PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering – Port Said University
Volume (21) No. (2) September 2017 pp. 78:87

Mechanical Properties of Self Compacting Recycled Aggregate Concrete

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ABSTRACT

Concrete wastes are generally delivered to the landfill sites for disposal. Due to increasing charges of landfill and scarcity of Natural Coarse Aggregate (NCA), recycled concrete aggregate (RCA) derived from concrete wastes is growing interest in construction industry. In the present study, RCA was used as partial and full replacements of NCA to produce durable Self-Compacting Concrete (SCC). Different SCC mixes were produced with RCA substituting 0%, 25%, 50%, 75%, and 100% NCA by weight, 20% MP and 3% admixture. The water to powder (W/P) ratio are variable after adding water absorption to concrete mixes. The effects of RCA on the key fresh properties such as filling ability, passing ability, and segregation resistance of SCC were investigated and the effects of RCA on hardened concrete such as cube and splitting strength , abrasion resistance , Cantabro test and RCPT test to evaluate durability. The test results revealed that the filling ability and passing ability of SCC were improved for all mixes. All mixes of SCC also possessed adequate segregation resistance. In addition, strong correlations were observed for passing ability, and segregation resistance. The test result of hardened concrete revealed that mixes up to 50%RCA gives normal strength and accepted durability. From the overall test results it could be concluded that RCA can be used to produce SCC substituting up to 50% NCA without affecting the key properties of fresh concrete, give normal strength and accepted durability.

Keywords: *filling ability, passing ability, recycled concrete aggregate, segregation resistance, self-compacting concrete*

1. INTRODUCTION

Self-Compacting Concrete (SCC) is a highly flowing concrete that spreads through congested reinforcement areas, fills every corner of the formwork, and gets consolidated under self-weight [1]. The concept of SCC was proposed in 1986 by Okamura [2], and the first prototype was developed in Japan in 1988 by Ozawa [3]. However, the development of SCC was first reported in 1989 [4]. By the early 1990’s, Japan started to produce and use SCC commercially. Since its inception, SCC has been widely used in large construction in Japan [2]. Globally, the use of SCC in civil engineering structures has been remarkably increased over the last two decades.

The basic ingredients of SCC are similar to those of normal concrete. The traditional concrete aggregates such as gravel or crushed stone, and river or mining sand are also used in SCC. Generally, the aggregates occupy 55–60% of the SCC volume [2] and play a substantial role in determining the workability, strength, dimensional stability, and durability of concrete. The aggregates also have a significant effect on the cost of SCC. Therefore, less expensive aggregates are desirable for use in SCC.

In addition, there is a critical shortage of natural aggregates in many regions of the world due to construction boom in developing countries and reconstruction [5].

Recycled aggregate has been used as a replacement of the natural aggregate. The potential benefits and drawback of using recycled aggregate in concrete have been extensively studied [1-8]. The use of recycled aggregate generally increased the drying shrinkage, creep and water sorptivity and decrease compressive strength and modulus of elasticity of recycled aggregate concrete compared to those of natural aggregate concrete [9-12]. The poor performance of the recycled aggregate concrete is associated with the cracks and fissures, which were formed in recycled aggregate during processing thereby rendering the aggregate having weaker and more susceptible to permeation diffusion and absorption of fluids [10]. This may also be due to presence of old recycled aggregate on interfacial transition zone and adhesive mortar in the recycled aggregate which makes recycled aggregate concrete more permeable than normal aggregate concrete [13], These drawbacks limit the utilization of the recycled aggregate with higher percentages (>30%) in the structure concrete.

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Many studies have shown that the using recycled aggregate in concrete suffers from durability problems [10, 14-21]. Hansen and Boegh [14] reported that compared with the reference concrete. The shrinkage of recycled aggregate concrete was increased by up to 60%. Domingo-Cabo[16] observed that the shrinkage of recycled aggregate using 100% recycled aggregate was about 70% higher than that of the control concrete after a period of 180 days. Olorunsogo and Padayachee [10] reported that at curing ages of 3, 7 28 and 56 days compared with natural aggregate concrete. The water absorptivity of recycled aggregate concrete was increased by 47.5%, 43.6%, 38.5% and 28.8% respectively although the process of water absorption in both types of concrete were similar and obeyed the same law.

In the present study, the RCA derived from tested concrete was used to produce SCC substituting 0–100% NCA by weight. The effects of RCA on the key properties of fresh SCC such as filling ability, passing ability, and segregation resistance, effect of RCA on hardened concrete such as compressive and splitting strength of SCC were observed. The effect on durability was studied.

2. MATERIALS AND METHODS

2.1. Materials

Two types of aggregates are used; crush dolomite and recycled concrete aggregate. The used fine aggregate is natural sand. The nominal size of both coarse aggregates is 20mm. The physical properties of recycle concrete aggregate (RCA), natural coarse aggregate (NCA) and fine aggregate (FA) are shown in Table1.

