JETIR.ORG
ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

AN EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOUR OF SIFCON-RCC COMPOSITE BEAMS

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Abstract: Slurry Infiltrated Fibrous Concrete (SIFCON) is rather new construction material. It could be considered as an exceptional type of FRC with high fibre content. The matrix usually holds cement-sand slurry or fluent mortar. In conventional FRC, the fibre content usually varies from 0.5-2% by volume, in SIFCON it varies from 3-20%. SIFCON is unique in its consistency and the method of mix preparation. In SIFCON the fibre bed is prepared and the slurry is infiltrated into the fibre bed. SIFCON is advantageous by its excellent energy absorption capacity, greater strength and high ductility.This study reports on the experimental study on flexural behaviour of SIFCON-RCC composite beams. Composite beam (SIFCON-RCC) comprises of 2 layers with RCC as the top and SIFCON as the bottom layer. Herein full SIFCON and full RCC beams are also examined for comparison. To improve the strength, wear resistance and durability of the concrete a small fraction of short crimped fibres (NOVOCON 1050) with aspect ratio 50 is used in our study. On the whole 12 beams of size 1.x0.1x0.2m were cast and tested. Among which 8 beams are SIFCON-RCC composite type. The effect of various volume of SIFCON (10,20, 30, 40, and 50%) in SIFCON-RCC beam on the flexural strength was investigated.

Key words: SIFCON-RCC, Steel fibres, Slurry mix.

I. INTRODUCTION

Concrete is the most extensively used material in civil engineering and is the primary component in most infrastructures. In the foreseeable future it shows that there seems to be no alternative to concrete as a construction material. But the strength of concrete is most important, and it is also necessary that the concrete is durable, workable and to provide a good service life. For example, in prestressed concrete bridges, the concrete should have not only high strength but also limited shrinkage and creep properties. This is for bridges, offshore structures, highway and airport pavements and machine foundations, concrete should possess high fatigue strength. For nuclear containers exposed to very high temperatures, the concrete must have high resistance to thermal cracking. All these requirements made the engineers to think seriously and to find out the appropriate technology for improving the performance of concrete.

To increase in demand and decrease in the supply of aggregates for the production of concrete and the results in need to identify new sources of aggregates. SIFCON gains a important role because, it eliminates the use of coarse aggregate. The principle of sustainable construction development requires prudent use of natural resources with best quality. SIFCON could be the one better solution.

II.SELECTION OF MATERIALS

The primary constituent materials of SIFCON are steel fibres and cement based slurry. The matrix can be contain only:

(a) Cement (slurry or cement paste).

(b)Sand and cement (mortar).

(c) Cement and other additives like fly ash or silica fume.

In most of the cases, the high-range water-reducing admixtures (super plasticizers) are used in order to improve the flowability of the slurry to ensure complete infiltration without increasing the water-cement ratio (W/C). The dosage of 10 super plasticizers has the greatest effect on fluidity, cohesiveness and penetrability of cement slurries.

A.CEMENT

With a given high-quality aggregate, the strength and permeability of concrete mixtures are controlled by the quality of the cement paste, which in turn, depends on the physical and chemical characteristics of the cement type and dosage of chemical and mineral admixtures, the original water-cement ratio, and the degree of hydration. Lankard, D.R.,1984 examined the two classes of high performance concrete mixtures that were designed to achieve compressive strengths of approximately 60 and 75 MPa at 28 days respectively. Criteria for comparing mixtures included workability, compressive strength, splitting tensile strength, and modulus of elasticity. Mixtures containing type III (rapid hardening) cement shows highest compressive strength at all ages, tested most significantly at early ages, when compared to type I (Portland) and type II (modified). ASTM type II cements were ground to a higher fineness than the normal type are generally well suited for making HPC.

