International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.2, pp 661-668, 2015

Flexural Behaviour of Fly Ash Based Slurry Infiltrated Fibrous Concrete

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Abstract: Slurry Infiltrated Fibrous Concrete (SIFCON) is considered as an exceptional steel fibre reinforced concrete (SFRC) which differs from the conventional SFRC in the amount of fibres used and method of fabrication. The matrix consists of cement-sand slurry without any coarse aggregates. This paper reports the influence of fibre volume percentage of hooked end steel fibres having length/aspect ratio 30/30, on the flexural strength and toughness (energy absorption capacity) of SIFCON beams. SIFCON beams were casted with 6, 8 and 10% volume fraction of fibres and for comparison, a control beam of full slurry without fibres is made. From the test results of experimentation, it is observed that SIFCON beams exhibit higher flexural strength and toughness characteristics when compared to the control beam. SIFCON beam with the highest (10%) fibre volume concentration exhibited superior performance among the beam specimens.

Key words: SIFCON, Fibre volume, Flyash, Flexural strength, Toughness.

1. Introduction

Among the various cementitious composites developed in civil engineering, SIFCON has been represented as a High performance Fibre Reinforced Concrete (HPFRC) which possess outstanding compressive, tensile, shear and particularly flexural strength along with extra-ordinary energy absorption capacities and ductility characteristics.

SIFCON was first developed in USA, in the year 1983 by Lankard [1] and SIFCON's basic properties like load-deflection curve, flexural strength and compressive strength, abrasion and impact resistance were studied. Homrich and Namaan [2] investigated SIFCON composites under compression and tension, in order to study the characteristics of stress-strain curves. The effect of low volume steel fibre fraction in FRC was studied by Ramakrishnan et al. [3] and it was reported that the mechanical performance is very high compared to non – fibrous concrete. Parameswaran et al. [4] examined the behaviour of steel fibre mortar specimens having high volume fraction of fibres in the range of 8%, subjected to flexure and reported that they possess flexural strength more than 40MPa.Sudarsanarao et al. [5] tested SIFCON slabs under flexure and compared it with FRC and PCC slabs. It was reported that compared to PCC and FRC slabs, SIFCON slabs display excellent characteristics in flexure. Ipek et al.[6] through his experimentations on prisms reported that increase in pre-setting pressure shows improvement in the flexural strength and toughness value. A maximum flexure strength of 67.54 MPa was achieved when pre-setting pressure given was 15MPa. Adel et al. [7] examined improvement in the mechanical properties of HPFRC with the change in mineral admixture and fibre concentration, and reported that flexural toughness of HPFRC is 33 times higher than plain concrete. From the above literatures, it can be noted that studies on the flexural strength characteristics of SIFCON beams have been very rare. Flexural behaviour is a very important aspect in case of beams as in practical applications they have to resist various flexural loads. Hence there is a need to conduct experimentations on SIFCON beams under flexure.

The aim of this research is to determine experimentally the flexural strength, load-deflection response and energy absorption capacity for SIFCON beams with 6, 8 and 10% fibre volume fraction. In this study, cement has been replaced by partial replacement of fly ash so as to minimise the shrinkage as well as heat of hydration problems and henceforth reduce the negative effects of global warming.

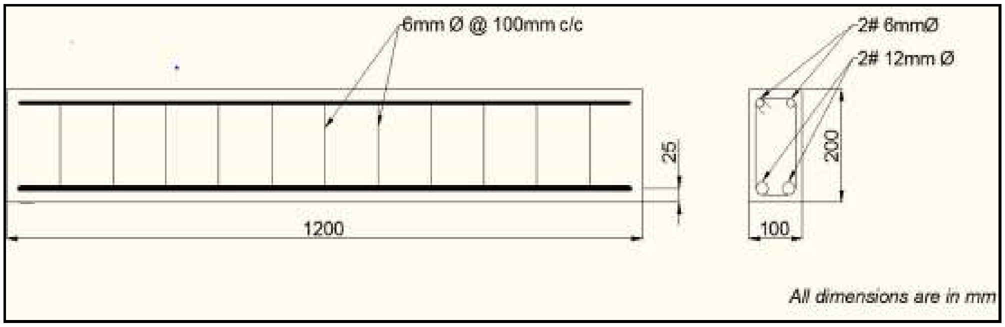


Fig.1. Beam reinforcement details

Fig.2. Casting of SIFCON beam

Fig.3.Universal Testing Machine

2. Experimental Investigation

The experimental programme comprises of casting and testing of three reinforced SIFCON beams of size 1.2× 0.1×0.2 m with variation in fibre concentration as 6, 8 and 10% by volume of concrete. In this investigation, cement has been replaced with 20% of fly ash by weight of cement. Results were compared with the control beam with full slurry and the reinforcement cage.

