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Effects of Glass and Steel Fibers on Fresh and Hardened Properties of Self-Compacting Concrete

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Abstract

Self-compacting concrete (SCC) has been versatile over compaction of concrete by manual or mechanical vibrators. Compaction of concrete by traditional methods generates delays and imparts additional costs. Further, much research has been done on the effects of fiber on traditional concrete, but it has rarely been on SCC. Here, fiber-reinforced SCC was prepared by adding glass and steel fibers to study the effect of fibers on fresh properties like workability and hardened properties like compressive, split tensile and flexural strength. Geometrically similar reinforced specimens with 1.0% and 1.5% flexural reinforcement were also prepared to understand the flexural behavior of reinforced SCC with and without fibers. It was observed that the addition of fibers reduced workability and increased mechanical properties like compressive, split tensile, flexural strength, first crack load, ultimate load, and energy absorption capacity. It was also observed that as the size of specimens increased, the ductility factor decreased.

Author Keywords. Self-compacting Concrete. Fibers. Flexural Strength. Energy Absorption Capacity. Ductility Factor.

Type: Research Article

1. Introduction

Concrete is the most consumed material in construction practices throughout the world. When properly designed, with correct ingredients quality, placing, and curing, it guarantees its excellent compressive strength and durability. However, it has been observed that proper consolidation is not provided during the practice, which may lead to deterioration in its strength and durability. To overcome this problem and provide a more uniform, well-consolidated end product, Japanese researchers in the early 1980s created a concrete mixture known as Self-consolidating concrete (SCC), also referred to as self-consolidating concrete, which can flow under its weight and fill the formwork, while maintaining homogeneity. It is such a versatile material that even in congested reinforcement, it gets consolidated without the need for vibration (Okamura and Ozawa 1996). Such SCC for real-life structure demands its behaviour in various loading conditions such as flexure, axial, and torsion. Few studies were carried out to increase the strength of the SCC by the addition of nanomaterials such as nano titanium dioxide and carbon nanotube in concrete (Sorathiya, Shah, and Kacha 2017; Barodawala and Shah 2018). In addition to this, its ductile behavior should also be known when it has to be used in seismic-prone areas.

Further, the ductile design of reinforced concrete beams is generally related to flexural failure in bending, but the presence of high shear force often reduces their flexural capacity. Many studies have investigated fiber-reinforced concrete beams' combined flexural and shear behavior (Craig et al. 1984; Lim and Oh 1999; Campione and Mangiavillano 2008; Özcan et al. 2009). To overcome the concrete ductility issues, some studies revealed that adding fibers makes the concrete ductile, increases its tensile and shear strength, and improves its durability. Additionally, it increases the first crack load by bridging fibers across the cracks (Ganesan and Shivananda 1997; Ganesan, Indira, and Santosh Kumar 2006; Dhonde et al. 2007; Barros, Gomes, and Barboza 2009). The most common types of fibers researchers attempted were steel, carbon, polypropylene, polyester, basalt rock, and glass; these fibers were typically used for concrete structural applications (Bhogayata and Arora 2017; Fallah and Nematzadeh 2017; Boz et al. 2018). Fiber material properties, type, shape, volume, and distribution in the concrete matrix directly influence the properties of fresh and hardened self-compacted concrete (SCC) (Katzer and Domski 2012; Abadel et al. 2016). Some researchers found that the fresh properties of SCC may be negatively affected when the volume fraction exceeds 0.5% of concrete volume (Khayat and Roussel 2000; Zeyad 2020). However, the increase in these properties will vary depending on the quantity and type of fibers used (Henager 1977; Gefken and Ramey 1989; Filiatrault, Pineau, and Houde 1995). The properties will not increase at the same rate as fibers were added. Fiber-reinforced self-compacting concrete (FRSCC) is a new building material that merges the advantages of the SCC with the positive effects of fiber addition to a brittle material (concrete). It is a ductile material that runs into the interior of formwork in its fresh state, filling it naturally, passing through the obstacles, and consolidating under the action of its weight. FRSCC can diminish two opposing weaknesses: cracking resistance in plain concrete and poor workability in fiber-reinforced concrete (FRC) (Ahmad and Umar 2018).

The objectives of the present study were to examine the effect of types of fiber on the fresh and hardened properties of self-compacting concrete. In this study, an experimental program entailed the effects of fibers and flexural reinforcement. In addition, this creates a benchmark to highlight the flexural behavior of (SCRC) beam specimens.

2. Experimental Details

To study the effects of adding fibers on workability, fiber-reinforced self-compacting concrete was prepared by adding glass and steel fibers. For hardened properties like compressive strength, split tensile strength, and flexural strength, cube, cylinder, and beam specimens were prepared and tested per IS 516-2013. The following section describes material properties, specimen size, reinforcement details, and testing procedures.

2.1. Materials

The nine different materials considered in this study are presented in Table 1. Using these materials, a self-compacting concrete mix was prepared with and without reinforcement and with and without fibers. A total of nine mixes were prepared with various proportions of ingredients, and these proportions were kept constant for all nine mixes. The nomenclature used to designate various mixes for fresh and hardened concrete specimens is presented in Table 3. The proportions were Cement to fly ash ratio 1: 0.27, 10 mm to 20 mm coarse aggregate was 1: 0.67. The unit mix ratio for binder, fine aggregate, and coarse aggregate was 1: 1.41: 1.24. The amount of superplasticizer dose was 2.225 liter/m^3. The amount of water was 160 liter/m$^{3.}$. Glass fiber reinforced self-compacting concrete (GFRSCC) was prepared by adding 350 gm/m^3 of glass fiber in plain self-compacting concrete (PSCC) and steel fiber reinforced self-compacting concrete (SFRSCC) was prepared by adding 32 kg/m^3 steel fiber in plain self-compacting concrete (PSCC). Photographs and physical properties of the glass and steel fibers are shown in Figure 1 and Table 2, respectively.

Sr. no	Name of the material	Size	Specific Gravity	Purpose
1	53-grade Ordinary Portland cement	90μ particles	3.12	Binder
2	Standard class-F fly ash	30-100μ particles	2.0	As mineral admixture
3	Locally available river sand	4.75 mm to 0.5 mm	2.7	Filler
4	Coarse aggregates	10-8 mm	2.8	Strength imparting material
5	Coarse aggregates	20-16 mm	2.8	Strength imparting material
6	Polycarboxylate ether based superplasticizer	liquid		To enhance the workability
7	TMT bars of Fe 415 grade.	6mm diameter	7.8	Flexural reinforcement
8	Glass fiber (Cem-FIL)	12mmx 0.14 mm	2.7	for Fiber reinforcement
9	Steel fiber (Dramix RCBN 35/65 hooked end)	35mmx 0.55mm	7.8	for Crack control

Table 1: Physical and mechanical properties of fibers

Glass fibers

Steel fibers

Figure 1: Photographs of fibers

Type of fiber	Fiber name	Density	Length	Dia meter	Aspect ratio	Tensile strength	Modulus of elasticity	Cross-section form	Surface structure
		(kg/m^3)	(mm)	(mm)	---	(MPa)	(GPa)	---	---
Glass	Cem-FIL	2700	12	0.014	857	1.7	72	Circular	Rough
Steel	Dramix RCBN35/65	7850	35	0.55	118.18	1100	200	Circular	Hooked end

