The Use of Recycled Coarse Aggregate in Self-Compacting Concrete - A Review

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A project report submitted to the Department of Civil Engineering of Sonargaon University (SU) in partial fulfilment of the requirements for the degree of Bachelor of Science in Civil Engineering

Department of Civil Engineering

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Section: 13 Semester: Fall-2021

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CERTIFICATION

This is to certify that the project paper on **The Use of Recycled Coarse Aggregate in Self-Compacting Concrete** is the confined record of project work done by us as a group and others for partial fulfilment of the requirement of the degree of B.Sc. in Civil Engineering from the Sonargaon University (SU).

This project work has been carried out under my guidance and is a record of successful work.

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It is hereby declared that this thesis/project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Dedicated

to

“Our beloved Parents”

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ABSTRACT

Self-compacting concrete (SCC) possesses several benefits in terms of production and placement over traditional concrete. Elimination of external or internal vibration of compaction, better flowability, workability, pumpability, and as well as increased bonding with congested reinforcement are some of the benefits of using SCC. And if we can use recycled coarse aggregate (RCA) as the coarse aggregate in SCC, there is a possibility to decrease the environmental impact of producing concrete. The work that we are presenting in this paper explores to construct upon the knowledge that we can get on this topic. We reviewed the workability, strength, and fracture properties of SCC's containing 0%, 25% 50%, 75% and 100% of coarse RCA from 4 different thesis papers. Reviewing those papers, we found out that if we use 25% and 50% RCA in SCC, there is little to no negative impact that can be observed for workability and strength properties in all of them . However, with increasing the level of RCA more than 50% showed decrease in strength tests.

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CHAPTER - 1

INTRODUCTION

1.1. General

Every year more than 26.8 billion tons of construction aggregates are being used all over the world. The use of aggregate is increasing every year in Bangladesh as well due to the growth in construction works. The maximum of the aggregate is obtained from natural resources. But for a country like Bangladesh where natural resources are limited and the anticipated pace of infrastructure development is quite fast, we can all concur with the fact that we need an alternative item if we want to preserve our natural resources and contribute something to the safety of the environment. Since the coarse aggregate forms the major volume of concrete there is a good opportunity to reduce the use of natural resources by using the recycled concrete as coarse aggregate. And in recent years the use of recycled aggregate has increased. The increase in building demolition is more than ever, making it necessary to reuse the waste from demolition. If we do not reuse this waste it will be disposed of in the landfill sites and that will create many environmental problems. As the use of self-compacting concrete is expanding as well this recycled concrete aggregate can be a significant element in that. Where SCC will provide better flowability, bonding with reinforcement, sustainability and RCA will provide an effective way to manage solid waste and help save natural resources. Nonetheless, using RCA might reduce the quality of concrete because it typically has poorer quality compared to natural coarse aggregate (NCA). But the water absorption is greater and the density is lower than NCA. But the cost of SCC is higher than traditional concrete due to the necessity of higher powder contents and admixtures [1]. Hence, to make SCC more cost-effective we can use RCA as the alternative to natural coarse aggregate (NCA) [4]. The use of RCA as coarse aggregate will reduce the cost of SCC and also the carbon footprint from the production of concrete.

1.2. Objectives

Following specific objectives mentioned below will be found in this paper:

1. Fresh concrete tests recycled coarse aggregate and natural coarse aggregate used self-compacting concrete.
2. Hardened concrete tests of recycled coarse aggregate and natural coarse aggregate used self-compacting concrete.
3. Comparison between recycled coarse aggregate used self-compacting concrete with natural coarse aggregate used self-compacting concrete.

1.3. Background of the Study

The waste from demolition is increasing as many buildings are being reconstructed. This solid waste from demolition has a great impact on the environment. Also, the amount of

natural resources we use in construction is very worrying. The carbon emission from the many machines such as vibrators is concerning for the well being of our environment. But we know that the use of recycled coarse aggregate and the use of self-compacting concrete is growing day by day. However, using both of these in the same project is still a new thing in Bangladesh. Not many people from Bangladesh have done any research on it either. Our motivation for this study was how we can reuse something so that we can save our natural resources. Also, we wanted to get an idea on whether we can use recycled coarse aggregate in self-compacting concrete to cut down its cost by how much possible. As we all know that self-compacting concrete is costlier than regular concrete.

