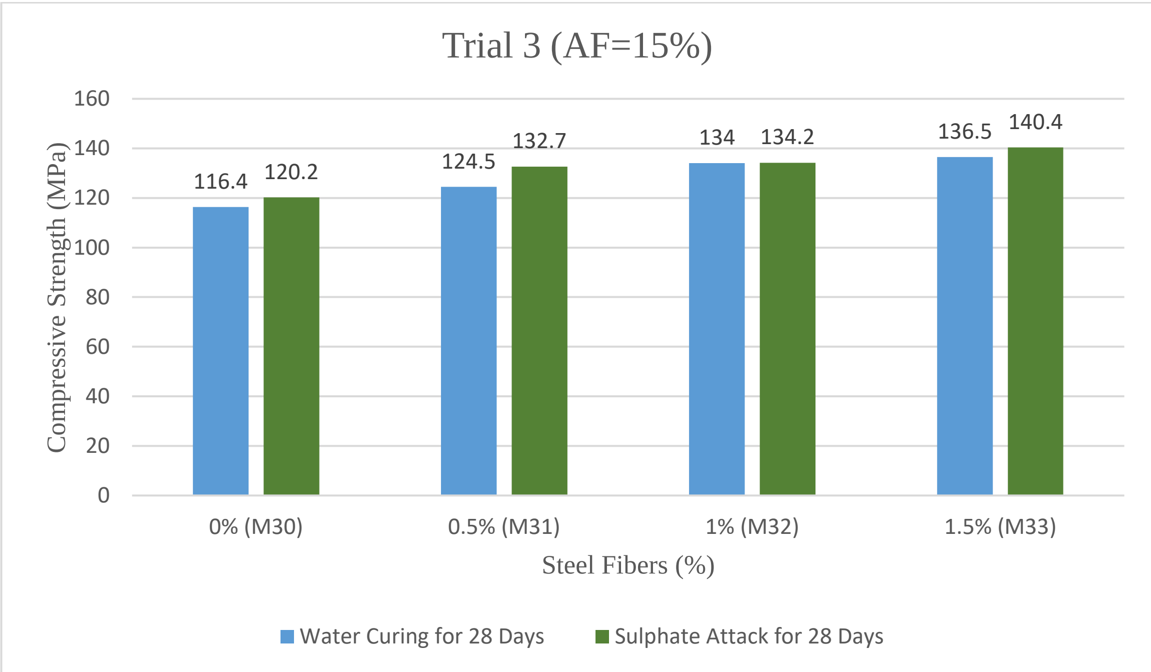


Fig.4.13: Comparison between compressive strengths of water cured and sulphate attacked specimens of Trial 3

4.5.4 Effect of sodium sulphate attack on Trial 4

In Trial 4 (containing 20% alccofine, 8% silica fume and 2% nano silica), the control mix M40 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows the compressive strength of 116.6 MPa after 28 days of sulphate attack which was increased about 4.29% from the compressive strength of specimen of normal water curing for 28 days which was 111.8 MPa. When the percentage of steel fibers were added about 0.5% of the weight of cement in the same mix which is denoted as M41, it was observed that the compressive strength after sulphate attack was 125.4 MPa as it is marginally increased by 4.23% from the compressive strength of specimen of normal water curing for 28 days which was 120.3 MPa. Subsequently, in M42 when the percentage of steel fibers were increased to 1.0% by the weight of cement the compressive strength noticed was 129.1 MPa which is increased to a rate of 1.17% from the compressive strength of 28 days normal water cured specimen which was noted as 127.6 MPa. At last, in M43 when the percentage of steel fibers were increased to 1.50% by the weight of cement the compressive strength after 28 days of sulphate attack was observed to be 137.2 MPa which was increased about 2.85% from the normal water cured specimen which was noted as 133.4 MPa.

