PERFORMANCE OF REINFORCED SELF COMPACTING CONCRETE SHORT COLUMN CONTAINING STEEL FIBERS

Sanjay Kumar[1]

1. National Institute of Technology Jamshedpur, India.

ABSTRACT. Self-Compacting Concrete (SCC) is that type of concrete, which gets compacted due to its self-weight and is deaerated (no entrapped air) almost completely while flowing through the form work. This paper aims to study the flow characteristics of SCC in fresh state and behavior of steel fiber reinforced self-compacting concrete (SFRSC) short columns in hardened state. This work comprises the study on the effect of M30 grade of self compacting concrete based on "Nan Su et.al" method with varying volume fractions of steel fibers ranging from 0.0% to 1.5% at every 0.5% interval, workability in fresh state and the compressive strength of cubes (150mmx150mmx150mm) in hardened state at 7, 28, 56 and 90 days of conventional water curing. In addition, twelve nos. of reinforced square column specimens of size (150mm × 150mm × 600mm) has been cast, cured in normal water and tested after 28 days of maturity to study the mechanical behavior of SFRSC under compression. Also, various parameters like load carrying capacity, ductility, energy absorption capacity and toughness index of steel fiber reinforced self-compacting concrete column (SFRSC) are compared with that of plain reinforced self-compacting concrete (with 0% steel fiber) column. It is clear from the experimental investigation that the ultimate strength has increased marginally by increasing the volume of steel fibers. The optimum volume fraction of steel fibers for better performance in terms of workability, strength and ductility has been found to be 1.0%.

Keywords: Self-compacting concrete; Steel fiber; Workability; Short columns.

Dr. Sanjay Kumar is an Associate Professor in the department of Civil Engineering at National Institute of Technology, Jamshedpur, India. His research interests include evaluation of building elements, Characterization of cementitious materials, mechanical properties of concrete, self-compacting concrete, fiber reinforced concrete and geopolymer concrete.

INTRODUCTION

The concept of Self-Compacting Concrete (SCC) was proposed by Prof Okamura at Tokyo University, Japan in 1988 [1]. The studies on the workability of self-compacting concrete were carried out by Ozawa *et al.* [2]. This type of concrete was designed by using high fine to coarse aggregate ratio, low water cementitous material, good aggregate grading and high range water reducing admixture and viscosity modifying admixture. The transition zone in this type of concrete is free from micro cracks. Several mix design methods for SCC was proposed by several researchers [3-5]. Nan Su *et al.* [5], carried out an investigation on a simple mix design for self-compacting concrete as it is easier for implementation and also consumes less time, also it requires a smaller amount of binders thus saves cost effectively. European Federation of natural Trade associations representing producers and applicators of Specialist building products (EFNARC) has drawn up specifications and guidelines for self-compacting concrete to provide a framework for design and use of high quality self-compacting concrete [6].

The efficiency of all fiber reinforcement dependent upon achievement of a uniform distribution of the fibers in the concrete, their interaction with the cement matrix, and the ability of the concrete to be successfully cast or sprayed was reported by Brown [7]. It had been also described that due to the large surface area of fibers and high quantity, fibers are sure to absorb more cement paste to wrap around thus increasing the viscosity of mixture resulting in slump loss [8]. Vandewalle *et al.* had been recommended to choose fibers not shorter than the maximum aggregate size to be effective in the hardened state. Usually, the fiber length is 2 to 4 times that of the maximum aggregate size [9]. The orientation and the distribution of the fibers affect the performance and the variation of characteristics of SFRSC in the hardened state. The study on the distribution of steel fibers in the L-Box had been reported by Mehdipour *et al.* [10]. The conclusions were that the fibers were remarkably well distributed, although a slightly increased segregation of fibers was observed compared to the coarse aggregates.

