Utilization of Plastic Waste as a Substitute for Coarse Aggregate in Concrete: Characteristics and Parameter Comparison

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Abstract. Concrete is a composite material made from cement, fine aggregates, coarse aggregates, and water. The issue of extensive exploitation has arisen due to continuous global development. Efforts have been made to reduce plastic waste through recycling. This aligns with research aimed at finding ways to make plastic waste more useful and replace certain materials, from furniture to construction materials. The goal of this research is to obtain the characteristics of processed plastic waste and compare various parameter values with coarse aggregates according to the requirements as concrete mix material (referring to the Indonesian National Standard). The methods employed include plastic waste sorting, washing, burning, and mixing with sand variations (2 variants) to add rigidity to the plastic, followed by pouring into molds. The plastic is then crushed to resemble coarse aggregates. The bulk density of plastic aggregates (PA) are 631.89 kg/m^3 (PA1), 706.85 kg/m^3 (PA 2) and 763.02 kg/m^3 (PA3). The spesific gravity of plastic aggregates are 0.99 (PA1), 1.09 (PA2) and 1.15 (PA3). The absorbtion of aggregates are -0.69 (PA1), 0.59 (PA2) and 0.32 (PA3).

Keywords: Plastic waste, plastic aggregate, bulk density, spesific gravity, absorbtion

1 Introduction

Concrete is a popular material choice in construction projects, especially as a material for structural elements (Suwarno, A. and Sudarmono, 2015). Therefore, it is easy to find this material in various constructions, including buildings, irrigation systems, bridges, and pavements. This widespread use is due to the ease of production and the high strength of concrete in withstanding pressure.

Concrete is a composite material composed of cement, fine aggregates, coarse aggregates, and water. As construction activities continue to increase, the demand for concrete rises every year. This has led to the extensive exploitation of the materials that make up concrete.

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Additionally, the production process of concrete generates harmful emissions of carbon dioxide (CO2) and particulate matter (PM10) (Jaskowska-Lemańska, et al., 2022).

According to data from the National Waste Management Information System (SIPSN) of the Ministry of Environment and Forestry (KLHK), Indonesia produced 36,424,899.07 tons of waste in 2022. Of this amount, plastic waste accounted for 18.03% or approximately 656,740,930.23 tons. This figure is concerning, given that plastic does not naturally decompose.

Indonesia is one of the largest rice-producing countries. According to the Central Statistics Agency (BPS), in 2023, Indonesia is projected to produce 53.63 million tons of dry milled grain (GKG). From this amount, a significant quantity of rice husk waste is expected to be generated.

As a sustainable development strategy, various studies have been conducted over the past decades, leading to the emergence of popular terms like environmentally friendly concrete, green concrete, and similar concepts. These measures aim to reduce the depletion of natural material stocks due to exploitation, minimize the environmental impact of concrete production, enhance mechanical properties, and save on recycling costs. This is particularly urgent given the increasing amount of waste that, if not recycled or decomposed soon, will continue to accumulate.

Agrawal, R., et al. (2023) conducted tests on the application of plastic waste in the construction material for paving blocks. Makoundou, C., et al. (2021) researched the application of rubber tire waste as a material in flexible pavement construction.

Islam, M. J., (2022) conducted a study on applying waste materials in concrete construction, specifically utilizing PP and PET plastic waste as a substitute for coarse aggregates in concrete. Tamrin and Nurdiana, J., (2021) researched the application of HDPE plastic waste as an additive and its effects on concrete performance. Alqahtani, F. K., (2021) conducted research on the application of plastic waste as aggregate material, specifically HDPE waste, with the addition of additives as "green lightweight aggregate".

Based on the description above, it is crucial to continue exploring the potential of plastic waste for use as a construction material. Not only does this serve as an alternative for utilizing the ever-increasing amount of plastic waste, but it also holds positive potential in reducing the exploitation of natural resources due to the production of construction materials.

2 Methodology

2.1 Plastic Aggregates

In this study, LDPE (Low-Density Polyethylene) plastic waste is reprocessed into cubic shapes with size 1x1x1 cm as shown in Figure 1. The cubic shape is chosen because its edges reduce the likelihood of slippage when embedded in concrete. To produce cubic-shaped plastic aggregates, molds are made from metal.

Fig. 1. Plastic aggregate material

To enhance the density, weight, and friction of the plastic aggregates, the plastic is mixed with sand. Three composition variations are used for comparison: plastic aggregate 1 (PA1) with a composition of 2500 grams of plastic and 0 grams of sand, plastic aggregate 2 (PA2) with a composition of 2000 grams of plastic and 600 grams of sand, and plastic aggregate 3 (PA3) with a composition of 2000 grams of plastic and 1400 grams of sand. The composition of the plastic aggregate variants is shown in Table 1 below.

