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Research Paper

Influence of Recycled Aggregate on Shear Behavior of Steel Fibrous SCC

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A B S T R A C T

Of all the different kinds of failures in concrete, shear failure is a sudden and brittle and occurs abruptly without any prior warning. To avoid these types of failures in concrete, beams are traditionally reinforced with stirrups at closer spacing based on design. An experimental study was carried out to study the shear behavior of steel fiber reinforced self-compacting concrete (SCC) beams with recycled concrete aggregate (RCA) as a complete replacement of both natural coarse and fine aggregate. The experimental program consists of 24 beams of which 12 beams were cast with natural aggregate and remaining 12 beams were cast using recycled aggregates as a complete replacement of natural aggregates. Due to the use of recycled concrete aggregates as coarse and fine aggregates, the compressive strength reduced by 7.8% and 8% for 30 and 70 MPa Concrete. The ultimate shear strength reduced by 14% and 12% due to use of recycled concrete aggregates for SCC30 and SCC70 beams respectively. The investigation indicates that the ultimate load and ultimate shear strength decreases as the spacing of stirrups increased. It was observed from the experimental results that addition of steel fibers enhanced the mechanical properties of both natural aggregate based self-compacting concrete (NASCC) and recycled aggregate based self-compacting concrete (RASCC). Also due to the addition of steel fibers the performance of SCC beams has improved. The shear strength obtained experimentally was compared with the existing models in the literature and the correlation was found to be satisfactory

1 Introduction

Sustainability is the need of the hour in construction industry. The nature of the construction industry is not environmentally friendly and the need for sustainable methods in construction is very crucial to ensure that natural materials are not depleted for future needs [1, 2]. Globally every year, more than 26.8 billion tons of normal concrete is used, which creates a very huge amount of construction and demolition waste [3]. The use of natural aggregate has increased drastically over the past few years in the construction industry. Due to depletion of natural resource such as lime stone and natural aggregates, there is an urgent requirement of replacing the main ingredients in concrete like cement and

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natural aggregates with locally available waste byproducts like mineral admixtures (fly ash, GGBS, silica fume) as substitute to cement and recycled concrete aggregates to natural coarse and fine aggregates. The use of mineral admixtures as partial replacement to cement is a well-established fact that its helps in improving the strength and durability performance of concrete and it is used by many researchers and by construction organizations. Although, the use of recycled concrete aggregate is well recognized as a sustainable material that can replace the natural coarse aggregates and offers solutions to this problem, but it is still considered as inferior to natural aggregate in terms of its structural properties [4, 5].Recycled concrete aggregates are prepared from crushed unwanted concretes and can be used as a replacement of natural aggregates in concrete production. In spite of having lesser density and greater absorption than natural aggregates, they can be used to produce concrete with good performance if they are added in the appropriate amounts. As we know that self-compacting concrete is a new generation high performance concrete which can fill into every corner of the form work without any segregation or bleeding. The preparations of SCC requires large amounts of binder content and relatively lesser amounts of coarse aggregates. The large quantities of binder content can be achieved by using mineral admixture like fly ash and silica fume which will not only satisfy the requirement of SCC and also supports in achieving required strength and durability. By replacing the natural aggregates with recycled concrete aggregates in SCC a sustainable and durable concrete can be achieved i.e. recycled aggregate based self-compacting concrete(RASCC). From the literature, it is established that due to the usage of recycled aggregate as a replacement of natural aggregates can result in decline of mechanical properties due to the existence of additional Interfacial Transition Zone (ITZ), which is the fragile link in the concrete where failure arises. Addition of steel fiber can overcome this deficiency and also increase the post cracking behavior of SCC with recycled aggregate concrete (RCA). Steel fiber reinforced concrete (SFRC) is a composite material that is characterized by enhanced post-cracking behavior due to the capacity of fibers to bridge the crack faces [6]. Addition of steel fibers in concrete improves the tensile strength before and after cracking and provides better crack control ability [7]. Self-compacting concrete is a highly flowable concrete, which can fill every corner of form work without any external vibration effort. Steel fiber reinforced self-compacting concrete (SFRSCC) combines the benefits of SCC in the fresh state by avoiding cracking and shows an improved performance in the hardened state compared to conventional concrete [8]. Although use of recycled concrete aggregate in place of natural aggregate has now received considerable attention as a sustainable method, its uses are still limited.

Recycled concrete aggregates are obtained by crushing waste concrete and then, the coarse fraction of crushed aggregates can be used to replace natural coarse aggregates and the remaining finer fraction can be used as fine aggregates in the concrete production process.

Several researches studied the effect of recycled aggregates on mechanical, durability and structural properties by replacing up to about 50% of natural aggregates. In the present study, natural aggregates are completely replaced with recycled concrete aggregates and the mechanical properties and shear behavior of self-compacting concrete are studied by incorporating steel fibers. The recycled aggregates are presoaked in water for 30 minutes before concreting was done, so that the recycled aggregates may not absorb excess water during mixing process of concrete. The parameters varied in the present study, are grade of concrete i.e. M30, M70 and spacing of stirrups. A total of 24 beams were cast and tested under four point loading out of which 12 beams are fibrous beams and remaining are non-fibrous.

The main objective of this study is to investigate the shear behavior of recycled aggregate based steel fiber reinforced self-compacting concrete (RASFRSCC) for different stirrup spacing for both lower and higher grade concrete and also to study the hybrid effect of steel fibers and stirrups on the mechanical behavior of beams, and to analyze the influence of Steel Fibers (SFs) on the failure mode and shear strength of RASFRSCC beams.

1.1 Research Significance:

Concrete is considered as brittle material with a very low tensile strength and shear capacity. The shear failure in reinforced concrete is sudden and brittle which occurs without any notice. The addition of steel fibers to concrete mix enhances the ductility and toughness and thus increases the shear capacity. Steel fibers help to bridge the cracks and reduce the crack propagation. This eliminates the possibility of sudden failure in concrete and also increases the shear strength. However, it is difficult to accurately predict the increase in shear strength as the interaction between steel fibers and the concrete mix is complex. The development of an accurate model for predicting the shear strength of SFRSCC is needed to enable designers to use this for building applications where shear becomes dominant. The work available in the literature for predicting the shear behavior of SCC/SFRSCC is scant and the available models in the literature on vibrated concretes needs to be checked for SCC based on experimental work.

Use of recycled aggregates as replacement up to 50% of natural coarse and fine aggregates has been widely used by many researches in the past few years. In the present study, an attempt is made to study the behavior of steel fiber reinforced self-compacting concrete under shear by using 100% recycled concrete aggregates as coarse and fine aggregates. The experimental results are compared with various models available in the literature on vibrated concrete using natural aggregates.

2 Materials Used

- **Cement:** Cement used in the present study was 53 Grade Ordinary Portland cement confirming to IS: 12269-2013 [9]. The specific gravity of cement was 3.14, initial and final setting time is 45 min and 560 min respectively.
- **Fly Ash:** The fly ash used in the experiments was obtained from Ramagundam thermal power station (NTPC) and sieved by 90 micron sieve and confirmed to IS 3812-1981[10]. The specific gravity was 2.2 and specific surface area of 335 m2/g.
- **Fine Aggregate (FA):** The fine aggregate used in the present study was conforming to Zone- 2 according to IS: 383-2002 [11]. It was obtained from a nearby river source. The specific gravity was 2.42, while the bulk density is 1450 kg/m3 and fineness modulus is 2.84.
- **Coarse Aggregate (CA):** Crushed granite was used as coarse aggregate. Coarse aggregates of 20 mm nominal size was obtained from a local crushing unit, which was well graded aggregate, according to IS: 383-2002 [11]. The specific gravity is 2.8, while the bulk density is 1500 kg/m3. Fineness modulus of coarse aggregates is 7.8.
- **Recycled Coarse Aggregate (RCA):** The RCA used in this study was obtained by crushing old specimens of concrete cubes, reinforced beams and slabs available in concrete laboratory of the National institute of technology Warangal. Before using the aggregates, they were washed to remove any unwanted substances, and presoaked for 30 minutes and then they were air-dried. The source of the RCA is 100% concrete. The Properties are given in table below.
- **Recycled Fine Aggregate (RFA):** The finer fraction obtained after crushing of concrete cubes and can be used as fine aggregates in the concrete. The aggregates were washed with water to remove any unwanted substances, and presoaked for 30 minutes and then they were air-dried and brought to saturated surface dry condition and used.

