Effect of Crumbed Rubber Treatment on Rubbeised Concrete Properties

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January 16, 2023

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ABSTRACT

The use of waste tire particles as a partial replacement of fine aggregate in concrete mixes can provide environment-friendly solutions for waste tire disposal problems. However, incorporating tire particles in concrete may affect its hardened properties due to the weak bonding between rubber particles and cement paste. Therefore, the aim of this study is to enhance this bond by using two different methodologies: cement paste and mortar pre-coating. Several concrete mixes were made with replacing the fine aggregate with (0%, 30% and 40%) rubber particles treated with the two methodologies by volume. The water-to-cement ratio and the aggregate-to-cement ratio kept constant (w/c = 0.4 and A/c=4.5). These mixes were examined in the fresh and hardened phases. The results showed that pre-coating rubber by mortar gave better results in terms of density, compressive strength and flexure strength.

Keywords: crumb rubber, rubberized concrete, pre-coating, treatment.

INTRODUCTION:

The increasing rates of accumulated waste tires is getting to become a serious disposal problem [1], the management of such a problem is a challenge because the rubber is non-biodegradable material[2]. Therefore, numerous researches were aimed to study the ability of utilizing the crumb rubber (CR) particles as an alternative aggregate in concrete mixes which can provide diverse technological and sustainability advantages. Rubberized concrete (RC) could be considered as a structural concrete when it satisfies the strength requirements. Zheng et al. suggested that the compressive strength of structural concrete should be in the range between 28 and 35 MPa[3]. However, Kosmatka et al. recommended that the minimum compressive strength of concrete is being 17 MPa[4]. Generally, if the concrete density is equal or more than 2000 kg/m^3, it can be rated as normal weight concrete[5].

The main challenge of using crumb rubber aggregate is to provide concrete within the specifications in spite of poor interfacial bonding between hardened cement paste and the soft rubber surfaces. Indeed, the concrete mechanical strength is highly dependent on load-carrying capacity of aggregate and the interfacial bond between the aggregate and cement paste (including the interfacial transition zone (ITZ) phase)[5, 6]. Some studies show that pre-coating the rubber with cement paste can enhance strength by between 30 and 50 %[7, 8].However, there is currently scarce data on the using different techniques of pre-coating/treating (P-C/T) rubber particles to produce plain rubberized concrete (PRC) in order to improve the bond between rubber particles and cement paste[5]. Therefore, this study aims to enhance this bond by two different methodologies: cement paste and mortar pre-coating using the common used materials in Libyan market.

EXPERIMENTAL STUDY

Materials

Portland cement with a compressive strength of 52 MPa (28-day) was used. Table (1) summarizes the physical and mechanical properties of the used cement. Natural sea sand obtained from Zlietn quarry used as fine aggregate with a specific gravity of 2.60, absorption rate of 0.3% and fineness modulus equal to 2.45. Crushed stone aggregate with sizes of 20 mm. The physical and mechanical properties of the used coarse aggregate are listed in Table (2). Moreover, fig. 1 illustrates the grain size analysis of fine and coarse aggregate. High-range water-reducing admixture (liboment FF) was added at different dosages (1%, 1.5% and 2%) in order to adjust workability. Crumbed rubber (CR) with specific gravity of 0.91 was used. The net volume approach was applied to determine the proportions of the concrete components. During the process, the rubber ratio is set to 30% and 40%, respectively, in terms of volume of fine aggregate. Mix proportions of the rubber concrete are shown in Table (3).

Table (1) Physical and mechanical properties of cement

Test	Results
Initial setting time	120 minutes
Final setting time	3 hours
Specific gravity	3.12
soundness	0.5 mm
Compressive strength of cement mortar at 3 days	26 MPa
Compressive strength of cement mortar at 28 days	52 MPa

Table (2) Physical and mechanical properties of coarse aggregate

Test	Results
Water absorption	0.91%
Specific gravity	2.6
Unit weight	1503 kg/m^3
Crushing index	10%

