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Production of High Strength Self Compacting Concrete Using Recycled Concrete as Fine and/or Coarse Aggregates

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Abstract: Self-compacting concrete (SCC) is a new type of concrete which can be placed in every corner of formwork under its weight without any segregation. On the other hand, several million tons of concrete wastes have been generated annually in the world; the use of recycled aggregate for concrete is limited because of low density and high absorption due to adhered cement paste. In this study, the fresh and hardened properties of (SCC) using recycled concrete aggregate as both coarse and fine aggregates were evaluated. The SCC mixtures were prepared by replacing 25, 50 and 75% of coarse and/or fine recycled aggregates. The used water-to-binder ratio was 0.30 Silica fume and Super-plasticizer were also used to produce self-compacting concrete. The experimental program of the current study consisted of thirteen concrete mixes which reflect the key variables and their effects on the fresh and hardened properties of the produced SCC. The obtained results in all of the studied mixes indicated that the properties of the recycled aggregates SCCs have only a slight difference, in their properties from the natural aggregates SCC. The recycled concrete aggregate as both coarse and fine aggregates can successfully be used for making of SCC.

Key words: Compressive strength · Pass ability · Recycle concrete · Self compacting · Sump flow

INTRODUCTION

Self-compacting concrete (SSC) is a highly flowing concrete that spreads through congested reinforcement, fills every corner of the formwork and gets consolidated under self-weight. The concept of SCC was proposed Okamura and Ouchi [1] and the first prototype was developed in Japan in 1988. However, the development of SCC was first reported in 1989. By the early 1990's, Japan started to produce and use SCC commercially. The basic ingredients of SCC are similar to those of normal concrete. The traditional concrete aggregates such as gravel or crushed stone and sand are also used in SCC. Generally, the aggregates occupy 55–60% of the SCC volume 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. The large volumetric in-waste or by-product materials from industry are going to landfills and have been increasing with time. Recycling and reusing of construction waste is a viable option in construction waste management. Rawshan *et al.* [2] investigated the effect of prefabrications in building systems in reducing waste. They showed that large amount of material wastage can be reduced by the adoption of prefabrication and revealed that the rates of reused and recycled waste materials are relatively higher in projects that adopt prefabrication. The application of Recycled Concrete Aggregate (RCA) in concrete started in the U.S. in 1942 by using demolished concrete pavement as recycled aggregate for stabilizing the base materials for road construction. In general, the RCA has high water absorption due to the cement paste from old concrete. In comparison, limited studies have been conducted to use RCA in SCC. Recently, Safiuddin *et al.* [3] have produced SCC substituting 0–100% natural concrete aggregates (NCA) by weight. The effects of RCA on the key fresh properties such as filling ability, passing ability and segregation resistance of SCC were observed. The research outcome shows that SCC

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possessing good filling and passing abilities and adequate segregation resistance can be produced using RCA up to 50% replacement of NCA. In addition, Myle *et al.* [4] evaluated the feasibility of using concrete containing coarse RCA and find RCA for using in low-modulus concrete pavement applications. Results of the laboratory testing program indicated that the properties in the fresh concrete (were similar in concrete mixes containing coarse RCA and fine RCA due to the modified water cement ratio. The compressive strength was slightly reduced in the concrete mixes containing 25 percent RCA. Adam *et al.* [5] investigated the workability, compressive strength and elastic modulus of normal strength concrete with recycled concrete aggregate (RCA) as replacement for coarse natural aggregate The results suggested that the RCA water absorption and deleterious material content can be used to prequalify the material for selected concrete strength and stiffness performance objectives. Also, Zoran *et al.* [6] researched the potential for usage of coarse recycled aggregate obtained from crushed concrete for making of self-compacting concrete, additionally emphasizing its ecological value. Kou and Poon [7] evaluated the fresh and hardened properties of self-compacting concrete (SCC) using recycled concrete aggregate as both coarse and fine aggregates. The results indicate that the properties of the SCCs made from river sand and crushed fine recycled aggregates showed only slight differences. The feasibility of utilizing fine and coarse recycled aggregates with rejected fly ash and for self-compacting concrete has been demonstrated. Kamal *et al.* [8] investigated the effects of time on the properties of fresh state of recycled self-compacting concrete (RSCC). The results indicated that; the long fresh duration reduced by 48% for the mixes with crushed red brick compared to the mixes with crushed ceramic. The cost of mixes with crushed ceramics was less than that of crushed red brick by 8%. Kasami *et al.* [9] utilized the recycled concrete powder as concrete additives. Two series of experiments were performed to make clear of the effect of recycled powder. The results indicate that the recycled concrete powder was usable for self-compacting concrete without further processing, despite the possible increase in dosage of high-range water reducer for a given slump-flow and in drying shrinkage. Mehta and Monteiro [10] found that the RCA must be washed in order to evaluate the water absorption for proper water/cement ratio determination.