Table 1: Material properties of ingredients used for SCC

Ingredient	Property	
Cement	Specific gravity	3.14
	Normal consistency	29.5%
Fly Ash	Specific gravity	2.2
	Fineness	335 m^2/kg
	Reactive Silica (SiO2)	62.94%
Coarse Aggregate (CA)	Specific gravity	2.8
	Bulk Density	1500 kg/m^3
	Fineness Modulus	7.8
Fine Aggregate (FA)	Specific gravity	2.42
	Bulk Density	1450 kg/m^3
	Fineness Modulus	2.84

Table 2: Physical Properties of Recycled Coarse Aggregates

Properties	
Bulk density(Kg/m^3)	1257
Percentage voids	48.35
Void ratio	0.92
Specific gravity	2.53
Fineness Modulus	7.15
Water absorption (%)	6.8

Table 3: Physical Properties of Recycled Fine Aggregates

Properties	
Bulk density(Kg/m^3)	1308
Specific gravity	2.16
Fineness Modulus	3.40
Water absorption (%)	8.4

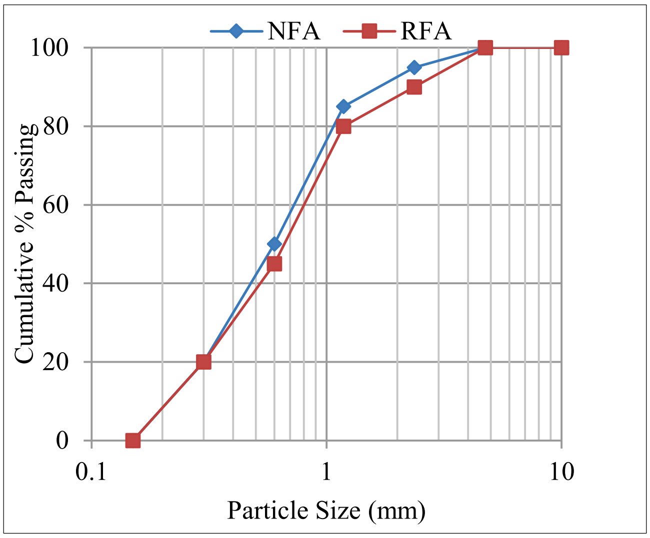

Figure 1 (a)- Particle size distribution of Natural and Recycled Fine Aggregate

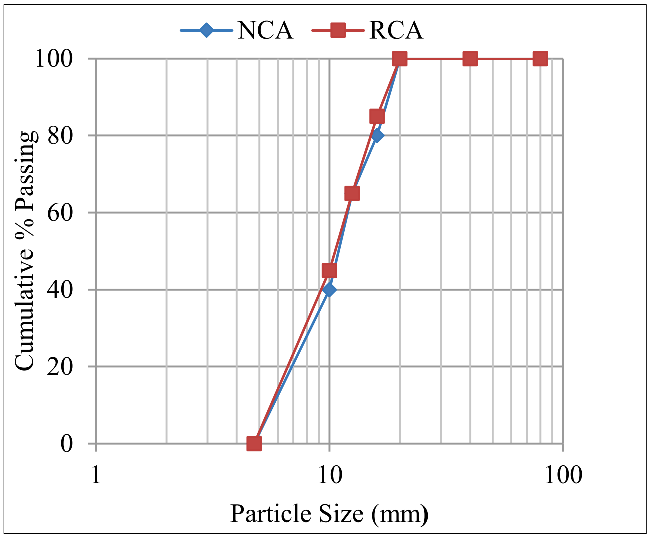

Figure 1 (b)- Particle size distribution of Natural and Recycled Coarse Aggregate

- **Water:** Potable water was used in the experimental work for both mixing and curing of specimens.
- **Silica Fume:** It is an amorphous (non-crystalline) polymorph of silicon dioxide and ultrafine powder, according to IS 5388-2003 [12] with an average particle diameter of 150 nm was used in the present study. The specific gravity of silica fume is generally in the range of 2.2 and specific surface area of silica fume ranges from 15,000 to 30,000 m2/ kg.
- **Superplasticizer (SP):** In the present study poly carboxylate ether based high range water reducing admixture confirming to ASTM C494 [13] obtained from Chyrso Chemicals, India commonly called as super plasticizers was used. Major advantage of using super plasticizer is to improve the flowing ability of high performances concretes at lower water-cement ratios.

- **Steel fiber [ASTM A820-2001 [14]]:** Crimped Steel fiber (from Apex Encon Projects Pvt Ltd., New Delhi, India) with nominal diameter of the fiber 0.5mm and cut length 30mm with aspect ratio of 60 were used. The Tensile strength and modulus of elasticity of the fiber is 850 MPa and 2.1x105 MPa respectively.
- **Tension reinforcement:** TMT bars of 12 mmand16 mm diameter of grade Fe 500 confirming to IS: 1786-2008 [15] whose yield strength was 500 N/mm2 and length 1160mm were used as tension reinforcement and 6mm Ø mild steel bars whose yield strength was 290 N/mm2 was used as stirrups (shear reinforcement) and also for top compression reinforcement.

3 Experimental Program

In the present study, a total of 24 shear deficient beams were designed and cast for two grades of SCC via. M30 and M70. The dimensions of the beam was fixed as 100x200x1200mm with a clear span of 1100mm. All beams were tested under Four-point loading. For compressive strength, standard cube mounds of 150mm x 150mm x 150mm made of cast iron were used. For split tensile strength, standard cylinder mounds of 150 mm φ x 300mm made of cast iron were used. For flexural strength 100 x 100 x 500 mm of standard prism mounds were used. In the present study, dosage of steel fibers is take as 0.5% by volume of concrete. From the literature, it was found that optimal dosage of steel fibers for self-compacting concrete as 0.5% per cubic meter of concrete based on fresh and hardened properties [16]. Table: 4 shows the details of beams with different a/d ratio, spacing of stirrups and percentage of steel fiber per volume of concrete. SCC30-0 beam indicates self-compacting concrete of 30 MPa concrete and without stirrups. SFRSCC30-0 indicates steel fiber reinforced self-compacting concrete of 30 MPa concrete and without stirrups. Similarly SCC30-180 indicates self-compacting concrete of 30 MPa concrete and with stirrups provided at 180 mm spacing and SFRSCC30-180 indicates steel fiber reinforced self-compacting concrete of 30 MPa concrete with steel fibers and with stirrups spaced 180 mm. The designation is same for higher concretes also, the only difference is grade of concrete instead of SCC30, SCC70 is used for 70 MPa concrete similar to 30 for 30 MPa concrete. The designation is similar for other 12 beams were recycled aggregate is used instead of natural aggregates.

Table: 4 Details of beams cast

Beam Designation	Stirrups Spacing, mm	Fiber Content Kg/m^3
SCC30-NS	No stirrups (Plain Beam)	0
SCC30-360	360 (4 Stirrups)	0
SCC30-180	180 (6 Stirrups)	0
SFRSCC30-NS	No stirrups (Fibrous Beam)	38
SFRSCC30-360	360 (4 Stirrups)	38
SFRSCC30-180	180 (6 Stirrups)	38
SCC70-NS	No stirrups (Plain Beam)	0
SCC70-360	360 (4 Stirrups)	0
SCC70-180	180 (6 Stirrups)	0
SFRSCC70-NS	No stirrups (Fibrous Beam)	38
SFRSCC70-360	360 (4 Stirrups)	38
SFRSCC70-180	180 (6 Stirrups)	38

The above beams were cast using natural aggregates, similarly 12 beams were cast using recycled aggregates as fine and coarse aggregates.

3.1 Mix Proportions:

Self-Compacting Concrete (SCC) mix was designed using the rational mix design method [17].The details of mix proportions are presented in Tables 5 and 6. Trial mixes were carried out by varying super Plasticizer dosage and binder content and the fresh properties were evaluated as per EFNARC Specifications [18] via, Slump flow, T50, V-Funnel, T5, J ring test and L-box.

Table 5: Mix proportions of 30 MPa and 70 MPa grade NASCC

Mix	Cement (kg/m^3)	Fly ash (kg/m^3)	Silica fume (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	Water (kg/m^3)	W/b	SP (kg/m^3)
30 MPa	350	324	0	746	945	203	0.30	5.73
70 MPa	600	226	48	780	874	247	0.28	6.03

Table 6: Mix proportions of 30MPa and 70MPa grade RASCC

Mix	Cement (kg/m^3)	Fly ash (kg/m^3)	Silica fume (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	Water (kg/m^3)	W/b	SP (kg/m^3)
30 MPa	350	324	0	665	782	203	0.30	5.73
70 MPa	600	226	48	695	724	247	0.28	6.03

3.2 Fresh Properties of M30 & M70 grade SCC without and with steel fibers:

The details of Fresh Properties for M30 and M70 grades SCC without and with steel fiber were shown in Table 7. It can be seen from Table 7 that, addition of steel fibers has reduced the flow properties but satisfied EFNARC specifications. Figure 2 shows the various tests conducted on workability of SCC. Due to the addition of steel fibers to SCC mix affected the fresh properties but are within the EFNARC specifications. This decreases in the fresh properties is due to the large surface area of fibers, which requires a higher volume of fluid paste or mortar to be properly surround and lubricate, and the significant inter-particle friction and interlocking among the fibers as well as between the fibers and aggregates.

