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"PERFORMANCE EVALUATION OF ULTRA HIGH PERFORMANCE CONCRETE USING DIFFERENT CEMENTITIOUS ADHESIVES & STEEL FIBRES"

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ABSTRACT—

A new concrete type with greater strength and durability, ultra-high performance concrete (UHPC) was created based on high performance concrete research. The proper proportioning of the mixture and material elements is essential for the effective manufacturing of ultra-high performance concrete (UHPC), which results in denser and comparatively more uniform particle packing. Because of its extremely low porosity, enhanced fatigue behaviour, and ultra-high strength characteristics, which result in superior resistance to harsh conditions, UHPC offers a practical and long-term solution for better sustainable building. Steel fibres are added to concrete to increase its flexural performance and durability, giving it more advantages for broader technical applications. Because of its greater initial cost, lack of contractor knowledge, and lack of widely accepted design rules, UHPC's uses in construction are currently somewhat limited. However, the cost of its materials should go down as long as research into making UHPC with locally accessible ingredients under typical curing circumstances continues. In order to demystify this durable and sustainable building material, this study aims to help engineers, consultants, and the construction industry better grasp the special qualities and capabilities of UHPC. In this study, we assess the effectiveness of UHPC by varying the cementitious adhesives' compositions, which range from 10% to 15% by cement weight. Steel fibres are also incorporated in a consistent amount to enhance its durability performance. The dynamic backdrop of UHPC, which is a useful resource for engineers and researchers working in the field of building materials, can be derived from the results.

Keywords: Ultra High Performance Concrete (UHPC), Workability, Durability, Strength Properties, Steel Fibres, Cementitious Adhesives.

1. Introduction -

By lowering the cross sections of structural members and the corresponding material and labour costs, ultra-high-performance concrete (UHPC), a new building material with improved mechanical and durability qualities, can result in more cost-effective construction. UHPC's wider application in the building sector has been limited by its comparatively expensive starting cost. To start an innovative UHPC with a lower initial cost, however, current research and investigations are addressing knowledge shortages. Additionally, the creation and broad adoption of UHPC design code provisions need to motivate construction industry participants to execute extensive applications. The recent drive by groups like the American Concrete Institute, which designated the use of high-strength steel reinforcing in concrete as a major research priority, makes this even more pertinent. In the near future, it is anticipated that the combination of UHPC with high-strength steel will provide unique structures. Tall buildings, rehabilitation projects, machine parts, military constructions, and structural and non-structural components are among the possible uses for UHPC. UHPC can be used to create structures that are lighter because of their reduced cross sections. Consequently, the precast concrete industry may make good use of UHPC. Additionally, UHPC was extensively utilized in highway bridges and pedestrian footbridges. An in-depth analysis of the literature on UHPC qualities was carried out in the current study and condensed to provide easy access to this dispersed data.

According to the ACI mixture design process, the main characteristics and priorities of conventional concrete (CC) are workability, compressive strength, durability, and economy. The primary ingredient in the creation of UHPC is Portland cement (PC), which is employed as a cementitious binder along with additional supplementary cementitious materials (SCM). Silica fume (SF) is typically utilized as an SCM. The manufacturing of UHPC is based on mechanical uniformity, maximum particle packing density, and minimum number of defects, taking into account both the macro and micro features of the design mix components. It is essential to take into account the materials' physical and chemical characteristics in addition to their micro and macro characteristics. The development of scientifically effective mix design techniques is essential to producing UHPC with long-lasting, feasible, cost-effective, and superior mechanical qualities. However, UHPC has several drawbacks, especially when it comes to cracking and shrinkage in the early phases of concreting because to drying and autogenous shrinkage. As a result, little research has been done on this concrete's long-term behaviour. Furthermore, UHPC is more expensive than regular concrete, which raises questions about its feasibility in situations where unusual concrete can more affordably satisfy design specifications. The principal constraint to the wider application of UHPC is the high cost of several expensive raw materials in the mix.

Composition of Ultra High Performance Concrete

Improving the combination materials' micro and macro characteristics is crucial to creating UHPC because it guarantees mechanical uniformity, maximum particle packing density, and a minimum size of defects. The rationale behind achieving UHPC's exceptional compressive strength and durability is based on four key ideas, which are listed below:

1. Low Water-Cement Ratio. It is essential to keep the water-to-cement ratio extremely low, usually between 0.20 and 0.25. This aids in hydrating the material to create a strong, compact structure. The low ratio minimizes brittle collapse, improves ductility, and decreases capillary holes.

2. High Particle Packing Density. By using fine binder ingredients, the fresh mixture's water consumption is reduced and a high particle packing density is encouraged. This affects the concrete's brittleness in addition to increasing its compressive strength.

3. Optimal Superplasticizer Dosage. To control the workability of UHPC, a high dose of superplasticizer must be used. This guarantees that the desired qualities of the concrete are maintained while it is adequately workable.

