Investigation on Strength and Durability of Slurry Infiltrated Fibrous Concrete

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Abstract – Slurry-infiltrated fibrous concrete (SIFCON) can be considered as a special type of fiber concrete with high fiber content. It is different from normal fibre reinforced concrete (FRC) in two aspects, viz., the fiber content and method of production. The matrix usually consists of cement slurry or flowing mortar. This slurry-based matrix must consist of fine particles to infiltrate the fibre network. Slurry infiltrated fibrous concrete is one of the new addition to the high performance concrete. Since, the usage of very high amount of cement in SIFCON not only affects the production costs, but also has negative effects on the heat of hydration and may cause shrinkage problems. Replacing the cement with supplementary cementitious materials seems to be a feasible solution to overcome these problems. These materials modify the microstructure of concrete and reduce its permeability thereby reducing the penetration of water and water-borne salts into concrete. The main objective of this project is to determine the effect of silica fume and ground granulated blast furnace slag on compressive strength, split tensile strength, flexural strength and durability behaviour on slurry infiltrated fibrous concrete. An experimental program was carried out with 10% fiber content and by replacing the cement with different percentages of silica fume (5%,10%,15%,20%,25%) and GGBFS (15%,30%,45%,60%,75%).The test result reveals that the incorporation of cementitious materials improve the strength as well as the durability nature of SIFCON. Also, the GGBFS replacement exhibit excellent performance in strength and durability when compared to silica fume replacement.

Index Terms – SIFCON, cementitious materials, fiber, GGBFS and FRC.

1. INTRODUCTION

Modern structural requirements demand materials with increasingly improved properties such as strength, stiffness, and impact and abrasion resistance. Fibre reinforced concretes prepared with different types of fibres have found many structural applications.

However, the ductility of fibre reinforced concrete basically depends on the volume fraction of fibres used in the production though various other factors such as type of fibre, its aspect ratio and tensile strength of fibre can also influence the ductility. Efforts have been made to incorporate fibres up to 6% but were affected by difficulties in placing and mixing. Special production methodologies developed in the modern days to overcome this difficulty have led to the development of another high performance material called as slurry infiltrated fibrous concrete (SIFCON).

1.1. Ordinary Portland cement

Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar and plaster. English masonry worker Joseph Aspdin patented Portland cement in 1824; it was named because of its similarity in colour to Portland limestone, quarried from the English Isle of Portland and used extensively in London architecture. It consists of a mixture of oxides of calcium, silicon and aluminium. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay and grinding this product (called clinker) with a source of sulfate (most commonly gypsum).

1.2. Slurry Infiltrated Fibrous Concrete

Slurry-infiltrated fibrous concrete (SIFCON) is a high-performance material invented by Lankard. It possesses excellent mechanical properties coupled with greater energy-absorption characteristics. SIFCON can be considered as a special fibre-reinforced concrete. Normally, fibre-reinforced concrete contains 1–3% fibres by volume, whereas SIFCON contains 6–20% of fibres. The other major 2 difference is in the composition of the matrix. In SIFCON, the matrix is made of flowing cement mortar slurry as opposed to aggregate concrete in normal fibre-reinforced concrete. The casting process is also different for SIFCON. In most cases, SIFCON is fabricated by infiltrating a bed of pre-placed fibres with cement slurry. Even though SIFCON is a new construction material, it has found applications in the areas of pavements repairs, repair of bridge structures, safe vaults and defence structures due to its excellent energy-absorption capacities. It is already established by the authors that SIFCON slab elements exhibit excellent behaviour in flexure and punching shear when compared to FRC, reinforced cement concrete (RCC) and plain cement concrete (PCC) slabs. Due to its extraordinary ductility characteristics, it has a lot of potential for applications in structures subjected to impact and dynamic loading. There are four main design factors that should be considered in a SIFCON product. These are slurry strength, fiber volume, fiber alignment, and type. The fiber volume depends on the fiber type and the vibration effort needed for proper compaction. Smaller or shorter fibers may pack denser than longer fibers and higher fiber volumes can be achieved with careful and sufficient vibration.