Table 2: Physical and mechanical properties of fibers

Type of concrete	Specimen designation	Description
Concrete without flexural reinforcement	PSC	Self-compacting concrete without fibers
	GFRSCC	Self-compacting concrete with 350 gm/m^3 glass fibers
	SFRSCC	Self-compacting concrete with 32 km/m^3 steel fibers
Concrete beam specimen with flexural reinforcement	PSCRC1.0%	Self-compacting concrete specimen without fibers having 1.0% flexural reinforcement
	GFRSCRC1.0%	Self-compacting concrete specimen with 350 gm/m^3 glass fibers having 1.0% flexural reinforcement
	SFRSCRC1.0%	Self-compacting concrete specimen with 32 km/m^3 steel fibers having 1.0% flexural reinforcement
	PSCRC1.5	Self-compacting concrete specimen without fibers having 1.5% flexural reinforcement
	GFRSCRC1.5%	Self-compacting concrete specimen with 350 gm/m^3 glass fibers having 1.5% flexural reinforcement
	SFRSCRC1.5%	Self-compacting concrete specimen with 32 km/m^3 steel fibers having 1.5% flexural reinforcement

Table 3: Nomenclature used to designate various mixes

2.2. Specimen size and reinforcement details

To test the hardened concrete's tensile, compressive, and flexural strength, geometrically similar self-compacting reinforced concrete (SCRC), cube, cylinder and beam specimens were cast. The beam specimens were tested in four-point bending (FPB) test setup. The width of specimen 'b' was kept constant at 100 mm. However, the length and depth of specimens were scaled. The concrete cover at the tension face of beam specimens was also scaled. Span to effective depth ratio $(l_{eff.}/d_{eff.})$ was kept constant as 3 in all three sizes of beams. Specimens were prepared as Rilem standard recordation (Shah 1990). The beams were reinforced with 1.0% and 1.5% flexural reinforcements. Two hanger bars, 6 mm in diameter, supported stirrups. Specimen geometry of the reinforced beam and reinforcement details are shown in Figure 2 and Figure 3, respectively. Table 4 and Table 5, respectively, specify size and reinforcement details.

Size of specimen	Width (b)	Overall depth (D)	Effective depth (d)	Length (L)	Effective span (l)	Effective cover
Small	100	100	90	370	270	10
Medium	100	150	135	505	405	15
Large	100	225	202	756	606	22.5

Table 4: Specimens geometry in mm

Size of specimen	% Area of flexural reinforcement	Flexural reinforcement	c/c spacing of stirrups in mm (Two-legged, 6 mm dia.)
Small	1.0%	2 nos. # 8 mm dia. (A_{st} = 100 mm^2)	65
Medium		2 nos. # 10 mm dia. (A_{st} = 156 mm^2)	65
Large		2 nos. # 12 mm dia. (A_{st} = 226 mm^2)	70
Small	1.5%	2 nos. # 10 mm dia. (A_{st} = 156 mm^2)	50
Medium		2 nos. # 12 mm dia. (A_{st} = 226 mm^2)	45
Large		2 nos. # 12 mm dia. + 1 nos. # 10 mm dia., (A_{st} = 304 mm^2)	50

