The Influence of the Addition of Fibers on Properties of Self-Compacting Concrete Produced with Recycled Coarse Aggregate

Pagidipalli Siddu Hussain, Kode Venkata Ramesh, Malasani Potharaju

Abstract: *All over the world, wide amount of demolishing waste is being generated posing lot of environmental issues. To address these issues, Self-Compacting Concrete (SCC) was made by replacing cement partially with mineral admixtures and NCA with RCA. The fresh and hardened properties for M30 grade of SCC made with NCA and RCA were evaluated. Cement in SCC was recouped partly with 30% Fly Ash, 20% GGBS by weight of the cement. Polypropylene fibers at 0.1% were added to study their influencing nature on the hardened state and fresh state properties of the SCC mix. Four sequences of SCC mixes of M30 were prepared by substituting the NCA with RCA at 25%, 50%, 75% and 100% derived from the dismantled concrete waste of M30 parent grade. SCC produced with the RCA up to 50% and with 0.1% addition of Fibers demonstrated comparable performance as that of SCC with NCA.*

Keywords: *Fresh State Properties, Self-Compacting Concrete; Fly Ash; GGBS; Polypropylene Fibers; Normal Aggregate; Recycled Coarse Aggregate.*

I. INTRODUCTION

The SCC flows beneath its own weight beyond any compaction even in obstructed reinforcement. It has also got distinct preference such as tremendous overall performance in each fresh properties and hardened state properties with excessive segregation resistance and flowability, low porosity, environment pleasant due to excessive intake of industrial waste products and advanced operating environment by means of decreased roaring and health threats. They found that SCC can be developed by adopting Recycled concrete, scoria aggregate and crumbed rubber by accompanying investigation on workability and mechanical properties with differed forms of SCC of Grade M25 developed by promoting RCA in merging with lightweight scoria aggregates and recycled crumb rubber by accompanying investigation on Hardened, workability properties of SCC of grade M20 developed by RCA in merging with light scoria aggregates and crumb rubber in the mix [1].

Examined the facets regarding SCC composed with Recycled Fine Aggregate (RFA) and Recycled Coarse Aggregate (RCA), and Comprising with NCA.

The outcomes designated that the breakdown came along with the usage of RCA which in-flip reduced the qualities of SCC. By Incorporating, Silica Fume with 10% and curtailing the water to binder ratio advanced the hardened properties of SCC [2]. Studied the effect of RCA from precast structural elements on the overall behaviour of SCC consisting of RCA in percentage by exchange with 20%, 50%, and 100%. The assessments effects of Split Tensile Strength (STS), Compressive Strength (CS), Flexural Strength (FS), in extension to Water Absorption, Ultrasonic pulse velocity (UPV), Density (ρ), stiffness, and porosity, every dynamic and static modulii are near the ones of the SCC with NCA [3]. Investigated the fresh state and rheological state equities for SCC proving RCA as both Coarse and fine aggregates. The Consequences screen that Bulkley and Herschel models affords the actual rheological depictions for SCC by using RCA [4]. Reviewed the equities of SCC composed with RCA. They stated that the qualities of the concrete gain alone a mild difference for RCA can efficaciously use by accomplishing the SCC [5]. They have reported that SCC mixtures incorporate both Steel and Poly-Propylene fibers offer the maximal strengths [6]. The usage of 50% RFA and RCA in SCC exhibited better enforcement and durability. The embodiment connected with 15% and 20% usage of Pozzolana in NSCC and RSCC reduced the depth of penetration by 50% of chloride ions and additionally diminishes the weight loss when specimens immersed beneath sulfuric acid attack [7].

The simultaneous of natural Pozzolana and RCA production depreciate cost environmentally-safe SCC. The strength and flowability peculiarities of SCC with substitution of supplementary material like fly ash with desperate percent restoration in heights on RCA with NCA was studied by Kumar Satish et.al [8]. The different flowability tests revealed that the High Range Water Reducing admixture (HRWR) implement solidity to the mix by curtailing bleeding and segregation.