Table 1: Basic physical properties of fine and coarse aggregates.

Physical properties	RCA	NCA	FA	Limits of ESS1109
Specific gravity	2.6	2.64	2.65	2.5 → 2.75
Unit weight(gm/cm^3)	1.65	1.7	1.55	-------
Absorption percent	1.9	1.7	1.3	Not exceed 2.5%

The size distributions of FA, NCA, and RCA were within the ESS1109 limits, as shown in Figures 1&2. RCA had porous surfaces consisting of reclaimed mortar and thus possessed a higher absorption value than NCA (Table 1).

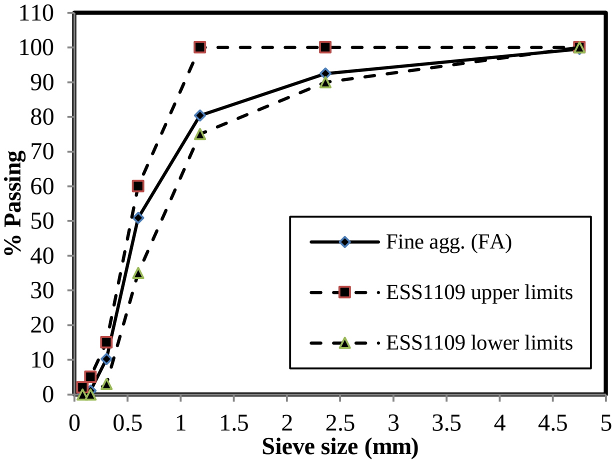

Figure1: Grading curve of fine aggregate and ESS1109 limits.

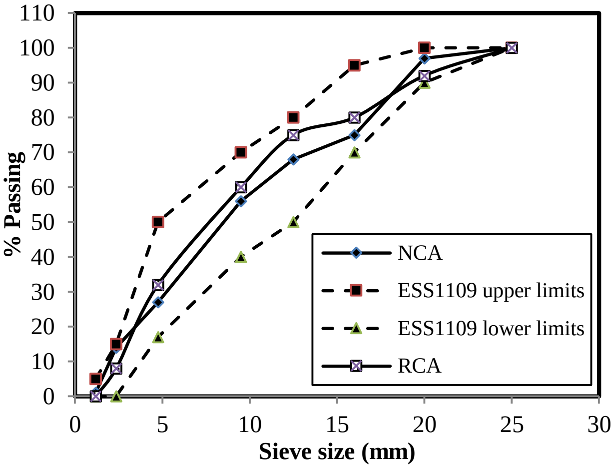

Figure2: Grading curve of coarse aggregate and ESS1109 limits.

The aggregates were bond together by means of paste, which contained cement and water. ASTM Type I Portland cement (C) was used as the binder. The mix water (W) used was normal tap water. Also, 20% marble powder (MP) was used as filling material and 3% admixture (Sikament-NN) was used to obtain the required fresh properties of SCC without segregation . The specific gravity of cement as tested was 3.12 and for marble powder was 2.42 .

2.2. Concrete Mix Properties

Five different mixes of six were produced with RCA substituting 20%, 25%, 50%, 75% and 100% NCA by weight where the six mix without RCA is control mix. The basic mix proportions of these concretes were calculated based on the absolute volume of constituent materials and 3% admixtures. The MP of these concretes were kept the same as used in the control mix (0% RCA) to observe the effects of RCA. The mix proportions of control and RCA concretes are shown in Table 2.

Table 2: Mix proportions of SCC mixes (volume of concrete: 1m^3).

Mix	C (kg)	W (kg)	MP (kg)	NCA (kg)	RCA (kg)	FA (kg)	A (litre)	W/P (%)
0% RCA	360	178	90	797	---	875	12	1.16
20% RCA	360	181	90	638	159	865	12	1.19
25% RCA	360	185	90	548	183	858	12	1.21
50% RCA	360	187	90	365	365	852	12	1.23
75% RCA	360	190	90	182	544	848	12	1.25
100% RCA	360	194	90	---	720	841	12	1.27

2.3. Test Methods and Procedures

Immediately after the completion of mixing, the freshly SCC mixes were tested to determine the filling ability, passing ability and segregation resistance.

The different hardened concrete compositions were submitted to the following tests: cube, splitting strengths, abrasion resistance test, contabro test and rapid chloride permeability test to evaluate durability

2.3.1. Filling Ability Tests

The filling ability is defined as the ability of SCC to flow in unconfined condition and fill every corner of the formwork under self-weight. The filling ability was measured with respect to slump flow, (T50 slump flow time, and V-funnel flow time). The slump flow was determined according to the test method given in ASTM C 1611/C 1611M [22].