In this paper, we attempted to evaluate both of our motivations and to get to a conclusion.

1.4. Limitation

Due to the wild spreading of Covid-19 in the world, all the labs and facilities are shut down in Bangladesh. Because of this, unfortunately, we weren't able to do the experiment by ourselves. The next best option was to review some already existing experiments and several other researchers' work on this topic. All the data that is shown in this review was taken from some existing papers where they represented the use of RCA in SCC. Those papers are mentioned in the reference section.

CHAPTER - 2

LITERATURE REVIEW

2.1. Introduction:

2.1.1. Self-compacting Concrete (SCC): Self-Compacting Concrete or Self-Consolidating Concrete, SCC, is defined as a Concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity. It was originally developed in Japan, to overcome the problems caused by lack of complete and uniform compaction through vibrators. It has since proved to be economically beneficial because of a number of factors:

1. Improved durability and compressive strength.
2. Easier placing and hence reduction in manpower at the time of placing better surface finishes.
3. Greater freedom in design which can lead to thinner concrete sections.
4. Reduced noise levels because of absence of vibration.

SCC can be used even in the presence of dense reinforcements due to its flowing, passing and filling abilities.

2.1.2. Recycled Coarse Aggregate (RCA): Recycled concrete aggregates are fragments and pieces of concrete buildings which are demolished or rebuilt. These crushed concretes are cleaned from dirt and broken to smaller pieces to manufacture aggregate which is termed as recycled aggregate. Crushed concrete aggregate eliminates the need for disposal by using the readily available concrete as an aggregate source for new concrete or other applications. Crushed concrete and applications are presented based on the specifications of ACI 555R-01, British Standard, and Building Contractors Society of Japan. The density of crushed concrete aggregate is smaller than natural aggregate density.

Water absorption of recycled aggregate is greater than of natural aggregate. It is one of the most significant properties that distinguish recycled aggregate from raw aggregates. Water absorption of recycled aggregate influences both fresh and hardened concrete properties. Recycled sand will be avoided, due to its absorption capacity, which would no doubt produce a shrinkage effect. Workability of recycled aggregate concrete is affected by the absorption capacity of the recycled aggregates.

2.2. Literature Review References

1. **M. Tuyan, A. Mardani-Aghabaglou, and K. Ramyar, "Freeze-thaw resistance, mechanical and transport properties of self-consolidating concrete incorporating coarse recycled concrete aggregate,"** *Materials and Design, vol. 53,* pp. 983–991, 2014.

The effects of coarse recycled concrete aggregate on freeze-thaw resistance, mechanical performance and transport properties of self-consolidating concrete (SCC) were investigated. Recycled concrete aggregate (RCA) was substituted for crushed coarse limestone aggregate as 0, 20, 40 and 60 wt% of limestone aggregate. Mixtures having three different water/binder (w/b) ratios (0.43, 0.48 and 0.53) were prepared. The properties of fresh concrete were determined by using the slump-flow, V-funnel and L-box tests. Compressive and splitting tensile strength, ultrasonic pulse velocity (UPV), water absorption, water sorptivity, chloride-ion penetration and freeze-thaw resistance of hardened concrete were determined. Test results indicate that in RCA containing mixtures, the viscosity of the SCC mixtures increased significantly. The compressive strength of SCC mixtures improved slightly with increasing the coarse RCA content up to 40%. In addition, water absorption and chloride-ion penetration of SCC mixtures increased slightly by the incorporation of RCA. On the other hand, the splitting tensile strength, unit weight, UPV, water sorptivity and freeze-thaw resistance of concrete decreased in RCA containing mixtures.

2. **K. Kapoor, S. P. Singh, Bhupinder Singh, "Evaluating the Durability Properties of Self Compacting Concrete made with Recycled Concrete Aggregates."** *Journal of Materials and Engineering Structures Volume 3, Pages 107-116, 2016*

This paper reports the durability properties of Self Compacting Concrete (SCC) made with Recycled Concrete Aggregates (RCA) as partial/full replacement of Natural Coarse Aggregates (NCA). The effect of RCA on fresh properties of SCCs was measured using slump flow test, V-funnel test, L-box test and J-ring test. Whereas the durability properties such as initial surface absorption, water permeability, capillary suction and rapid chloride penetrability were investigated to study the effect of varying content of RCA on SCC. The compressive strength of different SCC mixes was also determined for reference. The results indicate that increasing the content of RCA in SCC leads to deterioration in durability related properties of SCC. The compressive strength has also been found to decrease with increasing

RCA content. It has been seen that the reduction in the performance has been marginal up to 50% replacement level of RCA, but 100% replacement of RCA has been found to significantly affect the durability related properties and compressive strength.

