The Effect of the Rate of Waste Tire Powder Substitution on the Physical and Mechanical Properties of CEM II Cement

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1 ABSTRACT

Recycling of waste has a great importance in preservation of the energy and decreasing the global impact that has been created by production of new materials. There is an increasing debate about the use of waste tires because of their environmental and health affects. Waste tires can be used for a range of civil engineering applications. This study investigates the physical and mechanical properties of CEM II (reference) and waste tire powder substituted cements. For this purpose, waste tire powder was substituted as a replacement for CEM II cement in amounts of 0, 2.5, 5, 7.5 and 10 weight %. The effects of waste tire powder on compressive and flexural strength, setting time, water demand and volume expansion 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 waste tire powder substituted cement pastes. Besides these, a decrease were identified with the 2, 7, 28 and 56 days flexural and compressive strength tests for the waste tire powder substituted cement mortars according to reference cement mortars.

Keywords: Recycle, waste tire, cement, flexural strength, compressive strength.

2 INTRODUCTION

With advancing technol ogy, more and more industrial waste materials are disposed of in nature. This situation seriously damages the environment and human health [1-4]. 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 [5]. One of the most important of these waste materials is waste tires.

Due to growing need for vehicles, and advancements in the transportation sector, tire production has also recently gained speed. With increasing tire production, the volume of tire waste has also increased. Therefore, controlling tire waste has become a global problem. Methods to reuse and recycle this waste differ, to a large extent, based on usage areas and production difficulties, and require great effort. After a number of industrial processes, the recycling of waste materials might be achieved by four different methods. These are: direct evaluation, material evaluation, thermal evaluation and evaluation based on raw material [6-8].

Today, waste tires are used in many fields. Waste tires are utilized as lightweight aggregates due to their low unit weight, and are used in ground infill [8-10]. They are also used as asphalt and concrete aggregates due to their advantageous characteristics such as low unit weight, good insulation features, and high toughness. 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 [5, 11-16].

In recent years, a number of studies have researched the use of tire waste in the concrete sector. These studies are particularly focused on the use of waste tires that have been crumbled and powdered into different sizes and forms [6]. Concrete produced using waste tire powder is partially used as an aggregate, and is used in the construction of retaining walls and impact barriers. It is stated that deaths due to accidents would decrease if concrete with tire waste additives were used, since the energy from the impact would be absorbed [17].

There are a number of studies focusing on the use of waste tires in the cement sector as a fine aggregate [18, 19]. However, there are no studies regarding their use as cement substitute materials. For this reason, in this study, waste tire powder was substituted in CEM II cement in different proportions. The effects of this process were investigated, including the characteristics of the final product, such as compressive strength of cement paste and mortars, setting duration, water demand and volume expansion.

3 MATERIALS AND METHODS

3.1 Materials

In this study, CEM II cement, produced in the Mersin Cement Factory, and waste tire powder (WT), as a substitute material, from Ankara were used. Waste tire powder was taken from the very fine material obtained during the granulation of waste tires of different class and sizes, and sifted through a 125 µm screen. The results obtained from the chemical analyses of CEM II cement and waste tire powder are given in Table 1.

	Materials	
Chemical composotion: wt.%	CEM II, %	WT, %
SiO_2	19.94	18.30
Al_2O_3	5.42	4.08
Fe_2O_3	2.27	3.88
CaO	55.64	9.94
MgO	1.98	2.30
SO_3	2.50	3.57
Na_2O	0.22	1.06
K_2O	0.1	0.45
Loss on ignition	11.6	-
Free CaO	0.5	-

Table 1: Chemical specifications of materials

For the preparation of mortar specimens, CEN standard sand, conforming to TS EN 196-1 [20], and city water of the province of Mersin were used.

3.2 Methods

In this study, CEM II cement was used for the pr eparation of reference samples. Waste tire powder was substituted in CEM II cement at rates of of 0, 2.5, 5, 7.5 and 10%. Therefore, a total of five different cements were used and those were codified as R, 2.5 WT, 5 WT, 7.5 WT and 10 WT.

Cement paste and mortar mixtures were prepared in accordance with TS EN 196-1 [20]. The volume expansion values, water demands and setting duration values of cement paste specimens were determined in accordance with the Le Chatelier method, given in TS EN 196-3 [21].