The T50 slump flow time and V-funnel flow time (TV) was determined according to the test method given in EFNARC guidelines and specifications [23]. In T50 test, the time that a concrete sample requires for a spread of 50 cm diameter and for V-funnel test, the time that a concrete sample needs for flowing out of a V-shaped box is determined to measure the filling ability of SCC.

2.3.2. Passing Ability Tests

The passing ability is the ability of SCC to flow in confined condition and completely fill all spaces within the formwork under self-weight and with no vibration. The passing ability was determined with respect to L-box flow (LB) and U-box flow (UB) following the test method depicted in EFNARC specifications and guidelines [23].

2.3.3. Segregation Test

The Japanese sieve stability and column segregation tests were carried out to determine the segregation resistance of SCC mixes. The Japanese sieve stability test was conducted according to the procedure given by Nagataki and Fujiwara [24]. In this test, the mortar mass passing through a sieve size (5mm) was expressed as the percentage of the total mortar content of original concrete sample to quantify the segregation resistance of SCC with respect to segregation ratio (SR).

3. RESULTS AND DISCUSSION

The test results for filling ability (slump flow, T50 slump flow time and V-funnel flow time), passing ability (L-box flow and U-box flow), and segregation resistance of various SCC mixes are given in Table 3.

Table 3: Properties of fresh SCC mixes.

Concrete	Filling ability			Passing ability		Segregation Sieve stability
	Slump	T50 slump	V-funnel	L-box	U-box	
EFNARC Specification	**650 to 800 (mm)**	**2 to 5 (sec.)**	**6 to 12 (sec)**	**0.8 to 1**	**0 to 30 (mm)**	**5 to 15 (%)**
0% RCA	655	3	10	0.84	26	8.2
20% RCA	670	2.7	9	0.86	24	10
25% RCA	700	2.4	8.1	0.90	20	11.3
50% RCA	680	2.6	8.5	0.88	22	10.5
75% RCA	626	3.3	11	0.81	31	6
100% RCA	590	3.9	13.2	0.77	36	5.2

3.1. Filling Ability

3.1.1. Slump Flow

The slump flow varied in the range of 625 – 700mm. According to EFNARC specifications and guidelines [23] , the SCC with 0% , 20% , 25% and 50% RCA give the requirement for slump flow.

The effect of RCA on the slump flow of SCC is evident from Figure 3, which shows that the slump flow increased for 20% , 25% and 50% RCA compared with 0% RCA . This is mainly attributed to the reduced content of coarse aggregate.

At the reduced fine aggregate contents Table 2, more free water were available to improve filling ability of concrete in addition the paste volume per unit aggregate content become higher, thus reducing the friction between aggregate particles. As the result, the dispersion of aggregate increased leading to a greater slump flow.

The substantial in slump flow is mostly due to the increased amount of fine aggregate that caused to decrease the free water content in SCC mix.

A slight reduction in slump flow occurred owing to the adverse physical characteristics (angularity, surface roughness, surface porosity , etc.) of RCA.

The RCA used was more angular than NCA. The high absorption capacity of RCA also indirectly suggests that it was more porous and much rougher than NCA due to reclaimed mortar. The rough-textured RCA particles increased the harshness of SCC mix, and thus can decreased its slump flow at a greater RCA content.

The loss of cement paste into the surface pores of RCA can also decrease the slump flow of concrete. However , these effects were not predominate due to the reduction in post-mixing coarse aggregate content with a subsequence increase in amount of fine aggregate.

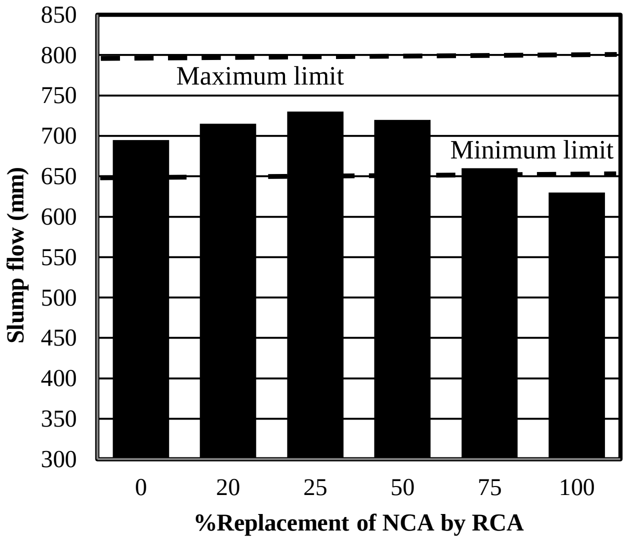

Figure 3: Effect of RCA on slump flow of concrete.

3.1.2. T50 Slump Flow Time

The T50 slump flow time varied in the range of 2.4 – 3.9 sec. According to EFNARC specifications and guidelines [23] , the T50 slump flow time of SCC were within the acceptable range.

