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EFFECT OF RECYCLED COARSE AGGREGATE, FOUNDRY SAND AND FIBERS ON RHEOLOGICAL PROPERTIED OF FIBRE REINFORCED SELF-COMPACTING CONCRETE

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Abstract:

Previous studies have proven that self compacting concrete and fibre reinforced concretes are more suitable and efficient in concrete technology. Hence, the current study is aimed at investigating the effects of hooked end and crimped steel fibres on the performance of fibre reinforced self-compacting concrete with RCA and foundry sand (RCA-FR-SCC). In the present study tests for rheological properties were performed. Totally 20 mixes with RCA of 0, 25, 50, 75 percentage of Natural Coarse Aggregate (NCA), and three different combinations of reinforcing hooked end and crimped steel fibers and 15% of optimum replacement of foundry sand. The results of the study have proven that the addition of fibres with both RCA and foundry sand in optimum percentage, can significantly improve rheological properties of RCA-FR-SCC.

Key Words: Self-compacting Concrete, Hooked end Fibres, Crimped fibres, Foundry sand, Recycled Coarse Aggregate

1. Introduction:

Demolition of buildings, bridges and old structures are frequent phenomena due to many reasons such as change of purpose, rearrangement of a city, structural deterioration, expansion of city, traffic directions and natural calamities. Nearly 850 million tons of construction and demolition(C&D) waste are generated in Europe each year, which shows 31% of the total waste production in Europe (Malešev *et al*. (2010)). In US, the total waste generated from C&D alone is nearly 123 million tons each year (Malešev *et al*. (2010)). There are no proper data available on the current generation of C&D in Asia. In the year 2005, the total C&D waste generated in Malaysia was nearly 19,100 tons per day (Siwar (2008)). In all over the world, the amount of concrete waste is derived from demolition of old structures. Mostly these wastes are disposed by landfilling. This disposal method may cause environmental and health hazard (Malešev *et al*. (2010)). The strength of concrete with RCA is usually very lower when compared to concrete with natural coarse aggregate (NCA). Most commonly, the concrete with RCA will reduce by 5 to 10% of compressive strength (ACPA (2009)). However, RCA reduces strength up to 25% depending upon the quality of RCA (Ajdukiewicz and Kliszczewicz (2002); Rahal (2007); Evangelista and de Brito (2007); Anderson *et al*. (2009); Juan and Gutierrez (2004)). The higher air content found in the concrete containing RCA lead to lower strength parameter (Anderson *et al*. (2009)). Beside concrete containing RCA has similar and sometimes higher strength than concrete containing NCA only if the RCA is derived from old concrete structures, which was produced with a low water to cement (w/c) ratio than the new concrete with RCA (Padmini *et al*. (2009)).

Foundry sand is available only in certain regions where more number of ferrous metal industries is available and due to the scarcity of river sand. Rafatsiddique et al. (2009) reported that the Foundry sand replaces natural sand because it is having high amount of clean and uniformly sized silica content. The main contribution of this paper, however, lies in the determination of fresh properties of SCC's incorporating hooked end and crimped steel with various levels and most primarily, the determination of total number of fibers in cross section using SEM and evaluation of ITZ of SCC. The outcome of this research project provides toughness, flexural strength and ductility behaviour of SCC with hybrid steel fiber. To the best of author's knowledge, no experimental/analytical investigations have yet been reported on impact resistance, SEM analysis of SCC with hybrid fibers. This research work seeks mainly to address the large gap in the current existing literature by inspecting the fresh and mechanical characteristics of SCCs incorporating hooked end and crimped steel fibers.

2. Materials & Mixing Procedure:

Ordinary portland cement conforming to IS 12269:1987 was used for all 25 mixes. Its consistency, initial setting time, fineness and specific gravity were 31%, 35minutes, 4% and 3.14 respectively. Both fine and coarse aggregate used were conforming to IS383:1970. By conducting sieve analysis, it was found that sand conforms to grading zone II as per IS 383-1970. The gradation curve for fine aggregate and FS is given in the figure 1.In this study the NCA with a maximum size 12.5mm was used.

