Relationship Between Compressive, Splitting Tensile and Flexural Strength Of Concrete Containing Granulated Waste Polyethylene Terephthalate (PET) Bottles as Fine Aggregate

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Abstract. This paper describes the experimental investigation of relationship between splitting tensile strength and flexural strength with the compressive strength of concrete containing waste PET as fine aggregates replacement. Waste PET was reprocesses and used as the artificial fine aggregate at the replacement volume of 25%, 50% and 75%. Cylindrical and prism specimens were tested to obtain the compressive, splitting tensile and flexural strength at the age of 28 days. Based on the investigation, a relationship for the prediction of splitting tensile and flexural strength was derived from the compressive strength of concrete containing waste PET as fine aggregate replacement.

Introduction

Polyethylene terephthalate commonly abbreviated as PET and widely used as the food, beverage and liquid containers. Generally, the empty PET packaging is discarded by the consumer after use and becomes waste PET [1]. The increasing growth of the population also contributes to the increasing growth of waste PET in landfill. The major problem for the waste production initially entails storage and elimination. The exponential growth in plastic waste from packaging incited a search for alternative means of recycling [2]. Since then, many attempts had been made to recycle waste PET in various fields. Alternatives such as recycling and reprocessed the waste into new plastic product are feasible except for land-filling, recycling of plastic waste to produce new materials, such as cement composites, appears as one of the best solution for disposing of plastic waste, due to its economic and ecological advantages [3]. A vast work has already been done on the use of plastic waste as an aggregate or a fibre in concrete. Frigione [1] and Marzouk et.al [2] and other researchers had tried replaced or recycling the waste PET as the artificial aggregate in concrete and some had add the reprocessed waste PET in concrete to produce fiber concrete.

Materials and Method

Ordinary Portland cement, coarse aggregate with maximum size 20 mm and sand were used as the ingredient in the concrete mixture. Discarded PET bottles were collected and processed to produce the granulated waste PET aggregate. The size of the waste PET aggregates used is between 0 to 5 mm. The materials and mix proportions used in this study are given in Table 1. Two types of specimens were prepared for this investigations; cylindrical and prisms specimens with dimensions of 100mm x 200mm and 100mm x 100mm x 500mm respectively. The total 36 specimens were fabricated and cured for 28 days. Compression test was conducted to BS 1881-Part 116-83. The determination of split tensile strength was done by BS 1881:117:83. For flexural strength of the material, prism specimen was arranged according to BS 1881:118:83
Table 1: Mix design of concrete with waste PET as fine aggregate replacement

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Density (kg/m³)</th>
<th>PET volume replacement (%)</th>
<th>PET volume replacement (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Fine aggregate</td>
<td>Coarse aggregate</td>
<td>Water</td>
</tr>
<tr>
<td>NC</td>
<td></td>
<td>295</td>
<td>885</td>
</tr>
<tr>
<td>25% PET</td>
<td></td>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td>50% PET</td>
<td></td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>75% PET</td>
<td></td>
<td>75%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Result for Mechanical Properties of PET Concrete

Based on Table 2, the inclusion of PET aggregate reduced the mechanical performance of the concrete. Similar findings also agreeable based on Choi et al [3], Marzouk et al. [2], Albano et al [4] and Frigione [1]. The reduction of the compressive strength attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste since PET aggregate was not participate on the hydration process with the binder. Beside, the low density PET aggregate compared to the natural aggregate also contributed to reduction respectively. It can be seen that the replacement using PET aggregate does not contribute to the strength of the concrete as does the natural fine aggregates, but it can be used as an alternative for reducing the dead load of concrete since the inclusion of PET aggregate reduce the density of the concrete respectively.

Table 2: Mechanical Properties of the granulated waste PET concrete

<table>
<thead>
<tr>
<th>Percentage of PET</th>
<th>Density (kg/m³)</th>
<th>Compressive strength(MPa)</th>
<th>Splitting tensile strength (MPa)</th>
<th>MOE (GPa)</th>
<th>Flexural strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>2372.59</td>
<td>26.69</td>
<td>3.52</td>
<td>30.00</td>
<td>4.99</td>
</tr>
<tr>
<td>25%</td>
<td>2343.22</td>
<td>22.83</td>
<td>2.99</td>
<td>23.00</td>
<td>4.75</td>
</tr>
<tr>
<td>50%</td>
<td>2322.79</td>
<td>20.37</td>
<td>2.38</td>
<td>15.00</td>
<td>3.80</td>
</tr>
<tr>
<td>75%</td>
<td>2231.94</td>
<td>15.20</td>
<td>2.02</td>
<td>9.00</td>
<td>2.61</td>
</tr>
</tbody>
</table>

Relationship between Compressive, Splitting Tensile and Flexural Strength of PET Concrete. Figure 1 shows the relationship between splitting tensile strength and compressive strength obtained from this study. As for comparison, Fig. 1 also showed relationship obtained by other study. Based on the figure, the relevant empirical expression obtained from this study is;

\[ f_t = 0.634 (f_c)^{0.5} \]  

Where \( f_t \) is the splitting tensile strength and \( f_c \) is compressive strength measures both in MPa. Based on the figure, the best regression line from this study approximate to the empirical relation suggested by ACI Building Code [5]. The empirical relation is expressed as;

\[ f_t = 0.59 f_c^{0.5} \]  

Eq. 3 and 4 are made by ACI Building Code [5] and Neville [6] respectively;

\[ f_t = 0.56 f_c^{0.5} \]  

\[ f_t = 0.23 f_c^{0.67} \]
The results of experimental and predicted splitting tensile strength from Eq. 1 to 4 listed in Table 3. ACI Building Code (Eq.2 and Eq 3) give a ratio closer to 1 eventhough it slightly overestimate the value for normal concrete and 25% of the PET replacement. For 50% and 75% of PET replacement, it seems that ACI Building Code had underestimate split tensile strength. Meanwhile, Eq. 4 that proposed by Neville significantly underistimate all the split tensile strength for the respective PET replacement.

The relationship of flexural strength against compressive strength are shown in Figure 2. Based on Figure 2, the suggested expression is given by;

\[ f_{fs} = 0.466f_c^{0.703} \]  

(5)

Where \( f_{fs} \) is the tensile strength and the \( f_c \) is the compression strength of the concrete composite. Other relations stated previously suggested by ACI Building Code [6], listed in the following empirical expressions;

\[ f_{fs} = 0.62f_c^{0.5} \]  

(6)

\[ f_{fs} = 0.94f_c^{0.5} \]  

(7)

The results of the flexural strength predicted by Eq. 6 and 7 for all specimens included in the analysis are listed in Table 4. Based on the table, the average experimental/predicted flexural strength is calculated. Significantly, the empirical expression from Eq. 7 is approximately give a closer value to the experimental result with the satisfactory average difference of 8%.
Summary
The relationship between compressive, splitting tensile and the flexural strength using waste PET as fine aggregate replacement were developed. Instead of reducing the concrete density, the idea of utilization of PET plastic in the concrete technology not only helps solving growing waste disposal crisis but also conserving natural resources by helping to reduce the quarrying of sand.

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References