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The minimum decrease in strength was organize by replacing RCA by 20% to the NCA. The Flexural Strength (FS), Split Tensile Strength (STS), Compressive Strength (CS), and shear strength of SCC reduction with the growth in the amount of replacing RCA. SCC significantly accomplish appropriate Compressive Strength up to 30% alternative of RCA [9].

The objective of this present paper is to exercise the consequence of the addition of fibers on the qualities of SCC produced with RCA.

II. MATERIALS AND THEIR PROPERTIES

A. Cement

The Cement appropriated in this study is Ordinary Portland Cement (OPC). The properties of OPC were obtained experimentally [10]. The properties were presented in Table (1).

Table 1. Physical Properties of Cement

S.NO	Characteristics	Values Achieved	Values according to IS Code
1	Initial Setting Time	80	30 minutes
2	Standard Consistency	32%	23% (Min)
3	Fineness of Cement	7	<10% residue on 90µ Sieve
4	Final Setting Time	360	600 minutes
5	Specific Gravity of Cement	3.14	3.15
6	Soundness of Cement	3mm	10mm
7	Compressive Strength (CS) [MPa]		
	28 Days	55.8	53

B. Fine Aggregate (F.A)

The Fine Aggregate used in this study was river sand which was passing through 4.75mm sieve confirming to Zone II of IS code [11]. The physical qualities of the fine aggregate were conferred in Table (2).

C. Coarse Aggregate (C.A)

The Natural Coarse Aggregates (NCA) used in this study was angular and of size, 12.5mm confirming to IS code [11]. The RCA was selected in this application was derived from the concrete specimens cast in the laboratory of grade M30. The physical qualities of both NCA & RCA are granted in Table (2).

Table 2. Physical properties of F.A and C.A

Aggregates		Tests			
		Specific Gravity	Water Absorption (%)	Bulk Density (Kg/m^3)	Fineness Modulus
F.A		2.73	0.78	1567	3.15
C.A	NCA	2.72	0.45	1569	7.36
	RCA	2.38	2.71	1356	5.96

D. Fly Ash (FA)

Fly Ash appropriated in this investigation was brought from NTPC, Parwada in the district of Visakhapatnam and it possess a specific gravity of 2.31 confirming to IS code [12]. The chemical properties were presented in Table (3).

Table 3. Fly Ash Chemical Properties

S.NO	Parameter	Test Results	Requirement according to IS:3812 (part-I):2003
1	$SiO_2 + Al_2O_3 + Fe_2O_3$	94.0	70 (min)
2	Silica as SiO_2	58.8	35 (min)
3	Magnesium as MgO	0.20	05 (max)
4	Sulphate as SO_3	0.27	03 (max)
5	Alkali as Na_2O	0.24	1.5 (max)
6	Loss on Ignition	3.00	50 (max)
7	Lime Reactivity	3.50	4.5 (max)

E. Ground Granulated Blast Furnace Slag (GGBS):

The GGBS appropriated in this study is acquired from Vizag steel plant. It possess a specific gravity 2.917 and confirms to BS: 6699:1992 [13]. The physical and chemical properties of GGBS were presented in Table (4).

Table 4. Physical & Chemical qualities for GGBS

S.NO	Parameter	Test results obtained	Requirement according to BS:6699:1992
1	Fineness (m^3/Kg)	345	275(Min)
2	Soundness (mm)	1.00	10 (Max)
3	Initial Setting Time (min)	160	> of OPC
4	Specific gravity	2.917	> 2.5
5	Mg content (% Mass)	8.92	14 Max
6	SO32^{-} content (% Mass)	0.7	2.5 Max
7	S^{2-} (% of Mass)	0.8	2 Max
8	Mn (% of Mass)	0.6	2 Max
9	Sulphide Sulphur (%Mass)	0.80	2 Max
10	Compressive Strength (N/mm^2)		
	i) 28 Days	47.0	32.5 Min
11	Chemical moduli		
i) CaO/ SiO_2		0.96	≤ 1
ii) $(MgO + CaO)/SiO_2$		1.34	≥ 1
iii) $CaO + SiO_2 + MgO$		78	67

F. Polypropylene Fibers:

The fibers appropriated in this study was Recron 3S of 12mm in length brought from Sri Krishna Teja Trading Corporation in Visakhapatnam.