2.1 Materials used

2.1.1 Cement

Ordinary Portland cement of grade 43 (conforming to IS 12269) was used. The specific gravity was found to be 3.01 and the initial and final setting time was found as 40 min and 340 min respectively.

2.1.2 Class F Fly ash

Low-alkali Class F fly ash procured from thermal power plant was used to enhance durability and strength and to reduce permeability and internal expansion of concrete. Its chemical composition is given in table 1.

Table 1 Chemical composition of cement and fly ash

S.No.	Chemical Composition (%)	CEMENT	FLY ASH
1	Silica (SiO_2)	21.8	58.3
2	Alumina (Al_2O_3)	6.6	31.7
3	Ferric oxide (Fe_2O_3)	4.1	5.9
4	Calcium oxide (CaO)	60.1	2.0
5	Magnesium oxide (MgO)	2.1	0.1
6	Sodium oxide (Na_2O)	0.4	0.8
7	Potassium oxide (K_2O)	0.4	0.8
8	Sulphuric anhydride (SO_3)	2.2	0.2
9	Loss on Ignition (LOI)	2.4	0.3

2.1.3 Fine aggregate

Natural sand passing through BIS sieve 4.75 mm and having fineness modulus 2.64 was used.

2.1.4 Reinforcement

All the four beams were reinforced with 12 mm diameter Fe 415 grade steel rods for main reinforcement and 6 mm diameter bars for shear reinforcement with 6 mm diameter two legged stirrups spaced at 100 mm c/c.

2.1.5 Fibres

Hooked end steel fibres of length 30 mm and 1.00 mm diameter giving an aspect ratio 30 were used. Orientation of fibres was done in random manner.

2.1.6 Water

Fresh water available from local sources was used for mixing and curing of beam specimens.

2.1.7 Superplasticizer

To enhance the flowing characteristics of slurry, a high-range water reducing agent CONPLAST-430 was used.

2.1.8 Mix Proportion

The slurry is made by mixing cement and sand in 1:1 proportion by weight, with water- cement ratio as 0.4 and 2% superplasticizer by weight of cement in order to increase the workability as well as to facilitate better infiltration of slurry to the fibre bed.

Table 2 Mix Proportions

Sl. No	Nomenclature of beams	Mix proportion	Volume of fibre	w/c ratio	Dosage of super Plasticizer	Mode of vibration
1.	SIFCON -6	Cement and sand (1:1 by wt.)	6%	0.4	2%	Hand tamping
2.	SIFCON -8	Cement and sand (1:1 by wt.)	8%	0.4	2%	and tamping
3.	SIFCON -10	Cement and sand (1:1 by wt.)	10%	0.4	2%	Hand tamping
4.	CONTROL SPECIMEN	Cement and sand (1:1 by wt.)	0% (without fibre)	0.4	2%	Hand tamping

2.1.9 Casting of Specimens

Steel mould was used to cast beams of required size. Initially the mould is placed on a smooth surface and the sides of mould are oiled so as to enable easy removal of specimen. The reinforcement cage is placed in the mould by providing a cover of 20 mm with the cover block. Cement, fly ash, sand, water and superplasticizer are weighed accurately and mixed for making slurry. Fibres are weighed according to the percentage by volume and SIFCON beams were made by using three layer technique. This technique follows the filling of fibres to one–third depth of mould and then slurry being poured to the pre-placed fibres up to this layer. Compaction was done to ensure complete infiltration of slurry into fibre pack. The process is repeated till the entire mould was filled and compacted. After 24 hrs of casting, beams were de moulded and cured in water for 28 days. After curing days, beams were dried in air and painted in white so as to get clear visibility of cracks. Grid lines are marked with 2.5cm spacing after white washing and then flexural test was conducted on the beams under two point loading.