The RCA of 12.5 mm size used in the experimental study was obtained from the demolished cubes tested in RMC plant in Coimbatore. The aggregates were crushed, cleaned and water washed for 30 minutes in the mixture drum. To reach the desirable workability as per EFNARC guidelines for SCC, the water demand to produce concrete with recycled aggregates is higher compared to natural aggregates, leading to the increase of the water/cement ratio, thereby, also increasing the porosity of the cementing matrix. The use of water-reducing admixtures may itself minimize this effect, since they may provide workability to the mixture without increasing the water/cement ratio. Table 1 reports the results of various physical properties of NCA and RCA. The FS which is used in this study was obtained from a metal casting industry at Coimbatore. Table 2 reports the results of various physical properties of Natural river sand, FS. Table 3 reports the Mix Proportioning of RCA-FR-SCC with FS.

Figure 1: Gradation Curve of Natural sand and Foundry sand

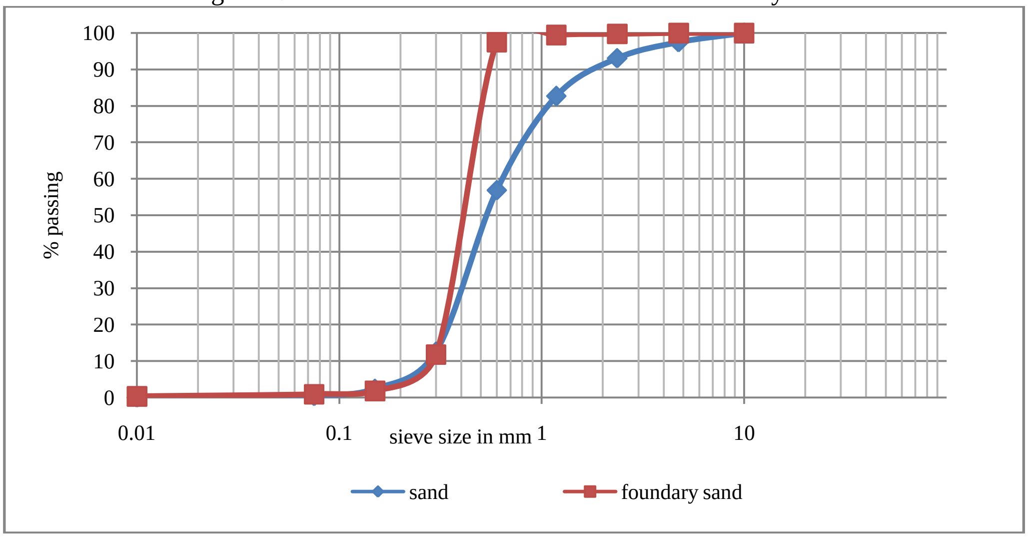


Table 1: Physical properties of coarse aggregates

Properties	Natural coarse aggregate	Recycled coarse aggregate
Specific gravity	2.76	2.34
Bulk density (loose), kg/m^3	1436.56	1205.86
Bulk density (rodded), kg/m^3	1640.86	1340.86
Water absorption, %	1.45	9.12
Impact value, %	15.28	19.57
Crushing value, %	23.46	28.18

Table 2: Physical properties of fine aggregates

Properties	Natural fine aggregate	Foundry Sand
Specific gravity	2.67	2.6
Fineness modulus	2.97	1.89
Water absorption, %	1	1.3
Passing through sieve size, mm	4.75	4.75

By conducting more trial mixes and by referring to past researches & literature review, it has been decided to replace 15% of FS as river sand, 7.5% of silica fume as supplementary cementitious materials and 25, 50 and 75 % of RCA as NCA. The super plasticizer used was a polycarboxylic-ether based admixture, commercially available in India. Potable water was used for mixing and curing of the concrete. In this present study, steel fibres namely hooked end fibre and Crimped fibres (H & C) has been added not more than one percentage of fibre volume ($V_f \leq 1\%$).