The above review indicated that, there is a need to investigate the possibility of utilizing the coarse and fine recycle aggregates of SCC produced by local materials in Egypt. The current study aimed to demonstrate the effect of using the recycled concrete aggregates produced in Egypt for making of high strength SCC.

Materials Properties and Mix Proportions: The physical properties of density and strength of concrete are determined by the proportions of the three key ingredients: water, cement and aggregate. Portland cement type CEM I 42.5R produced by Helwan factory comply with the Egyptian standard specifications [11], with content of 500 kg/m^3 was used. Table 1 shows the physical and mechanical properties of the used cement. Tap drinking water was used in this work. Super-plasticizer "Viscocrete 5930®" produced by Sika company was used to produce self-compacting concrete. Silica Fume was also used as mineral additives by 15% of the cement contents. Natural sand and crushed stone (Dolomite) with a nominal maximum size of 10 mm were used in this study. Recycle concrete aggregates (RCA) as coarse and/or fine aggregates were used as percentages of natural aggregates. RCA was obtained from crushing concrete with the same grading of natural aggregates. Tables 2 and 3 present the coarse and fine aggregates properties, respectively for the natural aggregates and RCA.

Research Program: This experimental investigation is carried out to study the effect of using the local produced RCA as coarse and/or fine aggregates in Egypt as partial replacement of natural coarse and fine aggregates on producing self compacting concrete (SCC). In this study, 13 concrete mixes with the same mix design were made. A reference mixture SCC produced only with natural aggregates. 3 series of concrete mixes with 25, 50 and 75% of the natural coarse aggregates replaced by recycle concrete coarse aggregates. For each series, fine RCA with (0, 25, 50 and 75) % as replacement of natural sand was used. For all mixes, the cement, silica fume, water and chemical admixture contents were (500 kg, 75 kg, 180 liters and 12 liters)/m^3, respectively.

Testing of Concrete: In order to obtain the desired rheological properties of fresh concrete, the following tests were used: slump flow test according to ASTM C 1611/C 1611M [13], V-funnel test and J-ring test.

Table 1: Mechanical properties of used cement.

Properties		Measured values	Limits of the E.S.S*
Fineness (cm^2/gm)		3500	--
Specific Gravity		3.15	--
Expansion (mm)		1.1	Not more than 10
Initial Setting Time (hrs)		1.9167	Not less than 1 hrs
Final Setting Time (hrs)		3.334	--
Compressive strength (N/mm^2)	2 days	18.6	Not less than 10
	28 days	50.8	Not less than 42.5 and not more than 62.5

* Egyptian Standard Specification No: 4756-1 /2009 [11]

Table 2: Properties of coarse aggregate.

Specimen	Nominal size (mm)	Specific weight	Volumetric weight kg/m^3	Absorption %	Crushing value%	Coefficient of abrasion %
Dolomite	10	2.80	1.59	2.0	19.3	14.5
Coarse RCA	10	2.60	1.52	2.7	24.6	26.8
Specification Limit *	-	-	-	2.50	30	30

* Egyptian Code for design and construction for concrete structures 203/2007 [12].

Table 3: Properties of fine aggregate.