2.1.10 Loading Arrangement and Testing

The flexural test of beams were conducted on a computerized universal testing machine (UTM) of capacity 1000kN. The beam specimens were erected and static load was applied as shown in fig.3 by two symmetrically placed point loads. For determining deflections in the beam, a dial gauge with least count 0.01mm was fixed at the bottom face, to the centre of beam. Loads were applied gradually in increasing rate till the specimen collapsed. For each load increment, central deflections were recorded. Ultimate load, the load at which the first crack occurred and the deflections corresponding to that were also observed.

3. Results and Discussions

Experimental investigations were carried on the beam specimens under two-point loading. The parameters like first crack load, ultimate load, load-deflection response, crack and failure pattern were assessed.

3.1 First crack load

The first crack load found for the three percentage variation SIFCON beams as well as control beam are presented in table 3.It can be seen from the table that SIFCON beam specimens exhibit higher first crack load than the control beam .Out of the three SIFCON beams, SIFCON -10, recorded the highest first crack load of 119 kN. The reason behind this is the presence of fibre in high volume fraction. When compared to the beam specimen made of full slurry, the SIFCON beam has a percentage increase of 103 to 283.87% for different fibre volume fractions. This indicates the superior performance of SIFCON beams in flexure.

Table 3 Maximum central deflection at first crack load and at ultimate load.

Sl. No	Nomenclature of beams	First crack load (kN)	Maximum central deflection at central crack load (mm)	Ultimate load (kN)	Maximum central deflection at ultimate load (mm)
1.	CONTROL	31.6	2.75	127.45	12.25
2.	SIFCON -6	57.5	4.5	180.4	12.5
3.	SIFCON -8	97.50	4.8	216.2	12.5
4.	SIFCON -10	119	5.5	244.2	13.25

3.2 Ultimate load:

The ultimate loads found for the beam with full slurry and SIFCON beams are presented in table 3.It can be noted from the table that an ultimate load of 244.2kN has been achieved for SIFCON beam with 10% fibre volume which is 12.9% higher than the beam with 8% fibres. This proves that, for the ranges tested, ultimate strength of SIFCON beams increases with increase in fibre concentration. When compared to the control beam, the ultimate flexural strength of SIFCON beams are 41.5 to 91.6% higher. It can be thus confirmed that SIFCON beams behave quite well than the slurry beam.

3.3 Load-deflection response:

The central deflection value corresponding to the first crack load as well as ultimate load is presented in table 3.The central deflection of SIFCON beams are higher than the beam with full slurry. A maximum deflection of 13.25 mm is observed for SIFCON-10, where as a maximum deflection of 12.5mm is noted for both SIFCON-6 and SIFCON-8 beam. The beam with slurry shows a deflection of 2.75 mm at first crack load and that of SIFCON-6, SIFCON-8, SIFCON-10 are 4.5 mm, 4.8 mm and 5.5 mm respectively. For all the beams, the load-deflection responses are plotted in fig.4.

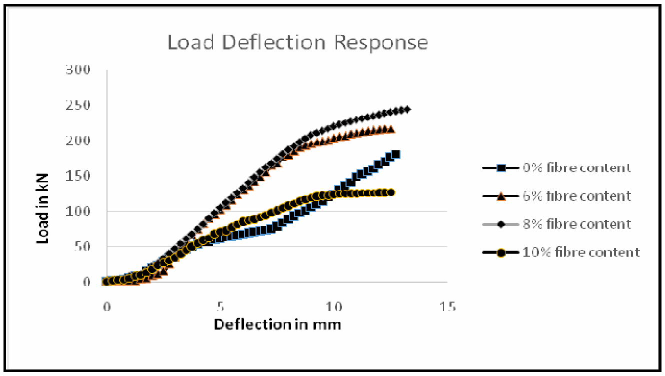
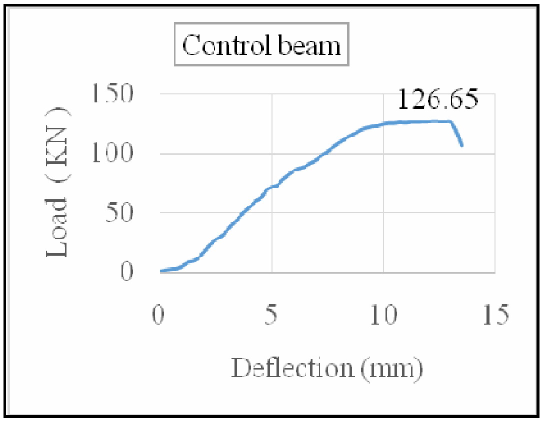
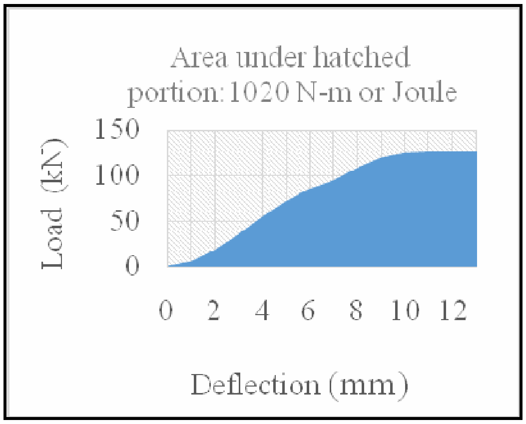