1.3. Supplementary Cementitious Materials

In its most basic form, concrete is a mixture of Portland cement, sand, coarse aggregate and water. The principal cementitious material in concrete is Portland cement. Today, most concrete mixtures contain supplementary cementitious materials that make up a portion of the cementitious component in concrete. These materials are generally by products from other processes or natural materials. They may or may not be further processed for use in concrete. Some of these materials are called pozzolanas, which by themselves do not have any cementitious properties, but when used with Portland cement, react to form cementitious compounds. Other materials, such as slag, do exhibit cementitious properties. For use in concrete, supplementary cementitious materials, sometimes referred to as mineral admixtures, need to meet requirements of established standards. They may be used individually or in combination in concrete. They 3 may be added to the concrete mixture as blended cement or as a separately batched ingredient at the ready mixed concrete plant. Supplementary cementitious materials are used to reduce the heat generation associated with cement hydration and reduce the potential for thermal cracking in massive structural elements. These materials modify the microstructure of concrete and reduce its permeability thereby reducing the penetration of water and water-borne salts into concrete. Watertight concrete will reduce various forms of concrete deterioration, such as corrosion of reinforcing steel and chemical attack. Most supplementary cementitious materials can reduce internal expansion of concrete due to chemical reactions such as alkali aggregate reaction and sulfate attack. Resistance to freezing and thawing cycles requires the use of air entrained concrete. Concrete with a proper air void system and strength will perform well in these conditions.

2. RELATED WORK

The first high performance fibre reinforced concrete (HPFRC) fabricated by slurry infiltration technique with high fibre volume content was slurry infiltrated fibrous concrete. There are four main design factors that should be considered in SIFCON product .These are slurry strength, fiber volume, fiber alignment and type. The available published literature on many design factors and strengthening of SIFCON is briefly reviewed.

HalitYazicietal. (2010) investigated the effects of steel fiber alignment and high-volume mineral admixture replacement Class C fly ash and ground granulated blast furnace slag on the mechanical properties of SIFCON. Ordinary Portland cement was replaced with 50% (by weight) FA or GGBFS in SIFCON slurries, and two different steel fiber alignments (random and oriented in one direction) were used. Test results showed that FA and GGBFS replacement positively affected mechanical properties and fiber alignment is an important factor for superior performance.

Murat Tuyan et al. (2012) indicated that fiber type, embedded length of fiber, curing conditions, fiber end condition, and matrix strength has a considerable effect on fiber–matrix bond. Increasing the diameter of the fiber and improving the curing conditions increased matrix–fiber bond. In addition, increasing bond strength was observed with increasing strength of SIFCON matrix. The pull-out toughness increased by increasing embedded length of fiber. It has been observed that hooked end fibers have shown better interface bond compared to the smooth fibers.

The compressive strength of SIFCON is close to each other in the case of parallel and perpendicular loading directions to fibers. Loading parallel to fibers causes separation type failure. Loading perpendicular to the fibers generally caused shear type failure. In this case fibers restrain the lateral deformation in one direction but there is no restrain effect in other lateral direction. In random fiber usage, the mixed type of failure was observed and random fibers increased the compressive strength considerably in all composites (Halit Yazici,2010).

Ashish et al. (2013) studied the effect of alternate wetting and drying on the properties of SIFCON. SIFCON is made from waste coiled steel fibres obtained from lathe machine shop. In this study, fibres having aspect ratios like80, 90, 100, 110 and 120 are used. Specimens are subjected to five cycles of alternate wetting and drying. The strength characteristics like compressive strength, tensile strength, flexural strength, and impact strength are evaluated. It has been observed that the compressive strength, tensile strength, flexural strength and impact strength of SIFCON goes on increasing as the aspect ratio of fibers in it goes on increasing. This is also true for SIFCON with and without subjecting it to alternate wetting and drying.

Katkhuda et al. (2009) studied the isolated effect of silica fume on tensile, compressive and flexure strengths on high strength lightweight concrete. Many experiments were carried out by replacing cement with different percentages of silica fume at different constant water-binder ratio keeping other mix design variables constant. The silica fume was replaced by 0%, 5%, 10%, 15%, 20% and 25% for a water-binder ratios ranging from 0.26 to 0.42. For all mixes, split tensile, compressive and flexure strengths were determined at 28 days. The results showed that the tensile, compressive and flexure strengths increased with silica fume incorporation but the optimum replacement percentage is not constant because it depends on the water–cementitious material (w/cm) ratio of the mix.

Kasim Turk et al. (2012) indicated that SCC mixtures with SF had the lowest sorptivity values compared to VTC, SCC with only PC and SCC with FA. Because SCC specimens with SF had the less porous zone and refinement of pore structure (Zhu and Batros.2003, Bai.2002). Furthermore, it is clear that the water sorptivity values of SCC specimens with SF decreased with increase in the replacement level of SF from 5 to 20% indicating the filler effect of SF as well as puzzolanic activity. However, there is systematic increase in absorption with increase in the replacement level of FA from 25to 40%. SCC with FA mixes exhibited absorption values of less than or equal to 1.36%, which is considered to be a low water absorption.