Specimen	Specific weight	Volumetric weight kg/m^3	Absorption %
Natural sand	2.70	1.53	1.10
Fine RCA	2.60	1.43	3.00
Specification Limit *	-	-	2.00

*Egyptian Code for design and construction for concrete structures 203/2007 [12]

The self compacting ability properties were evaluated directly by the diameter of flow, time that a concrete sample requires for a spread of 50 cm diameter, The V-funnel flow time (TV) which was determined following the procedure given in EFNARC specifications and guidelines [14] and in Egyptian Technical Specification for Self Compacting Concrete (ETSSCC) [15]. In this 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. The passing ability is defined as the ability of SCC to flow in confined condition and completely fill all spaces within the formwork under self-weight and without any vibration. In the present study, the passing ability was determined with respect to J-ring flow (JF) following the test method depicted in EFNARC and in ETSSCC specifications and guidelines [14, 15]. The hardened concrete properties were evaluated by density, 7and 28 days compressive strength, 28 days flexural strength and 28 days indirect tensile strength.

RESULTS AND DISCUSSION

Fresh Self Compacting Concrete Properties: The test results for the fresh concrete properties (slump flow, T50 slump flow time and V-funnel flow time) and passing ability (J-ring flow) for various SCC mixes are given in Table 4. In addition, Figures 1, 2, 3 and 4 show the effect of replacement of natural aggregates by course and/or fine RCA on the diameter of flow for concrete mixes.

The slump flow results obtained for the concrete mixes with different RCA contents are given in Table 4. The slump flow varied within the range of 605-685 mm. A minimum slump flow of 600 mm is generally recommended for SCC to ensure adequate self-consolidation capacity [15]. The effect of coarse RCA on the slump flow of SCC is evident from Fig. 1, which shows that the slump flow decreased for 4.9, 9.70 and 10.40 % for mixes with 25, 50 and 75% coarse RCA, respectively. This is mainly attributed to the decrease of the free water content in SCC mix due to the high water absorption of RCA. In addition, the greater surface roughness and angularity of RCA increase the friction between coarse aggregates and cement past. These two effects were more dominant for high percentages of RCA. As a result, the SCC mixes with 75% coarse RCA became more viscous and provided a lower slump flow values. Also, Figs. 2, 3 and 4 shows that the increase in the percentage of the used fine RCA as replacement of sand in concrete mixes decreased the slump flow. This is attributed to reduction in the free

Table 4: Fresh concrete test results of the studied mixtures

			Slump flow test		V – funnel test		
Mix No.	% Coarse RCA	% Fine RCA	Diameter of flow (mm)	$T_{50\,cm}$ (sec.)	t_0 (sec)	t_{5min} (sec)	J- RING TEST Diff. height (Δh)
1	0	0	720	4	6.2	8.2	10
2	25	0	685	4.5	6.6	9.3	12
3		25	660	4.7	7.2	10	13
4		50	650	4.6	8.2	10.5	15
5		75	645	5	8.8	10.6	16
6	50	0	650	4.6	6.9	9.5	13
7		25	645	4.8	7.3	10.1	15
8		50	625	4.85	7.4	10.1	17
9		75	610	5	8.9	11.2	18
10	75	0	645	4.3	9	12.8	17
11		25	640	5	9.7	13.1	18
12		50	615	4.9	10.9	13.5	19
13		75	605	5	12.1	14.7	22

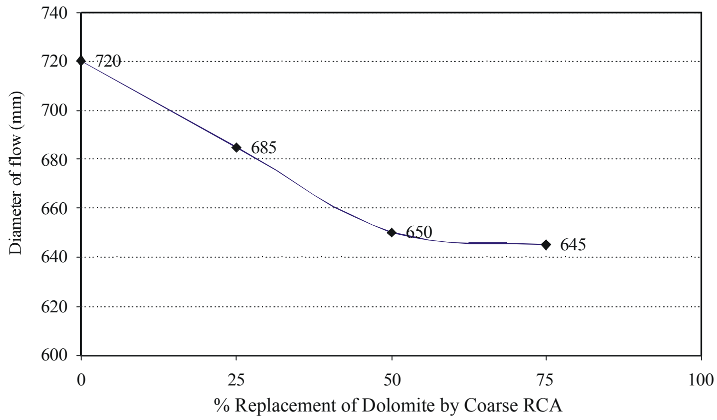

Fig. 1: Effect of coarse RCA replacement percentage on the Slump flow of concrete

