Impact Strength and Durability of Recycled Polyethylene Terephthalate Concrete

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Abstract. The impact strength and durability of polyethylene terephthalate (PET) concrete were studied by orthogonal test. PET concrete was produced by mixing melted PET with aggregate and fly ash. The effects of three factors on the properties of PET concrete were investigated. The results showed that the most important factor was PET/AG, followed by sand ratio and PET/FA. The best mix proportion of PET concrete was PET/AG of 1:3, sand ratio of 35% and PET/fly ash of 1:1. The PET concrete has good impact strength than C30 cement concrete, lower than C50 cement concrete. Under 300 times freeze-thaw cycles, the weight of PET concrete loss slightly. The mass loss rate of PET concrete is less than 0.25%. The weight loss of PET concrete after test is less than 0.5%. The corrosion resistance coefficient of 30 times cycle is 90% and 60 times cycles is 75%.

Introduction

Polyethylene terephthalate (PET) is widely employed as a raw material to produce bottles. PET bottles have already replaced the glass bottles to transport and store soft-drink because it have advantages of light quality. PET is a semi-crystalline polymer and has good mechanical properties. The world’s annual consumption of PET bottles of approximately 20 million tons. However, the number of recycled PET bottles is very low [1]. One of the recycled methods is using PET in the civil engineering. Because PET has some advantages such as high toughness, good durability and light weight [2].

Recently, recycled PET is used to produce concrete. This method not only provides an effective way of PET recycling [3], but also save raw mineral resources and reduce the environmental pollution caused by cement production [4]. Three ways to use waste PET in concrete. 1) Waste PET is depolymerized for unsaturated polyester resin as binder and produced polyester concrete. 2) Waste PET as raw material is produced fiber reinforced concrete. 3) Waste PET as fine aggregate is produced lightweight aggregate concrete.

F. Mahdi [5] depolymerized the recycled PET through glycolysis to produce unsaturated polyester resin (UPR) and used UPR to produce polymer mortar (PM) and polymer concrete (PC). The flexural strength of UPR polyester concrete was higher than Portland cement concrete. Ge Z. [6] used waste PET as binder to produce plastic mortar. The results showed plastic mortar had the characteristics of low water absorption and fast strength development.

The second way is using waste PET to produce fibers and fiber reinforced concrete [7]. However, PET fibers are only contained 0.3% to 1.5% in the fiber reinforced concrete by volume. In this case, compared with the first recycling method, only small amount of waste PET is reused [8].

The third way is using waste PET as fine aggregate to produce lightweight aggregate concrete [9]. Choi [10] used waste PET as lightweight aggregate in partial substitution of river sand in concrete. The concrete compressive strength decreased 6% and splitting tensile strength decreased 19%. Albano [11] analyzed the mechanical behavior of concrete contained 10% and 20% weight of WPET.
The compressive strength, flexural strength and elastic modulus of WPET concrete decreased as the weight and particle size of WPET increased.

The factors that influence impact strength and durability of PET concrete were not studied. This paper investigated mix design and the major factors, which could affect the impact strength and durability of PET concrete.

**Experimental**

**Materials**

The PET particles produced by the recycled PET bottles. The density of the PET particles was 1.35 g/cm$^3$, melting point was 260 °C, maximum particle size was 4 mm and minimum particle size was 2 mm.

The fine aggregate was local river sand with a fineness modulus of 2.87. Water absorption was 2.2% and specific gravity was 2.6. The coarse aggregate was washed local limestone. The maximum particle sizes were 10 mm. Both aggregate meet the requirements of the Fuller grading curves.

The admixtures used fly ash and partially replace PET to reduce the amount of PET and improve the concrete strength.

**Specimen Preparation**

Three factors was investigated the impact strength of PET concrete: A) PET/fly ash (PET/FA) ratio, B) PET and fly ash/aggregate (PET/AG) ratio, C) sand ratio by weight. Each factor had three different levels. The orthogonal experimental design was shown in Table 1.

Recycled PET particles were first mixed with fly ash and aggregates for 3 minutes and then heated to 260 °C. When PET particles were completely melted, melted PET was mixed with fly ash and aggregates for 2 minutes. After that, PET concrete was put into the mold and compacted for 1 minute at room temperature. After compaction, specimens were cured in preheated 180 °C oven for 1 hours and then put in the room until test (Figure 1).

