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Static and Dynamic Segregation Resistance of Self-Consolidating Rubberized Concrete

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Abstract: *An experimental investigation was conducted to evaluate the effects of partial replacement of fine aggregate with waste crumb rubber (CR) on the fresh properties and stability of self-consolidating concrete. In total, eight mixtures with a water-to-binder ratio (0.4), a binder content 500 kg/m^3, and varied percentages of CR (0-40% replacements by fine aggregate volume) were investigated. Slump flow and V-funnel tests were used to investigate the flowability of tested mixtures while the passing ability was evaluated using L-box test. Stability of mixtures was studied using four different techniques to evaluate the static and dynamic segregation resistance of coarse aggregate and CR aggregate. The results indicated that the addition of CR could adversely affect the flowability and passing ability of SCRC mixtures. Increasing the CR content also showed a clear instability for both coarse aggregate and suspension of CR particles themselves.*

Keywords: *self-consolidating concrete, crumb rubber, fresh properties, static and dynamic segregation*

1. Introduction

Utilization of waste rubber in construction industry is one of the effective techniques to promote the eco-friendly production. Each year millions of scrap tyres are wasted, which represent a potential waste management problem [1-3]. In the last two decades, significant research has been conducted to determine the applicability of using waste rubber as a replacement for fine and coarse aggregate. In addition, the low density of rubber aggregate compared to a conventional aggregate can contribute to the development of structural elements with a reduced self-weight [4].

Many studies well-investigated the properties of vibrated rubberized concrete in terms of plastic state and hardened state; however; only a limited number of studies have focussed on self-consolidating rubberized concrete (SCRC) [5]. Self-consolidating concrete (SCC) is a type of concrete that can spread and fill the formwork under its own weight without applying any type of compaction or mechanical vibration and without segregation or bleeding problems. It also has enough flowability and filling ability to fix the problem of concrete flowing through congested reinforcements [6-9]. The previous studies reported that incorporating rubber in SCC requires a significant increase in super plasticizer dosage [10-11]. Güneyisi [10] stated that increasing the rubber content caused an increase in T_{50} and V-funnel flow times. Topçu and Bilir [11] observed that increasing the rubber content increased the fluidity, but with an increased risk of segregation. Turatsinze and Garros [12] developed SCRC by using chipped rubber as a coarse aggregate, but the reduction of strength reached up to 33% and 73% at 10% and 25% replacements of sand by rubber, respectively. Similar behaviour was reported by other researchers [13].

The main objective of this research was to evaluate the effect of CR on the fresh properties and stability of the SCRC mixtures. The percentage of CR varied from 0% to 40% replacements by fine aggregate volume. The

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fresh properties tests included slump flow, V-funnel, L-box, and air content tests. While the stability of the tested mixtures was evaluated by using sieve segregation test, column segregation test, dynamic segregation, and visual observation for rubber particle distribution.

2. Experimental Work

2.1. Materials

The used cement (type GU) was similar to that of ASTM Type I. Natural crushed stones with a maximum size of 10 mm and natural sand were used for the coarse and fine aggregates, respectively. Each aggregate type had a specific gravity of 2.6 and absorption of 1%. A crumb rubber aggregate with a maximum size of 4.75 mm, specific gravity of 0.95, and negligible absorption was used as a partial replacement of the fine aggregate in SCRC mixtures. Glenium 7700 produced by BASF Construction Chemicals was used as an HRWRA to achieve the required slump flow of SCC mixtures. This admixture is similar to ASTM C 494 Type F with specific gravity, volatile weight, and pH of 1.2, 62%, and 9.5, respectively.

2.2. Scope of Work

The main objective of this stage was to evaluate the effect of using CR on stability of SCRC mixtures under static and dynamic condition. In total, eight mixtures were tested in this stage. The percentage of CR varied from 0% to 40% replacement of sand (by volume). A constant coarse-to-fine aggregate (C/F) ratio of 0.7 was chosen for all tested mixtures in this stage. This percentage was chosen based on previous research work [13, 14] carried out on SCC with different C/F ratios. In order to achieve an acceptable mixture flowability with no sign of segregation in all tested mixtures (especially when using crushed stones), a preliminary trial mixes stage was performed to determine the minimum water-to-binder (w/b) ratio and the total binder content that can achieve acceptable SCRC flowability without overdosing the HRWRA. The results of the trial mixes stage indicated that a w/b ratio of at least 0.4 should be used to obtain SCRC having 650 ± 50 mm slump flow with no visual. A total binder content of 500 kg/m^3 was also found to give reasonable fresh properties in all trial mixtures. A total binder content of 500 kg/m^3 and 0.4 w/b were used in all tested mixtures. The amount of HRWRA was varied in all tested mixtures to obtain a slump flow diameter of 650 ± 50 mm. The mixture proportions of SCRC containing different percentages of CR are shown in Table 1.

