THE EFFECT OF USING WASTE TIRE RUBBER POWDER ON THE PHYSICAL AND MECHANICAL PROPERTIES OF PORTLAND CEMENT

Yilmaz Kocak[1], Lale Alpaslan[2]

[1]Dumlupinar University, Kutahya Vocational School of Technical Sciences, Department of Construction, Kutahya, Turkey

[2]Duzce University, Institute of Sciences, Department of Construction, Duzce, Turkey

Abstract

Industrial wastes, which are left to the nature, dramatically damage to human health and environmental via progression of the technology with each passing day. Waste tires are one of these wastes. Waste tires and waste tire rubber powder (WTRP) can be used for a range of civil engineering applications. This study investigates the physical and mechanical properties of Portland cement (reference) and WTRP substituted cements. For this purpose, WTRP was substituted as a replacement for Portland cement in amounts of 0, 2.5 and 5 weight %. The effects of WTRP on water demand, volume expansion, setting time, flexural and compressive strength were determined by standard tests of cement. As a result, a relative increase according to reference cement pastes was determined in the setting time of the WTRP substituted pure cement pastes. Furthermore, the addition of WTRP was affected the physical and mechanical properties of the blended cements depending on the amount of WTRP.

Key words: *portland cement, waste tire rubber powder, flexural strength, compressive strength, recycle*

1. INTRODUCTION

Solid wastes are a serious problem in the context of sustainability and environmental issues in many countries around the world. Waste tires are one of the wastes. Many waste tires are currently stockpiled in many countries around the world. These stockpiles are a serious dangerous because they pose as potential environmental concern and fire hazards (Al-Akhras & Smadi 2004). These waste materials are now commonly used in a variety of sectors in order to reduce their harmful effects, to save energy and to provide recycling.

In recent years, waste tires and waste tire rubber are used in many fields as cement and construction technology. These studies are particularly focused on the use of waste tires that have been crumbled and powdered into different sizes and forms (Yeşilata et al. 2008). Waste tires are utilized as lightweight aggregates due to their low unit weight, and are used in ground infill (Amari et al. 1999; Humphrey 1999; Aiello & Leuzzi 2010). They are also used as asphalt and concrete aggregates due to their advantageous characteristics such as low unit weight, high toughness and good insulation features. In addition, they are used as shock-absorbers in wave breakers and railways. On the other hand, waste materials can also be used for erosion control, noise barriers in highways, swamp improvement, paving base material in road backfills, modified material in hot mix asphalt coatings, and seismic isolators in walking paths and buildings (Gönüllü 2004; Turgut et al. 2007; Topçu 1995; Topçu & Avcular 1997; Sugözü & Mutlu 2009; Snelson et al. 2009; Koçak et al. 2012; Koçak & Alpaslan 2015; Kocak et al. 2015).

There are a number of studies focusing on the use of waste tires rubber in the cement and concrete sectors as fine aggregate (Benazzouk et al. 2007; Benazzouk et al. 2007). However, there are very little studies regarding their use as cement substitute materials. For this reason, in this study, waste tire rubber powder was substituted in PC in different proportions. The effects of this process were investigated, including the characteristics of the final product, such as compressive strength, flexural strength, setting time, water demand and volume expansion of cement paste and mortars.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this study are Portland cement (PC) and waste tire rubber powder (WTRP). The PC was CEM I 42.5 R in accordance with TS EN 197-1 (TS EN 197-1 2012), which was provided from SET Istanbul Ambarli Cement Plant which is used as reference. WTRP was obtained from the A Commercial Business in Ankara (Turkey). WTRP, in the bottom during the making various grades and sizes of granules obtained from waste tires in very fine powder, and was obtained by sieving 125 μm sieve. In the preparation of cement mortar and paste specimens, CEN standard sand, conforming to TS EN 196-1 (TS EN 196-1 2009), and city water of the Buyukcekmece district of Istanbul province were used. The results obtained from the chemical analyses of PC and WTRP are given in Table 1.

Table 1. Chemical specifications of PC and WTRP

	Materials	
Chemical composotion: wt.%	PC, %	WTRP, %
SiO_2	19.88	18.30
Al_2O_3	5.24	4.08
Fe_2O_3	2.66	3.88
CaO	63.50	9.94
MgO	1.11	2.30
SO_3	2.78	3.57
Na_2O	0.40	1.06
K_2O	0.78	0.45
Cl^-	0.0071	-
Loss on ignition	3.72	-
Free CaO	1.43	-

2.2. Methods

In this study, PC was used for the preparation of reference samples. WTRP was substituted in PC at rates of 0, 2.5 and 5 weight %. Therefore, a total of three different cements were used and those were codified as R, 2.5 WTRP and 5 WTRP.

