The effect of recycled plastic waste polyethylene terephthalate (PET) on characteristics of cement mortar

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Abstract. This paper studied the effect of waste Polyethylene Terephthalate (PET) on the workability and mechanical properties of the produced cement based mortar. However, five different waste PET weight fractions of 0, 5, 15, 25 and 50% were replaced with river sand in cement mortar mixtures with constant cement content and water to cement ratio of 525 kg/m³ and 0.48, respectively. The workability of the mixtures is enhanced by increasing the replacement level of plastic waste PET. On the other hand, the dry density, compressive and flexural strengths were reduced as waste PET incorporation increased except the mix contained 5% of PET which improved the compressive and flexural strengths. As a result of the dry density and compressive strength results, it was determined that the mixture containing 25% waste PET is considered as a lightweight mortar and suitable for structural purposes.

Keywords: cement mortar, plastic waste PET, workability, mechanical properties.

1. Introduction

Generally, the vast expansion of the industrial sector in the world made the production a huge amount of plastic waste annually. According to the survey of the Freedonia Group, Inc, over 300 million metric tons of plastic waste are produced around the world each year, half of which is intended for single use, of which over 8 million tons are dumped in the oceans. It is known that the complete biological degradation of plastic waste takes thousands of years. However, landfill and burial of plastic waste create serious environmental problems because of the slow deterioration in soil quality and properties. This affects agriculture directly, as plastic waste affects root growth, and prevents the flow of groundwater. In addition, plastic waste contains many toxic elements such as cadmium; lead, etc., which melt in the soil when exposed to rainwater or even high humidity. In the case of burning plastic
waste, it releases toxic chemical toxins and very harmful to the environment such as dioxins. When recycling plastic waste to get new products, this leads to low quality products. Because of this dangerous phenomenon on the environment, many researchers have studied the possibility of finding solutions for the disposal of plastic waste, even partially, to help reduce the significant damage to the environment. However, K.D. Shah et al. [1] studied on the using of three different water to binder ratio for production of concrete mixtures with incorporation of plastic waste as fiber by 0 – 1.5% of the concrete volume and addition 0 – 30% of fly ash.

Y. Ghermouti and B. Rabehi [2] had investigated the possibility of recycling the waste of plastic bags to improve the performance of cement mortar by adding plastic bag waste (PBW) and use it as fine aggregate by replacing it with different proportions of sand (10-20-30% and 40%). And studing its effect on compressive and flexural strength and other physical and mechanical properties. The study showed that the residues of plastic bags (PBW) which additives of 10% and 20% reduce the compressive strength of cement mortar by 18-23%, respectively. They concluded that substituting sand with (PBW) reduces the speed of chloride ions to penetrate in cement mortar and as a result improves cement mortar behavior against the acidic medium and reduces the potential for mortar cracking.

E.P. Carneiro and J.M.L. Reis [3] had studies the mechanical characteristics of composite cement mortar partially replaced fine aggregate with non-biodegradable plastic resins which made of polyethylene terephthalate (PET) waste up to 20%. Furthermore, K.S. Kumar and K. Baskar [4] studied on the effect of replacing part of the coarse aggregate with various ratios 10, 20, 30, 40 and 50% of electronic plastic waste (damaged computer residue). The results showed a reduction in workability against the increase in ratio of plastic waste. On the other hand, there was a decrease in compressive strength, flexural strength, and splitting strength comparatively with the control mix. In addition, dry density of the concrete decreased, and the specimens showed high deformability before failure.

On the other hand, K.M. Eweed et al. [5] reported that the dry density, UPV, compressive and flexural strengths reduced as polyethylene plastic waste utilization level increased in the mortar mixtures comparing to the control mix. Furthermore, Olofinnade et al. [6] studied the effect of waste plastic as fine aggregate on the mechanical properties of concrete of different quantities and concluded that the mechanical characteristics were reduced by increasing waste plastic incorporation.

The Specific targets of this study include:

- Investigate the possibility of producing cement mortar made with plastic waste (PET) utilized.
- Study the effect of replacing the accumulating aggregates with the polyethylene terephthalate (PET) from the waste of the global factories.
- Investigate the mechanical and physical properties such as compressive and flexural strength, dry density and flowability of cement mortar made of plastic waste PET.
- Finally, contribute a solution to the phenomenon of environmental pollution, and provide an experimental study for the disposal of plastic waste.

2. Materials and methods

2.1 Cement: Ordinary Portland cement (OPC) obtained from Badoosh cement factory in Iraq used in the present research. Chemical and physical characteristics of cement are given in Table 1. Chemical composition being tested in Badoosh cement factory laboratories; this cement is conforming to ASTM C150 [7].

