STUDY ON FLEXURAL PROPERTIES

OF

ULTRA HIGH PERFORMANCE CONCRETE

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

MASTER OF ENGINEERING

IN

STRUCTURAL ENGINEERING

Submitted by:

ASHISH

(801624005)

under the supervision of

Dr. MANEEK KUMAR | **Dr. SAHIL BANSAL**

Professor and Dean of Student Affairs | Assistant Professor

Department of Civil Engineering

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

CIVIL ENGINEERING DEPARTMENT

THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY

(DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB

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DECLARATION

I, Ashish hereby declare that the work presented in this thesis entitled **(STUDY ON FLEXURAL PROPERTIES OF ULTRA HIGH PERFORMANCE CONCRETE)** in partial fulfillment 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** and **Dr. Sahil Bansal, Assistant 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.

Date: 17-08-18

ASHISH 17/8/18

(801624005)

Dr. Maneek Kumar
Professor and Dean of Student Affairs
Department of Civil Engineering
Thapar Institute of Engineering & Technology
(Deemed To Be University), Patiala, Punjab

25/8/18
Dr. Sahil Bansal
Assistant Professor
Department of Civil Engineering
Thapar Institute of Engineering & Technology
(Deemed To Be University), Patiala, Punjab

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ASHISH

ABSTRACT

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. Concrete plays a vital role in the development of infrastructure like as building, bridge, tunnels and highways etc. leading to utilization of large quantity of concrete. So, the demand of new type of concrete increase day by day which have high compressive strength, tensile strength, durability and serviceability of concrete for a long span time.

UHPC is a cementitious material exhibiting enhanced mechanical and durability properties, having low water to binder ratio less than 0.25, which help to reduce the cost of structure by reducing the cross-section of structural member. The mechanical properties of UHPC include compressive strength should be greater than 120 MPa. Due to the high compressive and tensile strength of UHPC allows to redesign and optimize structural members. Due to the great plastic and hardening properties of UHPC which does not require the reinforcement which help the built of complicated member of the structure with having high durability.

The objective of this study was to find the compressive strength and flexural property of UHPC with three different percentage of steel fibers (i.e. 0.5%, 1% and 1.5%) by volume of cement with cementitious material like nano silica, silica fume and ground granulated blast slag (GGBS) or alccofine as a partial replacement used. The silica fume, nano silica was kept at 8% and 2% respectively and alccofine was varied (10%, 15% and 20%) with cement. The water-binder ratio used was 0.18. The test result shows that the percentage of steel fibers and alccofine effect the compressive as well as the flexural strength of the UHPC. The compressive and flexural strength of UHPC is reported best at 1.5% steel fibers and 10% alccofine. A comprehensive literature review is carried out for better understanding of compressive and flexural property of UHPC which is compiled from many references representing research, development and deployment efforts around the world, this thesis report provides a framework for gaining a well understanding of UHPC.

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CHAPTER 1: INTRODUCTION

1.1 GENERAL

Concrete is the most commonly used construction material which has been used for centuries. It has been used for construction in many ancient structures. The first concrete structures were built by the Nabataea traders or Bedouins who controlled a series of oases and built a small empire in the regions of southern Syria and northern Jordan in around 6500 BC. By 600 BC, the Greeks had discovered a natural pozzolan material that developed hydraulic properties when mixed with lime. By 200 BC, the Romans were building very successfully using concrete. The famous "Pantheon" largest unreinforced dome built with the help of concrete by ancient Romans. In 1793 John Smeaton developed modern method for producing hydraulic lime for cement. He used limestone that was fired until it turned into clinker, which was then ground it into powder. The material was used in historic rebuilding of the Eddystone Lighthouse in Cornwall, England. In 1824 Joseph Aspdin was the first person to invented Portland cement. The first home built by using reinforced concrete was a servant's cottage constructed in England by William B. Wilkinson in 1854. However, the manufacturing of Portland cement actually began about 20 years later initiated by Isaac C. Johnson. At the time that demand has increased for durable and stronger materials cost of construction material has increased significantly. Due to research and development, in the mid 60's, got the strength of concrete between 40 to 80 MPa was developed and named High-Performance Concrete (HPC). The main highlights of the research were the development of reinforced concrete, pre-stressed concrete, fiber reinforced concrete, and self-compacting concrete. With the latest research and developments, there is a change in the definition of High-Performance Concrete. Earlier, concrete having compressive strength 34 MPa was considered high strength, whereas concrete having compressive strengths ranging from 41 MPa to 52 MPa was called as high strength concrete in 1960s.

Increase the demand of concrete also increase the research in the concrete field and researcher got the cementitious materials of new class have been developed. In the 1970s the bridge and high-rise building constructed with the strength of 60 MPa concrete.

Fig.1.1 Roman Pantheon [Source: www.ancient-origins.net]

Today, due to increase of demand of concrete researcher has been developed new concrete grade having compressive strength is 120 MPa or greater than called ultra-high-performance concrete. Due to the high strength of UHPC the requirement of cross -section of member & reinforcement are less in the structural member. So, the dead weight of structure also decrease & the cost of structure also reduces. The durability and strength of structure increase.

1.2 ULTRA HIGH-PERFORMANCE CONCRETE (UHPC)

Ultra-High-Performance Concrete (UHPC) is provide many benefits in the construction of concrete structures like as design thin member, complex shapes of structure, curvatures and highly customized textures that can't be achieved by using by traditional reinforced concrete elements. UHPC has very special properties then the properties of normal and high-performance concrete. This special type of concrete is developed for use in a particular application and environment, so that it gives excellent performance in the environment where it is exposed and withstand the design loads it is subjected to during its lifetime. Ultra-high-performance concrete increased strength, high durability and long-term stability when compared with High Performance Concrete (HPC).

1.2.1 Definition

Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) is a novel construction material exhibiting enhanced mechanical and durability properties, having low water to binder ratio, which help to reduce the cost of structure by reducing the cross-section of structural member. The composition of UHPC is cement (ordinary Portland cement), fine aggregates, coarse aggregates, silica fume, alccofine or ground granulated blast furnace slag (GGBS), nano-silica, very low amount of water and high tensile steel fibers.

UHPC is improve the micro and macro properties of its mixture ingredients to ensure mechanical homogeneity. By adding of superplasticizers, the required workability is obtained at a low water-binder ratio of fresh concrete. Because of high-packing density, the properties of UHPC like ductility, durability and mechanical performance behaves differently from high performance concrete and ordinary concrete. The compressive strength of UHPC is very high which varies between 120MPa to 150MPa and flexural strength varies between 12MPa to 50MPa.

1.2.2 Properties of UHPC

UHPC following properties: -

1. The typical compressive strength upto 250MPa.
2. Flexural strength upto 50MPa.
3. Elasticity Modulus lies between 40 to 70 GPa.
4. It is ductile, strong and durable.
5. The tensile strength range of 7 to 15 MPa.
6. It also shows increased resistance to abrasion, erosion and corrosion.
7. The creep of UHPC is generally less.

1.3 SELECTION OF MATERIALS

Ingredients used in UHPC should be carefully selected, checked, controlled and proportioning of the all ingredients which help to the production of UHPC. The selection of material plays important role to produce durable, strong and a uniform concrete mix. The various type of ingredients is used in UHPC are discussed below: -

1.3.1 Cement

Cement is a binder material used in concrete to bind the coarse and fine aggregate and other ingredients used in concrete mix. Portland cement is made by grinding of clay or shale and limestone or chalk. Cement manufacture plant is established where these raw material argillaceous materials such as clay or shale and calcareous materials such as limestone or chalk are available in bulk quantity. During the making of cement these raw materials are grinded and mixed properly depending on their purity and composition. These raw materials heated at a temperature of 1300^0 to 1500^0 in a kiln. After cooling the clinker gypsum added with the range of 3 – 5 % and clinker is grounded to the fine powder, called Portland cement.

Following physical properties of Portland cement used in UHPC:

Required water for standard consistency	: 29 (%)
Maximum Blaine fineness	: 4100 cm^2/gm
Minimum 7 days mortar cube strength	: 34.5 MPa
Minimum 28 days mortar cube strength	: 70.8 MPa
Initial setting time	: 130 (min)
Final setting	: 220 (min)

1.3.2 Supplementary cementitious materials

UHPC can’t be achieved by using basic material like as cement, water, and aggregate. Some cementitious materials are required to achieved the high strength of concrete. These materials are silica fume, nano silica fume, granulated blast furnace slag (GGBS) etc. These materials are generally added to meet the requirements of cementitious materials at lower water-cement ratio for making ultra-high strength concrete. These supplementary cementitious materials are reduced the water demand and also control the temperature rise in concrete at early ages.

1.3.3 Water-Binder ratio

Water- Binder ratio is the ratio of weight of water to the weight of cement/cementitious material weight used in concrete mix. Low water-binder ratio leads high strength and durability, due to low water-binder ratio concrete is difficult to work with and form. It reduces the workability of concrete mix. So, to get the desire workability use of plasticizers or super-plasticizers is recommended water-binder ratio is written:

$$\frac{\mathrm{W}}{C} = \frac{\text{weight of water}}{weight\ of\ cement}$$

For the development of UHPC the water-binder ratio should be in range of 0.15 to 0.30. Super-plasticizer is added to control the workability of concrete mix. In the present study the water-binder ratio of 0.18 have been considered.

1.3.4 Aggregates

Aggregate play important role in the concrete like as for economy factor, to reduce the crack in concrete, reduce shrinkage and provide the strength to the structure. Aggregates are granular materials such as gravel or crushed stone. Aggregates should be properly clean, hard and proper shape, strong particles free from any other fine material on surface, absorbed chemicals or coatings of clay could cause the deterioration of concrete.

Aggregates are present in the concrete around 60% to 75 % of total volume of concrete, aggregate are divided into several categories, and are either coarse or fine:

a) Coarse aggregates: When the aggregate is sieved through 4.75 mm from IS standard sieve, retained aggregate called coarse aggregate. They are the main ingredients of concrete mix gravel, cobble and boulders come under this category. Coarse aggregates must be very carefully selected for UHPC. Because the large size of coarse aggregate decreases the strength of concrete caused by some coarse aggregate with low strength then paste, weaker ITZ between the aggregate and paste and stress concentration at the contact point between those aggregates. For the developing the UHPC the size should be 12.5 mm or 9.5 mm for given w/b ratio, the strength of concrete is decrease when the size of coarse aggregate is increased. For the present study we have consider two sizes of coarse aggregate to get the desire strength that is 10 mm and 20 mm of coarse aggregate.

b) Fine aggregates: When the aggregate is sieved through 4.75mm from IS standard sieve, those aggregate passed through sieve called fine aggregate. Fine aggregate is classified as per the size of particles. They are crushed gravel stone, natural sand and crushed stone sand, silt and clay are also come under this category. Fine aggregate fills the voids in the coarse aggregate and increase workability, cost reduction, increase volume of concrete.

The fineness modulus of fine aggregate is 2.2 to 3.2. The fineness modulus of fine aggregate particles is between 2.2 to 2.6 is fine sand, from 2.6 to 2.9 is medium sand and 2.9 to 3.2 is coarse sand. For developing the UHPC the particle sizes of fine aggregate are between 2.5 to 3.2 are more suitable.

1.3.5 Admixture:

Admixture a material is other than the water, cement and aggregate used in concrete to control the hardening, workability and modify the property of concrete. Admixture are added in concrete before or during mixing.

Admixture are classified into two categories "Chemical Admixtures" and "Mineral Admixtures" which are discussed below:

(a) Chemical Admixtures**:** These admixtures are high performance, water-reducing, Retarding admixtures. Included are accelerators, retarders, water-reducing agents, super plasticizers, air entraining agents etc.

(b) Mineral Admixture: Mineral admixture also called the supplementary Cementitious Materials with cementitious properties which either can be natural or artificial. These admixtures are used when special performance is need like as increase strength, minimize permeability, low head of hydration etc.

Advantages of Admixtures:

1. Increase the workability of concrete at low w/c ratio.
2. To reduce the quantity of cement and make concrete economical.
3. To increase the resistance against freeze-thaw effect on concrete.
4. To reduce the early heat of hydration and overcome thermal cracking problem in concrete.
5. To increase the early strength of concrete.
6. To reduce water content for given workability.
7. Some admixture act as anti-bacterial agents.
8. Admixtures reduce the segregation and bleeding of concrete mix.
9. Increase the durability and strength of concrete.

Some admixtures are used in the present work to develop the UHPC are superplasticizers, silica fume, granulated blast furnace slag (GGBS) and nano-silica which are discussed in detail below:

a) Superplasticizers: It also called high rang water reducer have chemical admixture used to increase or modify the workability of concrete. It highly effective plasticizing effect on wet concrete. It enhancement workability at a given w/c ratio. Adding of this admixture in concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of mixture. For UHPC, polycarboxylic ether-based superplasticizer (PCEs) is used which is suitable for the making of ultra-high strength mixes.

The application instructions of chemical admixtures are as below:

- Dosage: To developing the UHPC the dosage of superplasticizer is selected based on site trials to get require workability. The range of adding of superplasticizer in concrete is lies between 0.5% to 3% by weight of cement.
- Over dosing**:** High workability, retardation of setting time and air entrainment are the results of over dosage. Using a high percentage of superplasticizer if required by ascertaining the performance in the lab trials only before using in actual site conditions.

b) Silica Fume: It is also known as micro silica. It is ultra-fine powder collected as a by- product of producing silicon metal or ferrosilicon alloys production in electric furnaces when high purity quartz is reduced with coal. It consists of spherical particles with an average particle diameter of 150 nm. The oxidised vapour of silica fumes in these furnaces is then cooled and condensed. The chemical and physical properties, it is a very reactive pozzolan of silica fume. Adding of silica fume can have high strength and can be very durable. The particle is very small approximately $1/100^{th}$ the size of average cement particles. Due to fine particles large surface area, and the high SiO_2 content, silica fume is a very reactive pozzolan when used in concrete.

Properties of silica fume used as admixture:

- Surface area of silica fume is large due to fine particles approximately 20,000 m^2/kg.
- Highly pozzolanic in nature.
- Silicon oxide (SiO_2) content in silica fume is about 90%.
- Particle size ranges between 0.1 and 0.2 micron.
- Particles are spherical in shape.

Due to addition of silica fume in concrete, flexural strength, split tensile strength compressive strength, abrasion resistance and bond strength of replaced concrete are higher than the normal concrete and hence protects reinforcing steel from corrosion.

Silica fume used in concrete as a replacement or admixture up to 15 % by weight of cement, although the ideal proportion is 7 to 10 percent. Addition of 15 percent, the potential exists for very strong, brittle concrete, so increases the water demand in a concrete mix. If dosage rates of less than 5 % will not require a water reducer. High dosage of silica fume requires high water reducer.

c) Ground Granulated Blast Furnace Slag (GGBS): It is by product from the blast furnaces used to make iron. Iron ore, coke and lime stone are fed into the furnace at 1500^0 C to 1600^0 C temperature. The iron ore is reduced to iron and molten slag floats on top of iron. After the molten iron tapped off, the remaining molten slag, which consists of mainly siliceous and aluminous residue is then water- quenched rapidly, resulting in the formation of glassy granulate. The glassy granulate is dried and ground to required size, which is known as Ground Granulated Blast Furnace Slag (GGBS). Typical chemical combination of GGBS is:

1. Calcium oxide = 40%
2. Silica = 35%
3. Alumina = 13%
4. Magnesia = 8%

Physical properties of GGBS are:

1. Colour of GGBS is off-white.
2. Specific gravity of GGBS is 2.9.
3. Bulk density is 1200 kg/m^3
4. Fineness lies in the range of 350-370 m^2/kg.

Advantages of GGBS when used with Portland cement are:

1. Increase the durability of structure.
2. It reduces voids in concrete hence reducing permeability.
3. GGBS gives a workable mix.
4. The structure made of GGBS constituents help in increasing sulphate attack resistance.
5. It reduces the temperature rise and helps to avoid early-age thermal cracking.
6. Improved and higher resistance to chloride attack and therefore reducing the risk of corrosion of reinforcement.
7. It is off-white in colour and substantially lighter than Portland cement.

8. The penetration of chloride can be decreased and therefore reducing the risk of corrosion of reinforcement.
9. It is off-white in colour and substantially lighter than Portland cement.

d) Nano Silica (NS): Nano silica have very fine particles size approximately 1000 times smaller than the average cement particles. Due to very fine particles have very high pozzolanic effect. Adding of nano silica have increase the strength and decrease the permeability of concrete. Nano-silica reducing the setting time and increasing compressive strength as well as the flexural stress. It is obtained by the direct synthesis of silica solution or by crystallization of nano-sized crystals of quartz. The compression strength of concrete is increase when 3% of nano-silica used as a replacement admixture of cement. Other side the increase the replacement of cement 4% of nano-silica the compression strength is decrease. Because of improper distribution of nano silica in the mixture there is no improvement in compressive strength with increase in nano silica content. For UHPC, a dosage of nano-silica 2% by weight of binding materials is taken.

1.3.6 Steel Fibers

When steel fibers used in concrete where the control of crack propagation is the most important design consideration. Steel fiber added in concrete also increase the flexural strength of composite. Increase the flexural strength depending on the proportion of fibers added and the mix design. Adding of steel fibers actually transforms the brittle material into ductile material. Steel fiber reinforced concrete exhibits better crack resistance, higher first crack strength, improved fatigue strength, higher resistance to spalling and higher post-crack flexural strength. Steel fibers influence on the first crack strength and ultimate flexural strength if the composite failure occurs by fiber failure rather pull out. The efficiency of the steel fiber depends on the fiber content, the geometry of the fiber, the mixing and compaction techniques, the shape and size of the aggregates and the mix proportions.

Many type of steel fibers is available in market. Four groups are categorized depending upon the manufacturing process:

Group I Cold-drawn wire

Group II Cut sheet

Group III Melt extracted

Group IV Milled from blocks

Steel fibers also categorized on the basis of shape as hooked steel fiber (Fig.1.2), straight steel fiber (Fig.1.3) and intended steel fiber (Fig.1.4).