The effect of RCA on T50 slump flow time of SCC is evident from Figure 4. The T50 slump flow time decreased for 20% , 25% and 50% RCA. This is mostly due to the reduced content of coarse aggregate however , the role of reduced coarse aggregate content in reducing T50 slump flow time was not predominate at 75% and 100% RCA due to the similar reason as discussed in section 3.1.1 .

The fine aggregate confines some mix water, thus decreasing the free water content in the concrete mix, in addition, the greater surface roughness and angularity of RCA increase the friction between coarse aggregates. These two effects were more dominate for 75% and 100% RCA. As a result, the SCC mixes with 75% and 100% RCA became more viscous and provided a higher T50 slump flow time.

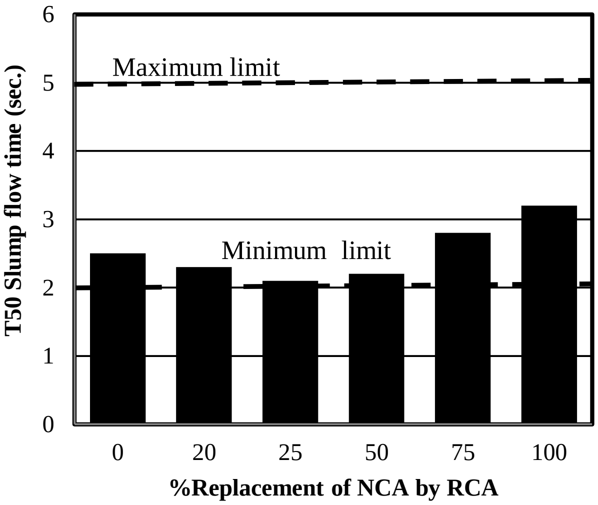

Figure 4: Effect of RCA on T50 slump flow time.

3.1.3. V-funnel Flow Time

The V-funnel flow time varied in range 8.1 – 13.2 sec. According to EFNARC specifications and guidelines [23] , the V-funnel slump flow time of SCC were within the acceptable limits except 100%RCA.

A high flow time can be caused by either a low flowing ability or blockage of flow. The lack of cohesiveness can caused accumulation of coarse aggregate in the tapered outlet of a V-funnel. This can lead to arching of coarse aggregate loading to the blockage of concrete flow. However, the good cohesiveness 100% RCA as indicated by T50 slump flow time, suggests that the blockage due to coarse aggregate arching was unlikely for this concrete. Therefore, the high V-funnel flow time was most mostly due to its low following ability, as perceived from the results of slump flow test.

The variation in V-funnel flow time followed a similar trend as observed in the case of T50 slump flow time. The effect of RCA on the V-funnel flow time of SCC is evident from Figure 5.

The flow time decreased for 20% , 25% and 50% RCA but significantly increased for 75% and 100% RCA. The reasons are the same as discussed in the case of T50 slump flow time (section 3.1.1).

The shorter flow time indicates the greater flowing ability of concrete [23]. However, a very small flow time does not necessarily give an indication of good flowing ability. In fact, the SCC mixes with a very low V-funnel flow time show excessive bleeding and/or segregation, thus causing blockage leading to intermittent concrete flow. Also, the SCC mixes with a very high V-funnel flow time are greatly viscous and therefore may exhibit intermittent concrete flow with a reduced flowing ability.

For instance, the SCC with 100% RCA provided a high V-funnel flow time of 13.2 sec.

This high flow time was linked with an excessive viscosity that interrupted the continuous flow of concrete through the lower opening of V-funnel

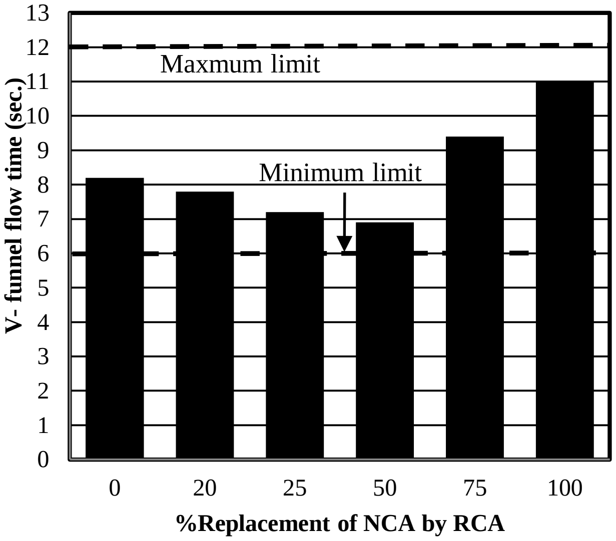

Figure 5: Effect of RCA on V-funnel flow time.

3.2. Passing Ability

3.2.1. L-box Flow

The ratio of heights at the beginning and end of flow varied in the range of 0.81 – 0.90. According to EFNARC specifications and guidelines [23] , the ratio of heights of L-box flow of SCC gives the requirement for L-box flow.