Table 3: Shows the mix proportions of SCC mixes

Mix No.	Mix type	Fibre Content*	Fibre V_f		Cement	Sand	Foundry sand	Coarse aggregate		Silica fume	Water	SP dosage
			H	C				Normal	RCA			
			(%)	(%)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)
1	CM	-	-	-	500	919.00	-	803.00	-	31	172	7.5
2	R25	-	-	-	500	919.00	-	602.25	200.75	31	172	7.5
3	R50	-	-	-	500	919.00	-	401.50	401.50	31	172	7.5
4	R75	-	-	-	500	919.00	-	200.75	602.25	31	172	7.5
5	R0F15	-	-	-	500	781.15	137.85	803.00	-	31	172	7.5
6	R25F15	-	-	-	500	781.15	137.85	602.25	200.75	31	172	7.5
7	R50F15	-	-	-	500	781.15	137.85	401.50	401.50	31	172	7.5
8	R75F15	-	-	-	500	781.15	137.85	200.75	602.25	31	172	7.5
9	R0F15	0.25C0.75H	0.75	0.25	500	781.15	137.85	803.00	-	31	172	7.5
10		0.5H0.5C	0.50	0.50	500	781.15	137.85	803.00	-	31	172	7.5
11		0.75C0.25H	0.75	0.25	500	781.15	137.85	803.00	-	31	172	7.5
12	R25F15	0.25C0.75H	0.75	0.25	500	781.15	137.85	602.25	200.75	31	172	7.5
13		0.5H0.5C	0.50	0.50	500	781.15	137.85	602.25	200.75	31	172	7.5

14		0.75C0.25H	0.75	0.25	500	781.15	137.85	602.25	200.75	31	172	7.5
15	R50F15	0.25C0.75H	0.75	0.25	500	781.15	137.85	401.50	401.50	31	172	7.5
16		0.5H0.5C	0.50	0.50	500	781.15	137.85	401.50	401.50	31	172	7.5
17		0.75C0.25H	0.75	0.25	500	781.15	137.85	401.50	401.50	31	172	7.5
18	R75F15	0.25C0.75H	0.75	0.25	500	781.15	137.85	200.75	602.25	31	172	7.5
19		0.5H0.5C	0.50	0.50	500	781.15	137.85	200.75	602.25	31	172	7.5
20		0.75C0.25H	0.75	0.25	500	781.15	137.85	200.75	602.25	31	172	7.5

*H – Hooked end fibre, C- Crimped fibre and
Eg: 0.25C0.75H represent 0.25% of Hooked end fibre volme fraction and 0.75% of Crimped fibre

The mix design was obtained based on EFNARC guidelines. In each mix NCA was replaced by RCA in the ratio of 0%, 25%, 50% and 75% by weight and the sand was replaced by FS. The ordinary portland cement was partially replaced with 7.5% of silica fume, which is constant in all the mixes. The SCC mixes were prepared by replacing FS and RCA and tested for fresh properties as per EFNARC specifications and guidelines.

Table 4: Properties of reinforcing fibres

S.No	Fibre Type	Length of the fibre	Diameter of the fibre	Aspect Ratio (l/d)	Tensile strength (kg/cm^2)	Elastic modulus (GPa)
1.	Hooked End Fibre (H)	70mm	0.7mm	100	21000	160
2.	Crimped fibre (C)	70mm	0.7mm	100	21000	160

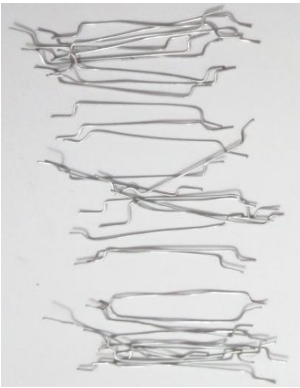


Figure 2 (a): Hooked End Fibre


Figure 2 (b): Crimped Steel fibre

3. Assessment of Rheological Properties of Fresh RCA-FR-SCC:

In L-Box test, the reached height was measured for the RCA-FR-SCC sample after passing throught the gaps specified with reinforced bars of diameter of 12mm. The height ratio measured was atleast of 0.7, flowing and blocking can be evaluated from this test. The results of physical properties of RCA-FR-SCC are represented in Figs 3 – 6. According to EFNARC guidleines for self compacting concrete, flow diameter and flow time (T_{50cm}) values should be in the range of 600 – 750mm, 3-9 sec, respectively.