Table 5: Reinforcement detail

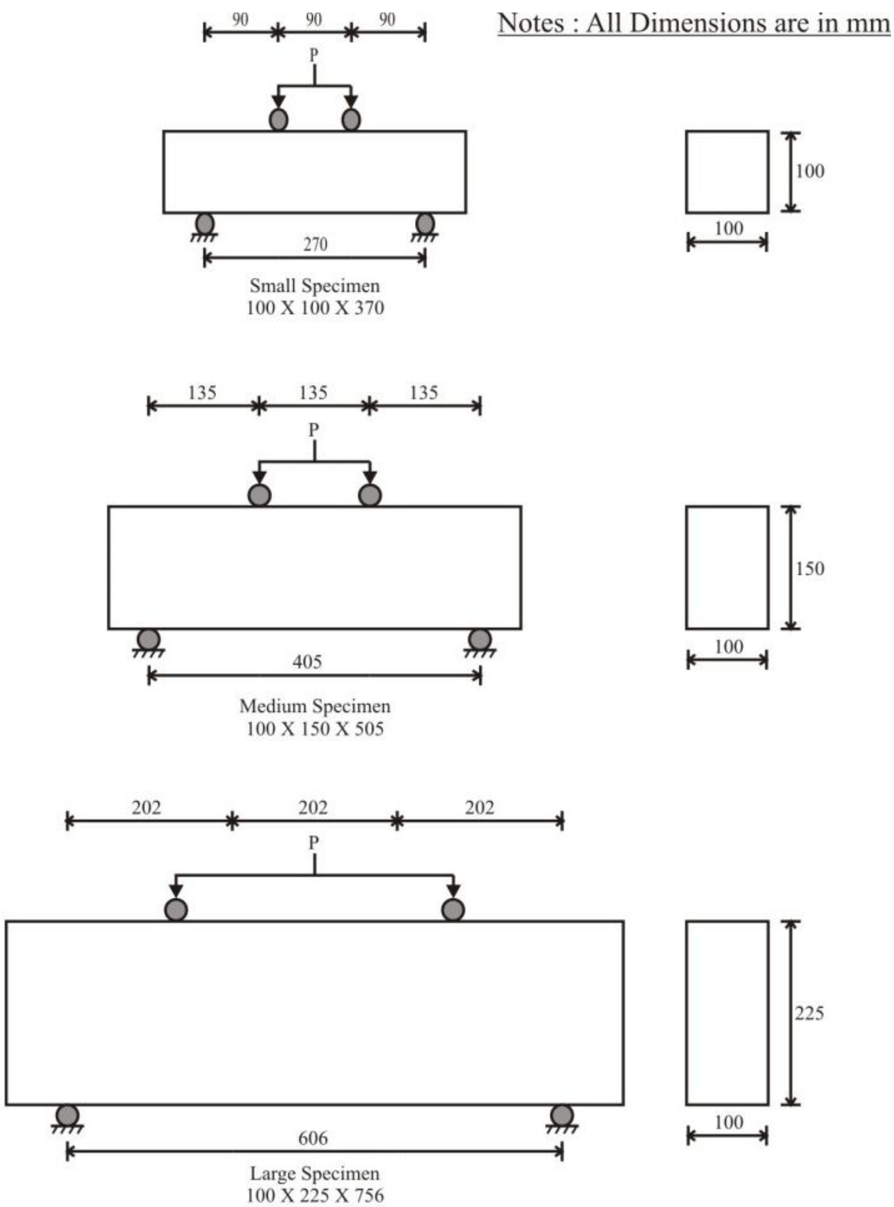


Figure 2: Specimen geometry of the reinforced beam

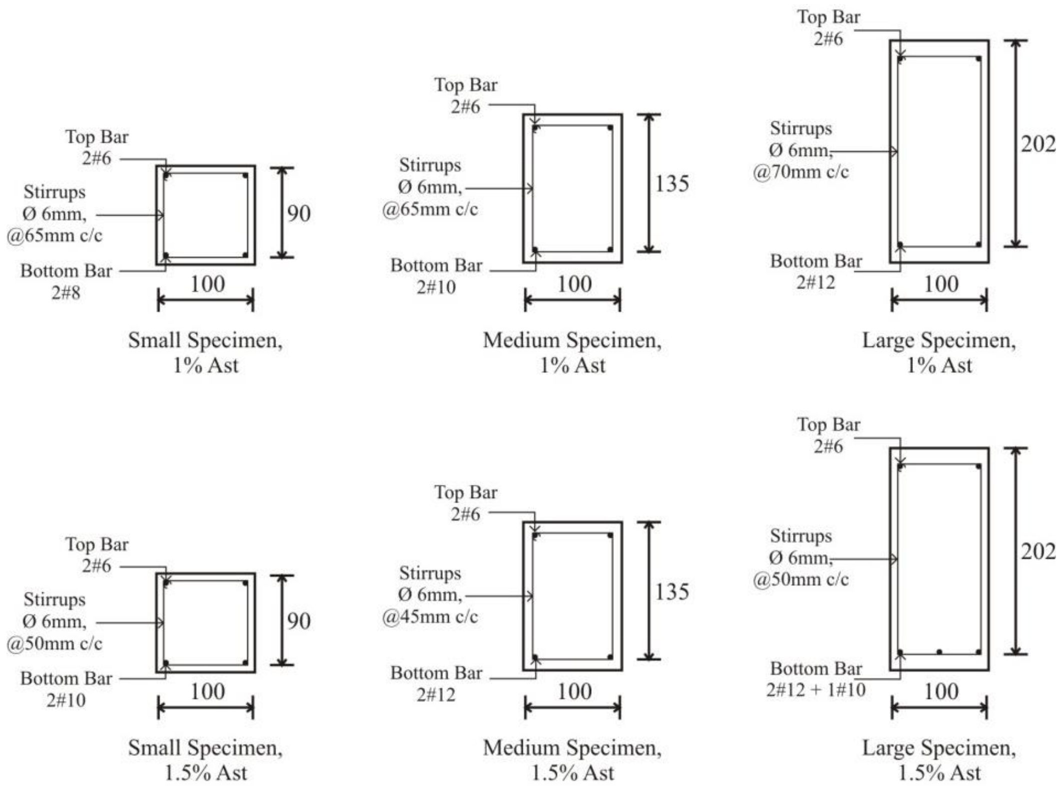


Figure 3: Reinforcement details

2.3. Test procedure

In this study, firstly, the ingredients were dry-mixed. Then fibers were added carefully with superplasticizers and water in different stages to avoid the balling effect and make uniform concrete. Such fresh concrete's properties of self-compacting concrete were tested as per the European Federation of National Associations Representing for Concrete (EFNARC) 2002. Each mix design was tested by more than one test method for the different workability parameters per EFNARC 2002. The filling ability of SCC was measured using the slump flow test and V-Funnel test. The passing ability of SCC was measured using the J-Ring test, L-Box test, and U-Box test, as shown in Figure 4.

After achieving the desired workability, the Mechanical properties of fiber-reinforced self-compacting concrete, like compressive strength, split tensile strength, and flexural strength, was determined as per the IS 516-2013. The compressive strength was determined by testing the concrete cube of size 150 × 150 × 150 mm. In contrast, split tensile strength was determined by testing a concrete cylinder of size 150 mm in diameter and 300 mm in height in a compressive testing machine of capacity 2000 kN. The flexural strength of concrete was measured by testing the beam of size 100 mm × 100 mm × 500 mm under four-point bending (FPB) test setup using the digital universal testing machine having 600 kN. Here, 18 numbers of geometrically similar beam specimens (with and without fibers) were cast. Out of these 18 nos, 9 nos of specimens were reinforced with 1.0% flexural reinforcement, while another 9 nos of specimens were reinforced with 1.5% flexural reinforcement. The reinforcement cage and geometrically similar beam specimens are presented in Figure 5. After the casting, they were cured for 28 days, and then they were tested. Four-point bending (FPB) test setup was used to test reinforced concrete (RC) beam specimens, as shown in Figure 6. A statically determinate system was ensured by adopting hinges and roller supports at two ends. The load was applied under a universal testing machine with 600 kN. The load was applied symmetrically at one-third points. A linear variable displacement transducer (LVDT) was used to measure the deflection of the center beam. The load was noted down at regular intervals of deflection. A magnifying glass identified the first crack.

Slump flow test

J-Ring test

V-Funnel test

L-Box test

U-Box test

Figure 4: Fresh concrete's properties characterization through test as suggested by EFNARC-2002

(a)

(b)

Figure 5: (a) Reinforcement cage and (b) Geometrically similar beam specimens

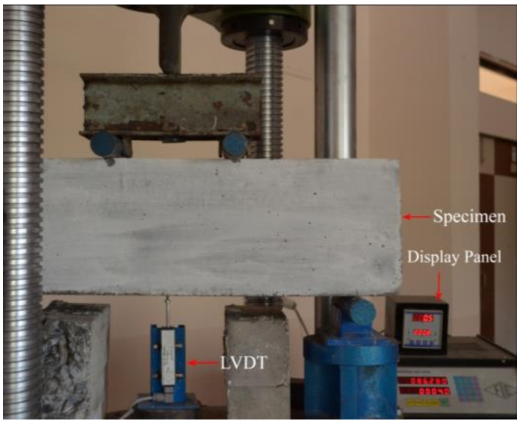


Figure 6: Testing of the specimen under four-point bending (FPB) test setup

3. Results and Discussion

In this section, results obtained for the test program, as narrated in section 2, were analyzed and presented multiple folds. The first is the effect of fibers on the fresh properties of the concrete, and the second is its effect on mechanical properties. First, crack load, deflection, flexural strength, energy absorption capacity, and ductility factor are discussed in the ultimate load.

3.1. Fresh properties

Fresh properties of self-compacting concrete-like filling ability, passing ability, and segregation resistance were evaluated per the guidelines described by EFNARC standards 2002. The results of the workability test, namely, slump flow, T_{50} slump flow, J-Ring, V-Funnel, L-Box, and U-Box for plain self-compacting concrete (PSCC), glass fiber reinforced self-compacting concrete (GFRSCC) and steel fiber reinforced self-compacting concrete (SFRSCC) are plotted in Figures 7 to 13.

From these results, it can be seen that the addition of fibers reduces the flow and filling ability. Better flow properties were observed for mixing with a lower volume fraction of fibers. The addition of steel fibers resists the flow of SCC compared to glass fibers. The observed slump flow was 720 mm for the addition of glass fibers, while it was 655 mm in the case of steel fibers in SCC. The apparent reason for low values of workability with the addition of fibers was the friction of fibers with the rest of the cementation paste.

Similarly, V-Funnel flow of 9 sec and 12 sec was observed, respectively, in the case of the addition of glass fibers and steel fibers in SCC. Also, L box and U box test results show that additions of fibers in SCC reduce the workability of self-compacting concrete. However, all results of the workability test are within the limit suggested by EFNARC standard, and still concrete was SCC.

