Advances in Technology Innovation, vol. 8, no. 3, 2023, pp. 219-228

Assessing the Performance of Melted Plastic as a Replacement for Sand in Paving Block

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Received 06 February 2023; received in revised form 06 May 2023; accepted 10 May 2023

DOI: https://doi.org/10.46604/aiti.2023.11508

Abstract

Plastic waste generates numerous environmental problems, such as garbage accumulation and plastic waste pollution in the oceans. This study aims to evaluate the effectiveness of melted plastic waste as a substitute material in paving blocks. The melted low-density polyethylene (LDPE) plastic is used as the cemented agent in the paving block. After melting, the melted LDPE plastic is mixed thoroughly with sand immediately and forms a paving block mold. The effectiveness of melted plastic as a bonding agent is evaluated based on the parameters of compressive strength, water absorption, and wear resistance. The results show that paving blocks with a melted plastic of 10% reach the required level of 9.39 MPa for the park. Hence, using melted plastic in paving blocks can be an alternative strategy to reduce plastic waste.

Keywords: compressive strength, composite paving block, plastic melter, water absorption, wear resistance

1. Introduction

One of the environmental issues is the increasing amount of plastic waste. According to the data from Indonesian Ministry of Environment and Forestry, plastic waste in Indonesia saw a 19% increase in 2020 compared to 2019. The leading causes of the growing volume of plastic waste each year are urbanization and changes in lifestyle [1]. Unlike organic waste which can be decomposed by bacteria, plastic waste takes a relatively long time, causing accumulation in the final processing site. Other harmful effects of plastic waste include solid plastic waste pollution in the oceans, as well as the introduction of microplastics and nanoplastics [2]. Moreover, Plastic waste can cause an explosion if it comes into contact with coal waste in the ocean [3].

According to Jambeck et al. [4], plastic waste is one of the solid wastes created in significant amounts. World plastic production reached 396 million tons annually in 2018 [5], equivalent to one megaton per day. This number is predicted to double over the next 10-20 years [6-7]. Indonesia is in second position as the country that produces the most plastic waste, with the amount of plastic waste in the sea reaching 1.29 million tons annually [8]. In order to prevent additional pollution of the environment and the nearby living beings, plastic waste issues need to be treated seriously. Applying the 3R principles, namely reduce, reuse, and recycle, in daily life can help lessen the adverse effects of plastic waste. Recycling is the process of converting waste into reusable materials. The benefits of the recycling process include saving energy, reducing pollution, and mitigating land damage and greenhouse gas emissions.

To reduce plastic production from new raw materials, it is essential to follow recycling after plastic consumption. Singh et al. [9] stated that 90% of plastic waste can be recycled. However, 80% of plastic waste currently ends up in landfills. Additionally, 8% is burned, and only 7% is recycled. Stockpiled plastic waste emits only 2% of CO_2 emissions [2], while long-term effects include the need for extensive land areas, as well as soil and groundwater pollution. Therefore, a solution is needed to overcome these problems, including recycling plastic waste.

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English language proofreader: Jing-Heng Yen

Heat quickly destroys plastic because it has a low boiling point. With such plastic properties, the melting process can be a simple alternative for plastic recycling in the first step. A plastic melter is a device used to melt raw plastic materials, and its design is kept as simple as possible to ensure easy operation. Furthermore, a plastic melter is a tool that melts certain types of plastic waste and reshapes it into new products, such as plastic bricks and concrete blocks. In this study, a plastic melter was developed. The melted plastic was utilized as a substitute material for paving blocks. Based on the waste generation study of IPB waste management 2018 [10], the type of plastic used was low-density polyethylene (LDPE). LDPE was the most significant fraction of plastic waste in the research location. This initiative aims to help reduce the environmental burden of plastic waste.

In construction, melted plastic is used as a substitute for concrete or paving block aggregate. Additionally, various forms of plastic are also used as a substitute for materials, such as plastic pellets, chopped plastic, and melted plastic. Mozumder et al. [11] used plastic pellets as a substitute for sand with variations of 0%, 2%, 4%, 6%, 8%, and 10% by weight of sand. The highest compressive strength was achieved when adding 4% plastic, and the compressive strength decreased significantly when adding 8% and 10% plastic. Sofyan et al. [12] performed sand substitution with plastic pellets with 10%, 20%, 30%, and 40% variations. The results showed that the compressive strength of concrete with plastic mixtures decreased by 56.06% compared to the control sample (0% plastic).

