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DURABILITY PROPERTIES OF SIFCON BY USING SILICAFUME AND STEEL FIBRES

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ABSTRACT--- Slurry infiltrated fibrous concrete (SIFCON) is one of the starting late made movement material that can be considered as interesting kind of high performance fiber reinforced concrete (HPFRC) with higher fiber content. In this examination on SIFCON normal port land concrete is displaced by 15% by weight of Silica Fume (SF) and five explicit steel fiber volumes of Plain Mild Steel Fiber (PMSF) 0%, 5%, 15%, 25%, and 35% are used. The silica fume substitution is proceeded with persistent 15% by weight of concrete on the mechanical properties of SIFCON have been gotten some information about. As showed up by the results extending of fiber volumes makes apex weight. The compressive quality for PMSF35 at 28 days is 42.08MPa, the split inflexible nature for PMSF35 fiber of at 28 days is 5.7MPa, the brief versatility for PMSF35 at 28 days is 4.06MPa and ultrasonic heartbeat speed an assistance for 3D square for PMSF35 at 28day is 4.4 km/s and for PMSF35 fibered chamber at 28 days quality is 4.9km/s uninhibitedly. Key **words:** SIFCON; Fiber reinforced materials; Silica fume; Admixtures; Mechanical properties; Composite; Steel fiber; Composites

CHAPTER 1

INTRODUCTION

1.1 Slurry Infiltrated Fibrous Concrete

Slurry Infiltrated Fibrous Concrete (SIFCON), which flows under its own weight and does not require any external vibration for compaction, has revolutionized concrete placement. SIFCON was first introduced in the late 1979's by USA researchers, is a highly workable concrete that can be flow under its own weight through restricted sections without segregation and bleeding. For SIFCON, it is generally necessary to use super plasticizers in order to obtain high mobility. Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. SIFCON was introduced in India in the Nineties (Parameswaran et al., 1993). European Federation of natural trade associations representing procedures and applicators of specialists and guidelines for SIFCON to provide a framework for design and use of high-quality SIFCON.

It is highly workable concrete which flows in densely reinforced and complex structural elements which flow under its own weight and adequately fill all voids without segregation and excessive bleeding in absence of need for vibration.

1.1.1 Basic principles of SIFCON

The basic principle of slurry infiltrated fibrous concrete as shown in **Fig. 1.2**

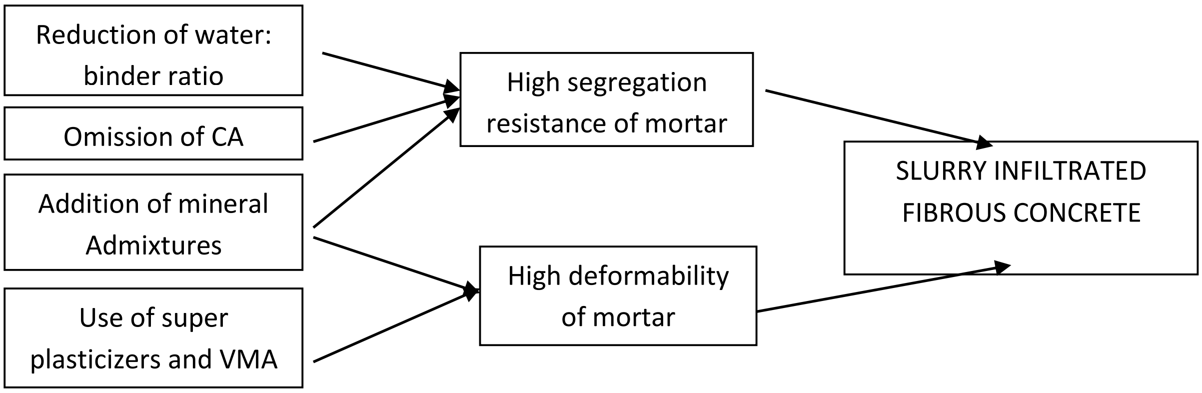

Fig. 1.2 Principle of SIFCON

1.1.2 Originate of SIFCON

The SIFCON is slurry infiltrated fibrous concrete used in congested reinforced structures and the history of origin as follows,

In 1979s, USA researcher investigates durable SIFCON structures. Later in 1990, this technology reached Europe and they added powders (cement, supplementary cementitious materials and inert materials) to increase plastic viscosity in SIFCON **Sonebi et al., (2004).**