B.AGGREGATES

In addition to the cement paste and to the aggregate ratio and aggregate type has a great influence on the concrete dimensional stability. The Concrete mixtures containing coarse aggregates and it are derived from limestone or basalt are generally known to the performed well in HPC. The use of a well graded clean aggregates that are free from silt, clay and friable particles is often overlooked in case of a normal concrete mixes. However, in HPC this cannot be overlooked for the concrete. Fine aggregates (<0.475 cm) with a medium-to-high fineness modulus between 2.5 to 3.0 are generally considered to be adequate. Coarse aggregate should have equidimensional particles; Generally 10 to 14 mm size is considered as optimum for HPC.(Pilar, et al, 1996)

C.STEEL FIBRES

A large variety of steel fibres have been investigated for use in SIFCON. To develop better mechanical anchorage and bond between the fibres and the matrix, the fibres can be modified along its length by inducing mechanical deformations or by roughening its surface. The most widely used types are hooked and crimped fibres. Surface deformed and straight fibres are used also, but they are less popular.

In most cases, the cross section of steel fibres is circular. It can be also rectangular, square, and triangular or flat. In most applications in the USA and Europe, steel fibres with hooked-ends have been used. Most common steel fibres have a length from 25 to 60mm, and a diameter ranging from 0.4 to 1 mm. Their aspects ratio (l/d), that is, the ratio of length over diameter or equivalent diameter, is generally less than 100, with a common range from 40 to 80.

D.MATRIX

The matrix of SIFCON does not contain coarse aggregate which, of course, cannot infiltrate through the tiny spaces between the steel fibres. The matrix compositions investigated in literature include cement, cement-sand, cement fly ash, cement- silica fume, cement-sand-fly ash and cement-sand-silica fume. Matrices containing mineral additives such as fly ash or silica fume were found to have better shrinkage characteristics. Typically, silica fume is reported to increase the strength, where as the addition of fly ash results in some reduction in strength. Moreover, an increase in the proportion of sand is reported to increase the compressive strength.

III.MIX PROPORTIONS

The primary variables in the mix proportioning are fibre content and matrix composition. The fibre volume fraction is commonly controlled by the placement technique and the fibre geometry. The recommended water cement ratio for the slurry mix (matrix) is 0.4 or less. Super plasticizers (SP) can be used if necessary, to improve the flowability of the slurry mix, which should be a liquid enough to the flow through the dense fibre bed without leaving honeycombs. Only fine sand should be used. Very fine sand of less than 0.5 mm in size is reported to use in preparing mortar SIFCON.

If fly ash is used as a cement replacement additive, about 20 % of the cement could be replaced with fly ash. If silica fume is used, the recommended dosage is 10 % by 6 weight of cement. Table shows some slurry mix designs by relative weight of constituents as taken from 11 different studies dealt with SIFCON.

As can be seen from Table, using mortar is more popular than slurry for making SIFCON. The sand proportion to cement by weight ranges from 0.2 to 2, and it is equal to 1 in most cases. Adding fly ash is popular as well to 14 improve the mix properties. In most cases, using super plasticizers is inevitable because of the relatively low W/C ratio, and the need to produce a highly flow able mix.

Some SIFCON slurry mix proportions from the literature (by weight of cement) SIFCON Composition

Cement	**Fine sand**	**Water**	**Fly Ash or Silica Fume**	**SP**
1	0.2	0.355	0.2	0.02
1	0.3	0.255	0.2	0.04
1	0	0.3	0.1	0.048
1	2	0.6	0	0
1	0	0.36	0	0.03
1	0	0.5	0	0
1	1	0.6	0.2	0
1	0.8	0.53	0.2	0
1	0.6	0.45	0.2	0
1	0	0.36	0.2	0
1	1	0.4	0	0.013
1	1	0.32	0	0.035
1	1	0.48	0.2	0.02
1	0	0.36	0.2	0.03
1	0	0.325	0.25	0.04
1	1.5	0.4	0.2	0.01
1	1	0.32	0.2	0.02
1	0.5	0.24	0.2	0.03
1	1	0.45	0	0.032