The requirements of flowability were satisfied as per EFNARC specifications for the control mix of self compacting concrete. The slump flow diameter and T_{50cm} flow time of control mix were 690 mm and 3.08sec respectively. The L-box blocking ratio (H_2/H_1), flowability and passing ability of control mix were 0.85, 8.13 sec and 9 mm respectively. Figure 3 to 4 represents the basic rheological properties such as slump flow diameter and T_{50cm} flow time of fresh SCC mixes with 0, 25, 50 and 75% of partial replacement of Recycled Coarse Aggregate (RCA) with NCA. Table 5 represents the L-box blocking ratio (H_2/H_1), flowability and passing ability of SCC mixes (0% of FS) with with 0, 25, 50 and 75% of partial replacement of RCA with NCA

Figure 3: Slump flow diameter of fresh SCC mixes (0% of FS)

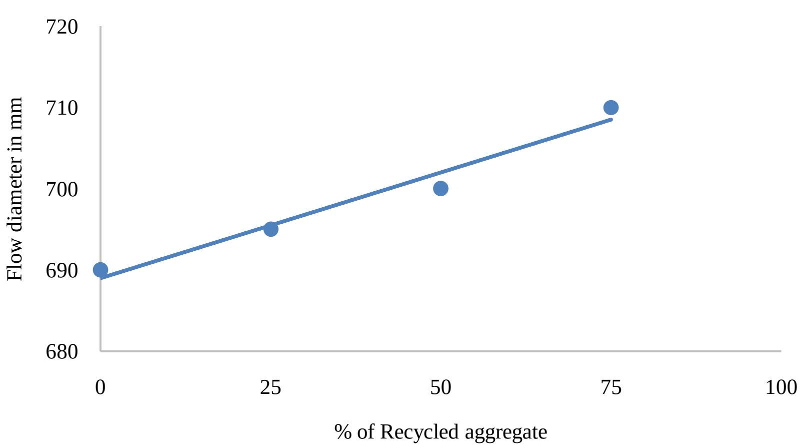
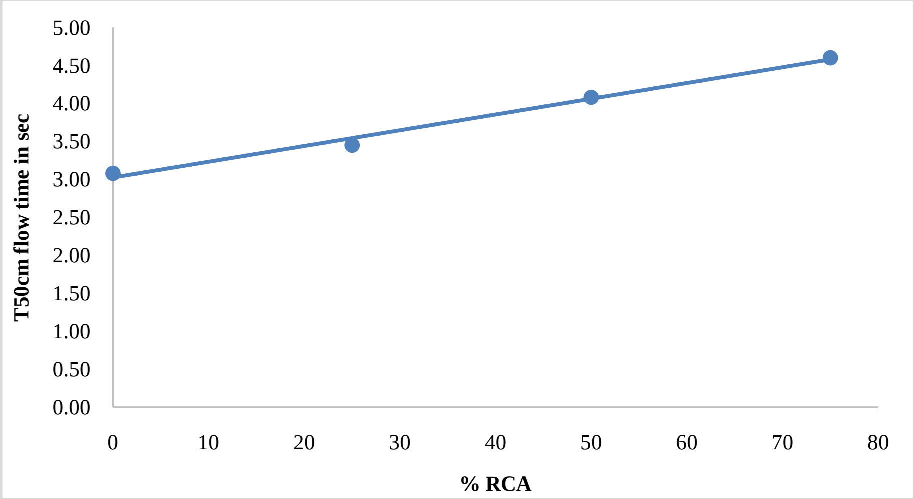


Table 5: The rheological properties of fresh SCC mixes

Mix Type	J- ring	L-box	
	D_f (mm)	H_2-H_1 (mm)	H_2 / H_1
CM	640	9.0	0.85
R25	675	9.0	0.87
R50	540	8.0	0.93
R75	560	8.0	0.95
R100	570	7.0	0.97

Figure 4: Represents the T_{50cm} flow time of fresh SCC mixes (0% of FS)



