ASSESSING THE PROPERTIES OF SELF-COMPACTING CONCRETE MADE WITH RECYCLED AGGREGATE

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ABSTRACT

Application of self-compacting concrete (SCC) in risky and mega construction projects is a popular practice now a days as better workability is achieved without using mechanical vibration. The determining criteria of SCC are: workability, self-passing ability and filling ability in congested reinforcement, without any segregation. Also, the concrete should impart proper strength. With the faster growing population around the world, old buildings are getting demolished every day to overcome accommodation problem. But another problem arises side by side as the demolition work produces huge amount of crushed concrete wastes, which is a great threat to our surroundings. Sustainable construction materials may be produced by conversion of these wastes into recycled aggregates, which may reduce bad effects on the environment as well as cost of production of construction materials. This research work represents comparison among SCC specimens made with different partial replacements (0%,20%,30%,40%,50%) of natural coarse aggregates (NCA) with 10-12mm and 10-20mm sized recycled coarse aggregates (RCA) derived from crushed pile head concrete to find out the suitable percentage and size of RCA which are compatible to meet the standard SCC recommendations. In this purpose, slump flow test, L-box test and V-funnel test were done to determine the SCC criteria. The compressive strength test and splitting tensile strength test were done to measure strength of hardened concrete. The test results showed that the quantity, size, hence presence of old attached mortar, water cement ratio, age and origin of RCA greatly affects the properties of green SCC made with RCA. The SCC production was fruitful up to 50% replacement of NCA by 10-12mm RCA. Also, the results based on 28 days curing, showed that, smaller RCA improves the SCC criteria and strength than that of bigger RCA.

Keywords: *Self-compacting concrete, recycled coarse aggregate, crushed pile head concrete, workability, old attached mortar.*

1. INTRODUCTION

Congested reinforcement can create many problems relating to placing and compacting concrete. The SCC was developed in Japan and continental Europe as a super solution to work in congested reinforcements, under water and high strength construction works. Its specialities over conventional concrete are its high workability, self-compaction ability that denies necessity of mechanical vibration, smoother surface finish, reduced noise pollution and safety of workers. SCC is now being used in mega projects, such as Rooppur Nuclear Power plant, of Bangladesh. However, production of SCC is not as easy as it seems. The main challenge is to maintain high workability and avoiding segregation at the same time which is very difficult. Because segregation leads to blockage, produces deformability and hampers concrete properties (Grdic et al.,2010). Another important issue in preparing the mix proportion of SCC as there is only few recommended standards and widely accepted or unified standard design procedure is yet to be developed. Hence trial and error process with precise monitoring are the possible ways to find out proper mix (Garcia-Troncoso et al., 2021). Again, addition of admixture and proper machineries are a must for quality control that affects the cost of production.

Researchers have found out that less proportion of NCA than natural fine aggregates (NFA) make the preliminary difference of SCC than conventional concrete (CVC). Therefore, the aggregate properties, especially the maximum size and gradation, play important role in controlling the quality of SCC. Concrete production always creates many types of environmental problems including the threat to non-renewable aggregate source. Researchers are emphasizing the use of RCA in concrete production. Since the rate of building demolition as well as construction of new buildings is increasing day by effective use of construction and demolition waste becomes essential to manage these waste and conserve nonrenewable natural resources. Using partial replacement of NCA by RCA in SCC production may lessen negative effect on the environment. Side by side, problems also arise as RCA contains old attached mortar, high porosity and irregular shape because of concrete demolition works. Utilization of RCA may result in deterioration of overall properties of SCC (Silva et al., 2016; Revilla-Cuesta et al., 2020). Use of RCA increases the possibility of segregation, reduction in workability and strength (Kou and Poon, 2009). To resolve the problem Rokonuzzaman and Serker (2023) suggested the removal technique of attached residual mortar of RCA. However, in this research untreated RCA is used. Analysing the test results of slump flow test, L-box test and V-funnel test, 50% replacement of NCA was found to be suitable for SCC mix. Also, to meet up the SCC criteria recommended by EFNARC (2002) and overcome the problems arisen, the replacement of NCA was done using 10-20mm and 10-12mm RCA.

The challenges in production of SCC made of RCA are discussed and the possible solutions are evaluated in this study. With the bigger RCA, the attached mortar content increases which increases the porosity and water absorption of RCA that later on leads to weaker internal particle bond, less strength, high water cement ratio and segregation (Nili et al., 2019). Although the quality of SCC may degrade to some extent because of utilization of RCA, it still may be used and adopted as a better solution to keep our material resources and the environment untouched.