G. Water:

The water adapted in this study was potable water which is free from salts, Alkalis, and oils.

H. Super Plasticizer:

The superplasticizer used was Armix Hyyecrete PC20. It has a specific gravity of 1.10 and confirms to IS code [14]. The properties are presented in Table (5).

Table 5. Results for MYK Armix Hyyecrete PC20

Parameters	Results obtained	Requirements as per IS 9103-1999
Relative Density at 27^{0}C	1.06	Within 0.02 of the value fixed by the manufacturer
pH at 27^{0}C	6.17	Min 6.0
Dry material	23.69%	0.95T≤DMC<1.05T
Chlorides Content	0.001%	Within ±10% of mfg. value or 0.2% whichever is greater
Ash Content	2.40%	0.95T≤AC<1.05T

III. METHODOLOGY

The present M30-grade concrete mix (1:1.57:1.33:0.28) was intended for SCC with NCA by adopting a water-to-powder ratio of 0.8 in accordance with EFNARC requirements. In place of OPC, a mix of 30% Fly Ash and 20% GGBS was replaced. To achieve the optimum replacement, four series of SCC mixes were introduced with 25%, 50%, 75%, and 100% substitutes of NCA with RCA. In order to improve the performance, 12 mm long polypropylene fibers at 0.1 percent were also added to the gravity of the cement.

The different amounts of SCC mix components were provided in Table (6). Cubes of size 150mm × 150mm× 150mm, Cylinders of size 150mm×300mm and Beams of size 100mm×100mm×500mm were casted to evaluate the Compressive Strength, Split Tensile Strength and Flexural Strength respectively.

The studied were conducted on the specimens as per Indian Standard Code [15]. To compare with the conventional concrete, all hardened and fresh properties of SCC developed with the use of RCA were studied.

Table 6. Quantities of Additives used in SCC

Mix Type	Cement [kg/m³] 50%	C.A [kg/m³]		F.A [kg/m³]	GGBS [kg/m³] [20%]	FA [30%] [kg/m³]	Water [lit]	W/P
		RCA	NCA					
RCA0	291	0	778	916	117	175	166	0.8
RCA25	291	194	583	916	117	175	166	0.8
RCA50	291	389	389	916	117	175	166	0.8
RCA75	291	583	194	916	117	175	166	0.8
RCA100	291	778	0	916	117	175	166	0.8

Table 7. Fresh state properties of SCC using RCA 30 by with and without fiber

Mix Designation	Slump Flow (mm)		T_{500} Slump Flow (sec)		V- Funnel (sec)		L- Box (H2/H1)	
	With Fibers	Without Fibers	With Fibers	Without Fibers	With Fibers	Without Fibers	With Fibers	Without Fibers
RCA0	575	580	3.5	4	10.6	12	0.92	0.96
RCA25	570	579	3.2	3	8.7	11	0.83	1.0
RCA50	572	584	4	5	11.4	13.3	0.89	0.89
RCA75	568	572	6	5.4	14.3	16.2	0.94	0.94
RCA100	542	552	7	5.6	14	16.7	0.98	0.98

The results obtained for sf and T500 slump are tabulated in Table 7. The T500 time, SF test and used to classify the viscosity and flowability of an SCC. The SF test indicates the flowability of concrete. All four series of SCC with fiber exhibited slump flow of SF1 class. The least slump exhibited by the fiber reinforced SCC with 100 % RCA was 542 mm. The Eurocode states that SCC ought to acquire the SF value at intervals 550mm and 850mm, while T500 instances much less two seconds bring about VS1 type, while T500 times more or equal to 2sec brings about a VS2 type. The L-box and slump flow tests of SCC mixes are displayed in fig.1 & 6 and the test outcomes of SCC using RCA with and without fiber are illustrated in table 7. The results are compared for SCC by replacing RCA by with fiber and without fiber respectively.

IV. RESULTS AND DISCUSSIONS:

The workability of SCC was described by Passing Ability (PA), Filling Ability (FA), and Flowing Ability. The three assessments are utilized to inspect the feasibility of SCC. They are measured by performing the L-box test, slump flow test (SF), and V-funnel test (VF).

