STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 11, Special Issue 1, 2023
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

Experimental Study on Fresh and Mechanical Properties of Crimpled Steel Fibers in Self-compacting Concrete

Bypaneni Krishna Chaitanya[1,*], L.N.K. Sai Madupu[2], S.V. Satyanarayana[3]

Abstract

The flow and strength characteristics of fiber-reinforced self-compacting concrete (SCC) with different aspect (l/d) ratios of fibers are recommended to be studied. After achieving a satisfactory SCC mix, crimped steel fibers with l/d ratio 30 are designated as CSF30; with l/d ratio 40 are designated as CSF40, with l/d ratio 50 is designated as CSF50 and with l/d ratio 62.5 is designated as CSF62.5 fibers are added at a fixed percentage of 2% by weight of cement. In this study diameter of fibers, 0.4 mm is constant, but lengths are varying as 12 mm, 16 mm, 20 mm, and 25 mm were added, and prepared different SCC-CSF mixes. Except for the blocking ratio, all other flow properties are within limits, when the aspect ratio of fibers is varied from 30 to 62.5. The up to l/d =50 blocking ratio is also within limits. If l/d =62.5, the SCC-CSF mix is failing in the blocking ratio test. There is a marginal increase in compressive strength and a considerable increase in split tensile strength and modulus of rupture by adding different l/d ratios of fibers.

Keywords: Self-compacting concrete, Crimpled steel fibers, Mechanical properties, Non-destructive properties, and Statistical analysis.

INTRODUCTION

SCC has characteristics that are comparable to liquid when it is fresh. Using it may lower both vibration-related noise and installation costs. It's also great for boosting productivity on building sites. With a "honey"-like consistency and a virtually horizontal concrete finish, SCC is a breeze to work with [1–6]. A novel approach to the formulation of self-compacting concrete mixes (SCC). This approach is less complicated, quicker to apply, and cheaper than the one created by the Japanese Ready-Mixed Concrete Association (JRMCA) since it uses a less total quantity of binder. By acting as a bridge to prevent the production of micro-cracks, micro-fiber boosts concrete's tensile strength. Because of their small size, microfibers may easily arrest the cracks. Large fibers have no discernible impact on preventing micro-cracking, but they may limit the spread of macro-cracking into larger cracks.

*Author for Correspondence
Bypaneni Krishna Chaitanya
E-mail: bkcht9@gmail.com

[1-3]Assistant Professor, R.V.R & J.C College of Engineering (A), Department of Civil Engineering, Guntur, Andhra Pradesh, India

Received Date: December 21, 2022
Accepted Date: May 10, 2023
Published Date: June 19, 2023

Citation: Bypaneni Krishna Chaitanya, L.N.K. Sai Madupu, S.V. Satyanarayana. Experimental Study on Fresh and Mechanical Properties of Crimpled Steel Fibers in Self-compacting Concrete. Journal of Polymer & Composites. 2023; 11(Special Issue 1): S65–S75.

By changing the percentage of crimped steel fibres with a fixed aspect ratio of 50, several FRSCC mixes were created (0.4 mm diameter and 20 mm length). SCC mixtures with 3% to 4% CSF are the strongest after 7 and 28 days of curing, respectively [7]. Two kinds of steel fibers were combined to study the impact of fiber inclusion on HFR-SCC workability. Fiber volume, length, and aspect ratios determine fiber effects.

SCC mixes with fiber inclusion (60 kg/m^3) have good compressive strength for 28 and 56 days, whereas ZP305 and OL6/16 have high split tensile strengthIS 10262:2019 and EFNARC. At 7 and 28 days of curing, SCC mixtures are strongest at 3% to 4% CSF [8].Ning li et al. 2021 [9]. In this work, the impact-related characteristics of self-compacting concrete (SCC) containing 0.5%, 0.75%, and 1.0% steel fibers are comprehensively examined (SHPB). Results reveal that steel fibers with a 1.0% composition may be utilized to make SCC with acceptable workability and increased impact resistance. Steel fibers enhance SCC's ITi and impact resistance. Adding 1.0% steel fibers increases SCC ITi by 18.8%. M. Mastali, A. Dalvand 2016. [10]. 144 specimens with 0.25%, 0.5%, and 0.75% fiber volume fractions were examined for mechanical characteristics and impact resistance. Combining silica fume with recycled steel fiber increased mechanical characteristics and impact resistance. Linear equations were also established to connect mechanical characteristics and impact resistance of high-coefficient specimens. Ramkumar K.B., Kannan Rajkumar P.R [2022] [11]. The results of the developed regression model are compared to the data gathered in the lab. Incorporating 0.40 percent hybrid hooked fibers and 0.10 percent micro-steel fibers improved the fresh concrete's performance as well as the hardened concretes. The elastic modulus, flexural strength, and split tensile strength that were predicted by the regression model agreed with those that were measured in the lab, demonstrating the model's accuracy. Ozgureren and Anas alrawashdeh [2022] [12]. Six batches of steel fibre reinforced self-compacting concrete (SFR-SCC) with two different steel fibre aspect ratios (l/d) of 60 and 80 at three different volume fractions (Vf) of 0.35%, 0.45%, and 0.55%, as well as a control mix, were produced. The cement used to cast all the samples had 2% silica fume (SF) added to it, and the water-binder ratio was kept constant at 0.34. As the aspect ratio of steel fibers is raised, the flexural strength rises, along with the toughness, split tensile strength, and impact resistance. Hassan M. Magbool and Abdullah M. Zeyad (2020, 13) [13]. The hook-end fibre (60 and 30 mm), long straight fibre (21 and 13 mm), and flat-end fibre (six distinct concrete mixes made with the addition of 1% of the volume fraction) are three of the five fibre kinds with varying forms and aspect ratios that are looked at. A replacement rate of 30% of cement mass is used for VPP. Examining concrete's mechanical and new characteristics is the study's secondary goal. Results indicate that steel fibre reduces the SCC's fresh attributes. Along with the displacement of the crack's mouth opening, the addition of steel fibre increases peak loads and deflection during failure. The characteristics of the concrete mixes' fracture toughness are also impacted.