1.1.3 Materials for SIFCON

Mixture proportions for SIFCON are given below and shown in **Fig.1.3**

- Has more powder (cement and silica fume) content
- Incorporates high range water reducers (HRWR, super plasticizers) in larger amounts
- Viscosity modifying agent (VMA) in small doses

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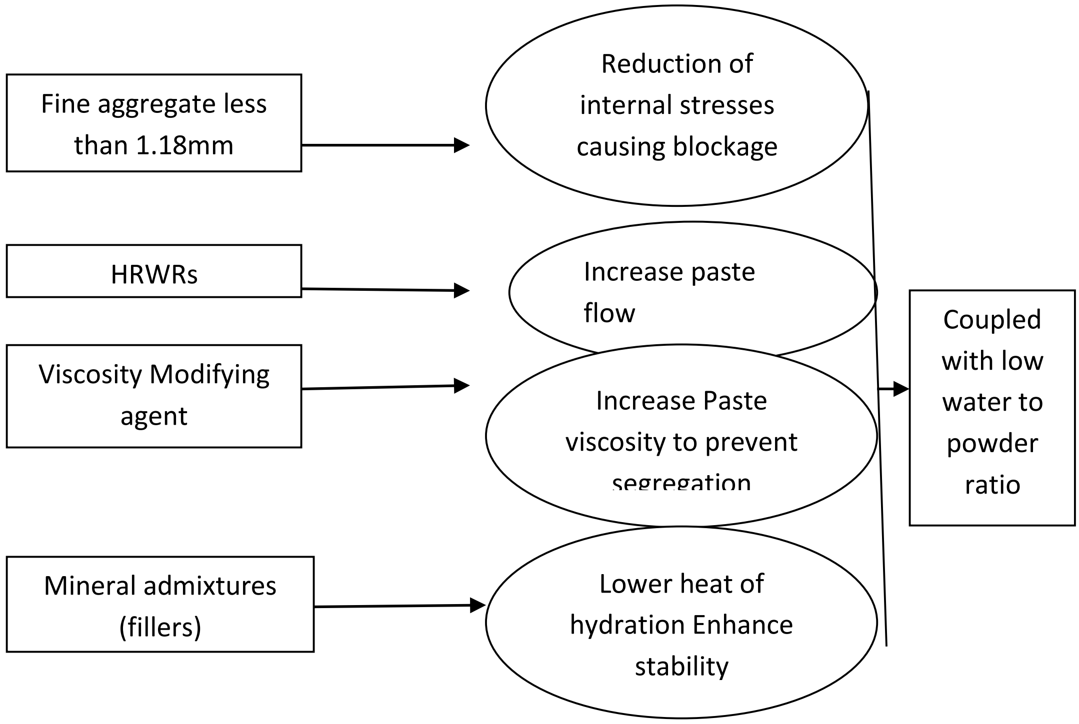

Fig. 1.3 Materials of SIFCON

1.2 Precursors

1.2.1 Super plasticizer

The role of super plasticizer is to reduce the water powder ratio which increases the flow of concrete without bleeding or segregation, which gives homogenous a mixture of SIFCON is shown in **Fig. 1.4.**

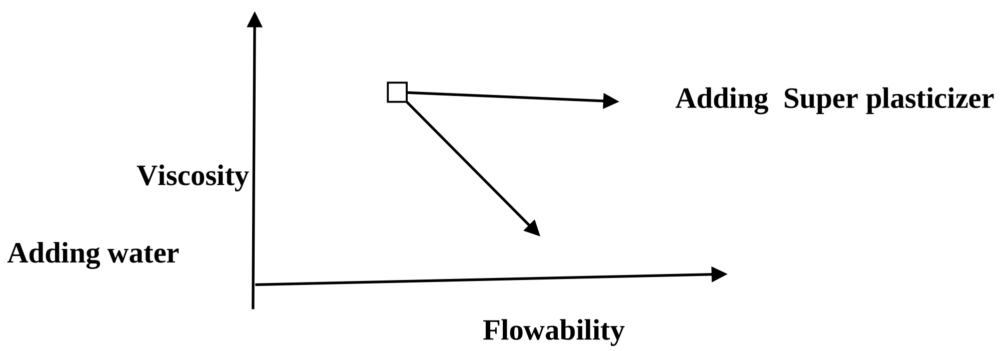

Fig. 1.4 Role of Super plasticizer

The type of super plasticizer:

- **Polycarboxylate ether (PCE):** It is free radical mechanism using peroxide initiators are used for polymerization process in this system.