3. **Sufian Kamaruddin, Wan Inn Goh, Ashfaque Ahmed Jhatial, Shahrifah Salwa Mohd Zuki, Amirul Faiz, "Self-compacting Concrete with Incorporation of Recycled Concrete Aggregates."** *International Journal of Integrated Engineering 11 (9), 164-173, 2019*

At the present the natural resources of aggregates are decreasing day by day due to usage of aggregates in construction industry rises. To overcome this problem, Self-Compacting Concrete (SCC) consisting of recycled concrete aggregate (RCA) has the potential to save the natural resources of aggregate and reduce the solid waste generation. In this research, natural aggregates were replaced using RCA at different percentages ranging from 0% to 100% with an increment of 25%. The mechanical properties like filling ability, passing ability, segregation resistance, compressive and tensile strength of M30 grade SCC were examined at 7 and 28 days water curing regimes. Based upon the results it was observed that the slump flow decreased when RCA was incorporated. Furthermore, a similar trend was observed in the compressive and tensile strength of SCC containing RCA where 4% to 6% loss in strength was observed compared to control samples.

4. **W. C. Tang, P. C. Ryan, H. Z. Cui, and W. Liao, "Properties of Self-Compacting Concrete with Recycled Coarse Aggregate,"** *Advances in Materials Science and Engineering 2016, 2016.*

The utilisation of recycled concrete aggregate (RCA) in Self-Compacting Concrete (SCC) has the potential to reduce both the environmental impact and financial cost associated with this increasingly popular concrete type. However, to date, limited research exists exploring the use of coarse RCA in SCC. The work presented in this paper seeks to build on the existing knowledge in this area by examining the workability, strength, and fracture properties of SCCs containing 0%, 25%, 50%, 75%, and 100% coarse RCA. The experimental programme indicated that at RCA utilisation levels of 25% to 50% little or no negative impact was observed for strength, workability, or fracture properties, with the exception of a slight reduction in Young's modulus.

5. **S. C. Kou and C. S. Poon, "Properties of self-compacting concrete prepared with recycled glass aggregate,"** *Cement and Concrete Composites, vol. 31, no. 2,* pp. 107–113, 2009.

The effects of recycled glass (RG) cullet on fresh and hardened properties of self-compacting concrete (SCC) were investigated. RG was used to replace river sand (in proportions of 10%, 20% and 30%), and 10mm granite (5%, 10% and 15%) in making the SCC concrete mixes. Fly ash was used in the concrete mixes to suppress the potential alkali-silica reaction. The experimental results showed that the slump flow, blocking ratio, air content of the RG–SCC mixes increased with increasing recycled glass content. The compressive strength, tensile splitting strength and static modulus of elasticity of the RG–SCC mixes were decreased with an increase in recycled glass aggregate content. Moreover, the resistance to chloride ion penetration increased and the drying shrinkage of the RG–SCC mixes decreased when the recycled glass content increased. The results showed that it is feasible to produce SCC with recycled glass cullet.

6. **Nischay T G, S Vijaya, B Shiva Kumaraswamy, "A Study on the Properties of Self Compacting Concrete using Recycled Aggregate in Fresh and Hardened State."** *International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 4 Issue 06, June-2015*

Construction and Demolition waste management issues have attracted researchers around the world. The boom in the construction sector and large-scale mechanization in concrete production has led to setting up of several ready-mixed-concrete (RMC) plants. The present study aimed at producing fine and coarse aggregates from the hardened concrete waste available at the RMC plant on the outskirts of Bangalore. The material characterization for both fine and coarse aggregates was carried out as per IS: 2386 (Part IV) – 1963. The test results have shown that the properties of recycled aggregates satisfy the codal provisions specified for natural aggregates. The M-20 self compacting concrete mix with 0%, 25%, 50%, 75% and 100% replacement of fine and coarse aggregates were done separately in two batches. Third batch mixes consist of both fine and coarse aggregates replacement of 0%, 25%, 50%, 75% and 100%. Further the fresh and hardened properties of M-20 self compacting concrete mix has been carried out systematically. It was observed that 50% replacements in all the three batches of M-20 concrete mix have exhibited satisfactory flow and compressive strength values.