4. Use of Fibres. The goal of adding fibres to the UHPC is to induce tension and bending tension. As a result, the concrete gains the required ductility and shear strength. However, the idea of adding coarse aggregates to increase the mixture's homogeneity is ignored in UHPC, in contrast to conventional concrete, where they are a necessary component.

As a result, we may group the common components in new UHPC developments as follows:

- Materials for binder
- Aggregates
- Chemical admixtures with fibres.

Binders - Compared to normal-strength and high-performance concrete, UHPC uses a comparatively larger percentage of cement. The UHPC compressive strength was found to rise with increasing cement content; however, compressive strength tends to decrease beyond an optimal cement content (about 1700 kg/m3), most likely as a result of limited aggregate participation. Because it requires less water, cement with a tri-calcium aluminate composition of less than 6% and intermediate Blaine fineness is chosen. UHPC was also developed using special micro-fine cements, which have particles smaller than ordinary Portland cement. Only a portion of the total cement hydrates due to UHPC's extremely low water/binder ratio (w/b), and the un hydrated cement can be substituted with crushed quartz, fly ash, or blast furnace slag. For example, crushed quartz, blast furnace slag, or fly ash can be used in place of up to 30, 36, and 40% of the cement by volume in UHPC combinations, respectively, without lowering the mixture's compressive strength. Furthermore, because silica fume has a much smaller particle size and an ideal spherical form, it can be added as a binder to UHPC to increase its workability by filling in the spaces between coarser particles. Through its pozzolanic reactions, silica fume also improves the strength characteristics of UHPC in addition to this micro filler effect. In order to produce tighter particle packing and pozzolanic reactivity in UHPC, which results in greater strength qualities, some research suggested silica fume dosages of 20–30% of the total binder material. For example, the ideal dose in UHPC was suggested to be 25% by cement weight of low carbon content ($<0.5\%$) silica fume.

Fly ash (FA), ground granulated blast-furnace slag (GGBS), silica fume, metakaolin, limestone powder, steel slag powder, and rice husk ash are among the most widely used supplemental cementitious materials (SCMs).

Portland Cement Type I–III and white cement are among the cement types that can be used to make UHPC, depending on the particular applications and environmental conditions. However, because of their high C_3S content and Blaine fineness, Type III and white cement are the most often utilized cements since they improve strength and reduce the amount of time that concrete takes to set. However, when extraordinarily high early stage strength is not a required condition, Type I cement may be taken into consideration because of its reduced cost and reactivity.

Silica Fume The typical addition of silica fume (SF) to the mixture ranges from 5% to 25%. Because of its tiny particle size, it increases the workability and packing density of concrete particles in amounts under 10%. However, because the SF's vast surface area tends to absorb free water, workability may be significantly reduced if the SF concentration surpasses 10% of the UHPC [53]. Furthermore, because of its high SiO_2 content, SF improves cement hydration and refines the microstructure of UHPC by imparting a seeding and pozzolanic action.

Rice Husk Due to its high content of amorphous silica, rice husk, an agricultural waste, can either fully or partially replace SF. Rice husk ash has a D50 between 5 and 20 µm, which is 50–100 times bigger than SF. But because rice husk ash has a bigger surface area (64,700 m2/kg) than SF (18,500 m2/kg), it absorbs more water and makes concrete less workable. Additionally, the rice husk ash slows down internal dehydration and reduces autogenous shrinkage by absorbing water during mixing and releasing it gradually throughout hydration.

Fly Ash The manufacturing of UHPC mostly uses fly ash, a by-product of coal power plants, with a focus on type C and type F fly ash. Fly ash of type C experiences both hydraulic and pozzolanic reactions, while fly ash of type F only experiences pozzolanic reactions because it lacks CaO. In order to substitute cement, fly ash is usually used in ratios of 10% to 30% for type F and 40% to 60% for type C. Fly ash's larger spherical shape than cement reduces inter-particle friction, which improves the concrete's workability.

Granulated Blast Furnace Slag (GGBFS) For a long time, concrete has used ground granulated blast furnace slag (GGBFS) as an additional cementitious ingredient. Slags like as copper, iron, and barium can be used in UHPC mixtures. Slag, as an alternative SCM, usually takes the place of cement in proportions between 30% and 60%. When compared to a comparable amount of fly ash, the angular forms of the slag particles increase inter-particle friction, which reduces the workability of UHPC.

Glass Powder In UHPC combinations, glass powder is used in a ratio of 10% to 50% in place of cement or SF. The glass powder's D50 spans from 1 to 20 µm, and its smooth surface reduces water absorption and inter-particle friction, making the concrete easier to work with.

Metakaolin Concrete's early strength and durability are improved by adding metakaolin, which is made from calcining natural clay. At the same time, adding metakaolin powder can improve autogenous shrinkage and smooth out the pore structure. It has been noted that metakaolina is used as an SF alternative in the manufacturing of UHP. It has been shown that a high metakaolin dosage in UHPC may cause the compressive strength to decrease. In particular, compressive strength falls by 6.7% while flexural strength rises by 2.6%. Metakaolin is a favoured option for UHPC manufacture due to its accessibility, affordability, and white colour.