2. EXPERIMENTAL PROGRAM

2.1 Experimental Materials

RCA for this study was collected from demolished one-month aged pile head concrete. The concrete was crushed and sieved to get the desired size RCA. At first 10 mm to 20 mm size aggregate was selected. The aggregates contain large amount of residual mortar as shown in Figure 1. Aggregates passing through 20 mm sieve were further crushed and it was noticed that the smaller size aggregates contain less amount of residual mortar. The physical properties i.e., water absorption and specific gravity of the aggregates, were determined following ASTM C 127 (1998). Nili et al., (2019) also found that with more old attached mortar bigger RCA is highly porous, which may result into high water absorption. The properties of coarse and fine aggregates are shown in Table 1. The gradation curves of aggregates used are illustrated in Figure 2.

Figure 1: 10-20mm and 10-12mm RCA from demolished pile head.

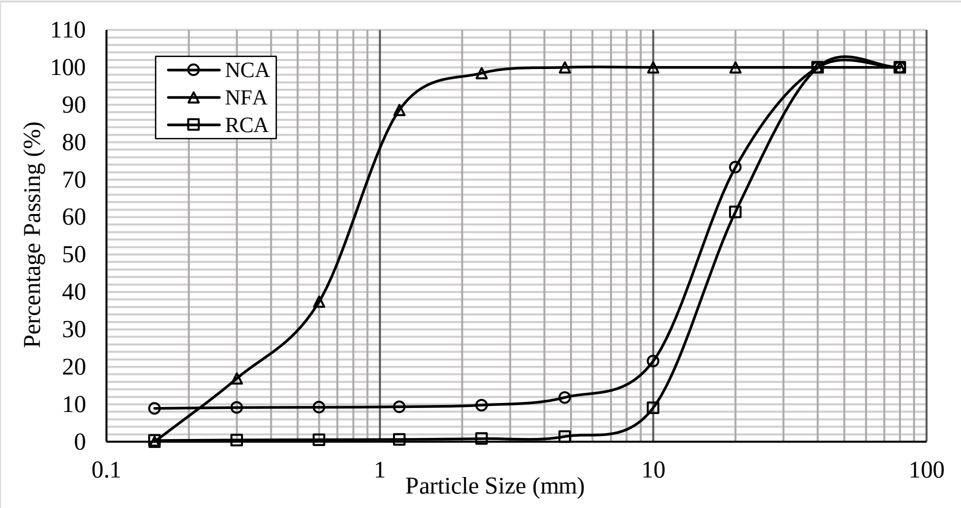

Figure 2: Gradation curve.

Table 1: Properties of aggregates

Properties	NCA	RCA	RCA	NFA
Size	10-20mm	10-20mm	10-12mm	<4.75mm
Specific Gravity	2.66	2.78	2.82	2.65
Water Absorption	2.04%	9.39%	10.21%	2%

Table 2: Properties of admixtures

Properties	Fly ash	Master Glenium SKY 8632
Aspect	Fine grey coloured powder	Reddish brown liquid
Specific Gravity	2.1 to 3	1.08
Dosage for SCC	32.65% of cementitious material used (Selected by trial-and-error process)	500-1500 mL per 1000kg of cementitious material used

A total of 48 concrete specimens were prepared and tested. All the SCC specimen were at first gone through workability tests and all the concrete specimens taken for both type of standard strength tests. To prepare the specimens, NCA, RCA, NFA, water, CEM I, fly ash and super plasticizer were used. To achieve the SCC recommendations, CEM I was used. Fly ash and the super plasticizer were collected from a local manufacturer. Master Glenium SKY 8632, a polycarboxilic ether-based chemical was used as super plasticizer to conduct high strength in SCC. The properties of fly ash and super plasticizer are shown in Table 2. At the time of concrete preparation, the aggregates were used in SSD condition.

2.2 Tests on Fresh SCC

Following test methods and standards were used to measure the workability of SCC:
Slump Flow Test: It's a measure of free flowability of SCC that was carried out following ASTM 1611 (1998).
L-box Test: Conforming EFNARC (2002), L-box test was performed to measure passing ability and flowability of SCC.
V-funnel Test: This test was performed to determine the segregation resistance and filling ability of SCC (EFNARC, 2002).

2.3 Tests on Hardened SCC

Compressive Strength Test: Concrete specimens of cylindrical shape, having 100mm diameter and 200mm height were used following ASTM C 39 (2021).
Splitting Tensile Strength Test: Cylindrical concrete specimens of 150 mm diameter and 300 mm height were used to conduct this test following ASTM C 496 (2017).

