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Determining optimum eco paving block compositions by using factorial design method

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Abstract. Some plastic waste processing into economically valuable recycle products has been done. By using a plastic waste processing machine, a variety of products made from plastic waste can be made, one of which is a paving block that is commonly used as building material. Basically, paving block are made from a mixture of cement and sand, but in this study, cement was replaced with processed plastic waste. So, this paving block is called as eco paving block to show the ecology side by using plastic waste as raw material. In this study, experiments were carried out using the factorial design as one of the Design of Experiment (DOE) methods to determine the optimal composition of the eco paving block. The result showed that the ratio of composition is 2:3 of sand and plastic can produce optimum eco paving block based on compressive strength. This paving block has an average compressive strength 9.91 MPa. It can be classified into D quality classification that can be used for yards, parks, and others.

Keywords: factorial design metod, eco paving block, plastic, compressive strength

1. Introduction

The amount of plastic waste that is not managed properly can potentially damage the ecosystem. Based on World Economic Forum (WEF) data, only 5% of plastic are effectively recycled, while the other 40% ends up in landfills, and the rest ends in ecosystems such as the ocean. Indonesia got second ranks as the largest contributor of plastic waste in the world with 5.4 million tons per year [1]. The principles of waste management are reduction in using of plastic products such as plastics bag, plastics packaging, etc., optimizing the use of plastic can be reused, producing or processing plastic into a product that is useful and has economic value, replace or avoid the use of disposables with items that can be used repeatedly, and respect to build a sense of caring and loving the environment so that, can get used to and wise before choosing or using a product.

Therefore, from the many methods, technologies, and ways to recycle plastic waste into a new product, the use of plastic waste processing machine is one of the technologies that is very effective and efficient in producing recycle products from plastic waste. The product that can be made from processing plastic waste is paving block. Basically, paving block made of cement and sand. Some communities or companies have produced eco paving block with various quality. Based on SNI 03-0691-1996, the classification for paving block is measured based on the compressive strength as shown in table 1.

Table 1. Quality standard of paving block classification [2]

Quality	Utility	Compressive Strength (MPa)	
		Average	Minimum
A	Road Hardener	40	35
B	Parking Lot	20	17
C	Pedestrian	15	12.5
D	City Park	10	8.5

Actually, some experiments to determine best composition of paving block by using plastic mixture has conducted with various material, parameters, and methods. Previous research used variation of plastic type ratio as parameter. The result showed that the best comparison of ratio is 1 of body of plastic bottle, 1 of plastic bag, 4 of cap of plastic bottle [3]. Other research found that optimum compressive strength occurred in the addition of 0.5% *polietilena tereftalat* fiber and it increased of 42.23% when compared to normal paving block [4]. While, the other study proved that the value of paving block compressive strength can be increased by using Polypropylene (PP) plastic waste as an aggregate substitution in the manufacture of paving block [5]. Meanwhile in other research showed that the utilization of High Density Polyethylene for making paving block. At normal temperatures, it can be very hard and suitable for making paving block [6].

In this study, an experiment will be conducted to obtain optimum composition and identify things that affect the quality of eco paving block by using experimental method of Design of Experiment (DOE) based on factorial design in order to obtain optimal product designs, so the product can fulfill to the standards of the quality. Paving block with good quality are paving block that have high compressive strength value (MPa) and low absorption value (percentage of water absorption).

2. Methods

2.1. Experimental Design

Design of Experiment (DOE) is a research conducted to study or discover something about existing processes or compare the effects of several conditions on a phenomenon [7]. Generally, DOE is used in designing an experiment to be able to find out the response and characteristics of a factor and element to a test variable [8]. Factorial design is a kind of DOE method usually that used to produce more objective experiments. In factorial design method, every possible combination of all factors and levels in the experiment to determine the effect of interactions between factors in factorial experiments could be investigated.

Factors and levels in this study obtained by interviewing the experts and did literature review from previous research. In this experiment, it is used two factors consist of types of plastic and ratio of plastic and sand. Two types of plastic that used for this study are HDPE (High Density Polyethylene) and PP (Polypropylene). This study has 18 of total treatments with three of replications. In order to increase accuracy in experiments, usually it is conducted randomization. Randomization is the design technique used to guard against each a nuisance factor [9]. By using Minitab Statistical Software, experimental design of this study can be seen in table 2.

Table 2. Experimental Design

Std Order	Run Order	Replications	Types of Plastic	Compositions	Std Order	Run Order	Replications	Types of Plastic	Compositions
9	1	2	HDPE	3	3	10	1	HDPE	3
8	2	2	HDPE	2	5	11	1	PP	2
11	3	2	PP	2	6	12	1	PP	3
7	4	2	HDPE	1	17	13	3	PP	2

Std Order	Run Order	Replica-tions	Types of Plastic	Composi-tions	Std Order	Run Order	Replica-tions	Types of Plastic	Composi-tions
12	5	2	PP	3	13	14	3	HDPE	1
10	6	2	PP	1	15	15	3	HDPE	3
1	7	1	HDPE	1	16	16	3	PP	1
2	8	1	HDPE	2	14	17	3	HDPE	2
4	9	1	PP	1	18	18	3	PP	3

2.2. Performing the Experiment

This experiment is focused on paving block made by plastic waste and sand. The choice of material is an effort to reduce the amount of plastic waste in the environment that is processed by using an plastic waste machine. The size of paving block for this experiment has length is 13 cm, width is 13 cm, and height is 6 cm with a modified cube base shape, as the shape of the paving block mold design shown in figure 1.