Mortar mixtures, used in bending and compression tests, each contained 450g cement, 1350g standard sand and 225 ml water, and mixed in a mortar-mixing machine, conforming to TS EN 196-1. The prepared mortars were poured into the 40x40x160 mm prismatic formworks. 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 56 days were tested under bending and compression in accordance with TS EN 196-1.

4 EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Physical Analysis

The grain size intervals, as well as specific weights and Blaine values of the materials used in this study are given in Table 2.

Mixtures	Range dimension (over sieve), % > 90 µm	> 45 µm	Specific gravity, g/cm^3	Blaine, cm^2/g
CEM II	0,2	3,4	2,93	4420
WT	13,1	28,7	2,41	4630
2.5 WT	2,2	6,6	2,85	4462
5 WT	4,6	12,5	2,81	4489
7.5 WT	8,4	23,8	2,78	4509
10 WT	12,2	39,6	2,69	4527

Table 2: Physical specifications of materials

The grain size values of CEM II cement are smaller in comparison to the waste tire powder. The Blaine value of waste tire powder, on the other hand, is higher in comparison to CEM II cement. This indicates that waste tire powder has a porous structure. The specific weight of CEM II cement is 2.93 g/cm^3, while this value drops until 2.78 g/cm^3, in the case of 10% waste tire powder substitution. This is due to the low specific weight of waste tire powder. When the waste tire powder with a low specific weight is substituted in CEM II cement, the specific weight values of the obtained cement samples with waste tire powder substitution also decrease (Table 2).

4.2 Water Demand and Volume Expansion

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

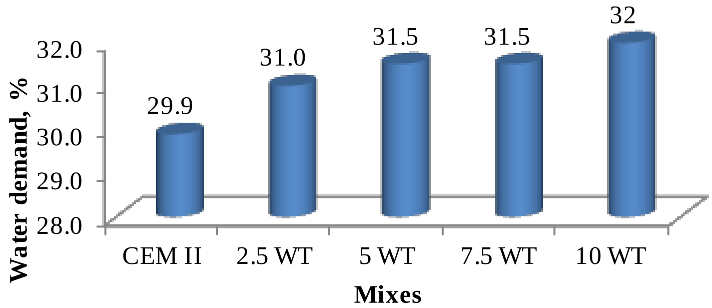

Figure 1: Water demand of CEM II and waste tire powder substituted cements

According to Figure 1, with increasing amounts of waste tire powder substituted to CEM II cement, 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 3.7%, 5.4%, 5.4% and 7% for 2.5-5-7.5 and 10WT cement paste specimens respectively, in comparison to CEM II cement.

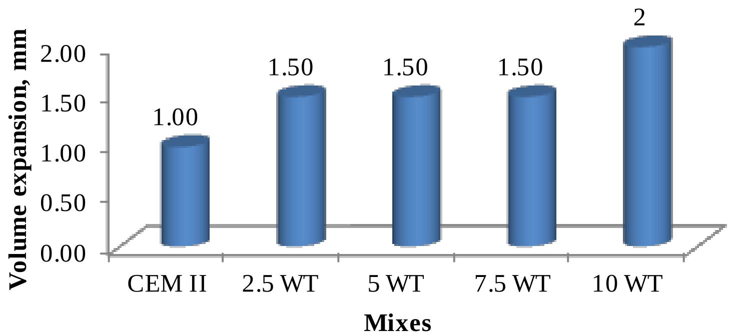

Figure 2: Volume expansion of CEM II and waste tire powder substituted cements

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 [15]. 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 CEM II cement is 1mm, and those obtained for 2.5-5-7.5 and 10 WT cement paste specimens are 1.5, 1.5, 1.5 and 2mm, respectively (Figure 2). The results indicated that the volume expansion values change between 1 and 2mm, and therefore, all values appeared to be lower than 10mm, which is the threshold value offered by TS EN 196-3 [21].

4.3 Setting Time

The initial and final setting times, obtained at the end of the tests carried out in accordance with TS EN 196-3, are given in Figure 3.