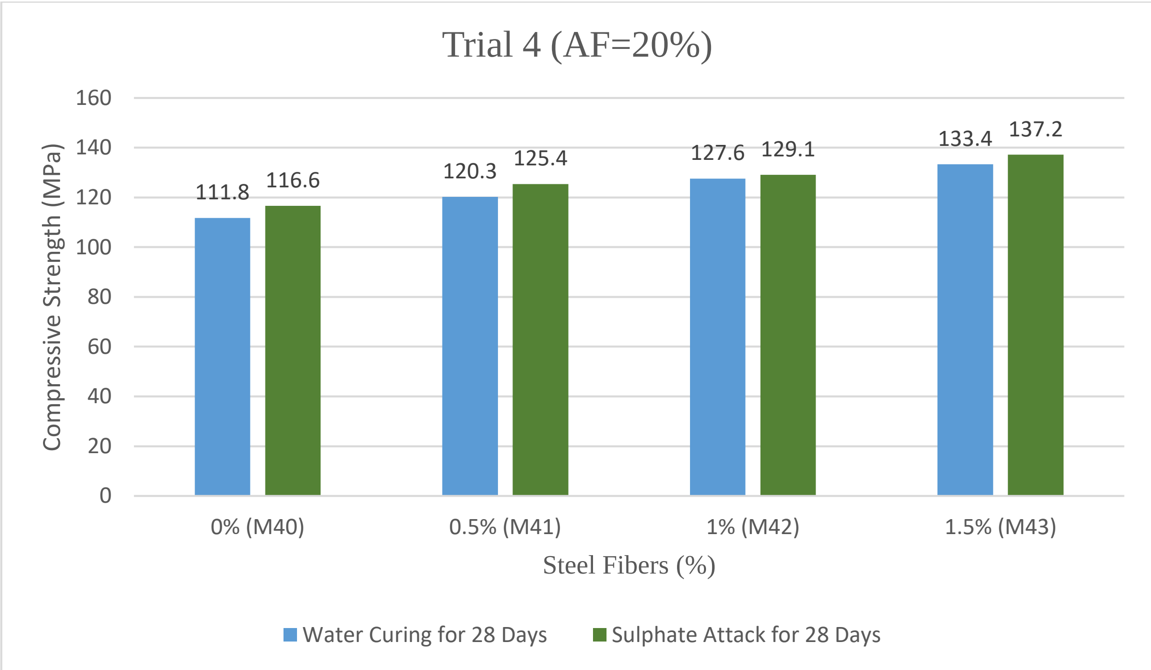


Fig.4.14: Comparison between compressive strengths of water cured and sulphate attacked specimens of Trial 4

As per the above graph shown we can say that the Trial 4 resists the sulphate attack at a decent level because the strength of concrete increases at 28 days of sulphate attack. All the four varying percentage of steel fibers mixes M40, M41, M42, M43 showed increase in compressive strength. Thus, the maximum increment in Trial 4 was noticed when 0% of steel fibers were added which shows 4.29% increase in the compressive strength of concrete when compared to compressive strength of normal water cured specimen. The average increment in the compressive strength after sulphate attack is about 3.13% which is higher than Trial 1. However, lower than Trial 2 and Trial 3.

4.5.5 Variation in compressive strength of Ultra High Performance Concrete Mixes after sulphate attack

The graph shown below denotes the variation in compressive strength of UHPC specimens after the sulphate attack for 28 days when compared with normal water cured specimens.