Table 7: Fresh properties of 30MPa and 70MPa grade SCC without and with fiber

Grade of Concrete	NASCC30		RASCC30		NASCC70		RASCC70		EFNARC 2005	
Dosage of Fibers	0%	0.5%	0%	0.5%	0%	0.5%	0%	0.5%	Min.	Max.
Slump Test, mm	750	640	730	620	720	680	720	680	550	800
T50 Slump flow, sec	3	5	3	5	2.5	4	3	4	2	5
V funnel, sec	6	6.5	6	7.3	10.5	11	10	12	6	12
V funnel @ T_5 min,	7.5	8.3	7	9.2	6.2	14	8	14	6	15
J-ring, sec	3	8	3	8	3	7	2	7	0	10
L- Box, mm	0.93	1	0.96	1	0.96	0.98	0.97	0.98	0.8	1

(a) Slump flow (b) J-ring (c) V-funnel (d) L-box

Figure 2- some tests on workability of SCC

3.3 Reinforcement Details:

The dimensions and typical reinforcement details for both mixes of SCC 30 MPa and 70 MP are shown in Figures 3 and 4. The stirrups spacing was varied in the shear span. Two stirrup spacing are considered. For 30 MPa SCC beams consist of 2-12mm Ø TMT bars as longitudinal reinforcement and 2-6mm Ø mild steel bars as compression reinforcement. Similarly, 70 MPa SCC beams consist of 2-16 mm and 1-12mm Ø bars as longitudinal reinforcement, 2-6mmØ mild steel bars as compression reinforcement and two legged 6mm Ø bars was used as stirrups.

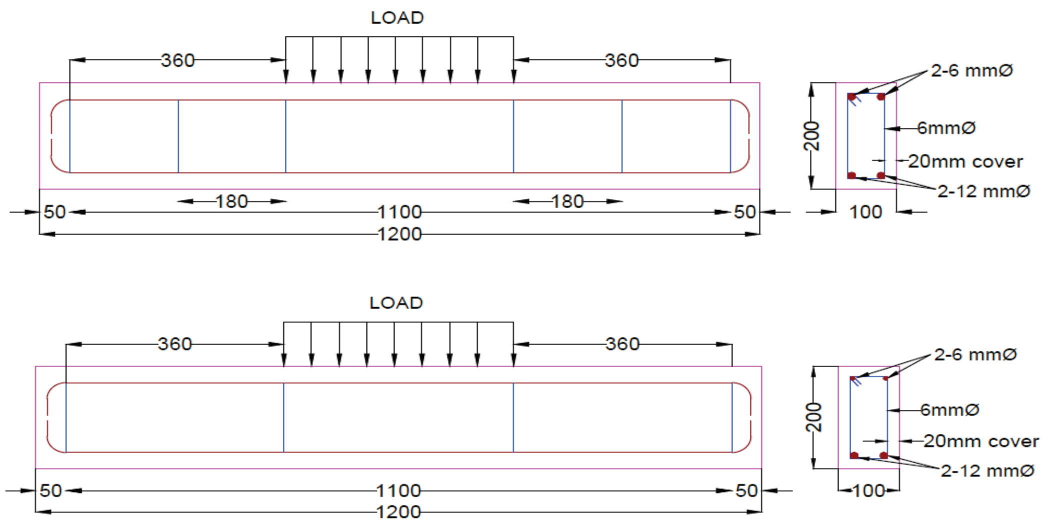

Figure: 3 Details of reinforcement for 30MPa mix with a/d=2

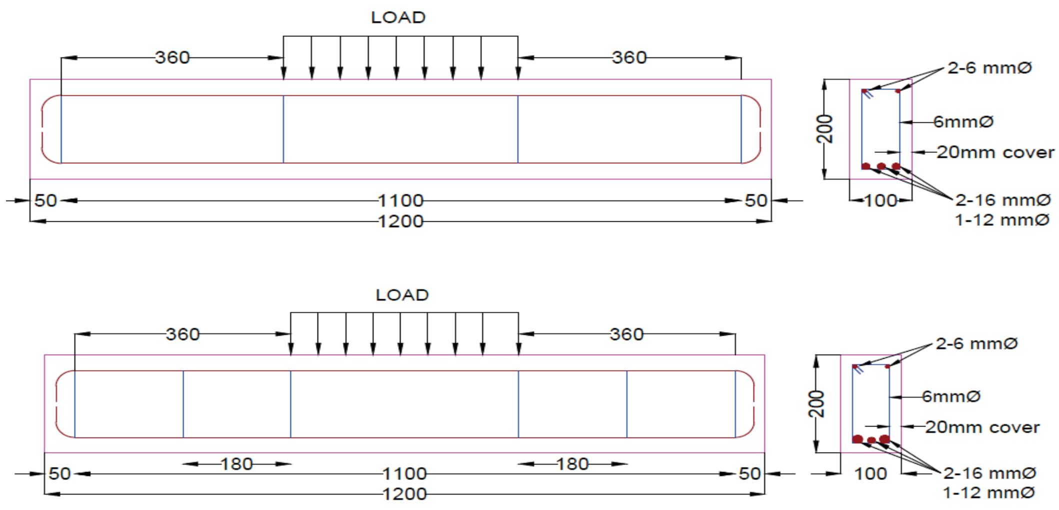

Figure: 4 Details of reinforcement for 70 MPa mix with a/d=2

3.4 Hardened properties of Self compacting concrete without and with steel fiber

The details of hardened properties of 30 MPa and 70 MPa of NASCC and RASCC without and with steel fiber at the age of 28 days are shown in Tables 8 and 9. All the tests were done as per IS: 516-2004 [19] specifications. Due to use of recycled aggregates, the compressive strength of was decreased by 8.68% and 7.9% and in presence of steel fibers, the compressive strength is of is reduced by 7.9% and 7.2% for 30 MPa and 70 MPa concrete when compared with NASCC. Whereas Split tensile strength is reduced by 10.7% and 6.12% and in the presence of steel fibers it is 4.5% and 7.8% respectively for 30 MPa and 70 MPa concrete when compared with NASCC. Similarly, in case of flexural strength is decreased by 8.2% and 3.4% and in the presence of fibers 7.26% and 8.15%. The variation of compressive, split tensile strength and flexural strength are shown in figures 5(a), 5(b) and 5(c)

Table 8: Hardened properties of 30 and 70 MPa of NASCC at 28 days

	30 MPa			70 MPa		
Dosage of steel fibers (%)	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural Strength (MPa)	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural Strength (MPa)
0	39.67	3.67	3.98	78.25	7.06	6.09
0.5	41.65	4.34	4.87	83.35	7.85	7.41

Table 9: Hardened properties of 30 and 70 MPa of RASCC at 28 days

	30 MPa			70 MPa		
Dosage of steel fibers (%)	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural Strength (MPa)	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural Strength (MPa)
0	36.5	3.46	3.68	72.99	6.13	5.89
0.5	38.32	3.92	4.54	78.86	6.63	6.84

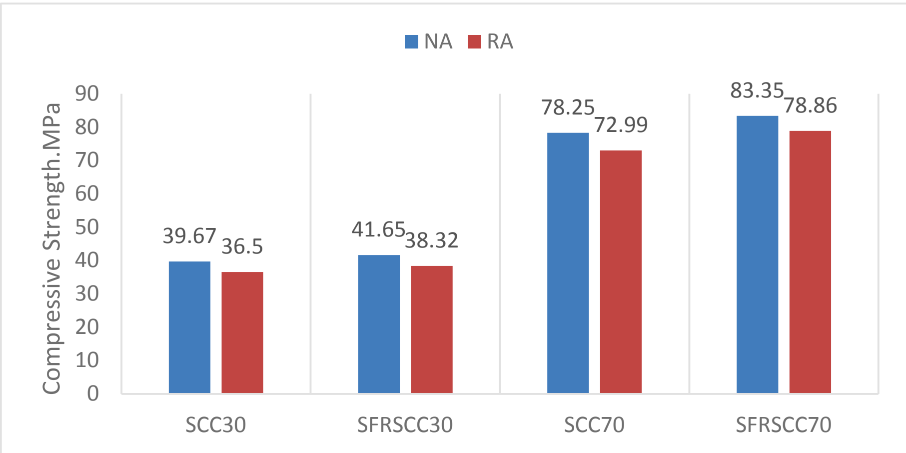

Figure 5(a)- Compressive strength vs Type of concrete (NASCC and RASCC)

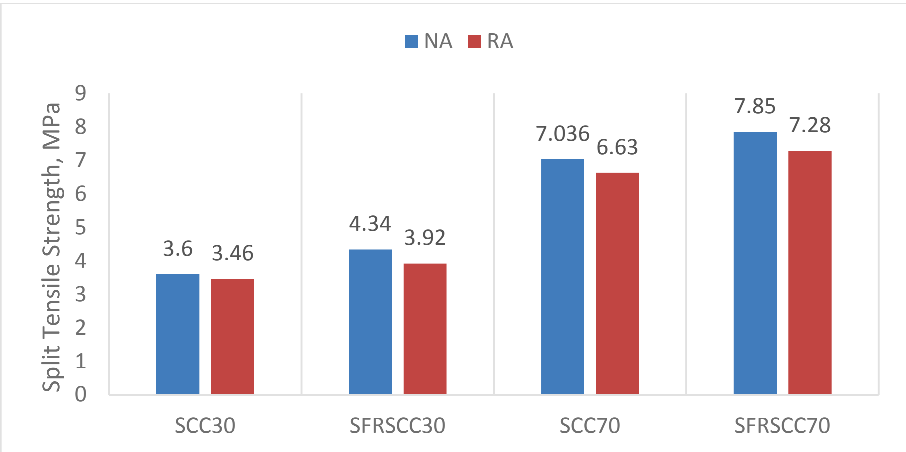

Figure: 5(b)- Split tensile strength vs Type of concrete (NASCC and RASCC)

Figure 5(c)- Flexural strength vs Type of concrete (NASCC and RASCC)

4 Results and Discussion:

At the end of the required curing period, the beams were tested on four point loading under 1000kN Dynamic testing machine. From the recorded data, the load vs deflection graphs were plotted and ultimate shear strength is calculated. The area under load vs deflection curves (Toughness) for 30 MPa and 70 MPa SCC without and with steel fibers was also evaluated.