METHODOLOGY OF SCC-CSF% MIXES

The optimum mix is obtained from trial mixes it satisfies all the flow properties. In that optimum mix crimpled steel fibers are utilized with a size of 0.4 mm in diameter and length of 12, 16, 20, and 25 mm used as per Standards (ASTM 820/96, ASTMC 116/95, and DIN 1045) are used for SCC mixes. The flow properties (i.e., filling ability, passing ability, and Viscosity,) were observed as per the EFNARC [14], ACI-237R-07 [14], and IS 10262:2019 [15].

Mechanical characteristics (i.e., Compressive, split tensile, and flexure strength tests), Non-destructive examination (i.e., Ultrasonic pulse velocity test and Rebound hammer), are done, and the results are studied. In this study crimpled steel fibers have been used in self-compacting concrete from Bakul Castings Pvt.Ltd and size of 0.4 mm in diameter and length of 12, 16, 20, and 25 mm used as per Standards (ASTM 820/96, ASTMC 116/95, and DIN 1045 with aspect ratios are 30, 40, 50, 62.5. The quantity of fibers added was at 2% by weight of cement.

EXPERIMENTAL PROGRAM

Materials

Ordinary Portland cement (OPC) of 53 grade conforming to various specifications of IS: 12269-1987(12). Fly ash was used as a mineral admixture The maximum size of aggregate is 12 mm and specific gravity is 2.71 and the bulk density value of a coarse aggregate is 1394.1 kg/m^3. The specific gravity of sand is 2.62 and the bulk density of fine aggregate is 1596.40 kg/m^3. Sieve analysis report confirming Zone-II. Polycarboxylate-based used as a superplasticizer (Master gelenium-8630) was used as a chemical additive. In these SCC-CSF mixes, steel fibers of ASTM 820/96, ASTMC 116/95, and DIN 1045 have different l/d ratios of 30, 40, 50, and 62.5, and the nominal length of steel fibers is 12 mm to 25 mm with 0.4 mm diameter of the fibers are used.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Mix Proportions

In SCC mix preparation composition plays a vital role, SCC, highly flowable and free from segregation, is easily placed at construction joints without any vibration. The SCC was prepared with the same as conventional concrete materials with (or) without VMA. In that, an optimized mix in SCC is chosen to study the effect of SCC-CSF mixture flow, mechanical properties, and quality of concrete. A constant range, for SCC-WCS: Cement is 425 kg/m^3, the Flyash is 92.35 kg/m^3, Coarse-grain-Crushed aggregates 667.5 kg/m^3, the natural sand is 988.07 kg/m^3, and the water to cement is 0.42. A PCE superplasticizer at 4.17 kg/m^3. SCC mixtures were made with tap water from the laboratory. The SCC group's performance was assessed using the EFNARC [15], IS10262:2019 [16]. In this study crimpled steel fibers have been used in self-compacting concrete (SCC) from Bakul Castings Pvt. Ltd and size of 0.4 mm in diameter and length of 12, 16, 20, and 25 mm used as per Standards (ASTM 820/96, ASTMC 116/95, and DIN 1045 with aspect ratios are 30, 40, 50, 62.5. The quantity of fibers added was at 2% by weight of cement) and properties are listed in Table 1. The number of fibers added was at 2% by weight of cement added then flow and strength properties were studied.