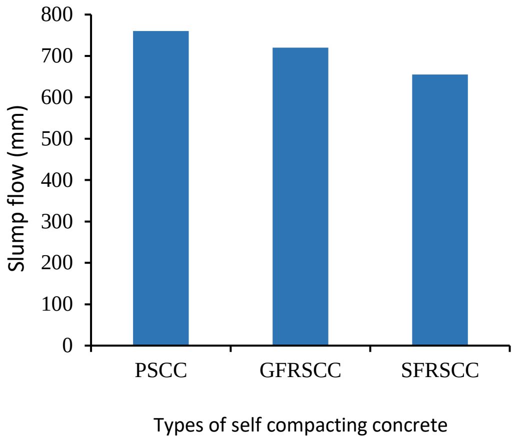


Figure 7: Slump flow versus the type of SCC

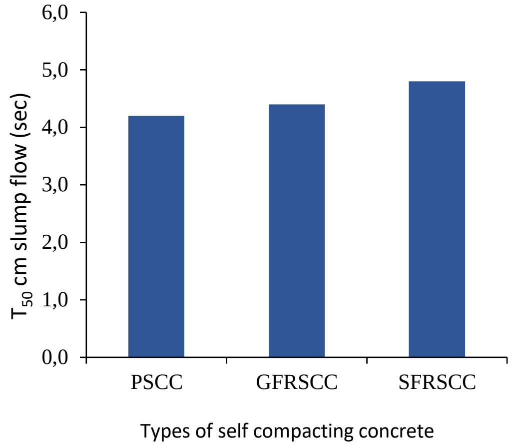


Figure 8: T_{50} cm slump flow versus the type of SCC

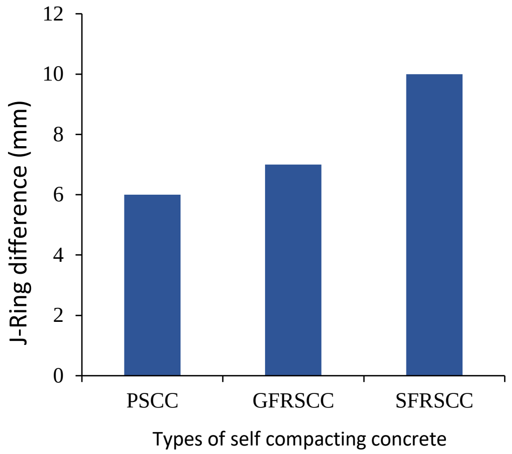


Figure 9: J-Ring difference versus type of SCC

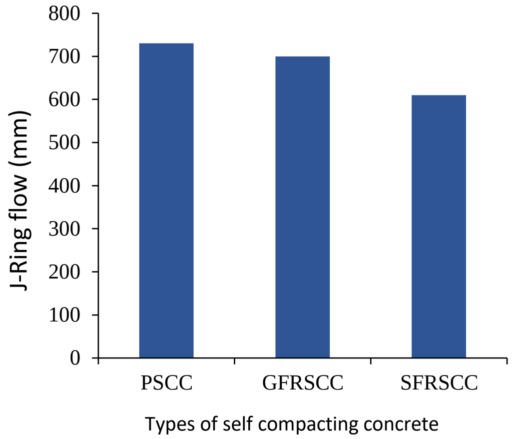


Figure 10: J-Ring flow versus type of SCC

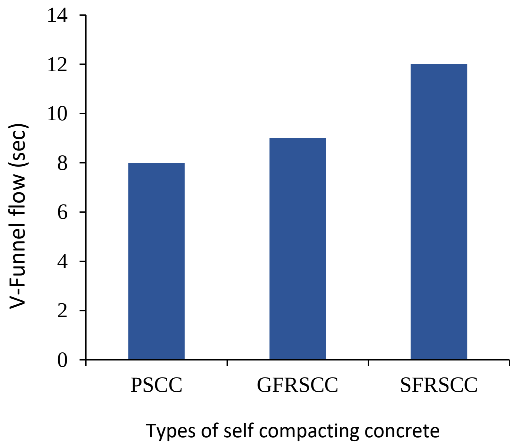


Figure 11: V-Funnel flow versus type of SCC

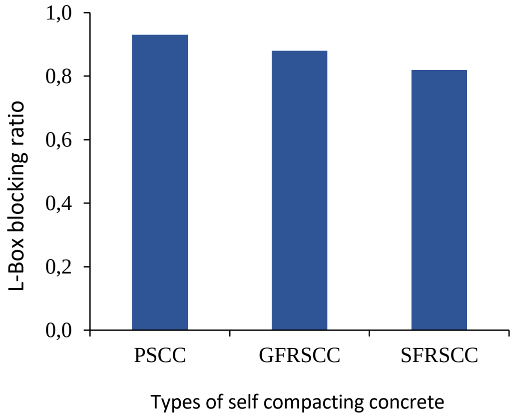


Figure 12: L-Box blocking ratio versus type of SCC

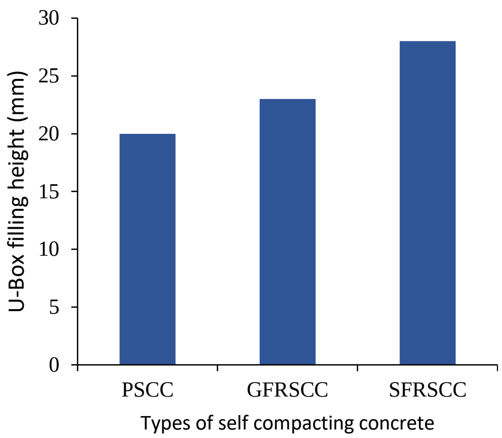


Figure 13: U-Box filling height versus type of SCC

3.2. Mechanical properties

Figures 14 to 16 show the harden properties of PSCC, GFRSCC, and SFRSCC specimens. It was revealed that with the addition of glass fibers, compressive strength was enhanced by 1.45%, and the same was increased by 6.30% when steel fibers were added to SCC. Fiber addition increased the compressive strength split tensile strength and flexural strength of self-compacting concrete. Due to the addition of glass fibers in SCC, Split tensile strength was increased by 10.30%, while flexural strength was increased by 10.04%. On the other hand, when steel fibers were used in SCC, an increase in split tensile strength and flexural strength was observed to be 31.36% and 34.47%, respectively.