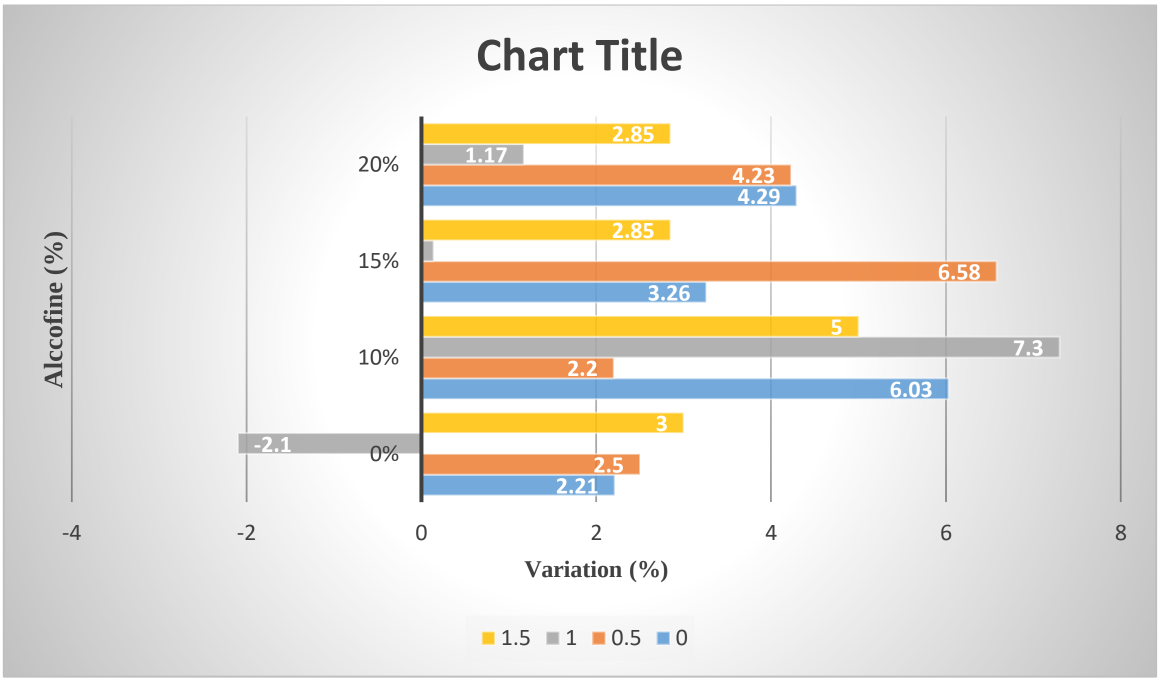


Fig.4.15: Variation in compressive strength of UHPC mixes after sulphate attack for 28 days.

It is observed in the graph shown, with increasing the percentage of alccofine and steel fibers the variation in compressive strength of concrete mixes occurs after sulphate attack. The maximum resistance towards sulphate attack was observed in Trial 2 which contains 10% of alccofine with average increment of 5.13% of compressive strength, while the peak was observed in M22 with 1% of steel fibers which was noted as 7.3%. Followed by the Trial 3 and Trial 4 mixes which showed average increment of strength of 3.20% and 3.13% respectively. The minimum resistance among all mixes was observed in Trial 1 which contains 0% of alccofine as the increment in compressive strength of 2.57%. Thus, we can conclude that all the mixes developed in this study resists the sulphate attack at a decent level while with addition of supplementary cementitious material like alccofine helps in resisting the sulphate attack more efficiently. As due to small particle size of materials like alccofine and silica fume the density of the microstructure increases in the concrete reduces the porosity of concrete and also due to high pozzolanic nature of these materials helps to resist such chemical attacks due to formation of strong internal bond. As is the trend generally that the concrete mixes containing SCM's generally show a 10 to 15% increase in strength as the curing age is increased from 28 to 56 days. it is observed from mixes subjected to sulphate attack that there is almost no change in the compressive strength of mixes. Thus, it can be said that although an expected increase in strength at 56 days is not there but there was no loss of strength either.

4.6 RAPID CHLORIDE PERMEABILITY TEST (RCPT) RESULTS

The Rapid Chloride Permeability Test (RCPT) is done to check the chloride ion ingress in the concrete and thus, defining its durability characteristics. The test procedure of RCPT was followed by ASTM C 1202. The results of this test are evaluated in TCP (total charge passed) which is denoted in coulombs. In this present study it is observed that the TCP (total charge passed) is very less and according to the standards of ASTM C 1202 the mixes falls under 'Very Low' and 'Negligible' categories.

Table 4.3: Rapid Chloride Permeability Test (RCPT) results

Mix	Steel fibers (%) by weight of cement	Total Charge Passed (coulombs)	Chloride Ion Penetrability
M10	0	208	Very Low
M11	0.5	260	Very Low
M12	1	302	Very Low
M13	1.5	307	Very Low
M20	0	172	Very Low
M21	0.5	188	Very Low
M22	1	229	Very Low
M23	1.5	235	Very Low
M30	0	121	Very Low
M31	0.5	152	Very Low
M32	1	173	Very Low
M33	1.5	157	Very Low
M40	0	91	Negligible
M41	0.5	116	Very Low
M42	1	103	Very Low
M43	1.5	146	Very Low

4.7 DISCUSSION OF RAPID CHLORIDE PERMEABILITY TEST (RCPT) RESULTS

4.7.1 Rapid Chloride Permeability Test (RCPT) on Trial 1

In Trial 1 (containing 0% alccofine, 8% silica fume and 2% nano silica), the control mix M10 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows an average charge passed of 208 C after the completion of the experiment. When 0.5% of steel fibers by weight of cement was added to the same mix which is denoted as M11, the resultant charge passed was noted as 260 C. In the M12 the charge passed was recorded as 302 C and finally when the mix M13 was prepared with 1.5% steel fibers showed the maximum charge among all mixes, which was recorded as 307 C.