A. Flowability:

SF and T_{500} tests are performed by Abrams cone and Graff's distribution tests. In the SF test, the final diameter of the spread concrete was measured and T_{500} is measured by recording the time required for the concrete to attain the 500mm spread circle which was expressed in (Fig 1).

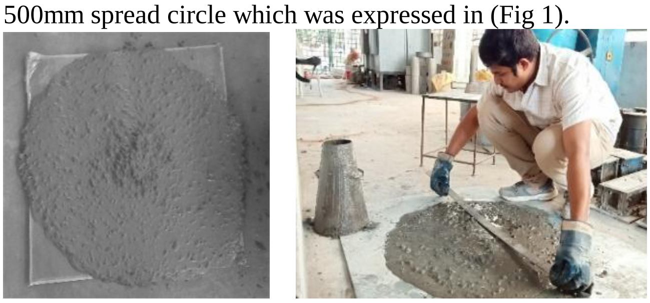

Fig: 1 Slump Flow and T_{500} test

Fig 2 shows the plot between the RCA substitution and slump flow for SCC with and without fiber. The SF values slightly curtailed with the escalation of RCA. The 0.1% addition of fibre to SCC has got very little influence on the SF with the decrease being 0.86%, 1.57%, 2.09%, 0.7%, and 1.84% respectively at 0%, 25%,50%,75%, and 100 % substitution of RCA. Though all four series of SCC exhibited a slight reduction in SF values, all of them maintained the same class i.e. SF1 as that of SCC without RCA.

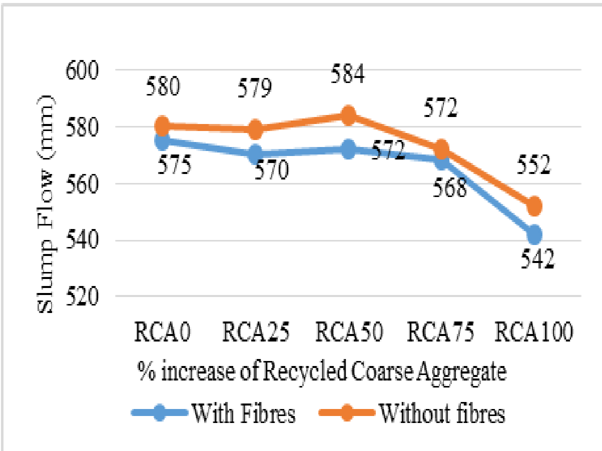

Fig: 2 Slump Flow Variation with the RCA percentage

B. Viscosity:

The VF test (Fig 3) is utilized to measure the viscosity of concrete. V - Funnel time is a measure of viscosity. The VF time is the time arrested by the concrete to flow over the VF under gravity. T_{500} / V funnel time represents the mix viscosity. It is classified as VS1 for the T_{500} time less than or equal to 2sec and VS2 greater than 2 sec. It is also classified as VF1 for a V-funnel time inferior than or equivalent to 8 sec and VF2 between 9 to 25 sec.

Fig: 3 V-funnel Test

Fig 4 shows the difference of T_{500} of SCC with the percentage replacement of RCA. The T_{500} SF values increased by the increment replacement of RCA. The addition of 0.1% fibers caused decrease in the time, the decrease being 14.28%, 6.6%, 25%, 11.11% and 25% respectively at 0, 25, 50, 75, 100 % replacement of RCA. All series maintained or met the VS2 class only similar to that of parent SCC.

