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THE EFFECT OF PET AND LDPE PLASTIC WASTES ON THE COMPRESSIVE STRENGTH OF PAVING BLOCKS

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ABSTRACT: Plastic is one of the most common environmental problems in the world. One way to reduce plastic waste is by reusing it to produce other materials such as partial replacement of sand in paving blocks mixture. Paving blocks (concrete brick) are a building material made of a mixture of water, aggregate, and portland cement. An experimental study was carried out to investigate the effect of low-density polyethylene (LDPE) plastic and polyethylene terephthalate (PET) plastic as a substitute for fine aggregates on the compressive strength of paving blocks. In this study, paving blocks are planned to be off plan C quality with a minimum compressive strength of 12.5 MPa, which is usually used as a pedestrian facility. Plastic wastes (LDPE and PET) are used as a partial replacement for fine aggregates, with 0%, 5%, 10%, and 15% volume variations of the fine aggregate. In addition, fly ash was added to LDPE mixtures (LDPEF) with the fly ash content used is 15% by replacing the weight of cement. The compressive strength test was carried out on cylinder specimens of 150 mm diameter and 300 mm length. The results show that the use of LDPE and PET plastic wastes as a partial replacement of fine aggregate decreased the compressive strength by 35.26%; 37.69%; 40.68% for LDPE, 34.15%; 52.22%; 56.53% for PET, and 23.14%; 18.01%; 24.65% for LDPEF, respectively. However, the compressive strength result of the tested paving blocks predominantly exceeds the minimum requirement for compressive strength of paving blocks quality C, 12.5 MPa.

Keywords: Plastic wastes, Paving blocks, Concrete bricks, Compressive strength, Fine aggregates

1. INTRODUCTION

Paving blocks or concrete brick is a composition of building materials made from a mixture of water, aggregate, and portland cement or similar hydraulic adhesive materials, with or without other additives that do not reduce the quality of paving blocks or concrete bricks [1].

To produce paving blocks that are more environment-friendly and economical, other materials can be used as a substitute for paving block mixtures, one of them is plastic waste. Plastic is one of the most common environmental problems in the contemporary world. The disposal of this plastic is considered a major challenge due to its non-biodegradable nature and pollutant [2,3].

According to the Central Pollution Control Board, the world produces nearly 150 million tons of plastic per year, equivalent to 4.8 tons per second [4]. Meanwhile in Indonesia, according to the Secretary General of the Indonesian Olefin, Aromatic and Plastic Industry Association (INAPLAS), plastic consumption has grown from 4.5 million tons in 2015 to 4.8 million tons in 2016 or grew by 5.2%. This increase in consumption is mainly encouraged by the growth of the food and beverage industry, where the industry uses a lot of plastic for its product packaging [5].

One alternative to reduce this plastic waste is the reuse of plastic to produce other materials [3]. In addition to waste plastic, many materials have been tried as replacement materials in concrete mixes, including recycled electrical cable rubber [6], waste polystyrene [7], and waste tyre rubber [8-12]. The construction industry can use a large amount of solid waste, one of which is in the production of paving blocks [13]. The use of plastic in the manufacture of paving blocks can increase the compressive strength of concrete brick, reduce the use of raw materials, be environmentally friendly, and it helps to reduce environmental problems [14,15].

Currently, many studies are being carried out regarding the use of plastic waste in paving blocks. Each year 60 million barrels of oil and other types of insulation would be saved by exploiting plastic foam insulation in buildings [16]. The compressive strength value by using 10% low-density polyethylene (LDPE) plastic as a substitute for sand in paving blocks is greater than the 0% variant (without plastic wastes mixture) which is 23.98 MPa and 23.68 MPa, respectively [4]. The application of pavement blocks is perfect on pathways and streetways as it is a simple way of finishing and laying, also cost-effective compared to conservative paving blocks [17,18].

This research focused on investigating the effect of using plastic wastes (LDPE and PET) as a partial substitute for fine aggregates on the compressive strength of paving blocks.

