Indo-Iranian Journal of Scientific Research (IIJSR)
Volume 1, Issue 1, Pages 31-37, October-December 2017

Strengthening Factor for RC Beams by Using Precast SIFCON Lamination

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Article Received: 03 October 2017 *Article Accepted: 19 October 2017* *Article Published: 28 October 2017*

ABSTRACT

Slurry infiltrated fibrous concrete (SIFCON) is a novel type of high performance fiber reinforced concrete made by infiltrating steel fiber bed with a specially designed cement based slurry. Laboratory experiments have shown that SIFCON is an innovative construction material possessing both high strength and large ductility. In the present study, the use of SIFCON has been investigated as an externally bonded strengthening material on reinforced concrete beams. The experimental programme has been carried out to study the behavior of flexural RC beams with precast SIFCON laminates. The concrete beams have been designed to obtain a concrete grade of M40. The steel fibres used in the study were hooked end steel fibres having 0.6mm diameter and aspect ratio of 50. Previous results indicate that the strengthening of RC beams with SIFCON laminates has significantly improved the cracking behavior in terms of significant increase in first crack load and the formation of larger number of finer cracks. The stiffness, ductility and energy absorption found are to be increase to a great extent.

Keywords: Stiffness, Ductility and Energy absorption.

1. INTRODUCTION

Reinforced concrete structures often have to face modification and improvement of their performance during their service life. The main contributing factors are change in their use, new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. In such circumstances there are two possible solutions: replacement or strengthening. Full structure replacement might have determinate disadvantages such as high costs for material and labor, a stronger environmental impact and inconvenience due to interruption of the function of the structure e.g. traffic problems. When possible, it is often better to repair or upgrade the structure by strengthening. In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or fiber reinforced polymer (FRP) bars to the surface of the concrete. A promising new way of resolving this problem is to selectively use advanced composites such as High Performance Fiber Reinforced Cementitious Composites (HPFRCCs). With such materials novel repair, retrofit and new construction approaches can be developed and that would lead to substantially higher strengths, seismic resistance, ductility, durability while also being faster and more cost - effective to construct than conventional methods.

SIFCON is a high-strength, high-performance material containing a relatively high volume percentage of steel fibres as compared to steel fibre reinforced concrete (SFRC). It is also sometimes termed as 'high- volume fibrous concrete'. The origin of SIFCON dates to 1979, when Prof. Lankard carried out extensive experiments in his laboratory in Columbus, Ohio, USA and proved that, if the percentage of steel fibres in a cement matrix could be increased substantially, then a material of very high strength could be obtained, which he christened as SIFCON. While in conventional SFRC, the steel fiber content usually varies from 1 to 3 percent by volume, it varies from 4 to 20 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 fiber content. While in SFRC, the steel fibres are mixed intimately with the wet or dry mix of concrete, prior to the mix being poured into the forms, SIFCON is made by infiltrating a low-viscosity cement slurry into a bed of steel fibres 'pre-packed' in forms / moulds. The matrix in SIFCON has no coarse aggregates, but a high cementitious content. However, it may contain additives such as fly ash, micro silica and latex emulsions. The matrix fineness must be designed so as to properly penetrate (infiltrate) the fibre network placed in the moulds, since otherwise, large pores may form leading to a substantial reduction in properties. A controlled quantity of high - range water -reducing admixture (super plasticizer) may be used for improving the flowing characteristics of SIFCON. All types of steel fibres, namely, straight, hooked, or crimped can be used. The HPFRCCs were developed in the 1990's to improve performance characteristics of fibre reinforced concrete.

Slurry Infiltrated Concrete (SIFCON) - High performance concrete is a recent development in concrete technology. It is designed to give optimized performance characteristics for the given set of materials, usage and exposure conditions, consistent with requirement of costs, service life and durability. ACI has defined high performance concrete as a concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practice. The development of high performance concrete is directly related to a number of recent technological milestones, in particular the discovery of the extraordinary dispersing action of superplasticizer, use of micro fillers like silica fume and fly ash, ability of fibres of different types, properties etc. The addition of steel fibers to high performance concrete makes it highly ductile and improves the energy absorption capacity.