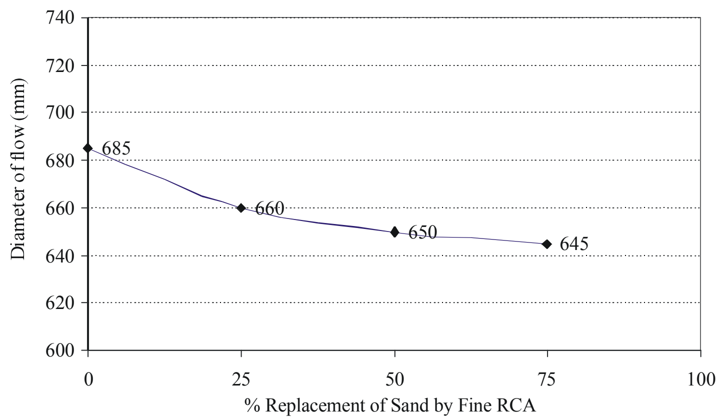

Fig. 2: Effect of fine RCA on the slump flow of concrete with 25% replacement of coarse RCA

water content in the SCC mix due to the high water absorption of RCA. The slump flow time T_{50} results of the concretes with different RCA percentages are given in Table 4. The T_{50} varied in the range of 4.5–5 seconds. The slump flow time T_{50} of SCC generally ranges from 2 to 5 seconds, the obtained values of T_{50} were within the acceptable range.

The V-funnel flow time results of the SCC mixes with various RCA contents are given in Table 5. The V-funnel flow time (t_0) varied in the range of 6.20-12.1 seconds. According to Egyptian Technical Specification for Self Compacting Concrete (ETSSCC) [15], the V-funnel flow time of SCC range from 6 to 12. Therefore, the V-funnel flow times were within the acceptable limits except the mix

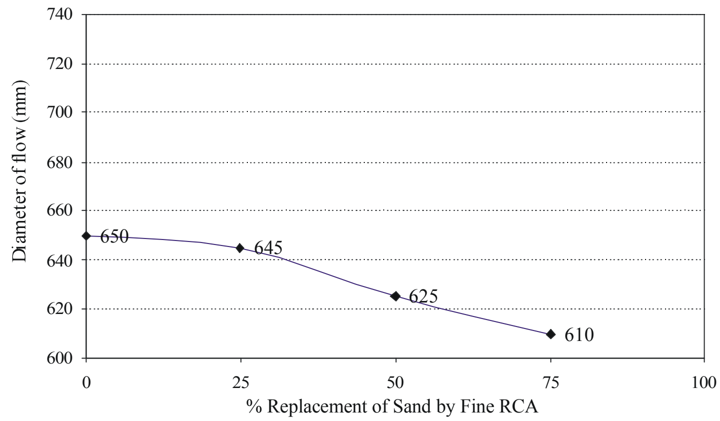

Fig. 3: Effect of fine RCA on the slump flow of concrete with 50% replacement of coarse RCA

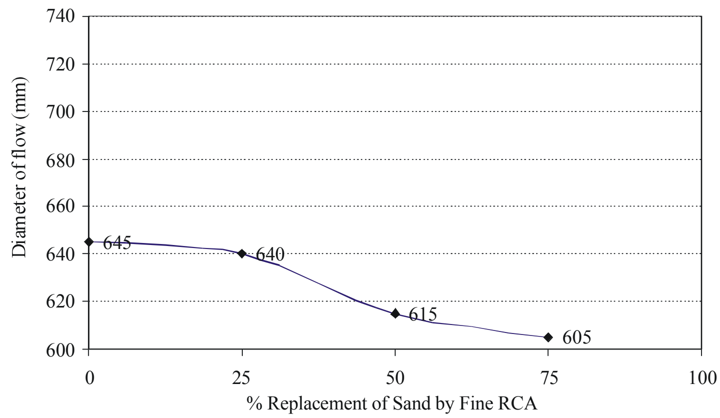

Fig. 4: Effect of fine RCA on the slump flow of concrete with 75% replacement of coarse RCA