The following graph shows that Trial 1 shows significant resistance towards chloride ion penetration as all mixes of varying steel fibers M10, M11, M12, M13 falls under the category of 'Very Low' chloride ion permeability. It is also observed that with increase in the percentage of steel fibers the total charge passed in concrete increases as seen in Trial 1 the control mix M10 with 0% steel fibers showed minimum charge passed and maximum resistance to chloride ion permeability followed by the mixes with increasing the amount of steel fibers. It is concluded that steel fibers helps the conductivity of chloride ions in the concrete whereas,

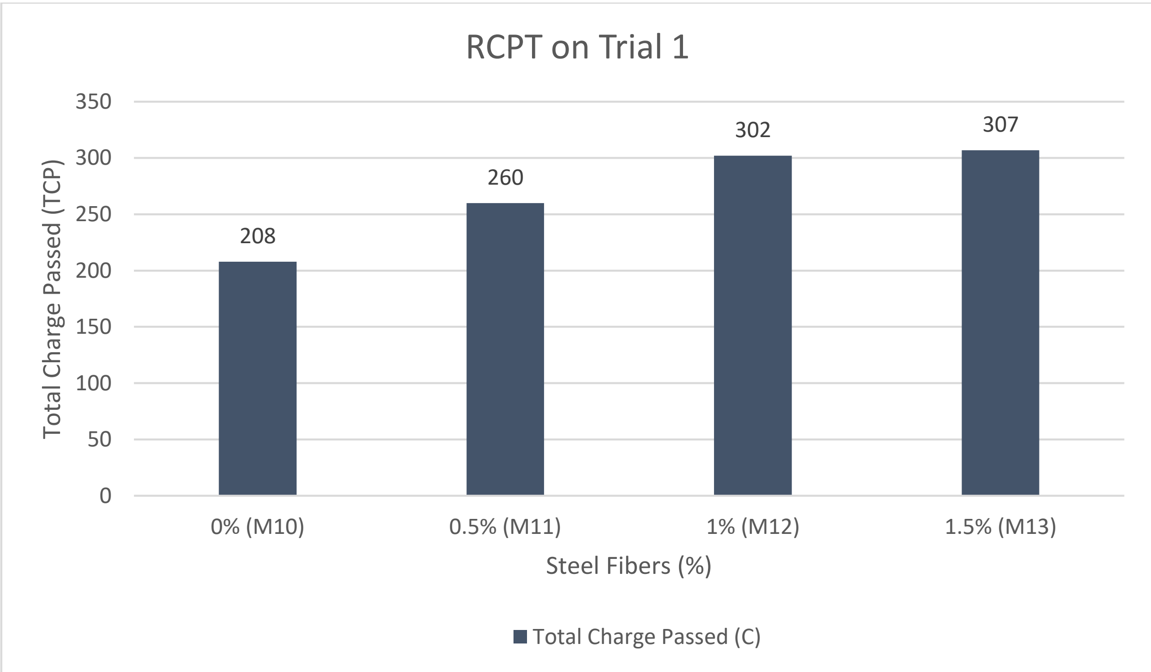


Fig.4.16: Shows total charge passed in Trial 1 specimens

4.7.2 Rapid Chloride Permeability Test (RCPT) on Trial 2

In Trial 2 (containing 10% alccofine, 8% silica fume and 2% nano silica), the control mix M20 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows an average charge passed of 172 C after the completion of the experiment. When 0.5% of steel fibers by weight of cement was added to the same mix which is denoted as M21, the resultant charge passed was noted as 188 C. In M22 with 1.0% steel fibers the charge passed was recorded as 229 C and finally the mix M23 prepared with 1.5% steel fibers showed the maximum charge among all mixes, which was recorded as 235 C.

It is observed in the following graph that with increasing the amount of alccofine the charge passed in the concrete decreases and also similar trend observed in Trial 1 is seen in which increasing the content of steel fibers total charge passed increases in the concrete. Hence, the Trial 2 shows significant resistance towards chloride ion penetration as all mixes of varying steel fibers M20, M21, M22, M23 falls under the category of 'Very Low' chloride ion permeability. As the microstructure of the UHPC becomes dense due to addition of supplementary cementitious materials like alccofine, silica fume and nano silica due to their small particle size and pozzolanic action. The Trial 2 performed better than Trial 1 in terms of resistance against chloride ion penetration.