Water/Binder Ratio UHPC combinations use a very low water/binder ratio (w/b). Richard and Cheyrezy (1995) observed a minimum w/b of 0.08; nevertheless, dense particle packing was not guaranteed by this ratio. To attain maximum relative density and spread flow, earlier research (Richard and Cheyrezy 1995; Larrard and Sedran 1994; Gao et al. 2006; Wen-yu et al. 2004; Shi et al. 2015) recommended an ideal w/b ratio of 0.13–0.20. Nevertheless, employing 0.25 w/b, researchers (Wille et al. 2011; Droll 2004) have obtained compressive strength more than 150 MPa (22 ksi). Thus, it might be said that the w/b is not the only factor influencing UHPC strength. Other crucial factors include the type of mixer, mixing techniques, curing regime, and mixture constituent characteristics. The addition of efficient superplasticizers (SP) can address the decreased workability of UHPC caused by its extremely low w/b. The compatibility of the mixture ingredients and the type of SP utilized have a considerable impact on the necessary SP dosage. A reduced dosage of SP may result from improved compatibility. In contrast to a mixture with larger surface area metakaolin at the same SP dosage, a UHPC mixture containing a limestone micro-filler is more workable and compatible (Rougeau and Burys 2004). Additionally, due to a better dispersing effect, it was discovered that adding SP gradually or gradually—as opposed to all at once—improved the workability of UHPC mixtures (Tue et al. 2008).

Super Plasticizers The addition of efficient superplasticizers (SP) can address the decreased workability of UHPC caused by its extremely low w/b. The compatibility of the mixture's constituents and the type of SP being used have a major impact on the necessary SP dosage. A reduced dosage of SP may result from improved compatibility. In contrast to a mixture with larger surface area metakaolin at the same SP dosage, a UHPC mixture containing a limestone micro-filler is more workable and compatible (Rougeau and Burys 2004). Additionally, due to a better dispersing effect, it was discovered that adding SP gradually or gradually—as opposed to all at once—improved the workability of UHPC mixtures (Tue et al. 2008). In order to improve the workability of UHPC mixtures, several research (Schmidt et al. 2004, 2012; Fehling et al. 2008) employed SP dosages ranging from 1% to 8% by cement weight. SP dosages of 1.4% to 2.4% by cement weight are often advised (Wille et al. 2011).

Aggregates According to Jun et al. (2008), damage at the interfacial transition zone (ITZ) between the cementitious matrix and aggregates typically causes failure in traditional concrete. Thus, removing coarse aggregates from UHPC mixtures lessens the vulnerabilities brought on by such ITZ. Additionally, reducing the ITZ defects causes the matrix's total porosity to decrease, which improves the mechanical strength (Mehta et al. 2006). Reducing the maximum paste thickness (MPT), which is also a crucial component in the mixture design of UHPC, is made possible by the fine aggregate, such as quartz sand. For a quartz particle size of 0.8 mm (0.031 in), the ideal sand-to-cement ratio was determined to be 1.4 (Wille et al. 2011).

Steel Fibres Although UHPC is extremely brittle due of its high strength and homogeneity, steel fibres can be added to make it ductile (Bayard and Ple 2003; Graybeal 2006; Wang et al. 2015). Steel fibres that are 13 mm (0.5 in) long and 0.20 mm (0.008 in) in diameter are the most widely utilized sizes (Schmidt et al. 2004, 2012; Fehling et al. 2008). For a practical and affordable UHPC mixture design, Richard and Cheyrezy (1995) suggested adding 2% of steel fibres by mixture volume.

Steel Fibres Extracted from Binding Wire

2. OBJECTIVES OF THE STUDY

Following are the objectives of this research –

- To ascertain the ideal ratio of raw binder components to create UHPC by adding steel fibres, taking into account the material's strength and workability.
- The impact of different binder components in varying amounts, such as fly ash, GGBS, quartz powder, silica fume, and rice husk, on ultra-high performance concrete.
- Research on the effects of varying amounts of additional cementitious ingredients on the characteristics of both fresh and cured concrete.
- Impact of a fixed percentage of steel fibre on ultra-high performance concrete performance.
- Research on Super Plasticizer using various cementitious materials in a UHPC mix percentage.
- UHPC's overall cost optimization to maximize benefits and manage energy usage.

3. Methodology –

3.1 Test on constituent materials

Cement: For the study, ordinary Portland cement in grade 53 that complies with IS 12269:1987 was utilized. Standard consistency tests, start and final setting time tests, specific gravity tests, and mortar cube compressive strength tests were performed on the cement. Cement undergoes laboratory testing to ascertain its compressive strength, starting and final setting times, and standard consistency.