Slurry Infiltrated Fibrous Concrete (SIFCON), an exceedingly improved version of conventional fibre reinforced concrete, is a unique high performance concrete with its unique properties in the areas of both strength and ductility. SIFCON is similar to FRC in the sense that it has discrete interlocking fibres that lend significant tensile properties to the composite matrix. In two aspects, however, it is different from normal FRC. In FRC, the fibre content usually varies from 1% to 3% by volume, whereas in SIFCON the fibre content varies from 4% to 20%. The matrix of SIFCON consists of low viscosity, cementitious slurry as opposed to regular concrete in FRC. The process of making SIFCON is also different because of the high fibre content. SIFCON is cast using a preplacing technique in which steel fibres are placed in the mould to its full capacity and infiltrated with cement based slurry whereas in FRC, the fibres are added to the wet or dry mix of the concrete.

The primary constituent materials of SIFCON are steel fibres and cement-based slurry. The slurry can contain only cement, cement and sand or cement and other additives like fly ash, silica fume etc. The matrix (cementitious slurry) plays an important role in SIFCON. It helps in transferring the forces between fibres and acts as a medium to keep the fibers interlocked. The fibres in SIFCON are subjected to frictional and mechanical interlock in addition to the usual bond with the matrix. The amount of fibres that can be incorporated depends on fibre aspect ratio, fibre geometry, and placement technique. More fibres can be incorporated if aspect ratios are low. The volume fraction can also be increased by mild vibration. With such a large volume of fibres, there is substantial enhancement of the tensile load carrying capacity of the matrix. This may be attributed to the fact that fibres suppress the localization of micro-cracks into macro-cracks and consequently the tensile strength of the matrix

The main advantage of SIFCON is that very high steel fibre contents can be obtained. The current practical range of fibre volumes for SIFCON is 4% to 20%. However, fibre volumes of up to 27% have been reported (Naaman et al 1992). Slurry infiltration becomes more difficult with this much magnitude of fibres; however, it can be overridden by adding superplasticizer into the slurry mixture.

Preparation of SIFCON - SIFCON is cast by infiltrating low-viscosity cement slurry into a bed of steel fibres ‘pre packed’ in forms/moulds in order to achieve monolithic mass. The placement of steel fibres in a form or mould or on a substrate is the initial step in the preparation of SIFCON. Fibre placement can be accomplished by manual methods or through the use of fibre dispensing units. External vibration may be applied while packing the fibres in the mould. The steel fibre loading is dictated by the packing density of the fibre involved which, in turn, is controlled by fibre aspect ratio and length. Using commercially available steel fibres, fibre loading of 5% to 18% by volume of concrete can be achieved.

Once the fibres are in placed in position, a fine grained, low viscosity, cementitious slurry has to be prepared as per the required mix proportion. The cementitious slurry is then poured on to the preplaced fibre bed with subsequent infiltration of the slurry aided by gravity flow or by external vibrator. It is also possible to infiltrate the fibre bed by pressure grouting from the bottom of the bed. The SIFCON matrix doesn’t contain coarse aggregates; however, it may contain fine sand and additives such as fly ash, micro silica, quartz powder and latex emulsions. Grain sizes of the aggregate phase in the cementitious slurry must be such that only a minimum of particles exceeds the size of the smallest opening in the packed fibre bed. Obviously, if this condition is not met, the fibre bed becomes clogged with aggregate particles and further infiltration becomes impossible. A controlled quantity of high-range water-reducing admixture (superplasticizer) may be used for improving the flowing characteristics of slurry while maintaining a low water-cement ratio. All types of steel fibres, namely straight, hooked, or crimped can be used. Since the infiltration of fibre bed by cementitious slurry is aided mostly by gravity flow, the possibility of using SIFCON in real concrete construction is more significant.

2. MATERIALS USED

Cement - Ordinary Portland cement of review 53 is utilized as a part of the RC beams and the concrete is utilized as a coupling material.

Coarse aggregate - Locally available crushed blue granite stones conforming to graded aggregate of nominal size 12.5 mm as per IS: 383 – 1970. Crushed granite aggregate with specific gravity of 2.77 and passing through 4.75 mm sieve and will be used for casting all specimens. Several investigations conclude that maximum size of coarse aggregate should be restricted in strength of the composite. In addition to cement paste – aggregate ratio, aggregate type has a great influence on concrete dimensional stability.

Water - Water used for mixing should be portable drinking water having pH values between 6 to 8 and it should be free from organic matters and the solid content should be within the permissible limits as per IS 456-2000 and conforming to IS 3025- 1964. In the present experimental study the water available inside the college campus is used for all purposes.