Steel Fibers in concrete can improve:

- Crack, Impact and Fatigue Resistance
- Shrinkage Reduction
- Toughness- by preventing/delaying crack propagation from micro cracks to macro-cracks.
- Ductility

Benefits of Steel Fiber Reinforced Concrete:

- Significantly reduced risk of cracking.
- Reduction in maintenance and repair cost.
- Stronger joints.
- Longer useful working life.
- High impact resistance.
- Helps in the distribution of localized stresses.
- Increase tensile strength.
- Resistance to freezing and thawing.

Fig.1.2 Hooked End Steel Fiber

Fig.1.3 Straight Steel Fiber

[Source: www.steelfiber.org]

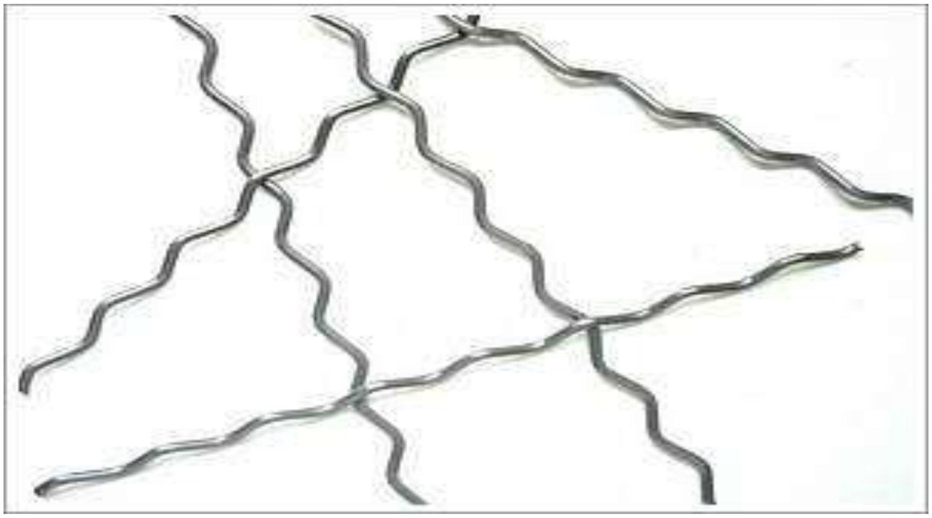


Fig.1.4 Crimped Steel Fiber [Source: www.steelfiber.org]

1.4 PERFORMANCE CRITERIA FOR UHPC STRUCTURES

Now these days due to high required of concrete for structure, we look for material with four distinctive properties Strength, Durability, Workability, and Affordability. For UHPC some or all these properties we need to improve by adding some extra material like admixtures to get desire result. We will discuss these four properties one by one as follows**:**

1.4.1 Strength

The strength of concrete play important role in the structure. If the strength of concrete is higher than the material will be less use in structure and the dead load of the structure also reduce than normal concrete. Also, the high strength concrete help to reduce the cross-section of the structure member. UHPC is almost like steel except its tensile capacity is still comparatively low so it cannot be used like steel.

1.4.2 Workability

With the help of workability of concrete, we constructed the structure easily without any extra cost. Workability of concrete also effect the cost and the time require to build the structure. It also helps to determine that a material is reliable and consistent.

1.4.3 Durability

Durability means the concrete is able to resist the weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different type of concrete is required different degrees of durability depending on the exposure environment and properties desired. Some of the ancient structure are still standing that made us think about the durability of structure. UHPC have good durability than the other type of concrete.

1.4.4 Affordability

The structure will build or not its depend on the cost. The cost of structure is depending on the material like is availability of material in local market, quality of material etc. If the potentially good but expensive material due to is more widespread application may become affordable due to is mass production. For i.e. stainless steel is good for many application constructions. Due to high use of stainless steel the higher price is hindrance to its widespread use.

1.5 APPLICATIONS OF UHPC

Due to the excellent performance of UHPC, its applications are increasing gradually in the recent years, especially in North America, Europe and Japan. The main applications of UHPC are buildings, bridges, structural strengthening and retrofitting, and some special applications. Some specific examples will be given in the following sections.

1.5.1 Bridge

UHPC use in a wide variety of highway infrastructure applications. UHPC can be used as girders, beams, deck panels, field-cast joints between different components, protective layers and etc. due to its advanced mechanical properties and durability. UHPC bridge are less in weight and high durability than the normal concrete.

Fig.1.5 UHPC Bridge, Wapelo County, USA [Source: www.ductal.com]

1.5.2 Buildings

UHPC are used to build the components of Building such as sunshades, cladding and roof components. UHPC could be used to produce very slender, durable and aesthetic structures. The first building build in the word by using of UHPC is the Museum of European and Mediterranean Civilizations (MUCEM) as shown in Fig.1.6, which is located in the port area of Marseille in France.

Fig.1.6 MUCEM, Marseille, France [GU ChunPing et al., 2015]

1.5.3 Structural strengthening and retrofitting

UHPC also used as an overlay to repair the reinforced or prestressed concrete bridge decks. UHPC could increase the mechanical properties and durability of the bridges and result in less maintenance. The bridge is repair with the UHPC is over the river La Morge, in Chateauneuf/Conthey nearby Sion, Wallis, Swiss as shown in Fig.1.7. The bridge deck had no waterproofing membrane and the curbs were severely damaged by chloride induced corrosion. Then the downstream curb, upstream curb and the upper surface of the bridge deck were replaced with UHPC. UHPC could also be used to repair and protect the hydraulic structures.

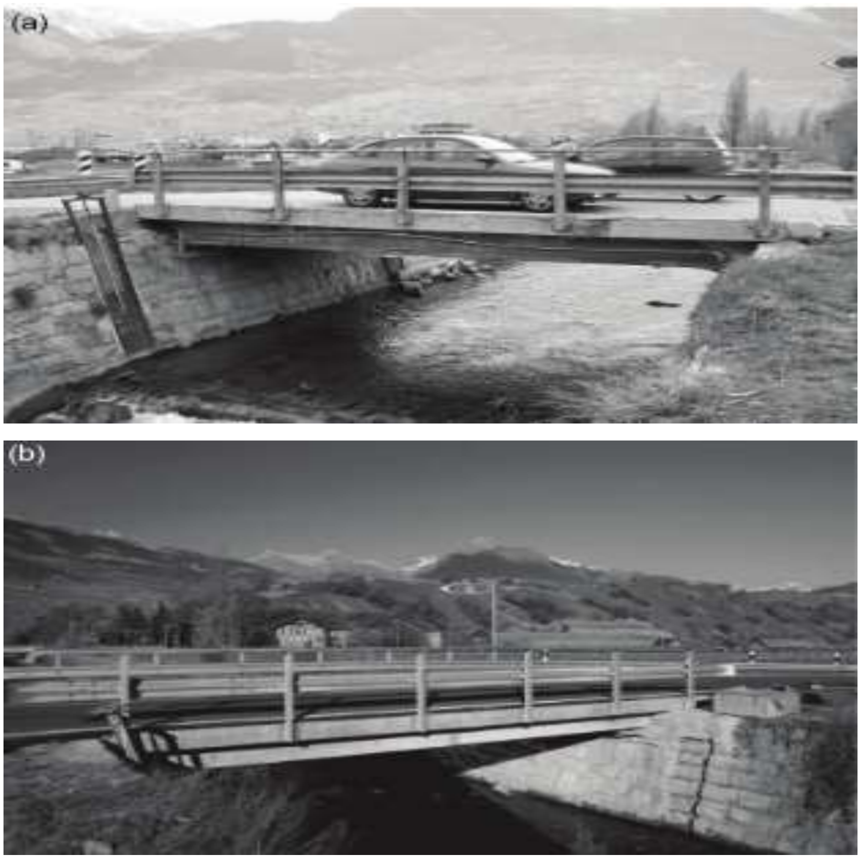


Fig.1.7 Comparison of this bridge before and after rehabilitation. (a) Before the rehabilitation; (b) after the rehabilitation

[GU ChunPing et al., 2015]

1.6 LIMITATIONS OF UHPC

The limitations of UHPC is follow:

1. Lack of design codes for UHPC.
2. Risk perception and lack of familiarity with UHPC.

3. Higher Initial cost.
4. High brittleness behaviour.

The compression strength is increase of concrete make is more brittle means decrease the ductility of concrete. The baggiest challenge limiting the use of UHPC by precast producers is that existing design codes are not readily flexible to this class of concrete having strengths many times that of conventional concrete. More research is required on the advanced properties of UHPC to provide a valid database for structural design. Even at the federal level where UHPC research has been conducted, officials perceive the risks associated with a greatly expanded use of a product with a limited history of performance. State highway engineers, in particular, are tentative to use new technology without a significant history of proven performance in large part because of their responsibility for public transportation care. This understandable aversion to the risk of specifying and manufacturing products with the relatively new UHPCs also drives up its cost. Whenever a new technology is perceived as risky, whether due to lack of knowledge, producer comfort level or history of use, market forces in any industry will increase the price of using that technology.

1.7 PREVIOUS WORK

The previous work to develop UHPC did deliver significant results. In the previous work to develop UHPC, varying proportions of mineral admixture like silica fume, nano silica and alccofine (GGBS) were used. Two trial mixes having alccofine 10% and 15% were made with three different w/b ratios of 0.22, 0.20 and 0.18. All the mix proportions created, the mix containing 2% nano silica, 8% silica fume and 10% GGBS with 1.5% steel fibers was the most promising mix provided the best result with a compressive strength of 138.7 MPa after 28 days. The purpose of the work was to achieve the strength at 28 day lies between 130 to 150 MPa.

1.8 OBJECTIVE OF THE PROPOSED WORK

The work is continuation of the earlier work done as mentioned in the previous subsection to develop the higher strength and the flexural strength of UHPC taking the best results obtained from it. The main objective of the proposed work is to study the flexural strength properties of UHPC with three different trial mixes containing 2% of nano silica, 8% silica fume, 10% alccofine in one trial mix and 15% alccofine in second trial mix and 20% alccofine in the other trial mix keeping percentages of nano silica and silica fume unchanged. Along with this, three different percentage of intended steel fiber i.e. 0.5%, 1.0% and 1.5%. After getting the desired strength, flexural strength tests are performed on various mixes.

CHAPTER 2: LITERATURE REVIEW

2.1 GENERAL

This chapter presents a review of literature about the work done by various researchers in the compressive and flexural strength properties of UHPC. The development regarding applications and performance of GGBS and silica fume in HPC that have taken place in the recent past are studied. Presently literature is focusing on the ultra-high strength concrete and its strength improvement by using of different types of fibers which are publicized in India and abroad in respected international conferences and journals. These research papers give the direction to use the various supplementary cementitious materials and admixtures to increase the properties of concrete also guides us in finding out the areas of improvements required to be researched upon. We have different latest and important research papers of Indian and inter-national authors whose extensive work in this respective field has encouraged us to carry out this present work.

2.2 STRENGTH CHARCTERISTICS OF UHPC

Adel A. Al-Azzawi et al. (2011) study to understand the behaviour of UHPC members with steel fibers used two different kind of admixtures for UHPC namely silica fume and high reactivity Metakaolin. Also, were used separately with three different steel fibers ratio 1.0%, 1.5% or 2.0% for each mix. Therefore, total six mix were considered for the study of UHPC. The compressive strength of these cube (50 mm× 50 mm × 50 mm) was tested at 3, 7, and 28 days of age.

Due to the lower content of C3A they used Sulfate resisting Portland cement to develop the UHPC. Because cement of lower C3A content always required lower w/c ratio compared with ordinary cement. The maximum particle size was the used sand was 600 µm confirming to B.S specification 882/1992. For experiment, straight brass coated steel fibers taking diameter of 0.18 mm and 13 mm long with aspect ratio of 72 were used. Two different type of mineral admixtures were used like Silica Fume (SF) and High Reactivity Metakaolin (HRM) with a high performance concrete superplasticizer based on polycarboxylic technology, Structure 335 in combination with Structuro 480.

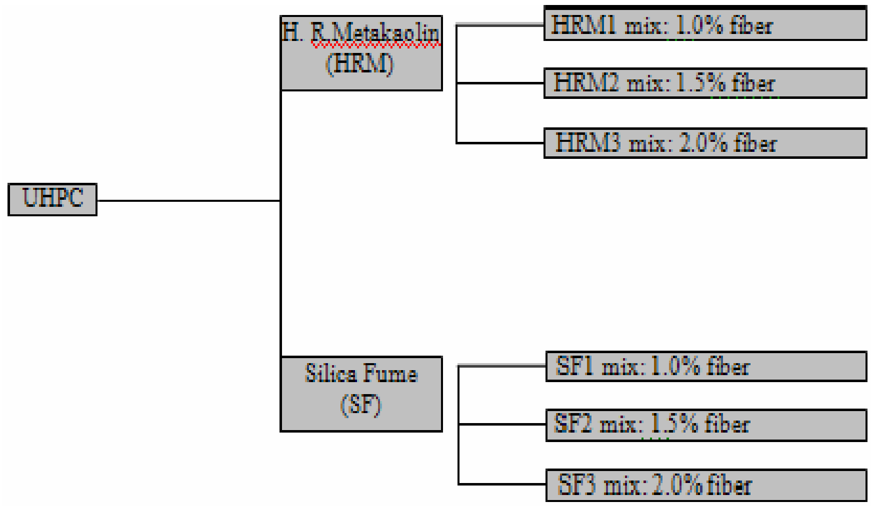


Fig.2.1 Mixes studied in the investigation [Adel A. Al-Azzawi et al., 2011]

The 50 mm cube specimens were used for the compression test after curing at the ages of 3, 7, 28 days for each mix. The Averey-Dension 2000 KN capacity compression testing machine was used for the specimens. The test results for this study are summarized in following Table 2.1:

Table 2.1: Compressive strength of UHPC at 3, 7, and 28 days [Adel A. Al-Azzawi et al. 2011]

Mix	Compressive Strength (MPa)							
	Cement (kg/m^3)	H.R. Metakaolin %	Silica Fume %	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	109	109	159
SF1	900	-	10 %	1.0%	0.186	122	122	191
SF2	900	-	10 %	1.5%	0.189	124	124	195
SF3	900	-	10 %	2.0%	0.19	127	127	198

As we can see clearly in the table that the maximum compressive strength of 198 MPa at 28 days was obtained for SF3 mix (Silica Fume and steel fibers of 2.0%) while a 28 days compressive strength of 159 MPa was obtained for HRM3 mix (High Reactivity Metakaolin and steel fibers 2.0%). Due to the adding of pozzolanic mineral admixtures (Metakaolin or Silica fume) the compressive strength is increase at early ages. Because the chemical reaction of pozzolanic materials started at early ages (3 and 7 days) and increase till the age of 28 days. It is explained by the high pozzolanic reaction of particles of these materials with calcium hydroxide released from cement hydration leading to pore size and grain size refinement processes which can strengthen the microstructure and reduce the micro-cracking.

Yang et al. (2010) studied to understand the structural behaviour of UHPC beams with steel bars. In this paper, compressive strength, flexural strength and workability of UHPC were studied. The coarse aggregates were not used to produce the UHPC and steel fibers added in the concrete mix were 2.0% of the total volume of concrete.

To develop the UHPC used the materials is with sand having diameter less than 0.5mm, quartz powder with average diameter of 10 µm, OPC, silica fume high performance polycarboxylate water reducing agent having density 1060 kg/m3 and steel fibers having length of 13 mm and diameter of 0.2 mm. The percentage of steel fibers added in the concrete mix was fixed at 2.0%. The flow chart and mixing sequence is shown in Fig.2.2 (a) and 2.2 (b) and proportions of the ingredients used to produce this UHPC are given by their weight ratios in Table 2.2 (a):

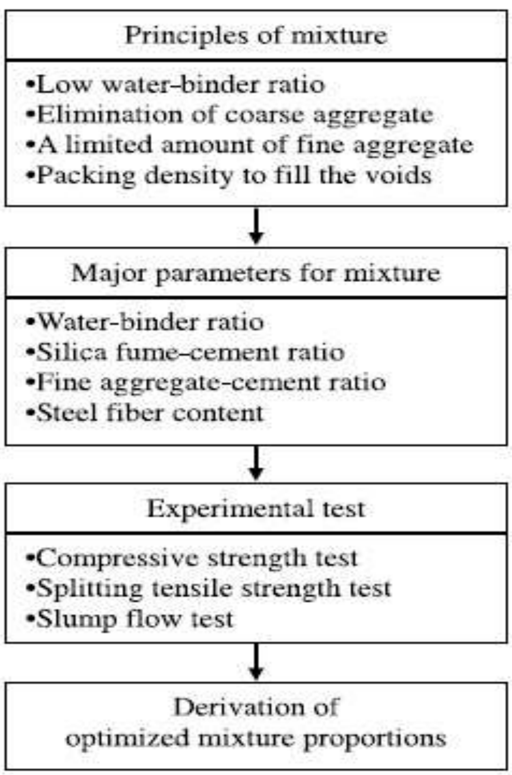


Fig.2.2 (a) Flow chart for the mix design of UHPC [Yang et al. 2010]

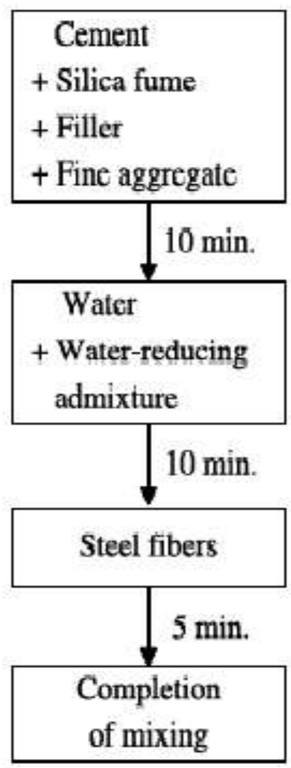


Fig.2.2 (b) Mixing sequence of UHPC [Yang et al. 2010]

Table 2.2(a): Proportion of materials in the UHPC mixture by weight ratio [Yang et al. 2010]

Water-binder ratio	Cement	Silica Fume	Filler	Fine aggregate	Water reducing admixture	Steel fiber by Volume of concrete
0.2	1.0	0.25	0.3	1.1	0.02	2.0%

The compressive strength test of UHPC, cylindrical specimens having diameter of 100 mm and height of 200 mm were made-up in four batches and ten cylindrical specimens were made-up for each batch. An average of these compressive strengths for each batch is reported in below Table 2.2 (b):

Table 2.2 (b): Material properties of UHPC [Yang et al. 2010]

Material properties	Batch 1	Batch 2	Batch 3	Batch 4
Compressive Strength (MPa)	190.9	192.2	196.1	196.7

For the experimental program included on a total of 14 beam specimens having dimensions as follows: a beam width of 180 mm, height 270 mm and length of 2900 mm with rectangular cross section. Two sets of seven beams each were prepared and tested. Beam width was designed to satisfy the requirement that the adjacent longitudinal rebar spacing was more than two times steel fiber length to avoid the fiber interlocking between bars.