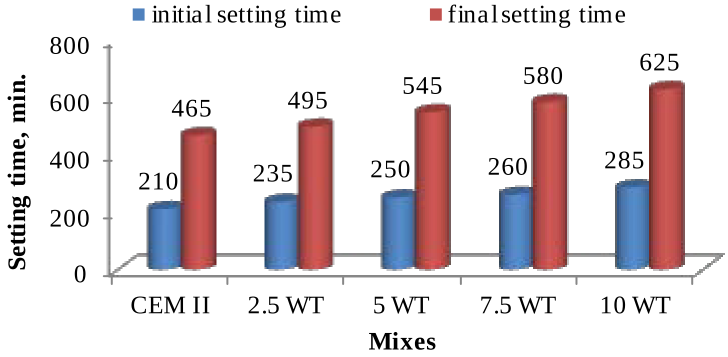

Figure 3: Setting time of CEM II and waste tire powder substituted cements

As increasing amounts of waste tire powder 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 210 minutes, is observed in CEM II cement paste, while the longest initial setting time, which is 285 minutes, is observed in 10 WT cement paste specimen. It was further observed that the initial setting time values of 2.5-5-7.5 and 10 WT cement paste specimens were increased by 11.9%, 19.1%, 23.8% and 35.7%, respectively, in comparison to CEM II cement. The final setting time values of 2.5-5-7.5 and 10 WT cement paste specimens, on the other hand, increased by 6.5%, 17.2%, 24.7% and 34.4%, respectively, in comparison to CEM II cement. 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, except for the 10 WT cement paste specimen is below 600 minutes [22]. According to the results of the experiement, the final setting time value obtained for a 10 WT cement paste specimen is out of range. Since the final setting values obtained for all cement paste specimens except for 10 WT are all within the appropriate intervals, 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 [23].

4.4 Flexural Strength

The cement mortar specimens were subjected to bending tests in accordance with TS-EN 196-1. The results obtained at the end of these tests are given in Figure 4.

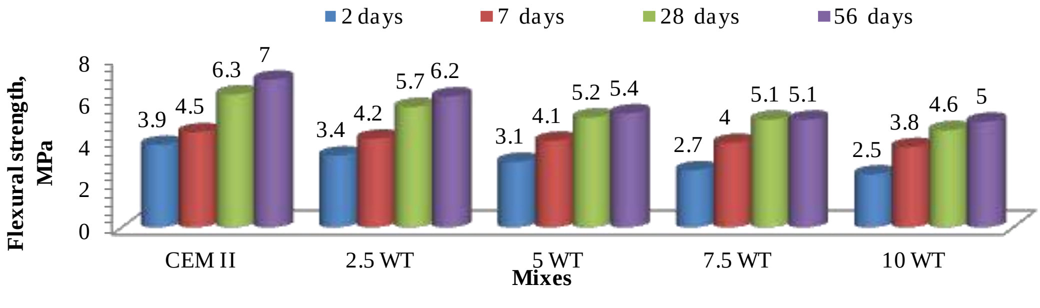

Figure 4: Flexural strength of CEM II and waste tire powder substituted cements

According to the obtained results, with increasing amounts of waste tire powder, flexural strength decreases (Figure 4). The strength of the mortar specimens produced using CEM II cement decreased by 12.8% after 2 days, 6.7% after 7 days, 9.5% after 28 days, and 11.4% after 56 days, in comparison to the 2.5 WT cement mortar specimen. The strength value decreased by 20.5% after 2 days, 8.9% after 7 days, 17.5% after 28 days, and 22.9% after 56 days, in comparison to the 5 WT cement mortar specimen. It was shown that the same strength values decreased by 30.8% after 2 days, 11.1% after 7 days, 19.1% after 28 days, and 27.1% after 56 days, in comparison to the 7.5 WT cement mortar specimen. Finally, compared to the 10 WT cement mortar specimen, the strength values were shown to decrease by 35.9% after 2 days, 15.6% after 7 days, 27.0% after 28 days, and 28.6% after 56 days. Based on the data obtained after the tests, the flexural strength obtained for all waste tire powder substitution rates were lower than the value obtained for CEM II cement.

4.5 Compressive Strength

The cement mortar specimens were subjected to compression tests in accordance with TS-EN 196-1. The results obtained at the end of these tests are given in Figure 5.