Ganesan and Ramana Murthy had been reported the test result on eight 200 x 200 mm square-section short columns where four specimens were cast with FRSC, fiber content V_f = 0 or 1.5% had been kept constant while transverse reinforcement spacing was varied in order to find the effect of confinement on strength and ductility and the results showed that incorporation of steel fibers to plain concrete improves peak strength and post-peak ductility in columns [11]. The addition of fibers increases the ductility of columns and can be used to reduce required amount of transverse reinforcement, particularly in moderate seismic zones reported by Massicotte *et al* [12]. Furthermore, the authors mentioned that although crack progression and cover failure was affected, addition of fibers did not significantly affect core confinement. The experimental investigation on SFRSC short circular column had been tested to evaluate the behaviour of hybrid fiber reinforced concrete column under axial loading involved the test series of fibers with two aspect ratios and varying fiber content [13]. They found early cover spalling was prevented in the SFRSC columns. They further mentioned that when aspect ratio is kept constant, increase in fiber content results in improvement of strength and ductility. Sharma *et al.* [14] had studied ninety-six square section high-strength steel fiber reinforced self compacting concrete columns under concentric loading. They concluded that by keeping the concrete strength and tie spacing constant, strength and ductility increases with increasing fiber content and the effect is more important in columns with low amount of transverse reinforcement. Moreover, they also suggested that short fibers have a more important effect on peak strength while long fibers helps to improve column ductility, and therefore a mix of short and long fibers can be used for improvement of column behaviour. In addition, they mentioned that as concrete strength is increased, ties and fibers become less effective and therefore, either fiber content or tie confinement one of them should be increased.

This paper aims to study the fresh and hardened properties of M30 grade of SFRSC mix using steel fibers of similar of aspect ratio is 58. In addition, the compression behaviour of 12 numbers of steel fiber reinforced self-compacting concrete short square column specimens of size (150mm × 150mm × 600mm) is studied with volume fractions of 0.0%, 0.5%, 1.0% and 1.5% of steel fibers and tested after 28 days of normal curing to investigate and evaluate the effect of the different parameters on the performance of columns under compression.

EXPERIMENTAL PROGRAMME

Materials

Ordinary Portland Cement (OPC) 53 grade of AMBUJA Cements Pvt. Ltd conforming to IS: 12269 (2004) having specific gravity 3.04 was used in present study [15]. Locally available sand confirming to zone II as per IS: 383 (1987) (Specific Gravity - 2.55, Fineness Modulus - 2.65, bulk density 1600 kg/m^3) and coarse aggregates (specific gravity and bulk density with 2.78, Fineness Modulus - 6.78 and 1560 kg/m^3) confirming to IS: 2386 (Part III) (1963) has been used in the present study [16 & 17]. Low calcium fly ash conforming to IS: 3812 (2003) has been used as mineral admixture for partial replacement for cement [18]. The chemical properties of fly ash used in this investigation are shown in Table 1.

Table 1 Properties of fly ash

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	SO_3
% by Mass	65.6	28	3	1	1	0.5	0.2

Viscosity Modifying Admixture (VMA) having pH value of 7.0 (Akarsh Specialities, Chennai, India) was used in present study. The basic properties of steel fibers used are mentioned in Table 2.

Table 2 Properties of steel fiber

Fiber Type	Aspect ratio	Length mm	Diameter mm	No. of Fibers / kg	Tensile Strength N/mm^2
F – 55/30	58	32	0.55	16720	1100

Mix proportions

Initial trail mixes for M30 grade of SFRSC are obtained using Nan Su mix design procedure and mixes are modified accordingly to get fresh and hardened properties [reference]. The total of four numbers of mixes viz. SF1, SF2, SF3 and SF4 representing the addition of fiber volume fractions of 0.0%, 0.5%, 1.0% and 1.5% of total weight of each concrete mix (by weight) respectively, whereas the cement, aggregate and the filler content were maintained constant for all the mixes. The doses of VMA and superplasticizer are calculated by trial and error method by maintaining a constant VMA dosage of 0.24 and by varying the superplasticizer dosage as tabulated in Table 3.

Table 3 Mix proportion of Fiber Reinforced Self-compacting Concrete (FRSC)

Mix	Cement kg/m^3	Fly ash kg/m^3	Fiber (%) kg/m^3	F.A kg/m^3	C.A kg/m^3	Water
SF1	521	78	0.0	852	652	272
SF2	521	78	11.86	852	652	272
SF3	521	78	23.72	852	652	272
SF4	521	78	35.62	852	652	272

Sample preparation and casting

The fresh concrete workability properties of SFRSC are standardized as per EFNARC specification in the present study [6]. To evaluate workability of fresh concrete, slump flow test, J-ring test, L-box test and V-funnel test are performed. The slump flow (D_f) is the mean diameter of the spread (from two perpendiculars) and T50 is the time taken by the spread to reach 500mm. The J ring test is used to determine the passing ability of the concrete, where the concrete has to pass through the bars. Here, the difference in height between the concrete inside and that just outside the J ring is measured which is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted. The L–Box test was used to check the filling and passing ability of SCC. The flow of concrete from the vertical portion of the L-Box to the horizontal portion of the L–Box is measured. V-Funnel test for assessing the viscosity, flow-ability and segregation resistance of SFRCC where the flow time for the concrete is recorded.