Table 1. Properties of steel fibers

Steel fiber properties	**Limits**
Chemical composition	According to EN1 0016/ O2C72D
Tension Strength	Min 1100 N /mm^2
Elongation	Max 4%
Young’s Modulus	E=210 N /mm^2
(l/d) ratio	30 to 62.5
Lengths	12,16,20 25 mm.
Diameter	0.4 mm
Shape	Crimpled

Mix Preparation

The Pan mixer consists of a steel drum, 40 liters capacity mounted on a frame. The drum is rotated at 20-24 RPM with the help of a motor or convey belt. For the preparation of SCC-CSF% mixes, the required raw materials are collected and gauged as per the design mix proportions Firstly, cement, fly ash, fine aggregate, and CSF is added and mixed well for 2 min to obtain a homogenous mix and then the same homogenous mix add coarse aggregate and mix it for 2-3 min. Around 50% of gauged water was added to the above dry continuous mix process to obtain a homogenous mix. When proper blending of the mixture is observed, gauged SP poured in the remaining 50% water was added and mixed well for 2-4 min to obtain a suitable flowable mix. The workability of mixes is determined with slump flow, L-box-funnel tests, and Visual stability index as per EFNARC [15], IS 10262: 2019 [17], and ACI-237R-07 [18]. Pan-type vertical-axis mixer aggregates are initially blended. Then cement and fly ash were gradually added if it’s uniformly blended added steel fibers with 70% water content. Finally, the remaining water content and the superplasticizer are incorporated after arriving satisfactory mix proportion for Self-Compacting Concrete

(SCC) by various trials, and control mixes (SCC). Cubes of 150 mm x 150 mm x 150 mm, Cylinders of 150 mm diameter x 300 mm height, and Plain beams of 150 mm x 150 mm cross-section and 750 mm depth are cast. The test specimens were demoted after 24 hrs. and kept in clean water for immersed curing**.** Take caution not to damage any corners while removing. SCC mixture samples were cured in curing tanks near the laboratory at 27±2°c for 7, 28, 56, and 90 days. After completion of curing, mechanical and NDT tests are done, and results are recorded and validated.

TESTS ON SELF-COMPACTING CONCRETE

Flow Properties

Self-compacting concrete is not the same as conventional concrete. The Slump Flow, the V-Funnel, and the

L-Box are high flowability concretes are done as per EFNARC [15], IS 10262:2019 [19]. Slump flow: the test aims at the filling ability of the SCC. The slump flow of 550 to 850 millimeters talks about diameter concrete spreads. Slump flow time (also referred to as the T_{500} test) is an extension of the slump flow test. It is the amount of time needed for the concrete to reach a 500 mm diameter. The typical time could be in the range of 2 to 5 seconds the concrete spreads out in all directions when the 200 mm slump cone is removed, this is termed the T500 time. For a given volume and time, the V-funnel test measures how long it takes concrete to flow through a tiny aperture; it indicates the filling ability, assuming that no blockage or segregation occurs. The L-block is concerned; the height difference at these two locations is the most important factor. If the concrete behaved like a genuine fluid, there would be no height difference. That is the difference that we want to monitor and measure as the output as blocking ratio (h_2/h_1) from this test which is called the L-box test (Figure 1).

Figure 1. Workability properties of SCC mix.

Destructive Properties

In SCC, fine aggregates are replaced with WCS to assess mechanical properties are done (i.e., Compressive strength, split tensile strength, and flexure strength) at different curing ages to satisfy structural criteria. IS 516:2004 is used to calculate compressive strength [20]. The cubes dimensioned (150*150*150 mm) size are cast and cured for 7, 28 days. For the samples having a dry surface placed on a capacity of 2000 KN, CTM Gently increases the load with help of a lever until the burst, then writes down the peak load of failure to assess the stress. The strongest factor affecting concrete's splitting tensile strength is the paste's quality. The interfacial transition zone and paste quality are influenced by fine aggregate properties (ITZ). A constant force is applied throughout the length of cylindrical concrete size (150 mm * 300 mm) in UTM of 100 tones capacity and note the failure load to determine the indirect tensile strength as per IS 5816:1999. The prism size (750*150*150 mm) is used to determine the modulus of rupture (also referred to as Flexure strength). All the beams are dried before pacing in UTM of 100 tones capacity. The load must be applied continuously until reaching the peak load and breaks under two-point loading as per IS 516:2004 [21].

Journal of Polymer & Composites
Volume 11, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Non-Destructive Properties

The Ultrasonic pulse velocity test with sensors passes waves through the concrete surface and the time takes for the sample to pass distance. To assess the quality, voids, and cracks present in concrete samples are done in three approaches as follows (Direct method, In-Direct method, and Semi-Direct method) from UPV. In this work, the direct method is studied to determine the velocities of SCC mixtures, as per IS 13311-1 [22]. Schmidt hammer and once the plunger strikes the surface of the concrete with a certain amount of energy. The extent of rebound number (N) gives us a measure of the hardness of the surface and is correlated with the strength of the concrete. The Schmidt hammer provides a calibration curve that enables us to estimate or determine the compressive strength based on the rebound number. The Schmidt hammer is perhaps the most used non-destructive tool as far as estimation of the strength of concrete is concerned as per IS 13311-2 [23].