In addition to plastic pellets, chopped plastic is also used as a substitute for aggregate in concrete. Nurmaidah and Pradana [13] used plastic fiber (chopped plastic) as a substitute for sand with variations of 0%, 3%, 6%, and 9% by weight of sand. With the same w/c value, adding up to 6% plastic can improve the compressive strength of concrete. However, the increase is not significantly different from the control sample (0% plastic). Qaidi et al. [14] used chopped plastic as a substitute for sand with variations of 0%, 25%, and 50%. The test results showed that adding plastic decreases compressive strength.

Previous studies also used melted plastic as a substitute for paving blocks. Agyeman et al. [15] researched paving blocks with melted plastic as an alternative binder. The results showed that paving blocks with a plastic mixture increase the compressive strength by approximately 40% more than paving block control at 21 days. Sudarno et al. [16] created a paving block using combinations of melted plastic and gravel. The results showed that paving blocks with 50% melted plastic and 50% gravel composition had the highest compressive strength, namely 50.97 MPa.

Many research studies have shown that using melted plastic as a cement substitute enhances compressive strength. The potential of melted plastic as a sand substitute in paving blocks was investigated in this study. Qaidi et al. [14] stated that the compressive strength of concrete with plastic mixtures tends to decrease due to the smooth surface of plastic, which results in a weaker bond. Therefore, in this study, melted plastic was mixed thoroughly with sand to produce a stronger bond with the concrete. The plastic was melted to significantly improve the adhesion between the plastic and the cement matrix. The melted plastic was used at 5%, 10%, and 15% of the weight of the sand.

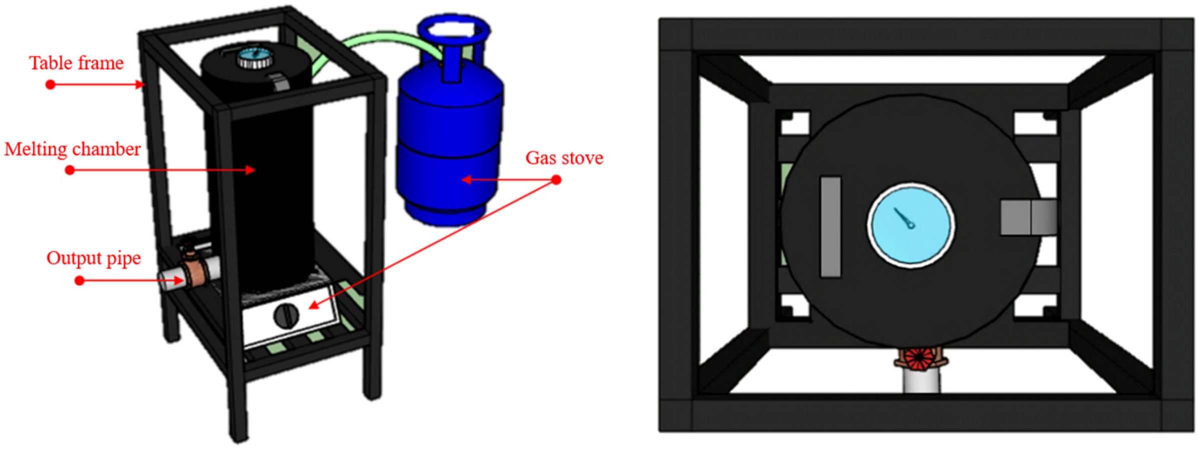
2. Material and Methods

2.1. Material

The materials used to make the plastic melter included black hollow iron measuring 3 × 3 cm and 4 × 4 cm, an iron tube with 10 inches diameter and 2 inches diameter, an iron plate with 1 mm thickness, and an analog bimetal thermometer with 3 inches diameter. The materials used to make paving blocks with a mixture of plastic were sand from Cimangkok Village (Sukabumi Regency, Indonesia), Portland composite cement (PCC), water, and plastic waste. The type of plastic waste was LDPE collected from Margajaya Urban Village, Bogor City, Indonesia.