2. RESEARCH SIGNIFICANCE

The study focuses on plastic wastes including polyethylene terephthalate (PET) plastic and low-density polyethylene (LDPE) plastic with and without fly ash content in the mixtures. In addition, this study reviews various approaches to use plastic wastes in paving block (concrete brick) designs for pedestrian facilities that focus on material composition and comparisons in the previous studies. The finding of this study could be used as a reference to make paving blocks that are more environment-friendly, lightweight, and economical material construction.

3. MATERIALS AND METHODS

3.1 Material Used

3.1.1 Cement

The cement used in this study is Portland Composite Cement (PCC) produced by PT Semen Padang in Indonesia.

3.1.2 Fine aggregates

Fine aggregates in the form of locally available sand are used, with a maximum size of 4.75 mm. Table 1 shows the properties of the fine aggregates.

Table 1 Properties of fine aggregates

Characteristic	Value
Fine modulus (FM)	2.85
Water content	1.42%
Bulk density	1.41 kg/L
Specific gravity	2.50
Absorption	3.09%

3.1.3 Coarse aggregates

Locally available coarse aggregates are used with the size of Ø5-10 mm and Ø10-20 mm. The properties of coarse aggregates are shown in Table 2.

Table 2 Properties of coarse aggregates

Characteristic	Value	
	Ø5-10 mm	Ø10-20 mm
Fine modulus (FM)	5.34	6.94
Water content	1.32%	0.77%
Bulk density	1.33 kg/L	1.38 kg/L
Specific gravity	2.61	2.53
Absorption	3.20%	2.81%

3.1.4 Water

The water used for the mixture and curing of paving blocks is tap water that does not contain acids or organic substances.

3.1.5 Polyethylene terephthalate (PET) plastic

The PET plastic used comes from plastic wastes from mineral drink bottles, as shown in Fig.1. This PET plastic is processed into fine aggregates by melting and then crushing to a maximum size of 4.75 mm [19]. Table 3 shows the properties of PET plastic that is used in a mixture of paving blocks. The process of PET plastic wastes to be fine aggregates is shown in Fig.2.

Fig. 1 PET plastic

Table 3 Properties of PET plastic

Characteristic	Value
Size	0.1 mm - 4.75 mm
Shape of PET	Irregular
Specific gravity	1.38 g/mL

Fig. 2 PET plastic processing

3.1.6 Low density polyethylene (LDPE) plastic

Figures 3 and 4 show the type of recycled LDPE plastic seeds. In this study, LDPE flattened round is used in mixtures of paving blocks. The properties of LDPE plastic wastes are shown in Table 4.

Fig. 3 Shape of LDPE plastic pellets

Fig. 4 Shape of LDPE plastic flattened round

Table 4 Properties of LDPE plastic

Characteristic	Value
Size	(3.0 - 4.75) mm
Shape of LDPE	Flattened round
Specific gravity	0.94 g/mL

3.1.7 Fly ash

Fly ash is one of the pozzolanic materials as the cement replacement in the concrete mix which is residue generated by the coal-burning process of the steam power plant. The fly ash used is materialized from the SBB Thamrin Nine Batching Plant, Jakarta, Indonesia.

3.2 Experimental Work

3.2.1 Mix design

Mix design is calculated based on (American Concrete Institute) ACI-211.4R-93. Paving blocks are planned to be off plan C quality with a minimum compressive strength of 12.5 MPa. The ratio of cement volume: sand: split is (1: 3.75: 3.46) with a w/c of 0.681.

Plastic wastes (PET and LDPE) serve as a partial substitute for fine aggregates, where the amount of plastic added to the paving blocks mixture is based on the fine aggregate volume. In a previous study, concrete paving blocks (cement: quarry dust: sand = 1: 1: 2) by weight or volume were produced to serve as control having tested the compressive strength and water absorption properties [20].

In this study, there are three variations of paving blocks such as PET, LDPE and LDPE fly ash (LDPEF) paving blocks. The fly ash content used is 15% by replacing the weight of cement. Tables 5 to 10 show the composition of the volume and weight of the material in a 1m^3 mixture of paving blocks containing PET, LDPE, and LDPEF.