![Figure 1. PET concrete.](image)

**Test Methods**

Cylinders of 150 mm×64 mm were cast for the impact strength test. The impact strength test were performed by a special equipment show in Figure 2. The hammer dropped down to the specimens by several times. Recorded the times of specimens touched the iron wall. The impact strength calculated by equation (1):

$$W = N + mgh$$  \hspace{1cm} (1)

where W, N, m, g, h denote impact strength, times of specimens touched the iron wall, hammer weight, acceleration of gravity, hammer dropped height.
Cubes of 100 mm×100 mm×100 mm were cast for the freeze-thaw cycle test and sulfate corrosion test. Freeze-thaw cycle and sulfate corrosion were tested according to the ASTM C666-97 and ASTM 1012, respectively.

All strength was obtained from three samples. The variation of three samples could not exceed more than 15%. The average of these three samples is presented and discussed in the next section.

Results and Discussion

Impact Strength

The impact strength of orthogonal experimental was shown in Table 1. K is the sum of each level in one factor. R is the range of orthogonal test result. In Table 1, the R of PET/AG is the highest and R of PET/FA is the least. It means PET/AG influences impact strength of PET concrete significantly. The best mix proportion of PET concrete is PET/AG= 1:3, sand ratio= 35%, PET/FA= 1:1.

<table>
<thead>
<tr>
<th>Level</th>
<th>Sand ratio (%)</th>
<th>PET/AG</th>
<th>PET/FA</th>
<th>Impact strength (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>1:1</td>
<td>4:1</td>
<td>60.46</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>1:2</td>
<td>2:1</td>
<td>80.61</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>1:3</td>
<td>1:1</td>
<td>161.23</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>1:1</td>
<td>2:1</td>
<td>80.61</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>1:2</td>
<td>1:2</td>
<td>161.23</td>
</tr>
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<td>6</td>
<td>35</td>
<td>1:3</td>
<td>4:1</td>
<td>201.54</td>
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<td>7</td>
<td>40</td>
<td>1:1</td>
<td>1:1</td>
<td>80.61</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>1:2</td>
<td>4:1</td>
<td>100.77</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>1:3</td>
<td>2:1</td>
<td>161.23</td>
</tr>
<tr>
<td>K₁</td>
<td>302.30</td>
<td>221.68</td>
<td>362.77</td>
<td></td>
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<tr>
<td>K₂</td>
<td>443.38</td>
<td>342.61</td>
<td>322.45</td>
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<tr>
<td>K₃</td>
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<td>524.00</td>
<td>403.07</td>
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<tr>
<td>R</td>
<td>47.03</td>
<td>100.77</td>
<td>26.87</td>
<td></td>
</tr>
</tbody>
</table>

The impact strength of C30 and C50 cement concrete were also tested, the result was shown in Figure 3. The PET concrete has good impact strength than C30 cement concrete, lower than C50 cement concrete.
Freeze-Thaw Cycle Test

In this test, the PET concrete mix proportion was PET/AG= 1:3, sand ratio= 35%, PET/FA= 1:1. The result of freeze-thaw cycle test of PET concrete was shown in Figure 4. Under 300 times freeze-thaw cycles, the weight of PET concrete loss slightly. The mass loss rate of PET concrete is less than 0.25%. The PET concrete shows good freezing resistance.

![Figure 4. Freeze-thaw cycle test of PET concrete.](image)

Sulfate Corrosion Test

In this test, the PET concrete mix proportion was PET/AG= 1:3, sand ratio= 35%, PET/FA= 1:1. The result of sulfate corrosion test of PET concrete was shown in Figure 5 and Figure 6. The weight loss of PET concrete after test is less than 0.5%. The corrosion resistance coefficient of 30 times cycle is 90% and 60 times cycles is 75%. The PET concrete shows good corrosion resistance.

![Figure 5. Specimen after sulfate corrosion.](image)

![Figure 6. Sulfate corrosion test.](image)

Conclusions

The best mix proportion of PET concrete is PET/AG= 1:3, sand ratio= 35%, PET/FA= 1:1. The PET concrete has good impact strength than C30 cement concrete, lower than C50 cement concrete.

Under 300 times freeze-thaw cycles, the weight of PET concrete loss slightly. The mass loss rate of PET concrete is less than 0.25%.
The weight loss of PET concrete after test is less than 0.5%. The corrosion resistance coefficient of 30 times cycle is 90% and 60 times cycles is 75%.

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