Beams was tested on loading frame by using four-point loading method and load was applied on top face of beam with the help of hydraulic actuated jacks. To measure the strain of the concrete and steel rebar used the strain gauges and electrical gauges strain and to measure the beam deflection used LVDTs were placed at loading points and center.

The maximum compressive strength 196.7 MPa got from batch four. The placing method of the UHPC even for identical rebar ratios and cross sections effect the flexural capacity of beam was found. Placing the UHPC at the mid-span provide comparatively lower performance than placing the UHPC at the ends of the beam. Results also show that orientation and arrangement of steel fibers are influenced by the placing method of UHPC.

Tuan et al. (2011) studied the feasibility of using of rice husk ash (RHA) as an alternate of costly silica fume to produce UHPC. Rice husk ash is an agricultural waste. Due to high surface are and have large amount of SiO2 rice husk ash is highly pozzolanic in nature. The objective of this study is find out the effect of RHA in combination with and without SF on the compressive strength property of UHPC.

To develop the UHPC materials were used OPC 43 cement having surface area of 4500 cm2/gm, rice husk ash, silica fume with mean particle size 0.1 to 0.15 µm, silica sand with mean particle size of 225 µm and polycarboxylate based Superplasticizer. Rise Husk Ash was prepared in a drum where RHA burnt under uncontrolled combustion conditions and the ash obtained was ground in a vibrating mill for 90 minutes. Fifteen different mixes were prepared whose procedure is shown in Fig.2.3 (a) and mixes shown in Table 2.3.

Table 2.3: 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 ($d_{RHAmean}$), 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
015-0.18-0.20-0.23	1	10	10	5.6

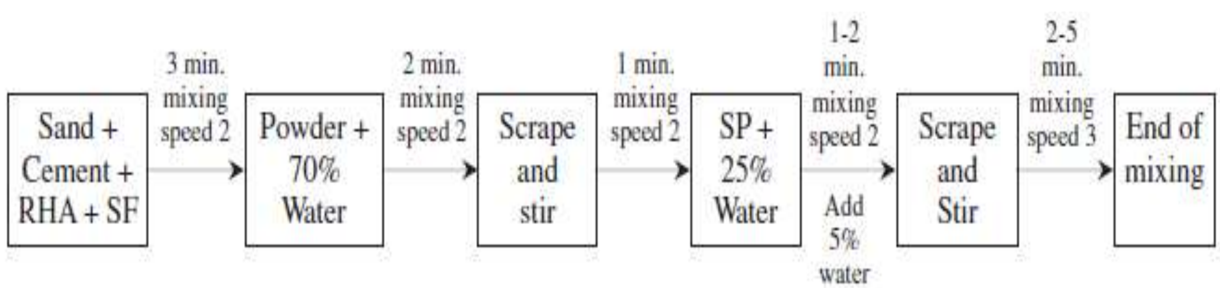


Fig.2.3 (a) Mixing procedure for UHPC [Tuan et al. (2011)]

The Fig.2.3 (b) shows that the highest compressive strength of UHPC was achieved by using of 10% SF replacement of cement. The use of RHA as a partial replacement of cement revealed the different behaviour of compressive strength development. The highest compressive strength of UHPC was obtained with 10% RHA at 3 and 7 days, as compared to the compressive strength of UHPC with 20% RHA as a replacement at 28 and 91 days. Based on these result, found that RHA can be used to produce UHPC as a replacement level less than 30%.

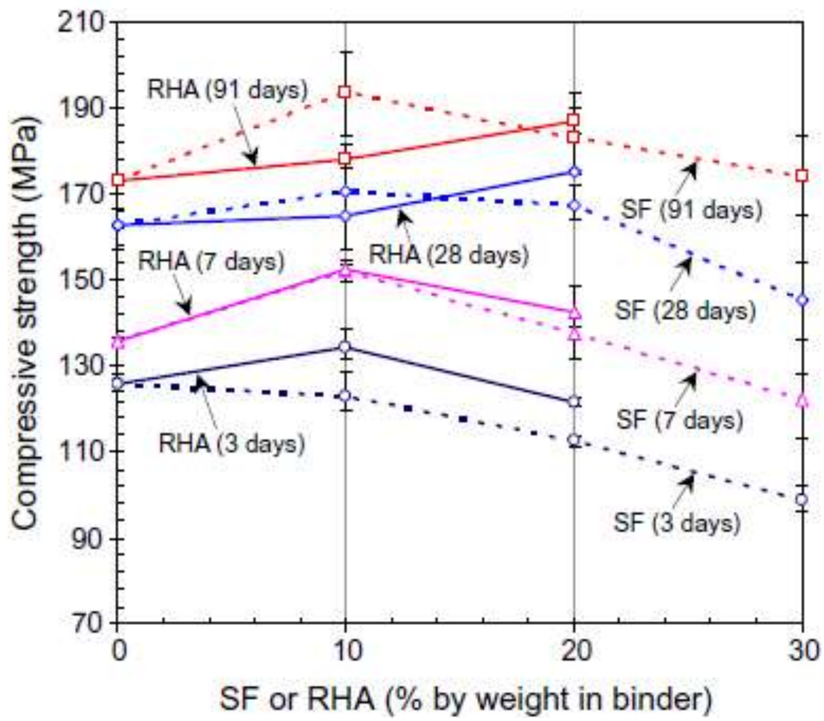


Fig.2.3 (b) Compressive strength of UHPC samples vs. % SF (dotted line) or % RHA (Solid line), w/b ratio = 0.18, dRHAmean = 5.6 µm. [Tuan et al. (2011)]

Prem et al. (2012) studied the mechanical properties of UHPC having compressive strength more than 150 MPa at the age of 28 days. The materials used to produce UHPC mix includes OPC 53 grade cement with specific gravity 3.15**,** Silica Fume with specific gravity 2.25, Quartz powder with specific gravity 2.59, sand of Grade I and Grade III with particle size range 0.6 mm to 2.36 mm and particle size range 0.075-0.15 mm respectively, coarse and fine aggregates, poly-acrylic ester based Superplasticizer and steel fibers with two different sizes (i.e S1 steel fiber with diameter 0.16 mm and 13 mm length, S2 steel fiber with diameter 0.16 mm and 6 mm length). The planetary mixer used for mixing having capacity of 300 kg. Five different mixes were casted with different percentages of steel fibers and w/c ratio was fixed at 0.22. The chemical compositions of ingredients used in the mix are given in Table 2.4 (a):

Table 2.4 (a): Chemical composition of ingredients [Prem et al., 2012]

Mix	Cement Kg/m^3	Silica Fume Kg/m^3	Quartz Kg/m^3	Fine Aggregate Kg/m^3	Water Kg/m^3	SP Kg/m^3	RF Kg/m^3	Steel Fibers	W/C Ratio
R1	788	197	315	866.8	173	14.77	2.0312	S1-2.5%	0.22
R2	788	197	315	866.8	173	14.77	1.6125	S1-2%	0.22
R3	788	197	315	866.8	173	14.77	0.9375	S2-2.5%	0.22
R4	788	197	315	866.8	173	14.77	0.75	S2-2%	0.22
R5	788	197	315	866.8	173	14.77	0	Nil	0.22

Twenty-four cubes of size (100×100×100) mm were casted to check compressive strength which was evaluated at 7, 14, 21 and 28 days are shown in Table2.4 (b).

Table 2.4 (b): Cube strength evaluated [Prem et al., 2012]

Mix ID	Compressive strength (N/mm^2)			
	7 Days	**14 Days**	**21 Days**	**28 Days**
R5	104	123	126	132
R4	129.8	149.7	156	164
R3	149.5	167.2	172	178.70
R2	147.2	162.3	167.3	170.29
R1	152.67	168.5	176.4	180.28

The compression testing machine having capacity 3000 KN were used for the compressive strength of the specimen. The rate of loading is defined at 0.2 KN/sec. The maximum compression strength was obtained at the age of 14 days (90% strength). Due to the addition of fibers in mix the compressive strength increased around 25% as compared to control mix.

For the experimental program Seven beams were casted to check flexural strength having size of beams is 70 × 70 × 350 mm. The flexural test was done according to ASTM 1609. The third-point loading method used to obtain flexural strength of beam specimen using a closed-loop, servocontrolled testing system. When the residual loads P_D 150 and P_D 600 are keep in the formula for modulus of rupture and obtained the residual strength values f_D 150 and f_D 600 as per ASTM 1609 standard. Toughness (T_D 150) of beam specimen of nominal depth D is area of load-deflection curve up to a net deflection of L/150. Equivalent flexural strength ratio $R^D{}_{T150}$ value obtained using below equation.

$$f_b = PL/bd^2$$

where f_b = residual strength in MPa, P = first peak load, b = measured width in mm of the specimen, d = measured depth in mm of the specimen at the point of failure.

$$R^D{}_{T150} = \frac{150T^D{}_{T150}}{f_1 bd^2} \ x\ 100\%$$

Using the above equations, the flexural strength of concrete is calculated which is shown in Table 2.4 (c).

Table 2.4 (c) Flexural Strength of UHPC [Prem et al., 2012]

Mix ID	**R1**	**R2**	**R3**	**R4**	**R5**
Flexural Strength (N/mm2)	44	42	34.7	32	16

Mix R1 show the highest flexural strength is highest having 2.5% fiber content whereas lower flexural strength was reported for Mix R5 having no fiber content. This is because fibers acts as crack arrestor in concrete and the concrete can take more loads and become more ductile.

Wang et al. (2012) Investigated of UHPC matrix with common technology and ordinary raw materials. The purpose of this study is observed the effect of GGBS content as a replacement on fluidity and compressive strength of UHPC. For the preparation of UHPC material the guidelines laid by the researchers includes: (a) The raw materials should be easily available and local (b) no specific process and special use of machinery require to prepare, mix, pouring and curing of concrete.

Water-binder ratio was taken between 0.14 - 0.18. Binder content was kept at 900kg/m^3 maximum to ensure necessary paste volume. To improve the micro-structure of binder, paste and to reduce the heat of hydration use the Superfine materials like Silica fume (SF), Ground granulated blast furnace slag (GGBS) and limestone powder (LP). The chemical compositions and physical properties of each cementitious material are listed in Table 2.5 (a).

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

Binder	Chemical composition (%)								Specific Surface Area (m^2/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	0.19	-	-	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

Three types of mixes were prepared by using GGBS as a replacement material of cement i.e. (0%, 20% and 40%) and silica fume content was kept 10% fixed. The objective was to study the fluidity of UHPC and influence of GGBS replacement of cement on strength. The mix composition is shown in Table 2.5 (b) and results are shown in Fig.2.4.

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)	Super-plasticizer (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

Mixture 2-1 concrete, having no GGBS, mixture 2-2 having 20% by weight GGBS replacement had higher fluidity, and lower compressive strength obtained at early ages (28 d and 56 d), but approximately equal strength at later ages (90 d, 180 d and 365 d). Mixture 2-3 having 40% by weight GGBS had a low compressive strength and fluidity at all ages compared to the control mixture 2-1.

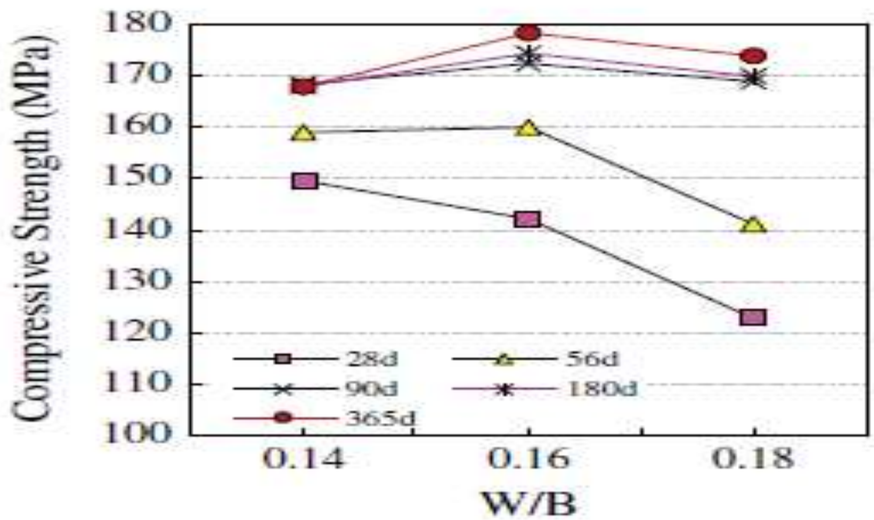


Fig.2.4 Influence of GGBS content on strength and fluidity of UHPC [Wang et al. (2012)]

Lower W/B ratio, due to the addition of cementitious materials i.e. GGBS, silica fume, lime stone powder and very high binder content and with high water reducing Superplasticizer UHPC can be produce and all the three mixes reached compressive strength of more than 150 MPa after 90 days.

Hudoba and Mikus (2013) Investigated the study of different type of column made with the UHPC for testing the failure mode. The strength level of UHPC is based on four fundamental issues; these are strength increasing of hardened cementitious matrix, increasing the bond strength between cementitious matrix and corns of aggregates, using fine aggregates having high strength and finally utilizing of confinement effect based on 3-axis state of material. Ultra-high strength concrete having strength increment is based on the very low water-cement ratio. Binder value represents the ratio of total amount water to the amount of cement, including silica fume and fly ash in it. For fresh UHPC, water binder ratio is kept less than 0.2. Due to low water-cement ratio needs to increase the dosage of high effective superplasticizer. The researchers developed a concrete mix having compressive strength 140 MPa in 28 days using local and regional raw materials. Cylindrical UHPC bars having diameter of 72 to 80 mm and length 1500 mm were used as an alternative reinforcement instead of classical core reinforcement in composite CC (concrete-concrete) columns.

Fig.2.5 (a) View of the column Reinforcement consisting of different types of cylindrical steel and UHSC core [Hudoba and Mikus, 2013]

Fig.2.5 (b) Set of columns prepared for laboratory test [Hudoba and Mikus, 2013]

Steel Reinforcement 4-12 mm diameter longitudinal steel bars and links of 6 mm have used. Five different types of column were used and for each type of column have three columns were cast. Table 2.6 lists the types of columns and their average value of compression failure capacity (KN).

Table 2.6: Test results of composite columns failure capacity [Hudoba and Mikus, 2013]

Type of column	**Column Reinforcement**	**Average value of Compression failure Capacity (KN)**
A	4ØR12	1712
B	4ØR12+ solid Ø 70 mm	2485
C	4ØR12+ smooth UHSC core Ø 72 mm	1973
D	4ØR12 + corrugated UHSC core Ø78 mm	2050
E	4ØR12 + UHSC core Ø 78 mm in corrugated steel tube	2140

By using local materials and common mixing and apparatus it is possible to get the compressive strength upto 140 MPa and the compressive strength get more than 140 MPa we require specific equipment for mixing, curing method, resp. hardening of UHSC under compressive conditions. Solid steel core reinforcement has advantages in the field of UHSC of composite column. The Cost of UHSC bars is cheaper than steel bars. The density of UHSC bars is three times lower than steel bars.

Yoo and Yoon (2015) studies the 10 large beams of UHPC beams reinforced with steel bars. The cross-sectional area of beam is 150 mm × 220 mm × 2500 mm. Four different types of mixes were prepared with different fiber reinforcement and different type of fibers and for each mix two beams are cast. The reinforcement ratio kept different like 0.94% and 1.50% and smooth and twisted steel fibers were used. The dimensions of smooth fiber taken were d_f = 0.2 mm and L_f = 13 mm and 19.5 mm and the dimension of twisted fibers was d_f = 0.3 mm and L_f = 30 mm. For control specimen no fiber was added in the mix of UHPC. Table 2.7 shows the results of compression and flexural test.

Table 2.7 Compression and Flexural test results [Yoo and Yoon, 2015]

Name	Compression test (ASTM 39 [30])			Flexural test (JCI-S-002-2003[31])		
	f_c (MPa)	ε_c (mm/mm)	E_c (MPa)	f_{MOR} (mm)	Δ_{MOR} (mm)	$CMOD_{MOR}$ (mm)
NF	200.9	-	45265.0	8.18	0.0034	0.028
S13	211.8	0.00453	46732.5	19.26	0.54	0.66
S19.5	209.7	0.00484	46880.5	30.69	0.75	0.94
S30	209.7	0.00458	46772.9	31.91	1.57	2.06
T30	232.1	0.00528	46971.6	32.24	1.06	1.36

Where fc = compressive strength

εc = strain at peak load

EC = elastic modulus

f_{MOR} = flexural strength (modulus of rupture)

Δ_{MOR} = deflection at peak load

$CMOD_{MOR}$ = CMODD at peak load

The four-point loading were used on UTM having maximum capacity of 2000 KN to testing of beams specimen. The loads, deflection and strain were simultaneously recorded. Due to the adding of steel fiber the load carrying capacity, cracking response and post-cracking stiffness improved. But the ductility decrease. In the above table show the results clearly that increased the steel fiber content (i.e. 2% by volume of steel fibers) load carrying capacity of beam increased approximately 27-54% and ductility of beam decreased by 13-73%. Improve the post-peak response and ductility of beam when the length of smooth steel fibers increased and use of twisted steel whereas no change was reported in load carrying capacity, cracking response and post-cracking stiffness. Sectional analysis incorporating the suggested material models was also performed based on AFGC/SETRA recommendations, and the ratios of flexural capacities obtained from experiments and numerical analyses ranged from 0.91 to 1.19.

Doo-Yeol Yoo et al. (2016) take the three different size of beam to investigate the size effect on the flexural performance of UHPC. UHPC beams with three different sizes of 50 × 50 × 250 mm^3, 100 × 100 × 400 mm^3 and 150 × 150 × 550 mm^3 and two different types of steel fibers used like smooth steel fibers with aspect ratio of 65 (d_f = 0.2 mm and L_f = 13 mm) and 100 (d_f = 0.3 mm and L_f = 30 mm) and twisted steel fibers with aspect ratio 100 were used to make UHPC beams. Control beam of UHPC made without steel fiber to study the size effect on the flexural performance of UHPC. For the best result image analysis is done at crack surfaces. Four-point test method use the testing of UHPC beams on the UTM machine.

