Construction and Building Materials 109 (2016) 55–62

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The effect of using polyethylene terephthalate particles on physical and strength-related properties of concrete; a laboratory evaluation

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HIGHLIGHTS

- Adding PET to mortar can influence the physical structure and strength of concrete.
- By using PET, the weight of produced concrete reduces.
- An increase at PET ratio and curing age makes samples more deformable before failure.
- The speed of sound in concrete decreases along with the increase of PET ratio in it.
- Using PET in concrete will significantly reduce environmental pollution.

ARTICLE INFO

Article history:
Received 12 May 2015
Received in revised form 23 December 2015
Accepted 30 January 2016
Available online 4 February 2016

Keywords:
Solid waste
Concrete
Environment
PET
Strength

ABSTRACT

The present study was an attempt to investigate the effects of adding plastic waste particles on the engineering properties of concrete. To this end, a mix concrete design was adopted in which pre-defined weight-based amounts of the concrete fine aggregates were replaced by equivalent waste fragments. At all the mixtures, the amount of the coarse aggregate (gravel) and the water–cement ratio remained constant. The results of laboratory tests showed that the added plastic fragments changed both physical and strength-related properties of newly produced concretes. More specifically, physical properties (e.g. density and ultra sound velocity) gradually decreased as the presence of plastic fragment ratios increased. On the other hand, compressive, tensile, and flexural strength of samples rose, when 5–10% of the concrete fine aggregates were replaced by the same percentage of polyethylene terephthalate (PET) fragments. The results also indicated that substitutions greater than 10% cause dramatic decline in all strength-related parameters of the concretes. It is therefore argued that replacement of fine particles with PET fragments may positively affect the strength-related values of the concrete samples provided that as long as the substation rate is under 10%.

1. Introduction

Engineering properties of concrete can change by adding different types of materials or adopting proper mix designs. The determining issue in this regard is the interaction between cement and concrete aggregates, on the one hand, and added materials, on the other. The ratio of added materials to concrete is also crucial, with numerous studies indicating the influence of these materials on concrete's engineering properties [24,2,35,21,8,5]. Various materials may be added to concrete with the aim of changing its engineering properties. Some of these materials will improve concrete properties, while others may have negative effects [20]. Additionally, changes in mix design may strengthen or weaken engineering properties of concrete. Considering the impact of additive materials, an interesting line of research has investigated the effect of waste on concrete properties (see: [33]). Additive materials like resin [7], fiber/rubber [6,12,41,19,42,3]; and also see: [31], slag [28,30], plastics [8,33], etc. are mixed with constituents of concrete to reinforce its engineering properties. Plastic materials are one of the most abundantly employed substances in commercial and industrial products (see: [33]). They have been used alone or in combination with other materials, like slag, not only to change concrete properties, but also to decrease environmental risks [45]. There are also other types of non-synthetic material utilized to strengthen concrete products, i.e. coal combustion

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http://dx.doi.org/10.1016/j.conbuildmat.2016.01.056

by-products, limestone powder waste and different forms of fly ashes [32,34,36,39,22].

One particular area that researchers have been is the influence of adding industrial wastewater (instead of fresh water) on concrete properties [15,46]. In the research performed by Ismail and Al-Hashmie [15], wastewater has been added to the concrete at various ratios; resulting in slight to moderate increase in compressive strength and hardness values of concrete and decrease of its flow rate [15]. Thus, as another environmental pollutant, industrial wastewater can also be used for concrete production.

Different researchers made attempts to find out whether plastic bottles or waste that are converted to fiber would have any effect on concrete properties [17,20]. The results demonstrated that fiber affects the concrete structure and reduces compressive strength and elasticity modulus. At the same time, it decreases concrete shrinkage and cracking. In fact, the influence of fiber on concrete is comparable with that of reinforcement bar [17]. Plastic wastes often have less weight per unit volume than concrete aggregates. Therefore, if they replace concrete aggregates, the unit weight of concrete and materials produced out of it will decrease. Because of their light weight, such materials are highly resistant to earthquakes and will significantly reduce the number of casualties once they are demolished and turned into debris [18,43,16,4,38,11,29].

The polyethylene terephthalate polymer has some special physical and chemical properties such as high pressure tolerance, chemical interaction resistance, light weight, high flexibility etc. [23]. It is therefore widely used for different industrial purposes ([26,17,25,42] and also see: [33]). After initial use, these bottle are taken to landfills or recycling sites as waste. Plastics are very resistant to decomposition and remain in the environment for tens or even hundreds of years. This long-lasting durability of plastics in the environment has become one of the environmental risks in the modern industrial society [33,8,25]. It may be claimed that the use of plastic waste as concrete aggregate is not economically justifiable; however, given that vast quantities of plastic waste are annually produced and this process increases physical pollution, especially in the form of burning waste, it seems that it is economically justified to exploit this material in another way. Several research projects have been conducted to detect the effects of replacing concrete's natural aggregates with various percentages of PET particles (with different sizes and shapes) [26,23,10,17,37,13]. In the majority of these studies, sand was the most common aggregate replaced by PET particles. The researcher was particularly interested in studying civil engineering issues, ranging from the workability of mortar [26,23,10] to flammability of final concrete products [37]. Accordingly, while Sahmaran et al. [27] and Turkmen [40] tried to find a way to compensate the declined values of mechanical strength of polymer concretes, Ge et al. [13] and Albano et al. [1] made attempts to produce a more light weight and sound proof concrete by using different types of synthetic substances in the mortar.