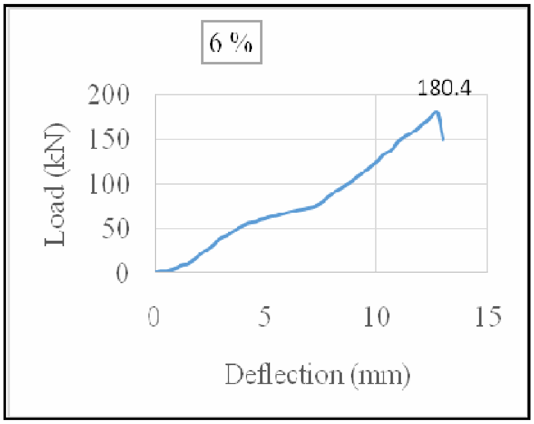
Fig.4. Load-deflection responses of different beam specimens



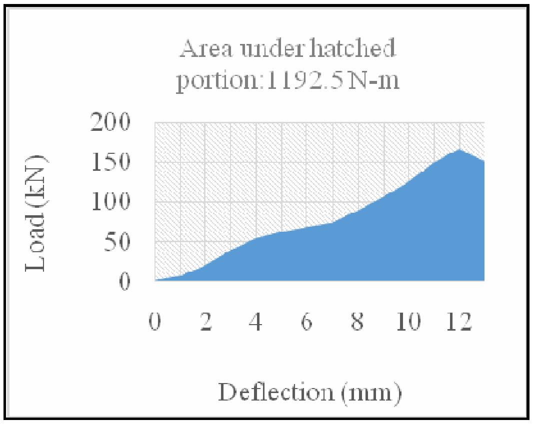
(a) Load-deflection curve for beam with full (0 % fibre) slurry



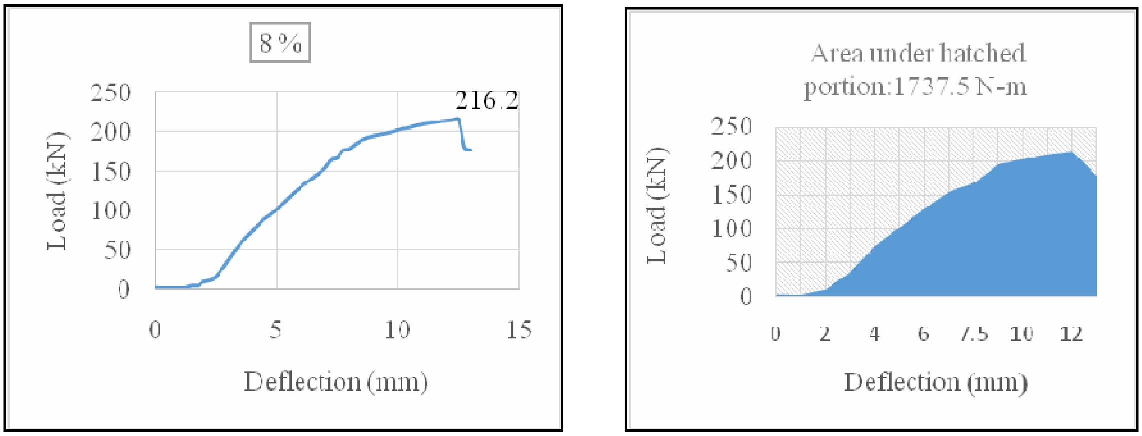
(b) Area under load-deflection curve. (0% fibre)