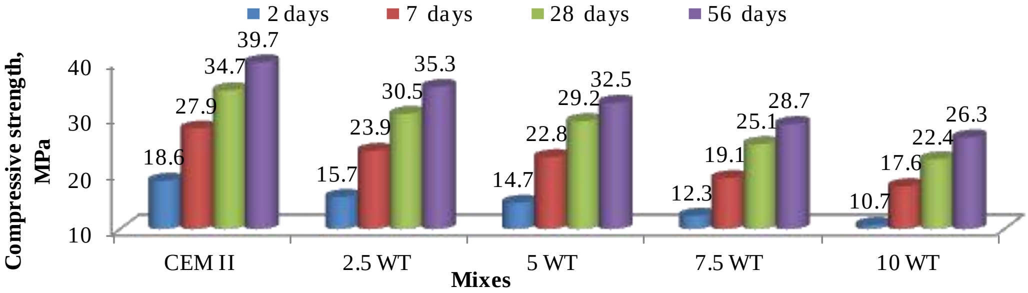

Figure 5: Compressive strength of CEM II and waste tire powder substituted cements

According to the obtained results, with increasing amounts of waste tire powder, flexural strength decreases (Figure 4). The strength of the mortar specimens produced using CEM II cement decreased by 15.6% after 2 days, 14.3% after 7 days, 12.1% after 28 days, and 11.1% after 56 days, in comparison to the 2.5 WT cement mortar specimen. The strength value decreased by 21.1% after 2 days, 18.3% after 7 days, 15.9% after 28 days, and 18.1% after 56 days, in comparison to the 5 WT cement mortar specimen. It was shown that the same strength values decreased by 33.6% after 2 days, 31.7% after 7 days, 27.7% after 28 days, and 27.7% after 56 days, in comparison to the 7.5 WT cement mortar specimen. Finally, compared to the 10 WT cement mortar specimen, the strength values were shown to decrease by 42.5% after 2 days, 36.9% after 7 days, 35.4% after 28 days, and 33.8% after 56 days. Based on the data obtained at the end of the tests, the compressive strength obtained for all waste tire powder substitution rates were lower than the value obtained for CEM II cement. However, it was shown that the strength rates increased as the hydration duration progressed, although waste tire powder is not a pozzolanic material.

After a general evaluation of the obtained results, it is seen that the strengths of all cement mortars with waste tire powder substitute are lower than 32.5 MPa, which is defined as the minimum strength value to be gained after 28 days by TS EN 197-1 [22]. However, when the strength of CEM II cement mortar after 28 days is 24.7 MPa, it might be concluded that these strength values obtained for this non-cementing material, which is, at the same time, a harmful waste material are not so low. In this case, it is considered that cement combined with waste tire powder should be used in non-load-bearing situations.

5 CONCLUSION

The general conclusions drawn at the end of the conducted tests and analyses can be listed as follows:

- According to the results obtained from sifting analyses, the grain size of the waste tire powder is larger than CEM II cement. However, the Blaine value obtained for waste tire powder appeared to be high, and therefore, has a porous structure.
- Since the specific weight of waste tire powder is low, the specific weight values obtained for cement specimens with waste tire substitute also appeared to be low.
- The workability is improved by increasing waste tire powder amounts. Therefore, it might be concluded that the water amount needed in order to obtain a homogeneous consistency does not change considerably.
- It was observed that by increasing waste tire powder amounts, a linear elongation occurs at the initial and final setting time values and that the obtained volume expansion values are appropriate.
- Since the flexural and compressive strength values of CEM II cement were low, the flexural and compressive strength values of the cement mortar specimens obtained with waste tire powder substitute also appeared to be low. A reason for this might be that waste tire powder does not exhibit advantageous behavior as cementing material.

In general, the desired results in terms of the flexural and compressive strengths of cement mortars produced using CEM II cement with waste tire powder substitute could not be obtained. However, use of waste tire powder can still provide advantages in terms of economic efficiency, sustainability and environmental protection. Furthermore, it is considered that the disadvantageous characteristics, in terms of flexural and compressive strength, might be overcome by using high-strength cements such as CEM I 42.5 R, 52.5 R, appropriate pozzolanic materials and chemical additives.

6 ACKNOWLEDGMENTS

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