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Assessment of the mechanical performance of crumb rubber concrete

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HIGHLIGHTS

- Enhancement study of CRC mechanical performance was carried out.
- Effect of pre-treatment period, SF additives, and cement content was assessed.
- 0.5 h pre-treatment, 0% SF, and 350 kg/m^3 cement were the best alternatives.
- More than 0.5 h pre-treatment did not significantly affect CRC properties.
- Higher than 350 kg/m^3 cement did not significantly affect CRC properties.

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ABSTRACT

Crumb rubber concrete (CRC) has some known shortcomings in mechanical performance compared to conventional concrete, particularly with respect to compressive strength. Many previous researchers have tried to overcome the material deficiencies using different methods; however, the results have often been contradictory and highly variable. In this research, three methods to improve and then assess the mechanical performance of CRC have been examined namely, rubber pre-treatment using sodium hydroxide (NaOH) solution, using silica fume additives, and increasing concrete cement content. The effect of the rubber pre-treatment time (0–2 h), silica fume content (0–15%), and cement content (300–400 kg/m^3) on CRC slump, short and long term compressive strength, and tensile strength were measured for fifteen concrete mixes prepared with 0% and 20% rubber content. Six 100 × 200 mm cylinders were prepared from each mix for evaluating the compressive strength at 7 and 28 days. Four additional 100 × 200 mm cylinders were prepared from two mixes for evaluating the compressive strength at 56 and 84 days. In addition, two 150 × 300 mm cylinders for each mix were prepared and tested to determine the indirect tensile strength at 28 days. The results showed that 0.5 h of rubber pre-treatment using NaOH solution, 0% of silica fume replacing cement by weight, and 350 kg/m^3 cement content were the best alternatives in this assessment range to enhance the CRC performance.

1. Introduction

Due to the health and environmental risks presented from used tyre waste [1] as well as the scarcity and cost of natural mineral aggregates [2], a significant body of recent research has focussed on utilizing used tyre rubber in concrete as a partial replacement of its mineral aggregates, resulting in a class of concrete called crumb rubber concrete (CRC). The recycling of used rubber conserves valuable natural resources and reduces the amount of rubber entering landfill [3]. Previous experimental studies on CRC materials have shown that using rubber in concrete enhanced its ductility, toughness, impact resistance, energy dissipation, and damping ratio [4–7]. However, it reduced its compressive strength, tensile strength, and modulus of elasticity compared to conventional concrete [8–13]. Some of the main reasons for this strength reduction are the low hydraulic conductivity and the smooth surface of rubber particles, which both result in poor rubber/cement interface adhesion [14–17]. This poor adhesion is also attributed to the existence of zinc stearate which is used in tyre formulation during manufacturing. This zinc stearate migrates and diffuses to the rubber surface creating a soap layer that repels water [9].

To increase the effectiveness of using rubber in concrete, several approaches have been previously introduced. Of these approaches; the chemical pre-treatment of rubber particles using sodium hydroxide (NaOH) solution, replacing part of the cement by silica fume (SF) additive, and increasing the rubberized concrete cement content are the most common. However, the degrees of

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effectiveness using these approaches have been inconsistent and scattered in research published to date. Balaha et al. [18] experimented with three different cement contents namely, 300 kg/m^3, 400 kg/m^3, and 500 kg/m^3 in rubberized concrete mixes containing up to 20% rubber replaced by sand volume, and they treated the rubber particles using NaOH solution for 30 min. In addition, they replaced 15% of cement by weight with SF. Their results showed that the CRC properties improved with cement content increase up to 400 kg/m^3. Beyond 400 kg/m^3 cement content, only slight improvements were observed. However, the slump was negatively affected when using 400 kg/m^3. Using SF and NaOH pre-treatment, increased concrete slump by 77% and 7%, respectively, increased compressive strength by 18% and 15%, respectively, and increased tensile strength by 9% and 6%, respectively. Eldin and Senouci [19] treated rubber particles in NaOH solution for 5 min before use in CRC and achieved 16% increase in the compressive strength. Pelisser et al. [20] used NaOH pre-treated rubber combined with adding 15% SF by cement weight to the concrete mix. They reported almost total recovery of the concrete compressive strength. Güneyisi et al. [21] have observed lower workability but higher compressive strength of CRC by using SF. In addition, the positive effect of SF on the strength decreased as the rubber content increased. Mohammadi et al. [22] used pre-treated rubber in NaOH solution for 20 min, 2 h, 24 h, 48 h, and 7 days. Their results showed that 24 h is the best treatment period for the rubber as it resulted in the highest compressive strength and flexural strength. However, this pre-treatment had no effect on concrete slump. Hamza and Ghedan [23] washed rubber particles in NaOH solution before adding a coupling agent called SILAN to the rubberized concrete. Their results showed that the compressive strength improved by 74% compared to non-treated rubber mix.

