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Investigation on the Mechanical and Water Absorption Properties of Eco-Friendly Bricks Produced from Waste Polypropylene (PP) Bumper

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Plastic waste is a growing environmental concern worldwide, and the development of sustainable solutions to manage plastic waste has become a critical priority. One promising solution is the conversion of plastic waste into useful products, such as bricks. This study investigates the potential use of waste polypropylene (PP) bumper, a common automotive plastic waste, to produce eco-friendly bricks. The waste PP bumper was collected from a local industry and mixed with sand in ratios ranging from 100 % PP to 40% PP. The produced bricks were subjected to compression, flexural, and water absorption tests. Results showed that the addition of sand to the PP waste bumper improved the mechanical and water absorption properties of the bricks. In particular, the plastic bricks with minimal inclusion of 5 % bitumen exhibited the highest compressive strength of 8.532 MPa and flexural strength of 1.287 MPa while maintaining low water absorption of 0.04 %. The results of this study suggest that waste PP bumper can be used as a viable raw material for eco-friendly brick production, and the optimal ratio of PP and sand can be determined based on the desired properties of the bricks. The future application of these eco-friendly bricks can be in construction projects in which able to replace traditional clay bricks and contribute to the reduction of plastic waste in landfills.

1. Introduction

Plastic waste has become a major environmental challenge across the world. The widespread use of plastic in various industries and daily life activities has led to the generation of large volumes of plastic waste, which is not only an eyesore but also poses serious threats to the environment and human health. It is estimated that over 300 $\times$ 10^6 t of plastic waste is generated annually (Rafey and Siddiqui, 2021), with a significant proportion of this waste ending up in landfills, oceans, and other natural environments.

The accumulation of plastic waste in these environments has serious consequences, including the loss of biodiversity, soil and water pollution, and the release of toxic chemicals into the environment. As such, there has been a growing need for sustainable solutions to manage plastic waste and mitigate its negative impact on the environment. One such solution is the conversion of plastic waste into eco-friendly building materials like bricks.

Eco-friendly bricks have been gaining popularity in recent years due to their ability to address two major environmental issues: plastic waste management and sustainable building practices (Haque, 2019). These bricks are produced using a combination of plastic waste and other materials like sand, cement, and clay. The

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incorporation of plastic waste in brick production not only diverts plastic waste from landfills and other environments but also improves the properties of the bricks, including their mechanical and thermal properties. Recent research has been conducted on the use of plastic waste in brick production, with promising results. Researchers have explored the use of different types of plastic waste, including polyethylene (PE) (Sarwar et al., 2023), polypropylene (PP) (Kulkarni et al., 2022), and polystyrene (PS) (Binici et al., 2007), in brick production. These studies have shown that the incorporation of plastic waste in brick production can lead to bricks with improved compressive strength, reduced density, and improved thermal insulation properties.

The use of plastic waste in brick production presents a sustainable solution to the plastic waste management challenge while also contributing to sustainable building practices. With more research and innovation in this area, eco-friendly bricks have the potential to become a mainstream building material, contributing to a more sustainable and environmentally friendly built environment.

Several studies have reported on the potential of using wastes in brick production. Martínez-López et al. (2021) studied the use of recycled polypropylene (PP) and polyethylene (PE) wastes in the production of polyester-based polymer mortars and found that the addition of PP and PE improved the mechanical properties of the mortars. De Silva and Perera (2018) explored the effect of waste rice husk ash on the structural, thermal, and acoustic properties of fired clay bricks and found that the addition of waste rice husk ash improved the thermal and acoustic insulation properties of the bricks. Saleh et al. (2020) investigated the use of grated poly (styrene) in the production of improved lightweight concrete and found that the use of grated poly (styrene) led to a reduction in the density and thermal conductivity of the concrete. Aneke and Shabangu (2021) produced green-efficient masonry bricks using scrap plastic waste and foundry sand and found that the addition of plastic waste and foundry sand improved the compressive strength of the bricks. These studies demonstrate the potential of using plastic waste in brick production to create sustainable and eco-friendly building materials with improved mechanical and thermal properties.