2.4 Working Sequence

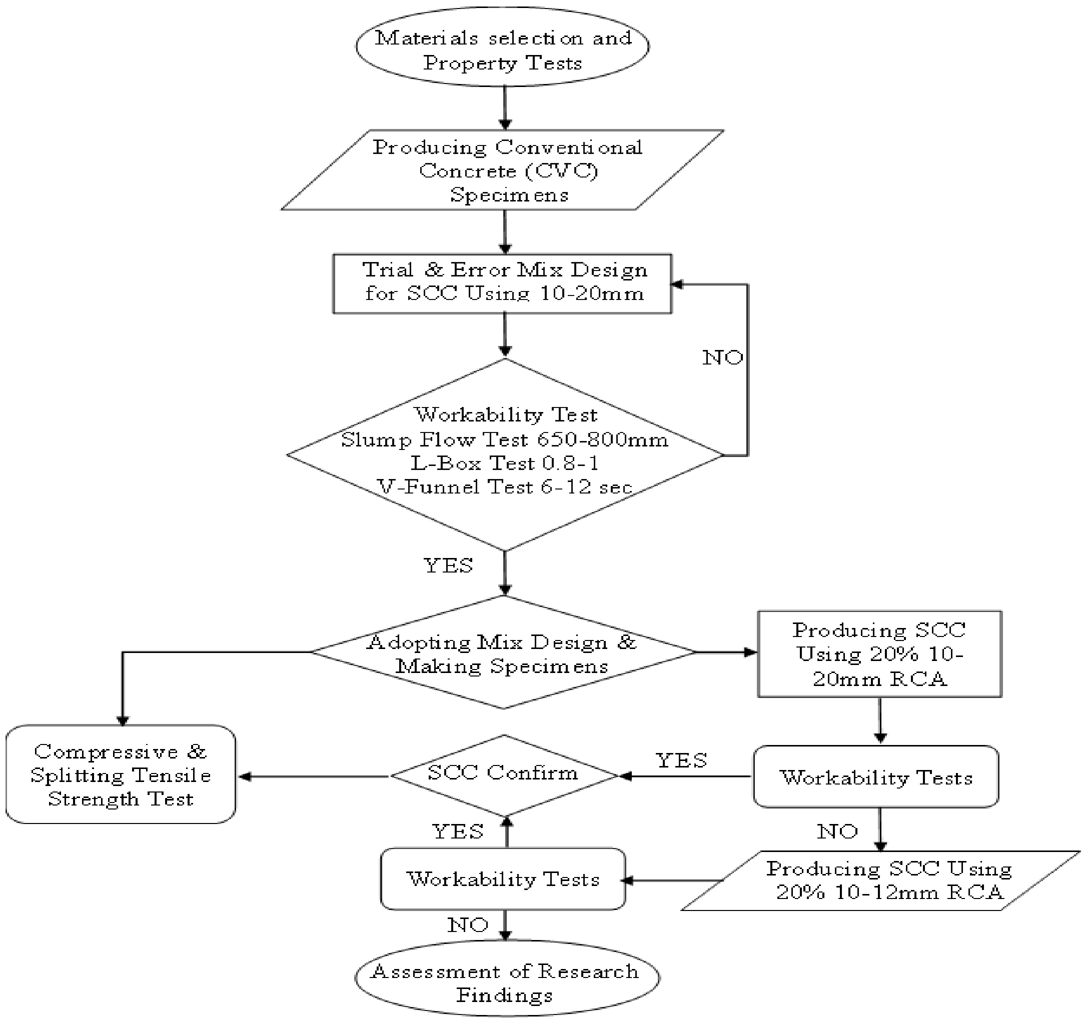

Figure 3: Working sequence.

The research was conducted following the flow chart shown in Figure 3. The flow chart shows working sequence for 20% replacement of NCA by RCA. This procedure was repeated similarly for 30%,40% and 50% replacement of NCA by RCA.

2.5 Concrete Mix Proportions

The ACI mix design procedure (2021) was used to prepare the CVC specimens. First, a manual mixing procedure was used in accordance with IS-10262 (2021) to produce SCC using only NCA. The first SCC was made without any RCA. This concrete is termed as SCC 0-0% RCA. Subsequently, because the initial mix did not match the SCC requirements, a trial-and-error method was used to produce SCC using of 20%, 30%, 40%, and 50% RCA replacement for NCA. In the second trial, the volume of NCA was decreased and a tilting drum mixer was employed in order to meet the SCC requirements. To meet SCC requirements, the trial was repeated twice in the 20% of NCA, with the RCA size being decreased from 10-20mm to 10-12mm.Table 3 displays the proportions of the CVC and SCC mix. 48 specimens were cast, with half being utilized for the test of compressive strength and the remaining half for the test of splitting tensile strength. The curing of the specimens was done in two steps. In the first step, the specimens were covered in moulds for four days and in second step, after demoulding they were kept in water. Curing was done for 28 days. Three specimens were collected for each proportion, and the average of these was used to determine the final result. Concrete mixing and preparing the test specimens are shown in Figure 4.