RESULTS AND DISCUSSIONS

Fresh Properties

Table 2. represents the flow properties of CSF mixes. From Figure 2 shows the slump flow of SCC-CSF mixes, it represents the slump flow decreasing with an increase in l/d ratio but within limits up to l/d =62.5. Figure 3 flow times of SCC-CSF mixes show the slump flow time. It represents flow time increasing with an increase in l/d ratio but within limits, up to l/d =62.5. V-funnel time is increasing as the l/d ratio increases but within limits up to l/d =62.5 as shown in Figure 3. As the l/d ratio increases, the H_2/H_1 ratio decreases. Up to l/d =, 50 L-box test results are within limits but with l/d= 62.5 the mix was falling as per Figure 4. Up to l/d ratio=50, there is a marginal decrease in blocking ratio percentages (14.84%). At l/d =62.5 there is considerable increase in blocking ratio (21.24%).

Table 2. Flow properties of SCC-CSF mix

Mix ID	Slump Flow Test		V-Funnel Test	L-Box Test
	T500 sec	*D avg, mm*	*sec*	*H_2/H_1*
PSCC	3.3	740	7.02	0.873
CSF30	2.2	740	7.55	0.9315
CSF40	2.6	710	8.2	0.810
CSF50	4	685	9.8	0.826
CSF62.5	3.7	675.5	10.05	0.764

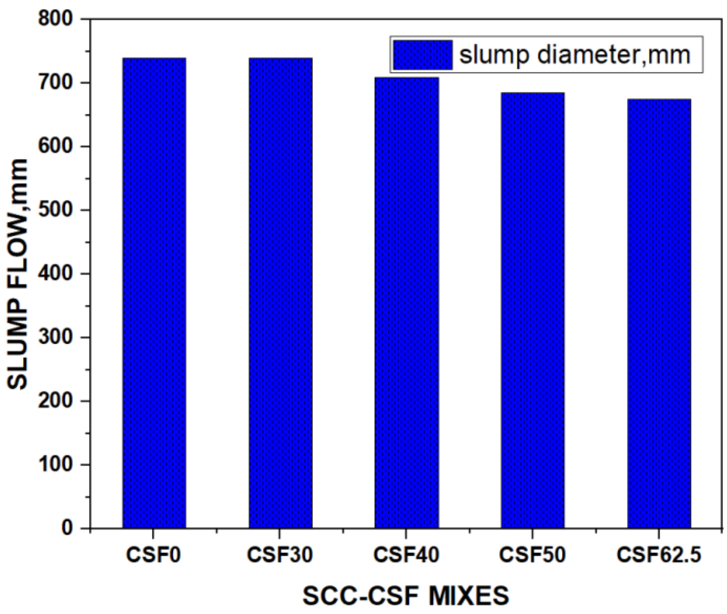

Figure 2. Slump flow of SCC-CSF mixes.

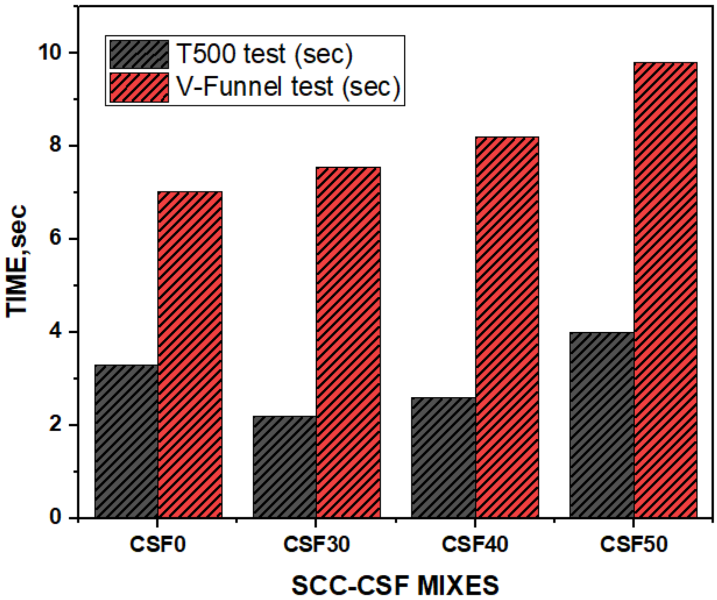

Figure 3. Flow times of SCC-CSF mixes.

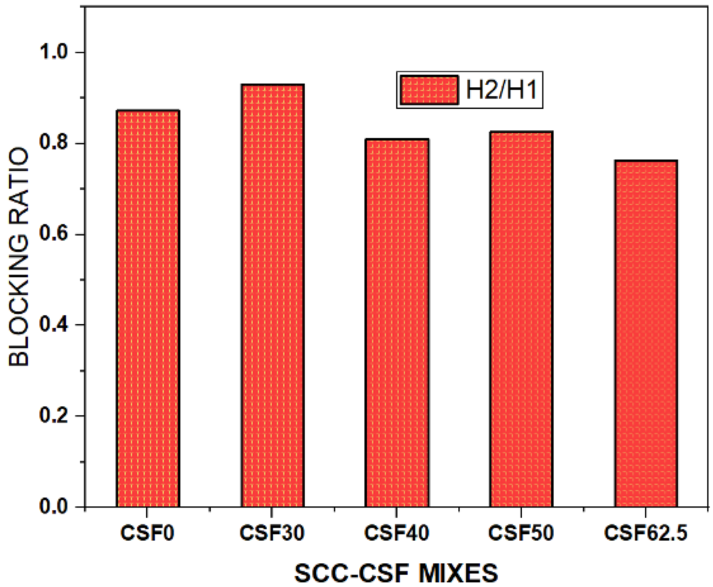

Figure 4. Blocking ratio of SCC-CSF mixes.