Cement paste and mortar mixtures were prepared in accordance with TS EN 196-1 (TS EN 196-1 2009). The volume expansion values, water demands and setting time values of cement paste specimens were determined in accordance with the Le Chatelier method, given in TS EN 196-3 (TS EN 196-3 2010).

Cement pastes and mortars are prepared according to Turkish Standard. Water demand, volume expansion and setting time of cement paste samples are determined according to Turkish Standard. In the preparation of mortar mixtures for flexural and compressive strength experiments, 450 g of cement, 1350 g of standard sand and 225 ml of water are used in each mortar mixture according to Turkish Standard. Prepared mortars are poured into three-segmented rectangular prism moulds of size 40x40x160 mm. These specimens were then shaken for one minute on a shaking table so the mortar settled into the formworks. These specimens were kept in a laboratory environment for 24 hours, and at the end of this duration, specimens were taken out of the formworks and kept in a curing pool. The

specimens taken from the pool after 2, 7, 28 and 90 days were tested in accordance with TS EN 196-1 (TS EN 196-1 2009).

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Physical analysis

Physical specifications of cement and WTRP were given in Table 2.

Table 2. Physical specifications of materials

Mixtures	Range dimension (over sieve), %			Specific gravity, g/cm^3	Blaine, cm^2/g
	>45 µm	>90 µm	>200 µm		
PC	4.7	0.3	0.0	3.15	3504
WTRP	45.4	17.9	2.2	1.70	2404
2.5 WTRP	7.3	0.5	0	3.11	3367
5 WTRP	7.5	0.5	0	2.88	3341

Particle dimension distribution, Blaine value and specific gravity are determined in the physical analyses. The grain size and Blaine values of PC are smaller in comparison to the WTRP. While the specific gravity of cement and WTRP are 3.15 g/cm^3 and 1.70 g/cm^3, respectively (Table 2). When the WTRP with a low specific gravity is substituted in cement, the specific gravity values of the obtained cement samples with WTRP substitution also decrease.

3.2. Water demand, volume expansion and setting time

The water demand, volume expansion and setting time values, obtained for cement paste specimens at the end of the tests made in accordance with TS EN 196-3 (TS EN 196-3 2010) are given in Figure 1, 2 and 3, respectively.

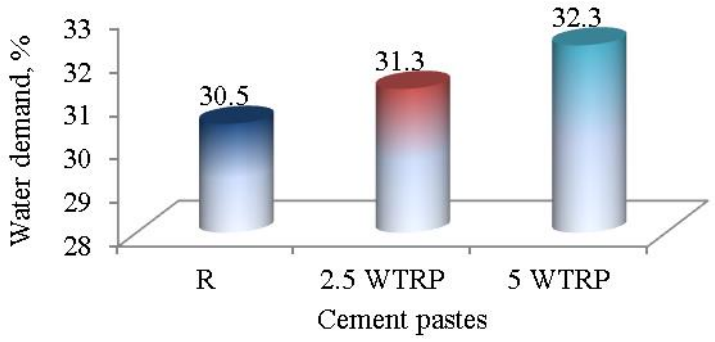

Figure 1. Water demand of PC and WTRP substituted cements.

According to Figure 1, with increasing amounts of WTRP substituted to PC, a relative increase is observed in the amount of water needed in order to obtain a homogeneous consistency. This increase is in the range of 2.6% and 5.9%, for 2.5 and 5WTRP cement paste specimens respectively, in comparison to PC.

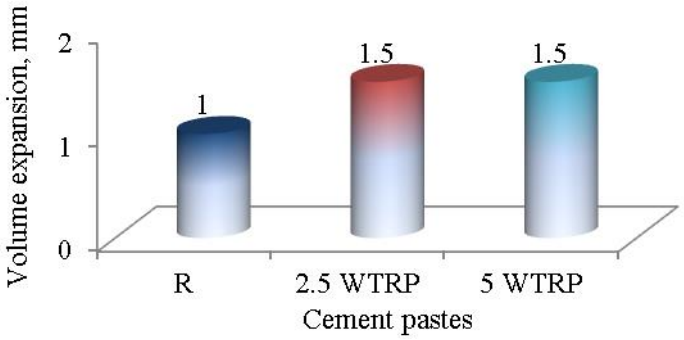

Figure 2. Volume expansion of PC and WTRP substituted cements.