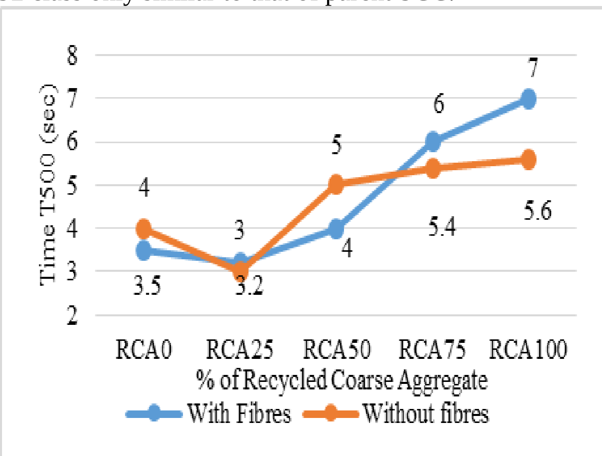

Fig: 4 T_{500} Slump Flow Variation of with percentage of RCA

Fig 5 represented the difference of VF time with the percentage of RCA. The VF time was increased by increment of the percentage of RCA. The time decreased with 0.1% use of fibers with the decrease being 13.2%, 2.3%, 16.6%, 13.28% and 19.28% respectively at 0, 25,50,75,100 % substitution of RCA. However, all SCC mixes have fallen in the same VF2 class.

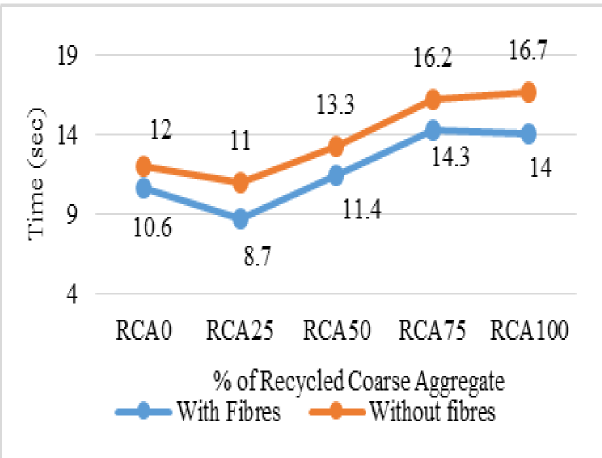

Fig: 5 V- Funnel Time variation with the RCA percentage

C. Passing Ability (PA)

L-Box determines the PA of workable concrete to pass over spaces between the reinforcing bars without segregation. The PA was classified into PA1 and PA2 as per the smallest gap through which SCC can flow. The L box is an apparatus (Fig. 6) provided with a gate between the vertical and horizontal sections. The concrete is discharged into the filling hopper and later the door is lifted to discharge into the plane section of the box. The passing ability (PA) is computed from the equation PA = H2/H1. H1 is the peak at the remaining concrete in the hopper and H2 is the peak at the concrete at the deadline of the parallel part.

Fig: 6 L-Box Test

The variation of the ratio of heights of concrete with the proportion of RCA was shown in Fig 7. The variation of the ratio of height was unclear with the inclusion of Recycled Coarse Aggregate (RCA) and Fiber. All series of SCC mixes met the criteria of the ratio of the minimum height of 0.8 and maximum 1.0 as per the guidelines given in the EFNARC. The difference in heights was increased by addition of Polypropylene fibers to the Recycled Coarse Aggregate which fibers act as secondary reinforcement to the SCC concrete when compare to without fibers.

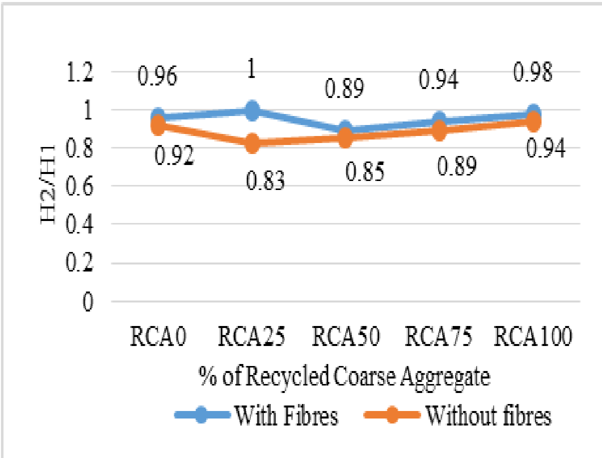

Fig: 7 Height ratio Variation with RCA percentage

D. Compressive Strength [CS]:

Cubes with size 150mm × 150mm × 150mm were used to assess the compressive strength. These cube specimens were under compressive testing machine after 28 days of curing.