Destructive Test (DT) and Non-Destructive Test (NDT) Properties

In testing, all specimens (cubes, cylinders, and beams) are cast and tested for the study of CSF0, CSF30, CSF40, CSF50, and CSF62.5, and the result is evaluated. Table 3 represents the hardened properties of the SCC-CSF mix for curing ages. Figure 5 represents the compressive strength (CMS) of SCC-CSF mixes at 7,28 days of curing. The CMS values range from 24.8 MPa-30.22 MPa and 31 MPa–37 MPa for 7 and 28 days of curing. There is an increase in CMS values with an increase in the l/d ratio of fibers added [24]. At 7 days rate of increments is 0.988%, 3.6%, 15.92% and 19.36% and 2.564%, 3.817%, 4.44% and 8.5% compare to CSF0 in 28 days. Figure 6 represents the split tensile strength (STS) of SCC-CSF mixes at 7,28 days of curing. The STS values range from 1.7 MPa–2.54 MPa and 2.5 MPa–3.12 MPa for 7 and 28 days of curing. Split tensile Strength increases with increases in l/d ratio of fibers, with l/d=30, l/d =40, l/d=50 and l/d=62.5 there is 0.59%, 28.88%, 38.88% and 49.765% increase at 7 days and 4%, 6.80%, 16% and 24.80% increase at 28 days. Modulus of Rupture also known as flexure strength (FTS) results is observed as shown in Figure 7.

Journal of Polymer & Composites
Volume 11, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

FTS values are increases with increases in the l/d ratio of fibers, with l/d=30, l/d =40, l/d=50 and=62.5, there is 1.46%, 3.85%, 5.55% and 8.12% increases in modulus of rupture as shown in Figure 6. The NDT like. UPV and RB(N) is done for SCC-CSF mixes shown in Figure 8 and Figure 9 after 7 and 28 days of curing. Figure 7 represents the incremental trend for SCC mixes at 7 and 28 days of curing. The UPV value for 7 days of curing is range from 4.16 to 4.864 km/s and 4.34 to 4.716 Km/s for 28 days of curing. The quality of SCC-CSF mixes is excellent as per IS: 13311 (Part-1):1992 [25]. Figure 9 represents the incremental trend for SCC mixes at 7 and 28 days of curing. The RB (N) value for 7 days of curing is range from 34 to 41 and 42.5 to 50.4 for 28 day of curing. The surface hardness SCC-CSF mixes are done as per IS: 13311 (Part-2):1992 [26].

Table 3. DT and NDT properties of SCC-CSF mix at curing ages

Mix ID	CMS, (MPa)		STS, (MPa)		FST, (MPa)	UPV, (km/s)		RB(N)	
	7 days	*28 days*	*7 days*	*28 days*	*28 days*	*7 days*	*28 days*	*7 days*	*28 days*
CSF0	24.8	31.22	1.7	2.5	5.49	4.16	4.34	37.87	42.50
CSF30	25.5	35.11	1.71	2.6	5.47	4.28	4.61	41.29	50.40
CSF40	27.22	36.44	2.19	2.67	5.60	4.41	4.56	30.37	42.30
CSF50	29.33	36.66	2.36	2.9	5.60	4.57	4.67	36.04	43.25
CSF62.5	30.22	37.11	2.54	3.12	5.83	4.86	4.71	34.17	46.00

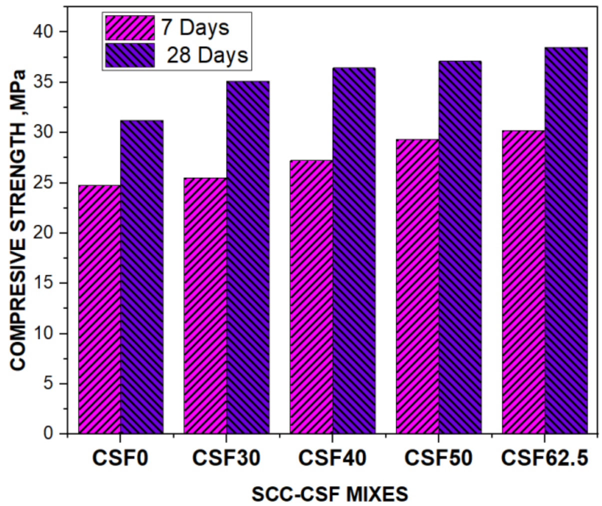

Figure 5. CMS of SCC-CSF mixes.

