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Application of Experimental Design in the Development of Plastic Waste-Based Roster

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ABSTRACT: The ever-increasing problem of plastic waste is an environmental issue that requires innovative and sustainable management. This research aims to develop a plastic waste-based roster product as an alternative solution to reduce plastic pollution while creating a functional and environmentally friendly product. This research used a quantitative approach with the Design of Experiments and Analysis of Variance method, along with the Newman-Keuls test to determine the effect of varying the proportion of plastic waste on the roster's compressive strength. The types of plastic used were High-Density Polyethylene (HDPE) and Polypropylene (PP), with three variations in the amount of plastic waste: 1.084 grams, 2.168 grams, and 4.336 grams. Additional materials used were sand, coarse aggregate, gypsum powder, cement, and water, the composition of which was constantly controlled. The manufacturing process includes plastic shredding, material mixing, molding, and compression testing using a Compression Testing machine type AMU 20. The results showed that a lower dose of plastic waste produced a higher compressive strength, with a maximum value of 8.04 MPa at a composition of 1.084 grams, while the highest composition produced the lowest compressive strength of 4.02 MPa. This study concluded that plastic waste can be utilized effectively in roster production, with a significant influence on product strength.

KEYWORDS: Compressive Strength, Experimental Design, Plastic Waste, Product Development, Roster

I. INTRODUCTION

The pervasive problem of plastic waste represents a growing global concern, exacerbated by rising industrial activity and consumer consumption. While plastics have become indispensable to modern society due to their lightweight, long durability and low cost, their unmanaged disposal poses serious threats to environmental integrity and public health [1].

The public's dependence on plastics remains high, despite awareness of associated health risks such as cancer, neurological disorders, hepatotoxicity and reproductive complications. Nonetheless, when managed responsibly, plastics need not inherently confer adverse effects [2] .

Recycling represents a primary waste mitigation strategy, and an emerging innovation involves repurposing plastic waste as a primary raw material for fabricating building rosters [3]. The roster is a perforated construction component that facilitates ventilation and provides natural lighting. This innovation offers dual benefits, such as reducing plastic waste accumulation and promoting the production of sustainable construction materials.

Roster is a hollow wall element, typically manufactured from concrete blocks, natural stone, or similar materials, are widely used in minimalist and modern architecture for ventilation purposes [4]. Their design varies to aesthetic and functional requirements and are increasingly applied in interior settings such as partition wall and fences.

Despite the roster's popularity owing to structural robustness, longevity and visual appeal. However frequently found quality defects on roster such as porosity and cracking as shown in figure 1.

Figure 1 Roster Cracked

Plastic waste is a major contributor to environmental pollution due to its inherent resistance to natural biodegradation. When improperly managed, it can contaminate terrestrial and aquatic systems, emit airborne pollutants, and ultimately disrupt ecosystems [5].

High-Density Polyethylene (HDPE) plastic is a thermoplastic polymer characterised by a high-density molecular structure, which imparts distinct mechanical and physical properties [6]. HDPE mostly commonly utilised in products demanding corrosion and weather resistance, such as container recycle bin, household goods and outdoor fixtures. The advantages of HDPE are its recyclability and potential environmental compatibility when processed correctly [7].

Polypropylene (PP) plastic is another versatile thermoplastic polymer possessing superior properties contributing to its widespread use, and it is suitable for a wide array of industrial and commercial applications [8]. The main characteristic of PP is its flexibility, which enables its use in various products requiring durability and ease of formability. Furthermore, this plastic is notably lightweight and exhibits low density, making it ideal for applications where weight reduction is essential.

Additional materials used were sand, coarse aggregate, gypsum powder, cement, and water. Sand is a natural material made up of small grains that are formed through the long-term weathering of rocks and minerals [9]. Coarse Aggregate is a primary material in casting concrete, serving both as a addition material and filler. It is characterised by a relatively large grain range size from 5 to 40 millimetre [10].

Gypsum Powder is a fine white to light grey powder obtained from gypsum rock, a sedimentary rock naturally containing calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$) [11]. Cement is a chemical binding material, that plays a vital role in construction as it used to combine various building materials for cohesion and strength development in composite material [12]. Water is chemical compound consisting of two hydrogen atoms and one oxygen atoms (H_2O). Water is colourless, odourless, and tasteless liquid on under normal temperature and normal pressure [13].