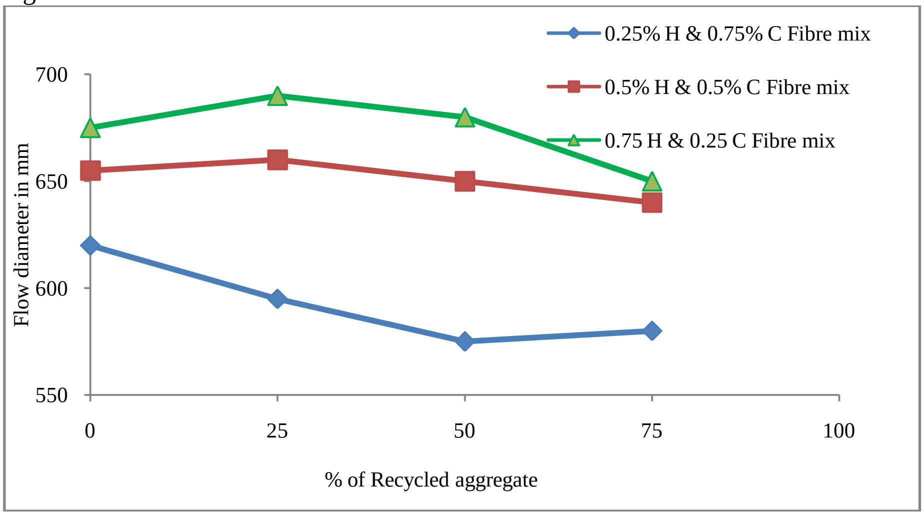
3.1. Influence on flow diameter and flow time of SCC mixes (0% of FS) with RCA:

Figure 3 & Figure 4 show clearly that the recycled coarse aggregate percentage increases, the flow diameter & flow time increases gradually for all mixes without incorporation of FS. RCA are especially very heterogeneous and porous in nature, and they may incorporate large number of impurities. Table 5 shows clearly that the RCA replacement percentage increases, the blocking ratio (H_2/H_1) increases for SCC mixes. It is clear that the basic requirements of the flow ability and segregation are satisfied as per EFNARC guidelines. Several test methods have been performed in attempts to obtain the properties such as flow diameter, T50 cm flow time, blocking ratio, flow ability and passing ability of RCA-FR-SCC.

Figures 5 to 9 provide a summary of the properties of the SCC with FS and with hybrid fibres in the fresh state. Incorporation of hybrid steel fibres has a significant effect on flow time, filling ability and passing ability of different RCA-FR-SCC when compared to conventional concrete. The V-funnel test was used to examine this increase of resistance to flow. Fig 5 to 9 represents the effect of aspect ratio of fibre (L/D) on the slump flow, flow time, blocking ratio, filling capacity and passing ability respectively.

Influence of Hooked end and Crimped Fibre in Slump Flow Test:

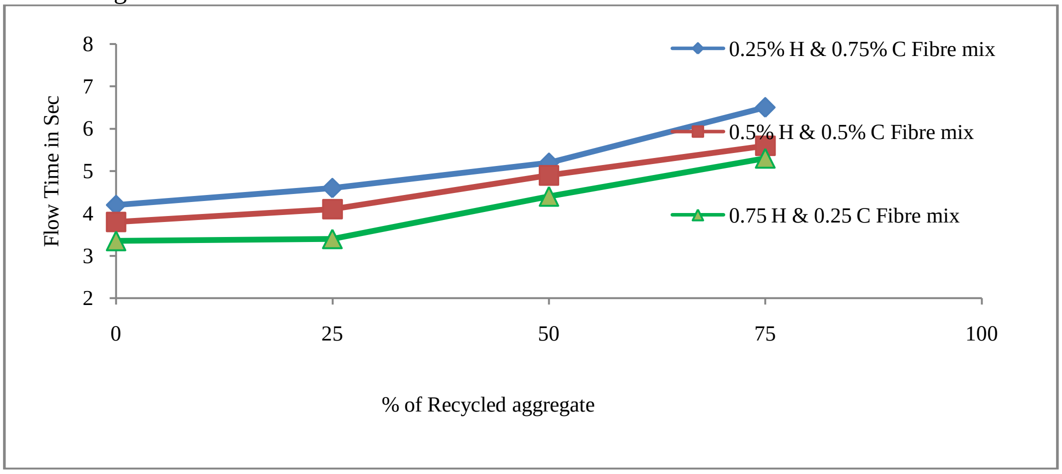
Figure 5: Effect of RCA on the flow diameter of RCA-FR-SCC mixes with 15% of FS



Slump flow diameter (Figure 6) is varying from 690 to 720 mm for all SCC mixes with RCA. This results in decrease in workability as stated by Grünewald S (2004) & Mahakavi et al. (2018).

