Annales de Chimie - Science des Matériaux
Vol. 46, No. 3, June, 2022, pp. 135-139
Journal homepage: http://iieta.org/journals/acsm

Effect of Recycled Rubber Powder on the Compatibility of Rubber-Cement Paste

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https://doi.org/10.18280/acsm.460304

Received: 22 January 2022
Accepted: 23 April 2022

Keywords:
recycled rubber powder, hydration, temperature profile, rubber-cement compatibility, setting time, inhibitory index

ABSTRACT

This study investigated the chemical compatibility of recycled rubber powder “RRP” with Portland cement by hydration test. Four mixes were prepared: pure cement paste and three rubber –cement pastes included 10%, 20%, and 30% of RRP. The compatibility of rubber - cement paste was evaluated by their temperature-time curves. The results of aptness and inhibitory index have shown that RRP rates higher than 10% was strongly inhibited the hydration reaction of cement. In addition, the setting time results revealed that rubber mixes require a longer curing time than pure cement paste, so the RRP could be used with cement-based materials as a setting retarder admixture. The recycling of rubber tire waste with cement-based materials could be reduced their accumulation in landfills and protects the natural and environment facing their harmful effects.

1. INTRODUCTION

Recent statistics reported that the waste rubber tires reached 1.5 billion full tires worldwide per year [1, 2]. This waste pollutes the natural sources of air, groundwater, and soil, because it contains polluted and toxic elements such as heavy metals [1-3]. Reliable environmental references recommended reusing them with building materials as a concrete aggregate [2-5]. However, many studies have shown that the inclusion of rubber particles with concrete composite produced a high reduction in their mechanical performance [6, 7]. These studies did not give convincing arguments to explain this behavior of rubber composites.

In our study, we assume that this behavior was due to the lack of chemical incompatibility (inhibition) between Portland cement and rubber aggregate. The inhibition characterized by a lower hydration temperature and an extended setting time [8-10]. In the literature, the compatibility of Portland cement with other materials has been evaluated by the hydration test [11-13]. The main criteria proposed by most researchers to evaluate the compatibility of cement binder were: the maximum hydration temperature and their corresponding setting time [11-13].

This study evaluated the chemical compatibility of RRP with Portland cement, in order to optimize their ratio with cement binder without causing the inhibition of their hydration reaction.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this investigation were: Portland cement of strength class 42.5, recycled rubber powder RRP obtained by mechanical shredding of waste rubber tires (Figure 1) and distilled water. Some physical properties of used materials are given in Table 1.

Table 1. Some physical properties of used materials

Properties	Cement	RRP 0 – 1.2 mm
Apparent density (Kg/m^3)	1020	475.50
Specific density (Kg/m^3)	3050	1070
Water absorption (%)	-	0.10
Finesse modulus	-	1.35

Figure 1. Rubber powder

2.2 Preparation mixes

Table 2. Composition of the mixes

Component proprety	mix			
	CWP	RCWP 10%	RCWP 20%	RCWP 30%
RRP (g)	0	45	90	135
Cement (g)	450	450	450	450
Water (g)	200	200	200	200

Table 3. The criteria used to assess the compatibility of mixes

Criterion	Classification index	Evaluation
setting time t_{max} Weatherwax and Tarkow [13]	$t_{max} \leq 15$ hours	Suitable
	15 hours> t_{max}< 20 h	Intermediately suitable
	$t_{max} \geq 20$ hours	Unsuitable
Aptness (A) Vilela and Du Pasquier [14]	$A \geq 80\%$	Very good
	$80\% > A \geq 60\%$	Good
	$60\% > A \geq 50\%$	Regular
	$A < 50\%$	Bad
Time ratio index (T_R) Olorunnisola [10]	$1 \leq T_R \leq 1.5$	Suitable mix
	$1.5 < T_R \leq 2.0$	Acceptable mix
	$T_R > 2$	Inhibitor mix
Inhibitory index (I) Hofstrand et al. [11]	$10 < I$	Moderate inhibition
	$50 < I$	High inhibition
	$I > 100$	Extreme inhibition

In order to examine the chemical compatibility of rubber-cement-water mixes, four pastes were prepared: pure cement paste and three cement-rubber pastes incorporating (10%, 20%, and 30%) of rubber powder, for the hydration test. The cement pastes were prepared in accordance with European standards EN 196-3 [15]. The composition of each paste was summarized in Table 2. The letters R, C, W, and P refer to rubber, cement, water, and Paste respectively, for example, RCWP10% indicates the paste, including 10% of recycled rubber.