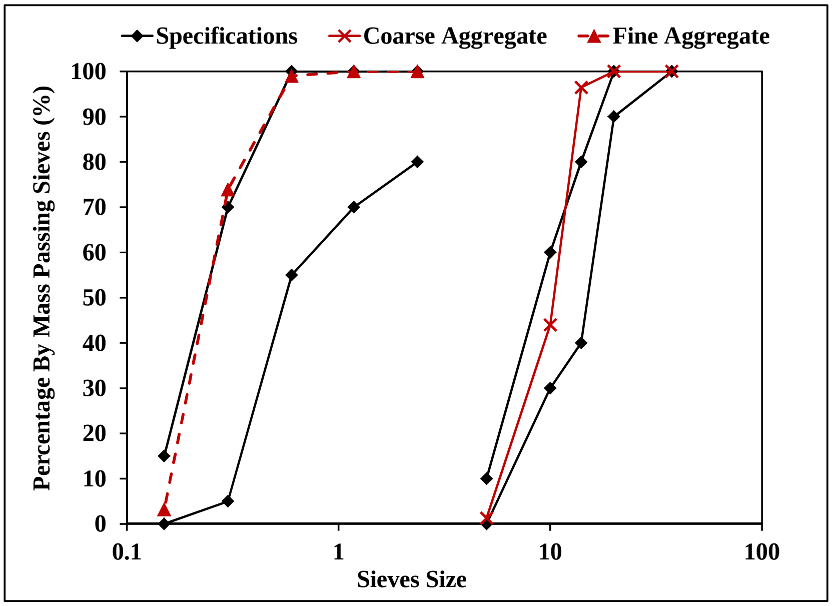

Fig. 1 Sieve analysis of fine and coarse aggregate

Concrete Mix Proportioning and Experimental Procedures

A series of tests were conducted to study the impact of curing the crumbed rubber on the properties of rubberized concrete. A total of seven mixes categorized into four groups were tested in this programme. Each group was composed of three identical specimens. NC mix is the control mix made with conventional concrete, the other three groups were made of concrete with partial replacement of rubber aggregates. RC-N specimens were cast with untreated rubber crumbs as fine aggregate replacement divided into two groups: RC-N30 with 30% crumbed rubber and RC-N40 with 40% crumbed rubber, whereas RC-P specimens contained cement paste treated crumbed rubber divided into two groups as well. In RC-M series, crumbed rubber treated with mortar was used.

The dimensions of the cubic specimens for the compressive strength, water absorption and density tests were 150×150×150 mm. In addition, 100×100×500 mm beams were used in flexural strength test. The compressive strength tests were conducted according to BS EN 12390-2009[9] at 28 days, and the flexural strength tests were performed according to ASTM C1018-97[10] for 40% crumbed rubber of all mixes. Water absorption and density tests were assessed according to ASTM C642 and ACI 211.1-91 respectively[11, 12].

All the concrete mixes were designed at a constant water-to-cement ratio of 0.4, aggregate to-cement ratio of 4.5, thus the cement content was 408.0 kg/m^3. Tire rubber was used as a replacement for the fine aggregate by volume with two designated rubber content of 30% and 40%. Mixing and slump measurements were conducted at room temperature (T = 23 ± 2°C), and the mean average of three readings was taken for all hardened concrete tests.

Regarding to the above variables, the concrete mixes were produced as per ASTM C192 standard in a power-driven revolving pan mixer[13]. All the mixes were tested for the slump in their fresh state, and then the mixes were poured into the moulds. Moreover, the compaction was accomplished by rodding 25 times in three layers along with applying a vibration for five seconds after rodding each layer. The specimens were demolded after 24 h and moved to a curing tank until 28-day according to ASTM C192.

Table (3) Mix proportions

Mix ID	CR%	HRWR%	Water (kg/m^3)	HRWR (kg/m^3)	Fine aggregate		Coarse aggregate (kg/m^3)	Cement (kg/m^3)
					Crumbed rubber (kg/m^3)	Natural sand		
NC	0	1	159.1	4.1	0	550.8		
RC-N30	30	1.5	157.1	6.1	98.3	385.5		
RC-N40	40	2	155.0	8.2	131.0	330.4		
RC-P30	30	1.5	157.1	6.1	98.3	385.5	1285.0	408.0
RC-P40	40	2	155.0	8.2	131.0	330.4		
RC-M30	30	1.5	157.1	6.1	98.3	385.5		
RC-M40	40	2	155.0	8.2	131.0	330.4		