To get the flexural stress from the measured load converted into flexural stress by using the equation as specified in ASTMC 1609. The equation is:

$$f = PL/bh^2$$

where P = Applied load

L = Span length

b = Width of beam

h = Height of beam

The result shows that the size of beam is increase the flexural performance of UHPC is decrease. Because the distribution and orientation of fiber is not proper. Shorter steel fibers with low aspect ratio increases the sensitivity to the size effect of UHPC beams compared with longer steel fibers. Finally, the insignificant size effect on the flexural strength of UHPC was with 2% by volume of steel for all the tested specimens.

Burroughs et al. (2017) investigated the ground limestone powder use as replacement for cement and silica powder to improve the performance of ultra-high-performance concrete used either as a partial or full mass of replacement. Fresh properties of UHPC like mixing time and workability improve after the addition the limestone powder in the mix. Three different type of percentage of limestone powder has kept for the study. The three dosages of limestone of 5%, 10%, 15% by mass as replacement of cement used and three dosages of silica powder replacement with limestone powder were 33%, 67% and 100% by mass. For the control mix 0% replacement of limestone powder with cement and silica fume powder used. For the compression strength the standard 50 mm^3 cubes were and the testing was in accordance with ASTM C109.

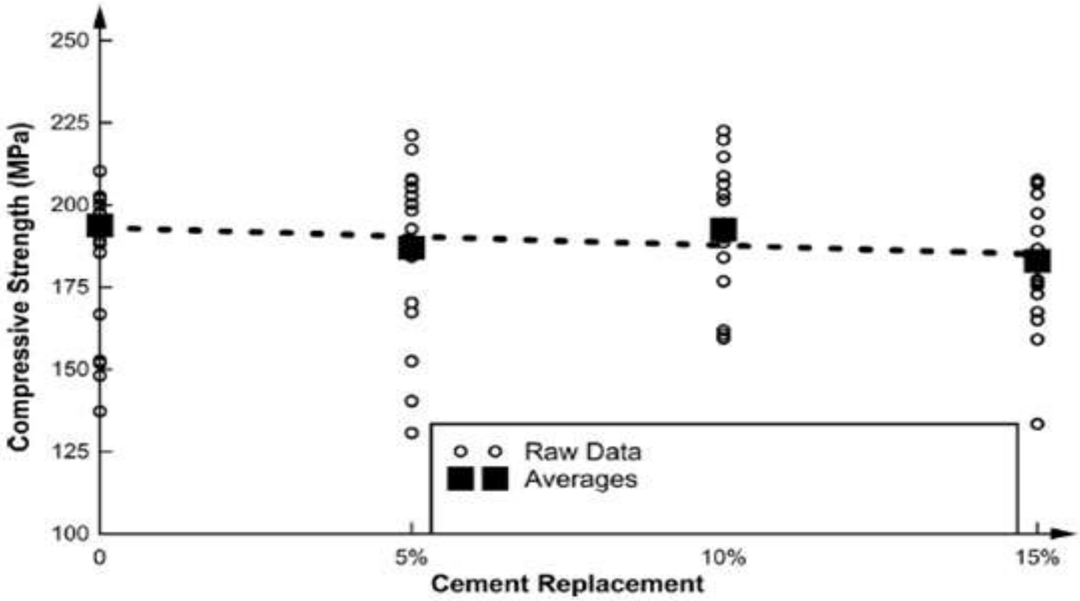


Fig.2.6 (a) Measured 14-d concrete compressive strength [Burroughs et al. (2017)]

The Fig.2.6 (a) shows the replacement of cement with limestone powder gave little effect on compressive strength. The fig. show that the variation in compressive strength results is not large for samples with 0% and 15% replacement than either 5% or 10% replacement.

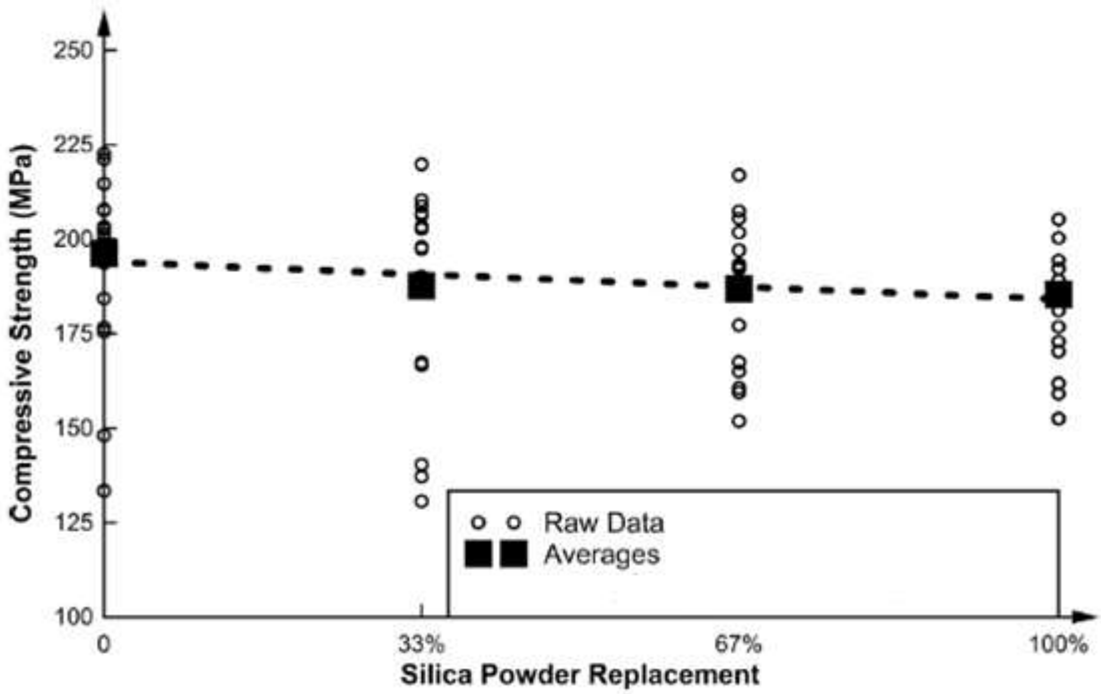


Fig.2.6 (b) Measured 14-d concrete compressive strength [Burroughs et al. (2017)]

Fig.2.6 (b) shows that due to the replacement of silica fume with limestone powder decrease the average compressive strength of UHPC. The loss was of the compressive strength less than 6% even at 100% replacement. Because the size of limestone particles is more than the silica fume so decrease the compressive strength.

So, the middle range of replacement is more better than the replacement 0% or 100% in mix.

CHAPTER 3: MATERIALS AND DESIGN METHODOLOGY

3.1 GENERAL

To get the desired compressive strength more than 120 MPa, for the production of UHPC using conventionally available material like cement, aggregates, silica fume, GGBS, nano-silica and steel fibers were used. In this chapter, we discuss about the material properties and various tests conducted of material to development of UHPC. The study aimed to get the material properties with their result help to mix design for achieve the desired strength.

3.2 CHARCTERISTICS OF MATERIALS USED

According to the relevant IS code the chemical and physical properties of various materials used for making UHPC determined in laboratory. The materials used for development the UHPC are evaluated to check for their acceptance for the making of mix design to achieve the target strength of concrete. The explanation of various materials along with their studied properties which were used in this study is detailed in the following sub-sections:

3.2.1 Portland Cement

Cement is a binder material used in concrete to bind the coarse and fine aggregate and other ingredients used in concrete mix. Cement is the binding unit of concrete. For a particular concrete mix, the selection and proper use of cement is important in obtaining the desired properties of mix and also as it has the greatest unit cost. Portland cement also called as Ordinary Portland Cement (OPC) is a fine powder type material which is produced by grinding Portland cement clinker. OPC is classified into 3 grades namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. For the undertaken study, OPC 53 cement was used throughout the course of investigation. The codal provisions referred for specification of OPC 53 are provided by IS 12269:2013. According to IS 12269 Ordinary Portland cement, 53 grades shall be manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker so as to produce a cement capable of complying with this standard. No material shall be added after burning, other than gypsum (natural mineral or chemical), water, performance improver(s), and not more than a total of 1.0 percent of air-entraining agents or other agents including coloring agents, which have proved not to be harmful. The cement used in the present study was fresh and without any lumps. The various physical test conducted on cement are specific gravity, initial and final setting time, fineness and compressive strength. The results of these tests are tabulated in Table 3.1.

Table 3.1: Properties of OPC 53 Grade Cement

Characteristics	Values Obtained Experimentally	Value Specified by IS 12269: 20.13	Test Method Referred to
Specific Gravity	3.12	-	IS 4031 Part 11
Standard Consistency %	31	-	IS 4031 Part 4
Setting Time (min.)			IS 4031 Part 5
Initial Final	100 250	30 (minimum) 600 (maximum)	
Compressive Strength (N/mm^2)			IS 4031 Part 6
3 Days 7 Days 28 Days	34 44 62	27 37 53	

3.2.2 Aggregates

Aggregates occupy 85% of the volume of concrete (i.e. a large volume in the concrete mix) and impart dimensional stability to concrete. It also helps in reducing cost of concrete as it occupies majority of volume of concrete mass. Aggregate is the broad category of basic materials used in construction which includes sand, gravel, crushed stone, saw dust, broken bricks etc. In our study, for the production of UHPC we have used two types of aggregates were used as outlined below:

1. Coarse aggregates having size 20 mm and 10mm.
2. Fine aggregates (i.e. sand) having particle size less than 4.75 mm.

Coarse aggregates help in making solid and hard mass of concrete, whereas fine aggregates increase the crushing strength of concrete, reduces shrinkage and cracking of concrete.

a) Coarse aggregates: Coarse aggregates have particles greater than 4.75mm but generally lie between 9.5 mm to 37.5 mm in diameter. Also, aggregates which passed through 75 mm IS sieve and retains on 4.75 mm IS sieve are termed as coarse aggregates. These aggregates are formed either by natural disintegration of rocks or by artificial crushing of rock or gravel. The quality standard as per the codal provisions in IS: 383-1970, states that aggregates should be hard, strong, dense, durable, clear, free from veins and adherent coating; and free from injurious amounts of disintegrated pieces, alkali, vegetable matter and other deleterious substances. Particles being flaky, scoriaceous and elongated need to be avoided.

In the present study, we have used two available crushed stones of 20 mm and 10 mm sizes were used. In order to remove dirt and dust the aggregates were washed and then dried to surface dry condition. The various physical properties of coarse aggregates are given in Table 3.2. The sieve analysis of coarse aggregate was done in the laboratory and the values obtained are shown in the Table 3.3 (a) for the 20mm aggregate and Table 3.3 (b) for the 10mm aggregate.

Table 3.2: Properties of Coarse Aggregates

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

Table 3.3 (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 3.3 (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	0	0.00	**Sum**	**636.5**
Total		**10000**		**FM = 6.36**	

b) Fine aggregates: Fine aggregates are those, most of whose particles passes through 4.75 mm sieve. Types of fine aggregates includes natural sand, which is formed by natural disintegration of rocks and crushed stone sand which is formed by crushing natural gravel. IS 383 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV. For this present study, the fine aggregates were conforming to grading zone II and were collected from a local supplier in Patiala. The fine aggregates were washed to remove contaminates like silt and clay and then dried to remove excess water. The various physical properties of fine aggregates are given in Table 3.4 (a). The sieve analysis of fine aggregate was done in the laboratory and the values obtained are shown in the Table 3.4 (b).

Table 3.4 (a): Physical Properties of Fine Aggregates

Characteristics	Values
Type	Natural Sand
Specific Gravity	2.65
Fineness Modulus	3.02
Grading Zone	II

Table 3.4 (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**		

3.2.3 Silica Fume

Silica Fume is a pozzolanic material which is also known as micro silica or condensed silica fume. Silica fume is used as a replacement for concrete which makes concrete more durable and increases its strength. Also, silica fume fills the voids between cement particles making the mix more dense and impermeable. The silica fume used in our studied was obtained from KGR Agro Fusions (P) Ltd., Ludhiana Punjab. The quality of silica fume is specified by ASTM C 1240 and AASHTO M 307. In order to use silica fume in UHPC its physical and chemical properties were must carefully studied. The properties of silica fume were provided by KGR Agro Fusions (P) Ltd.

a) Physical Properties: The physical properties of silica fume are listed in Table 3.5

Table 3.5: Physical properties of silica fume

Particle size (typical)	< 1 µm
Specific Surface	15,000 to 30,000 m^2/kg
Color	Bluish Grey
Bulk Density	550-700 kg/m^3
Specific Gravity	2.40

b) Chemical Properties: The chemical composition of silica fume varies with the type of furnace, composition of principle product etc. The chemical composition of the silica fume is tabulated in Table 3.6.

Table 3.6: 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%

3.2.4 Ground Granulated Blast Furnace Slag (GGBS)/Alccofine

Alccofine brand GGBS was used in the design mix as another replacement material for cement to study its effectiveness for development of ultra-high-performance concrete. Micro fine mineral additive, ALCCOFINE-1203“as shown in Fig. 3.1 is used for development of concrete. It is obtained from Ambuja Cements Ltd. (ALCCOFINE MICRO MATERIALS RANGE) having an average particle size of 4 to 6 microns. It is a low calcium based mineral additive manufactured through a controlled granulation process which results in unique particle size distribution. Due to high pozzolanic content and latent hydraulic property its hydration process is enhanced. Addition of alccofine improves the packing density of cement paste due to which water and admixture dosage demand is reduced which imparts strength and durability to concrete at all ages.

Fig.3.1: Alccofine-1203

The codal provisions for the specification and quality standards for Alccofine-1203 are given by IRC SP: 70, IS: 456, IS: 12089. The physical properties of Alccofine-1203 as provided by the manufacturer are listed in Table 3.7.

Table 3.7: Physical Properties of Alccofine-1203 [Manufacture]

Property	Unit	Content
Average Particle Size	Microns	4 to 6
Fineness	Cm^2/gm	12000
Specific Gravity		2.86 ± 0.02
Bulk Density	Kg/m^3	600 to 700

3.2.5 Nano Silica

Nano silica particles significantly affect the properties of concrete mix because of high specific area and high purity (greater than 99%). In the present study, nano silica used is of liquid form with colloidal solution. Its particle size is much smaller than silica fume and alccofine particles. The nano silica used in this research was manufactured by BEECHEMS, Kanpur and is shown in Fig.3.2.

Fig.3.2: Nano Silica

Nano silica used in the study is a white translucent liquid having no odour and has complete solubility. Specific gravity of nano silica is in the range 1.20-1.26 having particle sizes ranging from 1 - 100 nm.

3.2.6 Superplasticizers

Masterglenium Sky 8233 modified polycarboxylic ether based high- performance super plasticiser is used in this study. This product is being manufactured by BASF solutions. This product has been primarily developed for applications in high performance concrete where high durability and performance is required. This product is free of chloride and alkali and has compatability with all types of cement.

The Superplasticizer used in the present study satisfies the criteria as laid down in:

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

Fig.3.3: Masterglenium Sky 8233 Superplasticizer

The physical properties of Masterglenium Sky 8233 as specified by the manufacture are given in Table3.8.

Optimum dosage of Masterglenium SKY 8233 used in the experimental study was determined with trial mixes. As a guide, a dosage of 800ml to 2000ml per 100kg of cementitious material is normally recommended.

Table 3.8: Physical Properties of Superplasticizer [Manufacture]

Aspect	Reddish Brown Liquid
Relative Density	1.1 ± 0.01 at 25˚ c
pH	≥ 6 at 25˚ c
Chloride ion content	< 0.2%

3.2.7 Water

Water is used as a binding agent for the concrete mix. The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly, potable water was used for making concrete available in material testing laboratory. It was free from any detrimental contaminants and was of good potable quality.

3.2.8 Steel Fibers

Steel fibers are used in concrete to delay the propagation of cracks by arresting the advancement of cracks across the matrix and by creating a slow cracking propagation stage. As compared with unreinforced concrete, the ultimate cracking strain of reinforced concrete is increased many folds due to these fibers. These small, closely spaced and randomly oriented fibers transform a brittle material, having low tensile strength and impact resistance, to a much stronger composite with superior cracking resistance, improved ductility and distinctive post cracking behaviour prior to failure. The net result, is it transforms a brittle material to a ductile type of material which certainly increases the energy absorption characteristics of the fiber composite and its ability to withstand impact, repeatedly applied or shock loading. Steel fibers are of different types namely straight steel fiber, indentation steel fiber and hooked ends steel fiber. In the present study indentation steel fiber (SHAKTIMAN ® Steel Fiber) as shown in Fig.3.4 are used which were obtained from Stewols India (P) Ltd., Nagpur. The specifications of the fibers used are given in Table 3.9.

Table 3.9: Specification of steel fibers

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

Fig.3.4: Steel Fibers

3.3 TEST METHODS

The procedure or methods used for finding the properties of cement, coarse aggregates, fine aggregates and compressive as well as flexural strength of concrete are detailed below:

3.3.1 Specific gravity

Specific gravity is defined as the ratio of weight of a given volume of the substance to the weight of an equal volume of some reference substance (i.e. water), or equivalently the ratio of masses of equal volume of two substances. The procedure for calculating the specific gravity of cement is given in IS: 2720 – (Part 3): 1980 and procedure for calculating the specific gravity of aggregates is given in IS: 2386 (Part 3):1983.

3.3.2 Sieve analysis for coarse and fine aggregates

Sieve analysis is also known as gradation test which is generally performed to investigate the particle size distribution and fineness modulus of fine and coarse aggregates. For this purpose, predefined set of sieves were used, which are specified in IS codes. The procedure for sieving or sieve analysis is given in IS: 2386 (Part-1): 1963.

3.3.3 Compressive Strength of Concrete

In order to find out the compressive strength of UHPC, cubes of size 150 mm × 150 mm ×150 mm were cast under standard laboratory conditions and were tested after a curing period of 28 days. The time was calculated from the time when water was added to the dry ingredients. The testing method was carried out using 500 tons Automatic Compression Testing Machine (ACTM).

