Compressive Strength of Lightweight Concrete with the Use of Waste Polyethylene Terephthalate Bottles

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ABSTRACT

This research presents the development of lightweight aggregate concrete using fine aggregate that is manufactured from waste polyethylene terephthalate (WPET) bottles. WPET with the average diameter of 1-3 mm was used with four different contents of 5%, 10%, 15% and 20% by weight. In comparison to the control concrete, the 90-day WPET concrete compressive strength showed that the use of WPET particles up to maximum replacement level of 10% produces concrete with acceptable strength. However, the ultimate strength of concrete was gained at 5% of cement replacement by weight. It is concluded that the replacement of cement with 5% WPET improves the compressive strength of concrete compared to the control concrete.

KEYWORDS: Waste polyethylene terephthalate bottles, Lightweight concrete, Compressive strength, Recycling of polymers.

INTRODUCTION

There is a significant opportunity to reduce GHG (Green-house Gas) emissions through the development of energy conscious construction materials (Fernando et al., 2008). This can be achieved by maximizing the use of waste products, which are now merely used as landfill wastes (Tam et al., 2007).

The advantages of using wastes are twofold. Firstly, the use of virgin natural resources is reduced and therefore, recycling waste will preserve national capitals. Further, increasing waste recycling will improve the life of the human habitat. Secondly, wastes are being disposed of in a safe, effective and environment friendly manner. Hence, the use of PET waste in concrete will help preserve the environment.

Polyethylene terephthalate (PET) is known as one of the most commonly used plastic in the world. This material is extensively used as a raw material in the manufacture of beverage bottles, packaging containers and other consuming goods. Nowadays, these bottles have been replaced by glass bottles due to their lightness, easy transportation and storing. In 2008, the annual production was recorded to be 7.6 million of PET bottles around the world. This value with a growing trend (particularly in Asian countries, especially China and India) is on the rise (Vinyl Environmental Council of Japan, 2008). Generally, most of PET bottles become trash after one time usage and the garbage is buried or burned. Both methods cause significant environmental problems (Cheung Moon, 2008). One of the proposed ways of addressing this problem is to replace concrete with stone material of PET waste. This method can be used as a favorable activity to help in preserving the environment. On one hand there is a very large and growing demand on

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concrete production. On the other hand, this work would be economically justified by considering the scarcity of natural stone materials and their non-renewable feature.

The use of polymer combinations in concrete structures is relatively new. It should be considered as an effective solution to the reduction of environmental damages (Segre and Joekes, 2000; Li et al., 2004). Of course, it is worth noting that in the investigations conducted by Rebeiz et al., Silva et al. and Choi et al., PET is added as a lightening aggregate to concrete and its effect on concrete properties has been studied (Rebeiz et al., 1991; Silva et al., 2005; Choi et al., 2005).

Hence, in this context, we reported an easy procedure for the production of concrete with WPET used as a fine aggregate without any super-plasticizers in an attempt to develop a solution that not only provides a recycling option for PET bottles, but also stands to maintain or improve the compressive strength of the resulting concrete.

The weight of concrete elements is high and can represent a large proportion of the load on a structure (Choi et al., 2006; Yasar et al., 2003; Rossignolo et al., 2003). Therefore, using lightweight concrete with a lower density can result in significant benefits such as superior load-bearing capacity of elements, smaller cross-sections and reduced foundation sizes. A lightweight structure is also desirable in earthquake prone areas. Also, given the overall increase in beverage consumption globally, the substitution of glass for PET in the production of bottles leads to a growing concern pertinent to the end-use of PET bottles worldwide.

EXPERIMENTAL PROCEDURE

Materials and Mixtures

Cement

Ordinary Portland Cement (OPC) used was obtained from Dashtestane Cement Manufacturing Company of Iran conforming to ASTM C150 standards. The cement elements are shown in Table 1.

Table 1. Elements of portland cement (*% wt)*

Material	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**
Cement	20.46	4.69	3.71	62.04	3.49
Material	SO_3	Na_2O	K_2O	Loss on ignition	
Cement	2.08	0.39	0.67	2.21	

Figure (1): Shape of waste polyethylene terephthalate (WPET)

Waste Polyethylene Terephthalate (WPET)

Waste PET bottles were collected and their impurities removed. Then they were ground to become as tiny as possible; approximately 1-3 mm in size, as shown in Fig. 1.