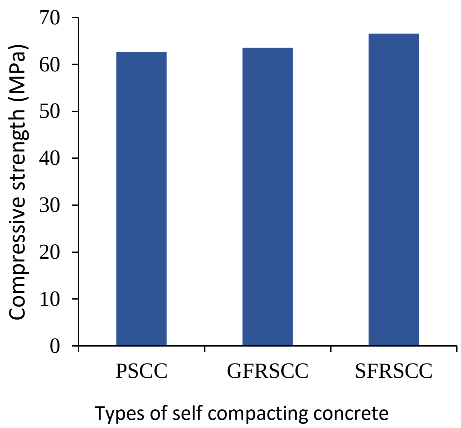


Figure 14: Compressive strength versus type of SCC

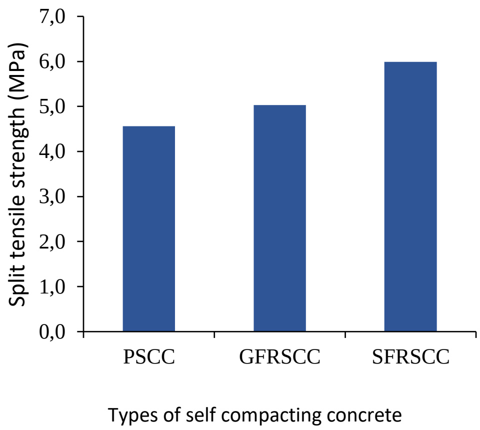


Figure 15: Split tensile strength versus type of SCC

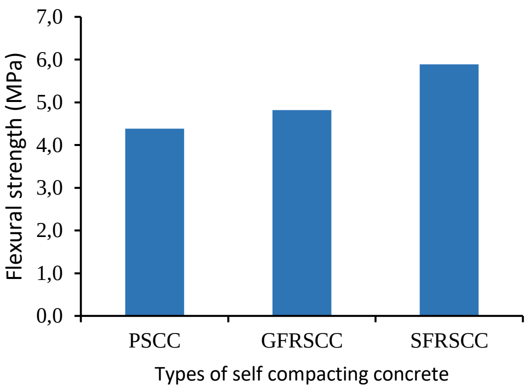
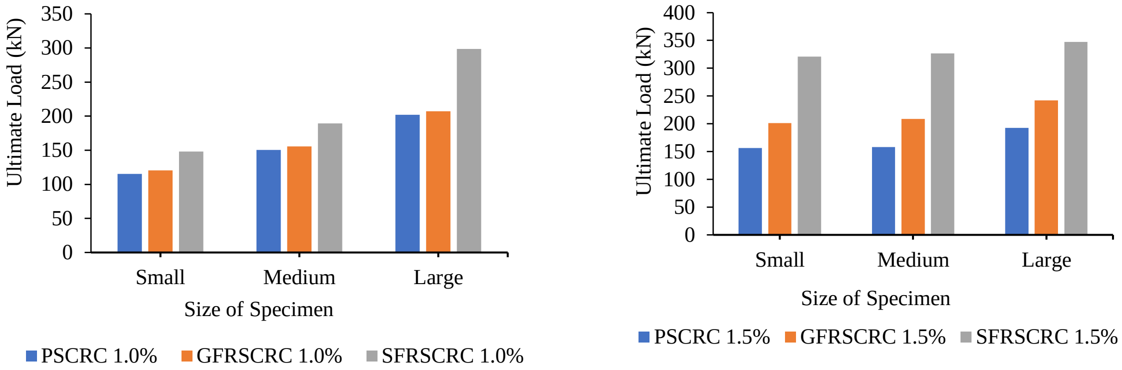


Figure 16: Flexural strength versus type of SCC

Thus, due to the higher tensile strength of steel fibers compared to glass fibers, the values of split-tensile strength and flexural strength in the case of SFRSCC had higher values in comparison to GFRSCC and PSCC specimens.

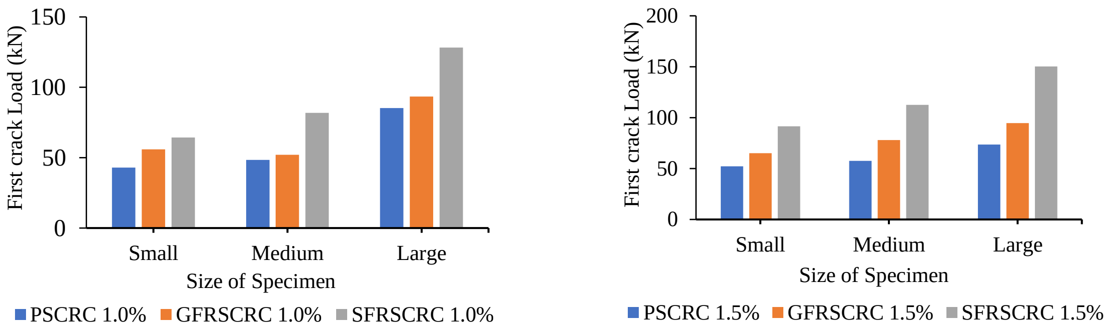
3.3. Ultimate load, first crack load, and deflection

The results of the ultimate load versus the size of the specimen and the first crack load versus the size of a specimen are presented in Figure 17 and Figure 18, respectively. Results show that the ultimate load was increased by 4.26% in GFRSCRC1.0% in small specimen sizes and 28.55% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% small-sized specimens, the ultimate load was increased by 1.23% and 23.24%, respectively, compared to PSCRC1.5%. Similarly, in the medium-sized specimens, the ultimate load was increased by 3.38% in GFRSCRC1.0% and 26.13% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% medium-sized specimens, the ultimate load was increased by 3.54% and 20.32%, respectively, compared to PSCRC1.5%. Further, a similar trend was observed in large-sized specimens too. The ultimate load was increased by 2.35% in GFRSCRC1.0% and 47.57% in SFRSCRC1.0 compared to PSCRC1.0%.



(a) (b)

Figure 17: Ultimate Load versus size of specimens
(a) with 1.0 % flexural reinforcement (b) with 1.5 % flexural reinforcement



a) (b)

Figure 18: First crack Load versus size of specimens
(a) with 1.0 % flexural reinforcement (b) with 1.5 % flexural reinforcement

While in the case of GFRSCRC1.5% and SFRSCRC1.5% large-sized specimens, the ultimate load was increased by 1.66% and 8.24%, respectively, compared to PSCRC1.5%.

It was observed that the first crack load was increased due to the addition of fibers in SCC. In small-sized specimens, the first crack load was increased by 29.86% in GFRSCRC1.0% and 49.33% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% small-sized specimens, the first crack load was increased by 10.22% and 41.05%, respectively, compared to PSCRC1.5%. Similarly, in medium-sized specimens, the first crack load was increased by 7.88% in GFRSCRC1.0% and 69.31% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% medium-sized specimens, the first crack load was increased by 19.76% and 44.97%, respectively, compared to PSCRC1.5%. Further, a similar trend was observed in large-sized specimens. The first crack load was increased by 9.5% in GFRSCRC1.0% and 50.24% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% large-sized specimens, the first crack load was increased by 22.70% and 63.89%, respectively, compared to PSCRC1.5%. Thus, it was observed that as the size of the specimens increased, the ultimate load and first crack load also increased. Further, it concludes that irrespective of any size, the addition of fibers increases the ultimate load and first crack load in both types of specimens, having 1.0% and 1.5% flexural reinforcements.

3.4. Flexural strength

Flexural strength is defined as the flexural capacity of the beam at the ultimate load (Bažant and Kazemi 1990; Gettu, Bazant, and Karr 1990; Rao, Vijayanand, and Eligehausen 2007). Figure 19 shows the variation of flexural strength calculated as Mu/fck bd2 for PSCRC, GFRSCRC, and SFRSCRC specimens reinforced with 1.0% and 1.5% flexural reinforcements.

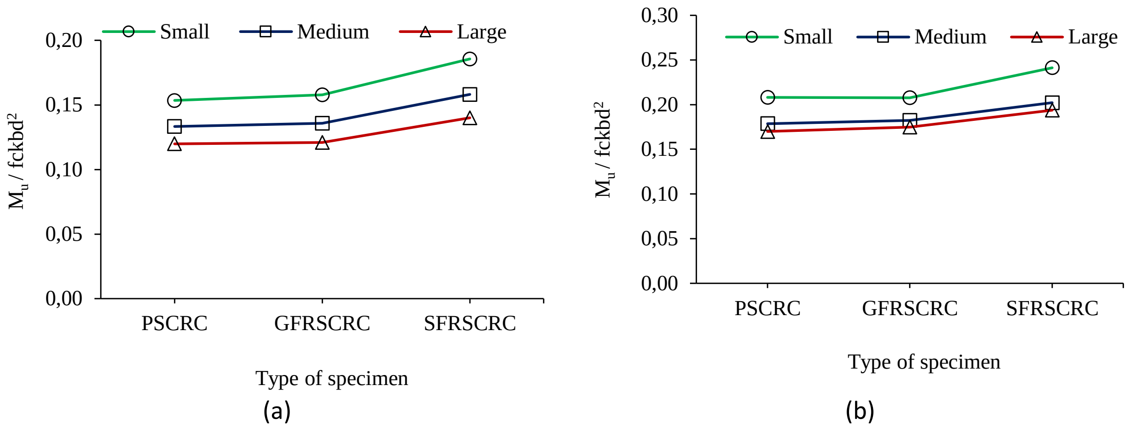


Figure 19: Flexural strength versus types of specimens
(a) with 1.0 % flexural reinforcement (b) with 1.5 % flexural reinforcement

It was observed that flexural strength increases with the addition of fibers in PSCRC in both types of specimens, having 1.0% and 1.5% flexural reinforcements.