Before testing the samples, the samples were wiped with cloth to remove surface water and dried for half an hour at room temperature after taking out from curing tank.

According to Indian standard procedure laid down in IS: 516-1959 the cubes were placed in the ACTM such a way that the load was supplied at the right angle to the faces of cube rotating them at 90˚. Load was applied continuously at the rate of 5 MPa per second until the failure of the specimen. The Fig.3.5 shows testing of cube specimen.

Fig.3.5: Automatic Compression Testing Machine (5000 KN Capacity)

3.3.4 Flexural Strength Test

In the experimental beams of size 150 mm × 150 mm × 700 mm were cast under standard laboratory conditions and were tested after a curing period of 28 days. The time was calculated from the time when water was added to the dry ingredients. The testing method was carried out using UTM. The beams were tested under two-point loading until failure. The load mechanism for testing beams is shown in Fig.3.6.

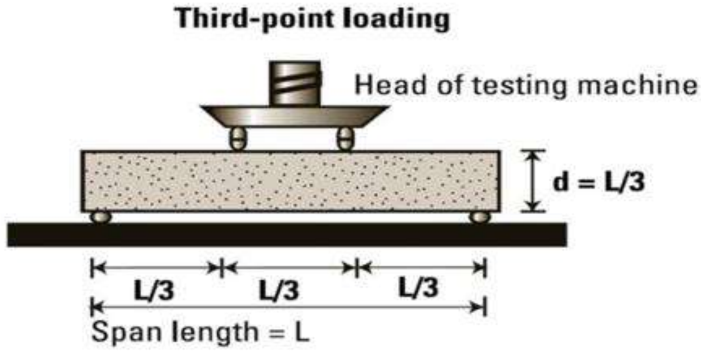


Fig.3.6: Flexural Strength Test Arrangement (IS: 516-1959)

The flexural strength of beams is tested by the method conforming to IS: 516-1959. The frame used in UTM machine for testing of beams was be so adjusted that the rollers of frame were at 5.0 cm from both the ends. The load was applied through two similar rollers mounted at the third points of the supporting span that is, spaced at 20 or 13.3 cm center to center. The load mechanism be divided the load equally between the two rollers, and all rollers were mounted in such a manner that the load is applied axially and without subjecting the specimen to any torsional stresses or restraints. The loading rate was kept at 400 Kg/min for 15.0 cm specimens. Fig.3.7 shows testing of beam specimen under automatic UTM machine.

Fig.3.7: Beam Testing Arrangement

Calculation of flexural strength: The Flexural Strength or modulus of rupture (**fb**) is calculated using the below provided expressions:

1. $fb = Pl/bd^2$ (when a > 20.0cm for 15.0cm specimen or > 13.0cm for 10cm specimen) or

2. $f_b = 3Pa/bd^2$ (when a < 20.0cm but > 17.0 for 15.0cm specimen or < 13.3 cm but > 11.0cm for 10.0cm specimen.)

where,

a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen (cm)

b = width of specimen (cm)

d = failure point depth (cm)

l = supported length (cm)

P = max. Load (kg)

3.4 CONCRETE MIX PROPORTIONING

3.4.1 Test Data for materials

1.	Cement Used	OPC grade 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	2.65
6.	Specific gravity of Silica Fume	2.4
7.	Specific gravity of Alccofine-1203	2.86
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 Coarse Aggregate	Conforming to Table 4 (IS: 383-1970)
12.	Sieve Analysis of Fine Aggregate	Conforming to Zone II (IS: 383-1970)

3.4.2 Mix proportions used in the present study

In the mix proportioning, fixed water-binder ratios of 0.18 were taken for the development of UHPC. Four trial mixes were prepared with different alcoffine content of 10%, 15% and 20% (M1, M2, M3 and M4). In addition to this, three different percentages (0.50%, 1.00%, and 1.50%) of steel fibers were added to each mix to study the variations in concrete compressive and flexural strength. Three cubes and two beams for each mix and each percentage of steel fibers were cast to study the behaviour of UHPC. The ingredients used in developing UHPC and their varying percentages are shown in Table 3.10 below:

Table 3.10: Percentage of ingredients in various trial mixes

Trial Mix	Silica Fume (%)	Nano Silica (%)	Alccofine (%)	Steel Fibers (%)
M00	8	2	0	0
M01	8	2	0	0.5
M02	8	2	0	1.0
M03	8	2	0	1.5
M10	8	2	10	0
M11	8	2	10	0.5
M12	8	2	10	1.0
M13	8	2	10	1.5
M20	8	2	15	0
M21	8	2	15	0.5
M22	8	2	15	1.0
M23	8	2	15	1.5
M30	8	2	20	0
M31	8	2	20	0.5
M32	8	2	20	1.0
M33	8	2	20	1.5

The final mix proportions used to develop UHPC matrix are shown in Table 3.11 (a), 3.11(b), 3.11 (c) and 3.11 (d). A constant workability, of 50 to 75 mm slump, was maintained for all the mixes by varying the Superplasticizer dosage 1.8%.

Table 3.11 (a): Mix Proportions for alccofine = 0%

Material	Trial 1
Water-Binder ratio	0.18
Water (kg/m^3)	150
Cement (kg/m^3)	750
FA (kg/m^3)	491.57
CA (20 mm) (kg/m^3)	679.34

CA (10 mm) (kg/m^3)	331.29
SF (kg/m^3)	66.70
NS (kg/m^3)	16.70
AF (kg/m^3)	0
Superplasticizer (kg/m^3)	15
Steel Fibers (kg/m^3)	0
	3.75
	7.5
	11.25

Table 3.11 (b): Mix Proportions for alccofine = 10%

Material	Trial 2
Water-Binder ratio	0.18
Water (kg/m^3)	150
Cement (kg/m^3)	666.70
FA (kg/m^3)	491.42
CA (20 mm) (kg/m^3)	679.12
CA (10 mm) (kg/m^3)	331.18
SF (kg/m^3)	66.70
NS (kg/m^3)	16.70
AF (kg/m^3)	83.40
Superplasticizer (kg/m^3)	15
Steel Fibers (kg/m^3)	0
	3.33
	6.7
	10

Table 3.11 (c): Mix Proportions for alccofine = 15%

Material	Trial 3
Water-Binder ratio	0.18
Water (kg/m^3)	150

Cement (kg/m^3)	625
FA (kg/m^3)	491.34
CA (20 mm) (kg/m^3)	679.01
CA (10 mm) (kg/m^3)	331.13
SF (kg/m^3)	66.70
NS (kg/m^3)	16.70
AF (kg/m^3)	125
Superplasticizer (kg/m^3)	15
Steel Fibers (kg/m^3)	0
	3.12
	6.25
	9.38

Table 3.11 (d): Mix Proportions for alccofine = 20%

Material	Trial 4
Water-Binder ratio	0.18
Water (kg/m^3)	150
Cement (kg/m^3)	583.33
FA (kg/m^3)	491.26
CA (20 mm) (kg/m^3)	678.91
CA (10 mm) (kg/m^3)	331.08
SF (kg/m^3)	66.70
NS (kg/m^3)	16.70
AF (kg/m^3)	166.70
Superplasticizer (kg/m^3)	15
Steel Fibers (kg/m^3)	0
	2.92
	5.83
	8.75

CHAPTER 4: RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter, results obtained from compressive and flexural test conducted on UHPC concrete mix, prepared using the proportions laid down in Table 3.11 (a), 3.11 (b) and 3.10 (c), are presented and discussed. The various combination percentages of silica fume, nano silica and GGBS were incorporated into the mix, along with OPC 53 grade cement and the aggregates, to determine the best proportion of materials that can provide the enhanced mechanical properties. The experimental program consisted of casting, curing and testing of concrete specimens at 28 days. The experimental program included the following:

1. Testing the physical and chemical properties of materials used for making concrete.
2. Trial mixing to design mixes for ultra-high-performance concrete.
3. Casting and curing of specimens.
4. Cubical specimens of size 150mm x 150mm x 150mm were tested for the compressive strength of concrete.
5. Beam specimens of size 150mm x 150mm × 700 mm were tested for the flexural strength of concrete.

4.2 COMPRESSIVE STRENGTH TEST RESULTS

4.2.1 Compressive strength

Compressive strength is the maximum compressive stress that a material can withstand without any fracture or rupture when a gradual load is applied. It is defined as the ratio of maximum load to the cross-sectional area of the specimen in compression test. Concrete is used in structure mainly to resist the compressive forces. Failure of concrete members under compression takes place in its vertical plane along the diagonal.

4.2.2 Test Procedure and Results

Cubes of size 150 mm ×150 mm ×150 mm were cast to test the compressive strength of both controlled as well as concrete mix with steel fibers. The mix compositions are given in Table 3.11 (a), 3.11 (b) and 3.11 (c). The mix with varying percentage of alccofine and steel fibers were prepared and cast into cubes. In this study, the mixing was done using a rotary mixer available in laboratory. The binder materials like cement, alccofine and silica fume were first hand mixed properly by use of trowel until a uniform colored blend is obtained. The mixer is cleaned properly and dried and subsequently coarse and fine aggregates in desired quantity are added into the mixer and mixer was rotated for 1-2 minutes. After this, the blend of binding materials is added to the mixer and was rotated to mix properly for 4-5 minutes. After all the necessary ingredients are added into the mix, half the quantity of water admixed with the superplasticizer and nano silica are added to the mix and mixer is rotated and remaining half water was added into the mix after 2-3 minutes. The mixer is rotated for 5-7 minutes to achieve the proper mix of desired concrete. A constant workability of 50 to 75 mm slump was maintained for all the mixes by varying the superplasticizer dosage. The cubes were tested at the age of 28 days. The time was reckoned from the time of addition of water to the dry ingredients. The specimens were tested on 500-ton ACTM as shown in the Fig.4.1 as per the procedure laid shown in section 3.3.3 in the previous chapter.

Fig.4.1: Cube under compression in Automatic Compression Testing Machine (ACTM)

The test results for 7 days and 28 days for control mix as well as modified mixes are shown in the Table 4.1, 4.2, 4.3, 4.4.

Table 4.1: Compression strength results for trial mix 1 having alccofine = 0%

Fiber	Water	Cement	FA	CA (20)	CA (10)	SF	NS	AF	7D	28D
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	750	491.57	679.34	331.29	8	2	0	66.5	101.90
0.50	150	750	491.57	679.34	331.29	8	2	0	69.7	105.20

1.00	150	750	491.57	679.34	331.29	8	2	0	75.0	108.10
1.50	150	750	491.57	679.34	331.29	8	2	0	78.2	115.25

Table 4.2: Compression strength results for trial mix 2 having alccofine = 10%

Fibers	**Water**	**Cement**	**FA**	**CA (20)**	**CA (10)**	**SF**	**NS**	**AF**	**7D**	**28D**
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	666.70	491.42	679.12	331.18	8	2	10	82.4	118.20
0.50	150	666.70	491.42	679.12	331.18	8	2	10	85.9	124.75
1.00	150	666.70	491.42	679.12	331.18	8	2	10	90.8	130.22
1.50	150	666.70	491.42	679.12	331.18	8	2	10	95.0	135.52

Table 4.3: Compression strength results for trial mix 3 having alccofine = 15%

Fibers	**Water**	**Cement**	**FA**	**CA (20)**	**CA (10)**	**SF**	**NS**	**AF**	**7D**	**28D**
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	625	491.34	679.01	331.13	8	2	15	79.35	115.50
0.50	150	625	491.34	679.01	331.13	8	2	15	82.3	122.95
1.00	150	625	491.34	679.01	331.13	8	2	15	86.2	127.0
1.50	150	625	491.34	679.01	331.13	8	2	15	90.4	133.70

Table 4.4: Compression strength results for trial mix 4 having alccofine = 20%

Fibers	**Water**	**Cement**	**FA**	**CA (20)**	**CA (10)**	**SF**	**NS**	**AF**	**7D**	**28D**
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	583.33	491.26	678.91	331.07	8	2	20	77.4	113.20
0.50	150	583.33	491.26	678.91	331.07	8	2	20	81.8	120.80
1.00	150	583.33	491.26	678.91	331.07	8	2	20	85.0	125.70
1.50	150	583.33	491.26	678.91	331.07	8	2	20	89.6	134.8

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 table 4.1 **Mix 1** show the result of mix trial having alccofine 0% (containing 2% nano silica, 8% silica fume) have compressive strength at 7 days is 66.5 MPa and 28 days 101.90 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the compressive strength recorded at 7 days 69.7 MPa and 28 days 105.20 MPa. When the percentage of steel fibers are increased to 1.00% the compressive strength found was at 7 days 75.0 MPa and 28 days 108.10 MPa. Again, the percentage of steel fibers increase to 1.50% and the compressive strength reported at 7 days 78.2 MPa and 28 days 115.25 MPa of the control mix. Fig.4.2 represent the trend of increase in strength with varying percentage of steel fibers in Mix 1.

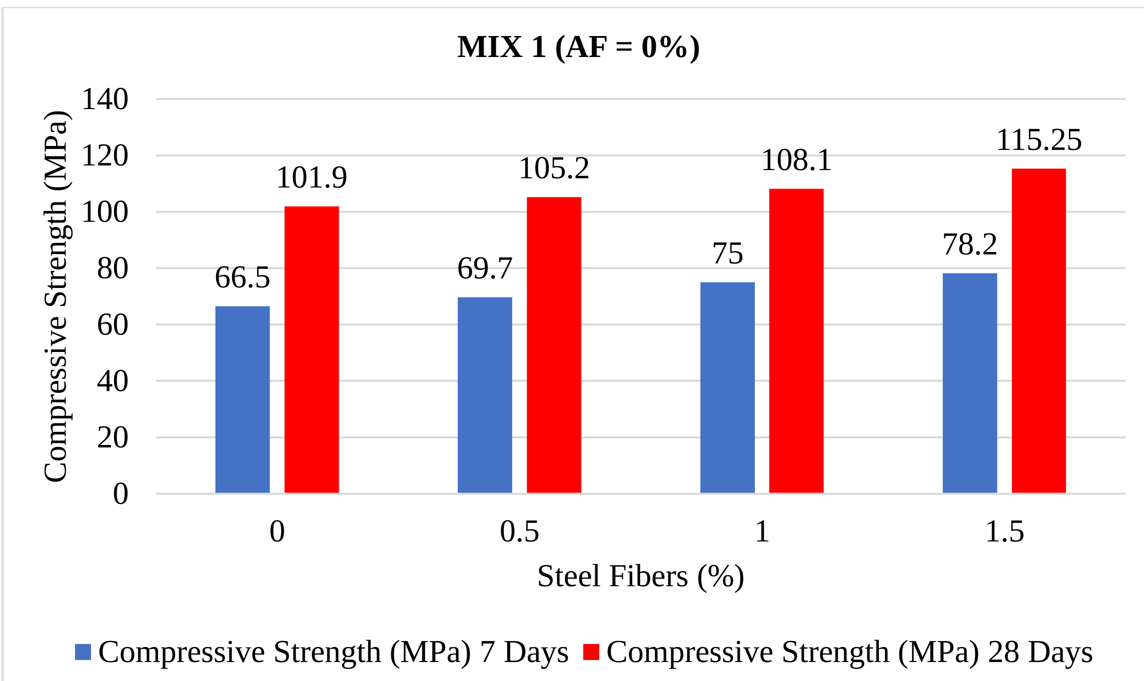


Fig.4.2: Variation of compressive strength for Mix 1 with AF = 0%

Fig.4.2 clearly show that the compressive strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 1 the compressive strength increase 4.81% at 7 days and 3.24% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the compressive strength increases at 7 days 7.60% and 28 days increased 2.75%. Again, the steel fibers added in mix 1.50% and compressive strength increase 4.27% at 7 days and 28 days increase 6.62%. Overall increase in the compressive strength is 13.10% at 28 days. Maximum percentage of compressive strength increase observed with 1.5% steel fibers at 28 days. The compressive strength should be in between 120 to 150 MPa but MIX 1 even with 1.5% fiber content could not achieve this strength. We can't get the desired strength for UHPC, only increase the percentage of steel fibers. For development of UHPC required some special material like nano silica, silica fume and alccofine etc.

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

The table 4.2 **Mix 2** show the result of mix trial having alccofine 10% (containing 2% nano silica, 8% silica fume) have compressive strength at 7 days is 82.4 MPa and 28 days 118.20 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the compressive strength recorded at 7 days 85.9 MPa and 28 days 124.75 MPa. When the percentage of steel fibers are increased to 1.00% the compressive strength found was at 7 days 90.8 MPa and 28 days 130.22 MPa. Again, the percentage of steel fibers increase to 1.50% and the compressive strength reported at 7 days 95.00 MPa and 28 days 135.52 MPa of the control mix. Fig.4.3 represent the trend of increase in strength with varying percentage of steel fibers in Mix 2.