Table 5: Hardened concrete test results of the studied mixtures

Mix No.	% Coarse RCA	% Fine RCA	Compressive strength (N/mm^2) 7 days	28 days	R7/R28 (%)	Density (g/mm^3)	28 days Tensile strength (N/mm^2)	28 days Flexural strength (N/mm^2)
1	0	0	63	87	72	2.43	4.89	10.20
2	25	0	56	80	70	2.37	3.60	10.08
3		25	53	75	71	2.45	3.31	10.02
4		50	53	74	71	2.44	3.11	9.96
5		75	52	72	72	2.38	3.09	9.93
6	50	0	55	78	70	2.38	3.36	10.08
7		25	51	72	71	2.29	3.23	9.79
8		50	51	72	71	2.39	3.17	8.86
9		75	49	69	70	2.34	2.93	7.80
10	75	0	52	71	72	2.36	3.10	8.40
11		25	51	71	72	2.32	3.07	7.80
12		50	49	69	72	2.42	2.92	7.47
13		75	45	63	72	2.26	2.83	7.03

that the natural coarse aggregates were represented by 75% coarse RCA and the sand was represented by 75 % fine RCA (mix No. 13). A high flow time can be caused by either a low flowing ability (filling ability/passing ability) or a blockage of the flow [16]. On the other hand, of all concrete mixes passed V- funnel test after 5 minutes (t_5). The results were not more than (t_0+3 seconds) and then they were compatible with the (ETSSCC) limits.

The results of J-ring flow test are given also in Table 4. Figs. 5, 6, 7 and 8 show the effect of coarse and/or fine RCA replacement of natural aggregates on the

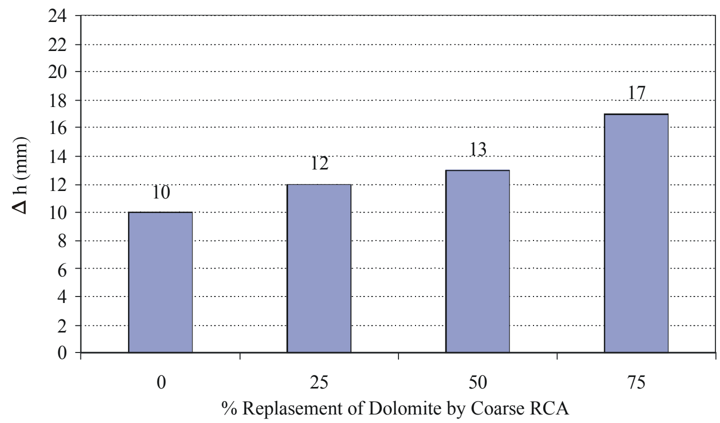

Fig. 5: Effect of coarse RCA replacement percentage on passing ability of SCC

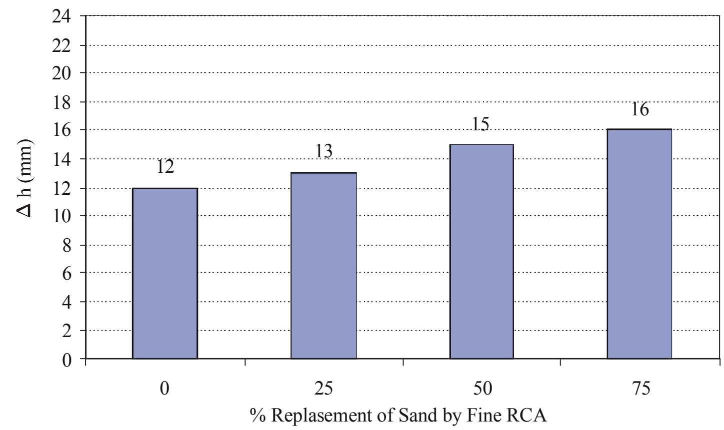

Fig. 6: Effect of Fine RCA on passing ability of SCC with 25% replacement of Coarse RCA