The effect of RCA on the L-box flow of SCC is evident from Figure 6, which shows that the L-box flow increased for 20% , 25% and 50% RCA compared with 0% RCA . In contrast, the L-box flow decreased at 75% and 100% RCA indicating a lower passing ability. The RCA used was more angular than NCA. The high absorption capacity of RCA also indirectly suggests that it was more porous and much rougher than NCA due to reclaimed mortar. The rough-textured RCA particles increased the harshness of SCC mix, and thus can decreased its slump flow at a greater RCA content.

The higher replacement of NCA by RCA made the concrete harsh and increased the blocking tendency of SCC mix. At a higher content, the rough surface texture and angularity of RCA also became predominant to reduce the passing ability of SCC due to increased friction.

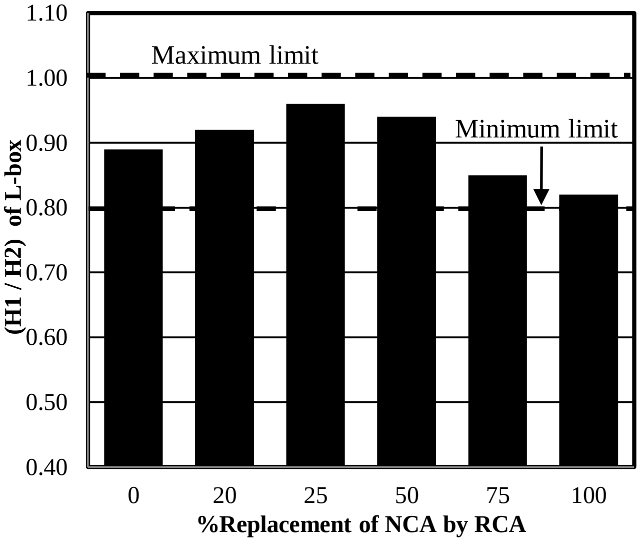

Figure 6: Effect of RCA on L-box flow.

3.2.2. U-box Flow

The difference in heights at the beginning and end of flow varied in the range of 20 – 36 mm. According to EFNARC specifications and guidelines [23] , the difference in heights of U-box flow of SCC generally from 0 to 30 mm. The SCC with 20% , 25% and 50% RCA give the requirement for U-box flow.

The effect of RCA on the U-box flow of SCC is evident from Figure 7, which shows that the U-box flow decreased for 20%, 25% and 50% RCA compared with 0% RCA. In contrast, the U-box flow increased at 75% and 100% RCA indicating a lower passing ability. The RCA used was more angular than NCA. The high absorption capacity of RCA also indirectly suggests that it was more porous and much rougher than NCA due to reclaimed mortar. The rough-textured RCA particles increased the harshness of SCC mix, and thus can decrease its slump flow at a greater RCA content.

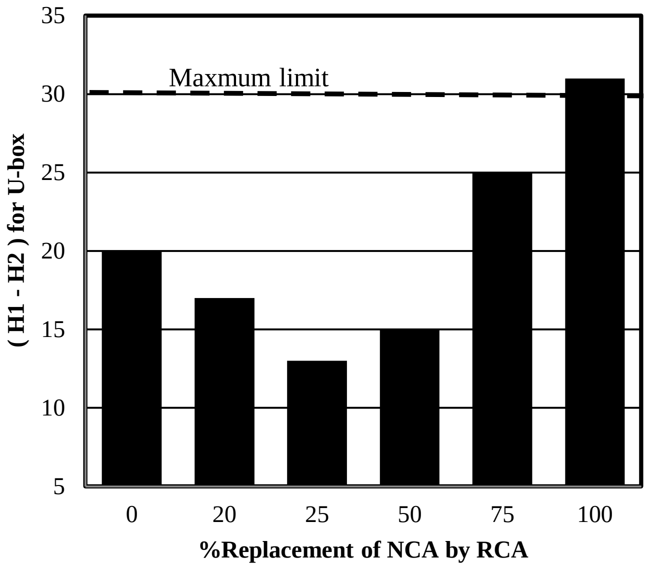

Figure 7: Effect of RCA on U-box flow.

3.3. Segregation Resistance

3.3.1. Segregation Ratio

The segregation ratio varied in the range of 5.2 –11.3 %. According to EFNARC specifications and guidelines [23] the segregation ratio of SCC exhibits an acceptable segregation resistance.

The effect of RCA on the segregation ratio is apparent from Figure 8. The SCC mixes with 20% , 25% and 50% RCA provided a higher segregation ratio than the control concrete (0% RCA) but mixes with 75% and 100% RCA gives lower segregation resistance . This is due to the less cohesive nature of these two RCA concretes at a lower aggregate content.