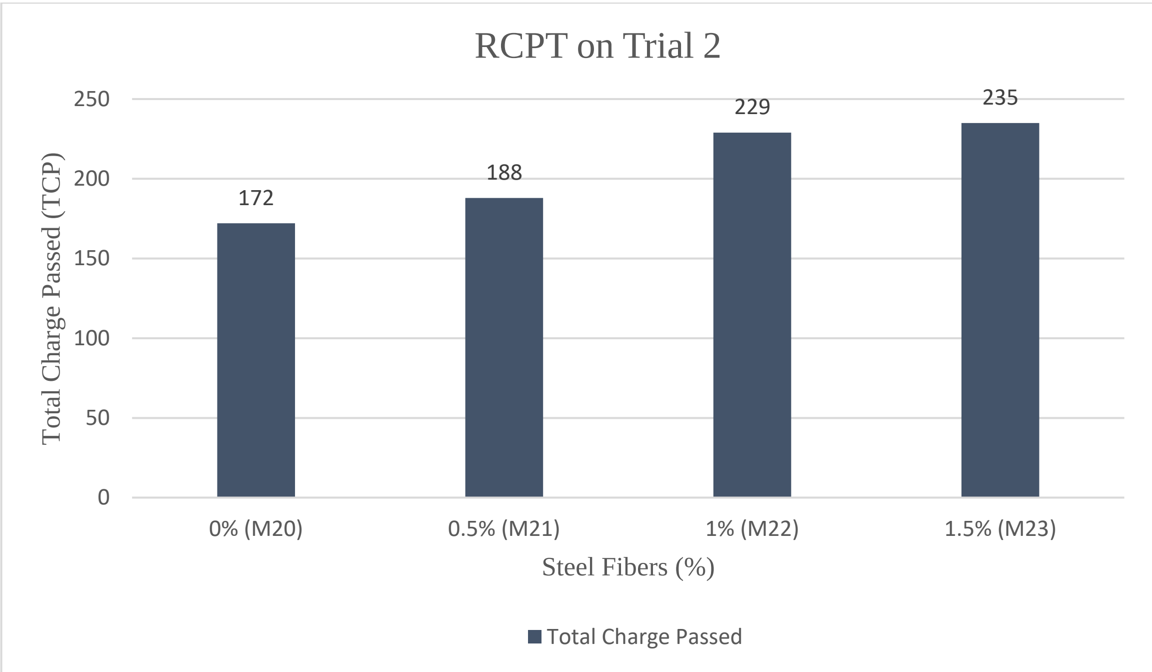


Fig.4.17: Shows total charge passed in Trial 2 specimens

4.7.3 Rapid Chloride Permeability Test (RCPT) on Trial 3

In Trial 3 (containing 15% alccofine, 8% silica fume and 2% nano silica), the control mix M30 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows an average charge passed of 121 C after the completion of the experiment. When 0.5% of steel fibers by weight of cement was added to the same mix which is denoted as M31, the resultant charge passed was noted as 152 C. In M32 with 1% steel fibers the charge passed was recorded as 173 C and finally the mix M33 prepared with 1.5% steel fibers showed the maximum charge among all mixes, which was recorded as 157 C.

Hence, Trial 3 shows significant resistance towards chloride ion penetration as all mixes of varying steel fibers M30, M31, M32, M33 falls under the category of ‘Very Low’ chloride ion permeability. Similarly, in Trial 1 and Trial 2 with addition of steel fibers the chloride ion penetration increases in the concrete as the least average charge passed was recorded with 0% steel fibers in Trial 3 this may be due to the high conductive nature of the steel fibers. However, with increasing the amount alccofine the charge passed in the concrete decreases as observed in Trial 3. The Trial 3 performed better than Trial 1 and Trial 2 in terms of chloride resistance.