Table 1. Composition of Plastic Aggregate Variants

No	Plastic Aggregate Variant	Code	Composition (gr)	
			Plastic	Sand
1	Plastic Aggregate 1	PA1	2500	0
2	Plastic Aggregate 2	PA2	2000	600
3	Plastic Aggregate 3	PA3	2000	1000

2.2 Plastic Aggregate Production

The production of plastic aggregates begins with the sorting of LDPE plastic waste. The LDPE plastic collected consists of used bottle caps from refillable beverages, as shown in Figure 1. After collection, the plastic waste is washed and shredded into small sheet-like pieces. The shredded plastic is then spread on a heating table for the melting process. For the PA2 and PA3 variants, which contain sand, the sand is mixed into the molten plastic until the mixture appears homogeneous. The molten plastic is then partially removed and placed into the mold, where it is compressed to ensure a dense fill. The plastic aggregate is then removed from the mold, resulting in the final plastic aggregate. The production process of the aggregates is shown in Figure 2.

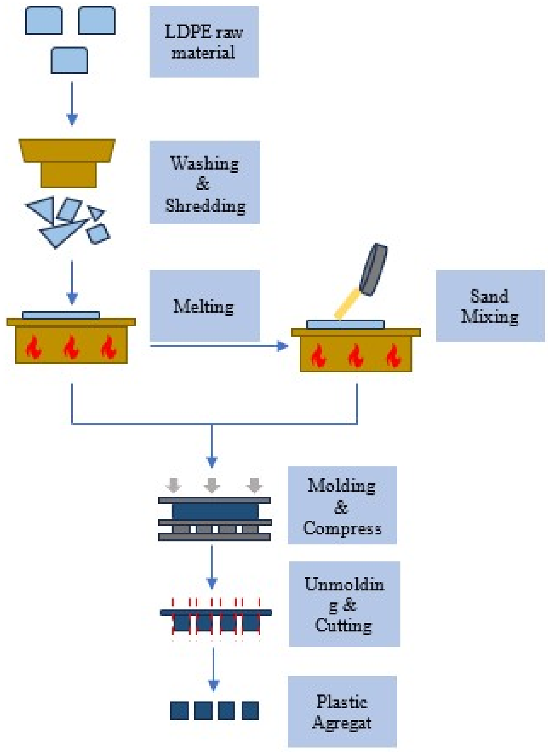

Fig. 2. The production process of the aggregates

2.3 Testing the Parameters of Plastic Aggregates

After the plastic aggregates are produced, their parameters and characteristics are tested and compared with those of coarse aggregates. The coarse aggregate used for comparison is crushed stone sourced from Binjai, North Sumatra, Indonesia. The crushed stone from this city is commonly used in concrete mixes. The comparisons are based on bulk density tests, specific gravity tests, absorption tests, and abrasion resistance tests.

3 Result and Discussion

3.1 Bulk Density of Aggregates

The results of the bulk density test for different types of plastic aggregates and coarse aggregates (CA) are visually represented in the Figure 3. The bulk density of plastic aggregates increases progressively from PA1 to PA3. This is expected as the sand content in the plastic aggregate mix increases. PA1, which contains no sand, has the lowest bulk density, while PA3, which contains the highest amount of sand, has the highest bulk density among the plastic aggregates. The addition of sand increases the aggregate's mass and its ability to fill voids, resulting in a higher bulk density.

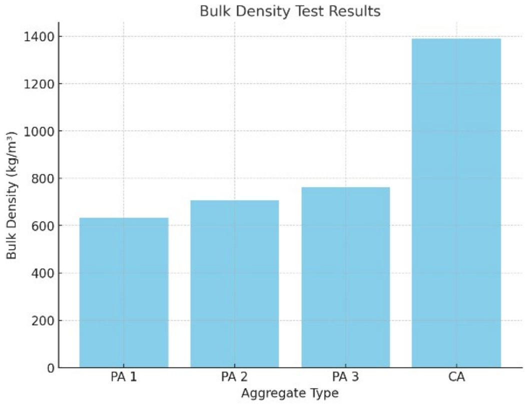

Fig. 4. Spesific Gravity of Aggregates

The coarse aggregate (CA) has a much higher bulk density (1390 kg/m³) compared to all the plastic aggregates (PA1, PA2, and PA3). This is a significant difference and highlights the lighter nature of plastic aggregates, even when mixed with sand. The coarse aggregate, being composed of natural stone (likely crushed stone or gravel), has a denser composition, which contributes to its higher bulk density. The bulk density test can be seen in Figure 4.

