Mechanical properties of polypropylene plastic waste usage and high-density polyethylene in concrete

Jonbi Jonbi¹, Wita Meutia¹, Antonia Rosalia Indra Tjahjani¹ Angga Firdaus¹ and Sahri Romdon¹

¹University of Pancasila, Indonesia

E-mail: nanojbg@gmail.com

Abstract. Using plastic waste as a construction material was one of the techniques used to overcome the inconsistencies associated with environmental pollution created by indiscriminate dumping of plastic waste. It was refined into aggregates that were utilized as a fractional replacement for coarse aggregates in concrete mixtures. The sole objective of this research work is to analyze the use of plastic waste in concrete. Two types of aggregates extracted from plastic waste namely: Polypropylene (PP) and High-Density Polyethylene (HDPE) were used in carrying out this study. The percentages of PP used were 5%, 10%, 15%, while 15%, 20%, 25% were used for HDPE. Similarly, the slump value, compressive strength, and tensile strength were tested for 28 days and at a concrete age of 3.7. The results obtained proved that a percentage increase in plastic aggregate would invariably reduce the value of slump, compressive strength, and tensile strength. The optimum percentage of PP and HDPE used were 10% and 15% respectively. This research contributed to providing an alternative to overcoming plastic waste.

1. Introduction
The increasing generation of plastic waste has become one of the major factors of environmental pollution and a serious problem which we must overcome. The fact that plastic is non-biodegradable makes it constitute a danger to the surroundings. The innovation of converting plastic waste into useful materials is very vital and needs to be applied, such as making use of it to replace coarse aggregates in concrete.

High Density Polyethylene (HDPE) and Polypropylene (PP) are examples of plastics that are used on a daily basis. Polypropylene is characterized by a high tensile strength and Young Modulus and has a density between 0.900 g / cm³ and 0.915 g / cm³ and molecular relationship [1,2]. High Density Polyethylene (HDPE) is a form of plastic with a density of 0.940 g / cm³ - 0.965 g / cm³ and a strong molecular relationship [3].

A recent study has revealed that the use of HDPE and PP wastes as materials in road construction is capable of improving the strength of the typical asphalt binders as one of the different ways of utilizing plastic waste [4]. Polypropylene, that is used as a synthetic fiber, has the ability to increase density of concrete [5]. HDPE waste processed into additional 25% fine aggregate can be utilized in concrete mixtures, and it is potent for minimizing natural aggregate usage [6].
The study involving the use of PET type plastic waste as fine and coarse aggregate in concrete mixture has both positive and negative effects. Although it cannot be used all alone as concrete, it can make concrete more durable [7].

This study undertakes an analysis of the mechanical properties of High-Density Polyethylene (HDPE) and Polypropylene (PP) types of plastic wastes as a partial replacement for rough aggregates in concrete mixtures.

2. Methodology
Waste materials of plastic origin such as polypropylene (PP) and High Density Polyethylene (HDPE) indicated in Figure 1, have been incorporated into plastic pellets by waste processing company in Bantar Gebang, Jakarta.

![Plastic Seeds (a) Polyethylene (PP), (b) High Density Polyethylene (HDPE)](image)

Cement OPC Type 1 coarse aggregate, fine aggregate obtained from PT Adhimix Precast Indonesia.

### Table 1. Proportion of mixtures per m³ for fc 25 MPa

| Material                | Code | B0 | PP1 | PP2 | PP3 | PE1 | PE2 | PE3 |
|-------------------------|------|----|-----|-----|-----|-----|-----|-----|
| cement (Kg)             |      | 486| 486 | 486 | 486 | 486 | 486 | 486 |
| Fine Aggregate (Kg)     |      | 603| 603 | 603 | 603 | 603 | 603 | 603 |
| Coarse Aggregate (Kg)   |      | 1121| 1064.9| 1008.9| 952.8| 946.9| 896.8| 840.8 |
| Plastic (Kg)            |      | 0  | 56.1| 112.1| 168.2| 167.1| 224.2| 280.2 |
| Water (Liter)           |      | 170| 170 | 170 | 170 | 170 | 170 | 170 |

In the mixture proportion shown in Table 1, B0 is a concrete specimen without a mixture of plastic waste (reference concrete). PP1 is a specimen obtained by replacing 5% of the coarse aggregate weight with polypropylene (PP) waste. PP2 and PP3 are specimens obtained by replacing 10% and
15% of the coarse aggregate with polypropylene (PP) waste respectively. PE1, PE2, and PE3 are specimens obtained by replacing 15%, 20%, and 25% of coarse aggregate with plastic waste of High Density Polyethylene (HDPE) respectively. Figure 3 shown the manufacture of specimens and curing.