Figure 4: Preparation of specimens.

Table 3: Mix proportions (kg/m^3)

Mix series	Water	CEM I	Fly ash	NFA	NCA	RCA		SP (%) by weight of binder	W/B
						10-20mm	10-12mm		
CVC	208	447	-	658.5	1074	-	-	-	0.47
SCC 0-0% RCA	190	339.75	113.25	705.26	937.44	-	-	-	0.42
SCC 1-0% RCA	220	490	160	790	700	-	-	0.6	0.34
SCC 2-20% RCA	220	490	160	790	560	140	-	0.4	0.34
SCC 3-20% RCA	220	490	160	790	560	-	140	0.4	0.34
SCC 4-30% RCA	220	490	160	790	490	-	210	0.4	0.34
SCC 5-40% RCA	220	490	160	790	420	-	280	0.4	0.34
SCC 6-50% RCA	220	490	160	790	350	-	350	0.4	0.34

3.RESULTS AND DISCUSSIONS

2.6 Fresh Concrete Properties

The workability tests are shown in Figure 5. The SCC 0-0% RCA showed deprivation from the requirements of workability test results for SCC as suggested in EFNARC (2002). The quantity of NCA being higher than NFA may be the possible reason for this. Because more the coarse aggregate, less is the flowability. Mixing procedure as well as testing sequence are also prime factors to develop segregation. Thus, the reduced amount of NCA may have made SCC 1-0% RCA to achieve the SCC criteria. The SCC 2-20% RCA did not satisfy the L-box standard, which was overcome in SCC 3-20% RCA by reducing the RCA size to 10-12mm RCA. Use of smaller size RCA (10-12mm) for further trials resulted into success for up to 50% replacement of NCA. The results of workability tests are shown in Table 4. Figure 6 shows the variation of slump flow test results with respect to SCC 1-0% RCA. Figures 7 and 8 show the variation of L-box and V-funnel test results with respect to that of SCC 1-0% RCA respectively. Depending on the workability test results it may be assumed that, bigger RCA with more attached mortar contains more porosity than smaller RCA (Théréné et al., 2020) which may generate high water cement ratio and influence bleeding in SCC 2-20%RCA. Hence smaller size RCA may be a possible solution to overcome this problem. Also, more the old attached mortar, more will be the friction which negatively affects the flowability (Mo et al., 2020). Again, smaller RCA are rounder in shape which causes less friction. With the increase in the amount of 10-12mm RCA, old attached mortar increases in further trials thus reducing the workability.

Figure 5: Workability tests and casting of SCC.

Table 4: Workability test results of SCC

Cylinder designations	Slump flow (mm)	L-box test result(h_2/h_1)	V-funnel test (sec)	Remarks
Recommended limit	650-800	0.8-1	6-12	
SCC 0-0% RCA	550	0.51	18	Did not meet the SCC criteria
SCC 1-0% RCA	755.65	0.8	7	SCC confirmed
SCC 2-20% RCA	749.30	0.74	11	Did not meet the SCC criteria
SCC 3-20% RCA	778.35	0.809	9	SCC confirmed
SCC 4-30% RCA	767.73	0.8066	10	SCC confirmed
SCC 5-40% RCA	759.68	0.805	10	SCC confirmed
SCC 6-50% RCA	731.73	0.8	12	SCC confirmed