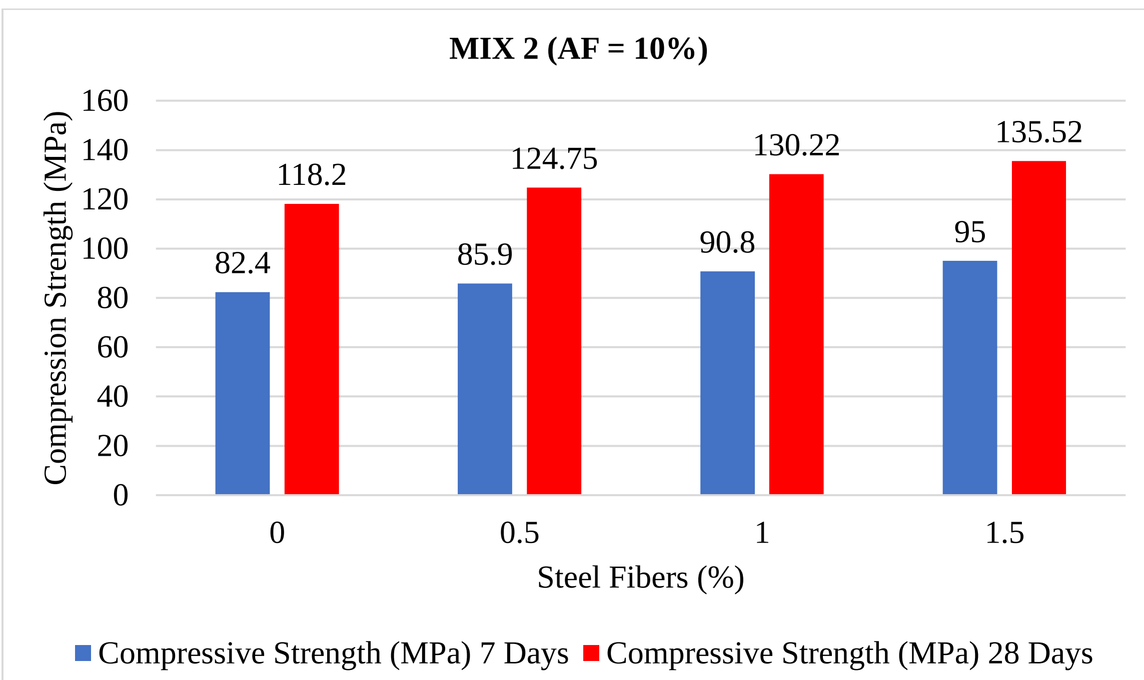


Fig.4.3: Variation of compressive strength for Mix 2 with AF = 10%

Fig.4.3 clearly show that the compressive strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 2 the compressive strength increase 4.24% at 7 days and 5.54% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the compressive strength increases at 7 days 5.70% and 28 days increased 4.38%. Again, the steel fibers added in mix 1.50% and compressive strength increase 4.63% at 7 days and 28 days increase 4.07%. Overall increase in the compressive strength is 14.65% at 28 days. Maximum percentage of compressive strength increase observed with 1.5% steel fibers at 28 days. The compressive strength of 135.52 MPa at 28 days which is lies in the range of UHPC. It is possible to develop a mix with a compressive strength of over 120 MPa at 28 days of curing with 1.50% steel fibers along with the optimum percentage of nano silica, silica fume and alccofine at the w/b ratio of 0.18.

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

The table 4.3 **Mix 3** show the result of mix trial having alccofine 15% (containing 2% nano silica, 8% silica fume) have compressive strength at 7 days is 79.35 MPa and 28 days 115.50 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the compressive strength recorded at 7 days 82.30 MPa and 28 days 122.95 MPa. When the percentage of steel fibers are increased to 1.00% the compressive strength found was at 7 days 86.20 MPa and 28 days 127.00 MPa. Again, the percentage of steel fibers increase to 1.50% and the compressive strength reported at 7 days 90.40 MPa and 28 days 133.70 MPa of the control mix. Fig.4.4 represent the trend of increase in strength with varying percentage of steel fibers in Mix 3.

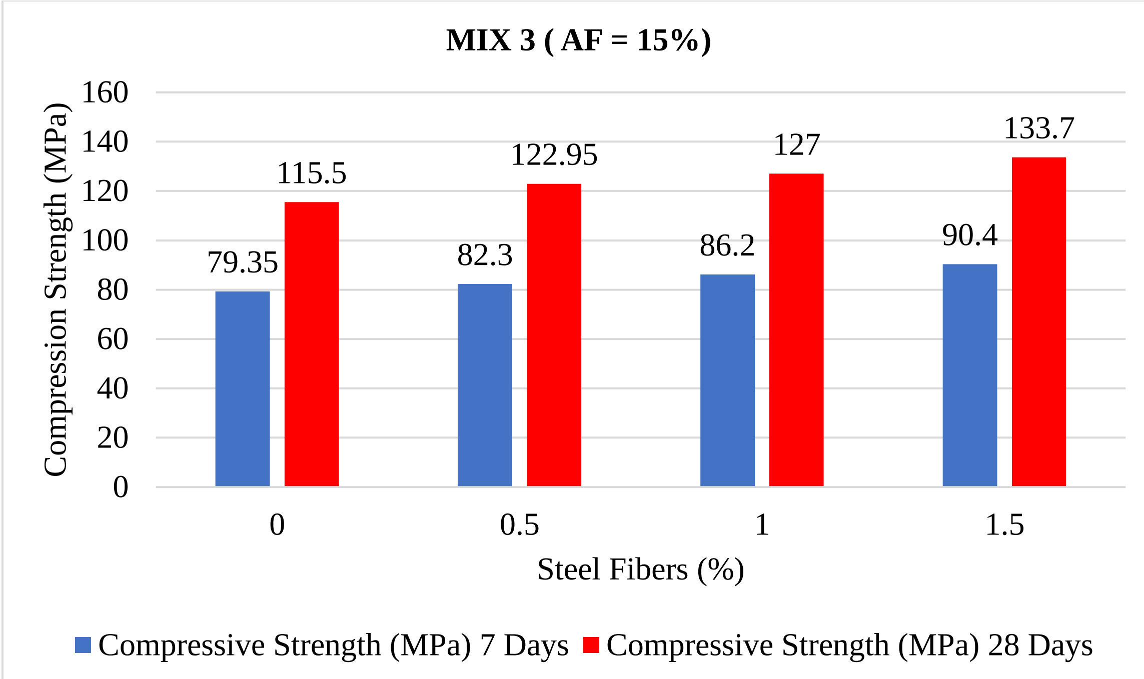


Fig.4.4: Variation of compressive strength for Mix 3 with AF = 15%

Fig.4.4 clearly show that the compressive strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 3 the compressive strength increase 3.72% at 7 days and 6.45% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the compressive strength increases at 7 days 4.74% and 28 days increased 3.30%. Again, the steel fibers added in mix 1.50% and compressive strength increase 4.87% at 7 days and 28 days increase 5.30%. Overall increase in the compressive strength is 15.76% at 28 days. Maximum percentage of compressive strength increase observed with 1.5% steel fibers at 28 days. The compressive strength of 133.70 MPa at 28 days which is lies in the range of UHPC. It is possible to develop a mix with a compressive strength of over 120 MPa at 28 days of curing with 1.50% steel fibers along with the optimum percentage of nano silica, silica fume and alccofine at the w/b ratio of 0.18.

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

The table 4.4 **Mix 4** show the result of mix trial having alccofine 20% (containing 2% nano silica, 8% silica fume) have compressive strength at 7 days is 77.4 MPa and 28 days 113.20 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the compressive strength recorded at 7 days 81.8 MPa and 28 days 120.80 MPa. When the percentage of steel fibers are increased to 1.0% the compressive strength found was at 7 days 85.0 MPa and 28 days 125.70 MPa. Again, the percentage of steel fibers increase to 1.50% and the compressive strength reported at 7 days 89.6 MPa and 28 days 134.8 MPa of the control mix. Fig 4.5 represent the trend of increase in strength with varying percentage of steel fibers in Mix 4.

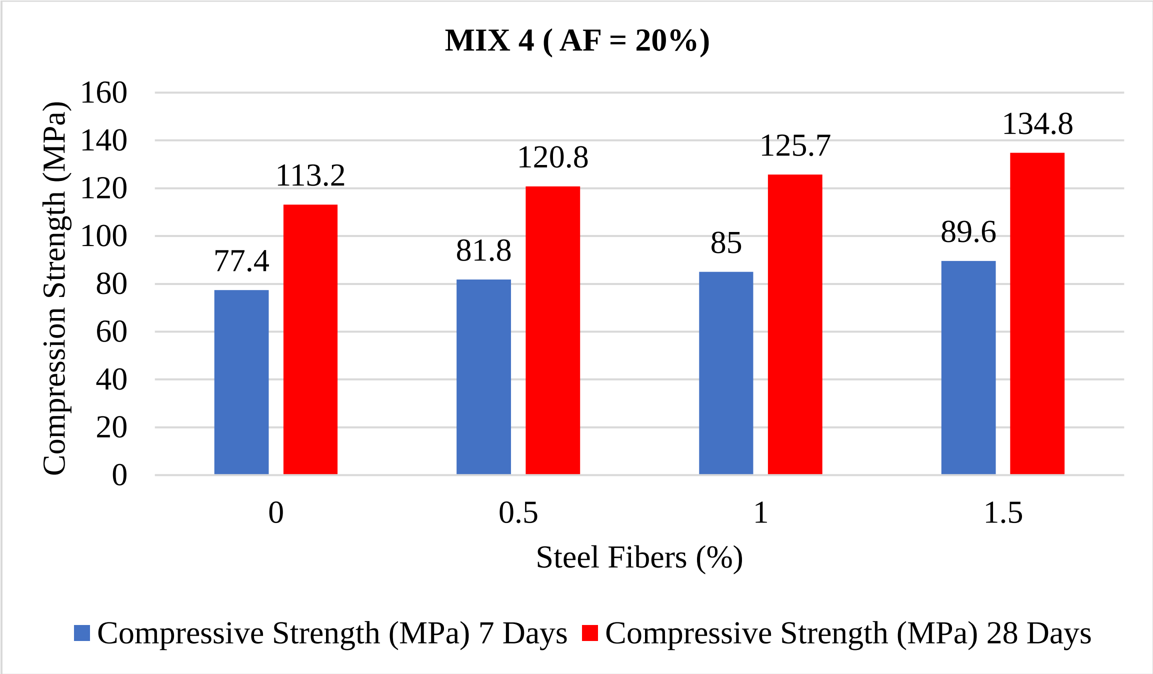
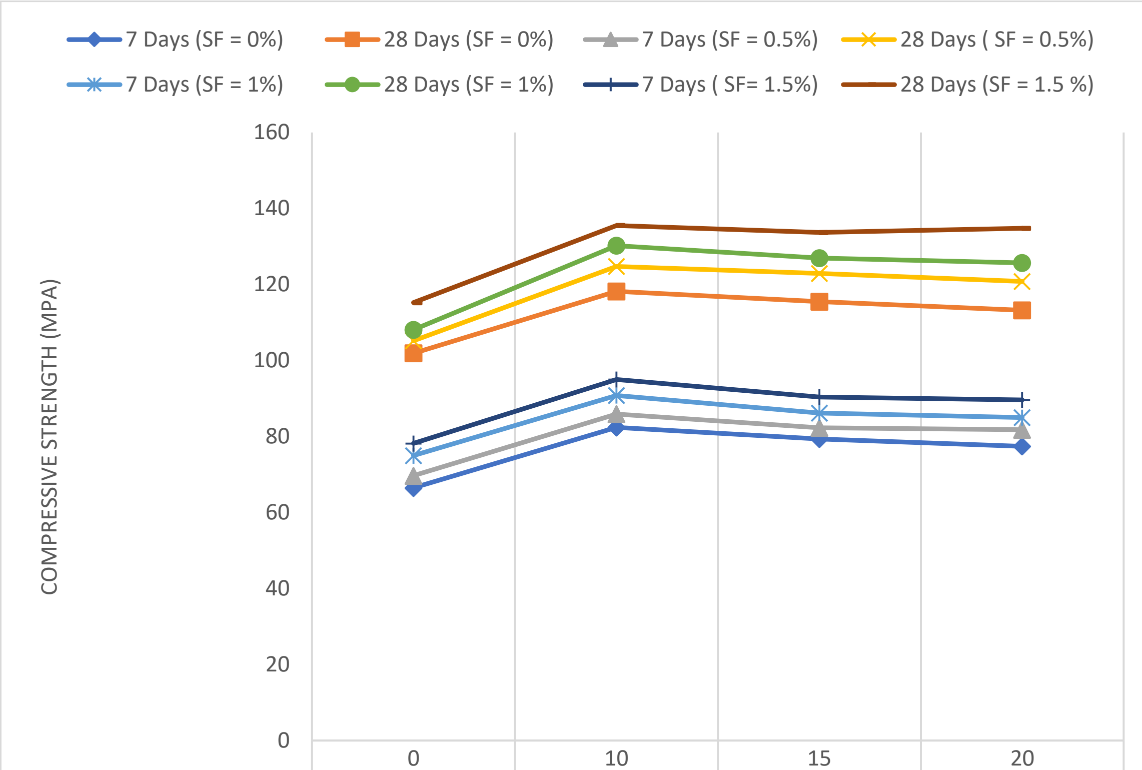


Fig.4.5: Variation of compressive strength for Mix 4 with AF = 20%

Fig.4.5 clearly show that the compressive strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 4 the compressive strength increase 5.68% at 7 days and 6.72% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the compressive strength increases at 7 days 3.90% and 28 days increased 4.05%. Again, the steel fibers added in mix 1.50% and compressive strength increase 5.411% at 7 days and 28 days increase 7.24%. Overall increase in the compressive strength is 19.08% at 28 days. Maximum percentage of compressive strength increase observed with 1.5% steel fibers at 28 days. The compressive strength of 134.80 MPa at 28 days which is lies in the range of UHPC. It is possible to develop a mix with a compressive strength of over 120 MPa at 28 days of curing with 1.50% steel fibers along with the optimum percentage of nano silica, silica fume and alccofine at the w/b ratio of 0.18.

4.3.5 Effect of variation of alccofine on compressive strength of UHPC

Effect on the compressive strength of UHPC due to variation of alccofine and steel fibers for all mix at curing of 7 days and 28 days is shown in Fig.4.6.



	0	10	15	20
7 Days (SF = 0%)	66.5	82.4	79.35	77.4
28 Days (SF = 0%)	101.9	118.2	115.5	113.2
7 Days (SF = 0.5%)	69.7	85.9	82.3	81.8
28 Days (SF = 0.5%)	105.2	124.75	122.95	120.8
7 Days (SF = 1%)	75	90.8	86.2	85
28 Days (SF = 1%)	108.1	130.22	127	125.7
7 Days (SF= 1.5%)	78.2	95	90.4	89.6
28 Days (SF = 1.5 %)	115.25	135.52	133.7	134.8

Fig.4.6: Effect of variation of alccofine on compressive strength of UHPC

Fig.4.6 shown that the alccofine increase the compressive strength of UHPC. The alccofine use as a replacement of cement (10%, 15% and 20%) with different percentage of steel fiber. The maximum compressive strength at 7 days and 28 days containing 2 % nano silica, 8% silica fume and 10% alccofine. The lowest compression strength recorded of Mix 4 at 28 days for 0.5% and 1% of steel fibers. The compressive strength lowest recorded for 1.5% of steel fiber in Mix 3.

Addition of steel fiber with low w/b ratio play a significant role in development of UHPC. Also, some special material required to get the desired strength of UHPC.

4.3.6 Ultra High Performance Concrete Mixes

All the mixes in this study, whose strength is more than 120 MPa at 28 days of curing are shown in below Fig.4.7.

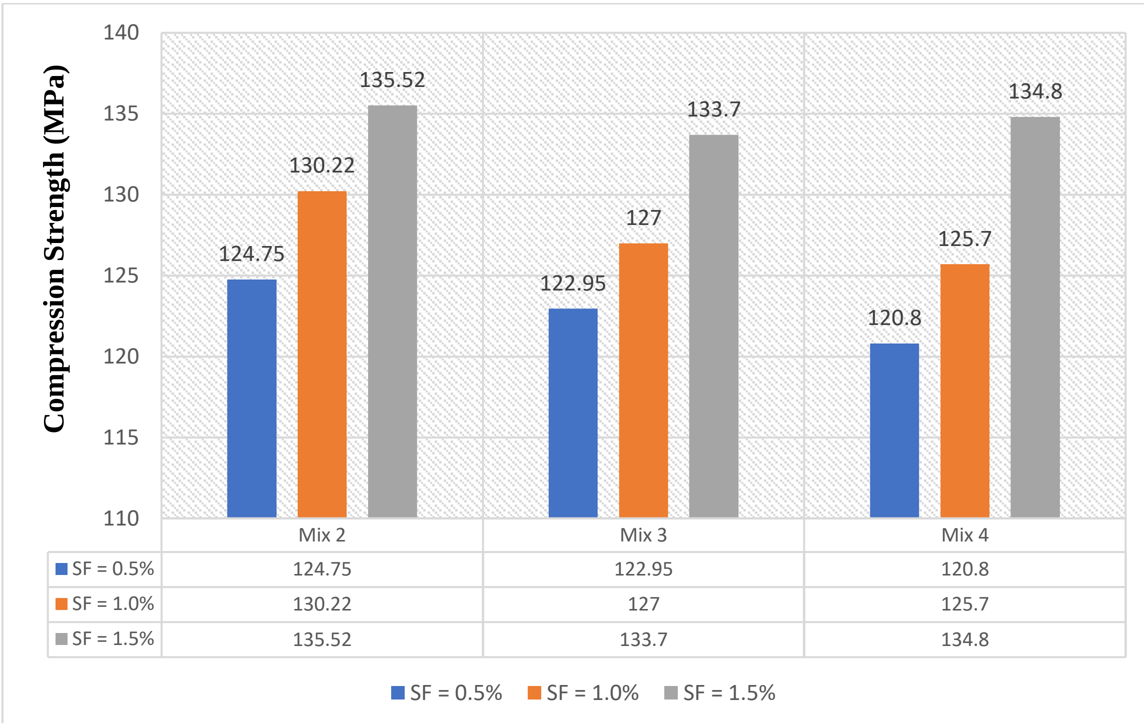


Fig. 4.7 UHPC range achieved for Trial Mix 2, 3 and 4

4.3.7 Crack pattern observed in cube of UHPC

The below fig. 4.8 shows the failure pattern of cube having AF 10% and steel fiber is 1.5%. Both macro and minor crack are occurred in specimen. Some crack occurred parallel to the direction of applied load and some occurred at angle of the applied load. Some portion of specimen are spalling due to the applied load.