Silica - Silica is another name for the chemical compound silicon dioxide. Each unit of silica includes one atom of silicon and two atoms of oxygen. If you have never heard of silica before, you might be surprised to hear that you probably come into contact with it every day. Silica makes up the mineral called quartz, and it is the most abundant mineral in the earth's crust. It is the main component of most sand and the primary ingredient in glass. Every time you pick up a glass to take a drink, you are using silica. Silica has been known to humans since ancient times, long before we knew it was made of silicon and oxygen. The art of making glass objects with silica dates back centuries. Today, there are many industrial uses for silica. These include abrasives, building materials, fillers, electronics, and water filtration.

Steel fibre - The marked brittleness with low tensile strength and strain capacities of high strength concrete (HSC) can be overcome by the addition of steel fibers. This paper investigated the mechanical properties of high-strength steel fiber-reinforced concrete. The properties included compressive and splitting tensile strengths, modulus of rupture, and toughness index.

The steel fibers were added at the volume fractions of 0.5%, 1.0%,1.5%, and 2.0%. The compressive strength of the fiber-reinforced concrete reached a maximum at 1.5% volume fraction, being a 15.3% improvement over the HSC. The splitting tensile strength and modulus of rupture of the fiber-reinforced concrete improved with increasing the volume fraction, achieving 98.3% and 126.6%improvements, respectively, at 2.0% volume fraction. The toughness index of the fiber reinforced concrete improved with increasing the fraction. The indexes *I*5, *I*10, and *I*30registered values of 6.5, 11.8, and 20.6, respectively, at 2.0% fraction. Strength models were established to predict the compressive and splitting tensile strengths and modulus of rupture of the fiber-reinforced concrete. The models give predictions matching the measurements.

3. MIX DESIGN

Based on IS 13920-

(a) Design stipulations:

i. Characteristics compressive strength	-	40 N/mm^2 required in the field of 28 days
ii. Maximum size of aggregate	-	20mm (angular)
iii. Degree of workability	-	0.90 compacting factor
iv. Degree of quality control	-	Good
v. Type of exposure	-	Mild

(b)Test data for materials:

i. Specific gravity of cement - 3.15
ii. Specific gravity of coarse aggregate - 2.77
iii. Specific gravity of fine aggregates - 2.67

Water Absorption

i. Coarse aggregate - 0.50%
ii. Fine aggregate - 1.0%

Free (surface) moisture

i. Coarse aggregate - Nil
ii. Fine aggregate - 2.0%

Target mean strength of concrete

f_{ck} = f_{ck} + ts
= 40+ (1.65x5)
= 48.25 N/mm^2

Selection of water-cement ratio:

The target mean strength of 48.25 N/mm^2 is 0.40
IS 456, from table 5, maximum water cement-ratio=0.45

Adopt water cement ratio is 0.40

Selection of water and sand content:
Size of aggregate = 20mm (zone II)
Water content per m^3 of concrete = 186 kg
Total aggregate by absolute volume = 40%
Required water content = 196.23 kg

Determination of cement content:

W/C ratio = 0.40
Water = 196.23 litre/m
Cement = 196.23/0.40
= 490 kg/m^3

Determination of coarse and fine aggregate content

$$V = \left[W + \frac{C}{S_C} + \frac{1}{P} \times \frac{fa}{sfa}\right] \times \frac{1}{1000}$$

$$0.98 = \left[196.23 + \frac{490}{3.15} + \frac{1}{0.315} \times \frac{fa}{2.60}\right] \times \frac{1}{1000}$$

$$f_a = 515.84\ kg/m^3$$

$$C_a = \frac{1-p}{p} \times fa \times \frac{sca}{sfa}$$

$$C_a = 1121.74\ kg/m^3$$

The mix proportion then becomes

Concrete mix design

Water	Cement	Fine aggregate	Coarse aggregate
196.23	490	515.84	1121.74
0.4	1	1.05	2.82

Concrete mix design = 1: 1.05: 2.28

4. FUTURE SCOPE

For the upcoming work, the project continuation is to compare the properties of conventional beam and SIFCON lamination beam. Next the testing of materials has been carried out for steel fiber and silica. After finishing the material test SIFCON lamination and beams is to be casted and cured for 28 days and strength test such as compression test and flexural test have been carried out for conventional and SIFCON lamination beam. And finally find the strength difference between the conventional beam and SIFCON lamination beam and also compare the strength achieved.

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