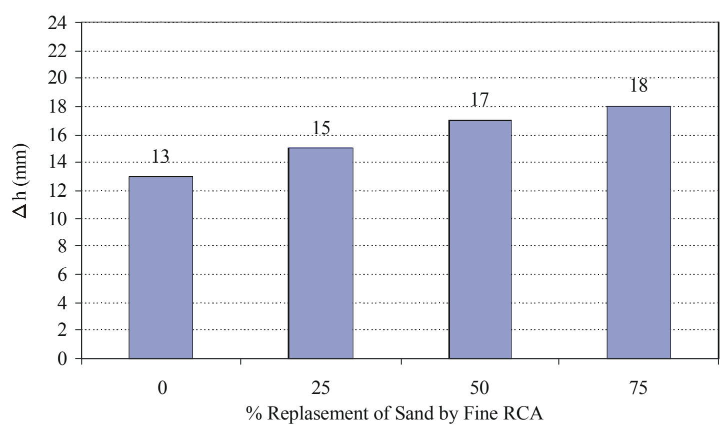

Fig. 7: Effect of Fine RCA on passing ability of SCC with 50% replacement of Coarse RCA.

passing ability of concrete. The maximum differences between the concrete height inside and outside the J-ring (Δh) shall be not more than 20mm according to ETSSCC [15], to ensure good passing ability without significant blockage. As shown in Table 4, all SCC mixes produced in the present study possessed reasonably good passing ability except mix No.13. Fig. 5 indicated that the increase in the percentage of coarse RCA used as replacement of natural coarse aggregates led to decrease the basing ability of SCC. Also, the increasing in fine RCA replacement ratios of natural sand decreased the basing ability of SCC (Figs. 6, 7 and 8). For all mixes, no segregation was observed during the carried out tests. Moreover, it is clear that the fresh concrete properties obtained from slump flow, V funnel test and J ring test provided the same trend for the all studied mixes.

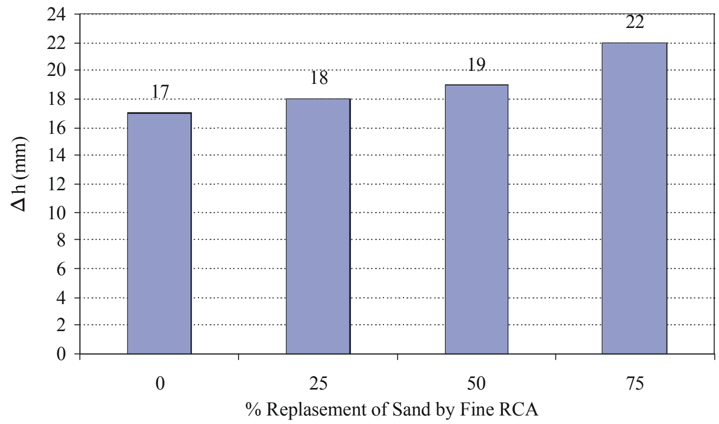

Fig. 8: Effect of Fine RCA on passing ability of SCC with 75% replacement of Coarse RCA

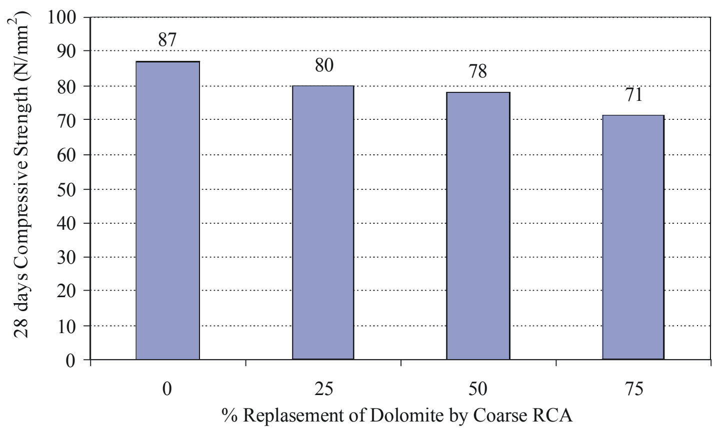

Fig. 9: Effect of coarse RCA replacement percentage on 28 days compressive strength

