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# An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete

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ABSTRACT

In this work, the utilization of shredded waste Poly-ethylene Terephthalate (PET) bottle granules as a lightweight aggregate in mortar was investigated. Investigation was carried out on two groups of mortar samples, one made with only PET aggregates and, second made with PET and sand aggregates together. Additionally, blast-furnace slag was also used as the replacement of cement on mass basis at the replacement ratio of 50% to reduce the amount of cement used and provide savings. The water–binder (w/b) ratio and PET–binder (PET/b) ratio used in the mixtures were 0.45 and 0.50, respectively. The size of shredded PET granules used in the preparation of mortar mixtures were between 0 and 4 mm. The results of the laboratory study and testing carried out showed that mortar containing only PET aggregate, mortar containing PET and sand aggregate, and mortars modified with slag as cement replacement can be drop into structural lightweight concrete category in terms of unit weight and strength properties. Therefore, it was concluded that there is a potential for the use of shredded waste PET granules as aggregate in the production of structural lightweight concrete. The use of shredded waste PET granules due to its low unit weight reduces the unit weight of concrete which results in a reduction in the death weight of a structural concrete member of a building. Reduction in the death weight of a building will help to reduce the seismic risk of the building since the earthquake forces linearly dependant on the dead-weight. Furthermore, it was also concluded that the use of industrial wastes such as PET granules and blast-furnace slag in concrete provides some advantages, i.e., reduction in the use of natural resources, disposal of wastes, prevention of environmental pollution, and energy saving.



## 1. Introduction

Lightweight aggregate is an important material in reducing the unit weight of concrete to produce earthquake resistant structures since the earthquake forces are linearly dependant on the mass of the structure (Kilic et al., 2003).

Lightweight aggregates are generally used to reduce the unit weight of concrete by replacing the conventional aggregates. Nowadays, there are many lightweight concrete applications made with natural or artificial lightweight aggregates in the literature (Topcu and Uygunoglu, 2007; Babu et al., 2005; Yasar et al., 2003; Demirboga and Gul, 2003; Malloy et al., 2001). However, the cost of artificial lightweight aggregate production is high due to requirement of high incineration temperature or thermal treatment (Topcu, 2006).

Therefore, different from the common materials, using waste plastic granules as lightweight aggregate in the production of lightweight concrete has attracted much attention from the researchers. This method provides both recycling of the plastic waste and production of a lightweight concrete in an economical way (Koide et al., 2002).

Polypropylene (PP), Poly-ethylene (PE), Poly-ethylene Terephthalate (PET) and Polystyrene (PS) are some of the plastic wastes used in lightweight concrete. The PET bottles are ahead of the wastes with its high increasing speed of consumption. At the beginning of 1980, PET bottles were begun to produce in Turkey at first time. Initially, the PET bottles were used as water package, however, later they were commonly used for packing various liquid foods (Pagev, 2008).

Due to the rapid increase in the use of PET bottles, solid waste problem is raised. It is known that a long time (more than a hundred years) is needed to degrade the waste PET bottles in the nature (Silva et al., 2005). Therefore, one of the reasonable methods for disposal of PET wastes, which causes environmental pollution, is using these wastes in the other industrial areas. Industry of construction engineering area seems to be appropriate with its high consumption capacity. This area can consume a large amount of PET wastes.

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In the recent years, a lot of experimental studies were carried out on using waste PET bottles as resin in polymer concrete (Rebeiz et al., 1991; Rebeiz, 1995; Rebeiz and Fowler, 1996; Abdel-Azim, 1996; Tawfik and Eskander, 2006). Polymer concrete is produced by replacing polymer with cement binders partially. In comparison to cement based materials, the cost of polymer concrete production is very high because of the high cost of virgin resins. Using waste PET bottles in the production of polyester resin decreases the cost of resin manufacture when compared to conventional normal resin production (Rebeiz et al., 1991). Unsaturated polyester resin based on recycled PET can be used to produce a good-quality polymer concrete (Siddique et al., 2008). However, the cost of producing polymer concrete from waste plastics is still high.

The other method is using waste PET bottles as PET fiber to produce fiber reinforced concrete (Silva et al., 2005; Ochi et al., 2007). However, the volumetric amount of fiber content in the fiber reinforced concrete is between 0.3% and 1.5%. This way recycles the small amount of plastic waste.

The most economical use of waste PET bottles in concrete is seemed to be that using shredded waste PET bottles directly as aggregate in the concrete or mortar production. Thus, the use of PET wastes as aggregate in concrete will provide benefit in the disposal of wastes and reduce the environmental damages due to the use of natural mineral aggregates resources.