The excessive amounts of MgO and CaO in the cement result in expansion in the cement paste. These expansions lead to cracking and damages inside the concrete. In order to detect the volume expansion due to cement, a Le Chatelier test was conducted. According to the results, the volume expansion value obtained for PC is 1mm, and those obtained for 2.5 and 5 WTRP cement paste specimens are 1.5 and 1.5 mm, respectively (Figure 2). The results indicated that the volume expansion values change between 1 and 1.5 mm, and therefore, all values appeared to be lower than 10 mm, which is the threshold value offered by TS EN 196-3 (TS EN 196-3 2010).

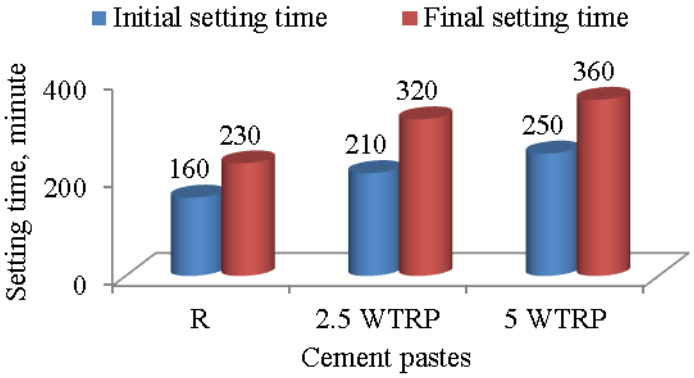

Figure 3. Setting time of and WTRP substituted cements.

As increasing amounts of WTRP are substituted to the cement, the initial and final setting times also increase (Figure 3). When the initial setting times given in Figure 3 are compared, it is seen that the shortest initial setting time, which is 160 minutes, is observed in PC paste, while the longest initial setting time, which is 250 minutes, is observed in 5 WTRP cement paste specimen. It was further observed that the initial setting time values of 2.5 and 5WTRP cement paste specimens were increased by 31.3% and 56.3%, respectively, in comparison to PC. The final setting time values of 2.5 and 5WTRP cement paste specimens, on the other hand, increased by 39.1% and 56.5%, respectively, in comparison to PC. When these values are evaluated, it is seen that the minimum of the initial setting time values obtained for all cement paste specimens is above 60 minutes, while the maximum of the final setting time values obtained for all cement paste specimens is below 600 minutes (TS EN 197-1

2012). According to the results of the experiment, it can be concluded that there will not be any problem in transporting and laying fresh concrete. Furthermore, the required strength will be obtained, and the formworks can be dismantled in an appropriate period of time. Therefore, the concrete will not be adversely affected by external environmental conditions (Şimşek 2000).

3.3. Flexural strength

The Flexural strength of the cement mortar specimens were determined at 2, 7, 28 and 90 days. The test results were shown in Figure 4.

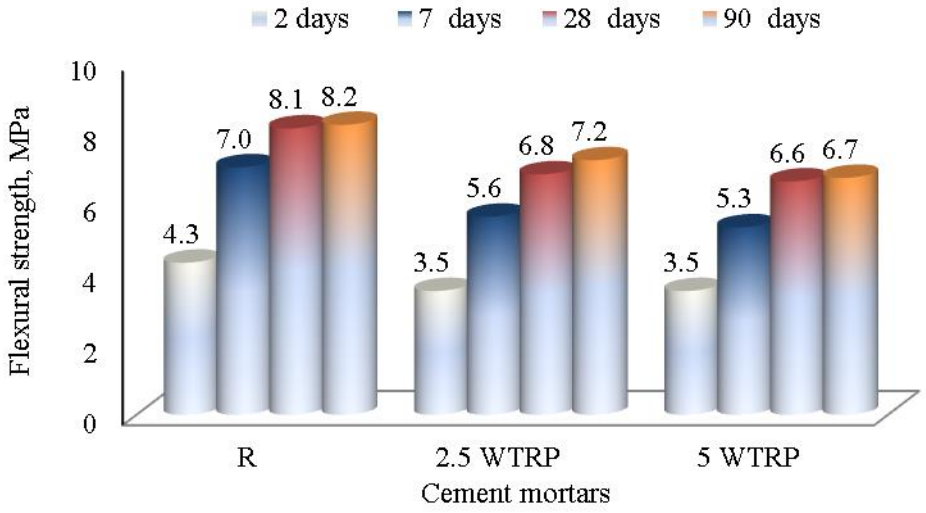

Figure 4. Flexural strength of PC and WTRP substituted cements.

