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A study of the potential of non-economic plastic waste as a substitute for paving block to enhance domestic waste reduction

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ABSTRACT

Reduction of inorganic waste, especially plastic, has been widely carried out in Indonesia using a community-based principle known as a waste bank. The reduction is limited to plastic waste with economic value, such as plastic bottles. However, the reduction leaves much non-economic plastic waste in multi-layered plastic packaging, plastic bags, mica, and styrofoam. This study aimed to examine the potential of non-economic plastic waste to become paving blocks. The current study was conducted using five compositions of non-economic plastic waste of mica, multi-layered, and styrofoam, with aggregates to produce plastic-paving blocks. All experimental paving blocks were measured for their compressive strength and water absorption capacity by Indonesian National Standard No. 03-0691-1996. The results showed that the compressive strength value in the range of 4.879–6.513 MPa, where three of the compositions were mica: aggregate (60%:40%); multi-layered: aggregate (60%:40%); and multi-layered: styrofoam: aggregate (60%:20%:20%) approached the compressive strength of paving block grade D. All observed paving blocks have met the water absorption quality standards for paving blocks with a potential of 1.471–4.879%. This indicates that these compositions have the potential to be used as paving blocks. It also suggests that these compositions can effectively resist water damage, enhancing their potential for use in construction. Moreover, current research has confirmed that mica, multi-layered, and styrofoam waste have the potential to be used as a substitute for paving blocks, although further research is still needed.

Keywords: domestic waste, non-economic plastic waste, reduction, paving block, waste banks.

INTRODUCTION

Waste has always been a complicated problem in developing countries (1–3), including Indonesia. Uncontrolled population growth simultaneously increases the amount of waste generated from human activities, both organic and inorganic. In 2023, the amount of waste produced in Indonesia reached 38.24 million tonnes, of which only 62.63% can be managed through prevention, reduction, reuse, recycling, and disposal. Meanwhile, as much as 37.37% of waste that is not managed goes directly to landfill disposal (4, 5).

One of the most challenging wastes to process is inorganic waste, consisting of plastic waste, ceramic shards, metals, etc. Plastic waste is one of the dominant wastes in Indonesia, reaching 30.00% of total domestic waste, consisting of plastic bags, packaging, and bottles (4, 6). Plastic waste reduction has been widely implemented in Indonesia through a community-based waste management initiative integrated with the government called waste banks. These waste banks, have successfully processed as much as 5.00–10.00% of plastic waste. Unfortunately, the waste bank only manages economical plastic waste, such as plastic bottles, even though the amount is less than plastic bags and packaging. The previous research reported that the amounts of plastic bags and packaging, called non-economical plastic waste, were 19.38% and 7.96%, respectively (7). The waste is generally burned by the community, which leads to air pollution. This alarming condition has caused plastic bags and packaging to be categorized as unmanaged waste in Indonesia, posing a significant environment and public health threat.

One alternative to managing non-economic plastic waste is to recycle it into other products (8, 9). Plastic, a strong and light material, is believed to be suitable as a substitute material for paving blocks (2, 10–12). Paving blocks are used for paving on light-class pavement, sidewalks, parks, etc., which can increase the area of water permeability and reduce surface runoff to minimize the potential for flooding (10, 11, 13). The conversion of non-economic plastic waste into paving blocks not only increases their economic value but also offers a hopeful solution for waste management (1), potentially reducing the environmental impact of plastic waste.

Several previous studies on plastic waste as a substitute for paving blocks have been carried out, but most used plastic bottles, which had an economic value. Sudarno et al. (14) reported that paving blocks made using plastic bottle waste showed a compressive strength value of 50.97 MPa. Mustakim et al. (6) also reported that polypropylene plastic waste, processed into paving blocks, shows high compressive strength and low water absorption of 23.30 MPa and 0.38%, respectively. Meanwhile, paving blocks made from cement with boiler ash and plastic bottle waste have characteristics equivalent to grade A for paving blocks, in accordance to Indonesian National Standard No. 03-0691-1996 (10).

Given the abundance of non-economic plastic waste in Indonesia, the potential to use it as a substitute for paving blocks is not only interesting, but also inspiring. The potential of non-economic plastic waste in paving block production still needs to be explored (15). This is a significant area of research that could have a profound impact on waste management, particularly in Indonesia and other developing countries. Therefore, the current research aimed to explore this potential based on compressive strength and water absorption ability and its implications for domestic waste reduction.