Aggregates

Locally available natural sands that residue on the 4.75 mm sieve were designated as coarse aggregates and those that pass the 4.75, 2.36 and 1.18 mm sieves were designated as fine aggregates.

Mixture Proportioning

A total of two series of mixtures were prepared in the laboratory trials. Series C0 mixtures were prepared as control specimens. The control mixtures were made of natural aggregates, cement and water. Six of those designed mixtures have the highest compressive strength. The proportions of the mixtures are presented in Table 2.

Table 2. Six control specimens with the highest compressive strength (Series C0)

Entry	Sample designation	Compressive strength (MPa)				
1	3340p0	7 days	14 days	21 days	28 days	90 days
2	0334p0	25	25.7	27.5	28	30.8
3	0442p0	24.4	25	26.4	26.8	29.4
4	0253p0	24.2	24.5	25.4	26	28.6
5	0550p0	26	26.5	29	29.7	32.6
6	0163p0	24.5	24.9	26.5	26.8	29.4

Sample designation: The first value is nominated as sand percent; the second value is the amount of remaining sand on 4.75 mm sieve; the third value is the amount of remaining sand on 2.36 mm sieve; the fourth value is the amount of remaining sand on 1.18 mm sieve; and the fifth value is nominated as WPET percent.

Series N mixtures were prepared with different contents of WPET particles. The mixtures were prepared with the aggregate replacement of 5%, 10%, 15% and 20% by weight. The water to-binder-ratio of all mixtures was set at 0.45. The binder content of all mixtures was 1000 kg/m^3. The proportions of the mixtures are presented in Table 3.

Preparation of Test Specimens

Series N mixtures were prepared by mixing the course aggregates, fine aggregates and powder materials (cement and WPET particles) in a laboratory concrete drum mixer. The powder material in the series C0 mixtures was only cement. They were mixed in dry condition for two minutes, and for another three minutes after adding the water. Cubes (20×20×20) cm were cast and compacted in two layers on a vibrating table, where each layer was vibrated for 10 s (Bui et al., 2005). The moulds were covered with polyethylene sheets and moistened for 24 h, then the specimens were remolded and cured in water at a temperature of 20^o C prior to the test days. The compressive strength tests of the concrete samples were determined as per ASTM C 39 after 7, 14, 21, 28 and 90 days of moisture curing. The compressive strength of the mixtures is also presented in Table 3.

Table 3. The preparation of samples with different amounts of PET and their compressive strength (Series N)

Entry	Sample designation	WPET (%)	Compressive strength (MPa)				
			7 days	14 days	21 days	28 days	90 days
1	3340p5	5	21.0	21.6	23.3	24.6	27.8
2	0334p5		26.0	26.5	28.3	30.3	34.3
3	0442p5		26.1	26.4	29.4	30.8	34.9
4	0253p5		26.3	27.0	30.3	31.8	36.2
5	0550p5		29.0	29.5	31.9	33.3	36.5
6	0163p5		29.0	27.1	31.1	33.3	37.9
7	3340p10	10	19.0	19.6	20.1	20.1	24.1
8	0334p10		21.0	21.7	23	23.0	28.2
9	0442p10		24.5	24.8	26.1	26.1	31.2
10	0253p10		25.1	26.0	27.1	27.1	31.7
11	0550p10		25.5	26.8	28.8	30.5	32.6
12	0163p10		26.0	25.9	27.3	27.3	34.6
13	3340p15	15	17	17.2	19.4	19.9	22.5
14	0334p15		18.2	18.7	20.8	21.0	23.8
15	0442p15		19.1	19.3	21.3	21.5	24.4
16	0253p15		21.5	21.7	22.1	23.5	26.6
17	0550p15		22.0	22.7	24.7	24.1	27.5
18	0163p15		22.4	22.2	23.6	25.0	28.4
19	3340p20	20	11.0	11.3	12.9	13.3	15.0
20	0334p20		11.8	12.3	13.6	14.0	15.87
21	0442p20		12.2	12.7	14.6	15.0	17.0
22	0253p20		13.1	13.4	14.9	15.5	17.6
23	0550p20		16.6	17.0	19	19.5	18.7
24	0163p20		15	15.3	16.1	16.4	21.9

EXPERIMENTAL RESULTS AND DISCUSSION

Compressive strength results obtained from the experimental investigations are shown in Tables 2 and 3, and the comparison between results is presented in the form of a curve (Fig. 2). Among the samples with different PET percentages, sample number 0550 showed the highest compressive strength and its curve was designed with different PET percentages. Each of the values is the average of three trails in each case of the testing program of this study. The results are discussed as follows.