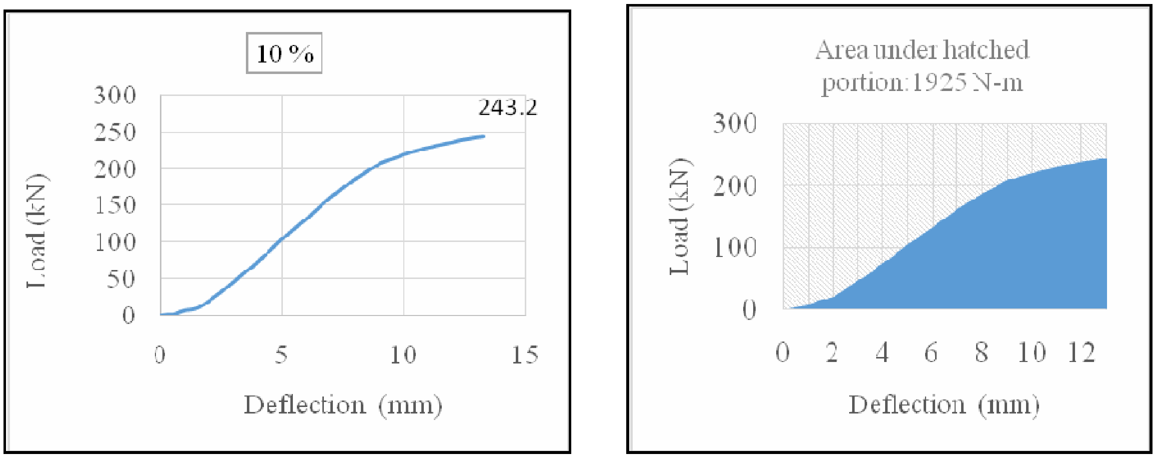
(c) Load-deflection curve (SIFCON -6)



(d) Area under load-deflection curve



(e) Load-deflection curve (SIFCON -8) **(f) Area under load-deflection curve**



(g) Load-deflection curve (SIFCON -10) **(h) Area under load-deflection curve**

Fig 5. **Energy absorption or toughness of different beam specimens**

3.4 Toughness

Table 4 Energy Absorption

Sl. No.	Nomenclature	Energy Absorption(Joules)	% increase w.r.t control beam
1.	SIFCON -6	1192.5	16.9
2.	SIFCON -8	1737.5	70.34
3.	SIFCON -10	1925	88.7
4.	CONTROL	1020	-

The energy absorption capacity of each beam specimen is presented in fig. 5.It is calculated by integrating the area under the load-deflection curve. The calculated energy absorption (Toughness value) of different beam specimens are presented in table 4. It is observed that SIFCON beams have higher absorption ability than the beam with full slurry. The SIFCON beam having 10% fibre volume exhibits the highest energy absorption capacity and it is recorded as 1925 Joules. From the table it is evident that the energy absorption capacity increased with increase in fibre volume fraction. An increase of 16.9% to 88.7 % is seen for SIFCON beams when compared to the beam with full slurry. The reason behind this increased energy absorption capacity may be because of crack–bridging, fibre pull-out mechanism and crack-deflections of SIFCON beam specimens. Therefore, it can be concluded that SIFCON beam specimen shows superior performance than beam with full slurry in flexure.