METHODS

This research was meticulously carried out through laboratory-scale experiments using five compositions of the ratio of non-economic plastic waste and aggregate for paving blocks in triplicate (Table 1). The total weight of the composition used for each paving block is 1.000 g or 1.00 kg.

The paving blocks are made using a combination of conventional and straightforward thermal techniques (7). Each non-economically plastic waste was chopped into 1.00–2.00 cm sizes and mixed with aggregate according to predetermined compositions, as seen in Table 1. Furthermore, the aggregate used in this research is a mixture of unused roof tile and ceramic fragments, making the process both sustainable and practical. This approach offers a promising solution to the plastic waste problem.

The heating machine is also heated to an initial temperature of 250 °C for the thermal process of the chopped plastic waste and aggregate mixture for 2 hours until the mixture is homogenized. Then, a homogenized mixture was formed as a paving block using a mold of 20.00 × 10.00 × 6.00 cm based on hydraulic principles. All stages of making paving blocks are based on the experience of local producers. The produced paving blocks can be seen in Figure 1. Furthermore, the compressive strength of all paving blocks is measured using a universal testing machine until the paving blocks are crushed by the Indonesian National Standard No. 03-0691-1996 (16). Referring to the similar standards, the ability of all paving blocks to absorb water is also tested by soaking for 24 hours. All measurements were taken on 14-day-old paving blocks produced.

Table 1. Composition of non-economic plastic waste and aggregate for paving block

Sample	Raw material of paving block	Ratio	Unit
1	Multi-layered plastic and aggregate	60%:40%	3 (three)
2	Styrofoam and aggregate	60%:40%	3 (three)
3	Mica and aggregate	60%:40%	3 (three)
4	Multi-layered plastic, styrofoam, and aggregate	60%:20%:20%	3 (three)
5	Multi-layered plastic, mica, and aggregate	60%:20%:20%	3 (three)

Figure 1. Paving block made from non-economic plastic waste and aggregate

RESULTS AND DISCUSSION

Characteristics of paving block in Indonesia

Indonesia has standards for determining the quality of paving blocks produced, as regulated in Indonesian National Standard No. 03-0691-1996 (16). Three main indicators are used to categorize paving block grades: compressive strength, wear resistance, and water absorption capacity. Furthermore, paving blocks have four grades according to their purpose (see Table 2). Paving blocks produced from various raw materials, including plastic waste, have to fulfill these standards before being used and implemented by the public.

Table 2. The quality of paving blocks based on the Indonesian National Standard No. 03-0691-1996

Grade	Compressive strength (MPa)		Wear resistance (mm/min)		Max. water absorption (%)	Utilization
	Average	Minimum	Average	Minimum		
A	40.000	35.000	0.090	0.103	3.000	Road
B	20.000	17.000	0.130	0.149	6.000	Parking equipment
C	15.000	12.500	0.160	0.184	8.000	Pedestrian
D	10.000	8.500	0.219	0.251	10.000	Park and other uses

Note: Indonesian National Standard No. 03-0691-1996 (16)

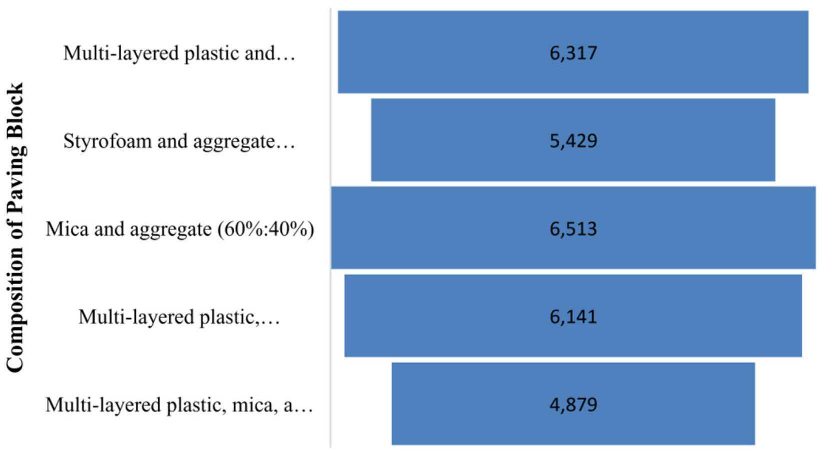

Figure 2. The compressive strength of paving blocks

Compressive strength of paving block produced from non-economic plastic waste

The results show that the compressive strength of all paving blocks is 4.879–6.513 MPa (Fig. 2), where those values show that no variation in the paving block meets the compressive strength requirements according to the Indonesian National Standard (16). The highest value of compressive strength was found in mica: aggregates (60%:40%); multi-layered plastic: aggregate (60%:40%); and multi-layered plastic: mica: aggregate (60%:20%:20%) which were close to the quality standard for grade D of the paving block.