The standard concrete cube specimens of size 150 mm × 150 mm × 150 mm were cast for different mixes of SFRSC to determine the compressive strength of concrete. All the specimens were tested at 7 days, 28 days, 56 days and 90 days after casting to determine the compressive strength at different ages. The reinforced concrete square column of size 150 (B) × 150 (D) × 600 (L) mm were cast, cured and tested to determine the load carrying capacity, ductility, energy absorption and toughness index with different percentages of steel fiber such as 0.0%, 0.5%, 1.0% and 1.5%. All the concrete column specimen of SFRSC was tested after 28 days of maturity. Four numbers of 8 mm diameter deformed steel bar were used as main longitudinal reinforcement and 6 mm diameter two legged steel reinforcement bar at a distance of 150mm center to center were used as lateral tie.

DISCUSSIONS OF RESULTS

Workability and Compressive Strength of different SFRSC mix

The properties of fresh self-compacting concrete slump flow, J-ring height differences, L-box and V-funnel flow test are presented in Table 4.

Table 4 Workability of FRSC

Mix Designation	Fiber content (%)	Slump flow (mm)	T_{500} (sec)	V–funnel (sec)	J-ring (mm)	L–box ratio
SF1	0.0	690	3.0	8.0	15	0.86
SF2	0.5	675	3.0	9.0	17	0.83
SF3	1.0	660	4.0	9.0	18	0.82
SF4	1.5	630	5.0	10.0	20	0.80

The test results indicate that, except for mix SF4, slump flow for all the mixes is within the EFNARC range of 650-800 mm. A maximum slump flow value of 690 mm is achieved for the control mix SF1. With the increase in the fiber content, the flow of various SFRSC mixes decreases. The slump flow time for all the mixes qualifies the permissible limits in between 2 to 5 sec as given by EFNARC. T50 cm slump flow varies between 3 and 5 sec. The lowest slump flow time of 3 sec is recorded for the control mix containing 0.0% steel fiber (SF1). An increase in the quantity of steel fibers leads to the increase in T50 cm time as observed. This is due to the increasing paste volume with respect to fibers content. According to the results of test, the V-funnel flow time varies between 9 and 11 sec and the minimum flow time is 8 sec the control mix containing 0.0% steel fibers. With the increase in steel fiber content, the mix fluidity of concrete decreases, consequently the V-funnel flow time increases. The J–Ring test shows that there is a steady increase in the difference of heights as the fiber content increases. In other words, as the number of fiber increases the flow of concrete on the base plate decreases. Also, it is observed that all the four mixes pass through the bars of L-box very easily and no blockage is seen in any of the mixes. It can also be said that as the length of fibers increases the blocking ratio decreases.

The compressive strength tests results of SFRSC mixes are given in figure 1. The compressive strength of SFRSC with the addition of 0.5% steel fiber the compressive is increased by 3% at 7 days; 2% at 28 days; 1.86% at 56 days and 1.83% at 90 days with respect to conventional cement concrete mix without steel fiber. Similar results are observed with the addition of 1.0%, and 1.50 % of steel fiber in control cement concrete mix. It is also noticed that the compressive strength of SFRSC with 1.0 % of steel fiber is 38.3 MPa, while with 1.5% steel fiber content it is 35.8 MPa at 28 days of curing. So, there is almost 8% reduction in compressive strength of concrete. The reason may be due to the increase of air content in concrete with increase of steel fiber content, reducing compressive strength marginally. There are several researchers who reported around 12% to 7.5% reduction in compressive strength of high-strength SCC, with addition of steel fibers, which is similar to the results in this study [19-21]. The present study is limited up to 1.0% of steel fiber addition with SFRSC mix.