Table 5 The composition of the material volume in 1m^3 mixture of paving blocks containing PET

Material	Composition (%)			
	PET 0%	PET 5%	PET 10%	PET 15%
Cement	0.10	0.10	0.10	0.10
Sand	0.35	0.34	0.32	0.30
Split	0.33	0.33	0.33	0.33
Water	0.20	0.20	0.20	0.20
Air	0.02	0.02	0.02	0.02
PET	-	0.02	0.04	0.05

Table 6 The composition of the material weight in 1m^3 mixture of paving blocks containing PET

Material	Composition (kg)			
	PET 0%	PET 5%	PET 10%	PET 15%
Cement	298.30	298.30	298.30	298.30
Sand	887.47	843.10	798.73	754.35
Split	836.96	836.96	836.96	836.96
Water	203.14	203.14	203.14	203.14
PET	-	24.49	48.99	73.48

Table 7 The composition of the material volume in 1m^3 mixture of paving blocks containing LDPE

Material	Composition (%)			
	LDPE 0%	LDPE 5%	LDPE 10%	LDPE 15%
Cement	0.10	0.10	0.10	0.10
Sand	0.35	0.34	0.32	0.30
Split	0.33	0.33	0.33	0.33
Water	0.20	0.20	0.20	0.20
Air	0.02	0.02	0.02	0.02
LDPE	-	0.02	0.04	0.05

Table 8 The composition of the material weight in $1m^3$ mixture of paving blocks containing LDPE

Material	Composition (kg)			
	LDPE 0%	LDPE 5%	LDPE 10%	LDPE 15%
Cement	298.30	298.30	298.30	298.30
Sand	887.47	843.10	798.73	754.35
Split	836.96	836.96	836.96	836.96
Water	203.14	203.14	203.14	203.14
LDPE	-	16.68	33.37	50.05

Table 9 The composition of the material volume in $1m^3$ mixture of paving blocks containing LDPE fly ash (LDPEF)

Material	Composition (%)			
	LDPEF 0%	LDPEF 5%	LDPEF 10%	LDPEF 15%
Cement	0.08	0.08	0.08	0.08
Sand	0.35	0.34	0.32	0.30
Split	0.33	0.33	0.33	0.33
Water	0.20	0.20	0.20	0.20
LDPE	-	0.02	0.04	0.05
Fly Ash	0.01	0.01	0.01	0.01

Table 10 The composition of the material weight in $1m^3$ mixture of paving blocks containing LDPE and fly ash (LDPEF)

Material	Composition (kg)			
	LDPEF 0%	LDPEF 5%	LDPEF 10%	LDPEF 15%
Cement	253.55	253.55	253.55	253.55
Sand	887.47	843.10	798.73	754.35
Split	836.96	836.96	836.96	836.96
Water	203.14	203.14	203.14	203.14
LDPE	-	16.68	33.37	50.05
Fly Ash	44.74	44.74	44.74	44.74

3.2.2 Manufacture of specimens

Totally, 36 cylindrical specimens of 150 mm diameter and 300 mm height were prepared for compressive strength tests, as shown in Table 11 and Fig.5.

3.2.3 The curing of specimens

The curing of the specimen is carried out in a water bath at the Materials and Structural Laboratory of the Department of Civil Engineering, Andalas University, as shown in Fig.6. The curing of the specimens was conducted for 28 days.

Table 11 The number of specimens

Specimen type	The number of specimens
LDPE	12
PET	12
LDPEF	12

Fig. 5 The molding of specimens

Fig. 6 The curing of specimens

3.2.4 The testing of specimens

Testing the compressive strength of the paving blocks (concrete brick) was carried out using a Universal Testing Machine at the Material, Soil Mechanics and Highway Laboratory, Department of Civil Engineering, Padang State University, as shown in Fig.7.