EXPERIMENTAL RESULTS AND DISCUSSION

Workability

The workability of the different mixes was determined using the slump test according to ASTM C143/C143M-2015[14]. The results are given in Table (4). As shown, the slump losses were about 50%, 25% and 12.5% for RC-N30, RC-P30 and RC-M30, respectively. However, as the percentage of crumbed rubber becomes higher (40%), the loss of workability increased to 75%, 62.5% and 62.5% for RC-N40, RC-P40 and RC-M40, respectively. In fact, the slump reduction with the increase of rubber content is related to the clear difference in the texture of rubber particles compared to of the replaced fine aggregate particles[15]. Moreover, the lower relative density of the crumbed rubber could be one of the reasons for this reduction. On the other hand, pre-treatment of rubber particles had a valuable effect on the concrete slump as mentioned above. This can be attributed to that the treatment of rubber gave the concrete mix more consistency compared to non-treated rubber mix, leading to relatively slow movement of rubber particles in the concrete matrix[15]. Herein it can be said that the pretreatment enhanced the bond between rubber particles and the cement paste.

Table (4) Results of fresh and hardened concrete tests

Mix ID	Slump (mm)	Water absorption (%)	Density (kg/m^3)	Compressive strength (MPa)	Flexural strength (MPa)
NC	40	3.20	2518.52	49.83	5.55
RC-N30	20	1.94	2322.96	30.74	-
RC-N40	10	2.03	2237.03	22.90	3.68
RC-P30	30	1.54	2344.69	35.24	-
RC-P40	15	1.71	2278.58	25.82	3.70
RC-M30	35	1.27	2349.63	38.09	-
RC-M40	15	1.29	2321.00	29.99	3.80

Properties of Hardened Concrete

Water Absorption

Water absorption (WA) results of the PRC tested as per ASTM C 642 [16] are illustrated in Table (4). It was observed that WA of the conventional concrete was the higher compared with the other mixes. The same observation was reported by Elchalakani[17], although most studies proved that conventional concrete give the lower WA[18-20]. However, using of treated crumb rubber lowered the WA for all mixes compared to non-treated rubber. For instance, at 30% CR, WA results were lower by 20.6% and 34.5% for cement paste and mortar pretreated CR, respectively, compared with non-treated rubber mix. This can be ascribed to that the cement paste and the mortar provide an insulating layer that prevents the rubber to absorb water[5].

Hardened Density

The hardened concrete density was determined as per ACI 211.1-91 as shown in Table (4). Since the density of rubber particles is less than that of fine aggregate, the density of concrete mixes was expected to be reduced[20]. Moreover, PRC with both methodologies has demonstrated an increase in density for both 30% and 40% FA replacement, this can be attributed to that the treatment of CR decrease the air content in the mix[5].

Compressive Strength

The compressive strength results obtained from experimental tests are listed in Table (4). As known, the compressive strength of the rubberized concrete specimens recorded a decreasing tendency with the increase of the rubber content[21]. On the other hand, the treatment of CR has a better influence on the behavior of the concrete in terms of compressive strength as shown in fig.2. For example, mixes made with 30% CR without pre-treatment showed a decrease in compressive strength by 38.31% compared with control mix. However, mixes made with 30% CR treated by cement paste and mortar exhibited better compressive strength results compared with that made with 30% CR without pre-treatment. For instance, the compressive strength of mixes made with 30% CR treated by cement paste and mortar were 29.28% and 23.56% lower than that of control mix, respectively. The same observation found for the mixes made with 40% CR. The reasons for this strength reduction can be attributed to that the soft surfaces of rubber particles might significantly minimize the adhesion between the boundaries of the rubber particles and cement paste. Furthermore, the reduction of the quantity of the solid material withstands the loading with increasing rubber content[22].