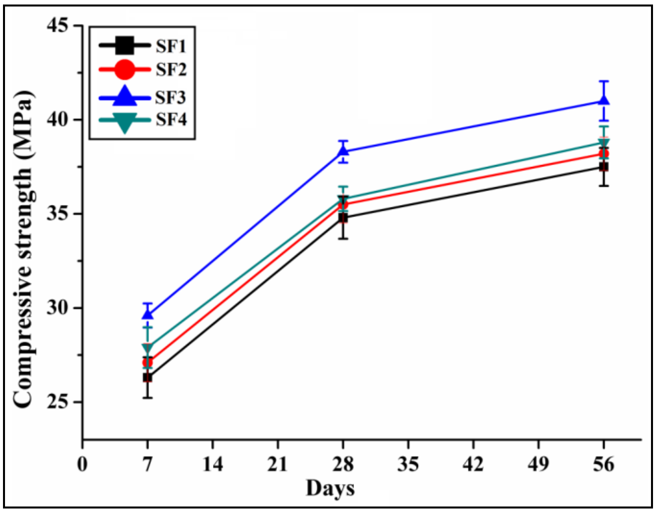

Figure 1 Variation of compressive strength of SFRSC at 7, 28, 56 and 90 days of maturity

Structural behavior of column (Load deformation, Ductility, Energy absorption, Toughness index)

The load was applied gradually at the rate of 50 kN/min with max displacement up to 50 mm and the deformation readings has been taken at regular intervals. The columns have been gradually loaded up to the ultimate load till failure. As the load level was increased gradually at each interval, the observed displacement was greater than that it was in previous interval. The axial load and their corresponding deformation have been reported in figure 3 for all types of mixes. When SFRSC columns are gradually loaded, the failure of SFRSC columns has been occurred after the formation of numerous cracks. The crack patterns of SFRSC columns with 1.5% of steel fibers based on the experiments conducted in the laboratory are shown in figure 2.

Figure 2 Test set-up of SFRSC Column

The load carrying capacity of SFRSC column with 0%, 0.5%, 1.0% and 1.5% of steel fibers is 539 kN, 870 kN, 998 kN and 968 kN respectively. The load carrying capacity of SFRSC with the addition steel fiber is more with respect to the self-compacting concrete without steel fiber. Also the result indicates that the load carrying capacity of the column has increased up to the addition of 1.0% of steel fibers in SFRSC concrete mix as noted in Table 5.

Table 5 Ultimate Load Carrying Capacity, Ductility Factor, Energy Absorption and Toughness Index of SFRSC Short Column with Different Percentages of Steel Fibers

Mix Designation	Ultimate load carrying capacity(kN)	Ductility factor	Energy absorption (kN-mm)	Toughness index
SF1 (0.0% of fiber)	539	1.26	982.53	1.54
SF2 (0.5% of fiber)	870	1.38	1743.77	1.82
SF3 (1.0% of fiber)	998	1.94	2908.38	4.26
SF4 (1.5% of fiber)	968	1.77	2773.82	3.39

The Ductility Factor of SFRSC column with 0.5%, 1.0% and 1.5% of steel fibers has an increase of 9.5%, 54% and 40.5% respectively. The energy absorption capacity has been calculated as the total area (OCD) under the load deformation curve as shown in figure 3.