2.2 Sand: River sand which passed sieve 4.75 mm was used as fine aggregate, supplied from Kenhshe area in Nineveh city/ Iraq. The fineness modulus and specific gravity of sand are 2.18 and 2.83; respectively. The grading analysis done according to ASTM C33 [8].

2.3 Polyethylene Terephthalate (PET): Plastic waste used in this investigation was polyethylene terephthalate (PET) waste. Water absorption capacity and specific gravity are 0.1% and 1.37; respectively, plastic waste size is 4.75 mm and less as shown in Figure 1.
2.4 *Styrene Butadiene Rubber (SBR)*: It is commercially available as Styrene–Butadiene Rubber (SBR) latex and type (RHEOMIX141) was used in this research which supplied by Henkel Polybit Industries Ltd. Its characteristics are presented in Table 2.

2.5 *Water*: Tap water was used in this research for mixing and curing of with 23°C ±2°C, accordance to ASTM C1602 [9].

| Chemical properties       | Weight percentage % |
|---------------------------|---------------------|
| CaO                       | 62.20               |
| SiO₂                      | 21.31               |
| Al₂O₃                     | 5.89                |
| MgO                       | 3.62                |
| Fe₂O₃                     | 2.67                |
| SO₃                       | 2.60                |
| L.O.I %                   | 1.59                |
| In. SUL.R                 | 0.55                |
| Free Lime                 | 0.92                |
| L.S.F %                   | 95.31               |
| C3S                       | 33.37               |
| C2S                       | 35.92               |
| C3A                       | 11.09               |
| C4AF                      | 8.12                |

| Physical properties       |                     |
|---------------------------|---------------------|
| 3 Day compressive strength| 23.0                |
| MPa                       |                     |
| 7 Day compressive strength| 30.4                |
| MPa                       |                     |
| Autoclave expansion       | 0.58                |
| %                         |                     |
| Finess Blain (cm²/g)      | 2636                |
| Initial setting time (minute) | 95               |
| Final setting time (minute) | 385              |

**Table 1.** Chemical and physical Characteristics of cement

**Table 2.** Physical properties of SBR

| Color                       | white milky liquid  |
|-----------------------------|---------------------|
| Shape And                   | Emulsion            |
| Solid In Aqueous            | 40±3                |
| Mixing With Water           | At any percent      |
| Density [G/Cc]              | 1.0±0.05            |
| Storage Condition           | Free from soft, no high temp. and/or high humidity |
| Butadiene                   | 40 by weight        |
| Styrene                     | 60 by weight        |
| Sodium Alkyl                | 0                   |
Sodium Phosphate | 0
---|---
Ph Value | 8.5-10
Fire | Non-flammable
Application Temp, [°C] | 5 to 45
Packaging | 5 liter, 25 liter, 200 liter

Figure 1. Polyethylene Terephthalate (PET)

3. Mix proportion and testing procedures
In this study, the cement mortar mixtures were designed and consist of one reference mixtures. The reference mixture (R1) which consist of cement, river sand and water to cement ratio of 525, 1521 kg/m³ and 0.48, respectively. However, all mixtures contained 10% of SBR with various ratios (0, 5, 15, 25 and 50%) of PET as a partial replacement of river sand.

**Compressive strength test:** The compressive strength was tested according to ASTM C109 [10]. 50*50*50 mm cubes were tested using a 2000 kN standard compression machine, the average of three cubes were adopted. Test was conducted at ages of 3 and 28 days.

**Flow test:** After mixing, flowability of mortar was measures performed in accordance with ASTM C230 [11] with the purpose of determining the flowability as well as the consistency of the fresh mortar.

**Flexural strength test:** Specimens (40*40*160mm) were prepared for flexural strength of hardened mortar was determined in accordance with ASTM C348 [12]. Average of three prisms were adopted. Test conducted at age 28 days.

**Dry density test:** Specimens of 50*50*50 mm were prepared for dry density test. Average of three cubes were adopted after putting the specimens in the oven at 110±5 °C for 24 h. Test was conducted at age of 28 days.

4. Results and discussion

4.1 Flowability
The workability of mortar is enhanced by increasing the replacement level of waste PET in the mixtures. Meanwhile, the results of flowability versus PET at variance percentage utilization are illustrated in Figure 2. It can be related to the plastic particles which have smooth exterior surfaces than sand and low absorption capacity. Consequently, the flowability of mortar improved with increasing PET content. This behavior and interpretation are reported by Safi, et al. [13] and A. Ramesan et al. [14].
4.2 Dry density

The results of dry density for all the mortar mixes were presented in Figure 3. The addition of 10% SBR led to increase the dry density of cement mortar in a small amount. While the dry density of the other mixes began to decrease gradually with an increase in the percentage of plastic waste PET. This may be because of the specific weight of plastic waste PET was less than the specific weight of the used sand. On the other hand, the dry density affected by the specific gravity of mortar constituents. Therefore, the specific gravity of waste PET is lower than sand. Consequently, it is expected that the dry density of the mortar will be reduced by increasing the replacement ratio of plastic waste. However, the density of sand decreased this fact reported by many researchers previously [15, 16].