Tables 10 and 11 shows the ultimate load and shear strength of fibrous and non-fibrous NASCC and RASCC beams for different spacing of stirrups.

Table 10: Ultimate load and shear strength of fibrous and non-fibrous NASCC beams

Designation	Ultimate Load kN	Ultimate Shear Strength (vu) (MPa)	Deflection (mm)	Toughness (kN-mm)
		NASCC30		
SCC30-NS	62.28	1.73	3.74	112.42
SCC30-360	86.77	2.41	4.12	182.2
SCC30-180	95.67	2.66	4.18	234.27
SFRSCC30-NS	77.32	2.14	5.18	152.03
SFRSCC30-360	102.35	2.84	5.21	328
SFRSCC30-180	117.92	3.28	6.90	464.1
		NASCC70		
SCC70-NS	88.43	2.45	3.58	228.50
SCC70-360	109.7	3.04	3.54	212.2
SCC70-180	115.7	3.21	4.92	365.7
SFRSCC70-NS	91.8	2.55	4.08	440.70
SFRSCC70-360	138.83	3.86	5.40	483.46
SFRSCC70-180	159.75	4.44	5.90	525.03

NS indicates No stirrups (plain beam)*

Table 11: Ultimate load and shear strength of fibrous and non-fibrous RASCC beams

Designation	Ultimate Load kN	Ultimate Shear Strength (vu) (MPa)	Deflection (mm)	Toughness (kN-mm)
		RASCC30		
SCC30-NS	54.68	1.52	2.99	186.9
SCC30-360	66.57	1.69	4.84	325.22
SCC30-180	83.36	1.85	5.98	473.18
SFRSCC30-NS	60.99	2.12	5.29	446.48
SFRSCC30-360	70.64	1.96	5.33	424.32
SFRSCC30-180	91.41	2.54	6.93	651.83
		RASCC70		
SCC70-NS	72.33	2.20	4.87	156.63
SCC70-360	82.16	2.28	4.41	454.17
SCC70-180	86.15	2.39	3.54	494.71
SFRSCC70-NS	79.60	2.21	4.43	179.11
SFRSCC70-360	119.18	3.31	5.7	667.94
SFRSCC70-180	142.01	3.94	7.67	1168.74

NS* indicates No stirrups (plain beam)

4.1 4.1 Load Vs Deflection Curves:

Addition of steel fibers in SCC not only helps in crack arresting mechanism but also improves the ultimate load carrying capacity by delaying the crack propagation from the experimental results following points are observed:

1. NASCC30-NS beam i.e. Self-Compacting concrete beam with no stirrups has shown lower load capacity and brittle failure pattern compared to that of NASFRSCC30-NS beam. Due to addition of steel fibers, the ultimate shear strength has increased by 23%.
2. Recycled concrete aggregates beams RASCC30-NS has shown both lower load carrying capacity and brittle failure compared to fibrous beam RASFRSCC30-0. In the presence of steel fibers, the ultimate shear strength increased by 12%.
3. NASCC30-NS has shown better shear resisting properties compared to RASCC30-NS beams. Due to use of recycled concrete aggregates, the ultimate shear resistance got reduced by 14%, where as in the presence of fibers shear strength enhanced by 11.9%.
4. In case of high strength concretes i.e. NASCC70-NS beam with no stirrups and fibers has shown higher shear strength compared to that of RASCC70-NS, due to use of recycled concrete aggregates. The ultimate shear strength got reduced by 18.2% for plain beam and for fibrous beams shear strength got enhanced by 8.22%.
5. Due to combined effect of stirrups and steel fibers, the ultimate shear strength of NASFRSCC30-180 beam has increased by 89% compared to that of plain beam without fibers (NASCC30-NS).
6. Similarly, in case of recycled aggregates beams due to the combined effect of stirrups and steel fibers, the ultimate shear strength of RASFRSCC30-180 increased by 67.2% compared to that of plain beam without fibers (RASCC30-NS).
7. In the case of higher strength concrete beams NASFRSCC70-180 beam, the ultimate shear strength got increased by 80% due to the combination of stirrups and steel fibers compared to that of plain beam without fibers and stirrups (NASCC70-NS).

8. In case of recycled aggregate beams with higher strength concrete due to the combined effect of stirrups and steel fibers, the ultimate shear strength of RASFRSCC70-180 has increased by 96.3 % compared to that of plain beam without fibers (RASCC70-NS).
9. Addition of steel fibers, not only improved the shear strength, but also there is an increase in toughness of the NASCC and RASCC beams.
10. As the spacing of stirrups decreased from 360 mm to 180 mm, there is an increase in shear strength.

From the above observations, it can be concluded that the addition of steel fibers has greatly enhanced the shear strength and the ultimate load carrying capacity of NASCC and RASCC specimens. Figures 6 and 7 shows the comparison of load deflection curves among NASCC and RASCC beams of 30 MPa concrete, and Figures 8 and 9 shows the comparison of load deflection curves among NASCC and RASCC beams of 70 MPa concrete for both fibrous and non-fibrous beams. From the load vs deflection curves the following points can be observed.

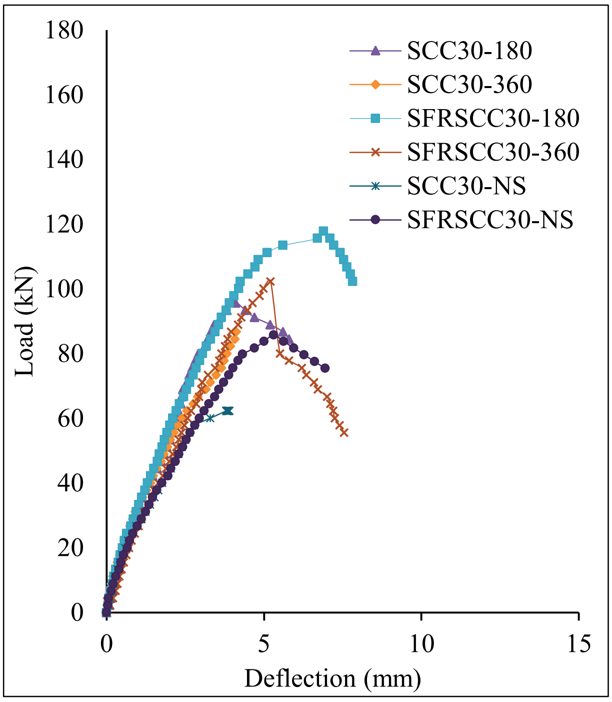

Figure 6: Load vs Deflection for NASCC30

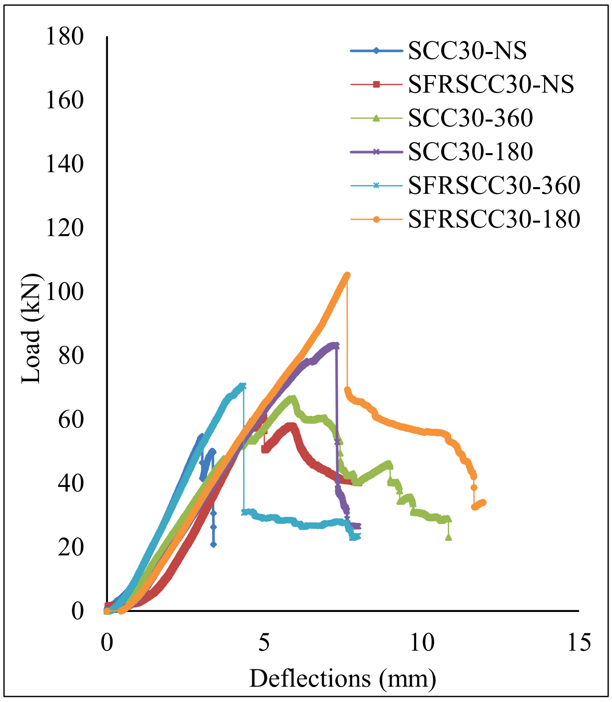

Figure 7: Load vs Deflection for RASCC30

4.2 Effect of Recycled aggregate on Shear Strength of Steel fiber reinforced Self-Compacting Concrete:

Figure 10 show a comparison of shear strength between NASCC30 & RASCC30 specimens. Similarly, Figure 11 shows the comparison of shear strength of NASCC70 & RASCC70 for both fibrous and Non-fibrous beams. The experimental results showed clearly that using recycled concrete aggregate's (RCA) the shear capacity decreased compared to beams cast with natural aggregates. The ultimate shear strength is reduced by 14% due to use of recycled concrete aggregates for SCC30 beams. Whereas, due to addition of steel fibers, the shear strength reduced by 10%. Similar behavior was observed in case of higher strength concrete beams i.e. SCC70.In the presence of stirrups the ultimate shear strength of RASCC beams is decreased by 13.15% and 4.36% for 30 MPa and 70 MPa concrete. Due to combination of stirrups and steel fibers, the ultimate shear strength is reduced by 10.36% and 11.26% for 30 MPa and 70 MPa concrete.