1. Le Chatlier's Test – To determine the specific gravity of cement.
2. Vicat's Apparatus – Used to determine the standard consistency, initial and final setting time of cement.
3. Compressive Strength – As per IS 4031 (Part 6) 1988, a cube of mould 70.6 mm used to determine the compressive strength of cement.

Above tests have been conducted on different samples of cement replaced with various supplementary cementitious materials as mentioned below.

CEMENT OPC (53 GRADE)	SILICA FUME	QUARTZ POWDER	FLY ASH	GGBS	RICE HUSK	NORMAL CONSISTENCY IN %	INITIAL SETTING TIME IN MIN	FINAL SETTING TIME IN MIN	Compressive Strength at 28 Days
100%	20%	10%	-	-	-	38	35	580	63.1
90%	20%	10%	10%	-	-	35	40	550	61.6
90%	20%	-	10%	10%	-	35	42	570	60.9
90%	20%	-	10%	-	10%	35	38	585	59.5
100%	20%	15%	-	-	-	35	32	560	60.5
85%	20%	15%	15%	-	-	32	42	540	60.8
85%	20%	-	15%	15%	-	32	45	560	59.9
85%	20%	-	15%	-	15%	32	38	575	58.7

3.2 PHYSICAL PROPERTIES OF FINE SAND (ZONE II)

S.No	Properties	Test Conducted as per IS 2386	Result of M sand
1	Water Absorption	Using Pycnometer	1%
2	Specific Gravity		2.62
3	Apparent Specific Gravity		2.65
4	Bulk Density	Using Cylindrical Measure of Capacity 3 L, Inside Dia – 15 cm & Inside Height – 17 cm	10.77 KN/M3
5	Fineness Modulus	Sieve Analysis	2.79

3.3 PROPERTIES OF STEE FIBRES

PROPERTIES OF STEEL FIBRE	**VALUES**
LENGTH IN MM	**50**
SHAPE	**CIRCULAR**
SIZE / DIA. IN MM	**1.6**
ASPECT RATIO (L/D)	**31.5**

3.4 Trial Mix design for conventional UHPC

Material	**Quantity (kg)**
Cement (OPC 53)	840 (1)
Silica Fume	240 (0.285)
Quartz Powder	120 (0.14)
Fine Sand	950 (1.13)
Superplasticizer	25 (0.03)
Water	140 (0.166)
Steel Fibers	85 (10)

3.5 Mix Proportions

MIX	CEMENTIOUS MATERIALS									
	CEMENT OPC (53 GRADE)	SILICA FUME	QUARTZ POWDER	FLY ASH	GGBS	RICE HUSK	FINE SAND	WATER	SUPER PLASTICIZER (PCE)	STEEL FIBRES
M1	100%	20%	10%	-	-	-	113%	16.6%	3%	10%
M2	90%	20%	10%	10%	-	-	113%	16.6%	3%	10%
M3	90%	20%	-	10%	10%	-	113%	16.6%	3%	10%
M4	90%	20%	-	10%	-	10%	113%	16.6%	3%	10%
M5	100%	20%	15%	-	-	-	113%	16.6%	3%	10%
M6	85%	20%	15%	15%	-	-	113%	16.6%	3%	10%
M7	85%	20%	-	15%	15%	-	113%	16.6%	3%	10%
M8	85%	20%	-	15%	-	15%	113%	16.6%	3%	10%

3.6 Tests on specimens

Concrete specimen testing is crucial for maintaining and verifying the material's quality. To investigate the impact of partially substituting phosphor gypsum for cement and thermosetting polymers for fine aggregate on workability and strength, all of the cast specimens underwent testing. As a result, the experimental study was separated into three primary sections. They are as follows:

1. Study on workability
    - Slump Flow test
2. Study on strength
    - Compressive strength test
    - Splitting tensile strength test
    - Flexural strength test
3. Study on Durability