2.2. Design and construction of plastic melter

The plastic melter has a table frame and a closed tubular melting chamber. The capacity of the plastic melting chamber is easily calculated by considering the following factors: the capacity of the melting device is determined at 12 kg, the specific gravity of the melted plastic is 0.94 g/cm^3, the multiplier of 110% is used as additional space, and the multiplier of 2 is used as an assumption of the melting time. Thus, the melting chamber capacity is 28 L. The melting chamber is determined as a closed tube with a diameter of 25.4 cm and a height of 55 cm. Fig. 1 depicts the 3D design of the plastic melter created with SketchUp software.



(a) Isometric view (b) Top view

Fig. 1 3D view of plastic melter

Plastic melter must be heat-resistant or high-temperature materials to ensure proper melting of the plastic. Iron and stainless steel are examples of high-temperature-resistant materials, which are durable and easy to clean. In this study, iron was used to make the plastic melter because it is generally more economical than stainless steel. In operation, the plastic melter is connected to a gas stove and equipped with a thermometer to monitor the melting temperature of the plastic. An output pipe measuring 2 inches with an open-close regulating valve is at the bottom of the melting chamber. Based on preliminary research in this study, the plastic melted at a temperature of 180 °C, as recorded on the top of the plastic melter. According to Hasaya etal., plastic melts at 148 °C and has a boiling point of 234 °C [17]. The plastic melting process was carried out during the performance test to achieve the expected temperature. The performance test results demonstrated that the plastic melter performed well, reaching the planned plastic melting temperature. After heating for 90 minutes and reaching its melting temperature, the valve at the bottom of the melting chamber was opened. Finally, the melted plastic can be used as a substitute for sand in paving blocks.

2.3. Sample mixture and evaluation

Table 1 Mix variations of paving block

Sample	Cement	Sand	Plastic	Water
	(g/cm^3)			
Control	0,34	1,36	0,00	0,17
5% plastic	0,34	1,29	0,07	0,17
10% plastic	0,34	1,22	0,14	0,17
15% plastic	0,34	1,16	0,20	0,17

Paving blocks were made with 1 Portland cement and 4 sand aggregates [18]. It is the best composition that produces optimal strength. The amount of water in the paving block was determined at 10% of the weight of the sand and cement [19].

Water helps chemical reactions occur during the binding process in paving blocks. Mix variations were made as shown in Table 1. By varying the plastic mixture's percentages to 5%, 10%, and 15% of the weight of sand, plastic melting can replace the need for sand.

The procedures for making paving blocks with the addition of melted plastic can be seen in Fig. 2. First, the sand is heated using a pan and stirred to distribute the heat evenly. Melted plastic is combined with heated sand in a pan during the sample mixture process to prevent the hardening of plastic. After mixing well, the pan is moved from the stove and the cement is added. Then, water is added after the melted plastic, heated sand, and cement are thoroughly mixed. The paving block dough is printed and pressed using a manual press. Mixing until the pressing process should be completed quickly to prevent the plastic from hardening rapidly.