The load is applied steadily at a rate of 140 kg/cm^2 per minute until the failure of the Specimens occurs as per IS 516-1959 [15] as shown in (Fig. 8) Compressive strength of the concrete was computed by the ratio of load at the failure to the area of specimen.

(a) (b)

Fig: 8 a) Testing of a cube
b) The failure mode of a cube

Table 8. Compressive strength (CS) Results using RCA with fibers and without fibers

Mix Designation	Compressive Strength (MPa)	
	With Fibers	Without Fibers
RCA0	47.88	40.44
RCA25	39.76	39.5
RCA50	39.03	38.63
RCA75	37.23	36.6
RCA100	36.07	35.13

The deviation of the CS for SCC with the percentage of RCA in both SCC with fibers and without fibers was plotted in Fig.9. The plot shows that the CS curtailed with the increase in the RCA percentage in both cases. However, the design strength was almost achieved by SCC with fibers and without fibers up to 50% replacement. The SCC with an excess of RCA beyond 50% caused a reduction in strength below the design strength. This may be due to the availability of more quantity of RCA which causes less availability of water for setting and hardening due to greater water absorption. The CS slightly increased with the 0.1% inclusion of fibers in SCC at all replacements of RCA, the increase being RCA by 18.39%, 0.65%, 1.03%, 1.72% and 2.68% respectively when compared to RCA without fibers.

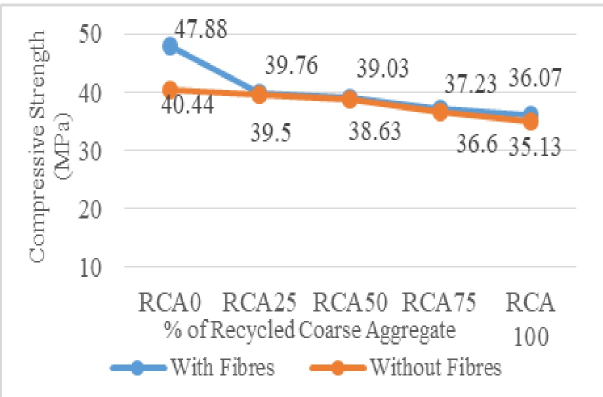

Fig: 9 Compressive Strength variation with RCA percentage

E. Split Tensile Strength [STS]

Cylinders of size 300mm × 150mm were used to test the split tensile strength. These specimens were tested under compressive testing machine at the age of 28 days. The load is applied progressively at the loading rate of 0.7 to 1.4 MPa/min until the Specimens fails according to IS 516 as exhibited in (Fig. 10).

Fig: 10 Failure of cylinder

Table 9. Split Tensile Strength Results using RCA with fibers and without fibers

Mix Designation	Split Tensile Strength (MPa)	
	With Fibers	Without Fibers
RCA0	3.43	3.27
RCA25	3.19	3.06
RCA50	3.12	3.00
RCA75	2.62	2.49
RCA00	2.32	2.23

Fig: 11 shows that the variation in STS in SCC with replacement of RCA with and without fibers. It can be recognized from the graph that the STS of SCC by with fiber and without fibers decreased with the inclusion of RCA. Though the SCC exhibited a reduction in strength, it was noticed that the expected tensile strength of 10% of compressive strength was attained up to 50% replacement of RAC. The decrease is due to a weak bond between the aggregate and cement paste in RCA concrete. However, the inclusion of 0.1% of fibers caused a slight increase in STS irrespective of the percentage increment of RCA, the increase being 4.9%, 4.25%, 4.0%, 5.22%, and 4.04% respectively at 0%, 25%, 50%, 75%, and 100% substitutions.

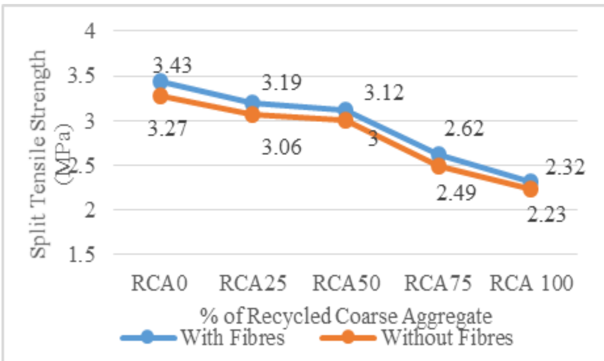

Fig: 11 Split Tensile Strength Variation with RCA percentage

F. Flexural Strength [FS]:

Beams of size 100mm × 100mm × 500mm were used to determine the Flexural strength. These Beams were tested by universal testing machine for 28 days of curing. The mass is applied moderately at the rate of 1.8kN/min till the Specimens fails as per IS 516-1959 [15] as shown in (Fig.12).

