The Effect of 0.8% Polyethylene Terephthalate Plastic Waste Substitution on the Flexural Strength on K-175 Concrete

Gunaedy Utomo¹, Andi Marini Indriani*, and Dinda Indah Damayanti¹

¹Department of Civil Engineering, Universitas Balikpapan, Balikpapan, Indonesia

Abstract. The use of plastics in daily life continues to increase in a variety of uses. One of the most commonly used plastic that is difficult to decompose is Polyethylene Terephthalate (PET) plastic. In recent years, such as the construction industry, has been trying to reuse the waste as construction material. Therefore, this research aims to contribute by exploring the effect of PET plastic fiber substitution as fine aggregate on the flexural strength of concrete. PET plastic fibers were used at 0.8% as partial replacement of fine aggregates and then chopped to a size of 5 cm long, 1-3 mm wide. The test results indicate that concrete containing 0.8% PET plastic fiber as a substitution of fine aggregate has a higher flexural strength value of 4.32% which is better than normal concrete. Therefore, using recycled PET fiber in concrete is needed as an eco-friendly and sustainable construction material in the future in order to minimize PET plastic waste and replace it as a concrete constituent material.

1 Introduction

The proliferation of plastic usage in everyday life continues to escalate across various applications [1]. Predictions suggest that global plastic waste production will soar to 53 million tons by 2030. The exponential rise in plastic manufacturing and widespread utilization of plastic products could have profound implications on various aspects of the world if not effectively managed [2]. This scenario is prevalent in numerous countries, Indonesia included [3]. Indonesia ranks as the second-largest contributor to marine plastic pollution, with an estimated 0.27-0.59 million tons of plastic waste entering its oceans [4]. Moreover, there is mounting global apprehension regarding plastic contamination.

Polyethylene Terephthalate (PET), one of the most prevalent yet exceptionally resistant-to-biodegradation plastics in natural environments, exacerbates these concerns [5]. The long-term ramifications of PET waste released into the environment pose significant hazards to ecosystems, food safety, and even human health in contemporary societies [6]. Presently, over 70% of global plastics are discarded as waste, with only 16% being recycled. The remainder is disposed of in landfills, incinerated, and tragically, finds its way into oceans or coastal areas [7].

* Corresponding author: andi.marini@uniba-bpn.ac.id
In recent years, the construction industry has endeavored to solve environmental problems such as improperly disposed solid waste [8] where construction is one of the most complex jobs [9] so the need to recycle PET plastic to reduce these impacts by utilizing PET plastic as a mixture for concrete. By replacing or adding PET plastic into concrete is an innovation that can help to minimize the use of natural resources since concrete is one of the main materials in the construction world that is flexible, strong, and cost effective. Concrete has high compressive strength [10] compared to other materials, concrete has relatively low tensile strength and ductility, which makes it easy to crack [11]. However, there are some local materials in East Kalimantan, Indonesia where aggregate availability is abundant, such as coarse aggregate from Petangis and fine aggregate from Samboja. Petangis coarse aggregate is a type of crushed stone and has harder and sharper characteristics and also has a darker stone color than other coarse aggregates, then Samboja fine aggregate has very fine granular characteristics with grain sizes smaller than 4.75 mm. Petangis coarse aggregate and Samboja fine aggregate can be seen in Fig. 1.