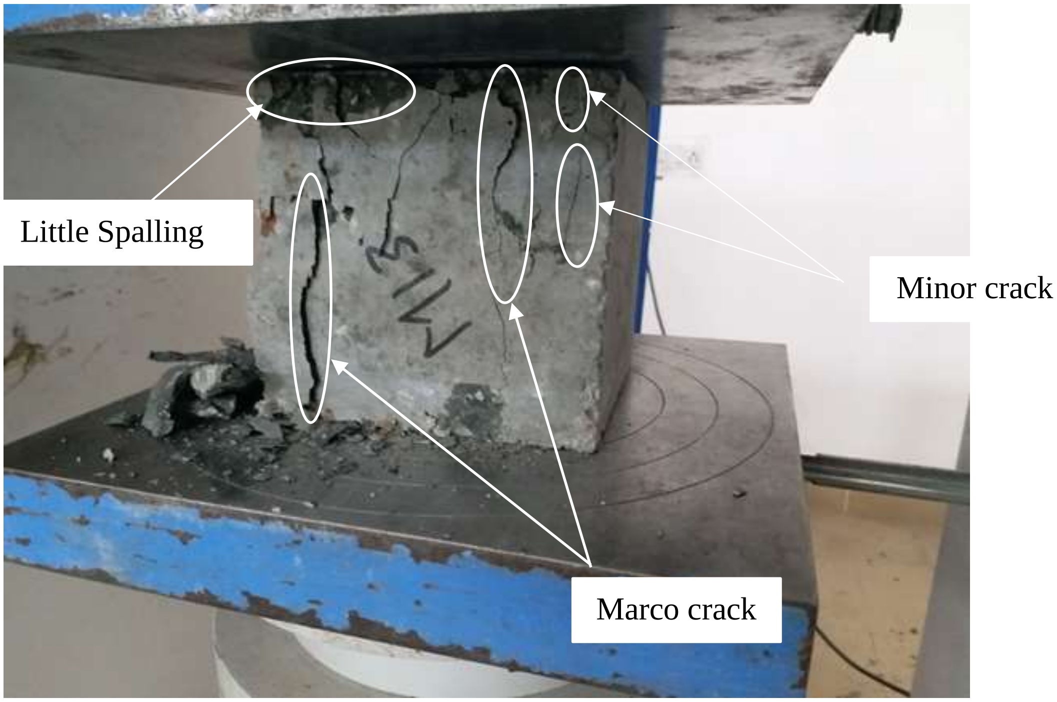


Fig. 4.8 Failure pattern of cube after testing

4.4 FLEXURAL STRENGTH TEST RESULTS

4.4.1 Flexural strength

Flexural strength test is the measure of tensile strength of concrete. Flexural strength also known as modulus of rupture or bend strength is defined as the stress material absorbs just before it yields in a flexure test. Flexural strength is basically the maximum capability of the material to withstand transverse load in yielding or fracture. It lies on range of 10% to 20% of the compressive strength of concrete depending on the type, size and volume of coarse aggregates used.

4.4.2 Test procedure and Results

Beams of size 150 mm × 150 mm × 700 mm were cast to test the flexural strength of both controlled as well as concrete mix with steel fibers. The mix composition is given in Table 3.11 (a), 3.11 (b), 3.11 (c) and 3.11 (d). The mix with varying percentage of alccofine and steel fibers were prepared and cast into beams. In this study, the mixing was done by a rotary mixer available in laboratory. The procedure of mixing was same as discussed in subsection 4.2.2

A constant workability of 50 to 75 mm slump was maintained for all the mixes. The beams were tested at the curing age of 7 days and 28 days. The time was calculated from the time of addition of water to the dry ingredients. The specimens were tested on UTM as shown in the Fig.3.7 as per the procedure laid sown in section 3.3.4 in the previous chapter.

Fig. 4.9: Beam under UTM

The testing of beam specimens under UTM is provided in Fig.4.8. The test results for 28 days curing for control mix as well as modified mixes are shown in the Tables 4.5 ,4.6, 4.7 and 4.8.

Table 4.5: Flexural strength results for trial mix having alccofine (M1) = 0%

Fiber	**Water**	**Cement**	**FA**	**CA (20)**	**CA (10)**	**SF**	**NS**	**AF**	**7D**	**28D**
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	750	491.57	679.34	331.29	8	2	0	5.51	11.20
0.50	150	750	491.57	679.34	331.29	8	2	0	6.4	11.98
1.00	150	750	491.57	679.34	331.29	8	2	0	6.71	12.67
1.50	150	750	491.57	679.34	331.29	8	2	0	9.54	14.25

Table 4.6: Flexural strength results for trial mix having alccofine (M2) = 10%

Fiber	**Water**	**Cement**	**FA**	**CA (20)**	**CA (10)**	**SF**	**NS**	**AF**	**7D**	**28D**
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	750	491.57	679.34	331.29	8	2	0	6.97	14.184
0.50	150	750	491.57	679.34	331.29	8	2	0	7.59	15.26
1.00	150	750	491.57	679.34	331.29	8	2	0	10.21	16.73
1.50	150	750	491.57	679.34	331.29	8	2	0	11.65	17.20

Table 4.7: Flexural strength results for trial mix having alccofine (M3) = 15%

Fiber	**Water**	**Cement**	**FA**	**CA (20)**	**CA (10)**	**SF**	**NS**	**AF**	**7D**	**28D**
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	750	491.57	679.34	331.29	8	2	0	7.46	13.18
0.50	150	750	491.57	679.34	331.29	8	2	0	8.81	14.10
1.00	150	750	491.57	679.34	331.29	8	2	0	10.02	14.69
1.50	150	750	491.57	679.34	331.29	8	2	0	11.23	15.78

Table 4.8: Flexural strength results for trial mix having alccofine (M4) = 20%

Fiber	**Water**	**Cement**	**FA**	**CA (20)**	**CA (10)**	**SF**	**NS**	**AF**	**7D**	**28D**
(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)	(%)	MPa	MPa
0.00	150	750	491.57	679.34	331.29	8	2	0	6.30	12.08
0.50	150	750	491.57	679.34	331.29	8	2	0	7.10	13.99
1.00	150	750	491.57	679.34	331.29	8	2	0	8.02	14.30
1.50	150	750	491.57	679.34	331.29	8	2	0	8.88	15.15

4.5 DISCUSSION OF FLEXURAL STRENGTH TEST RESULTS

In this experimental investigation, crimped steel fibers were used in four mixes (alcoffine 0%, 10%, 15% and 20%) with constant water to binder ratios (0.18). For all the mix types, three different fiber dosages of crimped shaped steel fibers were also investigated for studying variation in flexural strength and the results are tabulated in Table 4.5, 4.6, 4.7 and 4.8. In this discussion, result different alccofine content are analyzed and compared.

4.5.1 Effect of variation in percentage of steel fibers on flexural strength of concrete for Mix 1 (Alccofine = 0%)

The table 4.5 **Mix 1** show the result of mix trial having alccofine 0% (containing 2% nano silica, 8% silica fume) have flexural strength at 7 days is 6.51 MPa and 28 days 11.20 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the flexural strength recorded at 7 days 5.64 MPa and 28 days 11.98 MPa. When the percentage of steel fibers are increased to 1.0% the flexural strength found was at 7 days 6.71 MPa and 28 days 12.67 MPa.

Again, the percentage of steel fibers increase to 1.50% and the flexural strength reported at 7 days 9.54 MPa and 28 days 14.25 MPa of the control mix. Fig.4.10 represent the trend of increase in strength with varying percentage of steel fibers in Mix 1.

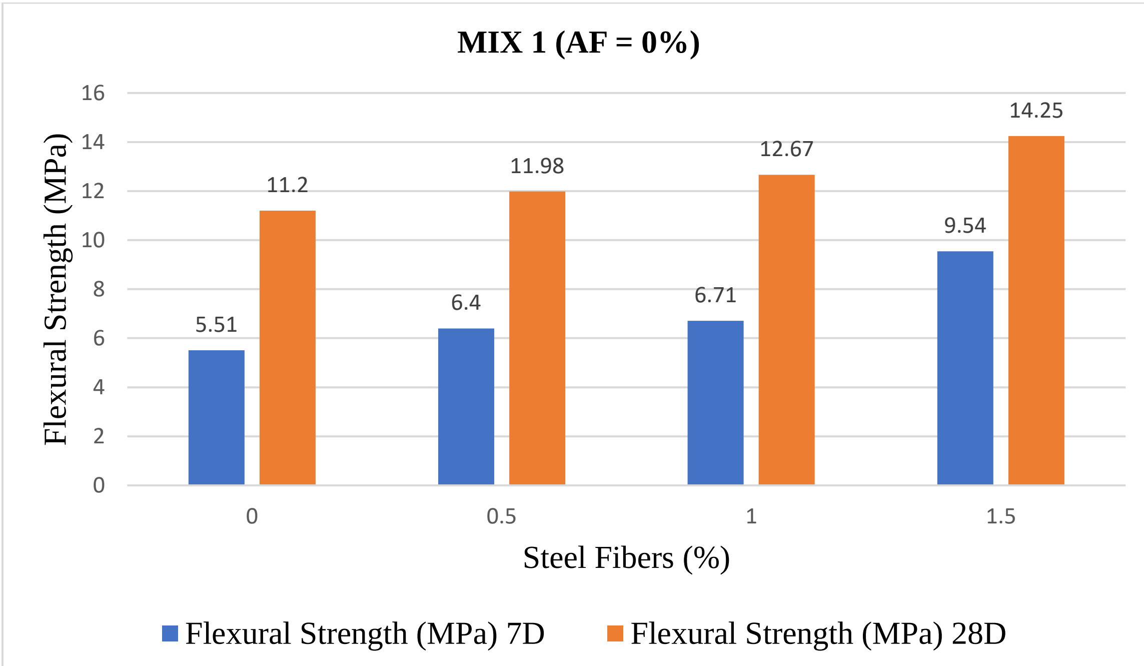


Fig.4.10: Variation of Flexural strength for Mix 1 with AF = 0%

Fig.4.10 clearly show that the flexural strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 1 the flexural strength increase 16.15% at 7 days and 6.96% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the flexural strength increases at 7 days 4.84% and 28 days increased 5.76%. Again, the steel fibers added in mix 1.50% and flexural strength increase 42.17% at 7 days and 28 days increase 12.47%. Overall increase in the flexural strength is 27.23% at 28 days. Maximum percentage of flexural strength increase observed with 1.5% steel fibers at 28 days.

4.5.2 Effect of variation in percentage of steel fibers on flexural strength of concrete for Mix 2 (Alccofine = 10%)

The table 4.6 **Mix 2** show the result of mix trial having alccofine 0% (containing 2% nano silica, 8% silica fume) have flexural strength at 7 days is 6.97 MPa and 28 days 14.18 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the flexural strength recorded at 7 days 7.59 MPa and 28 days 15.26 MPa. When the percentage of steel fibers are increased to 1.0% the flexural strength found was at 7 days 10.21 MPa and 28 days 16.73 MPa. Again, the percentage of steel fibers increase to 1.50% and the flexural strength reported at 7 days 11.65 MPa and 28 days 17.20 MPa of the control mix. Fig.4.11 represent the trend of increase in strength with varying percentage of steel fibers in Mix 2.

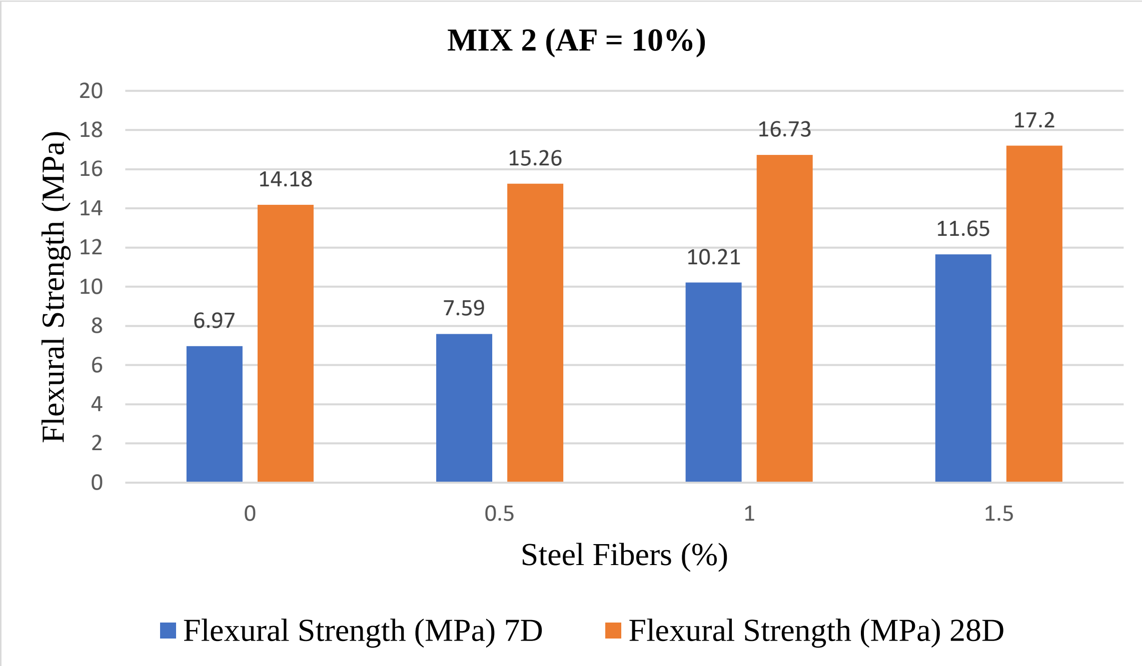


Fig.4.11: Variation of Flexural strength for Mix 2 with AF = 10%

Fig.4.11 clearly show that the flexural strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 1 the flexural strength increase 8.89% at 7 days and 7.60% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the flexural strength increases at 7 days 34.52% and 28 days increased 9.63%. Again, the steel fibers added in mix 1.50% and flexural strength increase 14.10% at 7 days and 28 days increase 2.80%. Overall increase in the flexural strength is 21.23% at 28 days. Maximum percentage of flexural strength increase observed with 1.5% steel fibers at 28 days.

4.5.3 Effect of variation in percentage of steel fibers on flexural strength of concrete for Mix 3 (Alccofine = 15%)

The table 4.7 **Mix 3** show the result of mix trial having alccofine 0% (containing 2% nano silica, 8% silica fume) have flexural strength at 7 days is 7.46 MPa and 28 days 13.18 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the flexural strength recorded at 7 days 8.81 MPa and 28 days 14.10 MPa. When the percentage of steel fibers are increased to 1.0% the flexural strength found was at 7 days 10.02 MPa and 28 days 14.69 MPa.

Again, the percentage of steel fibers increase to 1.50% and the flexural strength reported at 7 days 11.23 MPa and 28 days 15.78 MPa of the control mix. Fig 4.12 represent the trend of increase in strength with varying percentage of steel fibers in Mix 3.

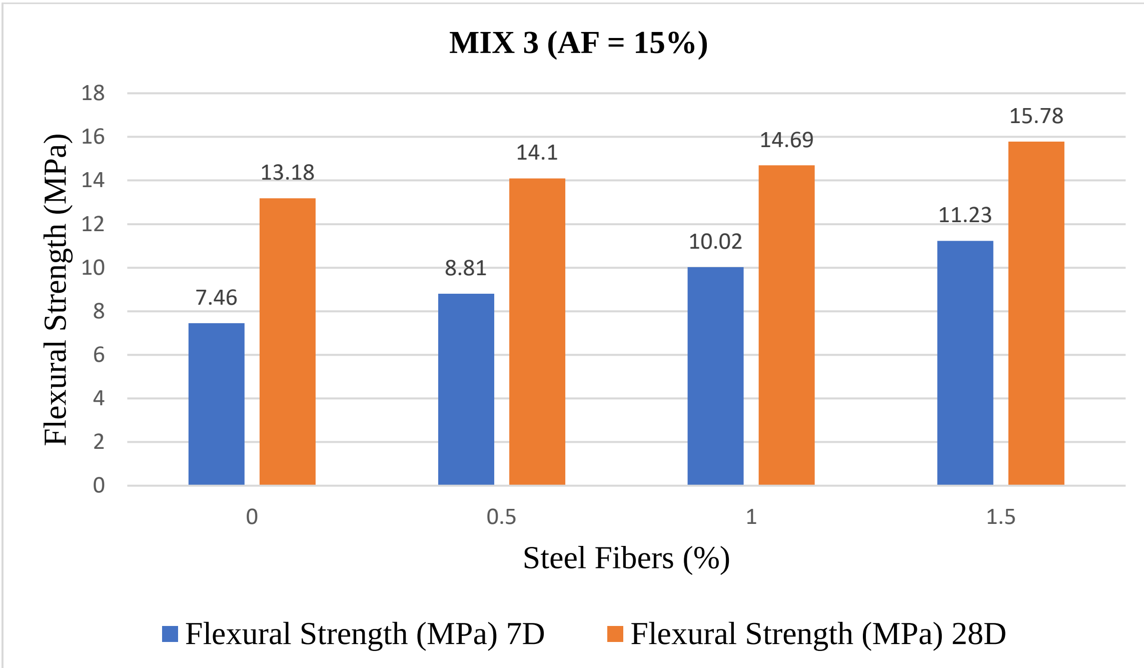


Fig.4.12: Variation of Flexural strength for Mix 3 with AF = 15%

Fig.4.12 clearly show that the flexural strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 1 the flexural strength increase 18.09% at 7 days and 6.98% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the flexural strength increases at 7 days 13.73% and 28 days increased 4.18%. Again, the steel fibers added in mix 1.50% and flexural strength increase 12.07% at 7 days and 28 days increase 7.42%. Overall increase in the flexural strength is 19.72% at 28 days. Maximum percentage of flexural strength increase observed with 1.5% steel fibers at 28 days.

4.5.4 Effect of variation in percentage of steel fibers on flexural strength of concrete for Mix 4 (Alccofine = 20%)

The table 4.8 **Mix 4** show the result of mix trial having alccofine 0% (containing 2% nano silica, 8% silica fume) have flexural strength at 7 days is 6.30 MPa and 28 days 12.08 MPa found without steel fibers. When the 0.50% (by volume of cement) steel fibers added in the mix the flexural strength recorded at 7 days 7.10 MPa and 28 days 13.99 MPa. When the percentage of steel fibers are increased to 1.0% the flexural strength found was at 7 days 8.02 MPa and 28 days 14.30 MPa.

Again, the percentage of steel fibers increase to 1.50% and the flexural strength reported at 7 days 8.88 MPa and 28 days 15.15 MPa of the control mix. Fig.4.13 represent the trend of increase in strength with varying percentage of steel fibers in Mix 4.