Roster can be categorised based on their raw materials, including concrete rosters, ceramic rosters, Glass fibre Reinforced Cement (GRC) rosters and wooden rosters. This research is develop based on the utilization of plastic waste focus on HDPE and PP types. The research aims to explore the potential of these two type plastics in producing strong, durable and environmentally friendly rosters. Utilising plastic waste as a raw material of roster not only helps reduce waste volume but also opens new opportunities for sustainable industry.

II. METHODS

A. Types of Research

This research adopts a quantitative research approach aimed at collecting and analysing numerical data, testing hypotheses, explaining the phenomena, predicting outcomes and examining relationship between variables.

The research focuses on developing a roster product using High-Density Polyethylene (HDPE) and Polypropylene (PP) plastic waste as easily recyclable materials. The primary objective is to develop an environmentally friendly roster product with functional and aesthetics value that meets consumer needs.

The experimental procedures involved a systematic series steps to collect the correct data to predetermined design, including material preparation, mould creation, shredder machine fabrication, roster production, and strength testing.

B. Experimental Design

The first phase involved meticulous experimental design, entailing the identification of independent variable, dependent variable, and also controlling the noise factor. Commonly used design is Completely Randomized Design or Randomized Block Design, depending on characteristic of research and managing experimental variability effectively [14].

C. Analysis of Variance

Analysis of Variance is an inferential statistical technique used to determine the existence of statistically significant differences among the means of three or more independent group [15]. The null hypothesis (H_0) indicates that no significant difference exists between the group mean, whereas the alternatives hypothesis (H_1) indicates that at least one pair of mean differs significantly.

D. Newman-Keuls Test

An approach combining experimental design with the Newman-Keuls test is often used to analyse data when researchers want to compare the mean of three or more groups [16]. Its main objective is to identify significant differences between groups after an overall effect have been founded by Analysis of Variance.

If Analysis of Variance indicates a significant difference, the Newman-Keuls test is applied as a post-hoc test. This test systematically performs pairwise comparison between all groups [17]. The advantage of Newman-Keuls test in its ability to moderately control the error rate, thereby reducing the likelihood of finding insignificant when conducting multiple comparisons.

III.RESULTS AND DISCUSSION

A. Application of Experimental Design

The Experimental Design was implemented to ensure that the results obtained from the experiment were valid, reliable and could be correctly interpreted using statistical tests. The Newman-Keuls method was used to specifically identify significant differences between the mean values of each groups based on analysis results of Analysis of Variance.

This experiment was designed by incorporating a plastic waste proportion factor with three dosage level: 1.084 gram, 2.168 gram and 4.336 gram. The controlled sand materials (119.056 gram), concrete aggregate (106.888 gram), gypsum powder (37.536 gram), cement (73.984 gram) and water (1.5 litres).

B. Mold Creating

At this step, a roster mould was fabricated with the following criteria: modern roster design, rectangle, featuring medium-sized ventilation holes and size is 20 centimetres x 10 centimetres x 10 centimetres. Based on these criteria, a roster mould design was created to become a roster according to the intended specifications as shown in figure 2.

Figure 2 Mold Design

C. Chopper Machine

A Chopper Machine was used to chop plastic waste into small pieces so that the waste can be processed and used as a material in the roster making process.

The chopper machine's blades designed to maximize the shredding efficiency of the plastic waste. Knife bearing were fabricated to serve as a hook or fastener for mounting the shredding blades onto the chopper machine, as shown in figure 3.

Figure 3 Chopper Blade

D. Roster Making

In this experiment, a roster was produced using plastic waste proportions of 1.084 gram, 2.168 gram, and 4.336 gram with the following controlled material composition: sand (119.056 gram), concrete aggregate (106.888 gram), gypsum powder (37.536 gram), cement (73.984 gram), and water (1.5 litre), as shown in figure 4, figure 5, figure 6, and figure 7.

Figure 4 HDPE and PP Plastic Waste

Figure 5 Plastic Waste Shredding Results

Figure 6 Dough Molding

Figure 7 Roster Product

E. Product Strength Testing

A compression strength test was conducted to determine the maximum load of the roster. This test was performed using compression testing machine type AMU 20 as shown in figure 8 and figure 9.

Figure 8 Compression Testing Machine **Figure 9 Roster Sample Testing**

Table 1 presents the calculation results of the compression strength test based on Standard Nasional Indonesia (SNI) for the roster product samples.