4.3 Effect of Spacing of Stirrups on Shear behavior of SFRSCC Beams

Effect of stirrup is one of the governing factor that effect the shear strength of reinforced concrete beams, from the experimental results it is observed that, with decrease in the spacing of stirrup, ultimate shear strength is increased. The ultimate shear strength of NASCC30 beams was increased by 10.3% without fibers and in the presence of steel fibers it has increased by 15.5% with decrease in the spacing of stirrups from 360 to 180 mm. In case of high strength concrete, the ultimate shear strength increased by 5.3% without fibers and by 15.06% in the presence of steel fibers. Similarly, In case of recycled aggregates for 30 MPa concrete as the spacing of stirrups decreased from 360 mm to 180 mm, the ultimate shear strength is increased by 25.2% without fibers and in the presence of steel fibers shear strength is increased by 29.4% for 30 MPa concrete. In case of 70 MPa concrete, ultimate shear strength increased by 4.85% and 19.2% for non-fibrous and fibrous concretes respectively. Figures 12 and 13 shows the variation of shear strength for different spacing of stirrup for both NASCC and RASCC beams. The combination of stirrups and steels fiber has shown positive hybrid effect on shear behavior of steel fiber reinforced beams and it is true for both 30 and 70 MPa concretes. Similar behavior was observed in case of recycled aggregate based concrete.