3.5 Cracking and failure pattern

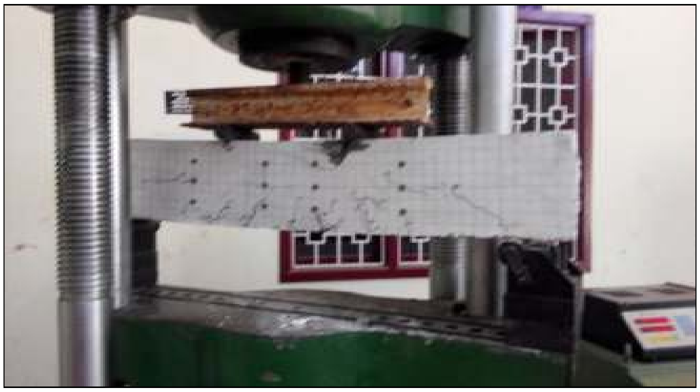


Fig 6. Crack pattern

Cracks and failure pattern are shown in fig.6. It is observed that crack pattern is almost similar for all the SIFCON beams. The cracks formed in SIFCON beams does not extend throughout width of beam as seen in usual reinforced cementitious composites. With increments in load, previously formed cracks widened a little, but formation of new cracks got delayed and it was random. Hair cracks are noted in SIFCON beam specimens. The propagation of cracks was faster in control beam with full slurry when compared to the SIFCON beams. Here diagonal cracks developed from flexural crack becomes more inclined under shear loading and flatter diagonal crack caused failure all of a sudden which shows the shear deficiency of beam.

3.6 Flexural strength

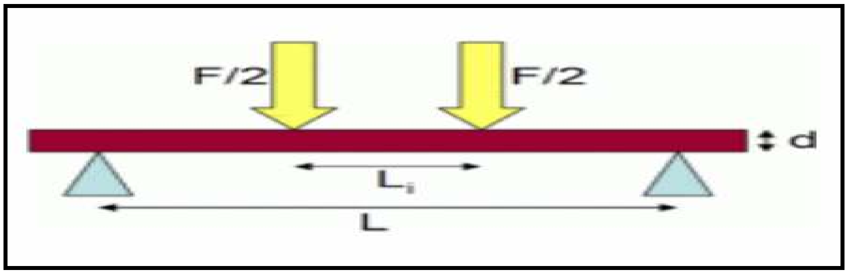


Fig.7. Two point loading arrangement

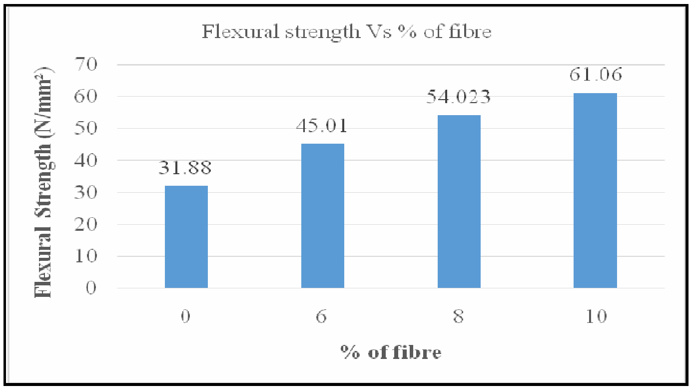


Fig 8. Flexural strength Vs % of fibre

All the beams are tested under two point loading as shown in fig. 7. The flexural strength is calculated for each beam specimen and is presented in table 5 and the same has been depicted in fig. 8. It can be observed from the table that the flexural strength increased with increase in percentage of fibre content.

Table 5 Flexural strength of beams

Sl.No	**Nomenclature of beams**	**Peak load (kN)**	**Flexural strength(N/mm²)**
1.	CONTROL	127.60	31.88
2.	SIFCON -6	180.40	45.01
3.	SIFCON -8	216.20	54.04
4.	SIFCON -10	244.20	61.06

Flexural strength is measured by

$$\sigma = \frac{3F(L - Li)}{2bd^2}$$

Where, F= force at fracture point
L=effective span
Li= inner span
b = width of beam and
d = depth of beam

4. Conclusions

From the experimental investigations carried on the SIFCON beams with different volume concentration of fibres, the following conclusions are drawn out.

1. The load carrying capacity of reinforced SIFCON beams is much greater than the control beam made with full slurry, with no fibres added. The beam specimen with highest fibre volume fraction (10%) has the highest load carrying ability.
2. The flexural strength of the SIFCON beam specimens increased with increase in fibre volume fraction and is found to be 40-91% higher than the control beam.
3. The energy absorption (toughness) capacity is highest for SIFCON beam with 10% volume fraction of fibre and is found to be 1.88 times more than that of control beam.
4. The first crack load of the SIFCON beams got delayed for every percentage increase of fibre. It is found to be 1.8-3.8 times more than that of the beam with full slurry.
5. Increase in depth of SIFCON showed positive effect on the reduction of number of cracks and spacing of cracks.

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