Limited research has been carried out on using waste PET granules as aggregate in concrete or mortar. In these studies, PET and the other plastic wastes (PE and PP) were used together by partially replacing with mineral aggregates (Shehata et al., 1996; Koide et al., 2002; Gavela et al., 2004; Choi et al., 2005). Marzouk et al. (2007) used only waste PET granules as aggregate in lightweight concrete. They concluded that, plastic bottles shredded into small PET particles may be used successfully as sand-substitution aggregates in cementitious concrete composities.

The main aim of this study is to investigate the influence of the use of shredded waste PET granules on the properties of mortar. This is achieved by examining physical and mechanical properties of mortars containing PET aggregates. Some mortar mixtures were prepared by using only waste PET granules, and some mortar mixtures were prepared with sand and waste PET granules together.

In addition, Granulated Blast-Furnace Slag (GBFS) was used in large amounts as a replacement of cement in concrete and mortar for decades. The use of GBFS in concrete exists in the standard of BS EN 15167-1 (2006). It is reported in many investigations that, the use of GBFS in concrete as a cement replacement has positive influence on the properties of the fresh and hardened concrete. GBFS increases workability of fresh concrete and mortars (Tokyay, 2003; Erdogan, 2003). Because of its low heat of hydration and its thermal development is going forward slowly, using GBFS in great ratios decreases the high temperature occurred in casting large block concretes. In addition, it decreases the risk of thermal cracking and also provides economical benefits (Osborne, 1999). It improves strength, reduces permeability and porosity, reduces alkali-silica expansion of hardened mortars and concretes (Geiseler et al., 1995; Soroka, 1993; Atis and Bilim, 2007).

Therefore in this study, GBFS was also employed as a partial cement replacement to obtain savings from the amount of cement used in the production of lightweight mortar made with lightweight PET aggregates. The use of GBFS in concrete provides ecological advantages apart from the energy savings and contribution to the properties of strength and durability of concrete.

**Table 2**
PET aggregate and sand gradations.

| particle size range (mm) | | PET (%) | Sand (%) |
|---|---|---|---|
| $d_{max}$ | $d_{min}$ | | |
| 4 | 2 | 15 | 27.3 |
| 2 | 1 | 67 | 19 |
| 1 | 0.5 | 16 | 17.3 |
| 0.5 | 0.25 | 2 | 28.4 |
| 0.25 | 0 | 0 | 8 |
| | | 100 | 100 |

**Table 3**
Sand grading with standard limit.

| Sieve size (mm) | Passed | | | |
|---|---|---|---|---|
| | TS 706 lower limit | TS 706 medium limit | TS 706 upper limit | Sand used |
| 4 | 100 | 100 | 100 | 100 |
| 2 | 59 | 75 | 84 | 72.7 |
| 1 | 33 | 57 | 66 | 53.7 |
| 0.5 | 20 | 36 | 47 | 36.4 |
| 0.25 | 8 | 14 | 25 | 8 |

## 2. Properties of materials used

The cement used was ASTM Type I Normal Portland Cement (NPC 42.5 N/mm$^2$). Initial and final setting times of the cement were $2^{30}$ and $3^{30}$ h, respectively. The specific gravity of the cement used was 3.09 g/cm$^3$ and Blaine specific surface area was 3220 cm$^2$/g.

GBFS used was obtained from Iskenderun Iron-Steel Factory located in Southern Turkey. According to ASTM C-989, 1994 hydraulic activity index, the GBFS used was classified as a category 80 slag. The specific gravity was 2.81 g/cm$^3$ and Blaine specific surface area was 4250 cm$^2$/g. The chemical composition of cement and GBFS are given in Table 1.

The shredded waste PET bottle granules used as aggregate were supplied from a commercial company SASA PET Bottles Plant, in Adana, in Southern Turkey. It was obtained by picking up waste PET bottles and washing, then crushing in granules by machines. Maximum size of PET aggregate was 4 mm, and its specific gravity was 1.27 g/cm$^3$. The grading of the PET aggregate is presented in Table 2.

Uncrushed, quartzitic, natural sand with maximum size of 4 mm was used in this investigation. The absorption value of the sand was 0.83% and, the relative density at saturated surface dry (SSD) condition was 2.66 g/cm$^3$. The grading of sand measured according to TS 706 EN 12620 (2003) is presented in Tables 2 and 3 with the standard specification. It can be seen from these tables that the current sand can be used in mortar production.

## 3. Mortar mixture proportions, sample preparation and testing methods

The PET–binder (PET/b) ratio used in the mixtures was 0.50; the water–binder (w/b) ratio was 0.45. Normal Portland Cement (NPC)

**Table 1**
Chemical composition of Normal Portland Cement (NPC) and Granulated Blast-Furnace Slag (GBFS).

| Oxide (%) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|---|
| NPC | 20.23 | 5.78 | 4.07 | 61.95 | 2.94 | 2.66 | 0.87 | 0.11 | 0.72 |
| GBFS | 36.70 | 14.21 | 0.98 | 32.61 | 10.12 | 0.99 | 0.76 | 0.42 | – |