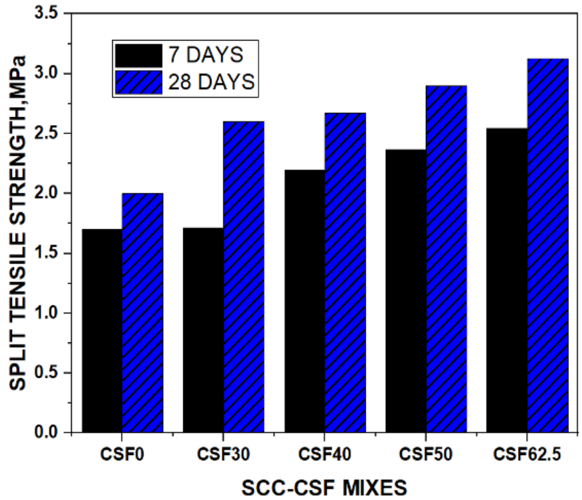

Figure 6. STS of SCC-CSF mixes.

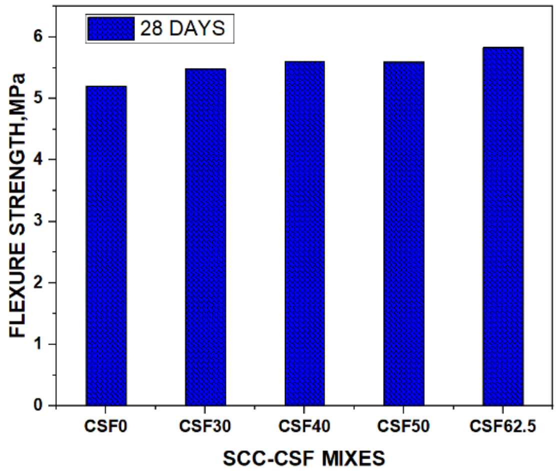

Figure 7. FTS of SCC-CSF mixes.

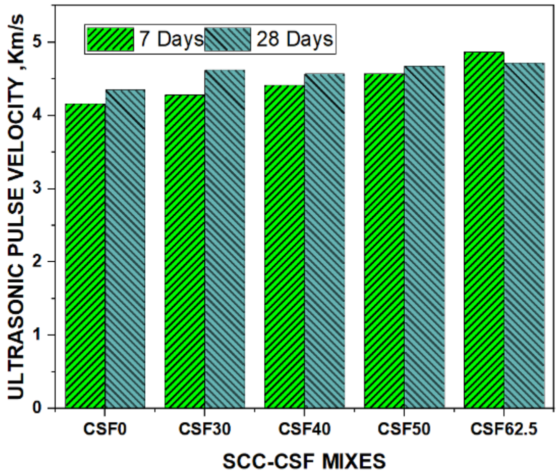

Figure 8. UPV for SCC-CSF mixes.

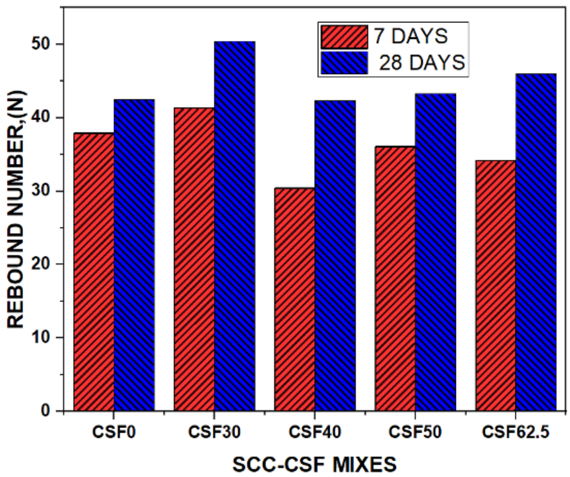

Figure 9. Rebound number (N) for SCC-CSF mixes.

STATISTICAL ANALYSIS

The statistical relation is developed for the SCC-CSF mixes of destructive and nondestructive properties. All the properties show good correlation between the mixes. Figures 10, 11, 12 and 13 represents the correlation properties of the mixes as shown below.

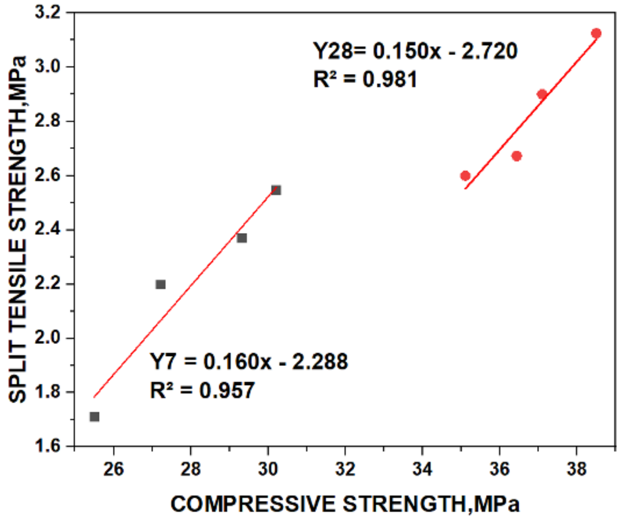

Figure 10. Correlation for CMS Vs STS for SCC-CSF mixes.

