The effect of shredded plastic waste PET and HDPE substitution on concrete characteristics

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Abstract. The incompetence of recycling schemes has gradually led to alternative ideas to tackle the problem of plastic waste. This research was conducted from the context of environmental and development issues that are growing in Indonesia. This research focuses on how to apply plastic waste into concrete mixtures. PET (Poly-Ethylene Terephthalate) and HDPE (High-Density Polyethylene) plastic waste is shredded into 10-25 mm sizes and substituted as much as 5%, 10%, 15%, and 20% replacing fine aggregate to improve concrete characteristics. The results showed that the PET substitution of 5%, 10%, and 15%, the compressive strength still met the compressive strength plan ($f'c = 25$ MPa). Whereas in the HDPE substitution variation, it is only the strength of the variation of 5% and 10% that still meets the compressive strength plan. In the split tensile strength test, there was a decrease in the strength of PET substitution with increasing percentage levels, while in HDPE substitution there was an increase in strength at levels of 5% and 10%. Overall, it was concluded that HDPE and PET shredding in concrete have an opportunity to help to reduce the build-up of plastic waste.

1. Introduction
Plastic waste is one of the commodities that contribute to the largest amount of polluting waste. This is inseparable from the nature of the plastic which is practically used and relatively cheap cost in production. Most of these are types of disposable plastic (disposal). For example, the use of PET and HDPE plastics as product packaging. PET plastic (Poly-Ethylene Terephthalate), which is usually used as the bottled mineral water, is the largest contributor to polluting waste circulating in the sea and on land, as well as HDPE (High-Density Polyethylene) plastic which is widely used as the packaging of vehicle oil, detergent, liquid soap, shampoo, and other cosmetic products. The survey conducted by the Sustainable Waste Indonesia (SWI) Institute funded by Danone Aqua shows that 350,000 tonnes of PET bottles are consumed annually by people nationwide; and only 216,047 tonnes of which have been collected for recycling[1].

Meanwhile, quoted from the World Economic Forum, 12 million tons of plastic, mostly single-use, enter into the sea from land annually. Plastic production is expected to increase by 40% in the next decade, making it nearly impossible for waste management and recycling schemes to cope with it[2]. This data shows that there is a need for a long-term option for the use of plastic waste into materials that can be efficiently useful in the future. This study offers an alternative solution to make use of plastic waste as a mixture in concrete.
In this study, PET and HDPE plastic waste was used in the shredded form with a length of 10-25 mm, a width of 2-5 mm, and a maximum thickness of 2 mm. In its utilization, it is expected that the substitution of shredded plastic waste to fine aggregate in the concrete mixture can have a good effect on the tensile strength and compressive strength of concrete.

Rahmani et al.,[8] examined the mechanical properties of concrete mixed by shredded PET waste. In this examination, 5%, 10%, and 15% of the PET mixture were used respectively to replace the total weight of sand. The positive results indicated that the replacement of sand by 5% to shredded PET increases the compressive strength by 8.86% and 11.97%. Meanwhile, in the study of N. Nursyamsi et al.,[9] identified that the average tensile strength of briquette mortar with a mixture of 10% and 20% of shredded HDPE plastic replacing the fine aggregate could be 9.743 kg / cm^2. In addition, N. Nursyamsi et al.,[10] also noted that added that a mixture of 20% LDPE shredded plastic can produce a briquette mortar tensile strength of 9.99 kg / cm^2.

![Figure 1. Shredded HDPE plastic](image)

### Table 1. Aggregate properties

| Examination               | Experimental Data |
|---------------------------|-------------------|
|                           | Fine Aggregate    | Coarse Aggregate |
| Specific Gravity          |                   |                  |
| Dry                       | 2.48              | 2.64             |
| SSD                       | 2.54              | 2.66             |
| Quasi                     | 2.63              | 2.70             |
| Absorption                | 2.35%             | 0.89%            |
| Bulk Density (kg/m^3)     | 1659.22           | 1474.57          |
| Void                      | 32.88%            | 43.96%           |
| Clay Content (through the filter no.200) | 2.4% | 0.53% |
| Sieve Analysis            | FM = 2.56        | FM = 6.28        |
Plastic waste is collected and then chopped with lengths between 10-25 mm, width between 2-5 mm, and a maximum thickness of 2 mm. Both of PET and HDPE are equally treated in this study.