The tests carried out on slump using ASTM C 143-90 standard as shown in Fig. 3. Compressive strength testing is termed ASTM C39 and tensile strength is termed ASTM C496 / C496M [8,9]. The compressive strength testing of the specimen is done in a cylinder which has a height of 20 cm and a diameter of 10 cm. The compressive and tensile strength tests were performed at concrete ages 3, 7 and 28 days. The number of specimens is 63 pieces.

Results and discussion

3.1. Slump test
Figure 4 indicates the slump value for specimens involving plastic waste, which is lower than the standard concrete slump value (B0: 12.5 cm). This indicates that workability reduces when certain percentages of both forms of plastic waste are incorporated[10,11]. The slump values for PP1, PP2, PP3 are 8.5 cm, 6.5 cm and 6 cm respectively while PE1, PE2, PE3 have slump values of 7.5 cm, 4.8 cm and 2 cm respectively. PP1, PP2, PP3 have higher slump values compared to PE1, PE2 and PE3.
The reduction in slump value is due to lack of uniformity in the shape of plastic particles which result in low fluidity. Decrease in the value of slump can be checked by using superplasticizer as done by Rai et al. [11].

3.2. Compressive strength
Figure 5 reveals the value of concrete compressive strength at the ages of 3, 7 and 28 days. At the age of 3 days, PP1 and PP2 were greater than B0 with the values 109% and 105% respectively. While the PP3 value was 79% of B0. PE1, PE2 and PE3 at 3 days reached 96%, 76% and 73% of B0 respectively. At the age of 7 days, PP1, PP2, PP3 values had become 102%, 93%, 86% of B0 respectively. In specimens PE1, PE2, and PE3, the values reached 100%, 65%, and 58% respectively. Achievements recorded at 28 days of concrete age by PP1, PP2 and PP3 were 86%, 85% and 79% of reference concrete respectively while the specimens PE1, PE2, and PE3 had values 100%, 58%, and 51% respectively.

Figure 4. Slump test result
The inclusion of plastic percentages reduces the value in concrete compressive strength. This is in line with the previous research which stated that there is a reduction in adhesive strength between cement paste and plastic surfaces and the plastic particles become bigger in size [10,11,12]. The concrete compressive strength of PE1, PE2 and PE3 has lower values compared to PP1, PP2, and PP3. This is due to the fact that HDPE has a shiny and smooth surface which makes it difficult to adhere to other materials in the concrete [3]. To overcome this problem of no adhesion, the polymer type styrene modified rubber and superplasticizer are used [13].

3.3. Tensile Strength
The results of tensile strength tests are shown in Fig. 6. The concrete tensile strengths PP1, PP2 and PP3 in the age of three days were 118%, 85% and 82% of reference concrete respectively. The percentages of tensile strength PE1, PE2 and PE3 are 113%, 101%, and 76% of B0 respectively. At the age of 7 days, the tensile strength for PP1 was 98%, PP2 was 91% and PP3 was 70%. Specimens of PE1, PE2, and PE3 had tensile strength values of 85%, 74% and 60% respectively. In the age of 28 days, the tensile strength of specimens PP1 was 82%, PP2 was 76% and PP3 was 77%. The value of PE1, PE2 and PE3 were 70%, 61% and 50% of B0 respectively.

Decrease in tensile strength occurred when the percentages of plastic waste decreased. It happened as a result of lower aggregate between cement paste and plastic waste. It is also partly due to the lower Interfacial Transition Zone (ITZ) of plastic waste [10].
Figure 6. Result of tensile strength test

4. Conclusion
The percentage inclusion of plastic aggregate in concrete mixture reduced slump value, tensile strength and compressive strength values. Plastic waste is also used as a replacement of coarse aggregate. The compressive strength of PP with optimal percentages 10% became 85%, while PE 15% became 100% from reference concrete. The compressive strength PP rose to 76% from reference concrete of 10% and PE 70% from 15%.

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