2.3 Hydration test

The chemical compatibility was evaluated by a hydration test. This was carried out by a same method that has been described by several researchers [10, 16, 17]. The hydration tests were carried out in sealed and thermally insulated containers (Dewar flasks). The temperature-time profiles were evaluated using a system of T-type thermocouples, connected to a multi-point data logger, were inserted (Figure 2). The prepared pastes were placed in the thermal insulation chamber. The temperature reading for each mix was taken at 1 min interval over a period of 48 h. The time taken to reach the maximum temperature was evaluated. The experimental device used in this study is illustrated in Figure 2.

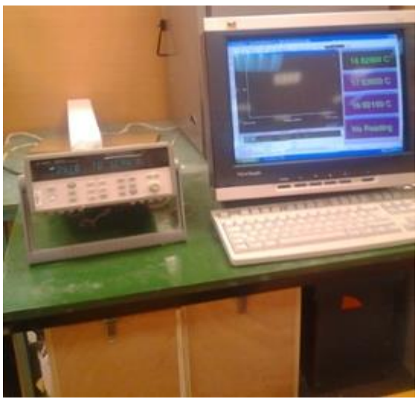

Figure 2. The experimental device of the hydration test

The compatibility levels of rubber-cement and pure cement pastes were assessed using the four criteria shown in Table 3. The criteria established by many researchers [11-14, 18-20] to assess the compatibility of cement mixes were: maximum hydration temperature Tmax, setting time t, Aptness (A) as in Eq. (1), time ratio index (t_R) as in Eq. (2), and Inhibitory index (I) as in Eq. (3).

$$A = (T_m - T_0 | T_M - T_0).100 \quad (1)$$

$$t_R = (t_{RC} | t_{PC}).100 \quad (2)$$

$$I = (t_{RC} - t_{PC} | t_{PC}).100 \quad (3)$$

where:

T_0, T_m, T_M: initial room temperature of the experiment, maximum temperature of cement – rubber-water mix and maximum temperature of the pure cement mix, respectively.

t_{RC} and t_{PC}: time to reach the maximum temperature of Rubber-Cement-Water mix and pur Cement-Water mix respectively.

3. RESULTS AND DISCUSSIONS

3.1 Hydration temperature

The hydration results were presented and summarized in Figure 3 and Table 4, respectively. Figure 3 illustrates the hydration temperature profiles as a function of time. It shows a reduction in the maximum hydration temperature with the rubber powder ratio. Indeed, the temperature decreased from 41.5°C to 27°C for a rubber rate ranging from 0 to 30%. This behavior reveals that rubber powder absorbed the heat, emitted by the hydration reaction and prolonged the hydration reaction of cement especially for the mixes RCWP20% and RCWP30%. The study conducted by Guelmine et al. [21] recommended limiting rubber aggregate with plain mortar lower than 9% in order to obtain an acceptable workability. We recommend limiting the rubber ratio in cement-based materials lower than 20% to avoid this harmful effect on their physical and mechanical performance.

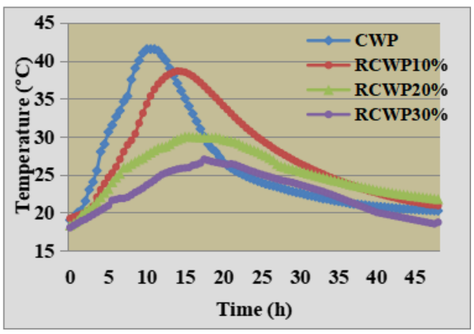

Figure 3. Hydration temperature as a function of the time for studied pastes

Table 4. Effect of recycled rubber powder on hydration of cement paste

Criterion	Mix			
	CWP	RCWP 10%	RCWP 20%	RCWP 30%
T_{max} (°C)	41.5	38.60	30.0	27.0
A (%)	-	87.2	48.89	35.55
Note	-	Very good	Bad	Bad
t_s (h)	9.5	14	15.50	17.50
Note	Suitible	Suitible	Inter-mediately suitible	Inter-mediately suitible
t_R	-	1.47	1.63	1.84
Note	-	Suitible	Acceptable	Acceptable
I (%)	-	47.37	63.16	84.21
Note	-	Medim	High	High