Other researchers reported less positive or contradictory results from these approaches. Deshpande et al. [24] used modified rubber by saturating it in NaOH solution for 20 min. Their results showed almost no difference between the compressive and tensile strengths of pre-treated and non-treated rubber mixes. However, 12% increase in the flexural strength was reported for the pre-treated rubber mix. Tian et al. [25] reported 3.7% reduction in CRC compressive strength using NaOH pre-treated rubber for 24 h followed by tap water wash for 3 h compared to non-treated rubber. Li et al. [26] treated rubber particles using NaOH solution for 30 min and found that the properties of pre-treated rubberized concrete were nearly the same as those of non-treated CRC. Turatsinze et al. [27] mentioned that the strength benefit due to the NaOH rubber pre-treatment was not substantial. Youssf et al. [9] investigated the effect of cement content, NaOH pre-treatment of rubber for 30 min, and replacing 10% of cement weight by SF on the mechanical properties of CRC. Their results showed that the losses in CRC compressive strength with 425 kg/m^3 cement content were less than when using 350 kg/m^3 cement content. In addition, they reported that when using pre-treated rubber, the concrete slump and tensile strength decreased by 25% and 13%, respectively. But, the compressive strength and modulus of elasticity increased by 15% and 12% respectively, compared to non-treated rubber. No effect was observed in their results when using SF except a slight increase in the compressive strength at rubber content of 20% by sand volume. Albano et al. [28] studied concrete composites containing scrap rubber previously treated with NaOH and SILAN coupling agent in order to enhance the adhesion between the rubber and the cement paste, but did not notice any significant changes when compared to the non-treated rubber composites.

The contradictions and variations in the previous research findings indicate the need for future research in CRC performance enhancement. This paper investigates the mechanical properties of fifteen CRC mixes. The effects of rubber pre-treatment period, SF content, and cement content on the fresh and hardened properties of CRC were examined with the aim of assessing the CRC mechanical performance. These data provide additional information necessary to support the further development of CRC.

2. Experimental program

Several factors could potentially affect the concrete properties, including water to cement ratio, rubber content, and cement content. This experimental programme focuses on the factors affecting the adhesion at the rubber/cement interface in the concrete matrix, such as the cement content, rubber pre-treatment, and SF content. The poor rubber/cement interface adhesion is one of the main sources of the deficiencies in the rubberized concrete properties [14–17]. Increasing the rubber content in concrete enhances its dynamic properties [4–7]. However, using more than 20% rubber in concrete may magnify the adverse effects on concrete characteristics, as recommended by Khatib and Bayomy [16]. In this research the performance of concrete mixes incorporating 0 and

Table 1
Proportions of concrete mixes.

Mix code	Rs (%)	Pre-treatment of rubber (period)	SF (%)	Mix proportions (kg/m^3)							
				Cement	SF	Sand	Dolomite		Rubber	Water	SP
							10 mm	20 mm			
M1	0	–	–	350	–	866	311	727	–	175	6.3
M2	20	NaOH (0.5 h)	–	350	–	693	311	727	55.5	175	6.3
M3	0	–	–	400	–	814	293	684	–	200	7.2
M4	20	NaOH (0.5 h)	–	400	–	651	293	684	41.8	200	7.2
M5	0	–	–	300	–	916	330	769	–	150	5.4
M6	20	NaOH (0.5 h)	–	300	–	733	330	769	58.8	150	5.4
M7	20	No treatment	–	350	–	693	311	727	55.5	175	6.3
M8	20	NaOH (1.0 h)	–	350	–	693	311	727	55.5	175	6.3
M9	20	NaOH (2.0 h)	–	350	–	693	311	727	55.5	175	6.3
M10	0	–	5	333	18	862	310	724	–	175	6.3
M11	20	NaOH (0.5 h)	5	333	18	690	310	724	55.3	175	6.3
M12	0	–	10	315	35	859	309	722	–	175	6.3
M13	20	NaOH (0.5 h)	10	315	35	687	309	722	55.1	175	6.3
M14	0	–	15	298	53	856	308	719	–	175	6.3
M15	20	NaOH (0.5 h)	15	298	53	685	308	719	54.9	175	6.3

RS, Per cent of sand volume replaced by rubber.
SF, Per cent of cement replaced by silica fume.
SP, Superplasticizer dosage.