CHAPTER - 3

METHODOLOGY

3.1. Materials:

For all the SCC mixes that Tang et al, 2016 [4] examined the binder content consisted of Ordinary Portland Cement (OPC), fly ash (FA), and silica fumes(SF). The OPC used in this work was ASTM Type I Portland cement, with a fineness of 3520 cm^2/g and a density of 3150 kg/m^3. The FA and the SF were used in accordance with EN 450-1:2005A [7] and ASTM C 1240-11 [8], respectively. The recycled aggregate used was a crushed and unwashed recycled concrete aggregate, with a nominal size of 10 mm sourced from a construction and demolition waste recycling facility. The coarse natural aggregate consisted of crushed granite with a nominal size of 10 mm. Table 1 presents the water absorption (24 hours) and density of the natural and recycled coarse aggregates. The fine aggregate used in the study was river sand, with a fineness modulus of 2.65. The particle size distributions of all the aggregates used were in accordance with the requirement of EN 12620:2002A [9].

In Kapoor et al, 2016 [2] Portland cement was used as the principal binder and FA war also blended with it in the concrete. The standard that was followed here for NCA is IS 383:1970. Crushed rock with a fineness modulus of 6.13 was used as NCA in the SCC mixes. The fine aggregates consisted of clean river sand with fineness modulus 2.64. Table 1 consists of the properties of Cement, sand and NCA.

And Kamaruddin et al, 2019 [3] also used the Ordinary Portland Cement as binding material (Grade 53) which has similar specifications given in MS EN 197-1:2007. River sand was used as fine aggregate and crushed rock was used as natural aggregates were utilized as coarse aggregates having maximum size was 12mm. The RCA was obtained from the waste of concrete and sieved from a 12mm sieve. The water absorption of sand, natural aggregates and RCA were analyzed using BS 1881-122:2011 [17] method and specific gravity was also examined by utilizing the BS EN 1097-3:1998 [18]. The physical properties of cement, sand, and natural aggregate are presented in Table 1.

In Nischay et al, 2015 [6] the material characterization of recycled coarse aggregate was done as per Indian standards. Here also the Ordinary Portland Cement was used as the binder like the other papers. However, there isn't any mention about the type of sand that was used in the mix. Also, they didn't mention what they used as NCA either. But the properties of cement, sand and NCA are shown in Table 1 like the other papers.

Table 3-1. Values for the properties of ingredients other than recycled aggregates used in the literature.

Ingredients	Name	FM	Water absorption (%)	Density (Kg/m³)	Reference
Cement FA NCA	OPC River sand Crushed granite	- 2.65 -	- - 1.15	3150 815 2650	Tang et al, 2016 [4]
Cement FA NCA	OPC River sand Crushed rock	- 2.64 6.13	- - -	430 846 602	Kapoor et al, 2016 [2]
Cement FA NCA	OPC River sand Crushed rock	- 3.10 4.17	- 1.08 1.28	- 1672 1620	Kamaruddin et al, 2019 [3]
Cement FA NCA	OPC Sand -	- 3.26 3.34	- 0.73 0.40	1600 1250-1690 1468	Nischay et al, 2015 [6]

Now, In Tang et al, 2016 [4] RCA was used with a nominal size of 10mm, 7.75% of water absorption and 2450 kg/m³ of density. Kapoor et al, 2016 [2] also used the same size (10mm). But other specifications such as FM, water absorption and density weren't declared in their paper. On the other hand, in Kamaruddin et al, 2019 [3] all the specifications were given. And it is all shown in Table 2. As for the Nischay et al, 2015 [6] no size for the coarse aggregate was mentioned in the paper but the FM, water absorption and density of the RCA were mentioned in the paper. All the properties of RCA from all 4 papers are shown in Table 2.

Table 3-2. Recycled aggregate properties used in the literature.