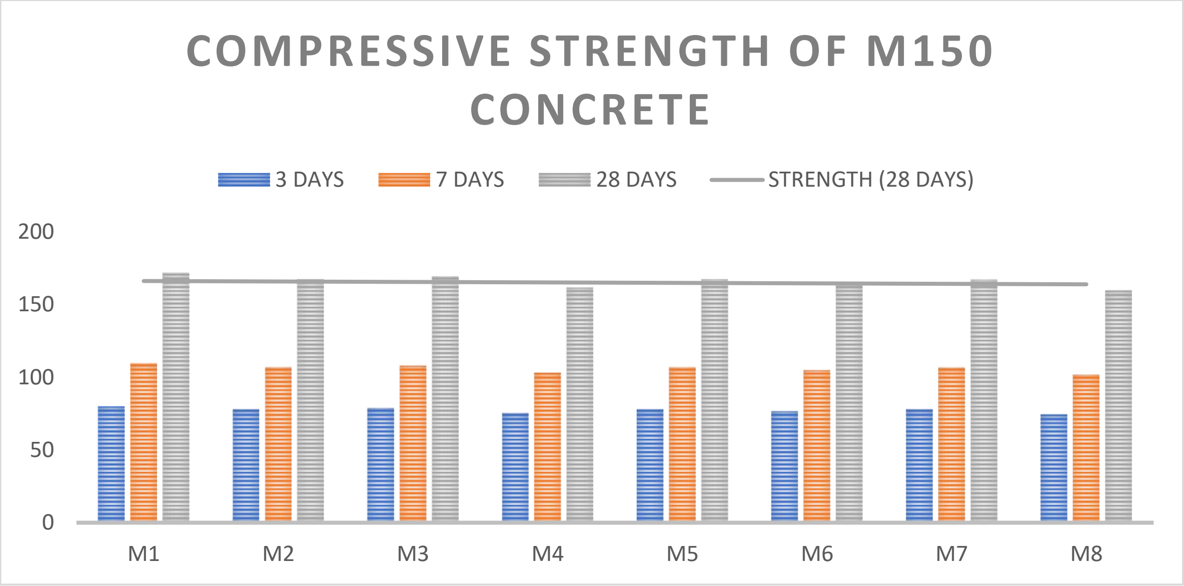
4. RESULTS –

Slump Flow Test –

MIX PROPORTIONS	VALUE OF SLUMP FLOW IN MM
M1	715
M2	695
M3	750
M4	650
M5	680
M6	660
M7	705
M8	635

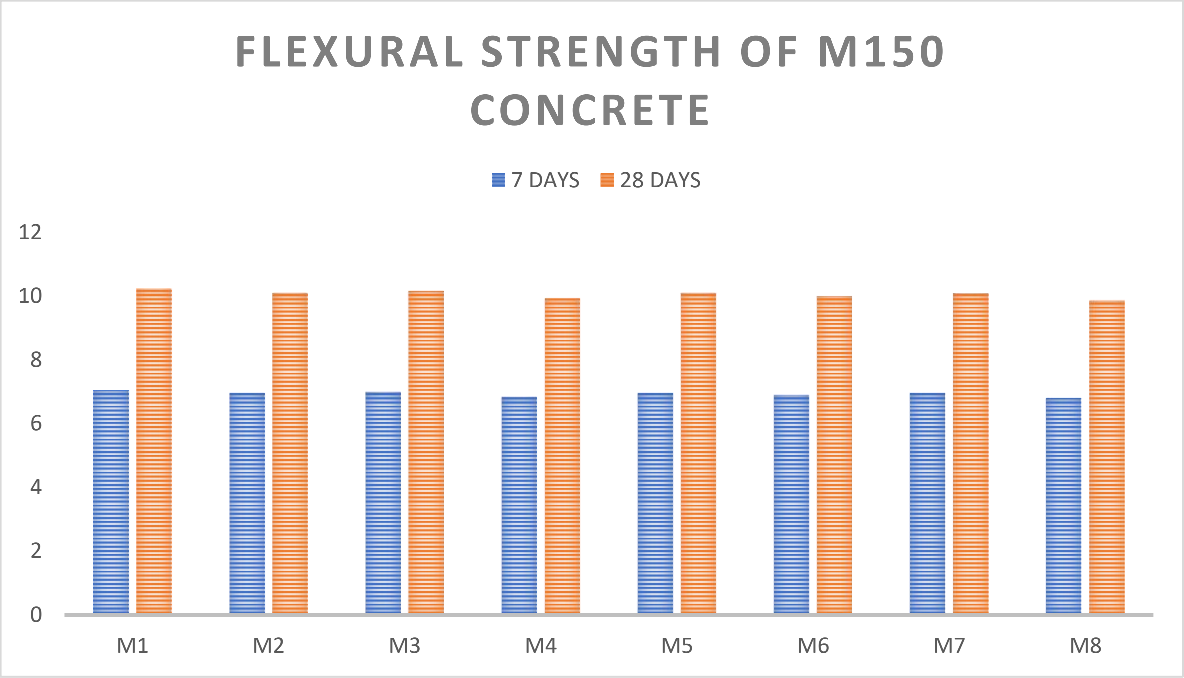
Tests on Hardened Concrete

Compressive Strength of M150 Grade of Concrete at 3,7 & 28 days with different mix proportions