While previous studies have explored the use of various types of plastic waste in brick production, the utilization of waste PP bumper from real industry in this context remains an understudied area. As a common automotive plastic waste, waste PP bumper presents a significant environmental challenge and finding sustainable solutions for its management is crucial. Therefore, the purpose of this study is to investigate the potential of waste PP bumper in the production of eco-friendly bricks, and to determine the optimal ratio of waste PP bumper and sand for producing high-quality bricks with improved mechanical and water absorption properties. By filling this research gap, this study aims to provide insights into the potential of using waste PP bumper for eco-friendly brick production and contribute to the development of sustainable solutions for managing plastic waste.

2. Methodology

2.1 Materials

Waste PP bumper, obtained from a local industry, HICOM Teck-See Manufacturing Sdn. Bhd., was used as the main raw material for producing eco-friendly bricks. Sand, bitumen, and other notable chemicals were purchased from Permula Chemical, Kuantan, and were used as additives in the brick production process. The selection of these materials was based on their availability, cost-effectiveness, and compatibility with the waste PP bumper. The use of waste PP bumper as the main raw material in brick production can contribute to the development of sustainable solutions for managing plastic waste and provide insights into the potential of using waste automotive plastics for eco-friendly brick production.

2.2 Process of brick making

The waste PP bumper was grinded into smaller size, and sand was washed thoroughly with water to remove any loose dirt or debris. The sand was further sun dried to remove moisture and sieved to obtain a fine sand size of approximately 0.02 to 0.05 mm. The PP was mechanically mixed with sand at different ratios ranging from 100 % to 40 % with respect to PP. A hotplate was used to heat up a stainless-steel pan to a fixed temperature of 195 ^{o}C. The mixed PP-sand was then heated inside the pan and stirred constantly to ensure the sand was evenly distributed throughout the molten plastic. Once the mixture was fully melted and mixed, it was poured into a custom brick-shaped moulds with the dimension of 210 mm × 100 mm × 75 mm to cool and solidify. The solidified sample were removed from the mould to obtain plastic brick samples. The composition of the plastic brick samples was shown in Table 1. All the samples were kept and further characterized with compression, flexural and water absorption tests.

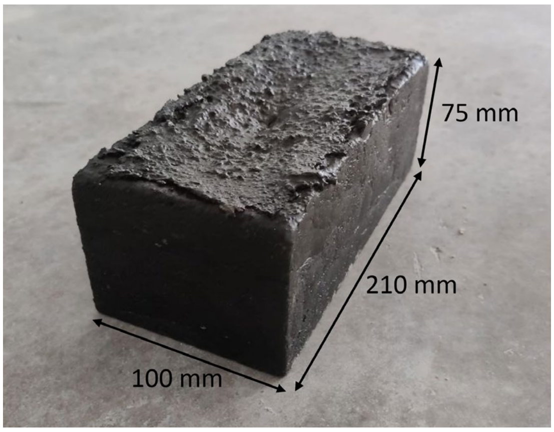

Figure 1: The sample of plastic brick used for mechanical and water absorption test

Table 1: Details of samples for plastic brick making

Samples	PP ratio (%)	Sand ratio (%)	Bitumen (%)
A1	100	0	0
A2	80	20	0
A3	60	40	0
A4	50	50	0
A5	40	60	0
A6	50	50	5

2.3 Compression test of plastic brick

The compressive strength of the plastic bricks was determined using a compression testing machine in accordance with the ASTM C39 standard. The bricks were placed on the lower platen of the testing machine and compressed until failure occurred. The rate of loading was maintained at 3.5 MPa/min, as per the ASTM standard. Three specimens were tested for each composition of plastic and sand, and the average compressive strength was calculated. The testing was conducted at room temperature and the samples were stored under standard laboratory conditions prior to testing. The results of the compression tests were used to evaluate the suitability of the plastic bricks for use in construction applications.

2.4 Flexural test of plastic brick

The flexural test for the plastic bricks was conducted following the ASTM C1609-10 standard. The test was performed using a universal testing machine with a loading capacity of 100 kN. The test was performed by placing the specimen on two support points 120 mm apart, and then applying a load at the centre of the specimen at a rate of 0.05 mm/min until failure occurred. The maximum load sustained by the specimen was recorded, and the flexural strength was calculated according to the standard equation. The test was repeated three times for each sample, and the average value was reported.

