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Comparative Study on Properties of Self-Compacting Concrete Made with Recycled Aggregate

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Abstract

In the field of construction, self-compacting concrete is gaining popularity around the world as mechanical vibration is not required for compaction. With the rise in population in the world, demolition of old structures is increasing to provide accumulation, producing crushed concrete wastes. So, recycling these wastes as aggregates to reduce pollution with green concrete is becoming a popular practice. This paper represents the comparison of properties of self-compacting concrete produced with the replacement of fresh aggregate by different percentages i.e., 0% and 20% by recycled aggregate, with possible influence of aggregate properties.The coarse aggregate size was kept between 10-20mm and 10-12mm.The properties of self-compacting concrete are workability in congested reinforcement without segregation, providing the required strength. These properties depend on the particle size of recycled coarse aggregates, the presence of attached mortar, etc. In this research, the fresh properties such as passing ability, filling ability, and segregation resistance were tested by using the slump flow test method, L-box test method, and V-Funnel test method respectively. For measuring the properties of hardened concrete, compressive strength and splitting tensile strength test methods were followed. The test results show that the workability and strength of self-compacting concrete decreases with the increase in recycled coarse aggregate.

Keywords: *Self-compacting concrete; recycled coarse aggregate; green concrete; attached mortar.*

1 Introduction

Concrete is a compound material composed of fine and coarse aggregate mixed with a fluid cement paste that hardens over time. Conventional concrete possesses several limitations, including bleeding and segregation. Compressive strength is directly related to the degree of compaction. It becomes very difficult to achieve the desired level of compaction, especially where the reinforcements are closely spaced. Self-compacting concrete (SCC) may be the possible solution to this case. SCC was first developed in Japan in 1988 and gained popularity due to its inherent properties of self-compaction and durability. SCC is now being used in Bangladesh in major construction projects such as Rooppur Nuclear Power Plant. SCC is a largely flowable and self-consolidating type of concrete that offers enhanced workability, bettered consolidation, reduced noise, and climate effects, increased design freedom, and enhanced surface finish. SCC comes with an advanced cost due to the use of specialty admixtures, fine aggregates, and complex mix design conditions that demand skills and extensive testing. SCC is sensitive to component proportions and requires close monitoring to maintain consistency. There's also a threat of segregation if not appropriately managed, and SCC may have limited bearing in heavily reinforced or high early-strength designs. Assessing the values and faults is key in determining SCC's suitableness for a specific construction design (Grdic et al., 2010).

Many researchers pointed out that the rate of building demolition is increasing, and there is a need to reuse these demolition wastes to reduce the dumping cost as well as to conserve nonrenewable natural resources. Recycled coarse aggregate (RCA) in SCC offers several advantages as it promotes environmental sustainability by reducing dump operations and conserving natural resources, reducing cost, and reducing the carbon trace associated with concrete manufacturing (Kapoor et al., 2016). However, the quality of RCA may vary considerably, negatively impacting the performance of SCC. Pollutants and contaminations in RCA, similar to residual mortar, can affect strength and durability. Gradation and particle shape differences from natural aggregates may impact workability, flowability, and mix design adaptations. Advanced humidity absorption of RCA can affect the water-cement ratio as well as the properties of fresh and hardened SCC. Thorough testing, quality control measures, and applicable mix design adaptations are vital for the successful objectification of recycled coarse aggregate into SCC, maximizing benefits while addressing implicit downsides (Silva et al., 2016).

This study investigates the impact of incorporating varying quantities of RCA in SCC as a substitute for fresh coarse aggregate. Through primary tests, it was determined that using 50% RCA achieved optimal sustainability (Revilla-Cuesta et al., 2020). However, in this research, 4 trial mixes were done for SCC where 20% RCA with 10-12mm size achieved the most satisfactory criteria. The fresh concrete behavior of these SCC mixes met the recommendations of EFNARC (EFNARC, 2002). The study further examined the progress of both fresh and toughened properties, comparing experimental and theoretical values deduced from compressive and splitting tensile strengths. This exploration confirms the suitableness of RCA for structural SCC as green concrete, emphasizing the significance of applicable dosage selection to meet concrete design purposes.