Table 1 Compression Strength Test Results (SNI)

Plastic Waste	Length (mm)	Width (mm)	Maximum Load (Kgf)	Unit of Force (N)	Kgf x N	Compressive Strength (MPa)
1.084 gram	200	93	1,525	9.81	14,960	8.04
2.168 gram	200	93	850	9.81	8,339	4.48

4.336 gram	200	93	762	9.81	7,475	4.02
1.084 gram	200	93	1,325	9.81	12,998	6.99
2.168 gram	200	93	900	9.81	8,829	4.75
4.336 gram	200	93	1,225	9.81	12,017	6.46
1.084 gram	200	93	1,425	9.81	13,979	7.52
2.168 gram	200	93	975	9.81	9,565	5.14
4.336 gram	200	93	1,325	9.81	12,998	6.99

Table 1 shows that using 1.084 grams of plastic waste gives the best results with a compressive strength value of 8.04 MPa. On plastic waste contains 2.168 grams, the resulting compressive strength decreases to 5.14 MPa. It is indicating a reduction in material strength as the proportion of plastic waste increases.

This decline becomes even more significant when the amount of plastic waste is raised to 4.336 grams, resulting in the lowest compressive strength of 4.02 MPa. These finding suggest that increasing the amount of plastic waste in the material mixture is inversely proportional to the compression strength achieved.

F. Analysis of Variance

Analysis of Variance is a statistical method used to compare the mean values across three variations of plastic waste material proportions. The following hypotheses are:

H_0: Three variations of plastic waste material proportions doesn't have different compressive strengths.

H_1: Three variations of plastic waste material proportions have different compressive strengths.

Based on the calculation from Sum of Square Between Treatment, the Sum of Square Within Treatment, and the Sum of Square Total, with K=3 and N=9, Analysis of Variance's Results as shown in table 2.

Table 2 Analysis of Variance

Variations Source	Df	Sum of Square	Mean Square	F Ratio
Between Treatment	2	11.3699	5.6849	5.89
Within Treatment	6	5.7899	0.9650	
Total	8	17.1598		

From Table F, with α = 5% and degrees of freedom V1 = 2 and V2 = 6, the F Table value = 5.14 is obtained. This shows that, simultaneously, the three variations in the proportion of plastic waste produce different compressive strengths. Analysis of Variance only provides information that the treatment variations simultaneously produce different results, but does not yet show which treatments produce significantly different results. Therefore, further testing using the Newman-Keuls test.

G. Newman-Keuls Test

The Newman-Keuls test is used to determine which treatments are significantly different, so that the difference between the mean of roster strength from the three variations in plastic waste material dosages are 1.084 gram, 2.168 gram, and 4.336 gram can be tested. With the test, the proportion of plastic waste material that produces the best roster strength can be determined. The following are steps of the Newman-Keuls Test:

1. The mean values of treatments are arranged from smallest to largest for stepwise pairwise comparison as shown in table 3.

Table 3 Average Treatment Value

Treatment	2.168 gr	4.336 gr	1.084 gr
Average	4.79	5.82	7.52

2. From Analysis of Variance (Table 2), the Mean Square Within Treatment = 0.9650 with a degree of freedom (df) = 6.

3. The standart deviation value for each treatment:

$$S_{\bar{X}i} = \sqrt{\frac{MSW}{ni}} = \sqrt{\frac{0.9650}{3}} = 0.5672$$

4. From Studentized Range Statistics Table (Tabel-q) as shown in figure 10, with a degree of freedom (df) = 6 and α = 5% obtained range value as shown in table 4.