1.2.2 Silica Fume

Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable. Silica fume is available from suppliers of concrete admixtures and, when specified, is simply added during concrete production. Placing, finishing, and curing silica-fume concrete require special attention on the part of the concrete contractor.

Silicon metal and alloys are produced in electric furnaces as shown in this photo. The raw materials are quartz, coal, and woodchips. The smoke that results from furnace operation is collected and sold as silica fume, rather than being land filled. Perhaps the most important use of this material is as a mineral admixture in concrete.

1.2.3 Steel Fibres

While in conventional SFRC, the steel fibre content usually varies from 1 to 3 percent by volume, it varies from 4 to 30 percent in SIFCON depending on the geometry of the fibres and the type of application. The process of making SIFCON is also different, because of its high steel fibres content. In this study the steel fibres used are plain mild steel fibres (PMSF), hooked end mild steel fibres (HEMSF) and crimped mild steel fibres (CMSF). The fibre percentages used in this study was 0%, 5%, 15%, 25% and 35%.

1.3 Objectives of Research

The objective of the research work is to find the structural properties of slurry infiltrated fibrous concrete with silica fume as a partial replacement of cement and adding steel fibres into SIFCON. The objects of the proposed research work are:

- To provide construction of durable SIFCON structures with skilled labour for placing and compacting concrete.
- To improve hardened SIFCON results adding admixtures in SIFCON.
- To minimize the silica fume waste, in which recent years it is considered one of the most important decorative building materials and its severalty affects the

environment and health problems when produced from furnace of silicon industries.

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CHAPTER 2
Review of Literature

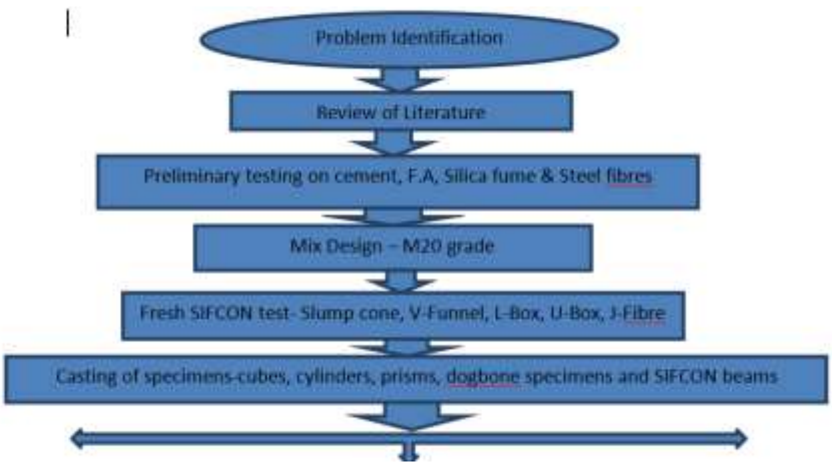
PatilDeepesh et al., (2016) have made to summaries the experimental investigation testing of mechanical and durability properties of Slurry Infiltrated Fibrous Concrete (SIFCON) using hooked ended steel fibers is carried out. Similarly the replacement of cement with fly ash in three different proportions as 5%, 10%, 15%, and replacement of fine aggregate with bottom ash in three different proportions of 10%, 20% and 30% was done. The main goal is to improve the tensile strength and flexural strength of concrete. To optimize this serious defect partial incorporation of fibers is practiced. In this study we have induced 2% and 3% fibers of the total volume of the specimen. For the study of durability of concrete, the cubes were kept immersed in MgSO4 for 28 days and the attack of chemical on concrete was studied. Mechanical tests such as compression test, flexural test, split tensile test were carried out on standard size of cubes, beams and cylinder respectively at the age of 7, 28, 56 days. In this investigation it was observed that the mechanical as well as the durability properties of SIFCON were severely affected in a positive manner by using the substitute as fly ash and by adding steel fiber reinforcement in defined percentage.