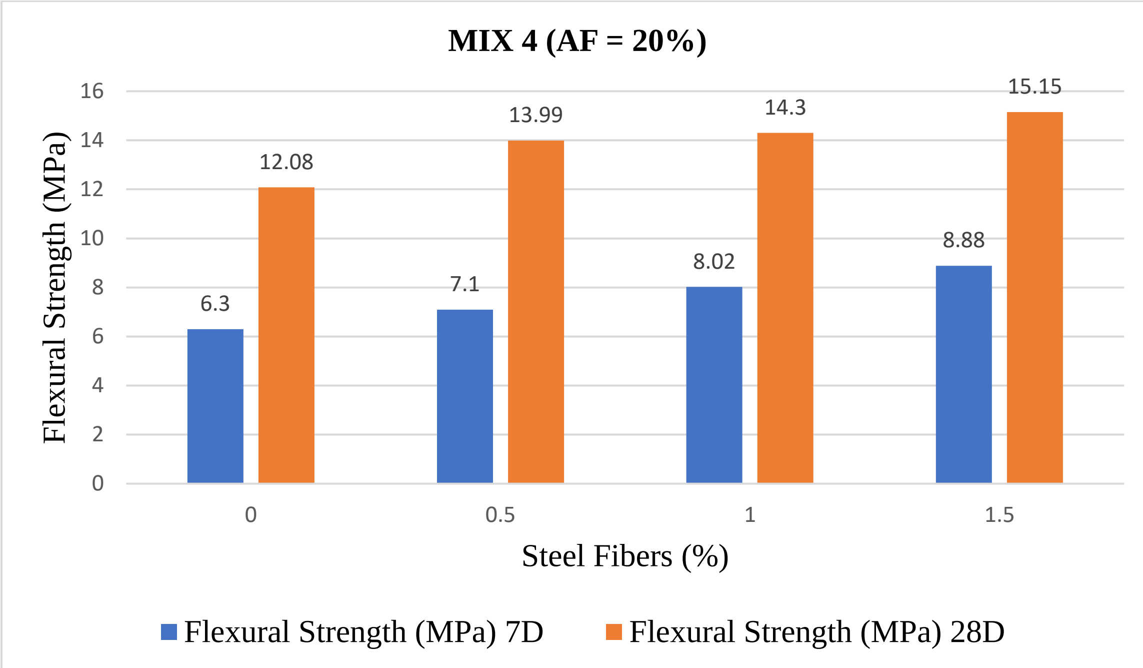
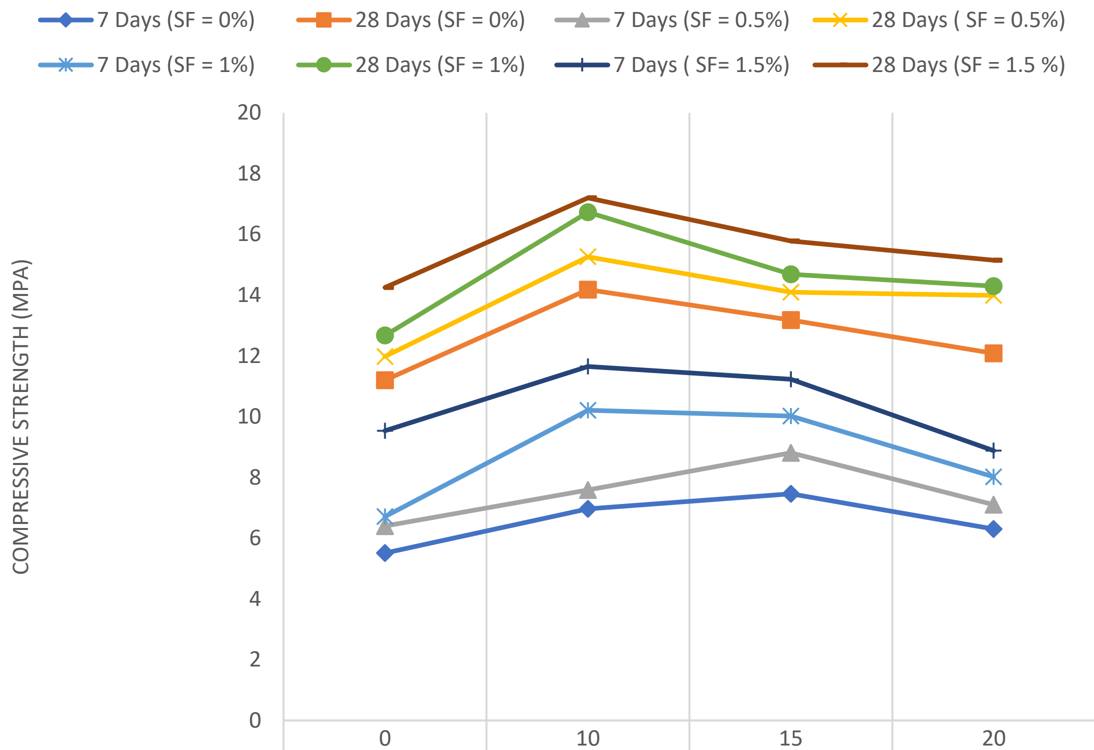


Fig.4.13: Variation of Flexural strength for Mix 4 with AF = 20%

Fig.4.13 clearly show that the flexural strength increases with the percentage of steel fibers increase. When 0.5% steel fibers added in the Mix 1 the flexural strength increase 12.61% at 7 days and 15.81% at 28 days. When the percentage of steel fiber increase 1.0% (of volume of cement) the flexural strength increases at 7 days 12.96% and 28 days increased 2.15%. Again, the steel fibers added in mix 1.50% and flexural strength increase 10.73% at 7 days and 28 days increase 5.94%. Overall increase in the flexural strength is 25.41% at 28 days. Maximum percentage of flexural strength increase observed with 1.5% steel fibers at 28 days.

4.5.5 Effect of variation of alccofine on flexural strength of UHPC

Effect on the flexural strength of UHPC due to variation of alccofine and steel fibers for all mix at curing of 7 days and 28 days is shown in Fig.4.14.



	0	10	15	20
7 Days (SF = 0%)	5.51	6.97	7.46	6.3
28 Days (SF = 0%)	11.2	14.18	13.18	12.08
7 Days (SF = 0.5%)	6.4	7.59	8.81	7.1
28 Days (SF = 0.5%)	11.98	15.26	14.1	13.99
7 Days (SF = 1%)	6.71	10.21	10.02	8.02
28 Days (SF = 1%)	12.67	16.73	14.69	14.3
7 Days (SF= 1.5%)	9.54	11.65	11.23	8.88
28 Days (SF = 1.5 %)	14.25	17.2	15.78	15.15

ALCCOFINE (%)

Fig.4.14: Effect of variation of alccofine on compressive strength of UHPC

Fig.4.14 shown that the alccofine increase the flexural strength of UHPC. The alccofine use as a replacement of cement (10%, 15% and 20%) with different percentage of steel fiber. The maximum flexural strength at 7 days and 28 days containing 2 % nano silica, 8% silica fume and 10% alccofine. The lowest compression strength recorded of Mix 4 at 28 days for 0.5%, 1% and 1.5% of steel fibers. Addition of steel fiber with low w/b ratio play a significant role in development of UHPC. Also, some special material required to get the desired strength of UHPC. The addition of steel fiber increases the flexural strength of the concrete.

4.5.6 Crack pattern observed in beam of UHPC

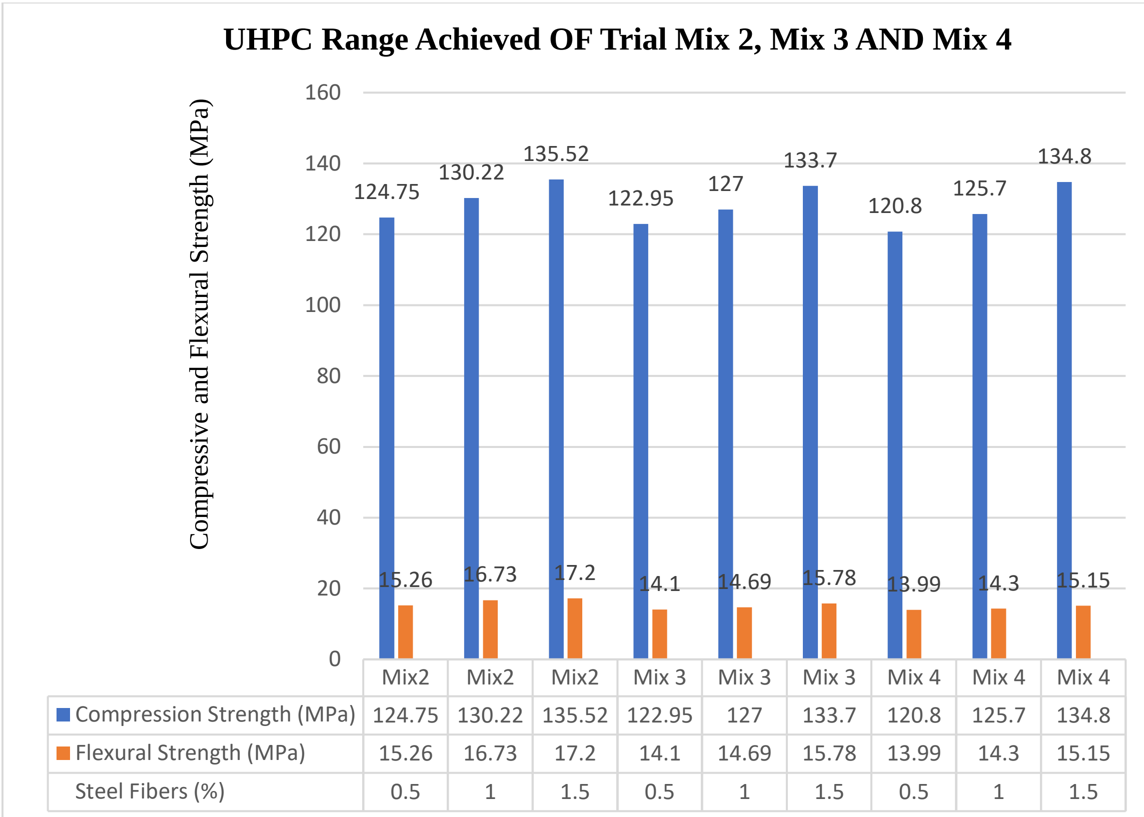
The below fig. 4.15 shows the failure pattern of beam having AF 10% and steel fibers is 1.5%. The crack was not observed when the load was increased linearly at the beginning of the test. The crack start at the bottom face of the beam is subjected to tension and increase linearly upward side in the beam. The fig. 4.15 Show that the crack is observed in the middle of the beam show the flexural failure.

Fig. 4.15 Failure pattern of beam

4.5.7 Comparison of compression and flexural strength of UHPC mixes

In this subsection, both compressive and flexural strength of all the mixes are compared in terms of the incremental increase in their strength. All the mixes in this study, whose strength is more than 120 MPa at 28 days of curing, are shown in below Fig.4.16.

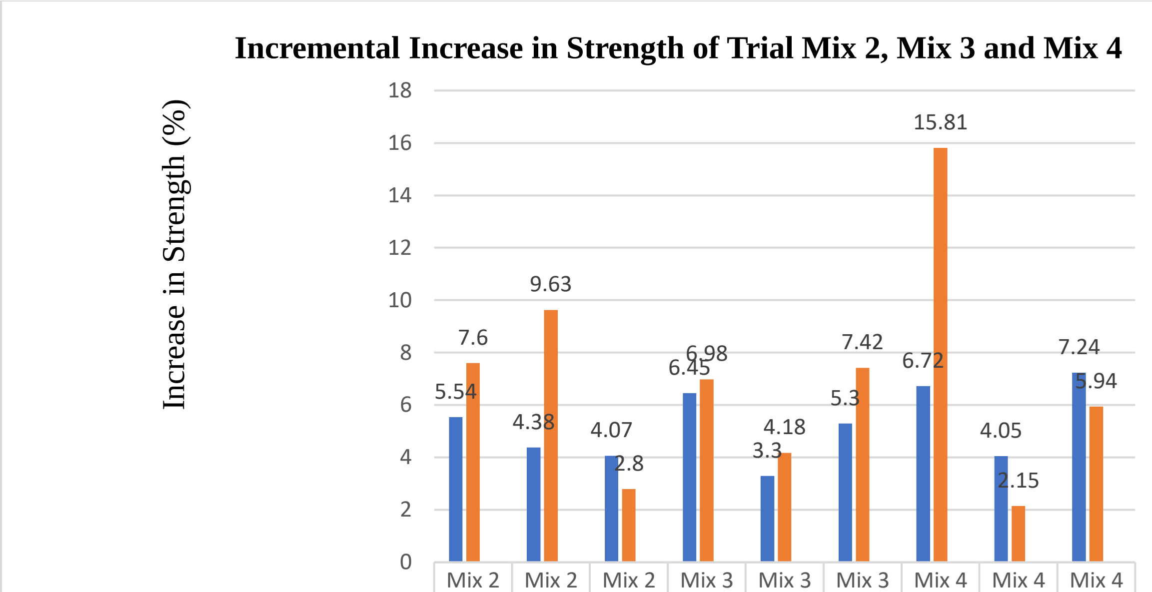
If we analyses, the results of compressive strength and flexural strength, the incremental increase in compressive strength is in range of 2.5% to 9% of 7 days and 28 days whereas for flexural strength the incremental increase is in the range of 3.5% to 42% of 7 days and 2.5% to 13% of 28 days. The incremental increase in compressive and flexural strength of UHPC mixes are shown in Fig.4.17.



	Mix2	Mix2	Mix2	Mix 3	Mix 3	Mix 3	Mix 4	Mix 4	Mix 4
Compression Strength (MPa)	124.75	130.22	135.52	122.95	127	133.7	120.8	125.7	134.8
Flexural Strength (MPa)	15.26	16.73	17.2	14.1	14.69	15.78	13.99	14.3	15.15
Steel Fibers (%)	0.5	1	1.5	0.5	1	1.5	0.5	1	1.5

Fig.4.16 Comparison of compressive and flexural strength for UHPC range achieved for Trial Mix 2, 3 and 4

From the Fig.4.16, it can clearly be the maximum compressive and flexural strength is for Mix 2 having w/b ratio of 0.18 and 1.5 % of steel fibers. Also, it can be analyzed that the flexural strength is only about 10 % to 13% of the compressive strength of concrete.



	Mix 2	Mix 2	Mix 2	Mix 3	Mix 3	Mix 3	Mix 4	Mix 4	Mix 4
Incremental increase in compressive strength (%)	5.54	4.38	4.07	6.45	3.3	5.3	6.72	4.05	7.24
Incremental increase in flexural strength (%)	7.6	9.63	2.8	6.98	4.18	7.42	15.81	2.15	5.94
Steel Fibers (%)	0.5	1	1.5	0.5	1	1.5	0.5	1	1.5

Fig.4.17 Incremental increase in compressive and flexural strength

From the above chart, we can clearly analyze that the increase in flexural strength is comparatively higher than the increase in compressive strength. All the mixes have a higher flexural strength and the Mix 2 reports the highest difference in percentage increase of flexural and compressive strength. Hence, it can be concluded that with addition of fibers in UHPC matrix, the tensile properties are improved more as compared to the compression.

CHAPTER 5: CONCLUSIONS

5.1 GENERAL

The present study was undertaken to develop UHPC and investigate the flexural and compressive strength of concrete at a constant water to binder ratio of 0.18. The crimped steel fibers were used to develop UHPC, at three different percentages of 0.5%, 1% and 1.5% by weight of cement to study the effect of fiber addition on compressive and flexural strengths. The cement was also partially replaced with nano silica, silica fume and Alccofine. Table 5.1 shows the percentage of cement replaced and steel fibers added in the mix for different concrete

Table 5.1: Percentage of ingredients in various trial mixes

Trial Mix	**1**	**2**	**3**	**4**
Silica Fume (%)	8	8	8	8
Nano Silica (%)	2	2	2	2
Alccofine (%)	0	10	15	20
Steel Fibers (%)	0.00	0.00	0.00	0.00
	0.50	0.50	0.50	0.50
	1.00	1.00	1.00	1.00
	1.50	1.50	1.50	1.50

Superplasticizer was used to maintain a workability between 50 mm to 75 mm (slump value) in all the mixes at the rate of 1.25% to 2.0% of the binder content. Four trial mix were prepared by varying the alccofine percentage (i.e. 10%, 15% and 20%) keeping a constant percentage of silica fume and nano silica at 8% and 2%, respectively. A total of 16 mixes were designed and specimen were casted for testing. Three cube and two beams for each mix are casted and tested under compression and flexural respectively.

5.2 CONCLUSIONS

The following conclusion regarding the characteristics, design and cost analysis can be drawn in this report based on the result discussed in previous chapter.

Compressive strength

- The supplementary cementitious materials like silica fume, nano silica and Alccofine plays a significant role in strength development of the UHP concrete mix.

- The addition of steel fibers in concrete mix marginally increased the compressive strength from 3.5% to 8.0% at 7 days and from 2.5% to 9% at 28 days.
- The addition of steel fibers in concrete mix increased the ductility of UHPC mixes.
- The maximum compressive strength was achieved with 10% alccofine replacement of cement compared to mix with alccofine content of 15% and 20%.
- The compressive strength of UHPC above 120 MPa is possible to be achieved with water to binder ratio 0.18, by using nano silica 2%, silica fume 8% and 10%, 15% & 20% alccofine with different steel fiber percentages.

Flexural strength

- The addition of steel fibers in the concrete mix significantly increased the flexural strength from 3.5% to 42% at 7 days and 2.5% to 13 % at 28 days. Thus, it can be concluded that flexural strength of UHPC mixes improves significantly with the addition of steel fibers and it improves the tensile properties more than the compressive properties.
- The maximum flexural strength was achieved with 10% alccofine replacement of cement as compared to mixes with alccofine content of 15% and 20%.
- The flexural strength for all trial mixes having alccofine content 10%, 15% and 20% respectively, were in the comparable range for most of the specimens, however, the trial mix 2 with 10% alccofine and 1.5% steel fibers showed better results than other.
- The maximum increment in flexural strength of 13 % at 28 days and 42% at 7 days was achieved with 1.5% fiber content.
- Hence, it can be concluded that, trial mix 2 (alccofine 10% & 1.5% steel fibers) specimens showed better compressive and flexural strength increment when incorporated with steel fibers as compared with other trial mix specimens.

5.3 SCOPE FOR FURTHER WORK

- Work can be extended to study the use of UHPC for retrofitting for different structural elements.
- Work can be extended to study the other properties of UHPC with different type of fibers like as shape, size and different dosages.
- Work can be extended to study the effect of different types of steel fibers on compressive and flexural properties of UHPC.

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