IV.SIFCON

Balaguru et al, (1987) Mechanical properties of Slurry infiltrated fibrous concrete (SIFCON) being a new kind of fibre reinforced composite material, limited literature is available regarding its application as structural elements. In the present study, experimental program was carried out to investigate structural behaviour of SIFCON beam. The beam specimens are corresponding to undergo a five test series that were tested to study load of deformation behaviour and ductility associated parameters and the ultimate moment capacity and failure of characteristics. The results are compared with the analytical values and a good agreement will be exhibited. SIFCON beams are demonstrated and improved the strength and ductility with the related properties. The failure characteristics present in multi crack behaviour with densely packed cracking. In an appropriate design method to evaluate ultimate moment capacity is finally presented.

Naaman et al, (1991) SIFCON Connections for Seismic Resistant Frames. The flexural tests conducted on restrained SIFCON beams were described and the load-deflection responses under flexural loading were reported. Two different types of beams i.e. SIFCON beams, and PCC beams were investigated. It was found that flexural performance of SIFCON beams is quite superior when compared to FRC and PCC beams..

.Analogous to preplaced aggregate concrete, SIFCON is preplaced fibre concrete with the placement of steel fibres in a mould or form, or on a substrate, as the initial construction step. As stated before, the amount of fibres that can be incorporated depends on fibre dimensions, especially aspect ratio (l/d), fibre geometry, and placement technique. External vibration can be applied during the fibre placement operation. The stronger the vibration, the higher achievable Vf.

Slurry

slurry infiltration

Finished SIFCON beam

PLACEMENT OF STEEL FIBRES ON THE MOULD:

One of the important aspects in the fabrication of SIFCON is fibre orientation. As might be expected, when steel fibres are placed onto a substrate or into a mould, a preferred fibre orientation occurs. The orientation is essentially two–dimensional, perpendicular to the gravity vector. The orientation effect is more exaggerated with some fibres than with others. In general, there is a trend toward a three-dimensional fibre orientation that accompanies reduction in fibre diameter and aspect ratio. The fibre orientation phenomenon must be considered when designing field installations of SIFCON or in preparing laboratory specimens. The preparation of test specimens of SIFCON requires special considerations relating mainly to the need of avoiding non-uniform fibre distributions and of avoiding unfavourable fibre orientation. The fibre density at the edges of the mould can be much less, compared to the interior. Additionally, a number of fibres may align vertically (parallel to the long cylinder axis) along the outer surface. If fibres are aligned along the diameter of the cylinder, a much higher compressive strength can be expected compared to a cylinder in which fibres are aligned along the axis of the cylinder. Actually, it is reported that specimens with fibres perpendicular to loading axis may exhibit twice the strength of specimens with fibres placed parallel to load direction.

Once the steel fibres have been placed on a substrate or in a mould, then they are infiltrated with a fine-grained cement-based slurry. The slurry must be flow able and liquid enough and have sufficient fineness to infiltrate thoroughly the dense matrix in the fibre-filled forms. The infiltration step is accomplished by simple gravity-induced flow or gravity flow aided by external vibration or pressure grouting from the bottom of the bed. The choice of infiltration technique is dictated largely by the ease with which the slurry moves through the packed fibre bed.

V.UNIT WEIGHT OF SIFCON

The unit weight of SIFCON is typically higher than concrete and normal FRC because of the relatively heavy weight of the high fibre content. For a slurry unit weight of 1920 kg/m3, the addition of steel fibres results in an increase in density is varying from 2160 to 3130 kg/m3, for steel volume fraction ranging from 5 to 20 volume percent. The unit weight increase is almost linearly proportional to the fibre content.

VI.COMPRESSIVE STRENGTH

SIFCON is known for its high compressive strength. The composite is also very ductile as compared to a plain matrix. The compressive behavior of SIFCON was investigated using both cast and cored cylinders, and the variables investigated included:

(a) Fibre orientation effect - parallel and perpendicular to the loading axis.

(b) Fibre geometry - hooked ends, crimped and deformed.

(c) Matrix composition - plain cement matrix, matrix containing sand or fly ash, silica fume, or their combinations.