2 Methodology

2.1 Materials

Specimens used in this research were prepared from conventional concrete (CVC) and SCC. For these concrete preparations, natural coarse aggregate (NCA), RCA, natural fine aggregate (NFA), water, CEM I, fly ash, and superplasticizer were used as ingredients. RCA was produced from the demolished and crushed pile heads. A conventional local crusher was used for crushing the bulk pile head into the desired size. Next, 10-20mm and 10-12mm sized RCA were separated by sieving.The RCA is shown in Figure 1. Standard tests were performed for NCA, NFA, and RCA by following suitable standards. The obtained physical and mechanical properties of these materials are shown in Table 1. The gradation curves of aggregates are illustrated in Figure 2. To obtain the criteria of SCC (EFNARC, 2002), CEM I was used. Fly ash was collected from local cement manufacturers. Master Glenium SKY 8632 was used as a chemical admixture which is a polycarboxylic ether-based superplasticizer, used for conducting high strength in SCC. Fly ash and the superplasticizer were used as admixtures, and their properties are shown in Table 2. The aggregates were used in SSD condition during each casting of concrete specimens to prevent micro-cracks in the specimens.

Figure 1. RCA from demolished pile head.

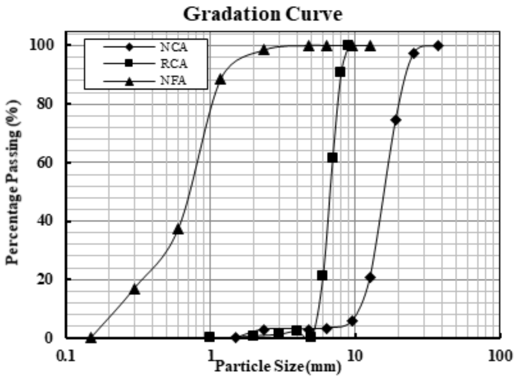

Figure 2. Gradation Curve of Aggregates.

Table 1. Properties of Aggregates

Properties	NCA	RCA	RCA	NFA
Size	10-20mm	10-20mm	10-12mm	<4.75mm
Specific Gravity	2.52	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-colored 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 100kg of cementitious material used

2.2 Standard Tests

2.2.1 Standard Tests for Determination of Properties of Materials Used

Tests were performed following ASTM C 127 and 128 (ASTM, 1998) to determine the properties of NCA, RCA, and NFA. RCA was produced from demolished pile heads which were fairly new concrete. The attached mortar to the aggregate contains more pores therefore water absorption became higher than the fresh aggregate. Nili et al., (2019) and Ali and Hamid (2015) also reported that RCA shows a higher percentage of water absorption mainly due to the presence of a large amount of attached mortar. The size of NCA was kept at 10-20mm and the RCA was adopted between 10-20mm and 10-12mm to obtain SCC criteria and strengths compared to conventional concrete.

2.2.2 Workability Tests of Fresh SCC

The workability of SCC was measured with the following test method and standards: L-box Test: For measurement of passing ability, the L-box test was performed following EFNARC (EFNARC, 2002). V funnel Test: This test was done specially for SCC to determine the segregation resistance (EFNARC, 2002).Slump flow Test: This test is performed to assess the free flow of SCC in the absence of obstruction. Slump flow was measured following ASTM 1611(ASTM, 1998).

2.2.3 Tests for Hardened SCC

Compressive Strength Test: This test was done on CVC and all the specimens of SCC (ASTM C 39, 2001) at the curing age of 28 days. The specimens were cylindrical having 100mm diameter and 200mm height. Splitting Tensile Strength Test: For both CVC and SCC, cylindrical specimens of 150mm diameter and 300mm height were used for testing (ASTM C 496, 2010).

2.3 Concrete Mix Proportions

CVC specimens were prepared following ACI Concrete Mix Design (2021). For each compressive and splitting tensile strength test, a total of six test specimens were prepared. In the preparation of SCC, the first goal was to achieve the special criteria of SCC. As SCC has no specific mix design yet, so trial-and-error process was adopted. The first trial was done for making SCC with 0% RCA following IS-10262 (2021), designated as SCC 0-0% RCA. The first trial did not meet the SCC criteria. The mix proportion was altered and the next trial was performed with 0% RCA specified as SCC 1-0% RCA. After success, the SCC specimens were made for different percentages of RCA i.e., 20% RCA with 10-20mm particle size, 20% RCA with 10-12mm particle size. The CVC and SCC mix proportions are shown in Table 3. These SCCs were prepared using a tilting drum mixer in the laboratory. A total of 30-cylinder specimens were prepared, half of which were used for compressive strength test and the rests were for splitting tensile strength test. After 4 days of casting, the specimens were demolded and kept in water for curing. For each proportion, 3 specimens were taken for a single test and the final result was the average of them.