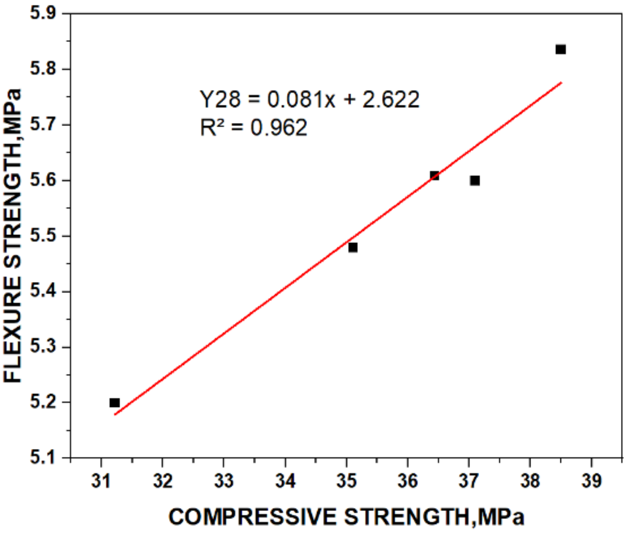

Figure 11. Correlation for CMS Vs FTS for SCC-CSF mixes.

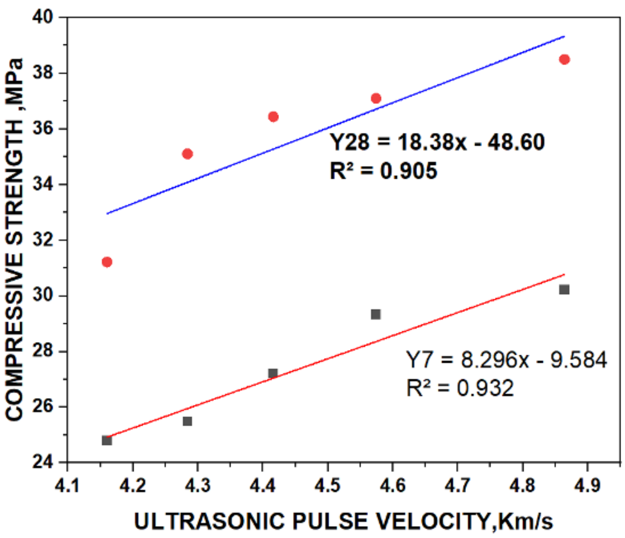

Figure 12. Correlation for UPV Vs CMS for SCC-CSF mixes.

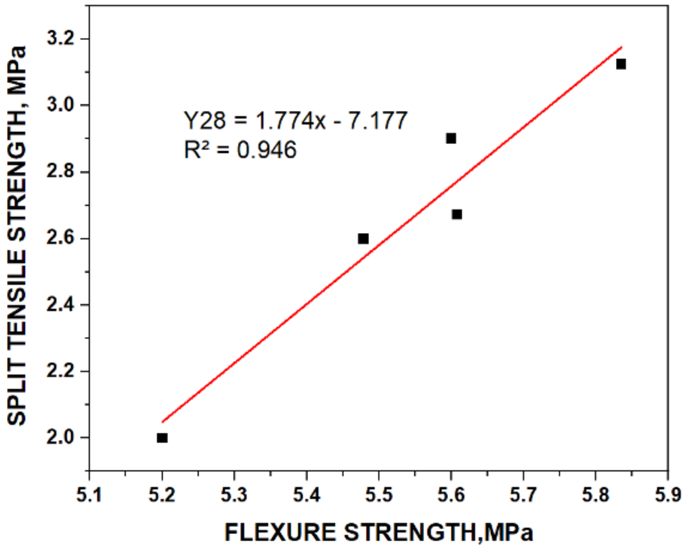

Figure 13. Correlation for FTS Vs STS for SCC-CSF mixes.

CONCLUSIONS

From this study, it can be concluded that fibers can be added aspect ratios up to 50, beyond that there is loss in FRSCC passing ability property. An increase in Compressive Strength is nominal with superplasticizer increase in the aspect ratio of fibers added but there is a considerable increase in Split tensile strength. The present paper deals with steel fiber reinforced self-compacting concrete. The CSFRSCC has a slump flow in the range of 675-740 mm, a flow time ranging from 2.1 to 4 sec, V-funnel flow in the ranging from 7.02 to 10.05 sec, and L-Box ratio ranging from 0.826 to 0.97. It was observed that it is possible to achieve self

Compaction concrete of 2 percentage fixed with different aspect ratios (CSFSCC30, CSFSCC40, CSFSCC50, and CSF SCC62.5).

Funding: No

Code availability not applicable.

Conflict of Interest

The author declared there is no conflict of interest on behalf of all authors.