Vijayakumar et al., (2017) proposed many researches in concrete is a composite material used in construction. Next to water, concrete is the most used material worldwide for construction of any desired shape or different structure. Concrete has low strength, low ductility and energy absorption. Different concrete require different degrees of durability depending on the exposure environment and properties desired. Concrete ingredients, their proportioning, placing and curing practices, and the service environment determine the ultimate durability and life of concrete. For this purpose to improve the concrete toughness and reduce the amount of defects by adding a some fibers to the concrete for this situation SIFCON type concrete is preferred and the fiber are uniformly distributed and it is different from fiber reinforced concrete (FRC). Slurry-infiltrated fibrous concrete (SIFCON) can be considered as a special type of fiber concrete with high fiber content. The fiber content of FRC generally varies from 1to3 percent by volume, but the Fiber content of SIFCON varies between 5 and 20 percent. The network is then infiltrated by a fine liquid cement- based slurry or mortar. It is not having coarse aggregate only have cement and sand or any cementitious material. In view of the above, the objectives of this study are to investigate and provide information about strength of SIFCON, mainly resistance to abnormal loads, impact loads and earthquake loads. Here straight stainless steel and E type glass fiber are used with different volume of fraction, 6%,8%,10%,12% and cement, sand, fly ash are used 1:1:0.5. The compressive strength of SIFCON is increased 26% when comparing to M30 concrete.

Alrubaie et al., (2019) proposed aSlurry infiltrated fiber concrete (SIFCON) is considered as a special type of high strength high-performance fiber reinforced concrete, extremely strong, and ductile. The objective of this study is to investigate the durability of SIFCON to corrosion in chloride environments. Six different SIFCON mixes were made in addition to two refinance mixes with 0% and 1.5% steel fiber content. All mixes were exposed to 10% chloride solution for 180 days. Half of the specimens were partially immersed in chloride solution, and the others were exposed to weekly cycles of wetting and drying in 10% chloride solution. The effectiveness of using corrosion inhibitors, mineral admixture, and epoxy protective coating were also evaluated as protective measures to reduce the effect of chloride attack and to improve the corrosion resistance of SIFCON mixes. Corrosion rates, half-cell potential, electrical resistivity, total permeability tests had been monitored monthly. The results indicated a significant improvement in performance for SIFCON mixes exposed to chloride environment, when using corrosion inhibitor or epoxy protective coating, whereas SIFCON mix contained mineral admixture (metakaolin) did not improve the corrosion resistance at the same level.

CHAPTER 3

Methodology



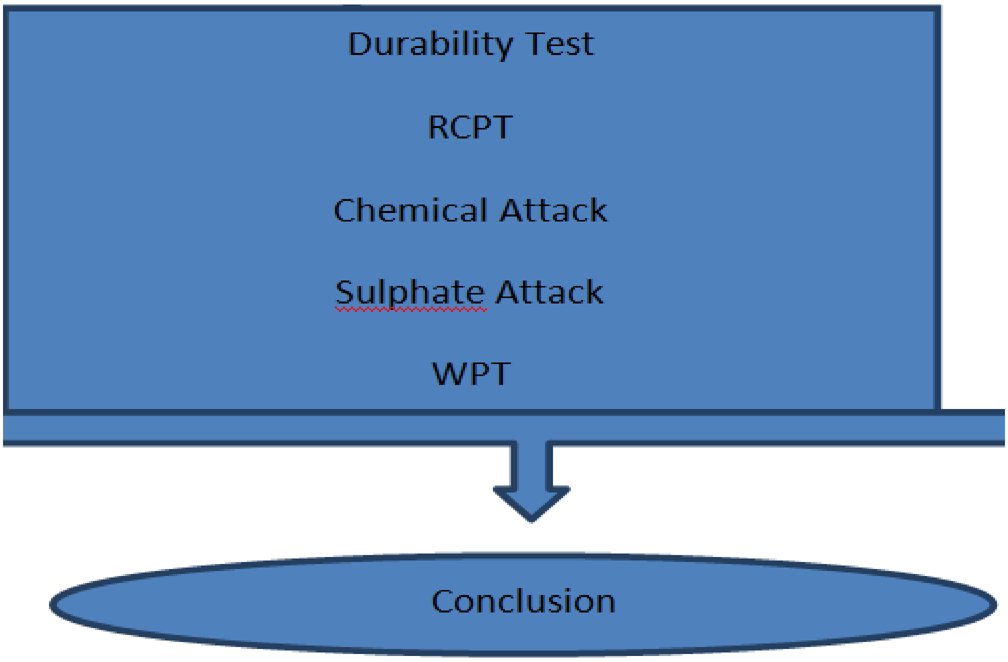


Fig. 3.6 Methodology

CHAPTER 4

Experimental Investigation

Durability Test

Following test were performed to find durability properties of SIFCON, to satisfy the IS 16700 (2017) code test criteria:

- Rapid Chloride Penetration Test
- Water Permeability Test
- Acid Attack Test
- Sulphate Attack Test

SIFCON mix for M20 grades design serves as a basic control mix. Silica fume SIFCON mixes are obtained by adding steel fibres to basic control mix in percentages varying from 0-35% at an increment of 0%, 5%, 15%, 25% and 35% by weight of cementitious materials. The compressive strength development and durability against acidic and sulphate attack is studied.

4.1 Rapid chloride penetration test (RCPT)

The passing of chloride ion in the concrete specimen was measured for at least three samples in an each ratio of mix having the silica fume.

4.1.1 Test Procedure

The Rapid Chloride Permeability of SIFCON test **AASHTO T277 (2000)** and **ASTM C1202 (2015)** are described below. In this test, a 100 mm diameter core or cylinder from the SIFCON is used. A 50 mm diameter specimen is cut from the SIFCON sample. The epoxy coating is given on either side of the cylindrical specimen. Then it is dried in vacuum chamber for 3 hours. Then the specimen is vacuum saturated for an hour after that it is soaked for 18 hours, finally it is placed in the test device. The test cell is filled with 3% sodium chloride (NaCl) solution on the left-hand side passes negative charge (-). The right-hand side test cell is filled with 0.3N sodium hydroxide (NaOH) solution passes positive charge (+). Then the system is connected to the sample for 6 hours with 60 V±0.1-volt potential. Each and every 30 minutes current is measured up to 6 h passing the positive charge on one side and negative charge on another side along with that chloride contamination and the temperature are also monitored.

The results are obtained in mill-amperes using current and time, chloride permeability is calculated in Coulombs for every 30 minutes to end of 6 h. The sample is removed after 6 hours from the cell and the coulombs passed through the specimen are calculated using the given **formula (4.3).** The higher coulomb values show more permeable and the lower value shows less permeable of the SIFCON as given in **Table 4.5** and **Fig. 4.12.**

The following formula is used for calculating the average reading of RCPT:

$$= 900 * (i1+2*i2+2*i3+2*i4+2\ldots\ \ldots\ \ldots i11+2*i12+i13)/1000 \qquad (4.3)$$

Where,

i-a reading taken at an interval of time.