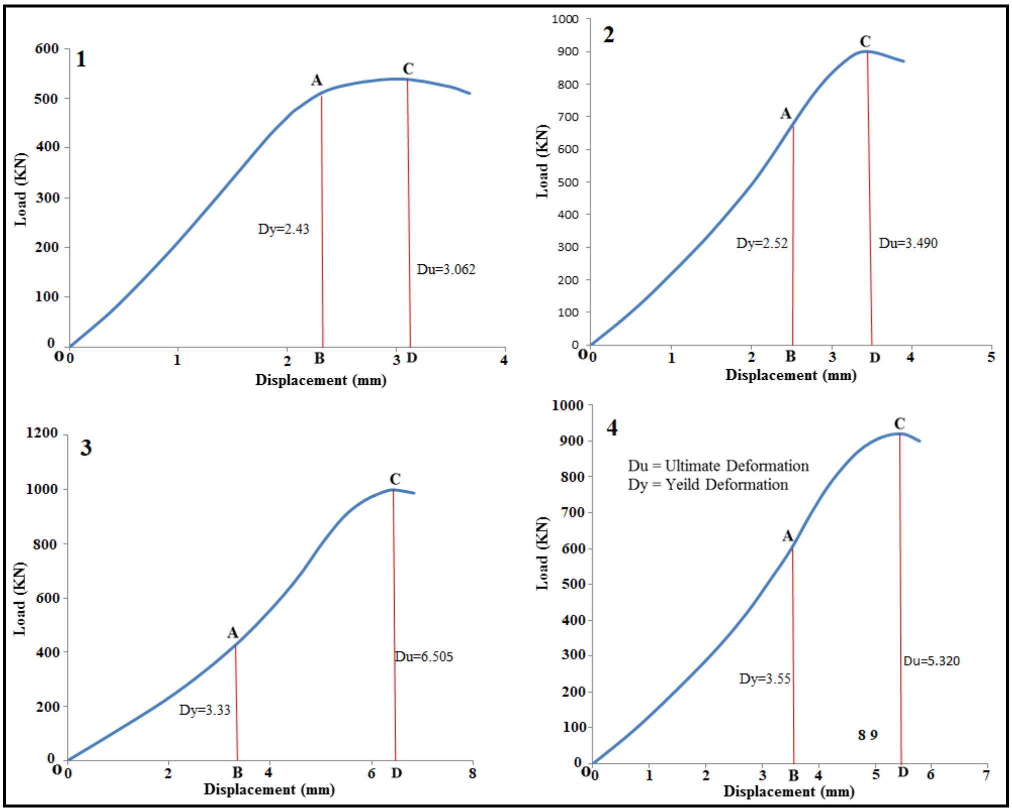

Figure 3 Load-deformation curve of axial loaded SFRSC column with 0.0%, 0.50%, 1.0% and 1.50% of steel fibers

The ductility value is calculated as the ratio of ultimate or maximum deformation (Du) to the yield deformation (D_y). The yield deformation has been determined from the load-deformation curve by assuming bilinear behavior of the column specimen. The ductility factor of the plain RSCC and SFRSC columns with 0.5%, 1.0% and 1.5% of fiber are found to be 1.26, 1.38, 1.94 and 1.77 respectively. The relative energy absorption capacity of conventional SFRSC column is 982.53 kN-mm, 1743.77 kN-mm, 2908.38 kN-mm and 2773.82 kN-mm for SFRSC column with 0.0%, 0.5%, 1.0% and 1.5% of steel fiber respectively. The energy absorption capacity of SFRSC column with 0.5% steel fiber is increased by 1.77 times more than conventional reinforced concrete column with 0% of steel reinforcement (refer Figure 3). Also, the energy absorption capacity of SFRSC column with 1.0% and 1.5% of steel reinforcement is 2.96 and 2.82 times more than conventional reinforced concrete column. It is also noted that the energy absorption capacity of reinforced column with 1.0 % steel fiber is more than all other types of column.
Toughness index is defined as the ratio of ultimate energy (calculated as the area OCD under the load deformation curve) to the energy at yield (calculated as area OAB under the curve up to yield). The toughness index values of the SFRSC columns with the addition of steel fibers by 0.5%, 1.0 % and 1.5% were found to be 1.54, 1.82, 4.26 and 3.39 respectively according to figure 3.

CONCLUSIONS

Based on the results obtained from the experimental investigations and after rational discussion, the following conclusions have been drawn on the fresh state, compressive strength and behavior of SFRSC under axial compression.

- The workability of FRSC for M30 Grade of self compacting concrete was found to be satisfactorily acceptable as per EFNARC standards. There is a gradual decrease in the workability of FRSC beyond the addition of 1.0% of steel fibers.

- The compressive strength and split tensile strength of FRSC mix increases constantly with the increase of steel fiber dosage as compared to the conventional M30 grade SCC mix up to the maximum fiber content of 1%.

- FRSC columns carried more amount of load with higher amount of ductility obtained from higher longitudinal displacement. The FRSC column having 1% steel fibers showed stiff slope graph hence it carried higher load with minimal axial deformation as compared to FRSC column with 0.5% steel fibers.

- The ductility factor and the energy absorption capacity of FRSC columns with axial loading have been increased even after the addition of 1.0% of steel fibers.

- The development of longitudinal crack width increases as the load applied on the specimen increases. The ultimate failure occurred in plain cement concrete column (0.0% of steel fiber) by crushing of specimen and spalling of cover concrete. The failure of FRSC column occurred after the formation of numerous cracks. The cover of FRSC concrete column remains intact while the failure of FRSC columns occurred due to crushing. This exhibits that only hair line cracks/minor cracks develop up to a certain level, thus restricting the growth/propagation of crack up to ultimate failure load level with the addition of steel fibers increases.