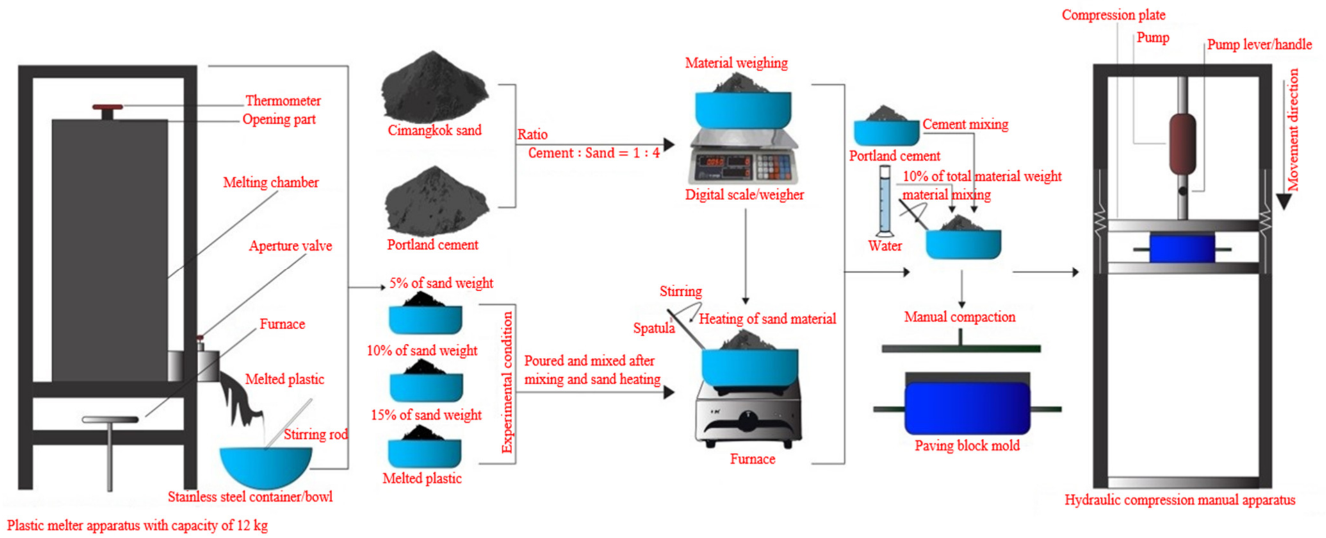


Fig. 2 Procedures for making paving blocks with a plastic

Paving blocks were cured for 28 days following concrete curing standards on SNI 03-0691-1996 [20]. The curing method was finished by immersing the paving block in water. After the curing period, the paving block evaluation was carried out on compressive strength, water absorption, and wear resistance, referring to the Indonesian standard of SNI 03-0691-1996 concerning concrete brick (paving block) [20].

Compressive strength testing requires a 7.5× 7.5× 7.5 cm cube-shaped sample test, or the sample can be adjusted along its shortest side. Based on SNI 03-0691-1996, which refers to SNI 03-1974-1990 concerning the concrete compressive strength test method, the sample test must be a cube to ensure that the strength is spread evenly across the three sides of the paving block [20]. The compressive strength test was carried out with three samples. The compressive strength test used the universal testing machine (UTM). The value of the compressive strength of the paving block can be calculated by:

$$\text{Compressive strength} = \frac{P}{A} \tag{1}$$

where P is the compressive load (N), and A is the sample area (mm^2).

The water absorption test on paving blocks was carried out by soaking them in water for 24 hours and then weighing them. After that, the paving blocks were dried in the oven for 24 hours at a temperature of ±105°C. Water absorption of paving blocks can be obtained by:

$$\text{Water absorption} = \frac{M-D}{D} \times 100\% \tag{2}$$

where M is the saturated mass (kg), and D is the dry mass (kg).

The wear resistance test on paving blocks was carried out using a test object measuring 5 × 5 × 2 cm. The wear resistance test procedure refers to SNI 03-0028 1987 concerning the test method for cement tiles. Wear resistance testing on the paving block can be found by:

$$\text{Wear resistance} = 1.26\ G + 0.0246 \tag{3}$$

where G is the mass loss (g/min).

Paving blocks must meet the Indonesian standards as presented in Table 2. In this study, paving blocks are planned to have D quality. Related to the quality of paving blocks, SNI 03-0691-1996 regulates the physical properties of paving blocks in each quality, as shown in Table 2.

Table 2 Physical properties of paving blocks (SNI 03-0691-1996)

Quality	Compressive strenght (MPa)		Wear resistance (mm/min)		Water absoption (%)	Usage
	Average	Min.	Average	Min.		
A	40	35	0.090	0.103	3	Pavement
B	20	17	0.130	0.149	6	Parking areas
C	15	12.5	0.160	0.184	8	Pedestrian
D	10	8.5	0.219	0.251	10	Parks

3. Result and Discussion

3.1. Properties test

Properties testing was carried out on the parameters of specific gravity, water absorption, organic content, silt content, and the distribution of grains of sand aggregate. The results of the sand properties test can be seen in Table 3, while the distribution of sand aggregates can be seen in Fig. 3. The organic test chart can determine the amount of organic sand. Based on ASTM C40/C40M-11, sand can be used if the organic test results are below the third color on the test chart in Fig. 4. According to the results of the properties test in Table 3, it is known that the aggregate meets the standards of most properties test parameters so that it can be used. On melted plastic, properties tests were also performed. Fig. 5 shows a plastic melter that is used to melt plastic waste. As shown in Table 4, the specific gravity of melted plastic is 0.94 g/cm^3 based on measurements.