Types	Size (mm)	FM	Water absorption (%)	Density (kg/m³)	Reference
RCA	10	-	7.75	2450	Tang et al, 2016 [4]
RCA	10	-	-	-	Kapoor et al, 2016 [2]
RCA	12	5.98	4.38	1418	Kamaruddin et al, 2019 [3]
RCA	-	3.1	3.43	1407.30	Nischay et al, 2015 [6]

In this work, 5 different SCC mixes were examined with percentages of substitution of natural coarse aggregates with RCA of 0%, 25%, 50%, 75% and 100%. Mix design details (based on aggregates being in the saturated surface dry condition) for each of these five mixes are presented in Table 3 [3] [4] [6]. In Kapoor et al, 2016 [2] 3 different mixes were examined with percentage of substitution of natural coarse aggregate with RCA of 0%, 50%, and 100%. Mix design for each of these three mixes are also presented in Table 3. The water/binder (w/b) ratio and superplasticizer dosage were the same for the five mixes examined [3] [4] [6]. For the experimental programme described in this paper, the natural and recycled coarse aggregates were immersed in water for 24 hours and left for 1 hour in the air before concrete mixing to reach surface dry condition [2] [3] [4] [6].

Table 3-3. Concrete mix details (1 m³ concrete).

Mix code	w/b ratio	Water (Kg/m³)	Cement (Kg/m³)	FA (Kg/m³)	SF (Kg/m³)	10 mm aggregate (Kg/m³)	River sand (Kg/m³)	Recycled 10 mm aggregate (Kg/m³)	Recycled 10 mm aggregate (%)	SP (1/m³)	Ref.
Control RCA25 RCA50 RCA75 RCA100	0.35	220	445	155	30	660 495 330 165 0	815	0 152 305 458 610	0 25 50 75 100	4.5	Tang et al, 2016 [4]
C-R0 C-R50 C-R100	-	277	430	185	-	602 301 0	846	0 301 602	0 50 100	-	Kapoor et al, 2016 [2]
M0 M1 M2 M3 M4	-	-	-	-	-	-	-	-	0 25 50 75 100	-	Kamarud din et al, 2019 [3]
B1-0 B1-1 B1-2 B1-3 B1-4	-	190	320	88	-	820 615 410 205 0	968	0 205 410 615 820	0 25 50 75 100	3.26	Nischay et al, 2015 [6]

3.2. Test Methods and Sample Preparation:

3.2.1. Fresh Concrete Tests: Three tests were done to investigate the fresh properties of the SCs in Tang et al, 2016 [4] and they are: the slump flow test, the L-box test, and the sieve segregation test. These three tests will assess the primary characteristic of fresh SCC. The slump flow test and the t_{500} time evaluate the flowability and viscosity of a SCC in the absence of any obstruction, respectively. The slump flow diameter is the measurement required for all SCC in accordance with EN 206-9:2010 [10]. The Eurocode states that SCC should have a slump flow value of between 550 mm and 850 mm, while □$_{500}$ times less than two seconds result in VS1 classification, while t_{500} times greater than or equal to two seconds result in a VS2 classification.

The L-box test was performed in accordance with EN 12350-12350-10 [12]. This test is used to assess the passing ability of SCC. EN 206-9:2010 (2010) [10] states that for an L-box with

three reinforcement bars the blocking ratio (value) should be greater than or equal to 0.80 [9].
The final workability test, the sieve segregation test, was performed in accordance with EN 12350-11:2010 [12]. The test examines the resistance of SCC to segregation by measuring the mass of fresh concrete which passes through a 5mm sieve when poured from a height of 50 cm ± 5 cm. EN 206-9:2010 states that the percentage passing the sieve ( ) should be less than 20% [9].

In Kapoor et al, 2016 [2] only slump flow tests and L-box tests were done. With slump flow tests, t500 values were also determined from the specimens. To test these EFNARC guidelines were followed. Although, no limit for slump flow test, the t500 value and L-box were mentioned.

EFNARC guidelines [21] were also followed by Kamaruddin et al, 2019 [3]. But here only the slump flow test and sieve segregation test were done. And the limit for slump flow test according to EFNARC guidelines [21] is 610-650mm. And the sieve segregation shouldn't be more than 10%.

As for Nischay et al, 2015 [6] we already knew that the Indian standard was followed here. But there was mention of limits for slump flow tests here. Only the slump flow test was done here for fresh concrete.

3.2.2. Hardened Concrete Tests: Standard concrete specimens are cast to study the strength properties (compressive strength, f_c, tensile strength, f_t, and elastic modulus,) according to the relevant British and European standards [4]. Notched concrete beams with the dimensions 75 × 75 × 250 mm are used to study the strength tests in Tang et al, 2016 [4]. The bending tests are conducted using a universal testing machine [2] [3] [4] [6]. Before testing the beam samples, a notch 20 mm in depth and 2 mm in thickness is saw-cut at the midsection of each beam [4]. However, no such thing was done in any other papers that we are reviewing.