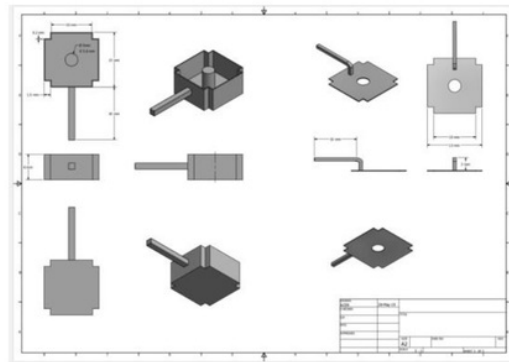


Figure 1. Paving block mould design

In conducting experiments, 18 of paving block samples were taken. The making of plastic paving block uses the help of plastic waste processing machine, as shown in figure 4 and 5.



Figure 4. Shredder machine



Figure 5. Extrusion machine

Based on Figure 4 and 5, there are two types of plastic waste processing machine used in making eco paving block with different uses and functions. Shredder is used to destroy and refine plastic waste, while extrusion machine is used to melt the results of chopping and as a medium used in the process of mixing between plastic seeds with fine aggregate (sand). Figure 6 showed the eco paving block that produced by using the machines.



Figure 6. Plastic paving block

¹ The variable response of this research is compressive strength of the eco paving block. The process compressive strength testing of eco paving block was carried out in the Concrete Laboratory, using CTM (Compression Testing Machine) as in figure 6.



Figure 6. Compression testing machine

2.3. Statistical data analysis

Analysis of variance is important analysis techniques to the factorial design method. Analysis of variance is a technique used as a tool to analyze the average difference between groups in an experiment or research by conducting a hypothesis test to test the interaction between one factor of the sample taken in an experiment to know the interaction between variables and their effect on a treatment. In this research has been used statistical software to compute p-value. The α -value has been selected is 0.05. If p -value is below α -value, there are factors or factor interactions are significantly affects the response variable. To be able to conduct the analysis of variance, the data must be normally distributed and homogeneous [10].

2.3.1. Model Adequacy Checking

In the analysis of variance, the uses of normal probability plot of the residuals to check the assumption of normality is usually more effective and straight forward [9]. If the underlying error distribution is normal, this plot will resemble a stright line. The other plot that used for model adequacy checking is plot of residuals versus fitted, plot of residuals versus, and histogram.

3. Result and Discussion

3.1. Compressive strength result

The results of compressive strength by using the compression testing machine to all eco paving block with all variation of treatment can be seen on the table 3.

Table 3. Compressive strength test results

Treatments	Types of Plastic	Compositions	CompressiveStrength (MPa)
1	HDPE	3	7.29
2	HDPE	2	9.99
3	PP	2	9.65
4	HDPE	1	8.42
5	PP	3	7.24
6	PP	1	8.4
7	HDPE	1	8.86
8	HDPE	2	9.87
9	PP	1	8.25
10	HDPE	3	7.51
11	PP	2	9.20
12	PP	3	7.52
13	PP	2	9.99
14	HDPE	1	8.25
15	HDPE	3	7.41
16	PP	1	8.08
17	HDPE	2	9.87
18	PP	3	7.52

From the table can be seen that the highest value of compressive strength is 9.99 MPa. It is obtained from treatment number 2 and 13. Both of treatments used the same compositions, these are 200 gram of sand and 300 gram of plastic. Therefore, the types of plastic are different.

3.2. Stistical analysis

To conduct ANOVA tests, the data must be normally distributed and homogeneous in nature. The normality assumption has conducted by using residual plots as shown in figure 7.

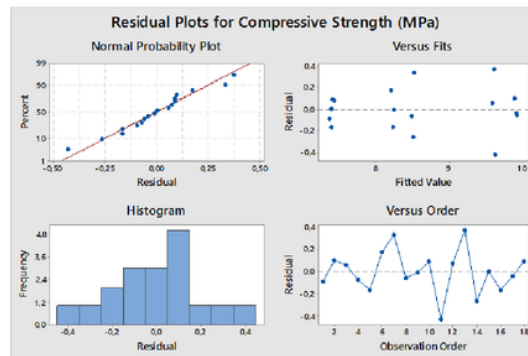


Figure 7. Residual plots

Based on residual plot, the residual value is obtained that follows a linear line, so the residual data can be assumed to be normally distributed and the requirements for the ANOVA test can be fulfilled. For the histogram, a pattern that follows a normal curve is obtained, so that it can be said that the data is normally distributed. Versus fits graph is used to see whether residuals have a constant value or not. The pattern produced on the garfik versus fits does not form a particular pattern and tends to be constant and identical to either the top or bottom of the zero line. As for versus order, it is used to describe whether the residuals are free from one another. The graph versus the order obtained shows a random pattern at the center of the line or the zero line on the y axis or does not have a certain pattern, so it can be said that the residual data are mutually independent. From all the graphs on the residual plot, it is obtained that the residual data meet the normal distribution assumption.