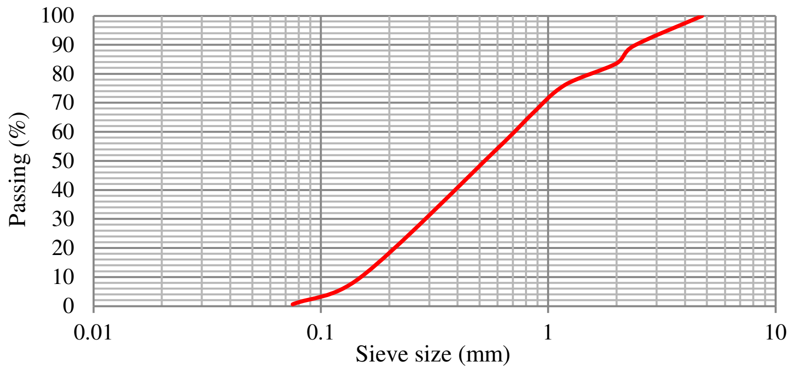


Fig. 3 Distribution of sand aggregate grains

Table 3 The result of the sand properties test

Parameter	Score	Standard	Standard
Specific gravity (SSD) (-)	1.95	1.6 - 3.2	SNI 1970-2008
Water absorption (%)	5.65	< 3	SNI 1970-2008
Organic content (-)	2	< 3	ASTM C40/C40M-11
Sludge levels (%)	0.6	< 5	SK SNI S-04-1989-F

Fig. 4 Organic impurities color chart (ASTM C40/C40M-11)

Fig. 5 Plastic melter

Table 4 Specific gravity of the sand

Parameter	Water	Sand
Weight (g)	81	76
Volume (cm³)	81	81
Specific gravity (g/cm³)	1.00	0.94

3.2. *Density of paving blocks*

As shown in Fig. 6, a comparison of the density of each sample tested is presented. The density of each paving block is observed to decrease as the number of plastic melts increases. It can be attributed to the lower specific gravity of the plastic compared to that of the sand, resulting in a decrease in the volume weight (density) [21]. Moreover, The concrete's pores in paving blocks with a plastic mixture can also lead to a reduction in density between particles. [22].

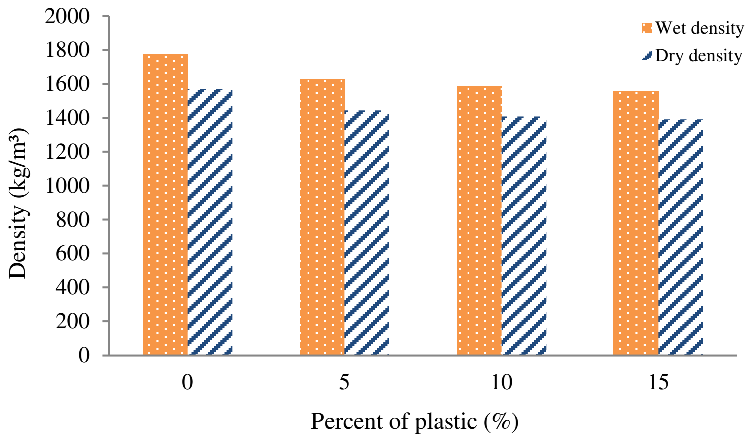


Fig. 6 The density of the paving block

3.3. *Compressive strength*

Fig. 7 depicts that paving blocks with plastic mixtures have various compressive strengths, namely 7.63-9.39 MPa. The result shows that paving blocks without plastic have higher compressive strength than those with a plastic mixture. According to SNI 03-0691-1996, the compressive strength standard for D quality is 8.5-12.5 MPa [20]. The D quality is the lowest quality paving block and can be used for parks. In this study, paving blocks with a 10% plastic mixture satisfy the D quality. However, paving blocks with 5% and 15% plastic mixture do not even meet the compressive strength standard for D quality paving blocks.

The results of this study are similar to several previous studies. Awodiji et al. [23] used HDPE and PET plastic as a substitute for coarse aggregate with a ratio of 1:1, 1:1.5, and 1:2. The results showed that the sand-HDPE combination had higher compressive strength than regular paving blocks (sand-cement). However, the sand-PET combination had a low compressive strength. Krasna et al. [24] used plastic with 0%, 25%, 50%, 75%, and 100% of sand. Compressive strength decreased with the addition of plastic. The compressive strength decreased by 7% to 59% from the compressive strength of paving blocks without plastic.