REFERENCES

1. Nan Sua, Kung-Chung Hsu and His-Wen Chai A simple mix design method for self-compacting concrete. Cement and Concrete Research 31 (2001), pp.1799–1807.
2. Okamura H, Ouchi M. Self-compacting concrete. Journal of Advanced Concrete Technology. 2003;1(1):5–15.
3. Bypaneni Krishna Chaitanya, Ilango Sivakumar. Experimental investigation on bond behaviour, durability and microstructural analysis of self-compacting concrete using waste copper slag. Journal of Building Pathology and Rehabilitation (2022) 7:85.
4. Chaitanya BK, Sivakumar I (2022) Flow-behaviour, microstructure, and strength properties of self-compacting concrete using waste copper slag as fine aggregate. InnovInfrastructSolut7:181. https:// doi. org/ 10. 1007/ s41062- 022- 00766-3
5. Chaitanya BK, Kumar IS (2022) Effect of waste copper slag as a substitute in cement and concrete—a review. IOP Conf Ser EarthEnviron Sci 982(1):012029. https:// doi. org/ 10. 1088/ 1755- 1315/982/1/ 012029
6. Krishna Chaitanya B, Sivakumar I (2021) Influence of waste copper slag on flexural strength properties ofof self-compacting concrete. Mater Today Proc 42:671–676

7. R. Vaishnav Kumar, BypaneniKrishna Chaitanya, L.N.K. SaiMadupu and N. Venkata Sairam Kumar. Evaluation of mechanical and flow properties of Crimpled steel fiber in self compacting concrete. Volume 45, Part 6, 2021, Pages 4835–4840.
8. Mustafa Sahmaran, AlperenYurtseven, I. Ozgur Yaman Workability of hybrid fiber reinforced self-compacting concrete Building and Environment 40 (2005), pp.1672–1677.
9. Ning Li, ZuquanJin, Guangcheng Long, Lou Chen, Qiang Fu, Yong Yu, Xiaoying Zhang, ChuanshengXiong. Impact resistance of steel fiber-reinforced self-compacting concrete (SCC) at high strain rates. Journal of Building Engineering, Volume 38,2021, 102212, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2021.102212.
10. M. Mastali, A. Dalvand. Use of silica fume and recycled steel fibers in self-compacting concrete (SCC). Construction and Building Materials, Volume 125,2016, Pages 196-209, ISSN 0950-0618.https://doi.org/10.1016/j.conbuildmat.2016.08.046.
11. Ramkumar K.B., Kannan Rajkumar P.R., Impact of hybrid steel fibres on fresh and mechanical properties of Self-compacting concrete, Case Studies in Construction Materials, Volume17, 2022, e01274, ISSN:2214-5095.
12. Anas Alrawashdeh, OzgurEren, Mechanical and physical characterisation of steel fibre reinforced self-compacting concrete: Different aspect ratios and volume fractions of fibres, results in engineering, Volume 13,2022,100335, ISSN 2590-1230.
13. Hassan M. Magbool, Abdullah M. Zeyad. The effect of various steel fibers and volcanic pumice powder on fracture characteristics of Self-Compacting concrete, Construction and Building Materials, Volume 312, 2021, 125444, ISSN 0950-0618.
14. IS:269:2015, Ordinary portland cement-Specification (Sixth Revision), Bureau of Indian Standard, New Delhi.
15. IS 9103: 1999, Concrete Admixtures-Specification (First Revision), Bureau of Indian Standard, New Delhi.
16. IS 383-2016, Specification for coarse and fine aggregates from natural sources for concrete, Bureau Of Indian Standard, New Delhi.
17. EFNARC, 2002. Specification and Guidelines for Self-Compacting Concrete.
18. EFNARC,2005.T he European Guidelines for Self-Compacting Concrete
19. IS:2386 (Part-3): 1963. Indian Standard methods of test for aggregates for concrete, Bureau Of Indian Standard, New Delhi.
20. IS 10262:2019, Concrete Mix, Proportioning Guidelines (first revision), Bureau of Indian Standard, New Delhi.
21. IS 516:2015, Methods of Tests for Strength of Concrete, Bureau of Indian Standard, New Delhi.
22. IS: 13311 (Part-1):1992, Non-Destructive testing of Concrete-Methods of Test-Part 1 Ultrasonic Pulse Velocity. Bureau of Indian Standard, New Delhi.
23. IS: 13311 (Part 2):1992. Non-Destructive testing of Concrete-Methods of test, Part 2 Rebound Hammer. Bureau Of Indian Standard, New Delhi.
24. B. Krishna Chaitanya and P. PrasanaKumar. Performance. Evaluation of glass fiber reinforced high-performance concrete with silica fume and nano-silica. IOP Conference Series: Earth and Environmental Science, Vol. 982 (012018), 2022.
25. N. Venkata Sairam Kumar, K.S. Sai Ram, Performance Of Concrete At Elevated Temperatures Made With Crushed Rock Dust As Filler Material, Materials Today: Proceedings, Volume 18, Part 7,2019, Pages 2270-2278, ISSN 2214–7853.
26. N. Venkata Sairam Kumar, K.S. Sai Ram. Experimental study on properties of concrete containing crushed rock dust as a partial replacement of cement, Materials Today: Proceedings, Volume 5, Issue 2, Part 2,2018, Pages 7240-7246, ISSN 2214–7853.