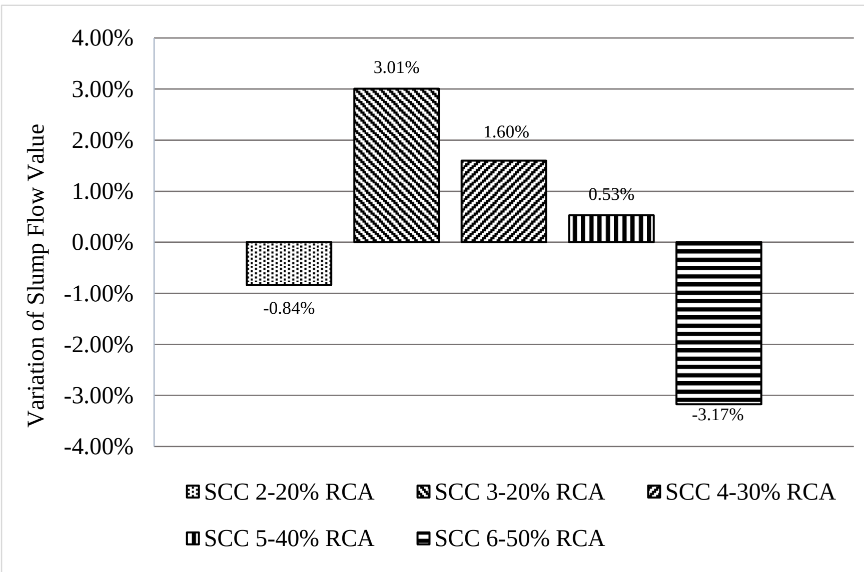

Figure 6: Variation of slump flow with respect to SCC 1-0% RCA.

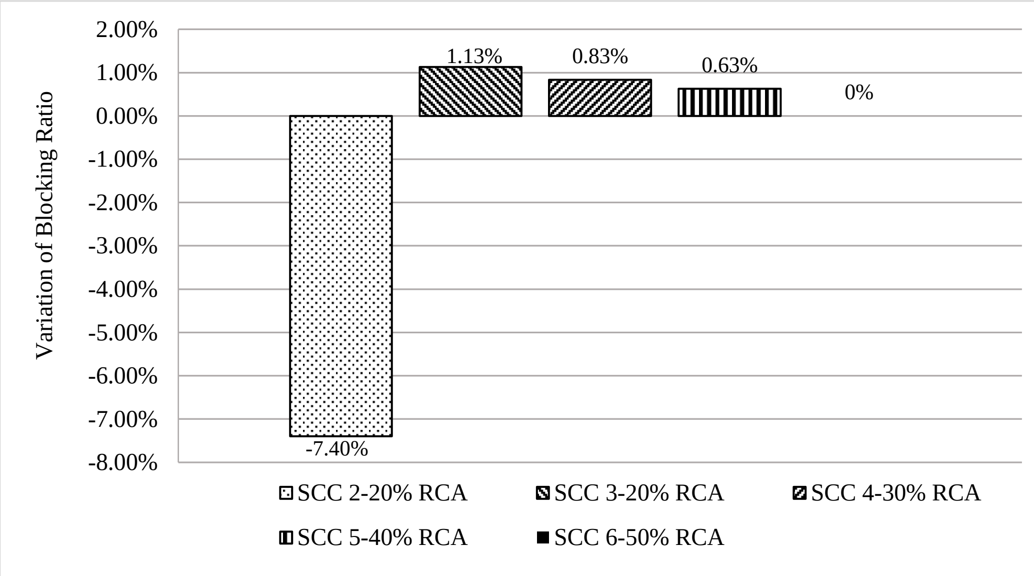

Figure 7: Variation of L-box test results with respect to SCC 1-0% RCA.

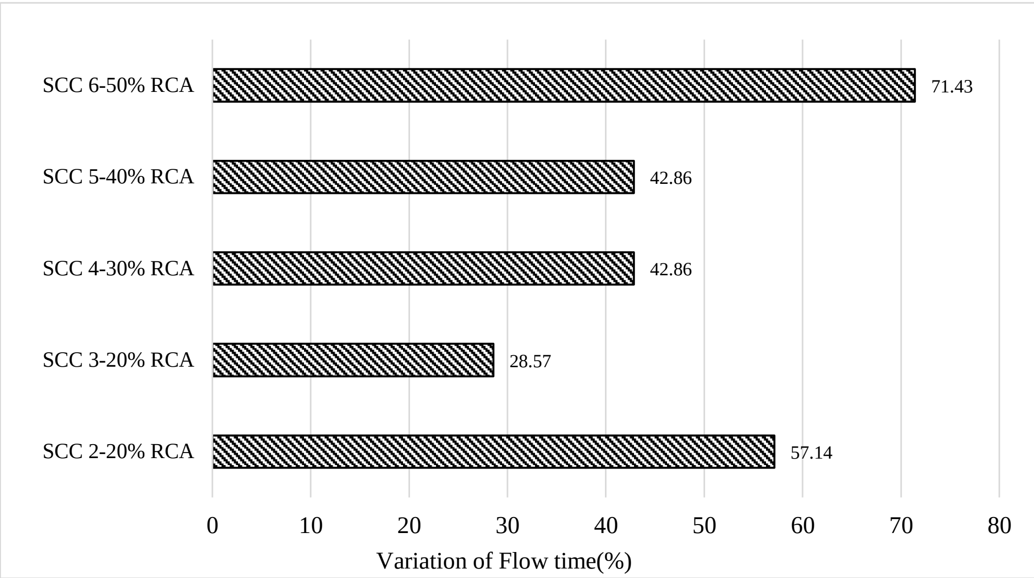

Figure 8: Variation of V-funnel test results with respect to SCC 1-0% RCA.