Figure 3. Preparation of specimens.

Table 3. Mix Proportions of Specimens (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	340	113.2	705.26	937.44	-	-	0.6	0.42
SCC 1-0% RCA	220	490	160	790	700	-	-	0.4	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

3 Results and Discussions

3.1 Fresh Concrete Properties

At first, a slump test was done on CVC. The obtained slump value was 150mm, resulting in a true slump. In the case of SCC 0-0% RCA, there seemed deprivation from the required values for L-box and slump flow tests. The target was to achieve SCC criteria (EFNARC, 2002). For SCC 0-0% RCA (IS-10262, 2021), the samples did not meet the standard criteria for slump flow and L-box test though the samples satisfied the V-funnel test. The size of NCA being 10-20mm, with a larger quantity than NFA, may be an influencer for decreasing the passing ability in L-box and the flowability in the slump flow test of SCC 0-0% RCA. To overcome this obstacle, we did a new trial designated as SCC 1-0% RCA, reducing the NCA amount to that of NFA. SCC 1-0% RCA resulted in satisfying the SCC criteria (EFNARC, 2002) as shown in Table 4. Following the same process, SCC 2-20% RCA specimens were prepared using both NCA and RCA of 10-20mm size, which did not achieve the recommendation for the L-box test (EFNARC, 2002). Here larger particle size of RCA might be the potential influencer for blocking of L-box, reducing the passing ability. After this, SCC 3-20% RCA was prepared using 10-12mm RCA, which satisfied the SCC criteria with some changes. Variations in slump flow, V-funnel, and L-box test results have been identified due to the change in RCA size which is shown in Figure 4. It's been found out that, keeping both the NCA and RCA of 10-20mm i.e., using larger RCA, SCC 2-20% RCA faced a 0.84% decrease in slump flow value than that of SCC 1-0% RCA. Again, using 10-12mm RCA in SCC 3-20% RCA resulted in a 3% increase in slump flow value than that of SCC 1-0% RCA. The V-funnel result increased by 28.57% for both SCC 2-20% RCA and SCC 3-20% RCA than SCC 1-0% RCA. The L-box result did not meet the SCC criteria for SCC 2-20%RCA, but SCC 3-20% RCA satisfied the recommendation for L-box (EFNARC, 2002), by 0.5% increase than SCC 1-0% RCA. RCA are highly porous due to the presence of attached mortar, so they have high water absorption (Théréné et al., 2020). A greater amount of attached mortar in RCA enhances the porosity and water absorption in the SCC. The attached mortar also increases friction influencing the interlocking behavior among the aggregates. All of these results in gradual lower flowability and passing ability with a gradual increase in the percentage of RCA (Mo et al., 2020). As the amount of attached mortar gets reduced in smaller RCA, this may have prevented blocking and bleeding of SCC, assuring a homogeneous SCC mixture. This may be the reason behind satisfying the L-box test by enhancing passing ability. As larger RCA get thicker water coating than that of smaller RCA, this may influence bleeding of SCC. RCA from demolished pile heads were used in this research. Recycled pile head aggregates are subjected to more irregular shapes and rough surfaces as more amount of NCA is used in their mix design (Munaga et al., 2020). As a result, the mix design also includes specialty. So, the origin of RCA can also be a significant influencing factor. The size of NCA and RCA is a considerable factor in this research. The larger aggregate size affects particle-to-particle bonding and fluidity. As a result, RCA size 10-20mm resulted in lower flowability than that of 10-12mm RCA.