Fig. 4. Bulk Denity Test on plastic aggregates

The lower bulk density of plastic aggregates, particularly PA1, could be advantageous in specific construction applications where lightweight materials are required, such as in non-load-bearing structures or insulating layers. However, the higher bulk density of PA3 suggests it may be more suitable for applications where a stronger material is needed while still incorporating recycled plastic, offering a balance between strength and sustainability.

3.2 Spesific Gravity of Aggregates

The specific gravity of plastic aggregates increases progressively from PA1 to PA3 as shown in Figure 5. PA1, with no sand content, has the lowest specific gravity (0.99), while PA3, with the highest sand content, has the highest specific gravity (1.15) among the plastic aggregates.

This trend indicates that as the proportion of sand in the plastic aggregate mix increases, the overall density and mass of the aggregate rise, contributing to a higher specific gravity.

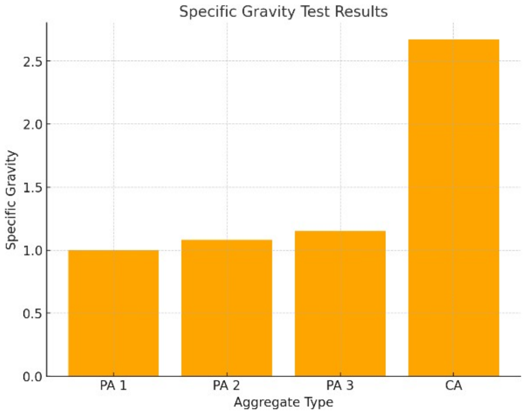

Fig. 5. Spesific Gravity Result of Aggregates

The coarse aggregate (CA) has a significantly higher specific gravity (2.67) compared to the plastic aggregates. This difference demonstrates the much higher density of traditional stone aggregates compared to the lighter plastic-based aggregates. CA's higher specific gravity reflects its denser and more compact structure, making it more suitable for applications requiring strong and durable materials. The spesific gravity test can be seen in Figure 6.

Fig. 6. Spesific Gravity Test on plastic aggregates.

3.3 Absorbtion of Aggregates

The results of the absorption test for the different aggregate types (PA1, PA2, PA3, and CA) are shown in Table 2. The absorption value for PA1 is recorded as -0.69%, which is an unusual result. This negative value can be attributed to the behavior of some plastic aggregate particles during the specific gravity test, where a portion of the PA1 particles floated on water as shown in Figure 7. This floating effect occurs because plastic has a lower density than water, and in the case of PA1 (which contains no sand), the low density leads to partial buoyancy, reducing the aggregate's apparent absorption capacity. The floating particles skewed the test results, leading to the negative absorption value. This indicates that PA1 is not suitable for use in applications where high water absorption is required, and it highlights the challenge of using pure plastic as a concrete aggregate.

Table 2. Absorbtion Result of Plastic Aggregate Variants

No	Aggregate Variant	Absorbtion
1	Plastic Aggregate 1	-0,69
2	Plastic Aggregate 2	0,59
3	Plastic Aggregate 3	0,32
4	Coarse Aggregate	0,62

Fig. 7. Floating AP1 sample in spesific gravity and absorbtion test

The absorption values for PA2 and PA3 are 0.59% and 0.32%, respectively. These values are more typical of aggregates, indicating that the plastic aggregate mixed with sand is capable of absorbing water, albeit at lower levels than natural aggregates. The higher absorption of PA2 compared to PA3 suggests that the proportion of sand in the mix influences the water absorption capacity. As PA3 contains a higher amount of sand, it absorbs slightly less water than PA2, making it more compact and less porous.

The absorption value of the coarse aggregate (CA) is 0.62%, which is consistent with typical crushed stone used in construction. This absorption value reflects the natural porosity of stone aggregates and is higher than that of the plastic aggregates PA2 and PA3. CA's higher absorption value demonstrates its ability to absorb water during concrete mixing, which can impact the hydration process and the final strength of the concrete.

4 Conclusion

The test results demonstrate that plastic aggregates, particularly when combined with sand, can offer comparable to traditional aggregates in certain respects, especially in terms of water absorption. However, the lighter nature of plastic aggregates and their lower specific gravity suggest that their use may be more appropriate for lightweight applications, unless further modifications are made. Overall, plastic aggregates present a promising alternative for sustainable construction, contributing to both environmental conservation and material innovation.

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