Waste materials like PET may have negative impacts on concrete's mechanical properties; however, since their employment in the production of polymer concretes is regarded as an environmentally friendly action, their application is still highly recommended. Considering the fact that the volume of plastic wastes are growing in an alarming rate on the global scale, any suggestion to reduce these substances from the environment may be warmly welcomed in future.

In the present study, the PET particles, a by-product of PET shredder machines, was used to improve the mechanical properties of concrete. Therefore, by applying the results of this research to the real world constructional practices, not only is the amount of these long lasting by-products reduced, but also the engineering behavior of the made concretes are strengthened. It has been proven that these particles could satisfactorily replace the fine aggregates in a concrete mix design, if a proper mix design is found and corresponding laboratory simulations are done prior to actual field utilizations.

2. Materials and methods

2.1. Samples preparation

Aggregate materials used in this study consisted of gravel, sand, and PET. Samples of these materials are shown in Fig. 1. The mineral aggregates consisted of natural rock-fragments with maximum diameter of 11.2 mm, which were sampled from a river bed in the northwest of Tehran, Iran (Fig. 1). These fragments were angular to almost rounded with different shapes. Most of these fragments were made of tuff. The rest were either carbonate or igneous rocks. For concrete production, the aggregates were used in granulated form, as the range of diameters was defined for them (Fig. 1). Aggregates were categorized into two different classes; coarse fragments whose particle diameters were greater than 4.9 mm and fine fragments with diameters smaller than 4.9 mm. Adopting two different gradations, plastic fragments were prepared from ground polyethylene terephthalate bottles. In the first gradation, fragment's diameter size was 2–4.9 mm (Pc) and in the second gradation, fragments were finer, with their diameter size ranging from 0.05 to 2 mm (Pf) (Fig. 1). Results of the sieve analysis tests, for all concrete's component (i.e. aggregates and PET particles), have been shown in Fig. 2.

To prepare the samples, different ratios of the concrete fine aggregates (5%, 10%, 15%, 20%, 25%, and 30%) were replaced with PET fragments. The water-cement ratio of 1:2 was selected. In all samples, the amount of the coarse aggregates (gravel) and cement were constant. However, there was variations in the percentage of the fine aggregates, some of which were replaced with PET. The plastic fragments were used in both 2–4.9 mm (Pc) and 0.05–2 mm (Pf) size ranges, and replaced Sc and Sf sized aggregates, respectively. Before being added to the mortar, both Pc and Pf particles were washed up by Tehran's tap water, graded into fine and coarse sizes (by using wet sieving method) and finally dried up for two days in an open air with direct sunlight exposure. The ratios of used plastic and natural materials are listed in Table 1. To produce the concrete specimens, the natural aggregates were saturated; they were then given some time to lose their unabsorbed water content. After a short while, the surfaces of the aggregates were almost dry, but they were still internally saturated. In this stage, the mixing process started. In all the concrete production processes, no lubricants were applied.

2.2. Laboratory tests

To conduct unconfined compressive strength, modulus of elasticity, fresh and dry density measurement, and ultra sound velocity tests, the specimens were prepared in cylindrical form. Then, the cylindrical concrete specimens, aged 3, 14, and 28 days, were tested for the above mentioned experiments. Beam and disc-shaped samples were also made for flexural and Brazilian tests, and these experiments were subsequently carried out on the samples aging 3, 14, and 28 days. Cylindrical specimens were also used to measure dry density.

Ultra sound wave velocity tests were performed by PUNDIT PC 1012 which determines ultra sound speed with an accuracy of 0.1 μs (micro second). For this purpose, cylindrical specimens were applied (see Fig. 3a).

Unconfined compressive strength test was accomplished on cylindrical specimens, whose diameters and lengths were 150 mm and 300 mm, respectively, (Fig. 3b), and were 3, 14, and 28 days old. Following ASTM C39 standard, the test was conducted by the use of an automatic loading machine with a maximum load capacity of 1500 KN. The modulus of elasticity was obtained from the results of unconfined compressive strength test. Flexural strength test was performed by single-point method, according to ASTM C293 (samples' dimensions were 450, 130 and 150 mm for their length, width and height, respectively). The California bearing ratio test was used to load on the specimens (Fig. 3c). The Brazilian test was carried out on disc-shaped samples by a non-automatic machine with a maximum load capacity of 1000 KN, according to ASTM D3967 (Fig. 3d). The diameter and thickness (length) of the Brazilian test samples were 100 and 50 mm, respectively. The detailed information of test values measured for samples with different curing ages are represented in Table 2.

3. Results and discussion

The results of fresh and dry density measurements showed that adding plastic fragments to concrete mixture decreased both fresh and dry densities of concrete. The maximum loss of density was equal to 9% and occurred in the samples which contained 30% of plastic fragments (Fig. 4a). On the other hand, an increase at concrete curing age augmented the value of the dry density of the concrete (Fig. 4b). The decline in density can contribute to the production of lightweight concrete. If this concrete is used in dif-