Fig. 7 Compressive strength test of cylinder specimens

4. RESULTS AND DISCUSSION

4.1. Workability of Paving Block using Plastic Wastes (PET and LDPE)

Workability is the property of paving block mortar determined by easy mixing, transportation, the casting of concrete, and finishing. The ease of workability can be seen from the slump value which is identical to the plasticity of paving blocks (concrete brick). Tables 12 and 13 show the slump value of paving blocks containing PET and LDPE plastic wastes**.**

Table 12 Slump value of paving blocks with different PET plastic content

No.	PET (%)	Slump value (mm)
1	0	47
2	5	35
3	10	26
4	15	25

Table 13 Slump value of paving blocks with different LDPE plastic content

No.	LDPE (%)	Slump value (mm)
1	0	47
2	5	30
3	10	23
4	15	22

Table 12 shows that the increasing amount of PET in the mixture decreases the slump value of the paving block (concrete brick). PET has a larger specific surface area compared to sand, so the friction between particles becomes greater. Therefore, the workability of the mixture becomes smaller.

The increased LDPE in paving blocks reduces the plasticity of the fresh paving block mixture and decreases the workability of the paving block. As can be seen in Table 13, the value of the slump is getting smaller with the increase of LDPE content in the mixture.

4.2. The Compressive Strength of Paving Block using Plastic Wastes (PET and LDPE)

The compressive strength (f’c) is the comparison of the ultimate load with the cross-sectional area of the specimens. The result of compressive strength test is based on the strength of concrete that is 28 days old. Based on ACI-211.4R-93, the planned compressive strength of paving blocks is C quality with a minimum compressive strength of 12.5 MPa.

The compressive strength of the paving block is analogous to the compressive strength of the concrete cylinder, so that the maximum load can be interpreted as the value of the compressive strength of the paving blocks (concrete brick). The results of compressive tests performed on paving blocks with variations in the LDPE and PET mixtures are shown in Tables 14 to 15 and Fig.8.

Table 14 Compressive strength test results

Variation (%)	Compressive strength (MPa)		
	LDPE	PET	LDPEF
0	19.32	19.32	15.36
5	12.51	12.72	13.55
10	12.04	9.23	14.46
15	11.46	8.40	13.29

Table 15 Percentage decreased of the compressive strength results

Variation (%)	Compressive strength (%)		
	LDPE	PET	LDPEF
0	-	-	-
5	35.26	34.15	23.14
10	37.69	52.22	18.01
15	40.68	56.53	24.65

Tables 14 and 15 show that the result of the compressive strength of the cylinder test specimen without the addition of LDPE plastic wastes is 19.32 MPa. The lowest compressive strength value is 11.46 MPa when replacing 15% of the sand volume with LDPE. Replacement of 5% and 10% volume of sand with LDPE results in the compressive strength of 12.51 MPa and 12.04 MPa, respectively.

Meanwhile, for specimens containing PET plastic waste content, the compressive strength results by replacing 5%, 10%, and 15% of the volume of sand with PET is 12.72 MPa, 9.23 MPa, and 8.40 MPa, respectively. For paving blocks containing combined LDPE and fly ash (LDPEF), on the other hand, the lowest compressive strength value is 13.29 MPa when replacing 15% of the volume of sand with LDPE plastic waste, which is slightly decreased compared with the specimen without the addition of LDPE plastic waste content (15.36 MPa). The replacement of 5% and 10% sand volume with LDPE plastic waste results in the compressive strength of 13.55 MPa and 14.46 MPa, respectively.

From Table 15, it is seen that the decrease in the lowest compressive strength value occurred when the LDPEF was 10% with a decrease of 18.01%, while the decrease in compressive strength value was greatest when PET was 15% with a large decrease of 56.53%.

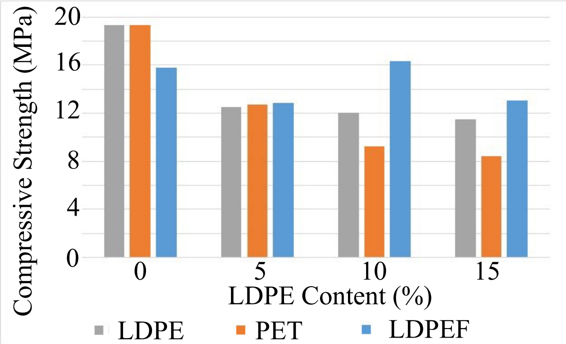

Fig. 8 Compressive strength of paving blocks using plastic wastes as a partial substitution of fine aggregate

According to the compressive strength result in Fig.8, it can be seen that the replacement of sand by LDPE and PET plastic waste causes a decrease in the compressive strength of paving blocks. The reason for this reduction in strength is associated with the smooth surface of the plastic which reduces the adhesion between plastic particles and cement paste [21,22].