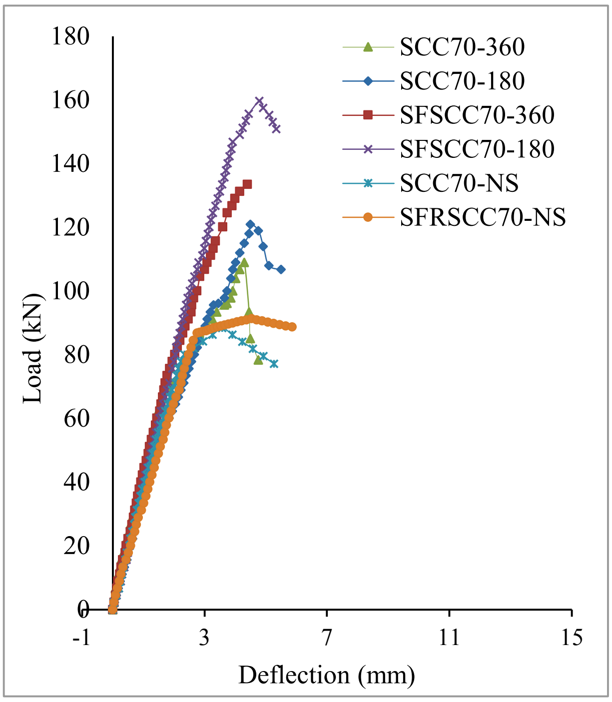

Figure 8: Load vs Deflection for NASCC70

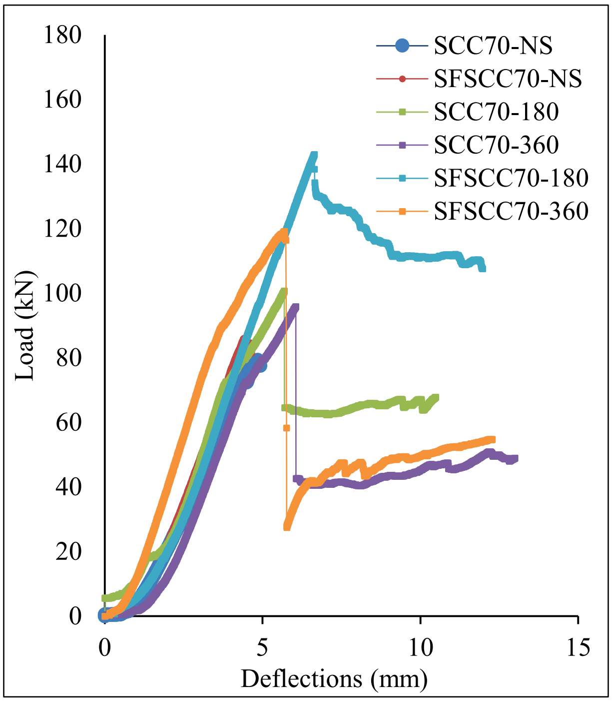

Figure 9: Load vs Deflection for RASCC70

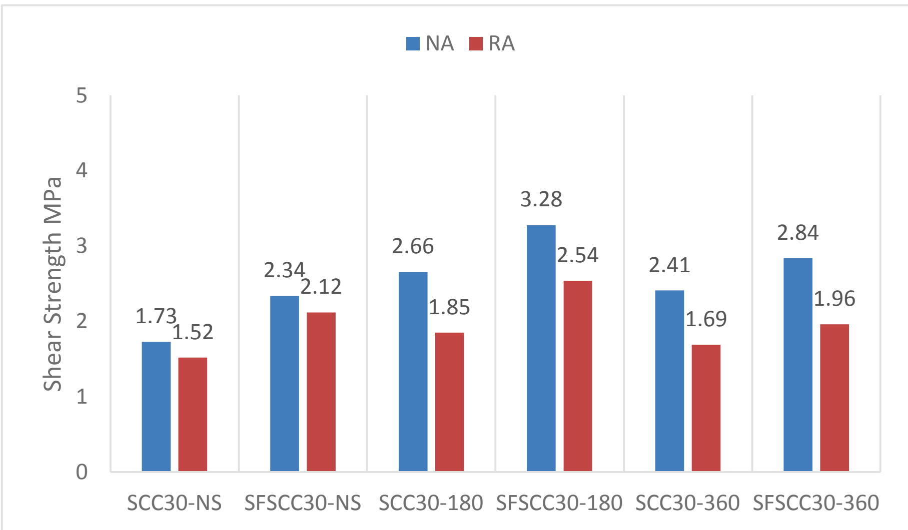

Figure 10: Comparison of Shear Strength for NASCC30 and RASCC30

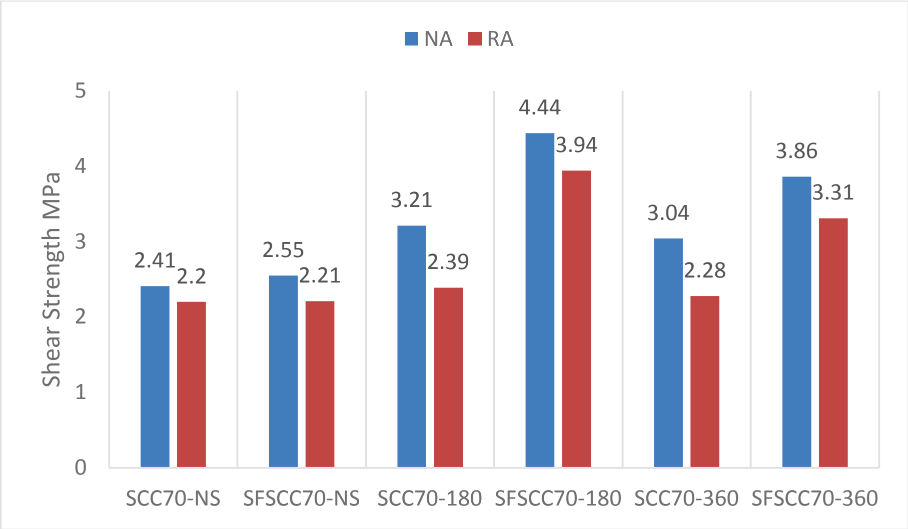

Figure 11: Comparison of Shear Strength for NASCC70 and RASCC70

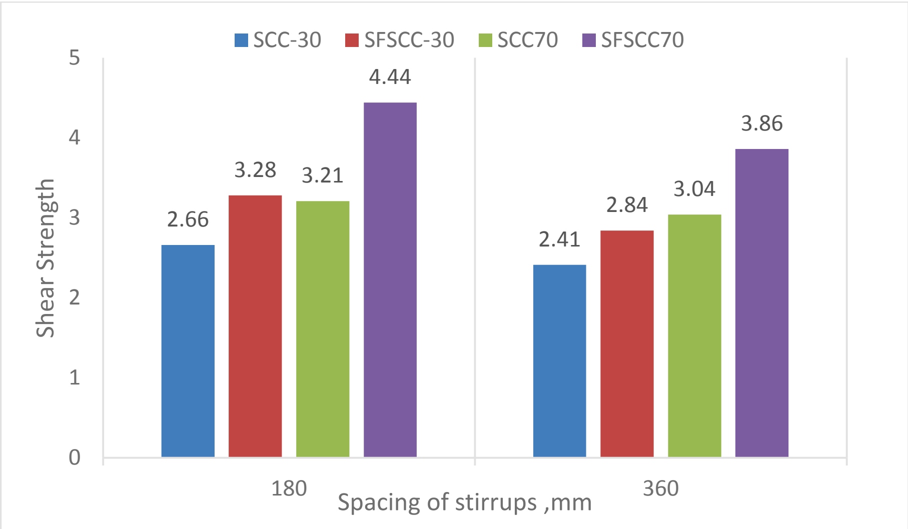

Figure 12: Shear Strength vs Spacing of Stirrups for NASCC Beams

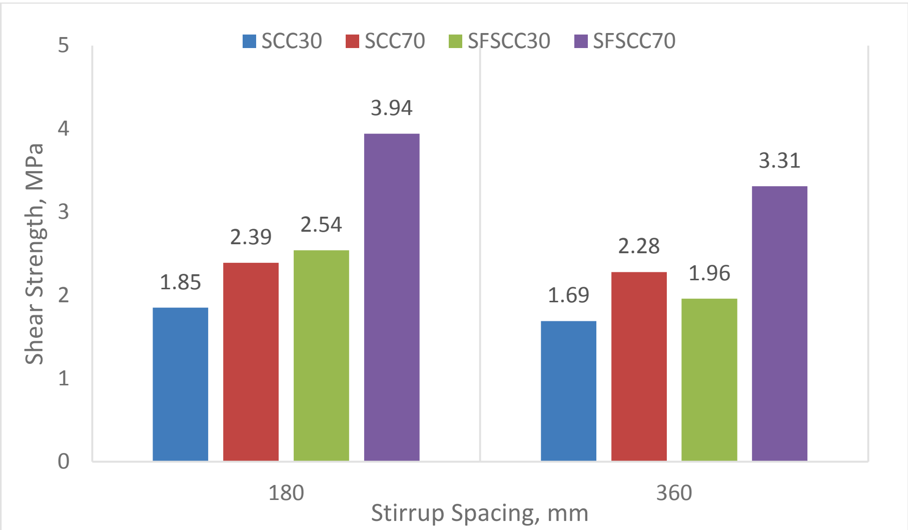

Figure 13: Shear Strength vs Spacing of Stirrups for RASCC Beams

5 Comparison of test results with models from Literature.

The experimental results obtained for ultimate shear strength of non- fibrous SCC and fibrous SCC beams are compared with shear strength models available for vibrated concrete and a comparison was made. The comparison for non-fibrous SCC is given in Table 12 and fibrous SCC in Table 13

5.1 Non-Fibrous SCC

a) Russo G and Somma G [20]

After a detailed investigation on 116 High strength concrete (HSC) beams with stirrups as shear reinforcement Russo et al, 2004 has proposed an model to calculate the average shear strength (V_{uc}).The parameters varied in the investigation were concrete compressive strength (fc), shear span to depth ratio a/d, and stirrup ratio. For beams without shear reinforcement, the shear stress is due to arch and beam action.

$$V_{uc} = V_a + V_b \tag{1}$$

$$V_{uc} = \xi[0.97\rho_s^{0.46}\sqrt{f_c^{,}} + 0.2\rho_s^{0.91} f_c^{'0.38} f_{y1}^{0.96} \left(a/d\right)^{-2.33}] \tag{2}$$

where,

$$\xi = 1/\sqrt{1 + d/\left(25d_a\right)} \tag{3}$$

$$\rho_s = \frac{A_s}{bd} \tag{4}$$

Where $v_a and v_b$ are the shear stresses due to the arch and beam actions respectively. ξ is the factor for taking into account size effect, d is the effective depth of the beam, d_a is the maximum size of coarse aggregate. f'_cIs the compressive strength of the circular cylinder. ρ_s is the longitudinal reinforcement ratio. f_{y1} is the yielding strength of the longitudinal reinforcement. a/d is the shear span-to-depth ratio. A third term must be added to equation (1) when stirrups are present.

$$V_u = V_{uc} + V_s \tag{5}$$

$$V_s = 1.75 I_b \rho_{st} f_{yst} \tag{6}$$

where,

$$I_b = \frac{0.97\rho_s^{0.46} f_c^{'1/2}}{0.97\rho_s^{0.46} f_c^{'1/2} + 0.2\rho_s^{0.91} f_c^{'0.38} f_{y1}^{0.96} (a/d)^{-2.33}} \tag{7}$$

$$\rho_s = \frac{A_s}{bd} \tag{8}$$

Where V_s is the shear stress due to the stirrups, $I_b$is the index of beam action, f_{yst} is the yielding strength of the stirrup, and ρ_{st} is the stirrup ratio evaluated with reference to the spacing s.

b) Chinese Code for Design of Concrete Structure, [24]

After detailed investigation on Beams with different grades of concrete and Stirrups ratio, an equation was proposed for vibrated concrete to calculate the shear strength.

$$V_u = \frac{1.75}{1+\lambda} f_t bd + f_{yst}\frac{A_{st}}{s} d \tag{9}$$

$$v_u = \frac{V_u}{bd} \tag{10}$$

Where V_u, is the shear load of the RC member, f_t is the tensile strength of the prism, $\lambda$is the shear span-to-depth ratio and v_u is the shear strength of the RC member and s is spacing

c) ACI 318 code, [25]

ACI committee 318 after a detailed investigation on beams with different grades of concrete, different yield strength and Stirrups ratio has given an equation to calculate shear strength for vibrated concrete.

$$v_u = \frac{1}{7}\left[\sqrt{f_c'} + 120\rho_s\left(\frac{d}{a}\right)\right] + \rho_{st} f_{yst} \tag{11}$$

Where v_u is the shear strength, f'_c is the average compressive strength of concrete, ρ_s is the longitudinal reinforcement ratio. f_{yst} is the yielding strength of the longitudinal reinforcement and a/d is the shear span-to-depth ratio.

5.2 Fibrous SCC

a) Narayanan and Darwish, [6]

Using steel fibers as shear reinforcement, Narayanan and Darwish has proposed a formula for shear stress due to fiber (v_f).The parameters varied in their investigation were volume fraction (F) of the fibers, fiber aspect ratio (l/d), concrete compressive strength f_{cu}, amount of longitudinal reinforcement(ρ_{st}), and the shear span/effective depth ratio a/d.

$$v_f = 0.41\tau F \tag{12}$$

Were $F = (\frac{l_f}{d_f})\ V_f k_f$, V_f is shear stress due to steel fibers, τ is the average fibre matrix interfacial bond stress, and τ=4.15MPa. F is the fibre factor. $(\frac{l_f}{d_f})$ is the fibre aspect ratio. k_f is the bond factor that accounts for differing bond characteristics of the fiber, it is assigned a relative value of 0.5 for round fibers, 0.75 for crimped fibers, and 1.0 for indented fibers. In the present case the value of $k_f = 0.75$ as crimped fibers were used in the study.

b) Ta'an and Feel [21]

A Model was proposed to predict the ultimate shear strength of fiber-reinforced concrete rectangular beams. A total of 89 beams were tested, all the beams have failed in shear. The factors influencing the shear strength of fiber concrete beams were found to be the shear span-to-depth ratio, main reinforcement volume, dimensions, and type.

$$v_f = \frac{8.5}{9} k V_f \frac{l_f}{d_f} \tag{13}$$

Where k is a factor reflecting the fiber shape. For crimped fibers, k = 0.75,V_f is the fibre volume fraction and $(\frac{l_f}{d_f})$ is the fibre aspect ratio.

c) Swamy RN and Jones R [22]

To assess the effectiveness of steel fibers used as shear reinforcement in lightweight concrete beams, a truss model to predict the ultimate shear strength was proposed

$$v_f = 0.37\tau V_f \left(\frac{l_f}{d_f}\right) \tag{14}$$

Where $\tau$is equal to 4.15 MPa as suggested by Narayanan and Darwish and V_f is the fibre volume fraction. $(\frac{l_f}{d_f})$ is the fibre aspect ratio.

d) Lim and Oh, 1999 [23]

An analytical model to predict shear strength of fiber reinforced concrete was proposed by Lim and Oh, 1999. A total of nine beams were cast by varying volume fraction of steel fibers and the ratio of stirrups to the required shear reinforcement.

$$v_f = 0.5\tau V_f \frac{l_f}{d_f} \cot\alpha \tag{15}$$

Where α is the inclination between the longitudinal reinforcement and the shear crack, and is equal to 45°and $\tau$is equal to 4.15 MPa as suggested by Narayanan and Darwish and V_f is the fibre volume fraction.

e) Chinese Guidelines for FRC [24]

After detailed investigation on Beams with different grades of concrete and Stirrups ratio Chinese code [CECS, 2004] has proposed an equation for fiber reinforced concrete.

$$V_{uf} = \frac{1.75}{1+\lambda} f_t bd\left(1+\beta_v \lambda_f\right) + f_{yst}\frac{A_{st}}{s}d \tag{16}$$

$$v_{uf} = \frac{V_{uf}}{bd} \tag{17}$$

Where V_{uf} is the shear load of the fiber reinforced RC member, and $\beta_v$is the influence coefficient it is taken as 0.75 for crimped fibre of the steel fibers, λ_f is fiber factor equals to $V_f(\frac{l_f}{d_f})$ and v_{uf} is shear strength of fiber reinforced RC member.