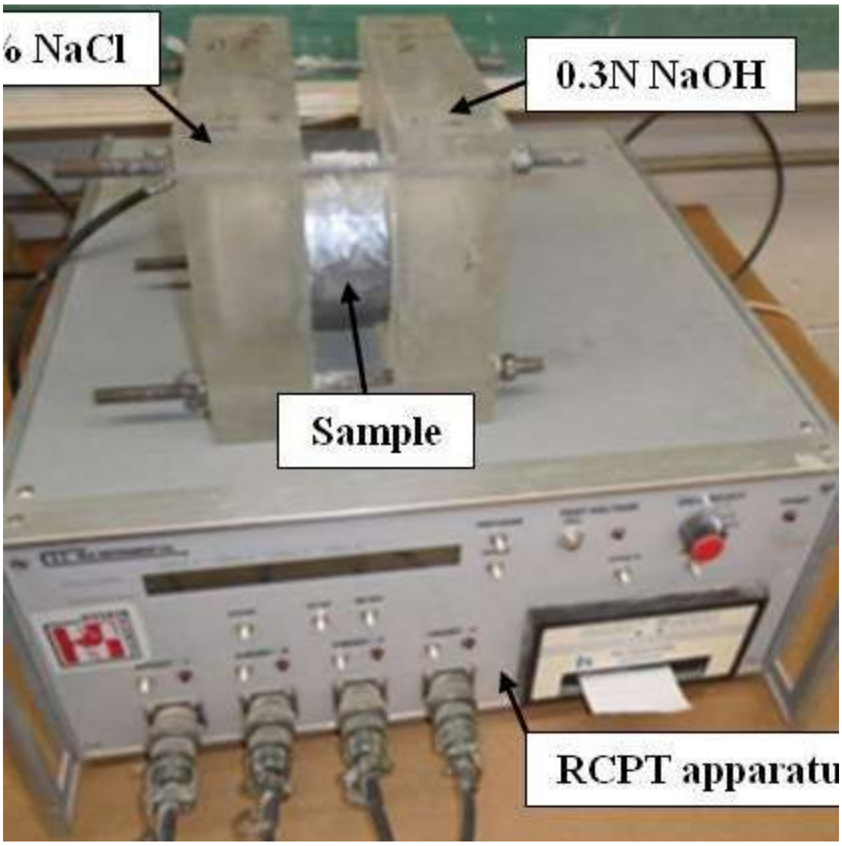


Fig. 4.12 RCPT test on SIFCON

Charge Pass (Coulombs)	Chloride Permeability	Remarks
>4000	High	High W/C ration (>0.60) conventional PCC
2000-4000	Moderate	Moderate W/C ratio (0.40-0.50) conventional PCC
1000-2000	Low	Low W/C ratio (<0.40)
100-1000	Very Low	Latex-modified concrete or internally – sealed concrete
<100	Negligible	Polymer-impregnated concrete, Polymer concrete

4.2 Water Permeability Test (WPT)

The permeability of concrete depends on the pores or voids present in the concrete. Because it is a mixture of cement, silica fume, sand, steel fibres and water material when combined together has pores and contains voids in it. Due to this the interconnected and continuous link between the materials in concrete is prone to permeate fluid or gases and deleterious materials like water, carbon dioxide (CO_2), sulphur dioxide (SO_2) and chloride (Cl) through the pores of the SIFCON which react with the reinforcement and damages the structure in the form of surface cracking and collapse **(Gulden et al., 2016).** The coefficient of permeability represents the rate of flow for water which transmitted through the saturated SIFCON specimen under the maintained hydraulic gradient. It is inversely linked to the durability of SIFCON. When the permeability value is less, the durability of SIFCON is more. These factors depend on the durability of concrete such as the amount of cementations material, fine aggregate size, water content, compaction and curing efficiency.

Fig. 4.13 Water Permeability Test

4.2.1 Test Procedure

The water permeability test was conducted as per **IS 3085 (1965)** and German Standard **DIN 1048 (1991)** where the SIFCON cubes of three sample specimens of size 70x70x70 mm were cast and cured for 28 days after it was kept in the cube compartment of the test set up shown in **Fig. 4.13.** The six cubes can be tested at a time where the test cell had the provision and assembly. To have water tightness the sides of the cubes are sealed with a mixture of wax and resin. The test was conducted for 3 days (72hrs) by applying constant water pressure of 5 N/mm^2 or 5 bar maintained throughout the study period. The water pressure applied to the SIFCON cube was by means of an arrangement consisting of air compression connected to the water tank through the valve to adjust the pressure. The depth of water percolating during the test period is noted until the steady-state is reached. The test was carried out at a temperature of 27°±2°C. If the porosity is greater than 2% in SIFCON, it is not used in construction as per specification.

In concrete, the water permeability coefficient usually varies between 10^{-16} and 10^{-10}m/s **(Schonlin et al., 1988).** The maximum permissible value of the water permeability coefficient of 15×10^{-12} m/s for a conventional concrete is recommended by IS 3085 (1965). The coefficient of permeability (K) is calculated by

$$K = D^2P/2TH \qquad (4.4)$$

Where,

D- Depth of penetration (mm),

P- Porosity of concrete measured as fraction,

T- Time in sec,

H- Pressure head = 1.5m.

Porosity is computed analytically by the quantities like mix ratio of the SIFCON mix, w/c ratio and the physical properties of the SIFCON mix ingredients.

$$P = \frac{[(w/c)-(0.17h)+(a/c)]}{(0.317+(1/Sfa)(Af/c)+(1/Sca)(Aca/c)+(w/c)+(a/c)} \qquad (4.5)$$

Where,

w/c-water cement ratio, h-Degree of hydration (50% for 0.3 w/c), a-Volume of entrapped air, S-Specific gravity of cement, Sfa-Specific gravity of fine aggregate, Sca-Specific gravity of coarse aggregate, Af, Aca, c-indicates the mix proportions, ratio of fine aggregate, coarse aggregate and cement.