In comparison with PSCRC, for the case of GFRSCRC, flexural strength was increased by 2.78%, 1.91%, and 0.89%, respectively, in small, medium, and large-sized specimens having 1.0% primary reinforcement; while in the case of 1.5% main reinforcement, flexural strength was increased by 0.26% and 2.07% and 2.94% respectively in small, medium and large size specimens. Similarly, when compared to PSCRC, in SFRSCRC having 1.0 % primary reinforcement, flexural strength increased by 20.93%, 18.65%, and 16.82%, respectively, in small, medium, and large size specimens; while in the case of 1.5% primary reinforcement, flexural strength was increased by 15.93% and 13.19% and 14.00% respectively in small, medium and large size specimens. Hence, it was observed that flexural strength in SFRSCRC specimens was more compared to GFRSCRC and PSCRC specimens. The reason is the mobilization of the tensile strengths of the fibers incurred in the GRSCRC.

3.5. Energy absorption capacity

For beam specimens, load-deflection curves are prepared and presented in Figures 20 to 23. The area under the load-deflection curve indicates the energy capacity absorbed by the beam (Rao, Vijayanand, and Eligehausen 2007). Also, toughness measures the energy absorption capacity. It is generally defined as the area under load–deflection curve of a flexural or stress-strain curve of a compressive test of the specimen (Arivalagan and Kandasamy 2009). The result of energy absorption capacity versus the size of specimens is shown in Figure 24.

It is seen that the energy absorption capacity was increased due to the addition of fiber in SCC. In small-sized specimens, the energy absorption capacity was increased by 10.81% in GFRSCRC1.0% and 52.15% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% small-sized specimens, the energy absorption capacity was increased by 45.40% and 102.13%, respectively, compared to PSCRC1.5%. Similarly, in medium-sized specimens, the energy absorption capacity was increased by 38.44% in GFRSCRC1.0% and 33.37% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% medium-sized specimens, the energy absorption capacity was increased by 14.43% and 34.78%, respectively, compared to PSCRC1.5%.

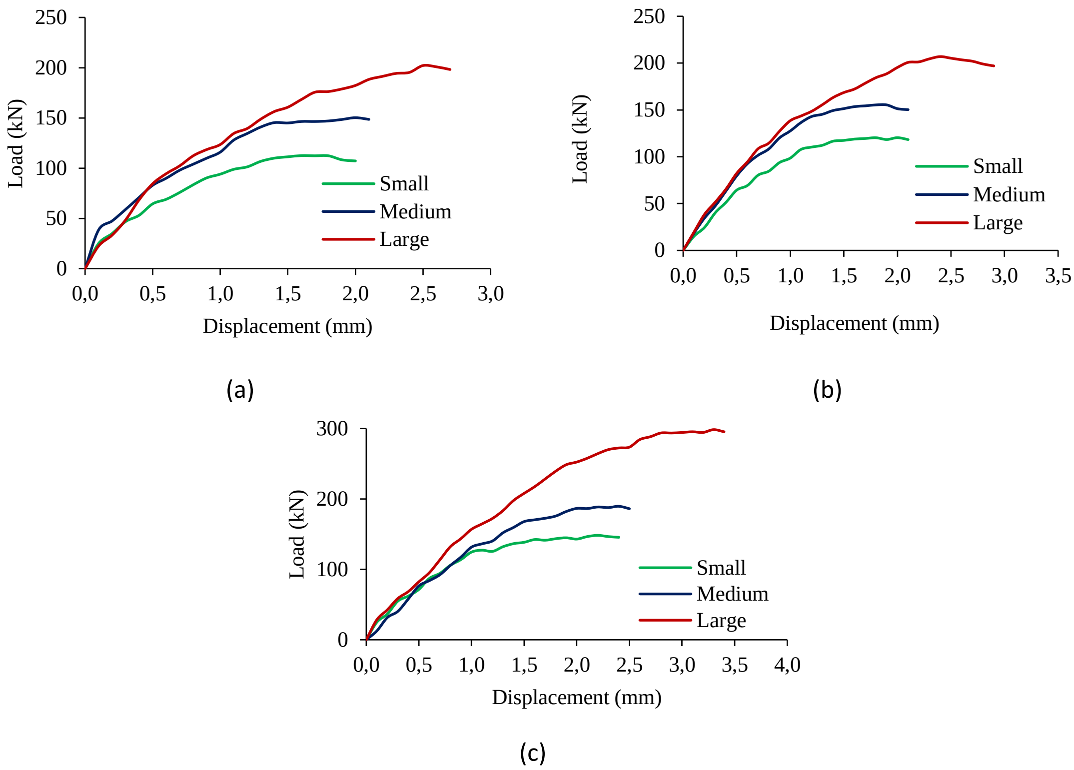
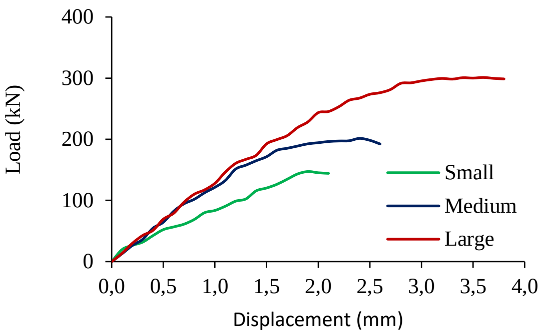
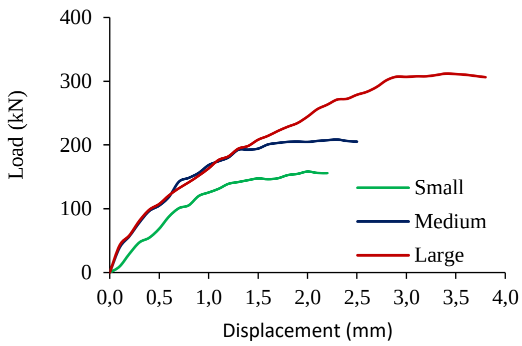


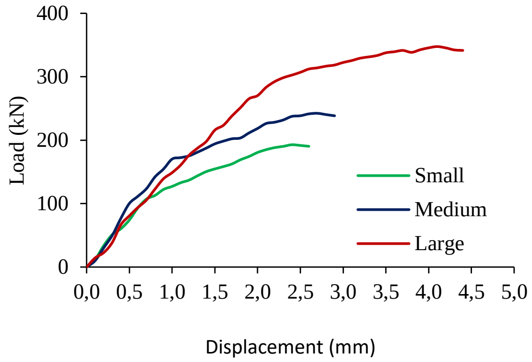
Figure 20: Load versus displacement curves for (a) PSCRC1.0%, (b) GFRSCRC1.0% and (C) SFRSCRC1.0%



(a)