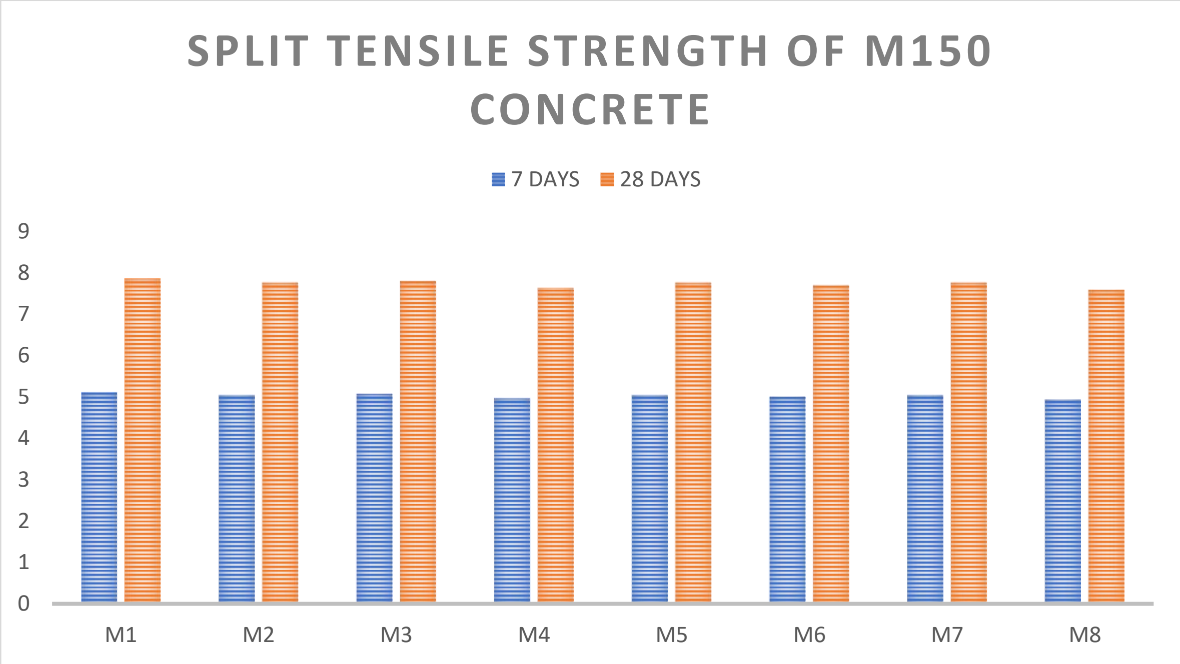
Flexural Strength Test Results –

Flexural strength is determined by casting beams of 10 cm by 10 cm by 50 cm. Beam tests are conducted when the specimen is 28 days old. The specimen is placed in the machine in accordance with IS: 516-1959, clause no. 8.3.1, page no. 17. The applied load increases at a rate of 108 KN/min.



Tensile Strength Test Results –

To measure split tensile strength, cylinders with dimensions of 15 cm in diameter and 30 cm in height are cast. Cylinders undergo testing when the specimen is 28 days old. The specimen is inserted into the machine in accordance with IS: 516-1959.

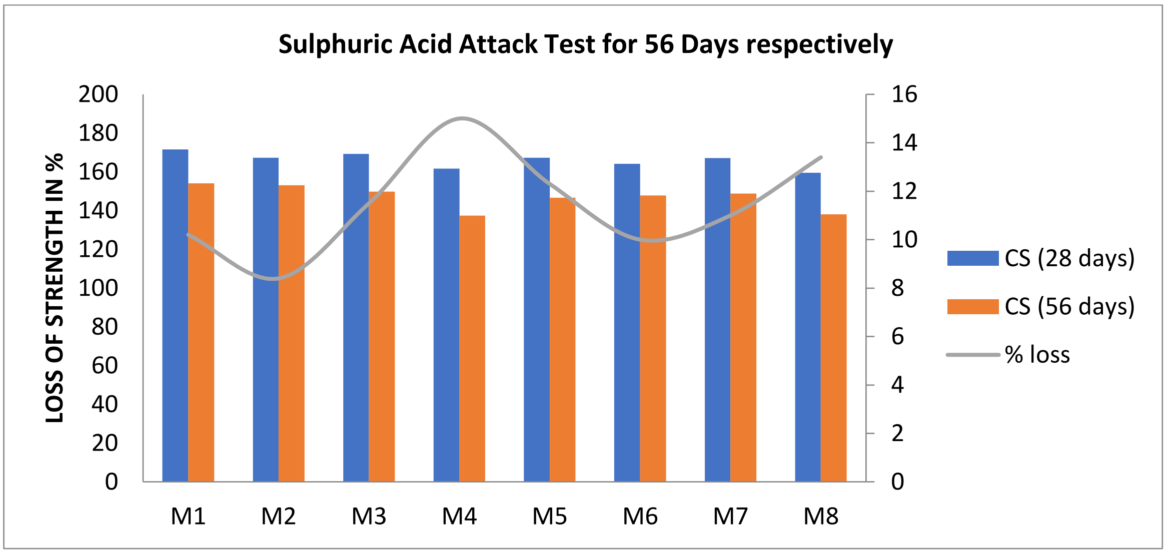


Durability Test -

The ability of concrete to withstand weathering, chemical attack, abrasion, and other degrading processes is what makes it durable. When exposed to its surroundings, durable concrete will maintain its original shape, quality, and serviceability. Acid resistance (attack by sulphuric acid), alkalinity (attack by sodium hydroxide), sea water assault, and water absorption tests were performed to investigate the durability of concrete.