Mercante et al. [25] reported that adding plastic to a mortar reduced its compressive strength. This reduction in compressive strength can be caused by decreased density in the paving block mixture [21]. The smooth and slick plastic surface can weaken the aggregates' bond. Several factors affect the decrease in compressive strength: the lower strength of plastic compared to natural aggregate, the weak bond between cement and plastic, and the increase in air content in concrete [26]. In addition, the low compressive strength value can also influence by the paving blocks made with a hand-operated manual press.

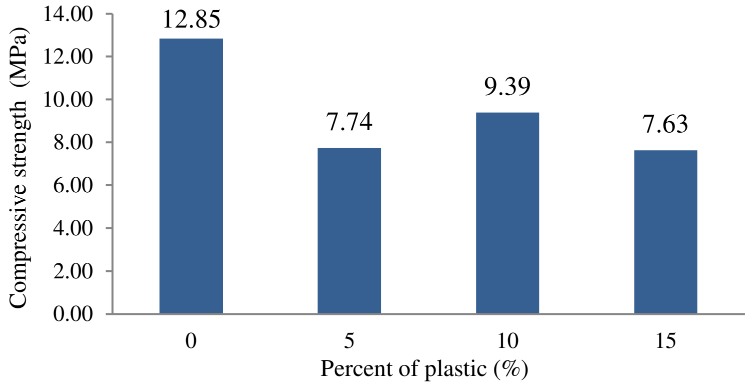


Fig. 7 Compressive strength of a paving block

3.4. Water absorption

Fig. 8 depicts the water absorption test results. It shows how paving blocks without a plastic mixture absorb more water than those with a plastic mixture. According to SNI 03-0691-1996, the maximum water absorption is 10% which is included in the D quality of paving blocks [20]. Water absorption in paving blocks shows a decreasing trend with the addition of melted plastic. In Fig. 8, all paving block samples have more than 10% water absorption, indicating that it does not reach the D quality.

Awodiji et al. [23] produced paving blocks using different combinations of sand-HDPE, sand-PET, and sand-cement with a ratio of 1:1, 1:1.5, and 1:2. The obtained results indicated that HDPE plastic is better than PET owing to its lower water absorption. The more plastic is used, the lower the water absorption, reaching 0%. Paving blocks with a plastic mixture has lower water absorption due to plastic's nature, which cannot absorb water [27]. Plastics tend to pass through the water rather than absorb water [22]. The amount of water absorption also indicates susceptibility to damage [25]. High water absorption causes the pores of the paving block to fill with much water. This condition reduces compressive strength, making it prone to cracking or destruction. Paving blocks with low water absorption last longer because they are less susceptible to chemical reactions, physical stress, and mechanical damage [27].

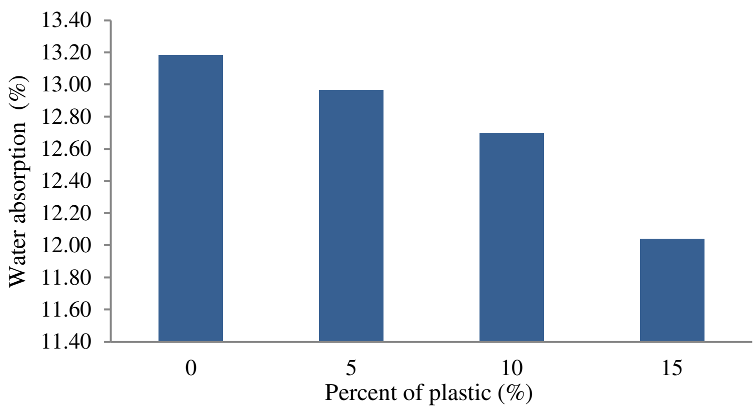


Fig. 8 Water absorption of a paving block

3.5. Wear resistance

The results of the wear resistance test showed that paving blocks without a plastic mixture (the control sample) outperform those with a plastic mixture. As shown in Fig. 9, the addition of plastic increases the wear value. Suardiana et al. [28] stated that adding plastic can reduce wear, which contradicts this study's results. One of the factors that affect wear is surface roughness. The plastic mixed in the paving block has a rough texture, causing the surface to wear out quickly. The high wear value on paving blocks can also be caused by cement that does not react (bind) to the plastic. However, as shown in Table 2, the minimum wear resistance for quality D paving blocks is less than 0.219. The value of wear resistance in this study was under the quality standard required by SNI 03-0691-1996 for concrete brick (paving blocks), classifying it as good [20].