![Shredded PET](image1.png) ![Shredded HDPE](image2.png)

**Figure 2.** (a) Shredded PET; (b) Shredded HDPE

The concrete mixed design is carried out based on ACI 211.1-91. The mixed design calculation is carried out using the properties materials that had been tested previously. Shredded PET and HDPE were substituted to replace fine aggregate, respectively 5%, 10%, 15%, and 20% in each proportion of the concrete mix with design quality $f'c = 25$ MPa. The concrete mixture can be seen in Table 2 which cement 14.89 kg, split stone 38.84 kg and water 7.2 litre.

### 3. Testing methods

#### 3.1. Slump test

The test for fresh concrete is to determine the concrete slump. Concrete slump is a measure of the thickness of fresh concrete. The slump value is also associated with the ease of working with concrete (workability). The tool used is an Abrams cone which has an open top and bottom with the dimensions of 10 cm as top diameter, 20 cm as bottom diameter, and 30 cm height. The cone is placed on an iron plate. The procedure for testing the concrete slump is based on SNI 1972-2008.
Table 2. Concrete mix in each variation (6 cylinders)

| No. | Variation of the sample | Sand (kg) | Shredded PET (gr) | Shredded HDPE (gr) |
|-----|-------------------------|-----------|------------------|-------------------|
| 1.  | Normal                  | 27.50     | -                | -                 |
| 2.  | 5% of PET substitution  | 26.13     | 155.96           | -                 |
| 3.  | 10% of PET substitution | 24.75     | 311.92           | -                 |
| 4.  | 15% of PET substitution | 23.38     | 467.89           | -                 |
| 5.  | 20% of PET substitution | 22.00     | 623.85           | -                 |
| 6.  | 5% of HDPE substitution | 26.13     | -                | 385.17            |
| 7.  | 10% of HDPE substitution| 24.75     | -                | 770.34            |
| 8.  | 15% of HDPE substitution| 23.38     | -                | 1155.50           |
| 9.  | 20% of HDPE substitution| 22.00     | -                | 1540.67           |

3.2. Water absorption (sorptivity)

The absorption value is closely related to the density and porosity of a material, because a large absorption value indicates the number of cavities contained in the material. The amount of absorption can also cause a decrease in the strength of the concrete, because the pores cause the bond between particles in a material to decrease. The amount of absorption in concrete is calculated using the formula:

\[ Ab = \frac{M_b - M_k}{M_k} \times 100\% \]  

Where;

Ab = Absorption (%)  
Mb = The mass of sample at saturated state of water (gram)  
Mk = The mass of sample at constant dried (gram).

The samples were 3 concrete cylinders with a diameter of 15 cm and a height of 30 cm for each variation.

3.3. Compressive strength

The value of \( f'c \) is the compressive strength of cylindrical samples with a diameter of 15 cm and a height of 30 cm as stipulated in SNI T-15-1991. The test is based on the strength of concrete that is 28 days old. The compressive strength value is obtained from the comparison of the collapse load of the sample with the area of the compressive cross-sectional area of the samples. The tests are carried out by using the Compressor Machine.

3.4. Split tensile strength

The tensile strength test is done by applying tensile stress to the concrete indirectly. The cylindrical specimen is laid down and pressed so that tensile stress occurs on the concrete. The samples in this study was 3 cylinders of 15x30 cm for each variation.

The indirect tensile stress is calculated by the equation:
\[ T = \frac{2P}{\pi LD} \]  

Where,

- \( T \): Splitting tensile strength (MPa)
- \( P \): Maximum applied load (N)
- \( L \): length (mm)
- \( D \): diameter (mm)

4. Results and discussion

4.1. Slump

From Figure 5, it can be seen that both of PET and HDPE mixture in the concrete causes the slump value to decrease, which means that the agility of the mixture is corroborated. The concrete will contain more air pores due to the difficulty of mixing or molding the mixture. The decreasing of slump value in the concrete mix can be solved if the water content is added to the mortar or an evaluation of the cement water factor is carried out so that the quality of the concrete is still appropriate.

4.2. Water absorption

From Figure 6. (a), it can be analysed that the increasing amount of shredded PET to replace the fine aggregate causes the absorption value to be greater. It means that the air pores contained in the concrete are increasing. The lowest and highest absorption values are found in the 10% variation, those are 0.712% and 2.331%. This result indicated an uneven accumulation of shredded PET during the molding process in this variation.

It can be analysed from Figure 6. (b) that the increasing levels of shredded HDPE to replace fine aggregate can also increase the absorption value. For the variation of 0% to 5%, the increasing level is
relatively small with an absorption value of around 0.8%. Meanwhile, for the variation of 5% to 20%, there is a significant increasing level which can be represented by the function \( y = 4.43x + 0.72 \) where \( y \) is the absorption value and \( x \) is the percentage of plastic substitution. The lowest absorption value in the HDPE mixture was 0.83%, while the highest value was 1.77%. Overall, the variation of PET substitution was slightly better than HDPE in terms of absorption value.