The calculation was done using equation 4.5; the decreased value permeability improves SIFCON resistance to re-saturation, sulfate and other chemical attacks and chloride ion penetration.

4.3 Chemical Attack Test

Due to permeability and alkalinity present in the SIFCON, the chemical attack resistance in the structures takes place. This can be measured by conducting tests like acid attack, sulphate attack and permeability in SIFCON. The weight loss and strength loss shows the difference between normal cured and chemical cured SIFCON. Depending upon the chemical resistance, the effect on the SIFCON can calculated. The silica fume present in the cement reduces the chemical attack as it has less CaO. The test conducted is given below.

The high content of CaO in control mix makes it vulnerable in a chemical solution, since it is readily soluble in an acid environment as claimed by other authors **(Vijayakumar et al., 2017).**

4.3.1 Acid Attack Test

The test is called acid ponding test because the SIFCON cube is kept under acid mixed water. To measure the acid exposure condition of the SIFCON with and without the addition of steel fibres with various percentages and in different curing days are noted. The specimen 70x70x70 mm cube was immersed in 5% of hydrochloric acid (HCl) mixed water for 60 days, after curing for 28 and 56 days in normal water then it is cured in acid solution. During the chemical curing, the acid solution is refreshed to maintain the pH<6. After this, the cube was taken out from the solution and weight loss was noted which was compared with the weight of normal curing where three samples were tested using a universal testing machine to find the strength of the cube which was compared with the normal curing SIFCON.

4.3.2 Sulphate Attack Test A sodium sulphate (Na_2SO_4) 5% solutions were prepared by taking a weight of sodium sulphate mixed with water. The SIFCON specimen of cube 70x70x70 mm age of 28 days and 56 days were immersed in this solution for 60 days. The chemical curing of sample exposure to the solution was taken out and surface dried. After that surface was cleaned, scrubbed and final surface dry weights of the cubes were noted, and then compressive strength was tested. The results of the sulphate resistance tests for various percentage of steel fibres addition in SIFCON mix at the age 28 and 56 days.

4.4 Water Absorption Test

For water absorption and sorptivity tests, the cube specimens were dried in the oven at a temperature of 105°C to a constant mass. This oven-dried weight was noted. Specimens were then cooled to room temperature and were immersed in water. Specimens were taken out of the water at regular intervals and weighed. The process was continued till constant weight (fully saturated condition) is achieved. The difference between saturated mass and oven dried mass expressed as a percentage of oven dried mass gives the saturated water absorption.

4.5 Sorptivity Test

Sorptivity test determines the ratio of capillary rise absorption by a concrete cube which rests on small support in a manner such that only the lowest 2 to 5 mm of cube is submerged. The increase in the mass of the cube with time is recorded. The sorptivity is calculated as, i = svt, where i = increase in mass in gm/mm^2, t = time measured in minute at which the mass is determined and s = sorptivity in mm/Vmin. As the increase in mass is due to the ingress of water, 1gm is equivalent to 1 mm^3, so that T can be expressed in mm. When specimen was kept in the water the value of 'i', i.e. the rise in the water level in the concrete was noted down, which manifests itself by a darker color.

5. CONCLUSION

By getting reasonable part of plain steel strands of 0%- 35% with lacking substitution of bond by silica fume in various volumes, the mechanical properties can be improved.

Working up the piece of fiber in solid augmentations compressive quality, split adaptability, direct steady nature and nature of SIFCON wrapped up.

The compressive quality at 28 days that displays the fiber results most inconceivable respect 42.08MPa with the extra substance of plain tricky steel fiber PMSF35.

The split flexibility at 90 days that demonstrates an estimation of 6.3MPa with PMSF 35% plain smooth steel fiber.

The short flexibility at 28 days that shows an estimation of 4.1MPa with PMSF 35% of steel fiber.

The quality estimation of ultrasonic heartbeat speed respect is 5.7km/s for square and 7.5km/s for chamber in the wake of including PMSF 35% of steel fiber, from this time forward the outcome is stunning for heartiness.

In setting on the examination did, the making in quality as for control blend is about 1.2 occasions for compressive quality, on different events for split flexibility, on various events for direct inflexible nature, 1.3times for ultrasonic heartbeat speed perfectly healthy, 2.3times for ultrasonic heartbeat speed in chamber.

Subsequently it is recognized that 35% usage of plain smooth steel fiber gives splendid quality in bond for all types of tests.

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