In Figure 9, the variation of workability test results with respect to RCA size were illustrated by comparing the test results of fresh SCC i.e. SCC 2-20% RCA and SCC 3-20% RCA with respect to SCC 1-0%RCA. For slump flow, inclusion of 10-20mm RCA resulted in 0.84% decrease of slump flow than that of SCC 1-0% RCA. On the other hand, using 10-12mm RCA increased the slump flow value about 3% than that of SCC 1-0% RCA. In case of V-funnel test results, the value increased in both cases i.e. about 57.14% and 28.57% for inclusion of 10-20mmRCA and 10-12mm RCA respectively. Next, for L-box test results, using bigger RCA decreased the blocking ratio about 7.5% from the obtained value of SCC 1-0% RCA. While using smaller RCA increased the blocking ratio up to 1.13% than that of SCC 1-0%RCA.

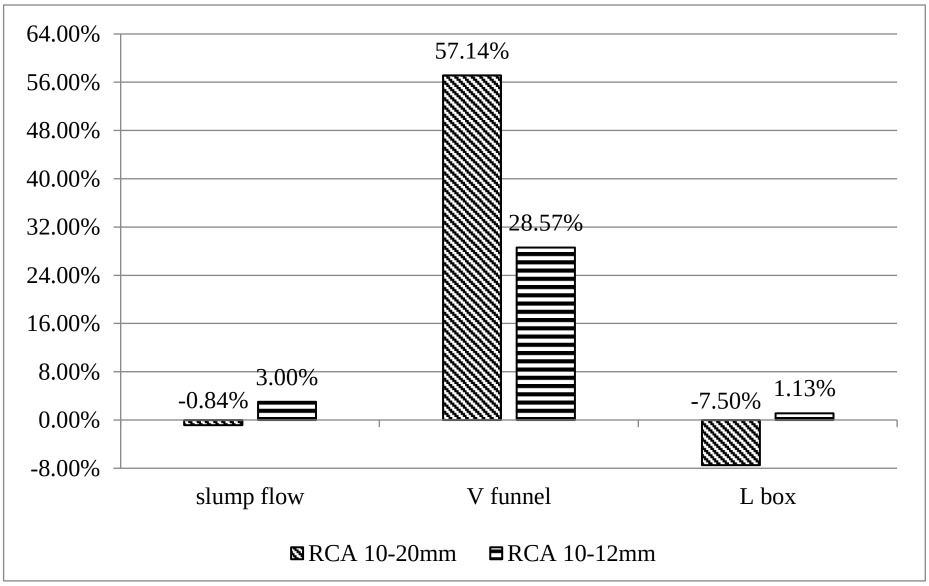

Figure 9: Variation of workability test results with respect to RCA size.

2.7 Compressive and Splitting Tensile Strength Test

The compressive and splitting tensile strength tests are shown in Figure 10. The test results of strength based on 28 days curing are illustrated in Table 5. The CVC obtained highest strength due to high amount of NCA. SCC 0-0% RCA did not achieve satisfactory strength possibly due to segregation. SCC 1-0% RCA achieved preferable strength due to proper mix. Incorporating bigger RCA of younger age may possess unhydrated cement in their old attached mortar. Later, this may result in high strength for SCC 2-20% RCA. Reducing the RCA size leads to a reduction in the amount of residual mortar which eventually reduces the amount of unhydrated cement particles. Hence, the reduction in the amount of unhydrated cement may also play an important role in the compressive strength reduction in SCC 3-20% RCA. SCC 1-0% RCA contains NCA only, which may be the possibility for SCC 2-20% RCA gaining more strength than it. Addition of recycled aggregate into the concrete also has some negative impact on the compressive strength. RCA itself contains one interfacial transition zone (ITZ). When RCA is used in the concrete it develops another ITZ. ITZ is also considered as the strength limiting factor of concrete (Etxeberria, 2020). Increasing amount of RCA enhances porosity and the formation of double ITZ which finally results in lower compressive strength. Figures 11 and 12 illustrate the variation of compressive strength with respect to SCC specimens and percentage variation of compressive strength with respect to SCC 1-0% RCA.
Splitting tensile strength gradually decreases with an increasing amount of RCA. Singh et al. (2019) explained the possible reason as the difference in the elasticity of old attached mortar and new mortar which causes microcrack to develop. Presence of microcracks in the interfacial transition zone usually

Figure 10: Compressive and splitting tensile strength tests.

reduces the tensile strength of the concrete. RCA influences weaker RCA-mortar matrix interface bond because of high porosity and water absorption (Santos et al., 2019). These may be the possible causes behind lower splitting tensile strength in SCC specimens made with RCA. Increase in RCA amount increases amount of old attached mortar in later specimens and thus reduces splitting tensile strength gradually. The variation of splitting tensile strength with respect to SCC specimens and percentage decrease in splitting tensile strength with respect to SCC 1-0% RCA are presented in Figures 13 and 14.