In Kamaruddin et al, 2019 [3] The compressive and splitting tensile strength of SCC containing the RCA were investigated by utilizing the British standards BS EN 12390-3:2009 [19] and BS EN 12390-6:2009 [20] respectively. The sample cubes having size 100mm x 100mm x 100mm and cylinders having diameter 100mm and 200mm height were tested for compressive and tensile strength for each sample.

However, In Kapoor et al, 2016 [2] Compressive strength tests were conducted under Compression Testing Machine in accordance with IS 516-1959 [22]. A water permeability test were also done in Kapoor et al, 2016 [2] for concrete's strength test. The test was carried out in accordance with BS EN 12390-8:2000 [23].

Nischay et al, 2015 [6] is the only paper where only the compressive strength was tested for hardened concrete tests. Also, no standard was mentioned here.

CHAPTER - 4

RESULTS & DISCUSSION

4.1. Fresh Concrete Properties:

4.1.1. Water Absorption of RCA: From Table 2 we can see that the porosity of RCA is increased compared to natural aggregates in all the papers. And for that RCA has a greater water absorption capacity [2-4] [6]. And this quality allows RCA to absorb some water from the mortar phase when it is in dry conditions and also maybe allows it to gain slightly more water content from the saturation phase. Which is not always ideal. As it will make the concrete porous inside [4].

4.1.2. Fresh Concrete Test Results: From [2] [3] [4] and [6] we got a table (Table 4) where the results of slump flow, blocking ratio, and sieve segregation for the control SCC and the other SCCs with different ratio of RCA for all the papers are presented in one place.

Table 4-1. Fresh concrete test result.

Mix code	Slump flow value (mm)	t_{500} value (s)	L-box value (ratio)	Sieve segregation (%)	Reference
Control RCA25 RCA50 RCA75 RCA100	710 700 720 710 700	2.9 3.7 3.9 4.1 4.3	0.94 0.95 0.97 0.92 0.93	9.90 7.70 6.30 6.00 5.20	Tang et al, 2016 [4]
C-R0 C-R50 C-R100	720 700 690	2.5 2.8 3.2	0.95 0.92 0.82	-	Kapoor et al, 2016 [2]
M0 M1 M2 M3 M4	655 640 635 630 620	-	-	5 5 4 3 3	Kamaruddin et al, 2019 [3]
B1-0 B1-1 B1-2 B1-3 B1-4	740 690 650 630 580	-	-	-	Nischay et al, 2015 [6]

EN 206-9:2010 [10] states that SCC should have a slump flow value of between 550 and 850 mm; the blocking ratio ≥ 0.80, and sieve segregation < 20%. Starting with the slump flow test, from Table 4 we can see that the value is within the limit that is stated in EN 206-9:2010 [10]. However, the t_{500} value has a greater percentage increase with increasing RCA content. As for Kapoor et al, 2016 [2] both the slump flow test results and the t500 value are decreasing as the RCA level increases. Although, no limit was given here to know if it is in limit or not.

Now for the L-box test result, as it was stated in the previous section this test measures the passing ability of the SCC, thus quantifying the suitability of the SCC for use in a member with congested reinforcement [4]. From Table 4 we can clearly see that the replacement of natural coarse aggregate with RCA has very little effect on the blocking ratio on both Tang et al [4] and Kapoor et al, 2016 [2] as these two are the only papers where L-box tests were done. The specimen where 75% and 100% of RCA were used has a little less value [4]. However, all the blocking ratios from Tang et al, 2016 [4] are within the limit of the standard that [4] followed. And Kapoor et al, 2016 [2] found 0.95, 0.92 and 0.82 in C-R0, C-R50 and C-R100 respectively. Indicating that the increase in RCA causes a decrease in blocking ratio.

Now Both Kamaruddin et al, 2019 [3] and Nischay et al, 2015 [6] have done slump flow tests and Kamaruddin et al, 2019 [3] we can see that the results are all in between 655mm to 620mm. Making the M0 where no RCA used exceeds the higher limit. Besides that, all the other specimens where RCAs were used are in the limit according to EFNARC guidelines [21].