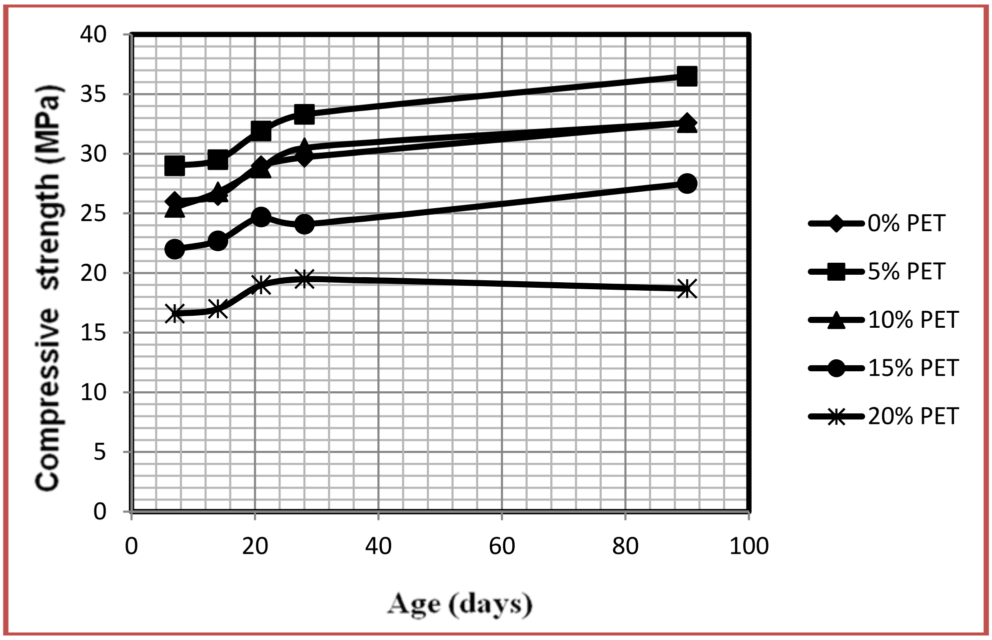

Figure (2): Compressive strength of concrete containing PET (MPa)

The comparative results of the 7-, 14-, 21-, 28- and 90-day samples show that compressive strength increases with 5% PET replacement in comparison to the control concrete, and then it decreases with increasing the amount of PET. When PET values reach 10%, the compressive strength will be similar to that of the control concrete, with the most consumption of waste PET instead of sands.

The two mixtures prepared with the percentages of 15% and 20% PET had low compressive strength values. Therefore, where lightweight concrete is important and desirable, these values can be used.

Specimens with more than 20% PET were fabricated and their measured compressive strength values were very low.

On the other hand, the amount of water with 5% PET (water-cement ratio of 0.40, 0.45 and 0.50) was changed to get the best result of 0.45. More water will reduce the samples' strength at 90 days. Sakr et al. (2005) revealed in their research that the observed changes in the mechanical properties may be related to the shape and firmness of aggregate, which seems somehow reasonable. This can be explained by PET having a flat, edged shape, while sand aggregates have a hard, round shape.

CONCLUSIONS

As the test results indicate, the use of different amounts of PET (for example 5%) will cause nearly an 11% compressive strength increase in 7-, 14-, 21-, 28- and 90-day samples; while adding 10% PET cannot change the concrete strength in comparison to the conventional concrete. Higher PET values will reduce compressive strength and sand consumption. On the other hand, these values will increase waste PET consumption. It also became clear that the use of PET will reduce the weight of samples. Hence, according to the acquired results, it is suggested to use 5% PET in this type of concrete to increase its resistance, as well as to use 20% PET to reduce the weight in bulk concrete.

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