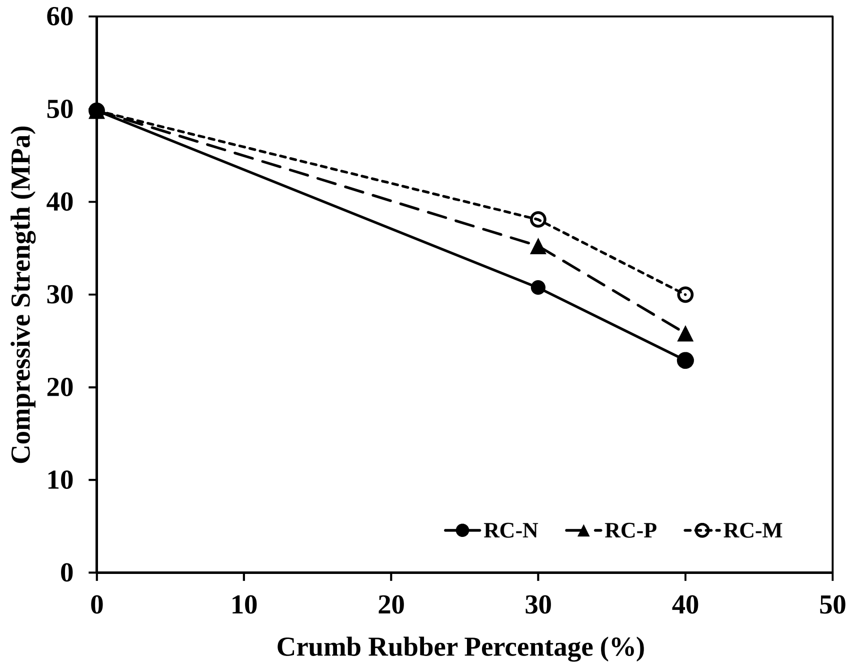

Fig. 2 Influence of pre-treatment of crumb rubber on compressive strength

Flexural Strength

Table (4) shows the results of the flexural test at age of 28 days for specimens of 40% CR. The results obviously showed that there is a reduction in strength when fine aggregate replaced with the crumbed rubber as in fig. (3). Conversely, the use of pre-treated CR gave a slight improvement of the flexural strength. The reduction of the flexure can be attributed to the weak bonding between hardened concrete and rubber particles which was improved by the layers of cement paste and mortar that covered the CR particles[23-26].

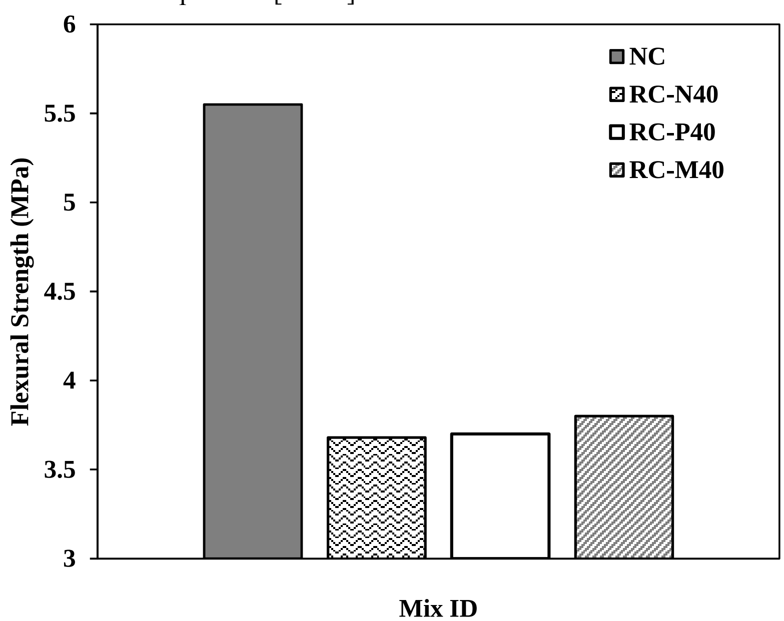

Fig. 3 Influence of pre-treatment of crumb rubber on flexural strength

CONCLUSION:

The results of this study can be summarized as following:

- As the percentage of CR increases the workability decreased. On the other hand, pre-treatment of CR with both methodologies gave better results for workability compared to non-treated CR.
- Due to the weak bond between the rubber particles and the hardened concrete, the compressive strength values reduce as the percentage of CR increases. Conversely, treating of CR enhances the strength. For instance, at 30% CR, the compressive strength increased with 14.64% and 23.91% for mixes treated with cement paste and mortar, respectively, compared to non- treated mixes. This enhancement can be attributed to that the surface roughness of treated particles will strengthen the bond between concrete particles.
- Mortar pre-treated CR showed higher flexural strength compared to both non-treated CR and cement paste pre-treated CR with 0.54% and 3.26% respectively, when replacing fine aggregate with 40% CR.
- Mortar pre-treated CR achieved the better results compared with cement paste treatment, this might be due to that mortar is more rough than cement paste, leading to high bond between particles.

ACKNOWLEDGMENT

The authors would like to thank Zeiad Elmabrouk and Ahmed Elzorgani, who carried out the experimental work of this research. Also, they do thank Al-Alia for technical and engineering consulting for providing the laboratory tests.

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