2.5 Water absorption test of plastic brick

In the water absorption test, the bricks were weighed before and after immersion in water for 48 h. The test was conducted in accordance with the ASTM C373-88 standard. The bricks were first dried in an oven at a temperature of 80 °C for 24 h to remove any moisture. After cooling, the initial weight of each brick was recorded. The bricks were then immersed in water at a temperature of 23 °C ± 2 °C for 24 h, ensuring that they were completely submerged. After 24 hrs, the bricks were removed from the water, and any excess water was wiped off with a damp cloth. The final weight of each brick was then recorded. The percentage of water absorption was calculated using the formula shown in Eq(1) where W is the water absorption percentage expressed in %, M_1 is the initial weight of the brick taken before immersion in water, and M_2 is the final weight of the brick taken after a specific period of immersion in water. The unit for M_1 and M_2 is grams (g). The average value of three specimens was reported for each sample. The average value of three specimens was reported for each sample.

$$W = \frac{M_2 - M_1}{M_1} \times 100 \quad (1)$$

3. Results and discussions

3.1 Compression test

Figure 2 illustrates the compressive strength of plastic bricks with various ratios and composition. The compression test results clearly indicate that the compressive strength values of the bricks increase as the ratio of plastic waste decreases. Among the tested ratios, A6 showed the highest value of compressive strength of 8.532 MPa, followed by A5, A4, A3, A2 and A1 plastic waste ratios with the value of 8.388 MPa, 7.94 MPa, 7.512 MPa, 7.117 MPa and 6.223 MPa respectively. However, the values decreased as the plastic waste ratio increased. This can be attributed to the fact that plastic waste does not possess cementitious properties and does not bind well like cement, which resulted in reduced strength. Additionally, the pliable and deformable nature of the plastic bumper waste may have also contributed to the decrease in strength with increasing waste proportion.

The compressive strength versus plastic waste ratio plot (Figure 2) exhibited a similar trend as a previous study on recycled plastic brick using polyethylene terephthalate (PET), which was conducted by Wahid et al. (2015). The findings of this study suggest that the addition of bituminous adhesive in the production of plastic bricks can improve the compressive strength values. Based on the results of the compression test, the findings suggest that the optimal ratio of plastic waste and sand to produce high-quality eco-friendly bricks is A6.

The findings also shows that PP and sand play a critical role in determining the compressive strength of the eco-friendly bricks. The PP waste bumper is used as a binder to hold the sand particles together, forming a solid structure. The plastic waste is melted and mixed with sand to create a composite material that is molded into brick shape. The sand helps to reinforce the structure and improve the compressive strength. The addition of bitumen as an adhesive also contributes to the strength of the bricks by improving the bonding between the PP waste and sand particles, resulting in a stronger and more durable structure.

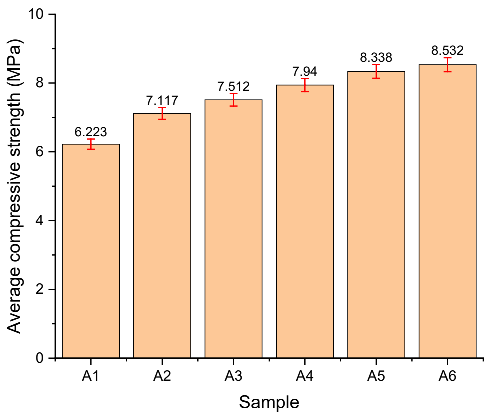

Figure 2: Effect of compressive strength on different plastic brick composition

3.2 Flexural test

The flexural strength of brick with different composition were displayed in Figure 3. The flexural test results clearly demonstrated that decreasing the ratio of plastic waste in the composite material increased its flexural strength. The highest flexural strength of 1.287 MPa was achieved A6 sample of plastic brick. This was followed by A5, A4, A3, A2 and A1. As the ratio of plastic waste increased, the flexural strength values decreased.

To the best of the author's knowledge, this study is the first to investigate the flexural strength of plastic brick composites with the addition of bituminous adhesive. The result is a significant contribution to the development of sustainable and environmentally friendly construction materials. The observed trend is consistent with previous research on the flakes type of plastic waste conducted by Siva et al. (2017), indicating the reproducibility and consistency of the results.

The addition of sand to the plastic waste bumper in the production of plastic bricks can increase the flexural strength of the composite material. Sand has a higher modulus of elasticity compared to plastic waste, which allows it to reinforce the composite material and improve its mechanical properties, including the flexural strength. The higher the amount of sand in the composite material, the higher the flexural strength of the plastic brick. This is demonstrated by the trend observed in Figure 3, where the flexural strength of the plastic brick increased as the ratio of sand increased.