ACKNOWLEDGEMENTS

Authors are thankful to the faculty members and staff of Department of Civil Engineering, for their assistance, and the Director, National Institute of Technology, Jamshedpur, India for his permission to publish the paper.

REFERENCES

1. OKAMURA H, OUCHI M, Self-compacting concrete development, present use and future. Proceedings of the 1st International RILEM Symposium on Self-Compacting Concrete. Stockholm, 7: 1999, pp. 3-14.

2. OZAWA K, KUNISHIMA M, MAEKAWA K, OZAWA K, Development of high performance concrete based on durability design of concrete structure. Proceedings of East Asia and Pacific Conference on Structural Engineering and Construction (EASEC–2). Thailand, 1: 1989, pp.445-450.

3. OKAMURA H, OZAWA K, OUCHI M, Self-compacting concrete. Structural Concrete 1(1): 2000, pp.3-16.

4. PETERSSON Ö, BILLBERG P, Investigation on blocking of self compacting concrete with different maximum aggregate size and use of viscosity agent instead filler. 1st International RILEM Symposium on Self-Compacting Concrete. Stockholm, 1999, pp. 333-344.

5. SU N, HSU K. C, CHAI H. W, A simple mix design method for self-compacting concrete. Cement and Concrete Research, 31(12): 2001, pp.1799-1807.

6. EFNARC: Specifications and guidelines of Self-compacting concrete. The European Federation of Specialist Construction Chemicals and Concrete Systems 2005.

7. BROWN J, ATKINSON T, Propex concrete systems (international) United Kingdom. Proceedings of FIBCON 2012. Nagpur, India, 2012, pp.13-14.

8. CHEN B, LIU J, Contribution of hybrid fibers on the properties of the high-strength lightweight concrete having good workability. Cement and Concrete Research 35(5): 2005 pp.913- 917.

9. VANDEWALLE. L, Hybrid fiber concrete: is there a synergetic effect? Advances in Construction Materials Springer, Berlin, Heidelberg, 2007, pp.219-228.

10. MEHDIPOUR I, LIBRE N. A, SHEKARCHI M, KHANJANI M, Effect of workability characteristics on the hardened performance of FRSCCMs. Construction and Building Materials, 40: 2013, pp.611-621.

11. GANESAN N, MURTHY J. V. R, Strength and behavior of confined steel fiber reinforced concrete columns. ACI Mater J. 87(3): 1990, pp.221-227.

12. MASSICOTTE B, MOSSOR B, FILIATRAULT A, TREMBLAY S, Compressive strength and ductility of steel fiber reinforced concrete. ACI Special Publication SP182 (10): 1999, pp.163-180.

13. MUTHUSWAMY K. R, THIRUGNANAM G. S, Experimental investigation on behaviour of hybrid fiber reinforced concrete column under axial loading. Asian Journal of Civil Engineering (Building and Housing) 15(2): 2014, pp.169-178.

14. SHARMA U. K, BHARGAVA P, SHEIKH S. A, Tie confined fiber reinforced high strength concrete short columns. Magazine of Concrete Research 59(10): 2007, pp.757-769.

15. IS: 12269-2004, Specifications of Ordinary Portland cement 53 Grade. New Delhi: Bureau of Indian Standards.

16. IS: 383-2016, Indian Standard code of practice for specification for coarse and fine aggregates from natural sources of concrete. New Delhi: Bureau of Indian Standards.

17. IS: 2386 (Part-III)-2002, Methods of test for aggregates for concrete Part-3., New Delhi: Bureau of Indian Standards.

18. IS: 3812 (Part-I & II) – 2013, Indian Standard pulverized fuel ash - specification part 1 & 2 for use as pozzolana in cement, cement mortar and concrete. New Delhi: Bureau of Indian Standards.

19. KHALOO A, RAISI E. M, HOSSEINI P, TAHSIRI H, Mechanical performance of self-compacting concrete reinforced with steel fibers. Constr. Build. Mater. 51 (31): 2014, pp.179-186.

20. IQBAL S, ALI A, HOLSCHEMACHER K, BIER T. A, Mechanical properties of steel fiber reinforced high strength lightweight self-compacting concrete (SHLSCC). Construction and Building Materials 98 (15): 2015, pp.325-333.

21. BARR B. I. G, LIU K, DOWERS R.C, A toughness index to measure the energy absorption of fiber reinforced concrete. International Journal of Cement Composites and Lightweight Concrete 4(4): 1982, pp.221-227.