For instance, research conducted by [12] explored the integration of PET fibers into concrete, yielding favorable outcomes in enhancing crack control and serving as a measure to mitigate environmental pollution. Similarly, [13] found that incorporating PET plastic fibers significantly enhanced the tensile, elastic, and flexural strengths of concrete specimens, with an optimal addition rate of 0.4%. Moreover, the substitution of 10% PET aggregates for fine aggregates improved the compressive, tensile, and flexural strengths of concrete, attributed to the flexibility and uniform distribution of PET aggregates within the mixture, consequently positively impacting the flexural capacity of the beams [14]. Conversely, [15] investigated the combined addition of sawdust and PET as fine aggregates, ranging from 40% to 80% in concrete, resulting in reduced compressive strength, split tensile strength, and flexural strength. In another study examining PET plastic as a fine aggregate substitute, [16] demonstrated that a 5% PET variation yielded optimum or superior results compared to regular concrete. Additionally, [17] conducted research involving PET plastic as a fine aggregate substitute, varying from 10% to 60%, which yielded positive outcomes, wherein the crack pattern produced by concrete containing PET plastic fibers was less pronounced than in normal concrete. Furthermore, research conducted by [18] utilizing Petangis gravel yielded the highest compressive strength of concrete compared to Palu aggregate.

Hence, as a new technological innovation, it can be incorporated with plastic fibers, especially PET, as well as classifying the characteristics of the material that will be used [19] which is an aggregate from East Kalimantan, Indonesia to improve the mechanical properties of concrete. This study aims to contribute to the growing research field by exploring the effect of Polyethylene Terephthalate (PET) fiber substitution as fine aggregate on the flexural strength of concrete.
2 Method

The materials used are Portland cement type I, coarse aggregate with grain size between 5 and 40 mm from Petangis, East Kalimantan, Indonesia. Fine aggregate with grain size between 0.15 and 4.75 mm from Samboja, East Kalimantan, Indonesia. Clean water, and PET plastic fibers that are manually cut or chopped to a width of 1-3 mm and a length of 5 cm, then the percentage of PET plastic added to the concrete mix as a fine aggregate substitution is 0.8%. The shape of the PET plastic is shown in Fig. 2.

![PET fibers](image)

Fig. 2. The size of PET (a) PET Length 5 cm, (b) PET width 1-3 mm, and (c) PET Plastic Fiber

The method of concrete mix planning with a slump value of 10 ± 2 cm. The proportions of concrete admixtures can be seen in Table 1.

<table>
<thead>
<tr>
<th>PET (%)</th>
<th>Cement (kg)</th>
<th>Water (kg)</th>
<th>Coarse Aggregate (kg)</th>
<th>Fine Aggregate (kg)</th>
<th>PET Plastic (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>373.75</td>
<td>185</td>
<td>1617.8</td>
<td>593.06</td>
<td>-</td>
</tr>
<tr>
<td>0.8</td>
<td>373.75</td>
<td>185</td>
<td>1617.8</td>
<td>588.32</td>
<td>4.745</td>
</tr>
</tbody>
</table>

In order to know the concrete mix according to the specified value, the slump test is carried out. After that, the concrete mixture is put into a test specimen mold measuring 15 × 15 × 60 cm and opened after molding for 24 ± 8 hours and then placed in a curing tub for 28 days. The flexural strength test method used in this research is with a two-point loading Universal Testing Machine.

3 Result and discussion

3.1 Slump test

The slump test in this study is used to evaluate the workability of concrete with a value of 10 ± 2 cm. Based on observations depicted in Fig. 3, it's evident that the slump value of concrete with 0.8% PET substitution is lower than the slump value of normal concrete. This finding aligns with research [20], which suggests that the diminished workability of concrete due to PET addition could be attributed to the flat shape of PET, resulting in a larger surface area compared to natural sand. Incorporating PET plastic fibers, measuring 1 - 3 mm wide and 5 cm long, contributes to locking and holding the concrete mixture, thereby reducing its workability [20].

As a result, greater friction develops among particles, resulting in reduced maneuverability of the concrete blend. Higher fiber content tends to raise the frictional resistance between the fibers and the concrete particles, impeding the unrestricted movement...
of concrete [22] [23]. This heightened frictional resistance subsequently lowers the slump value of the concrete.

![Fig. 3. Relation between Pet Substitution and Slump Value](image)

### 3.2 Flexural strength test

The average results of flexural strength test analysis of normal concrete and PET plastic concrete at 14 and 28 days of age are shown in Table 2.