Meanwhile, homogeneity tests are carried out as shown in table 8. The value of sig. is 0.168 or greater than the alpha value of 0.05, which means homogeneous data or compressive strength data of paving block for each treatment has the same variance.

Tabel 8. Homogeneity test

F	df1	df2	Sig.
1,900	5	12	,168

The data has fulfilled the analysis of variance assumptions, so it can be conducted. Based on table 9, there was no significant effect between types of plastic on the compressive strength. Meanwhile, the compositions of materials have a significant effect on the compressive strength, because the p-value obtained is 0,000 or less than the alpha value, which means rejecting H_0 or in the sense, material composition has a significant effect on the compressive strength.

Table 9. Analysis of variance result

Term	p-value
Types of Plastic	0.164
Compositions	0.000
Types of Plastic*Compositions	0.508

But the interactions of factor levels has no effect significantly on the compressive strength. It can be showed through the p -value is 0.508. It was greater than an alpha value. So, the main effect that can influence the compressive strength of the paving block is compositions as shown in figure 8.

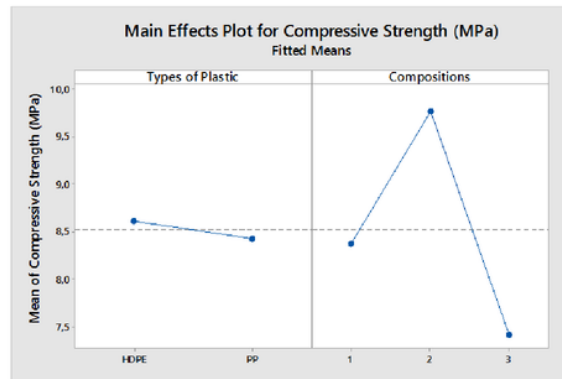


Figure 8. Main effects plot

It is known that the material composition factor has an influence between each level of composition when compared to the type of plastic factor¹ with a level 2 material composition that has a very significant effect on the compressive strength of eco paving block when compared to the composition of level 1 and 3. The greater slope, the more significant effect on the response variable.

Interactions between factors are also important to identify because interactions between these factors can influence the response variables, as in figure 9.

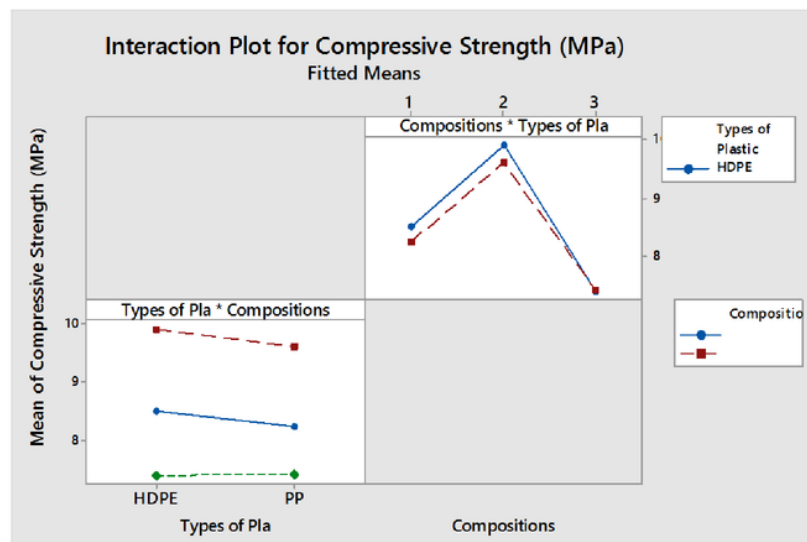


Figure 9. Interaction plot

³ Based on the interaction plot, it is known that to achieve optimal compressive strength on plastic paving block, used plastic with HDPE type with a composition of level 2 materials because the

interaction plot for the type of plastic and the composition of the material is located at the highest value among the other material compositions. So, it can be assumed that the optimum eco paving block compositions is the eco paving block made by 200 gram of sand and 300 gram of plastic with HDPE type. So, the optimum average value of compressive strength is 9.91 MPa. It can be determined the eco paving blocks can be categorized into quality D paving blocks based on paving block quality standard as shown in table 1.

4. Conclusion

Based on data processing and analysis that has been done, the conclusions can be obtained as follows:

1. Factors that has an influence significantly in making eco paving block is the ratio of composition, meanwhile the type of plastic has no effect to the compressive strength of the plastic
2. The optimum compositions for the eco paving block is the quantity of the plastic should be greater than quantity of sand with ratio 2:3 of sand and plastic which can produce an average compressive strength is 9.91 MPa.

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