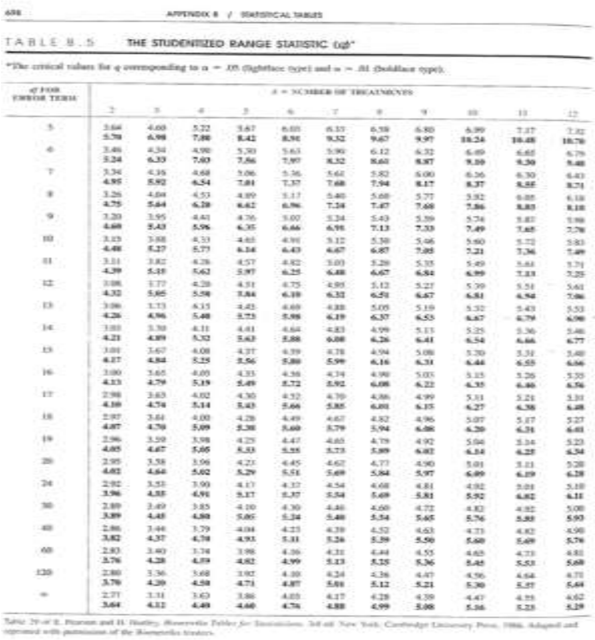

Figure 10 Studentized Range Statistics

Table 4 Range Value

P	2	3
Range Value	3.46	4.34

5. Each range value is multiplied by $S_{\bar{X}i}$, resulting the smallest significant range value for each P as follows:
   P = 2: RST = 3.46 x 0.5672 = 1.9625
   P = 3: RST = 4.34 x 0.5672 = 2.4616
6. Compare the difference between the two treatment mean value with each RST Value:
   a. Largest Mean Value vs Smallest Mean Value (1.084 gram vs 2.168 gram)
      = 7.52 – 4.79 = 2.73 > 2.4616
      Meaning: The difference in strength between 1.084 gram vs 2.168 gram is significant.
   b. Largest Mean Value vs The Second Smallest Mean Value (1.084 gram vs 4.336 gram)
      = 7.52 – 5.82 = 1.70 < 1.9625
      Meaning: The difference in roster's strength between 1.084 gram vs 4.336 gram is not significant.
   c. The Second Largest Mean Value vs Smallest Mean Value (4.336 gram vs 2.168 gram)
      = 5.82 – 4.79 = 1.03 < 1.9625
      Meaning: the difference in roster's strength between 4.336 gram vs 2.168 gram is not significant.

Based on Newman-Keuls test, it can be concluded that there is a significant difference in roster's strength between the proportions of 1.084 gram with 2.168 gram. The proportions of 1.084 gram of plastic waste material produced the best roster's strength, with an average compressive strength test of 7.52 MPa.

H. Roster Strength Comparison

Based on SNI 3.03439.1989 regarding the quality level of hollow concrete, it is explained that roster not included in Quality IV with an average of minimum concrete compressive strength of 20 Kg/cm^2. Based on this reference, roster concrete is included in category of Class I concrete, which is commonly used for non-structural work. This grade represents the lowest class of concrete and does not use steel as reinforcement material, consequently the average compressive strength of roster concrete of ≥ 2.5 MPa [18].

Research conducted by (Sulthon,2024) and (Umar,2019), rosters are one of non-structural element in building construction that function as partitions and air ventilation media, characterised by holes or gaps on their surface. It is also worth noting that the Roster's presence can enhance the aesthetic appeal of a room while also contributing to the circulation of air and natural light inside the room.

However, due to its hollow structure and lack of reinforcement, the compressive strength produced by roster is relatively lower than that of solid concrete elements. Based on the reported test results that the average compressive strength value of rosters appears in a range from 0.8 MPa to 2.5 MPa [19], [20].

Based on the reference on the compressive strength of rosters, a comparison of the results of the compressive strength test of rosters from this research, as shown in table 5.

Table 5 Comparison of Compressive Strength of Roster

	Roster A	Roster B	Roster C	Roster D
Roster Compressive Strength (MPa)	7.52	≥ 2.5	4.0	2.5

Description:
Roster A: This Research Roster
Roster B: SNI Roster
Roster C: Factory Roster
Roster D: Previous Research Roster

Table 5 shown that the roster produced in this research stronger than SNI roster, factory roster, and roster from previous researches, as it has the highest compressive strength (7.52 MPa).

CONCLUSIONS

The development of the roster utilising High-Density Polyethylene (HDPE) and Polypropylene (PP) plastic waste was carried out by mixing plastic waste in varying proportions: 1.084 gram, 2.168 gram, and 4.336 gram. Meanwhile the controlled materials were sand (119.056 gram), coarse aggregate (106.888 gram), gypsum powder (37.536 gram), and water (1.5 litres). From this material mixture produced rosters with considerable strength.

The variation in the proportion of High-Density Polyethylene (HDPE) and Polypropylene (PP) plastic waste significantly influenced the compressive strength of roster. The composition with 1.084 grams of plastic waste produced a compressive strength of 7.52 MPa. This strength exceeds the minimum SNI Standard (≥ 2.5 MPa) as commonly a compressive strength of rosters. This indicates that the roster based on plastic waste with a 1.084 gram composition possesses excellent potential for application in terms of compressive strength.

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