Table 5: Compressive and splitting tensile strength test results on 28 days curing

Cylinder designations	Compressive strength (MPa)	Splitting tensile strength (MPa)
CVC	33.47	1.88
SCC 0-0% RCA	19.31	1.80
SCC 1-0% RCA	30.95	2.74
SCC 2-20% RCA	32.41	2.05
SCC 3-20% RCA	27.06	2.008
SCC 4-30% RCA	20.96	1.98
SCC 5-40% RCA	17.838	1.513
SCC 6-50% RCA	15.755	1.302

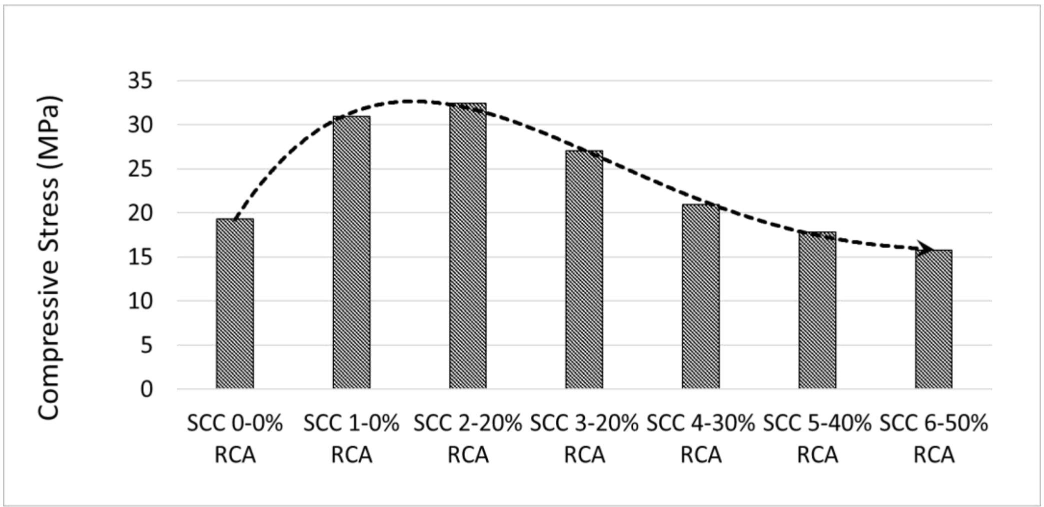

Figure 11: Variation of compressive strength with respect to SCC specimens.

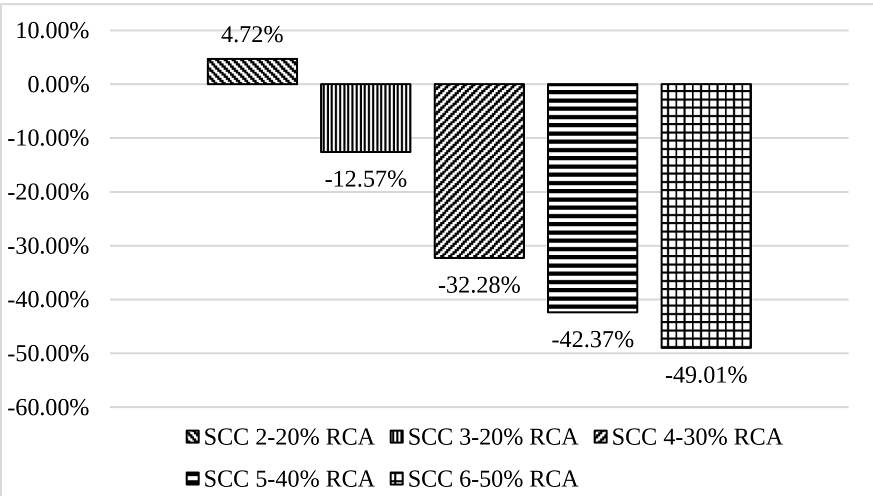

Figure 12: Variation of compressive strength with respect to SCC 1-0% RCA.