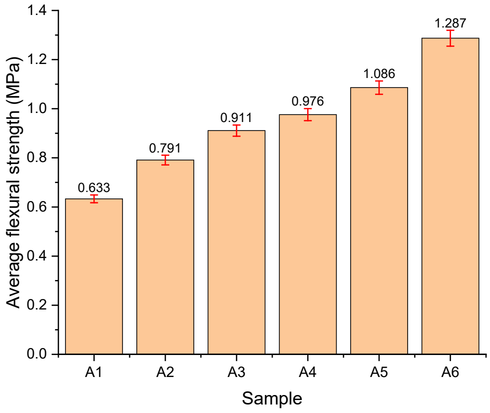

Figure 3: Effect of flexural strength on different plastic brick composition

Similarly, the addition of bituminous adhesive to the plastic waste and sand mixture also played a crucial role in increasing the flexural strength of the plastic brick composite. The bitumen acts as a binder, improving the bonding between the plastic waste and sand and increasing the overall strength of the composite material. The optimal ratio of plastic waste, sand, and bitumen for the production of plastic bricks with enhanced mechanical properties is A6, which exhibited the highest flexural strength.

3.3 Water absorption test

The findings on water absorption test rate for different composition of plastic bricks was demonstrated in Figure 4. The water absorption test conducted on the plastic waste bricks demonstrated excellent performance, as evidenced by the consistent absorption rate of 0.04% across all samples. The graph also indicated that the water absorption rate remained below 1% of the initial weight even after 48 hours. This is a significant improvement compared to the standard requirement for good quality bricks, which should not absorb more than 20% of water. These results suggest that the presence of plastic waste in the bricks contributed to their superior performance in terms of water absorption. This finding is consistent with previous research conducted on the mix of slid/clay waste by (Oliveira and Holanda, 2004).

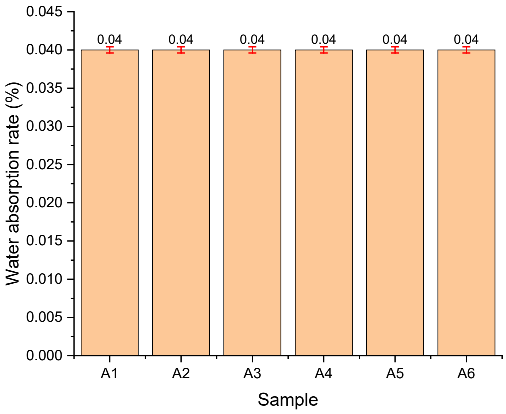

Figure 4: Water absorption rate of plastic bricks with different composition

Based on the results of the water absorption test, the presence of PP and sand in the plastic brick composite could have contributed to the low water absorption rate. PP is a hydrophobic material, meaning it repels water, while sand provides a more compact structure to the bricks, reducing the pore spaces and therefore the ability to absorb water. The addition of bitumen in the production of plastic bricks may have also played a role in reducing the water absorption rate. Bitumen is known to have water-resistant properties and may have helped to create a more water-tight composite material. These findings suggest that the use of sustainable materials

such as waste PP and sand, along with bituminous adhesive, can lead to the production of eco-friendly bricks with excellent water resistance properties.
In terms of mechanical properties, the results of the compression and flexural tests indicated that the optimal composition of plastic waste and sand to produce high-quality eco-friendly bricks was A6. Although all samples demonstrated the same water absorption rate of 0.04%, A6 exhibited the highest compressive and flexural strengths of 8.532 MPa and 1.287 MPa, respectively. These findings suggest that the optimal composition for producing plastic waste bricks with enhanced mechanical properties is A6.

4. Conclusions

Various sample of plastic bricks has been successfully prepared. The results of this study indicate that incorporating plastic waste into the manufacturing process of bricks can improve their mechanical and water absorption properties. Both compressive and flexural strength value increases as plastic waste ratio decreased. Furthermore, the addition of 5% bitumen into the plastic brick will increase the value of mechanical properties. The water absorption test showed that the plastic waste bricks performed excellently, with a water absorption rate of only 0.04%. This indicates that the presence of plastic waste can improve the quality of bricks, as good quality bricks should not absorb more than 20% of water. In conclusion, the findings of this study suggest that using plastic waste as a partial replacement for traditional materials in brick production is a promising solution for reducing plastic waste while also improving the mechanical and water absorption properties of bricks. This approach has the potential to contribute to a more sustainable and eco-friendly construction industry.

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