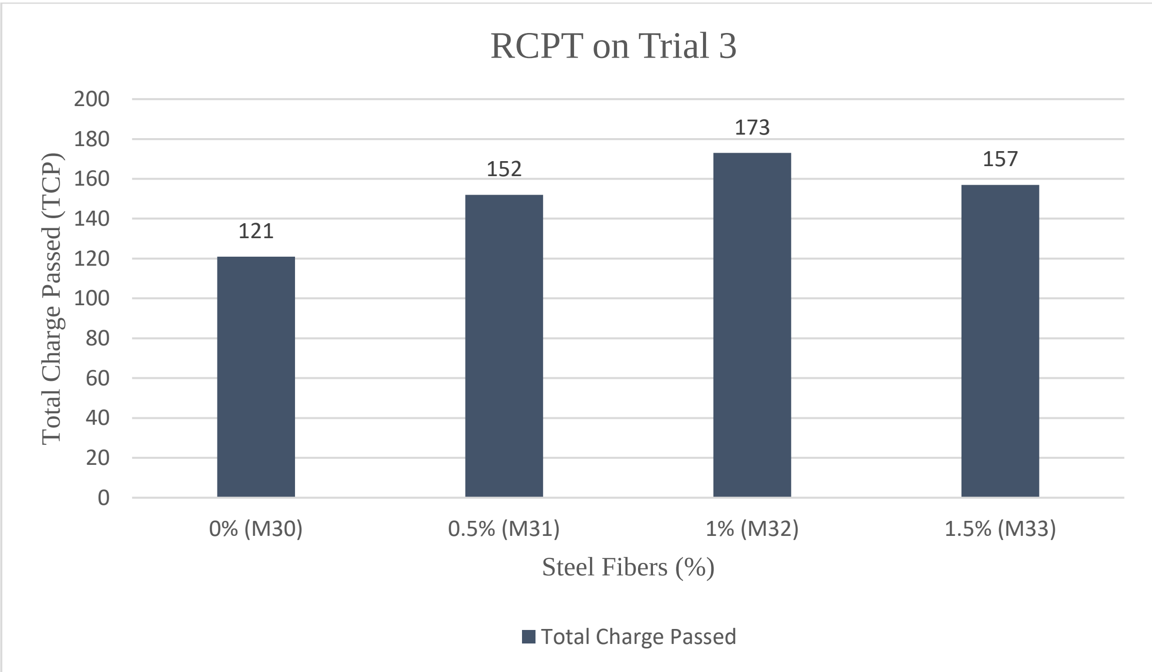


Fig.4.18: Shows total charge passed in Trial 3 specimens

4.7.4 Rapid Chloride Permeability Test (RCPT) on Trial 4

In Trial 4 (containing 20% alccofine, 8% silica fume and 2% nano silica), the control mix M40 specimen containing 0% steel fibers with the water-binder ratio of 0.18 shows an average charge passed of 91 C after the completion of the experiment. When 0.5% of steel fibers by weight of cement was added to the same mix which is denoted as M41, the resultant charge passed was noted as 116 C. In M42 with 1% steel fibers the charge passed was recorded as 103 C and finally the mix M43 prepared with 1.5% steel fibers showed the maximum charge among all mixes, which was recorded as 146 C.

As observed in the graph the Trial 4 shows the maximum resistance against chloride ion penetration among all mixes prepared in the study. The mix M40 with 0% steel fibers showed peak resistance of 91 C which falls under the category of 'negligible' chloride permeability. Followed by steel fibers mixes M41, M42, M43 which falls under the category of 'Very Low' chloride ion permeability. With the increase in steel fibers the charge passes at a higher rate because of the high conductivity of steel fibers. With the inclusion of 20% alccofine maximum resistance of chloride ion is observed in Trial 4, as increasing alccofine increases the density of microstructure of concrete and reduces the porosity of concrete hence, prevents the chloride ions to penetrate.