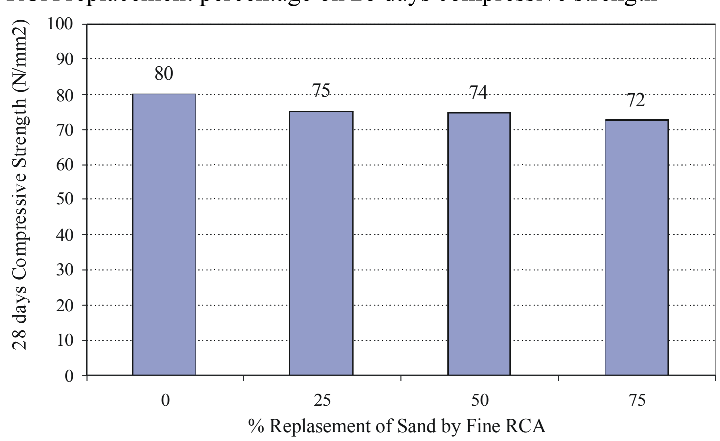

Fig. 10: Effect of fine RCA on 28 days compressive strength of SCC with 25% replacement of coarse RCA.

Hardened Self Compacting Concrete Properties: Effect of RCA Replacement Percentage on Concrete Density: Table 5 shows the average densities of all mixes after 28 days. Analyzing the results appearing generally that the density of hardened concrete slightly decreased as the rate of natural coarse aggregates replacement by RCA increased. This was expected, since the RCA presented a lower density compared to natural coarse aggregates due to higher porosity and lower density of cement past adhering to the aggregates surface.

Effect of RCA Replacement Percentage on Compressive Strength: Table 5 presents the average compressive strength results obtained with three cube testing

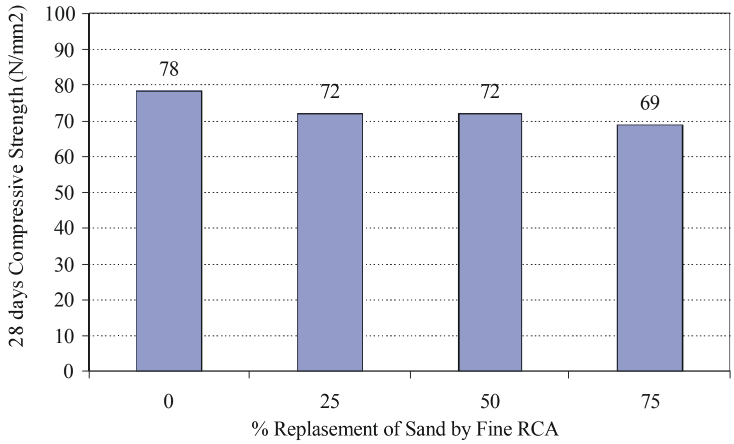

Fig. 11: Effect of fine RCA on 28 days compressive strength of SCC with 50% replacement of coarse RCA

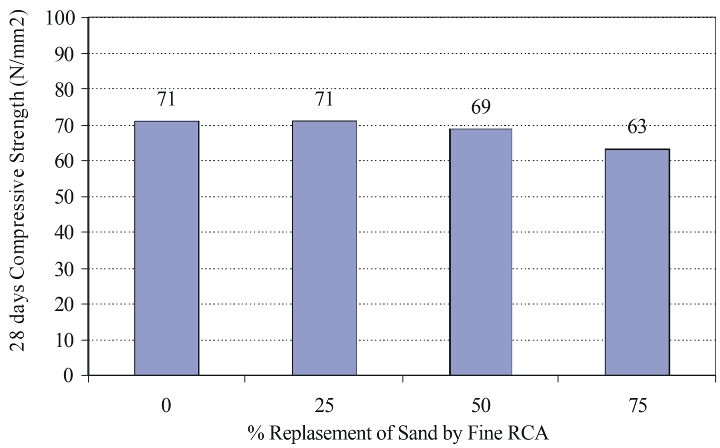

Fig. 12: Effect of fine RCA on 28 days compressive strength of SCC with 75% replacement of coarse RCA.

specimens at 7 and 28 days. In this Table, the percentages of compressive strength obtained at 7 days (R7) compared with 28 days compressive strength (R28) was also shown.