The low compressive strength value of paving blocks might be caused by the lower density of melted plastic waste than cement (2, 17–20). Jassim (11) and Uvarajan et al. (2) reported that the density difference reached 15.00%. Density is influenced by the type of plastic polymer, where multilayered plastic, mica, and styrofoam waste used in current research might be composed of very light polyethylene, polyvinyl chloride, and polystyrene polymers, respectively. They have low stiffness and heat resistance, making them easily deformed or damaged at high temperatures (21, 22). Those characteristics may cause the adhesion of non-economic plastic waste to aggregate relatively weakly, impacting the weak bonds between materials formed. The condition then influenced the low density and compressive strength of the paving blocks produced (2, 11, 18, 19, 23, 24).

Weak bonds between materials in paving blocks can be caused by a lack of aggregate, a crucial element essential in supporting structural loads on paving blocks (12, 25). Several research has also highlighted that the compressive strength of paving blocks may decrease when the plastic waste composition exceeds that of the aggregate due to pulverization (2, 11, 12, 19, 26). This aligns with current research, where aggregate use is only 20.00–40.00%, while non-economical plastic waste is 60.00–80.00%. A previous study also reported that the condition reduced not only the compressive strength but also the tensile strength of concrete (24). To achieve the desired compressive strength, the aggregates must be ample, well-mixed, and bound with melted plastic waste (2, 12, 24). Researchers recommend several compositions for plastic waste and aggregates of 1:1 (12, 21, 27); 1:3 (10, 28) 1:4 (3, 26); 3:7 (29). Moreover, Iftikhar et al. (29) stated that the compressive strength balance of paving blocks is formed in a composition with a maximum plastic waste content of 30.00% of the total weight (29). In essence, the compressive strength of paving blocks is significantly influenced by the type of plastic waste and the aggregate composition.

In addition, low compressive strength might be caused by the curing period of paving blocks, which in this study was only 14 days, whereas it should be at least 28 days (6, 11, 19, 30). Mustakim et al. (6) have reported that the compressive strength of paving blocks aged 14 days to 28 days increased by 13.17 MPa to 16.56 MPa. Parikshit et al. (30) also reported an increase in the compressive strength of paving blocks on the 7th day by 16.02–16.58 MPa to 32.00–32.02 MPa on the 28th day. It indicates that curing, which maintains the humidity of the paving blocks, might increase the bonding of the material and simultaneously improve the compressive strength of the paving blocks.

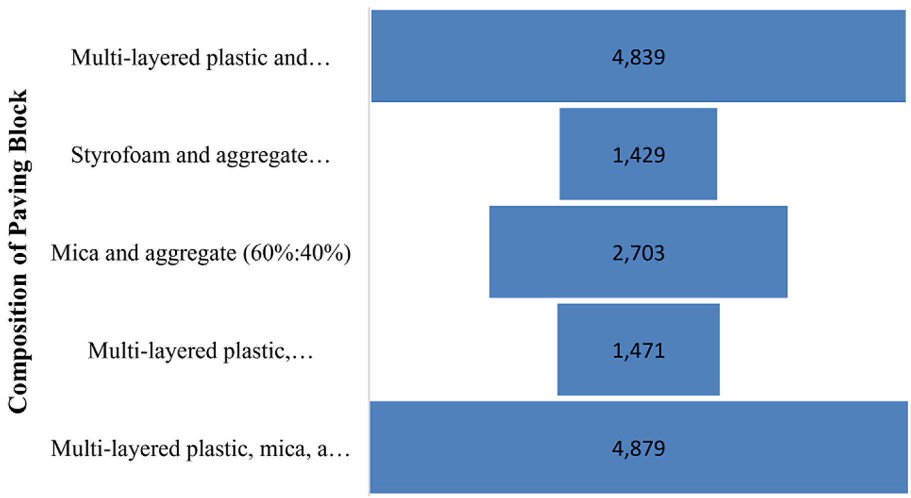

Figure 3. The water absorption capacity of paving blocks

Water absorption capacity of paving block produced from non-economic plastic waste

The water absorption capacity of paving blocks is 1.429–4.879%, as seen in Figure 3. Compared to the Indonesian National Standards (16), it is known that all paving blocks have met the quality standards. It shows that non-economic plastic can support achieving water absorption capacity following quality standards. Water absorption capacity is one of the main advantages of paving blocks, as the use can convert pavement areas into recharge areas that are able to minimize the flood potential.