Influence of Hooked end and Crimped Fibre in T_{50cm} Slump Test:

Figure 6: Effect of RCA on the flow time of RCA-FR-SCC mixes with 15% of FS

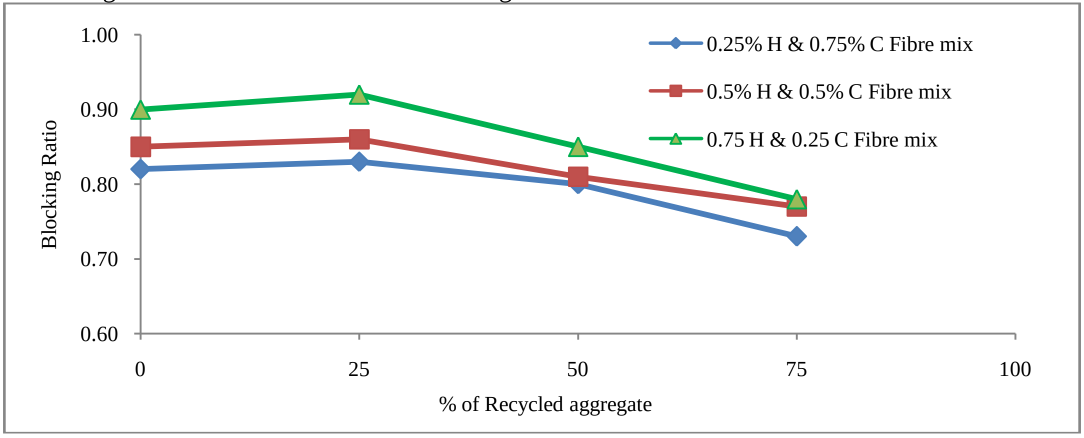


Slump flow T_{50cm} time (Figure 6) varies from 3.08 to 5sec for all SCC mixes with RCA. As the shape of hooked end and crimped steel fibres is more elongated when compared with coarse aggregates and RCA; the surface area is also higher Grünewald S.,(2004). for the same volume of concrete.

Influence of Hooked end and Crimped Fibre in Blocking Ratio of RCA-FR-SCC mixes (L - Box Test) (H_2 / H_1):

Blocking Ratio (Figure 7) of RCA-FR-SCC mixes varies from 0.85 to 0.97 for all SCC mixes with RCA.

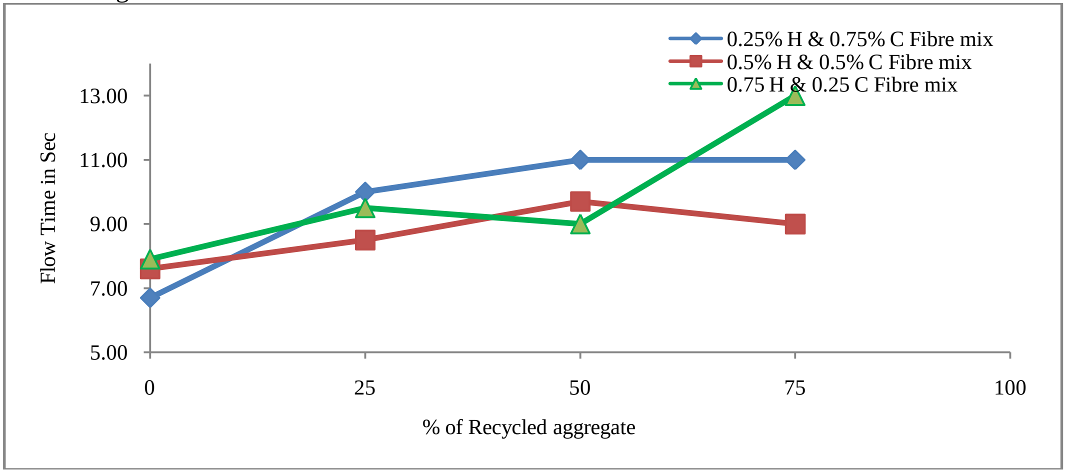
Figure 7: Effect of RCA on the blocking ratio of RCA-FR-SCC mixes with 15% of FS