3.2 Aptness

The aptness results were presented in Figure 4. Figure 4 shows a reduction in the aptness of rubber pastes (RCWP10%, RCWP20%, RCWP30%) compared to cement paste. It decreased with increasing recycled rubber powder rate. Indeed, it is about 87.20%, 48.89%, and 35.55%, respectively. Comparing the aptness indices obtained in this study with the classification values established by Vilela and Du Pasquier [14]: the mix RCWP10% has a very good aptness and other mixes have a bad aptness. These results reveal that the mix included 10% of rubber has a high compatibility, on the other, the other mixes have a low incompatibility. This trend confirms the results presented in the section above. So, we recommend limiting the rubber powder ratio lower than 20% with cement based materials.

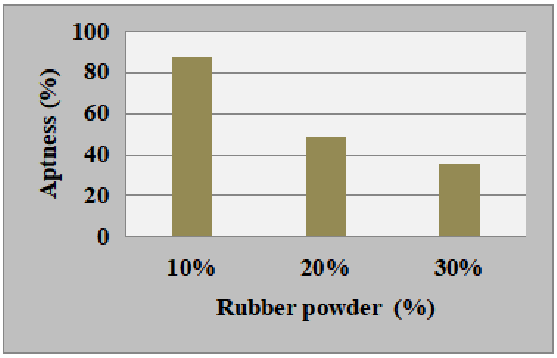

Figure 4. The aptness of the studied mixes as a function of rubber powder rate

3.3 Setting time

Figure 5 illustrates the setting times of studied mixes (CWP, RCWP10%, RCWP20%, RCWP30%) which were about (9.5, 14.0 h, 15.5 h, 17.5 h). The inclusion of rubber powder with cement paste increases their setting time. These increases were about (48%, 63%, and 84%) compared to the pure cement paste, respectively. This behavior is due to the nature of the rubber which delays the evaporation of mixing water of cement paste and prolongs their setting time. The research carried out by Wang et al. [20] revealed that initial and final setting times of concrete increased with increasing rubber content. In addition, according to the classification reported by Weatherwax [13], the mixes (CWP, RCWP10%) have a suitable setting time and the others have intermediately suitable setting times. This trend reveals that rubber mixes required a longer curing time than that the pure cement paste. This innovative property could be invested in a hot climate to delay the evaporation of mixing water of the concrete composites. Rubber powder could be used in cement-based materials as a setting time retarder admixture.

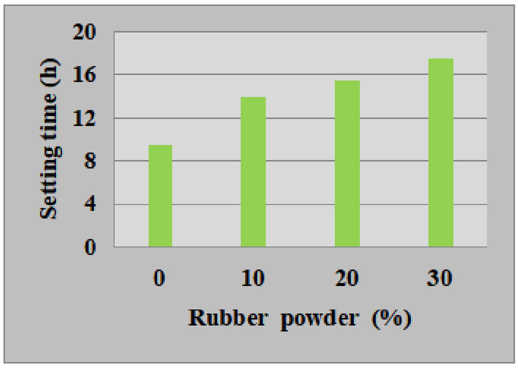

Figure 5. The setting time of prepared mixes as a function of the rubber powder rat

3.4 Time ratio index

The time ratio results are illustrated and summarized in Figure 6 and Table 4, respectively. According to the classification established by Olorunnisola [10] based on the time ratio index. Our results revealed that the time ratio index of rubber–cement pastes (RCWP10%, RCWP20%, RCWP30%) is about 1.47, 1.63, 1.84, respectively. It decreases with increasing rubber powder content. It is suitable for the RCWP10% mixes and acceptable for the other mixes. Our results showed that the inclusion of rubber powder with cement matrix up to 30%, does not reveal any problem according to the classification cited above. The results of this criterion are in contradiction with the results obtained for the hydration temperature, aptness and the setting time. In the literature, there is no research on this criterion for the rubber-cement composite. In this study, the time ratio index is less significant and does not reflect reality.