In addition, Figs. 9, 10, 11 and 12 show the effect of using coarse and fine RCA on the compressive strength at 28 days. In general, the compressive strength of the studied mixes after 28 days ranged from 63MPa for mix No. 13 to 87MPa for mix No. 1, i.e. high strength concrete. As shown in Table 5 and Figures (9, 10, 11 and 12), the compressive strengths at 28 days decreased with increasing of the percentage of coarse RCA used by 8, 10 and 18 % for replacements percentages 25, 50 and 75 % respectively. Also, it is clear, that the using of fine RCA has a significant effect on the compressive strengths at 7 and 28 days. It was observed that the replacement of fine RCA resulting in significant reduction in the compressive strength. It was also found that the all mixes achieved at 7 days 70-72% of the compressive strength developed up to 28 days. This means that the using of coarse and fine RCA as replacements of neutral aggregates have the same behavior on the compressive strength development.

Effect of RCA Replacement Percentage on the SCC Indirect Tensile Strength and Flexural Strength: As shown in Table 5 the indirect tensile strengths at 28 days decreased also with increasing in the percentage of coarse RCA used by 26, 31.3 and 36.6 % for replacements percentages 25, 50 and 75 % respectively. On the other hand, the using of coarse RCA as replacement of natural coarse aggregates has slight effect on the flexural strength for ratio up to 50 %. When the replacement percentage increased to 75% a reduction of 18 % was observed in the flexural strength. Otherwise, it is appeared that the using of fine RCA with the coarse RCA had clarified effects on the tensile and flexural strengths (Table 5).

CONCLUSIONS

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

- With respect to fresh concrete, the particularity noted during the tests was the need for adding more water to mix the concrete with recycled aggregates. This water is needed because of the high values of water absorption showed by recycled aggregates if compared with natural aggregates. This phenomenon is the reason for the reduced slump flow diameter and increased the V-funnel time.
- Despite the mentioned in the last item, the filling ability and passing ability were satisfactory for all SCC studied mixes. A slight reduction in the passing ability occurred at 75% coarse RCA with 75% fine RCA.
- The SCC mixes with coarse RCA percentage 75% was more viscous as indicated by the T50 slump flow time and V-funnel flow time results. The flow was intermittent and therefore the concrete mix required a relatively long time to flow out of the V-funnel.
- All SCC mixes showed a good segregation resistance.
- The physical characteristics of RCA such as surface roughness, angularity and surface porosity were not conducive to improve the fresh properties of SCC. These physical properties can act adversely to decrease the filling ability and passing ability of SCC especially at a higher content of RCA.
- The overall test results showed that coarse RCA can be used in SCC as a replacement of NCA up to 75% by weight without dispensing with the fresh properties of SCC.
- Using of fine RCA with coarse RCA can also produce SCC as a replacement of natural sand up to 75% by weight without dispensing with the fresh properties of SCC.
- For the density of the hardened concrete, there was a slight weight loss by increasing the incorporation of recycled aggregates. This loss can be related to the low density values of the RCA aggregates when compared with natural aggregates.
- Using of fine and coarse RCA as replacement of natural aggregates reduced the compressive, flexural and indirect tensile strengths. Despite of this observation, high strength self compacting concrete can be still obtained.
- The using of coarse and fine RCA as replacement of neutral aggregates showed the same behavior on the compressive strength development.
- The use of RCA as a partial replacement for natural aggregates in self compacting concrete is still very limited, so further study is required to produce RCA on a large scale basis, the cost of preparing the RCA must be taken into consideration.

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