TABLE I: Mixture Design for SCRC Mixtures

Mixture	Cement (kg/m^3)	C. A. (kg/m^3)	F. A. (kg/m^3)	CR (kg/m^3)	HRWRA (kg/m^3)	Density (kg/m^3)
500C-0CR	500	686.5	980.8	0.0	2.37	2367.3
500C-5CR	500	686.5	931.7	17.9	2.37	2336.2
500C-10CR	500	686.5	882.7	35.8	2.37	2305.1
500C-15CR	500	686.5	833.7	53.8	2.37	2273.9
500C-20CR	500	686.5	784.6	71.7	2.89	2242.8
500C-25CR	500	686.5	735.6	89.6	2.89	2211.7
500C-30CR	500	686.5	686.5	107.5	2.89	2180.6
500C-40CR	500	686.5	588.5	143.3	3.95	2118.3

Note: All mixtures have a 0.4 w/b ratio; C. A. = Coarse aggregates; F. A. = Fine aggregates; and CR = Crumb rubber

2.3. Flowability and Passing ability Tests

The time to reach 500 mm slump flow diameter and the V-funnel time were used to evaluate the mixture viscosity/flowability. These times were accurately measured for all tested SCRC mixtures using videotape recording. L-box heights were measured for all tested mixtures to evaluate the passing ability of SCRC. The aforementioned tests are detailed in the Self-Compacting Concrete Committee of EFNARC [15]. The percentage of the entrained air in the fresh SCRC mixtures was measured by following a procedure given in ASTM C231.

2.4. Segregation Tests

The segregation resistance (SR) of SCRC mixtures was assessed using a sieve segregation resistance test according to EFNARC (2005). Column segregation test was also performed (according to ASTM C1610) to determine the potential static segregation of SCRC mixtures. On the other hand, this study included an evaluation for the segregation possibilities of SCRC mixtures that can be occurred during the execution of the situ cast of concrete, which is called dynamic segregation. For each slump flow test, the concentration of coarse aggregate was determined in three redial zones: directly under the initial location of slump cone, between the outer edge of cone diameter to a diameter of 500 mm, and finally between a diameter of final spread and a diameter of 500 mm, as shown in Fig. 1, procedures given by Tregger et al. [16]. The distribution of the rubber particles in the mixture was also visually evaluated after splitting 100 mm diameter x 200 mm height concrete cylinder. The stability of rubber was classified into three cases; namely no segregation (NS), moderate segregation (MS), and heavy segregation (HS), as shown in Fig. 2.

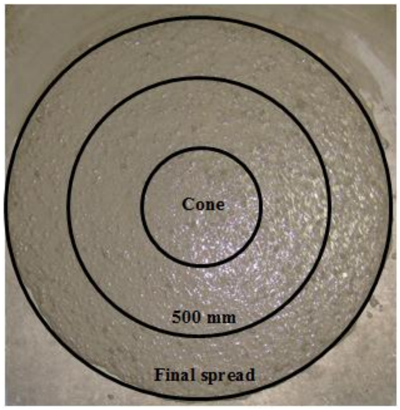

Fig. 1: The redial zones for dynamic segregation test.

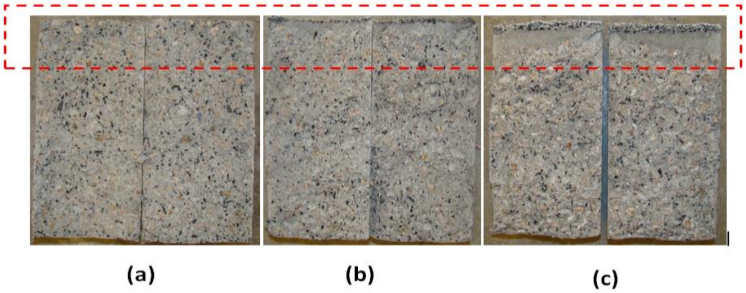

Fig. 2: Rubber particles stability (a) no segregation (NS), (b) moderate segregation (MS), (c) heavy segregation (HS)