The following is a summary of the results of various investigations.

Compressive strength of SIFCON depends on mix design, matrix strength, fibre orientation, fibre volume fraction, and fibre geometry. For every mixture, the resulted compressive strength value depends on fibre orientation, content, type, and dimensions.

Strength of SIFCON may be 2 times the strength of the plain matrix. An increase in matrix strength results in an increase of SIFCON compressive strength. Fibre geometries showed less influence than matrix strength. The SIFCON strength is higher when fibres are oriented perpendicular to loading axis, but it should be noted that even if dominant alignment was perpendicular to loading axis, some fibres are still aligned in other directions.

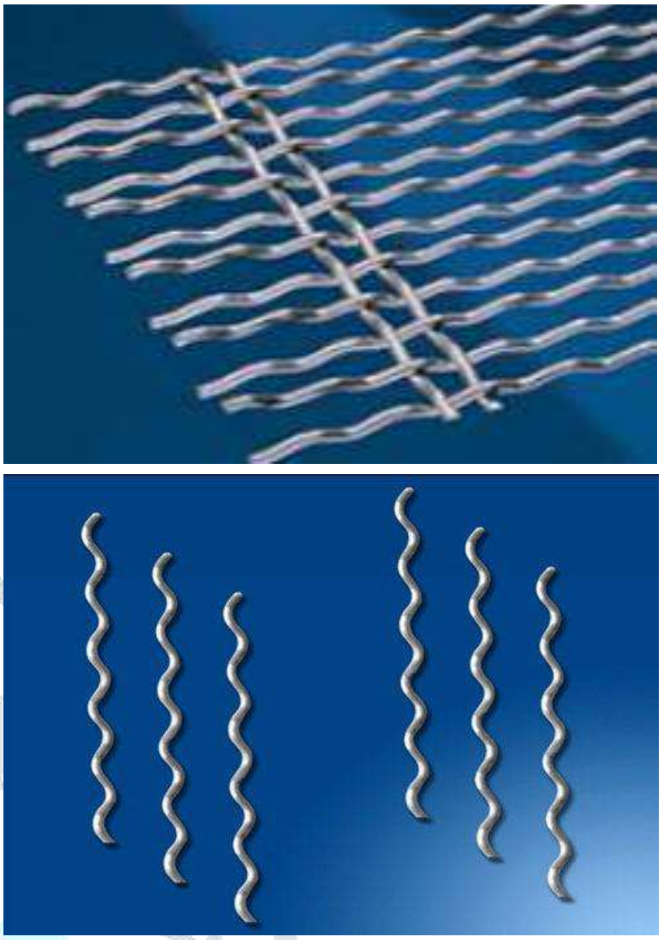
VII.FIBRE: NOVOCON 1050

The steel fibres used in our study were purchased from JEETMULL JAICHANDALAL PRIVATE LIMITED, CHENNAI.

FIBRE PROPERTIES

Steel Fibre Reinforcement: NOVOCON 1050

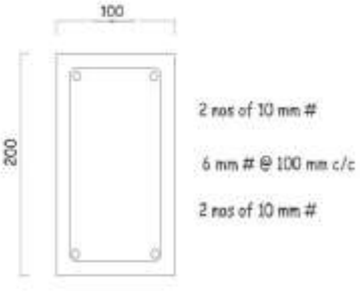
Crimped fibres



Fibre Type : Crimped fibres .
Material : Cold-drawn steel wire, with deformed ends.
Conformance : ASTM A 820/A 820M, Type I.
Fire Classification : UL Report File No. R14701 (N).
Tensile Strength : Minimum 152,000 psi (1,050 MPa).
Fibre Length : 2 inches (50 mm).
Equivalent Diameter : 0.039 inch (1.0 mm).
Aspect Ratio : 50.
Appearance : Bright and clean wire.

REINFORCEMENT

All the beams were reinforced with 4 nos. of 10 mm diameter Fe 415 grade steel. Two number at bottom and two numbers at top and 6 mm diameter 2 legged stirrups at 100 mm c/c.