A comparison is made between experimental results and with those predicted by using these models and these results are presented in Tables 12 and 13 for NASCC and NASFRSCC beams.

Table 12 Shear strength of NASCC beams without steel fibers.

Type	Russo et al. Vu MPa	Chinese code Vu MPa	ACI code 318-14 Vu MPa	Experimental Vu MPa
SCC30-NS	1.64	2.32	1.92	1.73
SCC30-360	1.97	2.78	2.01	3.04
SCC30-180	2.30	3.23	2.47	2.66
SCC70-NS	3.85	3.12	2.42	2.45
SCC70-360	4.12	3.57	2.38	2.60
SCC70-180	4.40	4.03	2.84	3.21

Table 13 Shear strength of steel fiber reinforced NASCC beams.

Type	Narayanan and Darwish Vuf MPa	Ta'an and Feel Vuf MPa	Swamy et al Vuf MPa	Lim and Oh Vuf MPa	Experimental Vuf MPa	Chinese code for FRC Vuf MPa
SFRSCC30-NS	2.56	2.15	2.75	3.14	2.14	3.58
SFRSCC30-360	2.89	2.48	3.08	3.47	2.84	4.03
SFRSCC30-180	3.22	2.81	3.40	3.79	3.28	4.49
SFRSCC70-NS	4.77	4.36	4.96	5.34	2.55	4.80
SFRSCC70-360	5.04	4.63	5.23	5.62	3.86	5.25
SFRSCC70-180	5.32	4.91	5.50	5.89	4.44	5.71

From the comparison, it was noted that the experimental results are close to Russo et al. model for plain (NASCC) beams and Narayanan and Darwish model is close for fibrous beams (NASFRSCC). The variation of experimental and predicted shear strength are shown in figures 14 and 15.

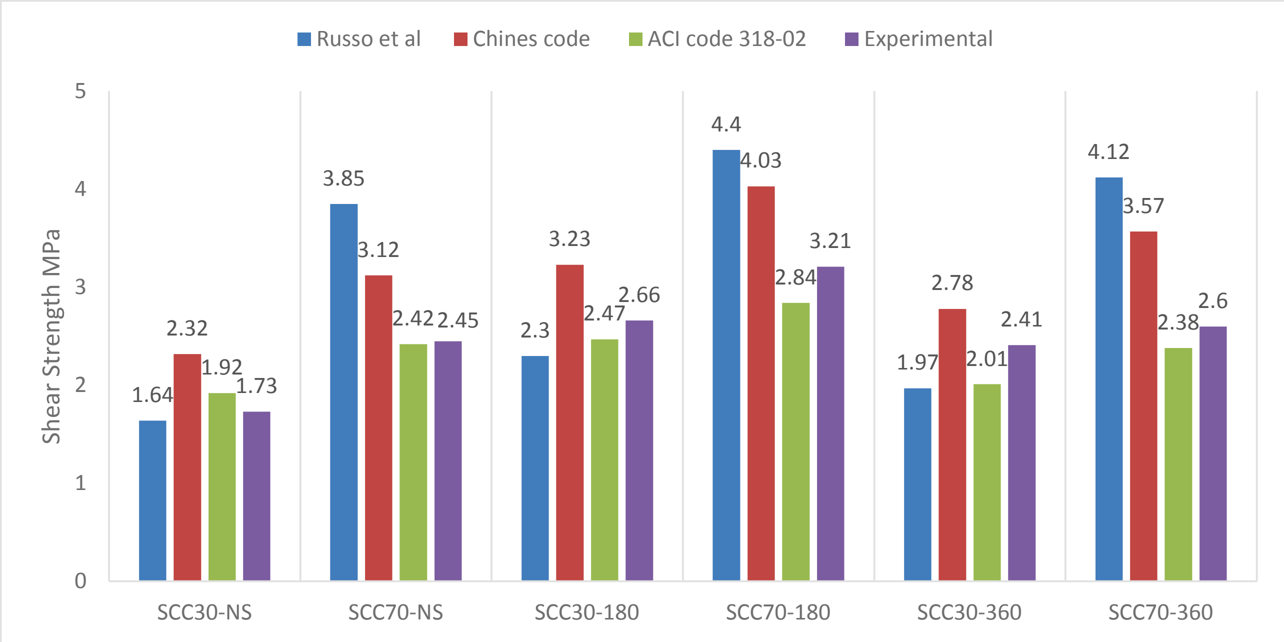

Figure 14: Predicted Shear strength vs Experimental for NASCC beams

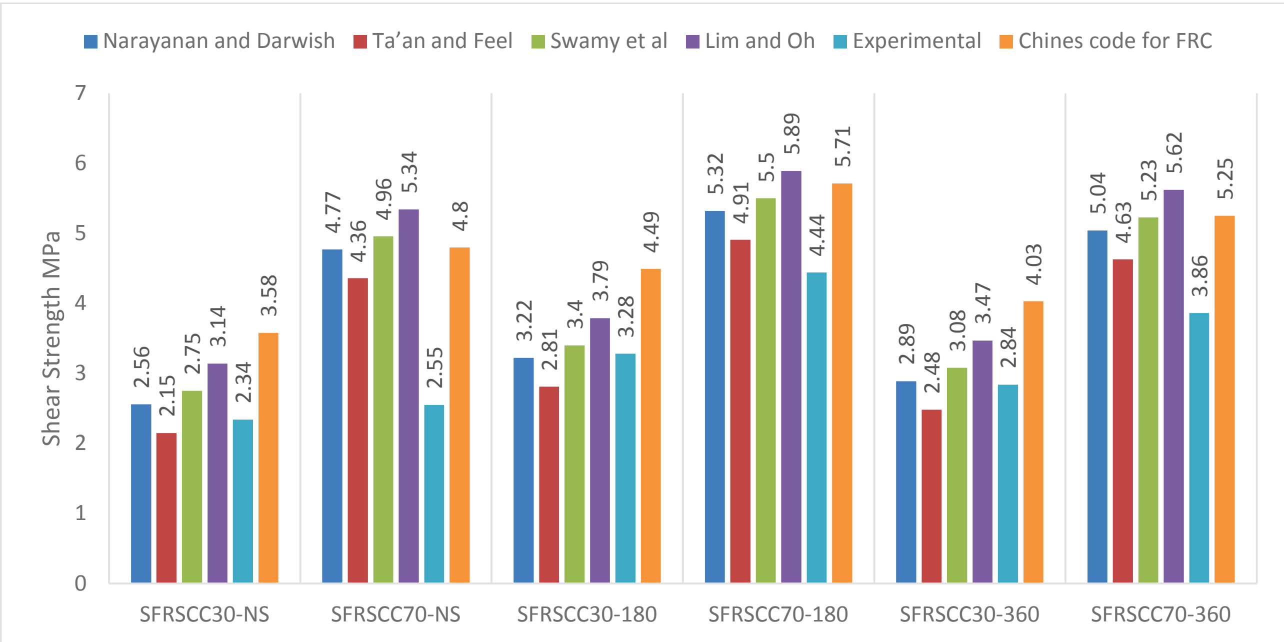

Figure 15: Predicted Shear strength vs Experimental for NASFRSCC beams

Similar comparison of experimental and predicted shear strength of RASCC beams with above models was done and those values are presented in Tables 14 and 15. Figure 16 and 17 shows the variation of predicted shear strength and experimental shear strength for RASCC and RASFRSCC beams. From the comparison is noticed that Russo et al. model for plain RASCC beams and Narayana and Darwish model for RAFRSCC are nearer to experimental results.

Table 14 Shear strength of RASCC beams without steel fibers.

Type	Russo et al. Vu MPa	Chinese code Vu MPa	ACI code 318-14 Vu MPa	Experimental Vu MPa
SCC30-NS	1.49	2.02	1.85	1.52
SCC30-360	1.82	2.78	1.46	2.41
SCC30-180	2.14	3.23	1.92	2.66
SCC70-NS	3.54	2.41	2.29	2.20
SCC70-360	3.81	3.57	1.96	2.6
SCC70-180	4.08	4.03	2.42	3.21

Table 15 Shear strength of steel fiber reinforced RASCC beams.