3. Discussion of Test Results

3.1. HRWRA Demand

Table 1 shows the demands of HRWRA for all tested mixtures. It can be noticed that up to 15% CR, there is no observed increase the HRWRA demand to achieve the target slump flow of 650 ± 50. Increasing this percentage (15%) up to 30% showed insignificant increase in the HRWRA, while with further increase in the addition of CR, the dosage of HRWRA increased. For example, compared to the control mixture with no CR, the addition of 40% CR showed 66.67% increase in the HRWRA demand.

3.2. Flowability

The results of T_{50} and V-funnel time were used to evaluate the flowability of SCRC mixtures. Table 2 shows that the mixture flowability decreased as the addition of CR increased in which the T_{50} increased from 1.2 to

3.71 seconds as the percentage of CR increased from 0% to 40%. Similar behaviour was observed in V-funnel tests in which for the same range of CR content (0% to 40%), the V-funnel time increased from 6.39 to 25.2 seconds. The characteristics of the produced SCRCs are specified to be appropriate for a given application. According to this, SCRC mixtures with up to 15% CR can be classified as VS1/VF1 which is recommended to be used in multiple applications such as floors, slabs, piles, and walls. Meanwhile, SCRC mixtures containing 20% to 40% CR can be classified as VS2/FV2, which is recommended to be used in certain applications such as ramps.

3.3. Passing Ability

The H2/H1 L-box ratio was used to evaluate the passing ability of all tested mixtures. As shown in Table 2, the passing ability decreased as the addition of CR increased. The L-box ratio decreased by 80.9%, when the percentage of CR increased from 0% to 40%. The reduction of the passing ability with the increased percentage of CR could be attributed to the high friction between crushed stone aggregate and rubber particles. According to the European Guidelines for Self-Compacting Concrete [15] and the Interim Guidelines for the Use of Self-Consolidating Concrete [17], the recommended value of H2/H1 in the L-box test is 0.75 or greater, which indicates limited uses for mixtures having H2/H1 less than 0.75. Based on the results of this investigation, incorporating CR up to 15% CR replacement showed H2/H1 results match that value recommended by the two guidelines, while further increase in the addition of CR made the SCRC mixtures fell outside the acceptable limit (H2/H1= 0.75).

3.4. Static Segregation

3.5. Sieve Segregation Resistance

The sieve segregation resistance (SR) values were used to evaluate the coarse aggregate segregation of all tested mixtures. As seen in Table 2, the results of SR indicated that increasing the percentage of CR heightened the risk of segregation. Varying the CR replacement from 0% to 40% increased the SR from 2.1% to 15.5%. According to EFNARC, up to 30% CR the values of SR fell inside the acceptable range (SR ≤ 15%) for SCC mixtures.

3.6. Column Segregation Test

Segregation index of column segregation test was determined to evaluate the potential static segregation of SCRC mixtures. Results in Table 2 show that increasing the addition of CR increased the segregation index, indicating a higher risk of segregation. Varying the addition of CR from 0% to 40% raised the segregation index from 2.33% to 20.69%. This finding could be attributed to low density of rubber that could encourage CR particles to accumulate at the top part of the column while the bottom part was occupied by coarse aggregates. According to the limits of column segregation test recommended by standard, up to 20% CR can match the acceptable limits for stable SCC mixtures.

3.7. Dynamic Segregation

Fig. 3 shows relative aggregate density drawn versus the radial distance (from the centre of final spread concrete to the midpoint for each redial zone). The relative aggregate density was obtained using

Relative aggregate density= (aggregate content of region/total aggregate content) / (volume of region/ total volume)

Increasing the CR replacement level showed a clear reduction in the dynamic segregation resistance of SCRC mixtures in which non-uniform distribution of coarse aggregate could be observed, as shown in Fig. 3. Varying the CR from 0% to 40% exhibited higher concentration of coarse aggregate in the area located under the initial location of slump cone compared to that measured at the final spread zone (the outer zone). This finding could be attributed to the same reason of the high friction and blocking between crushed stone aggregate and rubber particles, which may contribute significantly to resist the uniform spreading of coarse aggregate with mortar. From Fig. 3, it can be seen that up to 15% CR replacement level the dynamic segregation test showed reasonable distributions of coarse aggregate while exceeding this percentage led to exhibiting potential segregation problems for SCRC mixtures that can be occurred during the execution of the situ cast of concrete.