Fig: 12 Flexural Strength Test

Table 10. Flexural Strength Results for SCC using RCA with fibers and without fibers

Mix Designation	Flexural Strength (MPa)	
	With Fibers	Without Fibers
RCA0	4.14	4.03
RCA25	4.09	3.9
RCA50	3.95	3.46
RCA75	3.68	3.08
RCA100	3.33	3.04

The variation of FS of SCC with percentage RCA for SCC with and without fibers was shown in Fig: 13. It was observed that the FS reduced with the rise of RCA in both SCC with and without fibers. The required FS was almost achieved by SCC with and without fibers up to 50% replacement of RCA. The 0.1% inclusion of fibers resulted in increased FS at all replacements of RCA with the increase being 2.72%, 4.87%, 14.16%, 19.48%, and 9.54% respectively at 0%, 25%, 50%, 75% and 100% substitution of RCA.

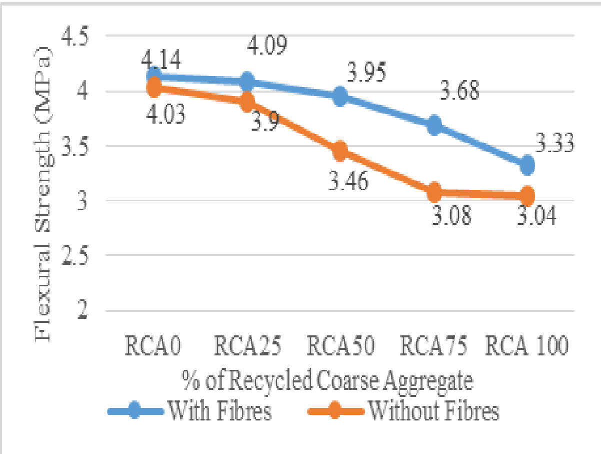

Fig: 13 Flexural Strength Variation with the RCA percentage

V. CONCLUSIONS

The mechanical properties of Recycled Aggregate SCC incorporated with fibers were presented in this paper. SCC mixes of M30 were prepared by substituting the Natural aggregate with 25%, 50%, 75% and 100% of RCA. Based on the present study, the following conclusions can be made.

1. Usage of GGBS and Fly Ash in the SCC mix can lessen the usage of cement and there by CO_2 gas into the atmosphere.
2. The workability of SCC characterized by Flowability, Viscosity, and Passing Ability was reduced with the incorporation of RCA. However**,** all Mixtures of SCC maintained the same class i.e. SF1 under flowability and VS2/VF2 under viscosity as that of SCC without RCA. All these mixes also met the criteria of passing ability by maintaining a minimum heights ratio of 0.8.
3. The amount of RCA used in SCC has a direct effect on mechanical properties. The design strength was almost achieved by SCC with and without fibers up to 50% replacement. The CS slightly increased by inclusion of 0.1% fibers in SCC at all replacements of RCA compared to that of SCC without fibers.
4. The STS for SCC using with and without fibers decreased by the addition RCA. Replacement of NA with RCA up to 50% maintained the minimum tensile strength. The addition of 0.1% of fibers caused a slight increase in STS irrespective of the percentage replacement of RCA.
5. The FS reduced with the escalation of RCA in both SCC with fibers and without fibers. The required FS was almost achieved by SCC with fibers and without fibers up to 50% replacement of RCA. The 0.1% addition of fibers resulted in increased FS at all replacements of RCA.
6. On the basis of the outcome of the present work, SCC of Grade 30 can be developed with the replacement of cement by 30% Fly Ash & 20% GGBS, NCA by RCA up to 50%, and addition of 0.1% of polypropylene fibers.

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