**Table 2.** 14 and 28 Days Flexural Strength Analysis

<table>
<thead>
<tr>
<th>No</th>
<th>% Plastic</th>
<th>Curing Days</th>
<th>Flexure Tester Readout</th>
<th>Flexural Strength (MPa)</th>
<th>The increase in flexural strength of PET concrete compared to normal concrete (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>14 Days</td>
<td>22.82</td>
<td>3.043</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.8</td>
<td>14 Days</td>
<td>23.87</td>
<td>3.182</td>
<td>4.57</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>28 Days</td>
<td>23.90</td>
<td>3.187</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
<td>28 Days</td>
<td>24.93</td>
<td>3.325</td>
<td>4.32</td>
</tr>
</tbody>
</table>

![Fig. 4. Flexural Strength of Normal Concrete and 0.8% PET Concrete](image)

Based on the data presented in Table 2 and Fig. 4, it is evident that the strength of concrete increases at both 14 and 28 days. Concrete containing PET plastic fibers exhibits a flexural strength of 3.182 MPa at 14 days, marking a 4.57% improvement, while at 28 days, the flexural strength is 3.325 MPa, showing a 4.32% enhancement compared to normal concrete. Concrete strength follows a linear increase trend until it reaches 28 days, with the rate of increase initially rapid upon molding but gradually slowing over time [24]. Hence, the standard strength of concrete is typically assessed at the 28-day mark. The augmented flexural strength can be attributed to the PET fiber particles' ability to withstand tensile forces [25]. This finding aligns with previous research by [26], which demonstrated that PET concrete outperformed normal concrete in terms of strength. Additionally, [27] noted that increasing the percentage of PET plastic waste content in concrete leads to a stepwise elevation in flexural strength. The higher the amount of plastic fiber, the greater the strength.
value, as the plastic in the concrete mixture resists loads, preventing direct collapse or fracture under loading conditions [28]. Moreover, the strong bond between the surface of PET particles and cement contributes to the enhancement in flexural strength [29]. The incorporation of fibers significantly impacts the flexural strength of specimens, owing to the fiber's characteristics that augment the flexural strength of beam specimens [30].

![Fig. 5. Crack Pattern Comparison: (a) Normal concrete; (b) Sketch of normal concrete; (c) Top view of normal concrete; (d) side view of normal concrete; (e) 0,8% PET concrete; (f) Sketch of 0,8% PET concrete; (g), (h) Side view of 0,8% PET concrete](image)

As per [31], the minimal increase in strain suggests that PET plastic fibers effectively withstand cracks in the beams (refer to Fig. 5). Previous studies have attributed this phenomenon to the interlocking nature of micro-cracks formed by PET fibers, which fortifies beam specimens, enabling them to endure stress. PET fibers act as reinforcement by impeding the propagation of fine micro-cracks that develop during the initial loading stages. Chemically inert, PET fibers serve as bridging reinforcements, preventing micro-cracks in beam specimens [8]. The incorporation of PET fibers aids in resisting micro-cracks in concrete structures, necessitating higher loads for the initiation of initial cracks [32] [33]. Additionally, concrete devoid of PET plastic admixture tends to fracture into distinct pieces upon failure. Conversely, PET concrete fosters multiple connection points between cracked surfaces owing to the properties and durability of PET plastic [34]. Compared to failures in normal concrete, cracks in PET concrete beams are notably finer and fewer in number, attributed to fiber reinforcement that bolsters the internal cohesion of concrete components [35].

4 Conclusion

From the findings, it can be inferred that incorporating PET plastic into concrete enhances the flexural strength of the concrete. Specifically, PET concrete aged 28 days exhibits a strength value of 3.325 MPa, representing a 4.32% increase compared to regular concrete.

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References

4. Indonesian Institute of Science (LIPI), 2018.