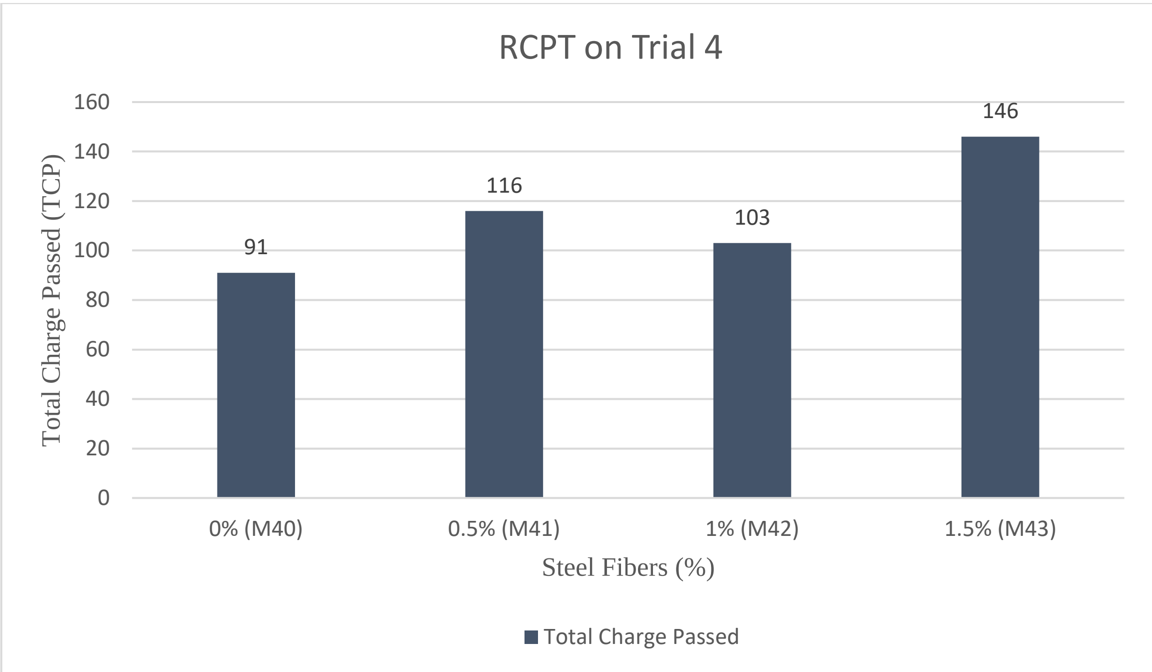


Fig.4.19: Shows total charge passed in Trial 4 specimens

4.7.5 Rapid Chloride Permeability Test (RCPT) results with increasing the percentage of alccofine

In Fig.4.18 shows the trend line graph in which increasing the percentage of alccofine the Total Charge Passed (TCP) decreases in UHPC specimens. As the least charge observed in the specimens containing 20% alccofine while specimens with 0% alccofine showed maximum chloride ion penetration among all mixes. It is also observed in every mix that with increasing the content of steel fibers the TCP increases it may be due to the high conductive nature of the steel fibers. Due to the small particle size of alccofine helps to increase the density of the concrete which leads to the reduction in porosity in the concrete due to which we can observe this kind of trend. It is concluded in this study that Ultra High Performance Concrete (UHPC) shows great resistance against chloride ion penetration as results of RCPT showed very less charge passed and thus, this type of concrete can be used in aggressive wastewater environment with having a longer life span compared to the ordinary concrete.

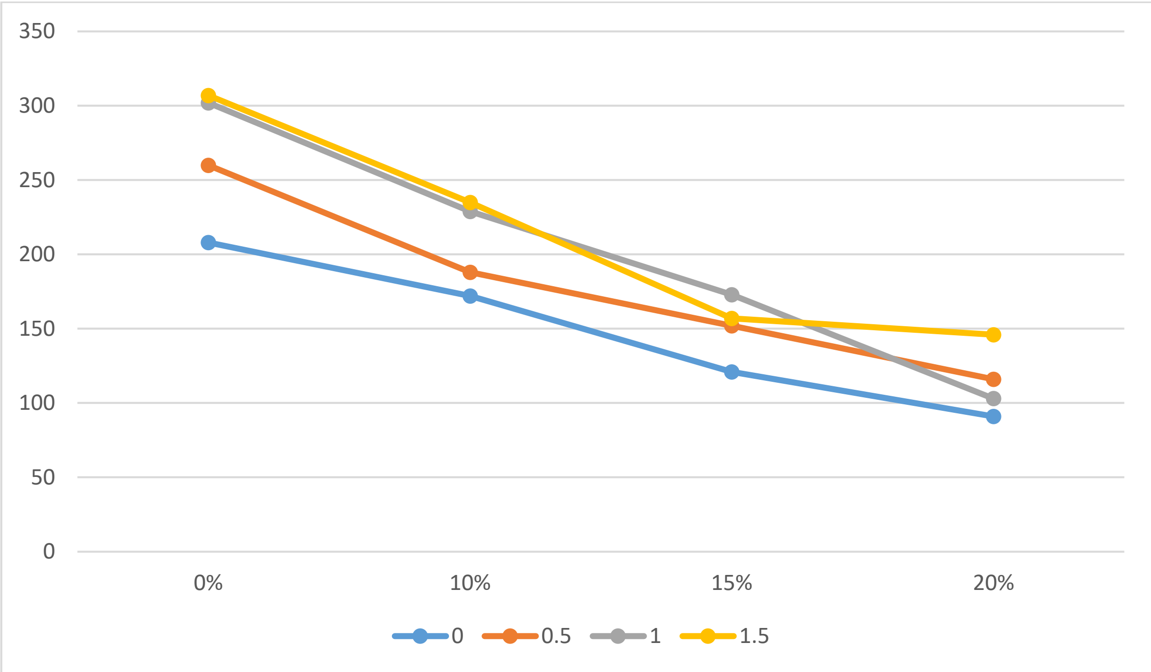


Fig.4.20: Total Charge Passed (TCP) with varying the percentage of alccofine

CHAPTER 5
CONCLUSIONS

5.1 GENERAL

The present investigation was carried out to develop Ultra High Performance Concrete (UHPC) having compressive strength of more than 120 MPa and also to study its durability properties with a water-binder ratio of 0.18. Three different percentages of crimped steel fibers (0.5%, 1.0% and 1.5% by volume of cement) were added to the UHPC mix to study the steel fibers effect on concrete. Supplementary cementitious materials like alccofine, silica fume and nano silica were used to replace the cement (OPC Grade 53) to achieve the desired properties. Table 5.1 shows the percentage of cement replaced and steel fibers added to the mix.