Now for the sieve segregation, we can see in Tang et al, 2016 [4] results that the segregation resistance of the SCCs increased with increasing RCA content. But all the SCCs are within the limit according to EN 206-9:2010 [10]. And Only other paper where the sieve segregation test was done is Kamaruddin et al, 2019 [3] where the results of the segregation resistance of the SCCs also increased with the increasing RCA content. But here also all the SCCs are within the limits according to EFNARC guidelines [21].

4.2. Strength Properties: All the collected results of strength tests from [2] [3] [4] [6] are included in another table (Table 5) where The test results for concrete compressive strength, splitting tensile strength, water permeability test and the static modulus of elasticity are presented.

Table 4-2. Strength properties of the used literatures

Mix code	Compressive strength, f_c (MPa)	Tensile strength, f_t (MPa)	Young's modulus, E (GPa)	Water permeability test (mm)	Ref.
Control RCA25 RCA50 RCA75 RCA100	59.4 63.7 65.3 60.0 53.8	4.1 4.9 4.1 3.9 3.8	31.5 30.3 29.5 28.5 24.5	-	Tang et al, 2016 [4]
C-R0 C-R50 C-R100	38 36 33	-	-	2.54 2.58 3.50	Kapoor et al, 2016 [2]

M0 M1 M2 M3 M4	35.92 34.97 34.09 32.98 31.21	2.87 2.79 2.72 2.63 2.50	-	-	Kamaruddin et al, 2019 [3]
B1-0 B1-1 B1-2 B1-3 B1-4	28.92 27.60 26.31 25.45 20.20	-	-	-	Nischay et al, 2015 [6]

From Table 5, it can be seen that the compressive strength of the concrete where 25% and 50% of RCA were used are significantly greater than the control mix. However, for 100% of RCA, the compressive strength is lesser than the control mix [4]. And for 75% of RCA, it can be seen that it has almost the same compressive strength as the control mix [4]. This phenomenon can be seen in other studies like [1] [11]. The increased surface roughness of recycled aggregate and the role of the differing water absorption coefficient of recycled aggregate could be the possible reasons for this phenomenon [1] [11]. However, as Tuyan et al, 2014 [1] stated if too much water is absorbed insufficient water content and poor hydration will reduce strength development in the concrete.

Now if you look at Kapoor et al, 2016 [2] there the specimen where no RCA were used has the highest compressive strength. However, the difference between the No RCA concrete and 50% of RCA made concrete is very low. But when Kapoor et Al, 2016 [2] used 100% of RCA in the concrete, the compressive strength dropped down quite significantly. There is a huge difference between Tang et al, 2016 [4] and The other literature paper's [2] [3] [6] compressive strength as we can see in Table 5 and compare them. Compared to [2] [3] [6] Tang et al, 2016 [4] used the most admixtures in the concrete mix as we can see in Table 3. This is probably the reason for having such compressive strength.

Kamaruddin et al, 2019 [3] has found quite a similar pattern in the compressive strength test results. And that is As the level of RCA is increasing the compressive strength of the concrete is going down. But M1 specimen where 25% of RCA and M2 specimen where 50% of RCA were used has somewhat closer compressive strength to M0 or specimen where no RCA were used.

Moving on to Nischay et al, 2015 [6] compressive strength test results, A peculiar result for compressive strength can be seen here. As we learned from Table 3 earlier Nischay et al, 2015 [6] has used super plasticizer in the mix. However, the result [6] has put out is quite low compared to other literature that we reviewed [2] [3] [4]. We still don't know the reason for that. But if we just look at the results and try to evaluate, here also we can see from B1-0 to B1-4 the compressive strength has been decreasing gradually. For 25% of RCA in B1-1 and for 50% of RCA in B1-2 the decrease level is not that noticeable. However, in B1-4 where 100% of RCA was used, the change in compressive strength compared to its control specimen is very low.