Type	Narayanan and Darwish Vuf MPa	Ta'an and Feel Vuf MPa	Swamy et al Vuf MPa	Lim and Oh Vuf MPa	Experimental Vuf MPa	Chinese code for FRC Vuf MPa
SFRSCC30-NS	2.41	1.89	2.60	2.99	2.12	3.11
SFRSCC30-360	2.73	2.48	3.08	3.47	2.84	4.03
SFRSCC30-180	3.06	2.81	3.40	3.79	3.28	4.49
SFRSCC70-NS	4.46	3.96	4.65	5.04	2.29	3.71
SFRSCC70-360	4.73	4.63	5.23	5.62	3.86	5.25
SFRSCC70-180	5.00	4.91	5.50	5.89	4.44	5.71

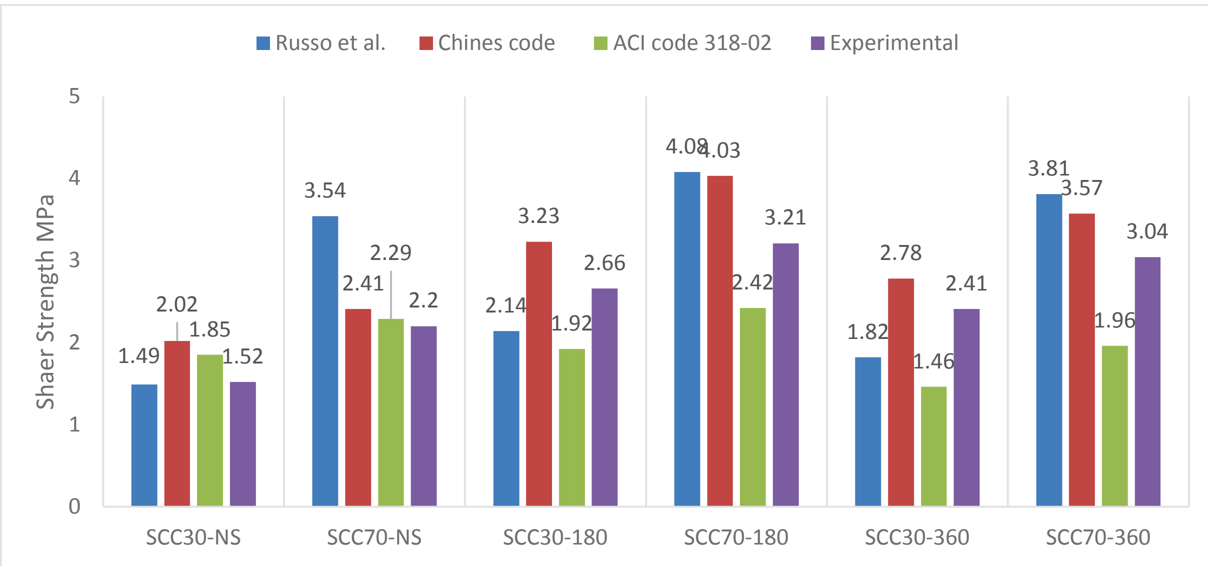

Figure 16: Predicted Shear strength vs Experimental for RASCC beams

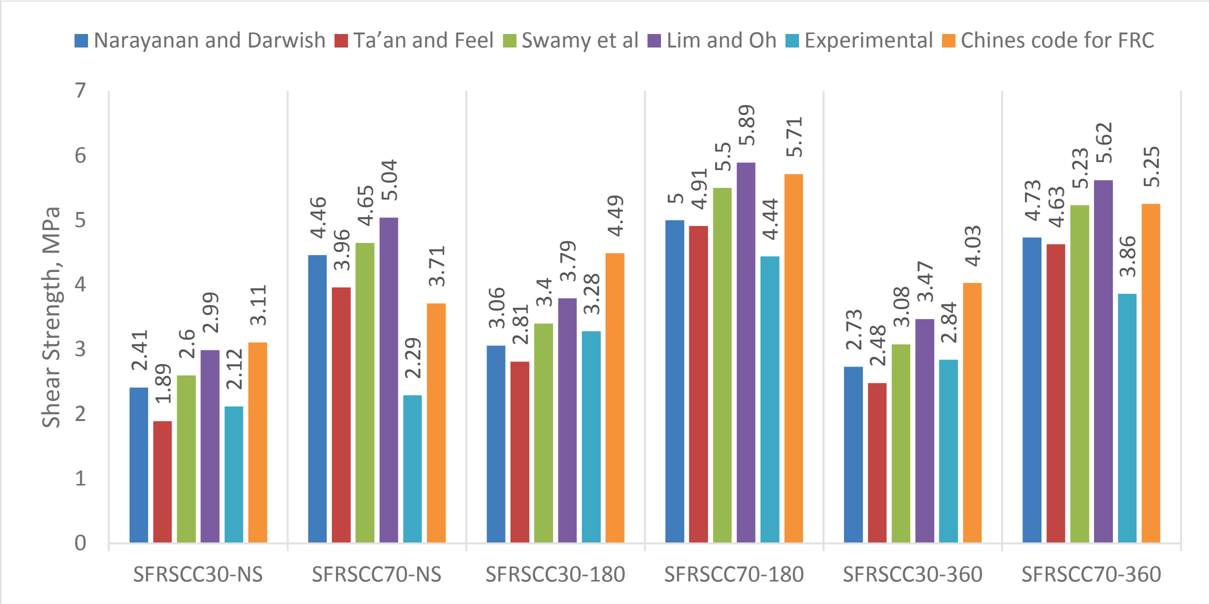

Figure 17: Predicted Shear strength vs Experimental for RASFRSCC beams

6 Details of Tested Beams and Crack Pattern

A total of 24 beams were cast and tested, of which 12 beams are of natural aggregates and remaining 12 are of recycled aggregates for both fibrous and non-fibrous beams. Figures 18&19 shows the failure pattern of NASCC30 and NASFRSCC30 beams.

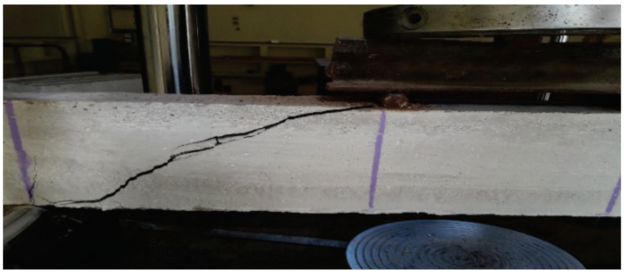

Figure 18 Failure pattern of NASCC30

Figure 19 Failure pattern of NASFRSCC30

Similarly, Figures 20 and 21 show the failure pattern of NASCC70 and SFRSCC70. It was noticed that non-fibrous beams failed suddenly with a brittle failure, where as in case of fibrous SCC, the mode of failure was more ductile.

Figure 20 Failure pattern of NASCC70

Figure 21 Failure pattern of NASFRSCC70

Figures 22 & 23 shows the failure pattern of RASCC30 and RASFRSCC30 beams , it was observed that addition of steel fibers has delayed the failure of the specimens and also increased the ultimate load carrying capacity.

Figure 22 Failure pattern of RASCC30

Figure 23 Failure pattern of RASFRSCC30

Figures 24 & 25 shows the failure pattern of RASCC70 and RASFRSCC70 beams. It was observed that RASCC beams failed suddenly after first crack occurred whereas the failure mode in case of RASFRSCC beams was more ductile due to the addition of steel fibers.

Figure 24 Failure pattern of RASCC70

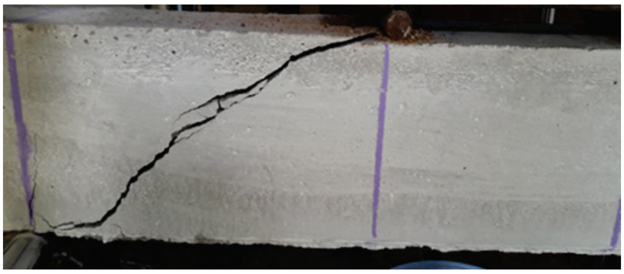

Figure 25 Failure pattern of RASFRSCC70

7 Conclusions

Based on the experimental study the following conclusions have been drawn: Addition of fiber has modified the failure pattern from brittle shear failure to a ductile flexural-shear failure. There is also an increase in the ultimate shear strength. This shows that steel fibers plays a very important role before and after cracking. This behavior is true for in NASCC and RASCC beams. Due to the use of recycled concrete aggregate as replacemnt of both coarse and fine aggregaets, the compressive is strength decreased by 8.68% and 8.9% for 30 MPa and 70 MPa concretes. The ultimate shear strength reduced by 14% due to use of recycled concrete aggregates in SCC30 beams where as due to addition of steel fibers, the shear strength was enchanced by 4%. Similar type of behaviour was obsedved for higher concrete beams also i.e SCC70 . As the spacing of strirrups was incresed from 180mm to 360mm, ultimate shear strength reduced by 9.5% for SCC30 beams, this effect was eliminated by addition of steel fibers. Due to addition of steel fibers the confiment of SCC has increased due to which the spacing of the stirrups could be increased. This was true with both NASCC and RASCC. The experimental results obtained were corelated with the various models available in the literature on vibrated concrete and it was noticed that the ultimate shear strength predicted by Russo etal model for plain SCC beams and Narayana and Darwish model for SFRSCC compared well with the experimental results.

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