According to the obtained results, with 2.5 WTRP cement used, the flexural strength of the mortar specimens produced decreased by 18.6% after 2 days, 20% after 7 days, 16% after 28 days, and 12.2% after 90 days compared to that with pure cement used. Finally, compared to the 5 WTRP cement mortar specimens, the flexural strength values were shown to decrease by 18.6% after 2 days, 24.3% after 7 days, 18.5% after 28 days, and 18.3% after 90 days (Figure 4). Based on the data obtained after the tests, the flexural strength obtained for all WTRP substitution rates were lower than the value obtained for PC.

3.4. Compressive strength

The compressive strengths of the cement mortar specimens are determined at 2, 7, 28 and 90 days. The results obtained at the end of these tests were given in Figure 5.

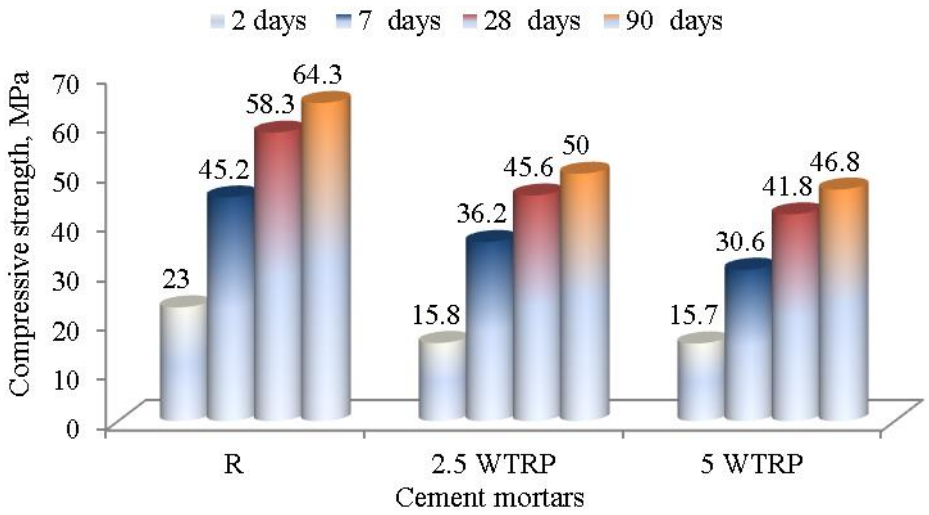

Figure 5. Compressive strength of PC and WTRP substituted cements.

According to the obtained results, with 2.5 WTRP cement used, the compressive strength of the mortar specimens produced decreased by 31.3% after 2 days, 19.9% after 7 days, 21.8% after 28 days, and 22.2% after 90 days compared to that with pure cement used. Finally, with 20ZC cement used, the compressive strength of the mortar specimens produced decreased by 31.7% after 2 days, 32.3% after 7 days, 28.3% after 28 days, and 27.2% after 90 days compared to that with pure cement used (Figure 5). Based on the data obtained at the end of the tests, the compressive strength obtained for all WTRP substitution rates were lower than the value obtained for PC.

After a general evaluation of the obtained results, it is seen that the compressive strengths of all cement mortars with WTRP substitute are greater than 32.5 MPa, which is defined as the minimum compressive strength value to be gained after 28 days by TS EN 197-1 [TS EN 197-1 2012].

4. CONCLUSION

The study investigated the possibility of using WTRP with PC as cement material. Based on the tests and analyses results of the study the following conclusions can be listed as follows:

- According to the results obtained from tests and analyses, grain size and Blaine values of the WTRP is smaller than PC.
- Since the specific weight of WTRP is low, the specific weight values obtained for cement specimens with WTRP substitute also appeared to be low.
- The workability is improved by increasing WTRP amounts. Therefore, it might be concluded that the water amount needed in order to obtain a homogeneous consistency does not change considerably.
- Since all values are lower than 10 mm, the obtained volume expansion values are appropriate.
- The initial and final setting times of WTRP pastes increased with increasing WTRP amounts.
- The flexural and compressive strength values of cement mortar specimens decreased with the increase of WTRP replacement level for all curing periods tested. In general, the desired results in terms of the flexural and compressive strengths of cement mortars produced using PC cement with WTRP substitute could not be obtained. However, use of WTRP can still provide advantages in conditions of economic efficiency, sustainability and environmental protection.