Influence of Hooked end and Crimped Fibre in Flow ability of RCA-FR-SCC mixes (V funnel Test):

Flow ability of RCA-FR-SCC mixes (figure 8) varies from 8.13 to 9.56 sec for all SCC mixes with RCA. This is due to fibre types with a high surface area and matrix is extensively cohesive which decreases the filling ability of SCFRC as reported by Donza et al. (2002). When the fibres which are not round (even if it is homogeneously distributed), theses fibres are not likely expected to fill up a mould homogeneously which also results in transportation of high entrapped air content (Grünewald S.,(2004))

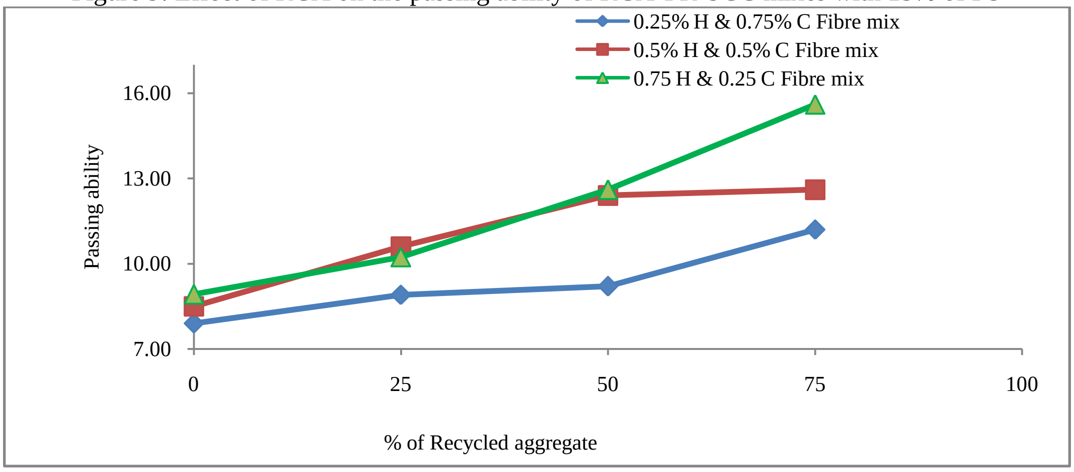
Figure 8: Effect of RCA on the flow time of RCA-FR-SCC mixes with 15% of FS



Influence of Hooked end and Crimped Fibre in Passing ability of RCA-FR-SCC mixes (J Ring Test):

Passing ability of RCA-FR-SCC mixes (Figure 9) varies from 9 to 7mm for all SCC mixes with RCA. In this present study, maximum quantity of fibre has been determined and added which cause the reduction in the workability in very minimal amount, whilst maintaining better workability.

Figure 9: Effect of RCA on the passing ability of RCA-FR-SCC mixes with 15% of FS



Conclusions:

This research work has been done mainly to address the large gap in the current existing literature by inspecting the fresh characteristics of SCCs incorporating hooked end and crimped steel fibers.

- The main contribution of this paper, however, lies in the determination of fresh properties of SCC's incorporating hooked end and crimped steel with various levels and most primarily.
- An experimental study was established to investigate the usage of alternative aggregates such as Recycled Coarse Aggregate and foundry sand for developing economical fibre reinforced self-consolidating concrete can significantly reduce the production cost of the RCA-FR-SCC by adding required amount of High Water Reducer/superplasticizer and mineral admixtures compared with the normal dosage of such chemical/mineral admixtures in SCC.
- Usage of RCA along with FS has significantly reduced the fresh properties like flow diameter and flow time of SCC with and without addition of hybrid steel fibres (Hooked end and Crimped fibres).
- Particularly, adding fibres more that (1%) in SCC, J-ring test and the L-box test had some blockage of SCC in apparatus. Hence it is recommended to added 1% of fibre volume fraction in self compacting concrete for efficient and effective results.

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