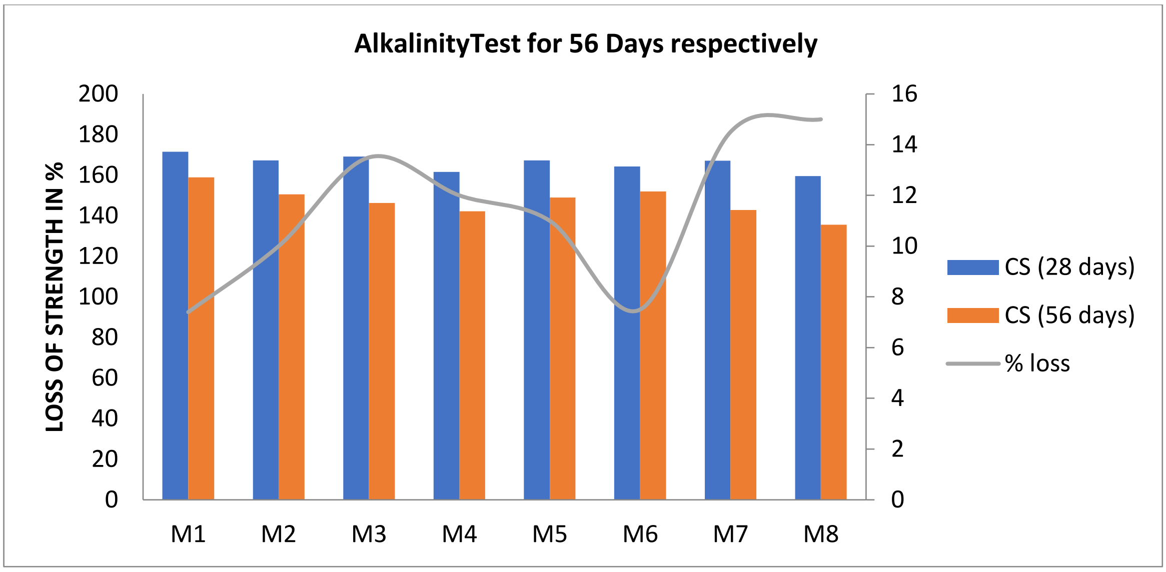
Sulphuric Acid Attack Test

The compressive strength of specimens immersed in H_2SO_4 solution for 28 days after gaining its complete strength (strength after 28 days) were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss.



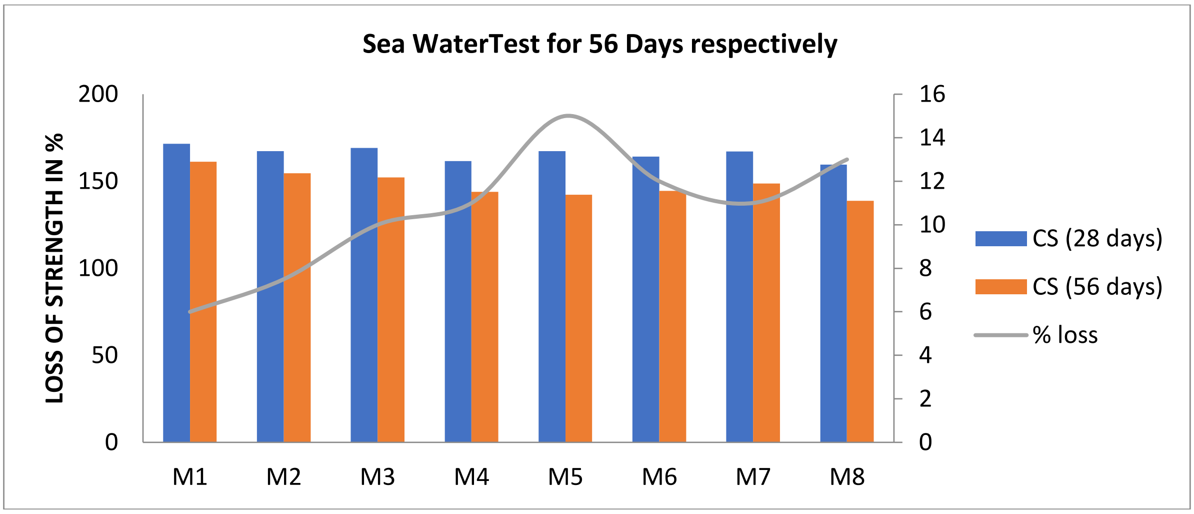
Alkalinity Test - Sodium Hydroxide Test

The compressive strength of specimens after NaoH exposure at 56 days (i.e. 28 days after gaining its strength) were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss in alkaline solution.