4.3. The Comparison of Compressive Strength Results of Paving Block Using Plastic Wastes (PET and LDPE) with The Previous Studies

The comparative result of PET paving block compressive strength with other data from the previous studies is shown in Fig.9.

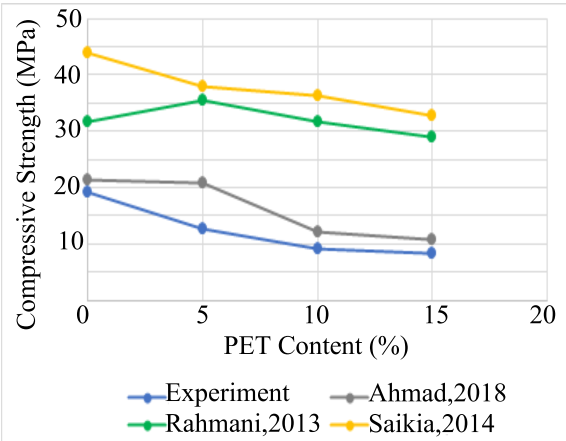

Fig. 9 The comparison of paving block compressive strength with different PET plastic content

Based on Fig.9, the result of the percentage change in the compressive strength of the specimens tested was lower than that of the previous study's data. The minimum percentage decrease in compressive strength of the test specimens in this study is 34.15%, while in the previous studies [14, 23] the minimum decrease was 2.34% and 14.09%. However, in another past study [24] the compressive strength increased by 11.97%.

Figure 10 shows the comparative result of LDPE paving block compressive strength with other data from previous studies.

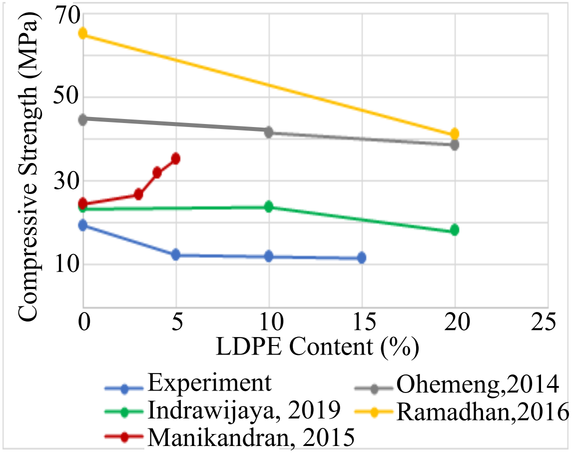

Fig. 10 The comparison of paving block compressive strength with different LDPE plastic content

From Fig.10, it can be seen that the compressive strength value tends to decline as the LDPE plastic content increases in the paving block [25-27]. The previous study data [27] show that the concrete mixture with the highest decrease value is 36.55%, while the minimum decrease value obtained from this study is 35.26%. However, the value of compressive strength has increased in another past study [28] with the highest increase being 43.60%.

5. CONCLUSION

The use of LDPE and PET plastic wastes as the partial replacement of fine aggregate decreased the compressive strength of paving blocks with the increase of plastic waste content. For paving blocks containing LDPE plastic waste, the use of 5%, 10%, and 15% plastic waste decreased the compressive strength by 35.26%, 37.69%, and 40.68%, respectively, while it decreased by 34.15%, 52.22%, and 56.53%, respectively for paving blocks containing PET plastic waste. As for the use of combined fly ash and LDPE plastic waste (LDPEF) in paving blocks mixture, the decrease of the compressive strength was respectively 23.14%, 18.01%, and 24.65%. However, the compressive strength result of tested specimens predominantly exceeds the minimum requirement for compressive strength of paving blocks quality C, 12.5 MPa, so it can be used for pedestrian facilities.

6. ACKNOWLEDGMENTS

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