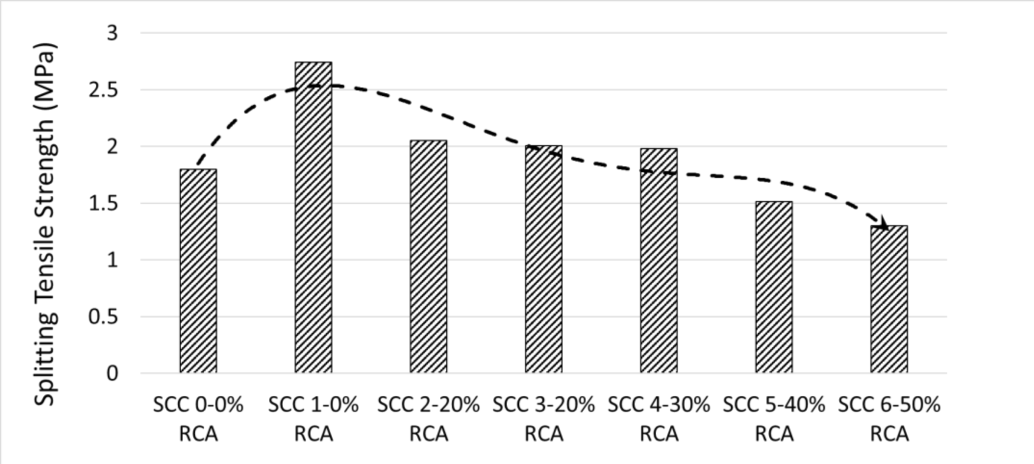

Figure 13: Variation of splitting tensile strength with respect to SCC specimens.

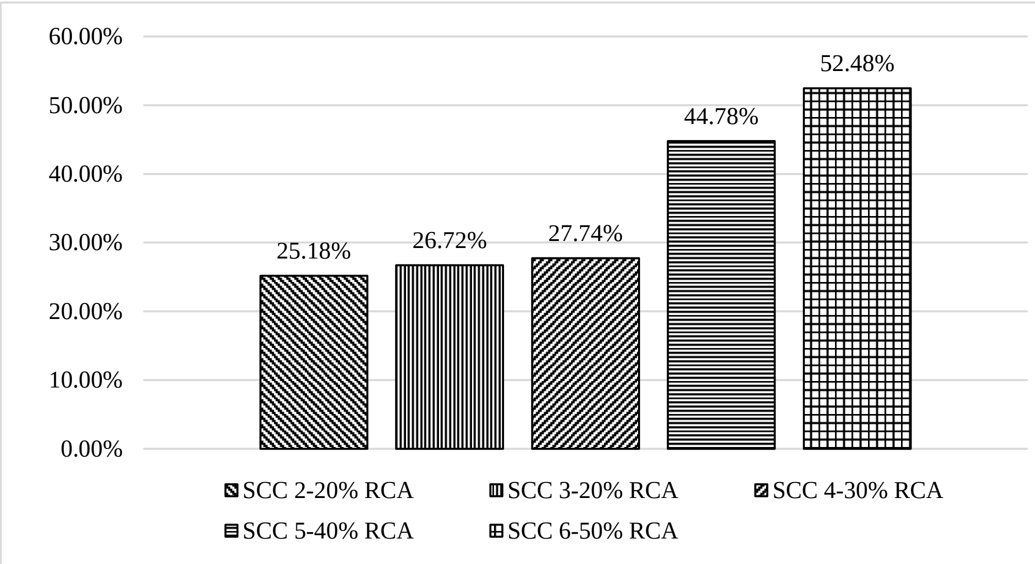

Figure 14: Variation of splitting tensile strength with respect to SCC 1-0% RCA.

4.CONCLUSIONS

The study depicts that there is distinct difference in the mix proportion for making SCC using NCA and RCA. Concrete properties at the fresh and hardened states also show some variations. Based on critical discussions, the following conclusions have been drawn:

- Mix design used for SCC using virgin aggregate should be modified to produce SCC using RCA.
- The quantity of NCA or RCA should be less than NFA in producing SCC.
- 10-12 mm RCA contains less residual mortar than 10-20mm RCA, which reduced the possibility of segregation, achieving SCC criteria. This also reduced weaker particle bonding between old attached mortar and new mortar, minimizing the possibility of microcracks.
- The irregular form and size of the RCA produced by the demolition of the pile head may have decreased the strength as well as flowability and passage ability.
- The property of RCA was also influenced by the age of the source concrete. The early demolished pile head's old attached mortar's cement was not hydrated completely. It may be assumed that the volume and size of voids in the transition zone will be larger. As a result, it leads to lower strength.

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