Table 5.1: Shows the percentage of cement replaced and steel fibers added to the mix.

Trial mix	Trial 1	Trial 2	Trial 3	Trial 4
Silica fume (%)	8	8	8	8
Nano Silica (%)	2	2	2	2
Alccofine (%)	0	10	15	20
Steel fibers (%)	0.0	0.0	0.0	0.0
	0.5	0.5	0.5	0.5
	1.0	1.0	1.0	1.0
	1.5	1.5	1.5	1.5

To obtain adequate workability for the concrete mix superplasticizer was used with its dosage ranging between 1.25% and 2.0% of the binder content. A total of 16 different mixes were prepared with varying percentage of alccofine and steel fibers.

5.2 CONCLUSIONS

The major conclusions regarding the of strength and durability characteristics of Ultra High Performance Concrete are presented below:

Compressive strength

- The supplementary cementitious materials like Alccofine (GGBS), silica fume and nano silica plays a significant role in development of strength and durability of the concrete mixes. It may be attributed the small particular size of the various supplementary cementitious materials which helps in filling the voids in the concrete matrix thereby reducing the porosity and increasing the density of concrete. Also, due their high pozzolanic nature they increase the production of C-S-H gel in the concrete which further forms strong bonds among the constituents of the concrete, thus making the concrete much stronger and durable.

- A significant increase of upto 16% in compressive strength of UHPC can be achieved with the addition of steel fibers. With the increase in steel fibers content compressive strength of the concrete mixes increased.
- The concrete mixes containing 10% alccofine showed the most optimum results in terms of compression test and resistance towards sulphate attack while concrete mixes containing 20% content of alccofine showed least chloride ion penetration.
- The compressive strength of more than 120 MPa of the UHPC mixes can be achieved with the water-binder ratio of 0.18 with different percentages of steel fibers having 8% silica fume, 2% nano silica and with all mixes of 10%, 15% or 20% of Alccofine as a replacement of cement.
- The UHPC mixes with the compressive strength above 130 MPa can be achieved with the water-binder ratio of 0.18 having 8% silica fume, 2% nano silica and with 10%, 15% or 20% of Alccofine with addition of 1% or 1.5% of steel fibers.

Sulphate attack

- With increase in the percentage of steel fibers the compressive strength and resistance towards sulphate attack significantly increases in the concrete for a constant water-binder ratio. This may be attributed to the fact that steel fibers improve the bond between different ingredients of concrete and also steel fibers acts as a finer material which helps in eliminating the voids thus, reducing the concrete porosity and making it much stronger and durable.
- Thus, it can be concluded that the UHPC mixes resisted the sulphate attack better, which can be attributed to the presence of SCM's which made the mixes very impermeable. The best resistance against sulphate attack was observed in mixes containing 10% of Alccofine.

Rapid Chloride Penetration Test (RCPT)

- The resistance towards chloride ion penetration is also very good as all UHPC mixes falls under the categories of 'Very Low' or 'Negligible' according to ASTM C 1202. With increase in percentage of alccofine the chloride ion permeability decreases. However, with increasing the percentage of steel fibers the permeability increases as steel fibers having high conductive nature which helps to pass the charge through concrete thus, increasing chloride ion content in the concrete. The maximum resistance to chloride penetration is shown by the UHPC mix containing 8% silica fume, 2% nano silica and 20% Alccofine with no steel fibers.

5.3 SCOPE FOR FURTHER WORK

- Work can be extended to study effect on UHPC by freezing and thawing where its behaviour is investigated in cyclic fatigue type durability.
- Work can be extended to study the behaviour of UHPC in salt water environment.
- Work can be extended to study the compressive strength and durability of UHPC by using different percentages, size and shape of the steel fibers.
- Work can be extended to study the use of UHPC for retrofitting for different structural elements.
- Work can be extended to study different properties like flexural strength, ductility of UHPC.

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