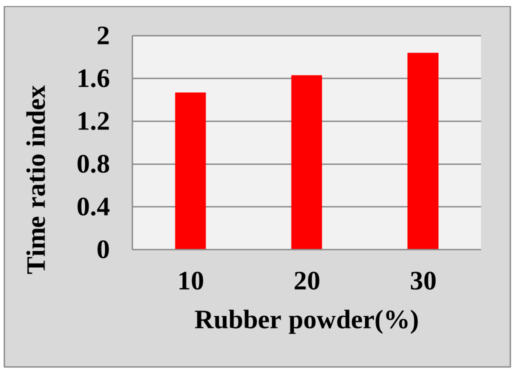

Figure 6. The time ratio index of the rubber mixes

3.5 Inhibitory index

Figure 7 shows that the inclusion of recycled rubber powder (10%, 20%, 30%) with cement paste strongly increases their inhibitory index. Indeed, these increases were about (47.37%, 63.16%, 84.21%) respectively. According to the classification developed by various researchers [9, 11, 12] based on the inhibitory index, we note that RCWP10% mix has an intermediate incompatibility and the other mixes (RCWP20%, RCWP30%) have very high incompatibility. These results reveal that rubber powder with cement paste higher than 10% strongly inhibited their hydration reaction. This trend means that the hydration reaction is incomplete and the mechanical performance of the rubber-cement mixes are lower. In the literature, there is much research confirmed this trend [18, 19]. We recommend limiting the rubber powder rate with concrete structures lower than 20%.

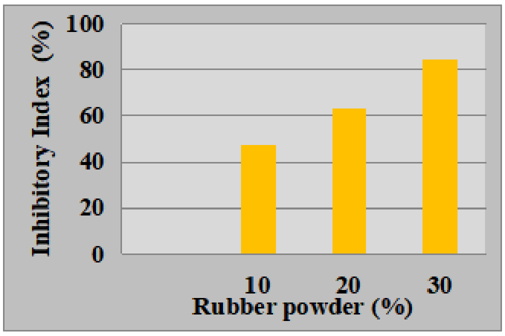

Figure 7. The inhibitory index as a function of the rubber powder rate

4. CONCLUSION

This study investigated the compatibility of recycled rubber powder with Portland cement. Based on the results obtained, the following conclusions were drawn:

- The aptness results showed that 10% of rubber powder was very compatible with cement binder, but 20% and 30% mixes highly inhibited the hydration reaction of cement binder. We recommend limiting the rubber-powder rate with cement-based materials lower than 20% to avoid this harmful anomaly which can reduce their performance.
- In terms of setting time, the mixes (CWP, RCWP10%) have a suitable setting time and the other mixes have intermediately suitable setting times. This trend revealed that rubber mixes require a longer curing time than pure cement paste. In addition, the rubber powder could be used in cement-based materials as a setting retarder admixture.
- Concerning inhibitory index, our results have shown that the recycled rubber powder rate higher than 10%, was strongly inhibited the hydration reaction. We recommend limiting the rubber powder rate in cement-based materials lower than 20%.

This study reveals that rubber aggregates could be reused in structural concrete with a ratio that does not exceed 10%. However, for secondary concrete structures, these aggregates could be reused in all safety because these structures do not require high resistance. The recycling of waste rubber tires with cement-based materials could be reduced their accumulation in the landfills and protects the environment.

In the future study, we will examine the physical and chemical treatment of rubber aggregates from waste rubber tires with the aim to improve their compatibility with cement-based materials.

ACKNOWLEDGMENT

Finally, the authors want to present the best regards to the Laboratory of Innovative Technologies of the University of Picardie Jules Verne IUT for their technical support during this research.

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