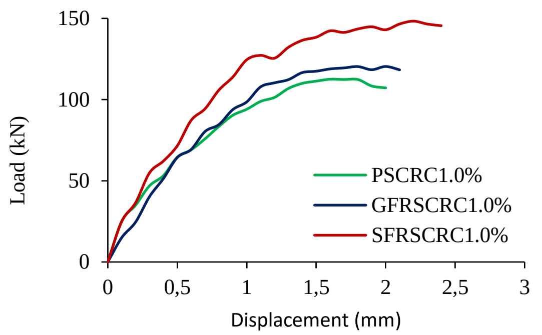


(b)

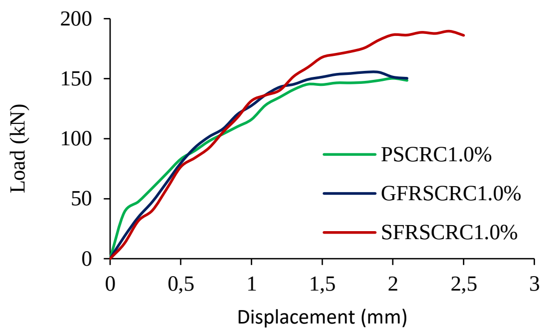


(c)

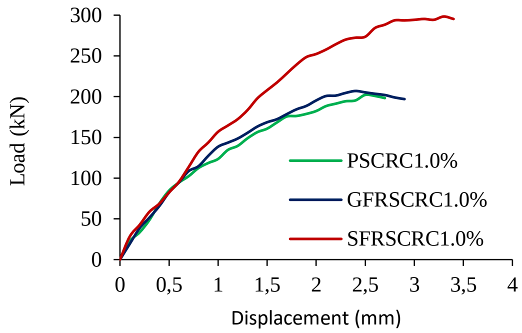
Figure 21: Load versus displacement curves for (a) PSCRC1.5%, (b) GFRSCRC1.5% and (c) SFRSCRC1.5%



(a) Small



(b) Medium



(c) Large

Figure 22: Load versus displacement curves
(a) Small (b) Medium (c) Large having 1.0% flexural reinforcement

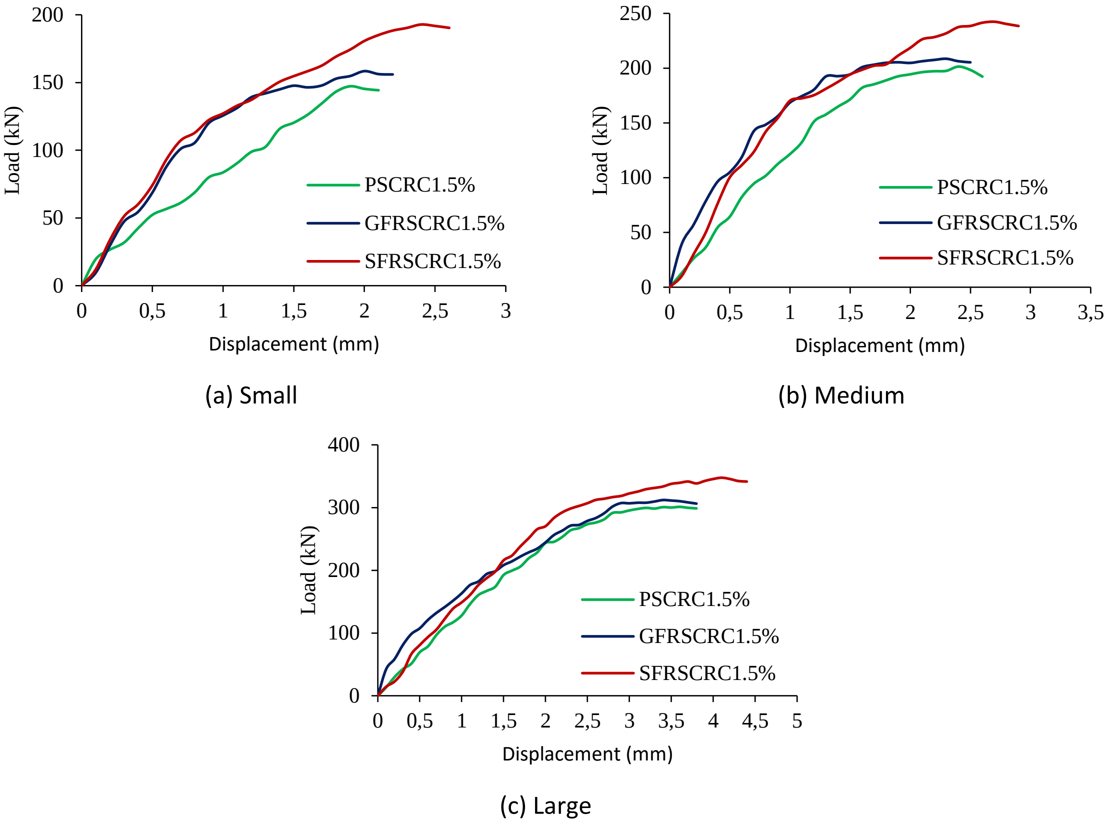


Figure 23: Load versus displacement curves
(a) Small (b) Medium (c) Large having 1.5% flexural reinforcement

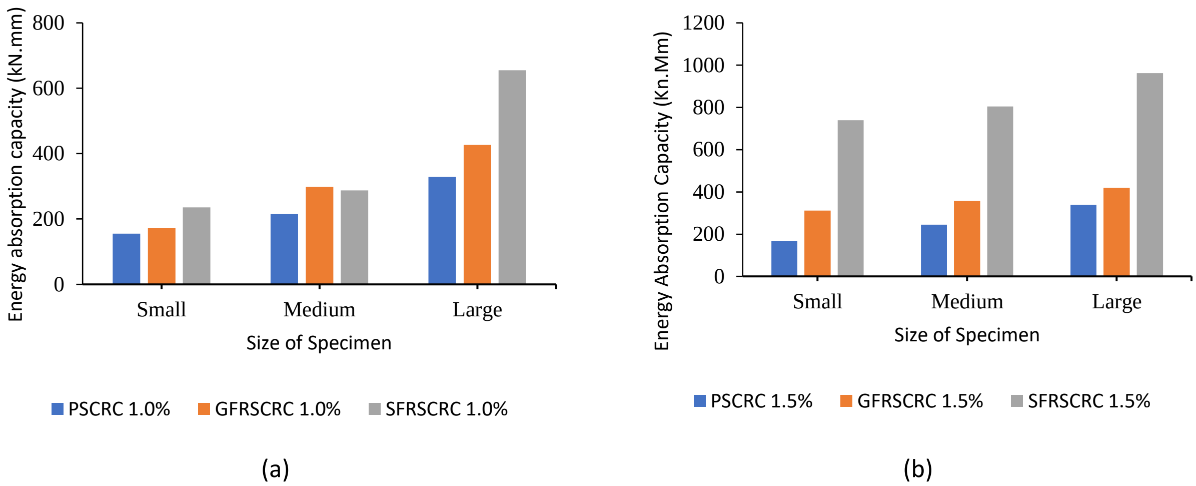


Figure 24: Energy absorption capacity versus Size of specimens
(a) with 1.0 % flexural reinforcement (b) with 1.5 % flexural reinforcement

Further, a similar trend was observed in large-sized specimens too. The energy absorption capacity was increased by 28.89% in GFRSCRC1.0% and 99.14% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% large-sized specimens, the energy absorption capacity was increased by 8.91% and 30.28%, respectively, compared to PSCRC1.5%. Therefore, it was also observed that as the percentage of flexural reinforcement is increased, the energy absorption capacity increases. SFRSCRC and GRSSCRC specimens have more toughness or energy absorption capacity than PSCRC.