The slump flow, T50 slump flow time, and V-funnel flow time results suggest that the SCC mixes with 20% ,25% and 50% RCA possessed a lower cohesiveness than the control concrete. A decrease in the cohesiveness increases the separation of mortar, thus resulting in a higher value of segregation ratio. However, the segregation ratio was reduced at 75% and 100% RCA. This is because increased in angularity and surface roughness at a higher RCA content contributed to increase the cohesiveness, leading to a reduced segregation ratio.

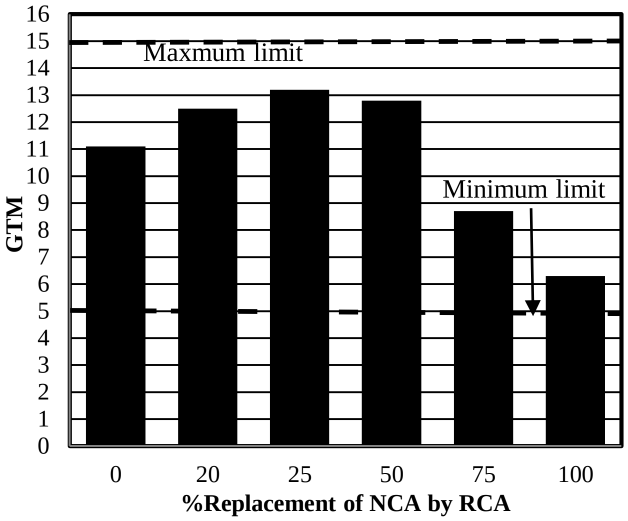

Figure 8: Effect of RCA on GTM.

3.4. Correlation Between V-funnel Flow Time and T50 Slump Flow Time

The relationship between T50 slump flow time and V-funnel flow time results is shown in Figure 9. It is obvious that the V-funnel flow time and T50 slump flow time of the SCC mixes were strongly correlated with a linear relationship.

The correlation coefficient was 0.9986, which suggests a strong relationship. The strong correlation was noticed because both T50 slump flow time and V-funnel flow time varied with the RCA content in a similar way.

Such strong correlation implies that either T50 slump flow or V-funnel flow test is adequate to assess the relative viscosity and cohesiveness of SCC.

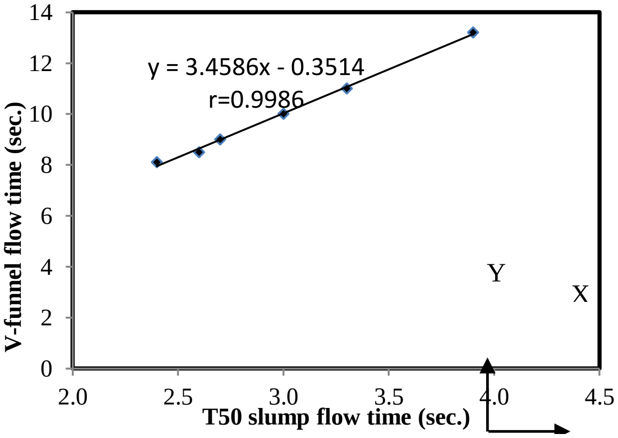

Figure 9: Correlation between V-funnel flow time and T50 slump flow time.

3.5. Segregation Ratio vs. Slump Flow

The relationship between slump flow and segregation ratio is shown in Figure 10. It is clear that the segregation ratio and slump flow of the SCC mixes were strongly correlated with a linear relationship. The correlation coefficient was 0.977, which indicates a strong relationship. The strong correlation was obtained since both slump flow and segregation ratio varied identically with the content. Such strong correlation also suggests that slump flow can give an indication for the segregation resistance of SCC.

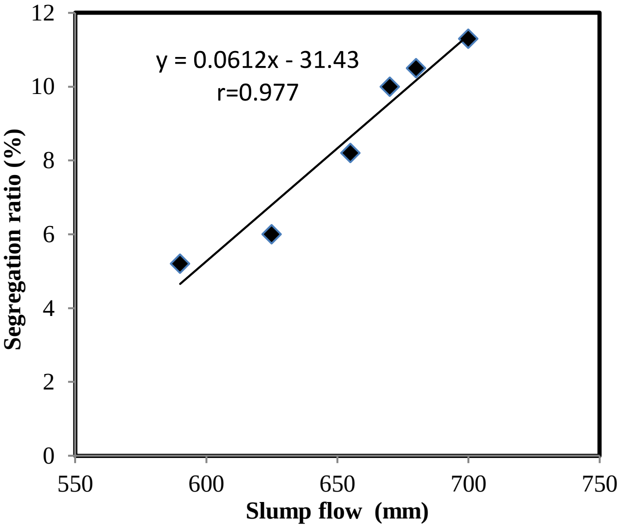

Figure 10: Correlation between segregation ratio and slump flow.

3.6. Hardened Concrete

3.6.1. Cube and Splitting Strength

The test results for cube and splitting strength of various SCC mixes at age of 28 days are given in Table 4.