3.8. Segregation of CR Particles

The visual observation for hardened splitted cylinders was used to evaluate the rubber particles segregation under static condition for all tested SCRC mixtures. Table 2 shows that no sign of segregation was observed in the hardened splitted cylinders up to 15% CR replacement, but mixtures from 20% to 40% CR appeared to be medium-to-heavy segregated. This finding is attributed to the low density of the rubber (0.95), which makes it easy for the rubber to float toward the concrete surface during mixing.

TABLE II: Fresh Properties for Tested SCRC Mixtures

Mixture	Slump flow		L-box	V-funnel	SR	Air	CR	S_{Column}	f'_c
	D_s (mm)	T_{50} (sec)	H2/H1	T_0 (sec)	%	%	Stability	%	MPa
500C-0CR	700	1.20	0.89	6.39	2.1	-	1.5	2.33	52.95
500C-5CR	690	1.55	0.83	6.95	2.4	NS	2.00	3.64	44.54
500C-10CR	687	1.74	0.79	7.57	2.5	NS	2.3	3.28	42.09
500C-15CR	675	2.00	0.75	8.75	3.5	NS	4.3	3.64	37.35
500C-20CR	670	2.31	0.54	12.5	6.3	MS	4.8	4.71	32.56
500C-25CR	655	2.51	0.33	14.6	9.4	HS	6.5	9.52	28.83
500C-30CR	640	2.80	0.25	16.2	13.3	HS	5.9	16.00	24.73
500C-40CR	630	3.71	0.17	25.2	15.5	HS	6.8	20.69	17.66

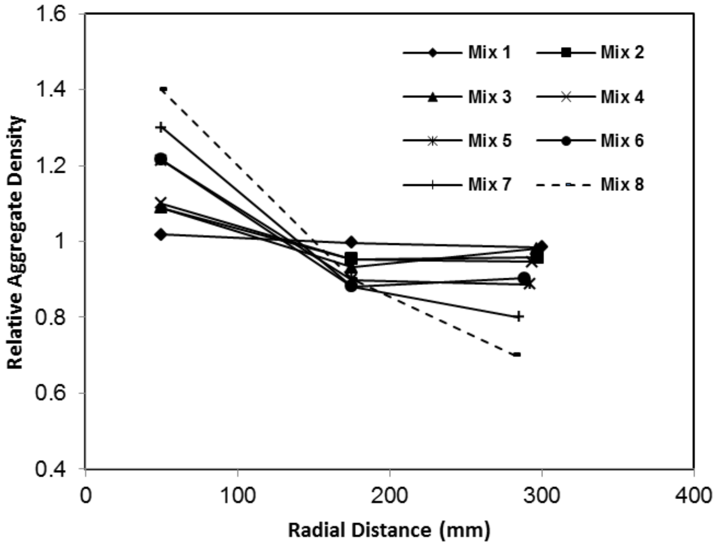

Fig. 3: Relative aggregate density measured in the redial divisions for slump flow.

4. Conclusions

This study investigated the effect of using CR as a replacement for fine aggregates on the fresh properties and stability of SCC mixtures. The percentage of CR replacement varied from 0% to 40% of fine aggregate volume. The fresh properties were evaluated using slump flow, V-funnel, L-box, static segregation, and dynamic segregation tests. Increasing the percentage of CR in SCRC mixtures reduced the flowability and passing ability, while the air content and HRWRA demand increased. The results of both static and dynamic segregation tests presented that the addition of CR could reduce the stability of SCRC mixtures with an increased risk of segregation. The results also showed that although the column segregation and sieve segregation tests gave applicability for developing SCRC mixtures (with 500 kg/m^3 binder content and 0.4 w/b) up to 20% CR replacement level, the dynamic segregation test and the visual investigation of rubber particles distribution in hardened splitted cylinders limited the use of CR up to 15%. Also, using percentage of CR higher than 15%

resulted in a significant drop in the ratio of H1/H2. Therefore, based on the mixture composition that was used in this investigation and by combining the results of passing ability and segregation resistance tests, it can be conclude that SCRC mixtures with up to 15% CR replacement level can be developed safely with acceptable fresh properties and stability.

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