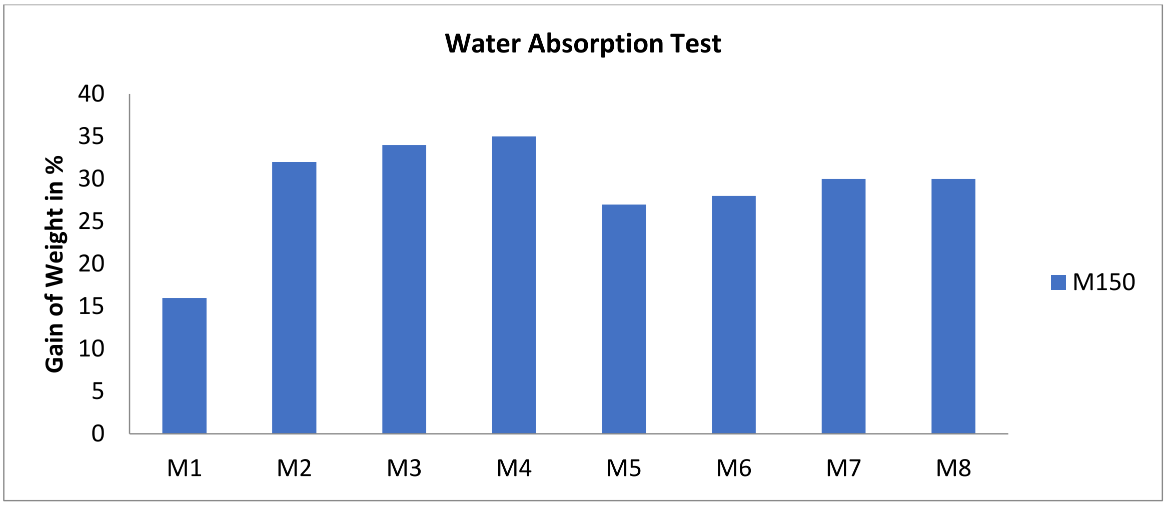
Sea Water Attack Test

The compressive strength of specimens after sea water exposure i.e. immersed in NaCl solution at 56 days (i.e. 28 days after gaining its strength) were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss in NaCl solution.



Water Absorption Test –

This test method is used to determine the rate of absorption of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. Water absorption is measured by measuring the increase in mass as a percentage of dry mass. It can be seen that surface water absorption is higher than internal water absorption for all the specimens. This is due to the rapid loss of water at the cover concrete during curing. Water Absorption = (M2-M1)/M2 100%. The samples are dried in hot air oven once at particular time and temperature and afterwards cooled in a desiccator. The samples were weighed shortly after cooling. The substance is then immersed in water at predetermined temperatures; typically, 23°C for 24hrs or till balance is attained.



5 CONCLUSIONS –

It was important to note that the quantity of by-product played a vital role to the properties of concrete. From all the studies, following points have been concluded:

- Adding fly ash and GGBS to a traditional cement and silica fume mixture improved workability. At 10% fly ash substitution for cement, the highest workability was achieved.
- In comparison to the standard mix M1, the M3 mix's compressive strength dropped by up to 1% after fly ash and GGBS were added. Furthermore, when various ratios of fly ash and other supplemental cementitious materials were used, the strength values dropped by up to 5%.
- For the traditional mix, the cylinder's splitting tensile strength was greater. When fly ash is added to M3 mixes up to 10%, the splitting tensile strength decreases by up to 1% compared to M1.
- It is discovered that M1 beams have a higher flexural strength. A significant 5% reduction in strength compared to a standard mix is evident in the residual mix fraction. It again exhibits very minimal degradation as compared to the M3 mix, which may be preferable.
- When compared to other materials, concrete that contains 10% fly ash substitute exhibits almost the same durability properties in acid and alkalinity. The compressive strength of M2 decreased significantly after 56 days in a sulphuric acid solution, by as much as 8%, demonstrating that fly ash can increase UHPC's tolerance to acidic environments.
- After 56 days of curing in NaOH solution, the percentage strength loss for mix proportions containing fly ash was approximately 10%, but the value increased by just 1% to 2% when compared to a standard mix.
- When fly ash is added, the durability of seawater drops in comparison to a standard mix because the rate of deterioration is roughly double that of other supplemental cementitious materials.
- When fly ash is added, the mix absorbs less water than a typical mix, increasing durability in terms of permeability.
- The cost of concrete drops by 1% to 2% when fly ash is used. For ultra-high performance concrete, admixtures and other supplemental cementitious materials can be used to produce cost-effective solutions instead of silica fume. By partially replacing cement and silica fume with fly ash and GGBS, an economical solution for this grade of concrete can be found. Additionally, it can lower the quantity of natural resources needed in the production of concrete.

Recommendation –

Concrete's strength, durability, and resistance to corrosion are all improved early on by fly ash. The ideal percentage of fly ash to utilize is up to 10% of cement replacement, which produces satisfactory results. By adjusting the percentage of fly ash and GGBS, much more can be accomplished. Fly ash substitution of cement above the ideal percentage also appears to be less expensive than traditional concrete. For M150 grade, it is around 1% less expensive than 1 m3 of standard concrete. Given that UHPC is costlier than traditional concrete and frequently used in large, heavy structures that may call for special mixing, research into the addition of additional cementitious material can provide insight into the performance of this type of concrete.

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