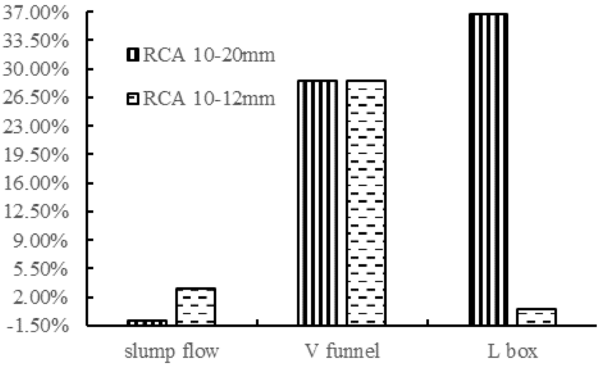

Figure 4. Variation of workability test results of SCC with respect to RCA size.

Figure 5. Slump flow test, L-box test, and V-funnel test of SCC.

Table 4. Workability Test Results of SCC

Cylinder Designation	Slump flow (mm)	V-funnel test (sec)	L-box test (h2/h1)	Remarks
Recommended limit	650-800	6-12	0.8-1	
SCC 0-0% RCA	550	12	>1	Did not meet the SCC criteria
SCC 1-0% RCA	755.65	7	0.805	Successfully met the criteria
SCC 2-20% RCA	749.3	9	>1	Did not meet the SCC criteria
SCC 3-20% RCA	778.35	9	0.809	Successfully met the criteria

3.2 Compressive and Splitting Tensile Strength

The comparison of compressive strength and splitting tensile strength among CVC and SCC specimens are shown in Table 5. It can be seen that the compressive strength of CVC remains higher than SCCs. In SCC 2-20% RCA, the compressive strength decreased by 6.27% and the splitting tensile strength decreased by 11.22% than that of SCC1-0% RCA. For SCC 3-20% RCA, 1.94% decrease in compressive strength and 7.65% decrease in splitting tensile strength was found, compared to SCC 1-0% RCA. The logical causes of the decrease in compressive strength were stated as the high porosity of RCA, irregular shape with attached mortar, percentage of mortar present, and weak RCA-mortar matrix interface bond (Santos et al, 2019). With the reduction in RCA size, the amount of old mortar also gets reduced, which may contribute to the strength increase in SCC 3-20% RCA than that of SCC 2-20% RCA. Also, smaller RCA discourages the possibility of microcrack production more than that of larger RCA, enhancing the strengths of SCC. For 10-20mm RCA, splitting tensile strength reduction can be identified as the difference in the elasticity of new and old cement mortar which produces microcracks (Singh et al, 2019). Also, the SSD condition of RCA might result in bleeding later, increasing the water-to-binder ratio. As the role of admixture is not clear here, this increased water-to-binder ratio could result in the weaker strength of the interfacial transition zone. Figure 6 shows testing of compressive and splitting tensile strength tests.

Figure 6. Compressive Strength and Splitting Tensile Strength Testing.

Table 5. Compressive Strength and Splitting Tensile Strength Test Results

Cylinder Designation	Average Compressive Strength (MPa)	Cylinder Designation	Average Splitting Tensile Strength (MPa)
CVC	33.47	CVC	1.88
SCC 0-0% RCA	19.31	SCC 0- 0% RCA	1.68
SCC 1-0% RCA	30.95	SCC 1-0% RCA	1.96
SCC 2-20% RCA	29.01	SCC 2-20% RCA	1.74
SCC 3-20% RCA	30.35	SCC 3-20% RCA	1.81

4 Conclusions

From this study, the following conclusions are drawn:

1. SCC may be produced using 10-20mm NCA, along with 10-20mm RCA and 10-12mm RCA.
2. The production satisfies the SCC criteria with a slight reduction in obtained test values for inclusion of 10-20mm RCA, compared to SCC made with 10-12mm RCA.
3. Replacement of NCA with increasing quantity of RCA resulted in a reduction in workability mainly due to the presence of more attached old mortar.

4. Smaller RCA particles (10-12mm) improve workability by reducing attached mortar, porosity, and bleeding. This offsets issues like old mortar and irregular aggregate size.
5. RCA collected from demolished pile heads are subjected to irregular shapes and rough surfaces with more crushed NCA. As a result, particle-to-particle bonding and fluidity of SCC may be affected.
6. Use of smaller size RCA in SCC results in higher strength than that of larger size RCA. This may happen as smaller particle reduces the presence of microcrack and less old mortar contributes to strength.

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