Table 4: Cube and splitting strength of various SCC mixes at age of 28 days.

Concrete	Cube strength (kg/cm²)	Splitting strength (kg/cm²)
0% RCA	285	24
20% RCA	273	22
25% RCA	255	20
50% RCA	253	20
75% RCA	245	18
100% RCA	238	17

The effect of RCA on relative cube and splitting strength of SCC is evident from Figure 11 , which shows that the cube and splitting strength decrease as RCA percentages increase.

The percentages of decreasing of cube strength reached to 4 , 10 , 11 , 14 and 16 for RCA percentages 20% ,25% , 50%, 75% and 100% respectively, and for splitting strength the decreasing reached to 6 , 17 , 17 , 23 and 27 for RCA percentages 25% , 50% , 75% and 100% respectively. Mixes with 75% and 100% RCA give strength less than normal strength of concrete.

Increase in RCA content reduce the coarse aggregate content and increase W/P ratio because absorption percent of RCA greater than NCA it lead to reduction in strength.

There is an inverse relationship between the compressive strength and RCA replacement percent. As the replacement percent of RCA increased, the compressive strength was reduced.

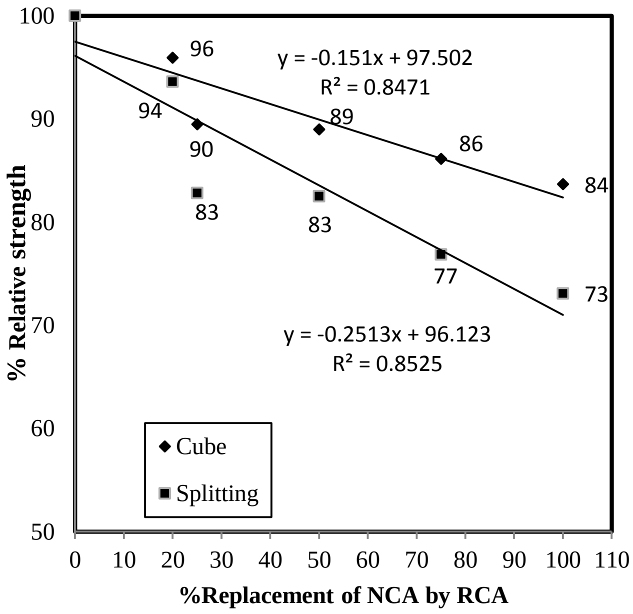

Figure 11: Effect of RCA on cube and splitting strength of hardened concrete.

3.6.2. Abrasion Resistance Test

Loss in thickness by abrasion for of various SCC mixes are given in Table 5.

Table 5:Results of abrasion resistance test (loss in thickness) of various SCC mixes.

Concrete	W (gm.) before	W (gm.) after	Δ m (gm.)	Δt (mm)
0% RCA	859	824	35	2.85
25% RCA	844	808	36	2.99
50% RCA	841	803	38	3.16
75% RCA	837	798	39	3.26
100% RCA	835	795	40	3.35

The effect of RCA on loss in thickness of SCC is evident from Figure 12 , which shows that the loss in thickness increases as RCA percentages increase.

Abrasion resistance depends mostly on the wear of cement paste, constituted by the fine aggregate and the cement and its connection to coarse aggregates. In other words, even tough the NCA more resistance to abrasion than RCA.

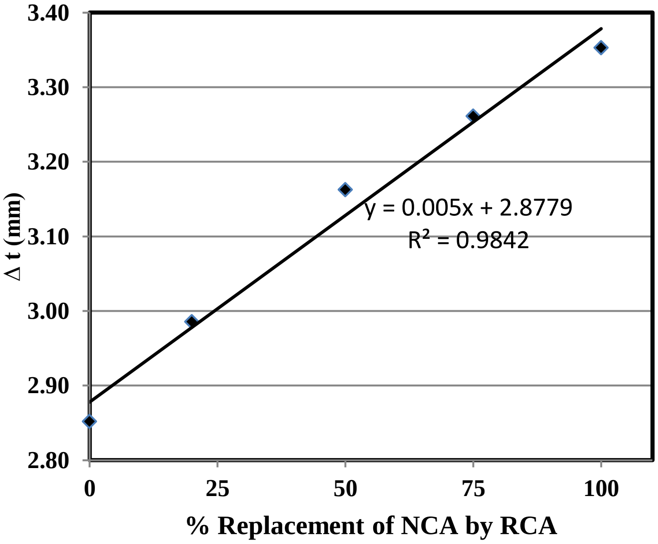

Figure 12: Effect of RCA on loss of thickness by abrasion of hardened concrete.

3.6.3. Cantabro Test

Test loss in weight of various SCC mixes are given in Table 6.

Table 6: Results of Cantabro test (percentages of loss in weight) of various SCC mixes.