4.3. The mass of samples

The plastic shredded substitutions for both of PET and HDPE in this study did not significantly affect the mass of sample (shown in Figure 7). This study found only slight differences between HDPE substitution that has 0.473% than PET substitution.

4.4. Compressive strength

Figure 8. (a) shows that the substitution of PET to fine aggregate in concrete tends to decrease compressive strength. As shown is Figure 8. (b), the HDPE substitution for fine aggregate in concrete tends to decrease compressive strength. The effect appears with the use of HDPE substitution is similar to the PET. The workability of the mixture is increasing as a consequence of many air pores that form in the concrete. The results that meet the plan are only at a variation of 5% and 10%. It shows that 5% variation produces 27.97 MPa and at 10% variation produces 25.28 MPa.

Overall, the HDPE substitution is only superior at 5% variation, in which it shows the result of 26.97 MPa for PET and 27.97 MPa for HDPE. Moreover, it can be seen that there was an inhomogeneity of the concrete mix which caused the lowest and highest compressive strength to be found in the 10%
variation of the PET substitution, those were respectively 19.15 MPa and 33.22 MPa. Whereas for HDPE substitution, the highest compressive strength was 32.19 MPa and the lowest was 18.54 MPa.

![Figure 8](image_url)  
**Figure 8.** (a) Average compressive strength of PET substitution; (b) Average compressive strength of HDPE substitution

### 4.5. Tensile strength

It can be seen from the Figure 9. (a) that the average tensile strength of PET substitution is relatively unchanged at variations of 0% and 5%. However, there has been a decrease of 3.64% when the 10% variation is applied. At the 15% variation, the split tensile strength strengthens again by 1.85% from the 10% variation and decreases by 2.8% at the 20% variation against the 15% variation.

From Figure 9. (b) the tensile strength of HDPE substitution mixture shows better results than normal concrete at 5% and 10% variations, while the tensile strength at the 15% variation tends to be the same with normal concrete. However, it shows that at the 20% variation there was a decrease of 3.64% of normal concrete tensile strength.

The results in the tensile strength examination indicates that the HDPE substitution mixture was dominant than the PET substitution. A possible explanation of it is due to the shredded texture of HDPE that is stiffer than PET. The highest and lowest tensile strengths in the variation of PET and HDPE substitution were 2,972 MPa and 2,406 Mpa.

![Figure 9](image_url)  
**Figure 9.** (a) Average tensile strength of PET substitution; (b) Average tensile strength of HDPE substitution

### 4.6. Correlation between compressive strength and tensile strength

Based on the standard correlation between compressive strength and tensile strength of $0.5 - 0.6 \sqrt{f'c}$, it can be seen that all variations of HDPE substitution mixtures have fulfilled the equation. Whereas in
the PET substitution variation, it can be seen that all variations are satisfactory except for the 10% variation. It is possible because there is an error during the compaction of the sample preparation or uneven distribution of PET in the mixture, which causes the compressive strength or tensile strength to be less accurate. The values of the compressive strength and tensile strength are presented in Table 3.

Table 3. Correlation between compressive ($f'_c$) and tensile strength of the concrete

| Substitution Variation | Tensile Strength Value |
|------------------------|------------------------|
|                        | PET                    | HDPE                   |
| Normal (0%)            | 0.506 $\sqrt{f'_c}$   | 0.506 $\sqrt{f'_c}$   |
| 5%                     | 0.518 $\sqrt{f'_c}$   | 0.526 $\sqrt{f'_c}$   |
| 10%                    | 0.491 $\sqrt{f'_c}$   | 0.545 $\sqrt{f'_c}$   |
| 15%                    | 0.526 $\sqrt{f'_c}$   | 0.560 $\sqrt{f'_c}$   |
| 20%                    | 0.533 $\sqrt{f'_c}$   | 0.558 $\sqrt{f'_c}$   |

5. Conclusion

This study concluded that the shredded PET and HDPE at a certain degree and percentage and can be used to replaced the fine aggregate and it will still produce an acceptable strength characteristics. The weakness that can be seen from the concrete mixture of PET and HDPE is that the bond or adhesion force between the shredded and the concrete matrix is weaker than the cohesion force between the concrete matrix itself. It can be seen in the split tensile test that the shredded plastic in the sample is not broken by the maximum load. While in the normal concrete, the sample split immediately and other concrete-forming materials such as coarse aggregate break and split along the split line when it reaches the maximum load. Further research should be carried out to explore the additives material that can help to repair the bond of the concrete matrix by using shredded plastic.

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