As illustrated in Figure 3, the water absorption capacity of styrofoam: aggregate (60%:40%); mica: aggregate (60%:40%); and multi-layered plastic: styrofoam: aggregate (60%:20%:20%) is close to the quality of grade A paving blocks with the maximum value on 3.000%. Meanwhile, multi-layered plastic: aggregate (60%:40%) and multi-layered plastic: mica: aggregate (60%:20%:20%) are close to grade B. However, there are lower values of water absorption in the composition using styrofoam waste of 1.429% and 1.471% for the styrofoam: aggregate (60%:40%) and multi-layered plastic: styrofoam: aggregate (60%:20%:20%), respectively. This shows that the components of styrofoam can reduce the water absorption capacity.

The water absorption capacity of the paving block decreases along with the increasing utilization of plastic waste in the paving blocks (2, 31). This is because melted plastic waste causes the air cavities in the paving blocks to shrink, thereby reducing water permeability and increasing water resistance (10, 32). The low water absorption of paving blocks from waste plastic minimizes damage or disintegration potential due to wet and dry conditions or lower physical-chemical pressure. Moreover, it could have more durability and longer lifetime (3, 10, 15). Furthermore, the water absorption capacity of the paving block needs to be limited. Due to high water absorption capacity, the bond between the plastic and any materials in the paving block can be weakened.

The challenges and recommendation for plastic-paving block production

On the basis of the results, it is known that the optimum compressive strength value in current research is shown by mica: aggregates (60%:40%); multi-layered plastic: aggregate (60%:40%); and multi-layered plastic: styrofoam: aggregate (60%:20%:20%), which are closest to grade D of the paving block according to the Indonesian National Standard No. 03-0691-1996 of 8.500 MPa. In addition, those of compositions have also met the water absorption quality standards for paving blocks, which are below 10.00%.

The current study outputs indicate that the three types of non-economic plastic can be used as adhesives to replace cement in paving block production (12). However, to fully realize the potential, further research is needed to increase its adhesive properties, simultaneously increasing the compressive strength of paving blocks. It might be accomplished by ensuring the melted plastic is more cohesive to consistently and stably form the eco-paving block product (33). One of the possible ways is to modify the simple melting technique using CO_2 to run the process more stably, as performed by Rachmawati et al. (9). Related to this purpose, further research that can be done is to investigate the use of a combination of types of plastic waste as adhesive materials, then vary the gradation of particles and aggregates in paving blocks.

It makes the use of plastic waste as a substitute for paving blocks not only reduces the amount of plastic waste but also decreases emissions from the conventional paving block manufacturing process. It is due to cement is the most significant contributor of emissions from concrete paver blocks (1, 29). Plastic waste as an adhesive to replace cement in paving blocks is expected to reduce cement utilization and lower the price of paving blocks (28). According to Awodiji et al. (12) and Birnin-Yauri et al. (3), plastic-paving blocks can be recommended for light pavements such as low-traffic roads, pedestrians, and parks. This ongoing research will enhance the understanding of paving block production and pave the way for more sustainable and eco-friendly materials in the future.

CONCLUSIONS

The three paving block compositions, in terms of mica: aggregate (60%:40%); multi-layered plastic: aggregate (60%:40%); and multi-layered plastic: styrofoam: aggregate (60%:20%:20%), are the compositions that are closest to the minimum quality standards for paving blocks according to Indonesian National Standard No. 03-0691-1996. Despite being at the lower end of the quality standards, these compositions have successfully met the water absorption quality standards for paving blocks. The current research has proven that mica, multi-layered plastic, and styrofoam waste have the potential to be adhesive materials to replace cement for paving blocks. However, to fully realize this potential and to expedite the adoption of sustainable construction practices, further research is urgently needed to determine the appropriate type, combination, and composition of non-economic plastic waste for producing paving blocks that meet quality standards.

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