ACKNOWLEDGMENTS

The authors would like to thank Duzce University Scientific Research Unit for providing financial support for this research (Project Code Number: 2011.03.HD.011). They would also like to thank SET Ambarli Cement Plant executives and the staff for their invaluable contributions on this study.

REFERENCES

Aiello, MA & Leuzzi, F 2010, Waste tyre rubberized concrete: Properties at fresh and hardened state, Waste Management, vol. 30, pp. 1696–1704.

Al-Akhras, NM & Smadi, MM 2004, Properties of tire rubber ash mortar, Cement & Concrete Composites, vol. 26, pp. 821–826.

Amari, T, Nicolas, JT & Iddo, KW 1999, Resource Recovery from Rubber Tires, Resources Policy vol. 25, pp. 179–188.

Benazzouk, A, Douzane, O, Langlet, T, Mezreb, K, Roucoult, JM & Queneudec, M 2007, Physico-Mechanical Properties and Water Absorption of Cement Composite Containing Shredded Rubber Wastes, Cement & Concrete Composites, vol. 29, pp. 732–740.

Benazzouk, A, Douzane, O, Langlet, T, Mezreb, K, Roucoult, JM & Queneudec, M 2008, Thermal Conductivity of Cement Composites Containing Rubber Waste Particles: Experimental Study and Modelling, Construction and Building Materials, vol. 22, pp. 573–579.

Gönüllü, MT 2004, Atık Lastiklerin Yönetimi, Katı Atık Geri Dönüşüm Teknolojileri Semineri, İstanbul, Turkey, pp. 1–11 (in Turkish).

Humphrey, DN 1999, Civil Engineering Application of Tire Shreds, The Tire Industry Conference, Hilton Head, South Carolina, pp. 1–16.

Kocak, Y, Gulbandilar, E & Alpaslan, L 2015, Prediction The Effects Of Blast Furnace Slag And Waste Tire Rubber Powder On The Setting Time Of Portland Cement With Fuzzy Logic, Materials, Methods & Technologies 17th International Conference, vol. 9, pp. 298–307.

Koçak, Y, Subaşı, S, Yaman, Y, Uğur, LO & Ateş, A 2012, The Effect Of The Rate Of Waste Tire Powder Substitution On The Physical And Mechanical Properties Of Cem II Cement, 1st International Conference On Architecture & Urban Design, Tirana, Albania, pp. 1235–1240.

Koçak, Y & Alpaslan, L 2015, Physıcal And Mechanıcal Propertıes Of Blast Furnace Slag And Waste Tıre Powder Replaced Cements, 2nd International Sustainable Buildings Symposium, Ankara, Turkey, pp. 426–431.

Şimşek, O 2000, Yapı malzemesi II, Ankara Üniversitesi Basımevi, Ankara, Turkey.

Snelson, DG, Kinuthia, JM, Davies, PA & Chang, SR 2009, Sustainable Construction: Composite Use of Tyres and Ash in Concrete, Waste Management, vol. 29, pp. 360–367.

Sugözü, İ & Mutlu, İ 2009, Atık Taşıt Lastikleri Değerlendirme Yöntemleri, Teknolojik Araştırmalar Dergisi, vol. 1, no. 1, pp. 34–46 (in Turkish).

Topçu, İB 1995, The Properties of Rubberized Concretes, Cement and Concrete Research, vol. 34, pp. 304–310.

Topçu, İB & Avcular, N 1997, Collosion Behaviours of Rubberized Concretes, Cement and Concrete Research, vol. 27, pp. 1893–1898.

TS EN 197-1 2012, Cement- Part 1: Compositions and conformity criteria for common cements, Turkish Standards, Ankara, Turkey.

TS EN 196-1 2009, Methods of testing cement-Part 1: Determination of strength, Turkish Standards, Ankara, Turkey.

TS EN 196-3 2010, Methods of testing cement-part 3: determination of setting time and soundness, Turkish Standards, Ankara, Turkey.

Turgut, P, Işıker, Y & Yeşilata, B 2007, Kompozit Yapı Malzemelerinde Isıl Özellik Ölçümü-2: Hurda Lastik Katkılı Betonlar İçin Ölçüm Sonuçları, Makina Mühendis Dergisi, pp. 565: 33–39 (in Turkish).

Yeşilata, B, Turgut, P & Demir, F 2008, Atık Taşıt Lastikleri ile Potansiyel Uygulamalar ve Beton İçerisinde Kullanımı, Çimento ve Beton Dünyası, vol. 71, pp. 65–74 (in Turkish).