Figure 2. Flow vs mixes types of modified mortars

Figure 3. Dry density of modified mortars.
4.3 Compressive Strength

The compressive strength characteristic of the cement mortar mixes gradually decreased as replacement level of plastic waste increased in the mixtures and illustrated graphically in the Figure 4. Except for the addition of 5% of the PET, there was an increase that could not be ignored in compressive strength as shown in Figure 4. In comparison, there were decreases in compressive strength by increasing the proportions of PET. On the other hand, the reason of strength reduction is due to the weak adhesion between plastic waste PET and cementitious materials, reduced strength of plastic waste PET than natural sand, higher air content in mixtures, and limited cement hydration reactions at the surface of the plastic waste PET [15, 17]. Generally, the compressive strength decreased with increasing of lightweight aggregates incorporation and density of concrete and mortar previously reported by many investigators [18 - 20].

However, only a few researchers reported an enhancement in compressive and flexural strength due to incorporate plastic waste PET as a partial replacement of sand at lower replacement levels as reported by S. Bahij et al. [21]. According to Rahmani et al. [22], when the applied load reaches its maximum value, the increasing possibility of interlocking between the PET particles on the fractured surfaces increases due to the special form of the PET particles and their flexibility.

![Figure 4](image.png)

**Figure 4.** Reduction in compressive strength at various ages with increasing % of PET.

4.4 Flexural strength

Since flexural strength is a function of the compressive strength property of concrete, there was behavior likewise to the behavior of compressive strength. The flexural strength of the mixtures tested at 28 days curing age which found the results decreased by increasing waste plastic PET amounts in the mix except the mixture which contained 5% of PET which increased about 16% as shown in Figure 5. The reason is essential can be attributed to the weak interfacial bonding between plastic waste and cement paste because of the bleeding water located around the PET aggregate particles and plastic waste is a hydrophobic product that decreases the water demands for cement hydration. This agrees with M. Frigione [23] and Z.Z. Ismai et al. [24]. High deformability exhibited by specimens containing a higher percentage of plastic waste compared to control specimens. This agrees with Azhdarpour et al. [25]. In addition, the flexibility and special shape of PET particles led to increasing the flexural strength at lower replacement levels up to 5% due to increasing the probability of interlocking between PET particles on the fracture surface when the applied load reached the higher value [22].
The flexural strength significantly affect by the compressive of concrete mixtures. However, the relation between compressive strength and flexural strength may give indicative information on the strength of cement mortar. Moreover, the relationship between compressive strength and flexural strength of cement mortar can be shown in Figure 6.

**Figure 5.** Flexural strength of control and modified mortars

**Figure 6.** Compressive strength vs flexural strength of modified mortar.
5. Conclusions

This research is an experimental study on the possibility of using Styrene-Butadiene Rubber (SBR) 10% as an additive material and Polyethylene Terephthalate (PET) plastic waste as a partial replacement of sand in the modifying of cement mortar. Dependent on the outcomes, the main conclusions can be summarized as below:

- Replacing plastic waste PET up to 5% as a partial replacement of fine aggregate could increase the compressive strength of cement mortar. Then the specimens with 15, 25 and 50% partial replacement of plastic waste PET decreased the compressive strength of mortar mixtures. The specimen with 5% replacing of plastic waste PET had the highest compressive strength at ages 3 and 28 days.
- The compressive strength of the cement mortar was enhanced with increasing curing ages from 3 to 28 days by 66% and 58% for the mix contained 0 and 15% PET, respectively.
- The flexural strength enhanced about 16% when PET was used as a partial replacement of 5% with fine aggregate. Then the flexural strength decreased of cement mortars with 15, 25 and 50% partial replacement of plastic waste PET. The specimen with 5% replacing of plastic waste PET had the highest flexural strength at age 28 days.
- Flowability is significantly improved by increasing of plastic waste PET percentage as a partial replacement of fine aggregate.
- The dry density dropped with increasing PET incorporation in the mixtures and obtained lower than 1850 kg/m³ which indicate clearly lightweight cement mortar can be produced by using plastic waste PET and suitable for structural purposes.
- A strong relationship was observed between the compressive and flexural strengths of R².
- It has been successfully demonstrated that high amounts of waste PET materials can be recycled in the production of cement-based mortars.

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