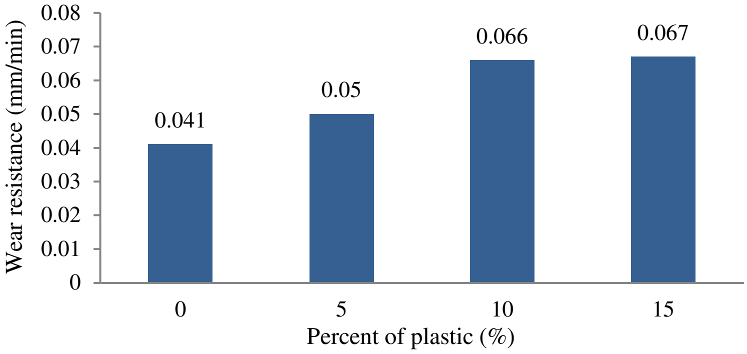


Fig. 9 Wear resistance of the paving block

3.6. Discussion

Analysis was performed on the compressive strength, water absorption, and wear resistance of paving block quality based on SNI 03-0691-1996, revealing that adding plastic to paving blocks tends to reduce the quality of paving blocks. Paving blocks with 10% plastic have a compressive strength of 9.39 MPa and qualify as D quality, which can be used in parks. However, paving blocks with 5% and 15% of the plastic mixture do not meet the quality required by SNI 03-0691-1996 [20]. Regarding water absorption parameters, paving blocks with the plastic mixture in all different proportions result in exceeding 12% absorption. It also did not reach the D quality. Compared to the control sample (0% plastic), the paving block with plastic mixture has lower water absorption. On the other hand, the wear resistance of paving blocks with the addition of plastic achieves the expected quality of D. Based on the results, paving blocks with the addition of plastic can only fulfill one of the three parameters required for D quality, namely, wear resistance. However, paving blocks with a mixture of plastic have the potential to be used at a 10% variation. Paving blocks with a 10% plastic mixture have a higher compressive strength than those of 5% and 15% plastic.

Melted plastic has a better ability than other forms of plastic to bond with other aggregates in paving blocks. Paving blocks with 10% melted plastic meet quality D for compressive strength. Furthermore, paving blocks with a melted plastic mixture also have a low water absorption rate. The lower the water absorption capacity, the better quality of the paving block. It means paving blocks will be more durable. Further research and testing such as a scanning electron microscope (SEM) test is needed to prove the bonding effect of melted plastic aggregate.

Manually pressed paving can impact the quality of the resulting paving blocks. The density of different paving blocks can be affected by differences in human power when making them, thereby influencing their durability. Hence, additional research into the effect of plastic on paving blocks made with an automatic press machine is required. Adding plastic to construction materials like paving blocks has good potential. It is a step toward recycling plastic waste and reducing the environmental burden of plastic. Yin et al. [29] stated that adding plastic can increase concrete's tensile strength. It is due to the ability of plastic to resist crack initiation in concrete. Furthermore, concrete with a melted plastic mixture also has a smaller decrease in flexural strength than that with the addition of plastic in large size [25].

4. Conclusion

This study investigated LDPE plastic waste in the form of melted plastic. In paving blocks, melted plastic substitutes sand at 5%, 10%, and 15% of the sand weight. The compressive strength, water absorption, and wear resistance of conventional and melted plastic forms of paving blocks were analyzed based on SNI 03-0691-1996. The following conclusions have been drawn:

1. Paving blocks with a plastic mixture have lower compressive strength than the control sample (0% plastic). The compressive strength of paving blocks with a mixture of 10% plastic meets D quality, while the 5% and 15% variations do not meet D quality standards.
2. The water absorption of the paving blocks with the plastic mixture is superior to the control sample (0% plastic). However, it does not meet the D quality standard. As the plastic increases, the water absorption decreases.
3. The wear resistance of paving blocks with a plastic mixture is advantageous. The more plastic, the more wear-resistant paving blocks.

According to SNI 03-0691-1996, paving block with melted plastic tends to decrease in quality. However, paving blocks with a plastic mixture at a 10% variation have the potential to be used. Recycling plastic into substitute materials for paving blocks can help reduce the negative environmental impact of plastic. Finally, the results indicate that concrete containing a melted plastic mixture can be used as non-structural concrete.

Conflicts of Interest

The authors declare no conflict of interest.

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