Thus, it was concluded that, irrespective of any size and percentage of flexural reinforcement, steel fiber reinforced self-compacting reinforced concrete (SFRSCRC), the glass fiber reinforced self-compacting reinforced concrete (GFRSCRC) has more excellent resistance to fracture compared to plain self-compacting reinforced concrete (PSCRC) which is represented by the higher area under the load-displacement curve. Also, SFRSCRC shows higher resistance to fracture than GFRSCRC because steel fibers have higher tensile strength than glass fibers. Such material behavior is ideal for the construction of earthquake-resistance structures.

3.6. Ductility factor

The ductility factor measures the brittleness of reinforced concrete (RC) beams. The ductility factor may be defined as the deflection ratio at the failure to the deflection at yield or the first crack (Rao, Vijayanand, and Eligehausen 2007). As there was no information on the effect of size on the ductility of reinforced concrete beams, the present study was undertaken to investigate the effect of specimen size, percentage of flexural reinforcement, and fiber addition on the ductility of SCRC beam specimens (Zhao et al. 2005; Rozière et al. 2007; Roux, Réthoré, and Hild 2009). In the code of practice, the design strength of reinforced concrete (RC) members in flexure were considered to be constant. When the concepts of fracture mechanics are used, there could be an improved safety margin against failure, and the prediction of failure could be possible with reasonable reliability (Otter and Naaman 1988; Okamura and Ouchi 1999; Lawler and Shah 2002; Rao, Vijayanand, and Eligehausen 2007). The ductility factor for each specimen was calculated and presented in Figure 25, which shows that the addition of fibers in SCRC specimens increases the ductility factors of specimens.

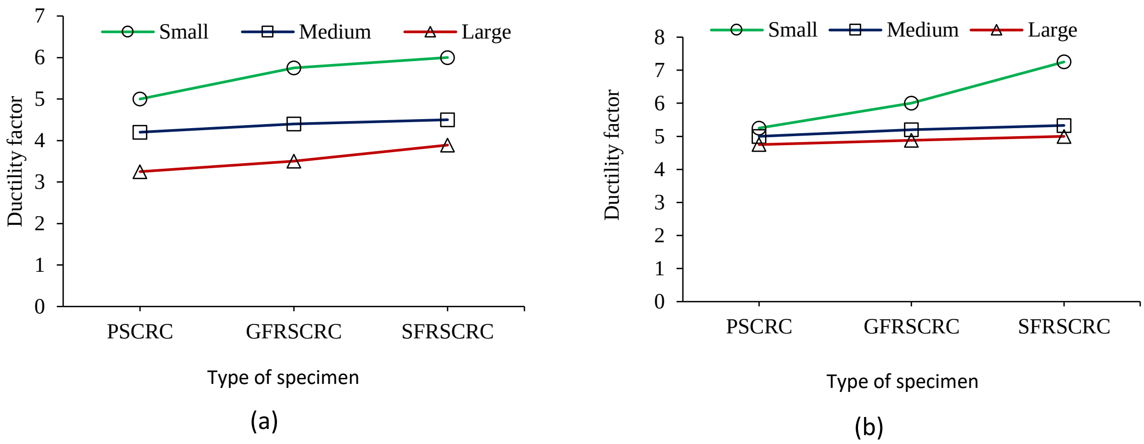


Figure 25: Ductility factor versus types of specimens
(a) with 1.0 % flexural reinforcement (b) with 1.5 % flexural reinforcement

In small-sized specimens, the ductility factor was increased by 15.0% in GFRSCRC1.0% and 20.0% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% small-sized specimens, the ductility factor was increased by 14.29% and 38.10%, respectively, compared to PSCRC1.5%. Similarly, in medium-size specimens, the ductility factor was increased by 4.76% in GFRSCRC1.0% and 7.14% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5%.medium sized specimens, the ductility factor was increased by 4.0% and 6.6%, respectively, compared to PSCRC1.5%. Further, a similar trend was observed in large-size specimens too. The ductility factor was increased by 7.69% in GFRSCRC1.0% and 19.69% in SFRSCRC1.0% compared to PSCRC1.0%. While in the case of GFRSCRC1.5% and SFRSCRC1.5% large-sized specimens, the ductility factor was increased by 2.63% and 5.26%, respectively, compared to PSCRC1.5% (Jindal and Hassan 1984; Hota and Naaman 1997; Khayat, Hu, and Monty 1999).

Thus, it was concluded that specimens become more ductile with the addition of fibers in small, medium, and large specimens in both 1.0% and 1.5% flexural reinforced specimens. The ductility factor decrease as the beam depth increases from 100 mm to 225 mm. Ductility factors were 5.0, 4.2, and 3.25, respectively, in PSCRC small, medium, and large beam specimens with 1.0% flexural reinforcement. A similar trend was observed in the case of PSCRC beam specimens reinforced with 1.5 % flexural reinforcement. Finally, it was concluded that as the size of the specimens increased, the ductility factor decreased. Specimens become more brittle with an increase in their sizes.

4. Conclusions

This study prepared fiber-reinforced self-compacting concrete by adding glass and steel fibers in plain and reinforced SCC. The tests on fresh self-compacting concrete were performed as per EFNARC standards. Cube, cylinder, and beam specimens were prepared and tested per IS 516-2013. The careful analysis of the results leads to the following conclusions:

1. Fresh properties of self-compacting concrete were affected by the addition of the fibers. It was seen that the addition of fibers reduces the flow and filling ability of SCC. The glass fibers had a more negligible effect on workability, whereas steel fibers had more effect on workability, but still, the concrete was able to exhibit the self-consolidation property.
2. Mechanical properties of fiber-reinforced self-compacting concrete, like compressive strength, split tensile strength, and flexural strength, were increased with glass and steel fibers. It achieved a 10-15 % rise approximately, whereas steel fibers addition shows a 20-30% rise in mechanical properties.
3. It was seen that the first crack load, ultimate load and deflection of steel fiber reinforced self-compacting reinforced concrete (SFRSCRC) specimens were more compared to glass fiber reinforced self-compacting reinforced concrete (GFRSCRC) and plain self-compacting reinforced concrete (PSCRC) specimens.
4. It was seen that the flexural strength of SFRSCRC specimens was more compared to GFRSCRC and PSCRC specimens.
5. It was observed that irrespective of any size and percentage of flexural reinforcement, SFRSCRC specimens and GFRSCRC specimens have more excellent resistance to fracture compared to PSCRC specimens which were represented by the higher area under load-displacement curves.
6. SFRSCRC specimens show higher resistance to fracture than GFRSCRC specimens due to steel fibers having higher mechanical properties than glass fibers. It is concluded that the beam's energy absorption capacity increases with the addition of fibers in self-compacting concrete. Such material behavior is ideal for the construction of earthquake-resistance structures.
7. The ductility factor measures the brittleness of reinforced concrete (RC) beams. It was seen that as the size of specimens increased, the ductility factor decreased. Specimens become more brittle with an increase in size. In addition, it was seen that specimens become ductile with the addition of fibers in all three sizes of specimens with 1.0% and 1.5% flexural reinforcement.

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