Oner et al. (2007) investigated on optimum level of ground granulated blast-furnace slag (GGBFS) on the compressive strength of concrete. GGBFS was added according to the partial replacement method in all mixtures. The test results proved that the compressive strength of concrete mixtures containing GGBFS increases as the amount of GGBFS increase. After an optimum point, at around 55% of the total binder content, the addition of GGBFS does not improve the compressive strength. This can be explained by the presence of unreacted GGBFS, acting as a filler material in the paste.

Bassuoni et al.(2007) studied the Resistance of self-consolidating concrete to sulphuric acid attack with consecutive pH reduction Self-consolidating concrete (SCC) is increasingly being used in numerous concrete applications some of which are vulnerable to sulphuric acid attack. The mixture design of SCC is different than that of normal concrete, and thus its long-term durability characteristics are still uncertain. This study aims at investigating the resistance of a variable range of SCC mixture designs to sulphuric acid attack.

3. METHODOLOGY

The methodology explains about the types and details of the experiments.

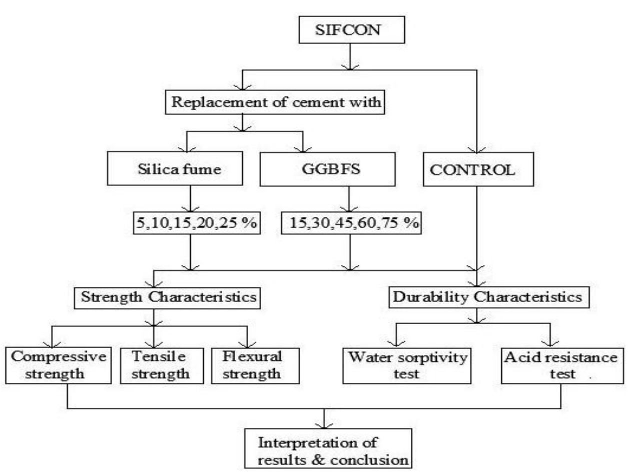

Fig 1 Methodology flow chart

3.1. Materials used

Cement, fine aggregate and fiber were used in casting of concrete .The purpose of this investigation is to know the property and behaviour of materials. The aim of this action was to ease the promotion of ‘new’ material to the concrete construction industry. The specifications and properties of these materials are under.

3.1.1. Cement

The cement used was Ordinary Portland Cement (53 grade). Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar and plaster. It consists of a mixture of oxides of calcium, silicon and aluminium. Portland cement are made by heating limestone with clay and grinding this product with source of sulfate. Specific gravity of cement used is 3.15.

3.1.2. Fine aggregate

Sand used for the experimental program was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was first sieved through BIS 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. Fine aggregate was tested as per IS 2386-1963. The fine aggregate belongs to grading zone II.

Table 1 Properties of Fine Aggregate

S. No	Properties	Observed value
1.	Fineness modulus	2.43 %
2	Specific gravity	2.7 1

3.1.3. Supplementary Cementitious Materials

Supplementary cementitious materials are used to reduce the heat generation associated with cement hydration and reduce the potential for thermal cracking in massive structural elements. These materials modify the microstructure of concrete and reduce its permeability thereby reducing the penetration of water and water-borne salts into concrete. Silica fume conforming to ASTM C 1240 and ground granulated blast furnace slag conforming to ASTM C 989 was used. The specific gravity of silica fume and GGBFS was found to be 2.21 and 2.91 respectively.

3.1.4. Fiber

Fibers work with concrete utilizing two mechanisms, the spacing mechanisms and the crack bridging mechanism. The spacing mechanism requires a large number of fibers well distributed within the concrete matrix to arrest any existing micro - crack that could potentially expand and create a sound crack. The second mechanism termed crack bridging requires large straight fibers with adequate bond to the concrete. Steel fibers are considered to be a prime example of this fiber type which is commonly referred to as large diameter fibers or macro fibers. Benefits of using larger fibers include impact resistance, flexural and tensile strengths, ductility and fracture toughness.

3.1.5. Water

Fresh water available from local sources was used for mixing and curing of SIFCON, conforming to IS: 456-2000.

3.1.6 Super plasticizer and acids

Super plasticizers, also known as high range water reducers, are chemicals used as admixtures where well-dispersed particle suspensions are required. These polymers are used as dispersants to avoid particle aggregation, and to improve the flow characteristics of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste. To improve the workability of SIFCON, CONPLAST- 430, a high –range water reducing agent has been used. Sulphuric acid and hydrochloric acid was used for curing.

4. RESULTS AND DISCUSSION

The compressive strength results of silica fume and GGBFS are presented in table 5.1.It can be seen from the table, the strength is increased with curing age for all cementitious materials replacement. It is clear from the figure1 the replacement of silica fume by cement increased the strength when compared to control SIFCON. At the age of 28 days the optimum percentage attained at 15% replacement of silica fume (95.01 N/mm^2) and at the age of 7days optimum percentage attained at 20% replacement of silica fume (88.04 N/mm^2).The strength value at 25% replacement gets decreased when compared to control SIFCON.