VIII.RESULTS AND DISCUSSIONS

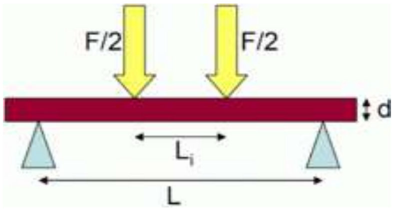
In most field applications, SIFCON is subjected to bending stress, at least partially. Hence, the behaviour under flexural loading plays an important role in field applications. Flexural tests have been conducted for all 12 beams under two point loading.

After testing

Before testing

FLEXURAL STRENGTH

The measured beams are occurred by testing beams under 2 point loading also called 4 point loading including the reactions. Beam Dimensions: 1. m length × 0.1 m breadth x 0.2 m height



Beam under 2 point loading

Where F = the load applied to a sample of test length *L*, width *b*, and thickness *d*.

L= center to center distance of the supports.

Li= inner span.

The following table presents the flexural strength of the tested beams. The flexural strength is computed using the average load of two specimens in each category.

RCC (%)	**SIFCON (%)**	**PEAK LOAD (kN)**	**FLEXURAL STRENGTH (N/mm^2)**
100	0	54.95	14.42
0	100	72.6	19.06
90	10	72.4	19.10
80	20	71.1	18.66
70	30	72.9	19.14
60	40	88	23.10
50	50	73.15	19.20

CRACK PATTERN

Regarding the crack pattern DIAGONAL TENSION FAILURE is noted in all the specimens. The diagonal crack starts from the last flexural crack and turns gradually into a crack more and more inclined under the shear loading as noted in Fig. Such a crack comes not proceed immediately to failure, although in some of the longer shear spans this either seems almost to be the case or an entirely new and flatter diagonal crack suddenly causes failure. More typically, the diagonal crack encounters resistance as it moves up into the zone of compression becomes flatter and stops at some point such as that marked 1 in Fig 4.5. With further load, the tension crack extends gradually at a very flat slope until finally sudden failure occurs, possibly from point 2. Shortly before reaching the critical failure point at 2 the more inclined lower crack 3 will open back, at least to the steel level and usually cracks marked 4 will develop.

Beam failure pattern

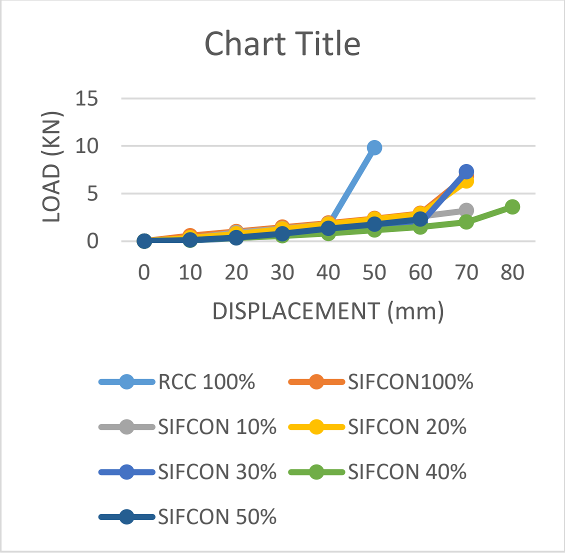
LOAD Vs DISPLACEMENT

Even though SIFCON has typically higher compressive strength than normal concrete, its uniqueness is much more important in the area of energy absorption, ductility and toughness. A great energy absorbing capacity and a ductile mode of failure, make SIFCON suitable and perfect for applications involving impact, blast, and earthquake loading.