The tensile strength results show a relatively identical pattern to the compressive strength results in both Tang et al, 2016 [4] Kamaruddin et al, 2019 [3] as these two are the only literature among the 4 we reviewed that have done splitting tensile strength. And that is the tensile strength initially increasing at the lower levels of RCA utilisation, followed by a decrease in strength where the RCA content is more than 50% [4]. It can be seen from the table that the tensile strength of RCA25 is much higher compared to the control mix. However, as the level of RCA increases the changes become more subtle. We found some other research papers where they did a similar test and the result was kind of similar [1] [11]. Increasing the level of RCA to 50% and more causes a decrease in tensile strength [1] [11]. The reason behind it can be the higher porosity and lower specific gravity of the RCA compared to the natural aggregate [1]. But for Kamaruddin et al, 2019 [3] there is no increase in tensile strength found in any of the specimens from M1 to M4 where RCA were used. Instead Kamaruddin et al, 2019 [3] had reduction in tensile strength as the RCA level increased.

Now, we can see in Tang et al, 2016 [4] that the decrease in modulus of elasticity goes higher with the increase of RCA content. Such decreases are to be anticipated given the fact that the modulus of elasticity of concrete is related to the modulus of elasticity of the coarse aggregate as stated in Kou et al, 2009 [5]. Now, as this is the only literature paper among the four that has done modulus of elasticity test we weren't able to compare it to others in this test. But it can be said from modulus of elasticity results that as the RCA level increases the concrete become more brittle [4].

There is an another strength test result can be found in Kapoor et al, 2016 [2] where a water permeability test were done. This test was performed in accordance with BS EN 12390-8:2000 [23]. From the test results, increase in the depth of water penetration can be seen in C-R50 where 50% RCA was used compared to control mix. And this increase go much higher compared to control mix in C-R100 where 100% RCA was used [2].

Evaluating these strength test, the results suggest that the use of RCA in proportions of 25% and 50% do not negatively affect the compressive strength and the tensile strength of SCC compared to control mix [2] [3] [4] [6]. Even the use of 100% RCA in the SCC exhibits quite a low reduction of compressive and tensile strength compared to the control SCC in Tang et al, 2016 [4] for its use of more admixtures. However, this is not the case for all of the literature that we reviewed. Most of them showed decrease in both compressive and tensile strength, water permeability test when the level of RCA increased. However, in Tang et al, 2016 [4] it is Young's modulus that increased with the increase of RCA across all SCCs. And that can cause brittleness of concrete that is constructed with 100% RCA.

CHAPTER - 5

CONCLUSIONS

Now, before conclude, a quick comparison between NCA used SCC and RCA used SCC can be done here after evaluating four literature's tests and their results:

Table 5-1. A comparison between NCA used SCC and RCA used SCC.

NCA used SCC	RCA used SCC
NCA used SCC absorbs less water as the NCA is less porous compared to RCA	RCA used SCC absorbs more water because of RCA's high water absorption rate.
The workability and flowability here is prominent.	The Workability and flowability is slightly less here but not noticeable.
The strength of the concrete is better than RCA used SCC.	With a significant amount of RCA in the SCC, the strength properties get close to NCA used SCC.
Concrete is less brittle.	Concrete is more brittle.
More costly than RCA used SCC.	Less costly than RCA used SCC.

This paper builds by studying and investigating research papers on SCC and the effect on SCC's workability, strength characteristics, and fracture properties when the various levels of RCA are used in the mix. From all of the discussion and references, we found that the viscosity of the SCCs increases with the increase of RCA content as stated in Tang et al, 2016 [4]. This also happens for sieve segregation resistance [3] [4]. There can also be seen a notable reduction in the passing ability for RCA utilisation beyond 50% but the reduction was still within allowable limits.

As we go further into the research and investigate the strength characteristics such as compressive strength, tensile strength, modulus of elasticity, water penetration test of the SCCs, we found out that there was not much mentionable impact upon the strength of SCC where RCA was used within 25%-50%. But the issue was with 75%-100% RCA. The compressive strength, tensile strength, modulus of elasticity and water permeability in for 75% of RCA and 100% RCA was notably reduced compared to the control SCC [2] [3] [6]. However, for Tang et al, 2016 [4] the results of all the tests was higher than the other three literature because of its higher use of admixtures. Although Tang et al, 2016 [4] got higher test results in every test the brittleness that comes with lower modulus of elasticity is concerning. And that means if the SCC is constructed entirely with RCA it will possibly face brittleness.

After all these test results from four research literature that was reviewed by us we can conclude by saying that we can improve the environmental and economic aspects of SCC without impacting the properties such as workability, strength characteristics if we use RCA within 25% to 50% in the concrete. Saying that some increase in concrete brittleness can occur at this lower level of RCA replacement as well.

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