Concrete	W (gm.) before	W (gm.) after	C.T(%)
0% RCA	4918	4550	7.5
25% RCA	4896	4520	7.7
50% RCA	4848	4450	8.2
75% RCA	4819	4395	8.8
100% RCA	4817	4330	10.1

The effect of RCA on percentages of loss in weight of SCC is evident from Figure 13 , which shows that the percentages of loss in weight increase as RCA percentages increase.

Loss in weight increase as RCA increases because the weak connection between RCA and cement paste. It is evident from cube and splitting strength.

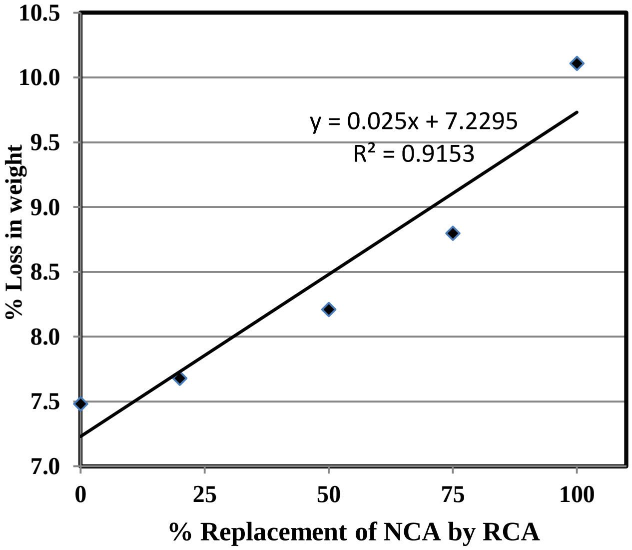

Figure 13: Effect of RCA on percentages of loss in weight of hardened concrete.

3.6.4. Rapid Chloride Permeability Test.

Rating of chloride permeability for various SCC mixes is given in Table 7.

Table 7: Results of rating chloride permeability of various SCC mixes.

Concrete	Charge Coulombs	Chloride permeability
0% RCA	71	Negligible
25% RCA	86	Negligible
50% RCA	102	Very Low
75% RCA	124	Very Low
100% RCA	125	Very Low

The effect of RCA on rating chloride permeability of SCC mixes is evident from Figure 14, which shows as RCA percentages increase the charge(Coulombs) increase.

Permeability of concrete depends on pore of concrete. Pore of concrete increased as RCA percentages increase and increase the charge .

The charge value 71 to 125 Coulombs is typically specified which is characterized as very low chloride permeability.

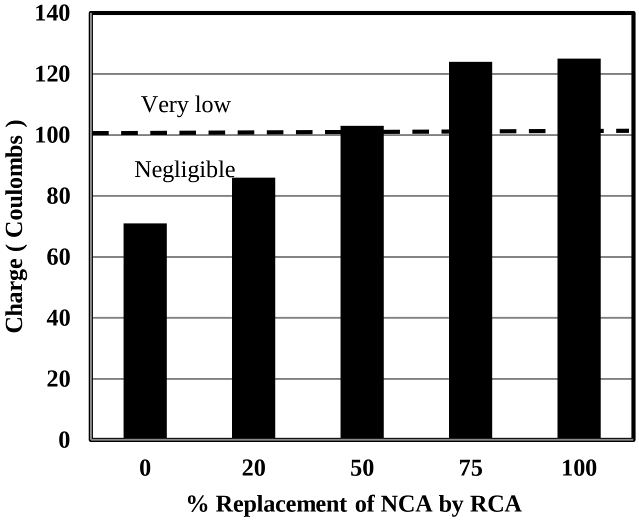

Figure 14: Effect of RCA on rating of chloride permeability of hardened concrete.

4. CONCLUSIONS

The following conclusions can be drawn based on the findings of the present study as folloows:

The filling ability and passing ability of SCC was improved at 20%, 25% and 50% RCA mainly due to reduced coarse aggregate content and relatively high paste volume per unit aggregate content. The SCC mixes with a RCA content higher than 50% more viscous as indicated by the T50 slump flow time and V-funnel flow time results. All SCC mixes had good segregation resistance, as noticed from the results of the Japanese sieve stability test. The segregation indices of concretes obtained from this test were significantly below the maximum limit (15%). The low values of segregation ratio at 75% and 100% RCA were obtained due to the significant non-uniform distribution of coarse aggregates that occurred during concrete placement mostly because of aggregate collisions at a relatively low fluidity.

The compressive strength decreased by about 12% and splitting strength decreased by about 9% by increasing recycled concrete aggregate contents in the mix.

The loss in thickness and weight of SCC mixes increased by about 6% by increasing RCA percentages from 25% to 50% . Increasing RCA percentages increase the rating of chloride permeability but according to ASTM C1202 if the rate from (100-1000) it is very low which was obtained with 50% , 75% and 100% RCA.

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