Load Vs displacement

DEFLECTION(mm)

LOAD (kN)	**RCC 100%**	**SIFCON 100%**	**SIFCON 10%**	**SIFCON 20%**	**SIFCON 30%**	**SIFCON 40%**	**SIFCON 50%**
0	0	0	0	0	0	0	0
10	0.24	0.56	0.30	0.35	0.08	0.1	0.11
20	0.65	1	0.90	0.75	0.31	0.34	0.37
30	1.14	1.46	1.30	1.25	0.66	0.54	0.79
40	1.6	1.9	1.8	1.78	1.04	0.8	1.32
50	9.8	2.36	2.1	2.3	1.42	1.15	1.76
60		2.9	2.6	2.84	1.86	1.48	2.3
70		6.8	3.2	6.3	7.3	2	
80						3.6	



Load Vs Displacement graph

Typical stress-strain (load-deformation) relationships of 100% SIFCON,100% RCC and other SIFCON-RCC composite beams are presented in Figures 4.4. This shows

(a) 40%SIFCON-60%RCC and 50% SIFCON-50%RCC composite beams has least displacement on comparing the rest of the beams.

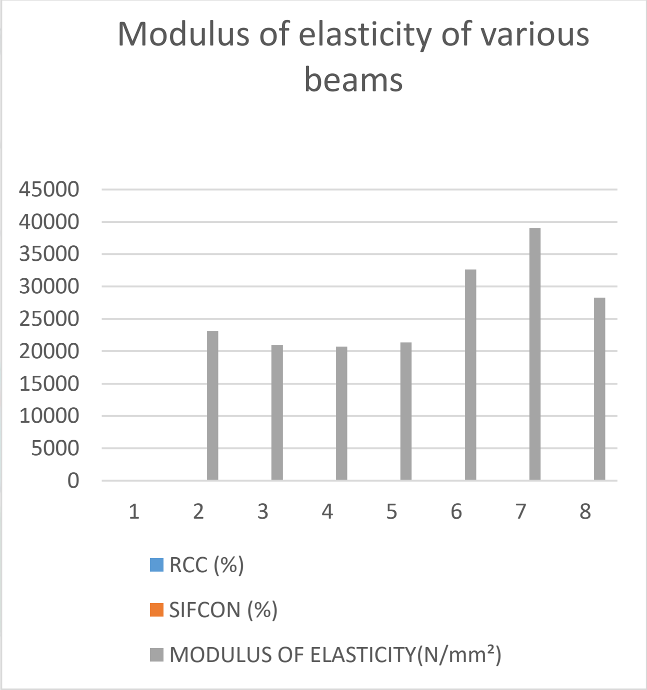
(b) More will be the rigidity of the member if less is the displacement which ultimately increases the load carrying capacity.

SIFCON VOLUME (%) Vs MODULUS OF ELASTICITY

The modulus of elasticity of all the beam specimens was found individually from the Stress Vs Strain graph of each beam. The following table presents the modulus of elasticity of the beams with various SIFCON depth ratios.

Modulus of elasticity of various beams

RCC (%)	**SIFCON (%)**	**MODULUS OF ELASTICITY (N/mm²)**
100	0	23158
0	100	20953
90	10	20720
80	20	21349
70	30	32633
60	40	39067
50	50	28282



SIFCON volume (%) Vs Modulus of elasticity

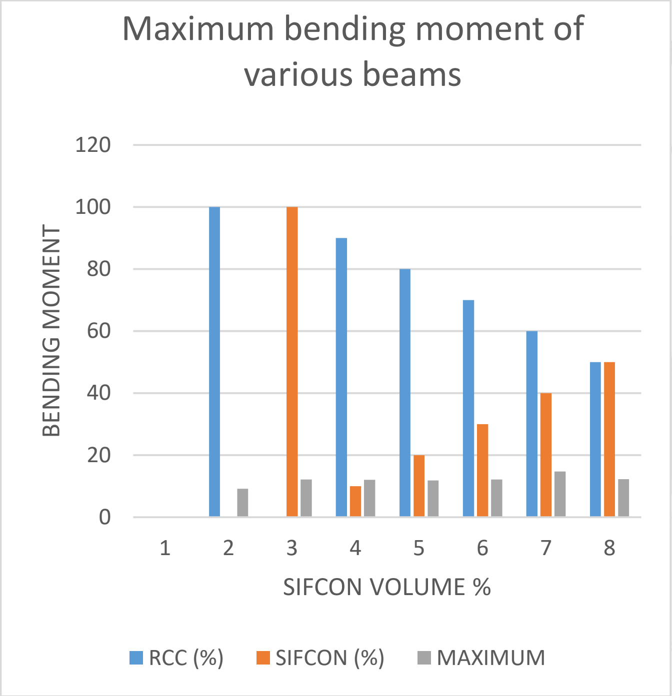
From the above-mentioned graph it's clear that there is a gradual increase in modulus of elasticity with increase in depth from 10% to 40%. At 50% there is a sudden drop in the young's modulus.