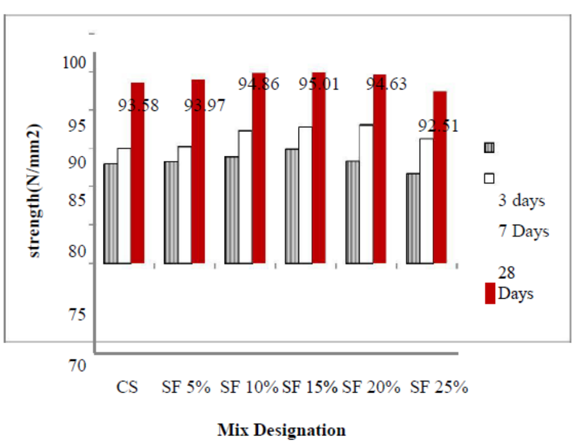

Fig 2.1 Compressive strength of control SIFCON and SF

S.NO	Specimen	Average Compressive Strength (N/mm^2)		
		3 Days	7 Days	28 Days
1	CS	82.97	84.96	93.58
2	SF 5%	83.21	85.22	93.97
3	SF 10%	83.88	87.32	94.86
4	SF 15%	84.90	87.76	95.01
5	SF 20%	83.28	88.04	94.63
6	SF 25%	81.67	86.23	92.51
7	GGBFS 15%	85.97	88.44	96.08
8	GGBFS 30%	86.22	91.26	105.90
9	GGBFS 45%	83.64	93.24	98.22
10	GGBFS 60%	81.72	93.97	97.28
11	GGBFS 75%	79.58	89.42	94.86

Table 5.1 Compressive strength of silica fume & GGBFS replacement in SIFCON

Similarly the compressive strength of GGBFS increased when compared to control SIFCON. The optimum percentage attained at 30% replacement of GGBFS at 28 days curing (105.90 N/mm^2).At the age of 3 days the strength gets decreased at 75% replacement of GGBFS

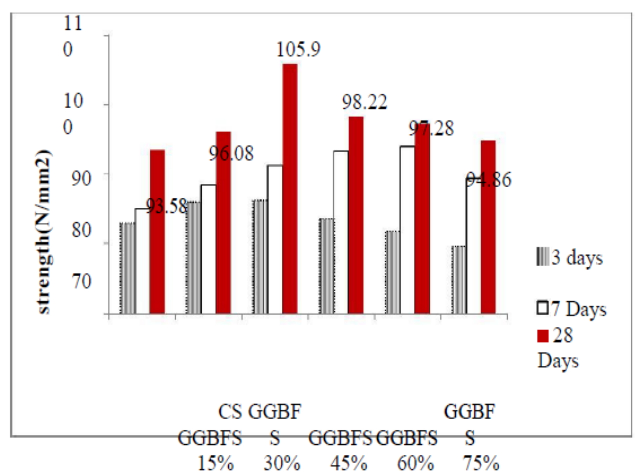

Fig 2.2 Compressive strength of control SIFCON and GGBFS.

Furthermore, the GGBFS strength gets increased when compared to silica fume. The workability of silica fume is less when compared GGBFS. To increase the workability of silica fume certain percentage of super plasticizer is added to the concrete by the weight of the cement.

5. CONCLUSION

It is observed that the utilisation of supplementary cementitious materials is well accepted because of the several improvements possible in SIFCON composite and due to overall economy. It improves the consistency and workability of fresh concrete because an additional volume of fines is added to the mixture. These materials modify the microstructure of concrete and reduce its permeability thereby reducing the penetration of water. The effect of silica fume replacement increases the compressive and split tensile strength and the maximum strength attained at 15% replacement. Similarly the GGBFS replacement also increases the compressive and split tensile strength and the optimum strength attained at 30% and 60% respectively. The strength gain due to silica fume replacement in compressive strength is almost similar to that in split tensile strength for SIFCON. But the strength gain due to GGBFS ranges between 30- 60%. The optimum flexural strength attained at 20% silica fume replacement and 45% GGBFS replacement. On comparing both GGBFS exhibit excellent performance at maximum percentage than silica fume. Durability of structure during long – term exploitation is of key importance for safe and efficient functioning of concrete constructions. Results shows that water absorption capacity of SIFCON decreases with increase of supplementary cementitious materials thus indicates a good durability nature of SIFCON and may be attributed to the decrease in number of pores in the specimen due to the optimum amount of cementitious materials.

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