SIFCON VOLUME (%) Vs MAXIMUM BENDING MOMENT

The maximum bending moment of each beam specimen are tabulated below.

Maximum bending moment of various beams

RCC (%)	SIFCON (%)	MAXIMUM BENDING MOMENT (kNm)
100	0	9.16
0	100	12.11
90	10	11.98
80	20	11.86
70	30	12.16
60	40	14.67
50	50	12.20



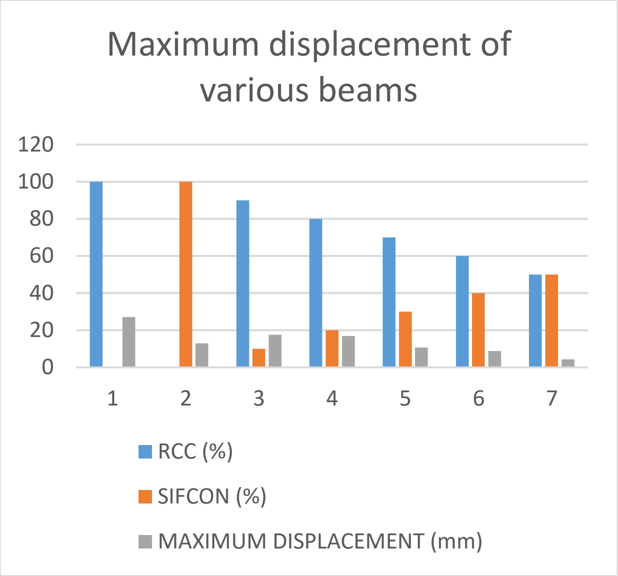
SIFCON volume (%) Vs bending moment

SIFCON VOLUME (%) Vs MAXIMUM DISPLACEMENT

The displacement of each beam specimens with the gradual increase in load is found. The maximum displacement of each beam specimen is tabulated below.

Maximum displacement of various beams

RCC (%)	SIFCON (%)	MAXIMUM DISPLACEMENT (mm)
100	-	27
-	100	12.94
90	10	17.54
80	20	16.85
70	30	10.67
60	40	8.69
50	50	4.29



SIFCON Volume (%) Vs Maximum displacement

From the above graph it is distinct that the displacement for 100% RCC is too high. The maximum displacement is getting reduced with increase in SIFCON volume, but for 30% SIFCON there is an abnormal increase. On the whole 40% SIFCON and 50% SIFCON composite beams has less displacement. If less is the displacement more will be the rigidity of the member.

IX.CONCLUSION

This study deals with an experimental research carried out to investigate Flexural strength of SIFCON-RCC composite beams.

The following conclusions were derived based on the obtained results.

a) On comparing the flexural strength of RCC and SIFCON, SIFCON proved to be the best.

b) On comparing composite beams of SIFCON volume 10%, 20%,30%,40% and 50% among themselves and with 100% SIFCON, 40%SIFCON+60%RCC combination showed better results with high flexural strength, high modulus of elasticity and less displacement.

c) Regarding the cost consideration, though SIFCON has greater strength, when compared to RCC, it is costly. SIFCON-RCC composite beam with 40% SIFCON minimizes the cost without compromising the strength.

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