Journal of Applied Engineering and Technological Science
Vol 6(2) 2025: 1412-1428

DEVELOPMENT OF RAMMED EARTH MATERIAL TECHNOLOGY BY UTILIZING PLASTIC WASTE AS REINFORCEMENT ON THE PARTITION WALLS OF THE BUILDING ROOM

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Received: 21 August 2024, Revised: 08 February 2025, Accepted: 18 March 2025
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ABSTRACT
In order to improve the compressive and bending strength of rammed earth materials for use in partition walls, this study investigates the incorporation of plastic trash. The goal of the research is to enhance the performance of sustainable construction materials while addressing the environmental problem of plastic waste. Using a Universal Testing Machine (UTM), compressive and bending strength tests were performed after 30 days for rammed earth mixtures containing four different amounts of plastic trash (0%, 1%, 3%, and 5%). According to the findings, adding plastic trash can increase compressive strength by up to 3%, reaching a maximum strength of 5.17 MPa. However, compressive and bending strength significantly decreased when the plastic percentage was increased over 3%, with the 5% plastic showing the worst performance. According to these results, plastic trash can enhance material performance, but its use requires careful optimization. By putting forth a novel technique for recycling plastic trash, the study supports sustainable building practices and provides a workable substitute for non-load-bearing applications such as partition walls. This study advances our understanding of green building technologies and offers workable ways to cut down on plastic waste in the building industry.
Keywords: *Rammed Earth, Partition, Material, Wall, Plastic Waste.*

1. Introduction

Indonesia is the nation with the fourth-highest population in the world. With 270.2 million people living in 2020. Population growth has an impact on the stages of development (Anysz & Narloch, 2019). Indonesia is rapidly becoming more urbanized and industrialized, which is driving up demand for building material. The demand for building materials has grown as a result of this expansion, raising questions about the sustainability of these materials from an environmental standpoint. At the same time, the nation's 66 million tons of plastic garbage per year provide a serious environmental concern (Wangmo et al., 2021). Adding to the idea of sustainable building, the ancient building method known as rammed earth is regarded as environmentally friendly because of its low embodied energy and minimal influence on the environment (Gomes et al., 2014; Serrano et al., 2016). This strategy is innovative since it encourages sustainable building practices while also lowering plastic waste. This approach immediately tackles the pressing need to repurpose non-biodegradable waste, in contrast to other green materials that just concentrate on lowering emissions. Buildings are responsible for more than one-third of the world's energy use and CO_2 emissions (Jiang et al., 2022), therefore turning plastic trash into building materials is a creative and timely solution. The desire to lessen environmental damage brought on by plastic trash and the worldwide push for sustainable building technologies only serve to increase this urgency. For building partitions, rammed earth reinforced with plastic trash offers a versatile, affordable, and environmentally beneficial option, particularly in commercial settings where flexible and lightweight materials are needed.

Buildings with materials derived from the earth are methods as well as materials that are proven to be environmentally friendly / sustainable but still maintain the sturdiness of their construction (Miqueleiz et al., 2012; Oti et al., 2009). Rammed earth constructions are now competitive with traditional materials because of their low embodied energy (Morel et al., 2001). Earthen building construction methods are being reexamined in light of the onset of man-made climate change as a potential way to construct buildings in an eco-friendly manner; however, in comparison to more established methods like steel and concrete, there has been a lack of development of building codes and standards (Bui et al., 2009). The process of creating earth, which is somewhat moist and compacted using a wood rammer in a formwork, is known as "rammed earth". Earth is layered within a shuttering at a depth of 10 to 15 cm. Every layer is spread out with a foot, and then the edges of the rammer are tamped down. The layers of rammed earth are 6–10 cm thick after compaction. The formwork is moved horizontally to continue wall building after all layers within a shuttering have been compacted (Hamard et al., 2020).

Today's technology and innovation lead to sustainable green materials without harming the environment. Green materials include being made by utilizing existing environmental waste or by utilizing natural energy for buildings. Plastic waste in Indonesia is increasing today. Indonesian Central Bureau of Statistic (BPS) 2021 data states that Indonesia's plastic waste reaches 66 million tons per year, so that Indonesia has been named the second largest producer of marine plastic waste in the world based on Jambeck's research in 2018 (Wangmo et al., 2021). Meanwhile, the need for plastic materials cannot be separated from the lives of the Indonesian people. Therefore, this research develops rammed earth technology materials by utilizing plastic waste as reinforcement on the partition walls of building spaces so that it is expected to be a solution to reduce plastic waste in Indonesia.

Therefore, in order to compete with more traditional building materials like steel and concrete, rammed earth's mechanical qualities must be improved to meet modern construction standards (Nabouch et al., 2016). Although prior research has concentrated on stabilizing rammed earth using additions like cement and lime, nothing is known about employing plastic waste as reinforcement in rammed earth construction. This work fills that gap by investigating how plastic garbage might improve rammed earth's bending and compressive strengths, providing a novel method to both waste management and sustainable building practices.

In order to create a novel building material that lessens plastic waste and encourages sustainable building, the aim of this study is to assess the effects of adding plastic trash to rammed earth mixes on compressive and bending strength. By giving a workable answer to Indonesia's plastic waste problem and fresh perspectives on the creation of environmentally friendly building materials, this study seeks to advance the domains of trash management and green building technology.

2. Literature Review

Clay is the only binder used in traditional rammed earth construction, also known as un-stabilized rammed earth. To improve the durability and mechanical qualities of stabilized rammed earth, additional binders such cement, lime, or coal ash are applied. However, using these binders raises the expense of building and has an adverse effect on the environment. Earth is being used more often in modern architecture due to its superior environmental performance, which includes minimal emissions, no waste from demolition, the ability to use recycled materials or industrial byproducts as additives, etc (Rodríguez-Mariscal et al., 2021; Zhang et al., 2024).

New versions of rammed earth material technology have appeared and gained popularity in some parts of the world. Rammed earth material technology that has been developed for a long time, in the form of wall or floor layers made of several layers of compacted soil or unsustainable rammed earth construction categories. While the new version uses cement and clay water or stabilized rammed earth construction categories (Kariyawasam & Jayasinghe, 2016). Rammed earth walls are monolithic constructions created by compacting the tillage in a progressive layer in a rigid formwork. Soil, sand, and gravel are the basic materials used for the construction of unstable rammed earths, while stabilized rammed earths involve mixing inorganic additives such as cement or lime into the base material. The compressive strength of rammed earth material is determined by factors such as soil type, particle size distribution, and stabilizer used so that this material is able to become a structural element that is resistant to fire, absorbs heat in the middle of the day and releases heat at night. The size of the rammed earth for load-bearing walls is 12 inches. It uses a wide roofing system to protect this wall material from being exposed to rain. This size is very thick to make rammed earth the material of the walls in the building. By reducing and adding mesh reinforcement (wire mesh) in the rammed earth layer, it can reduce the size of this material and have the same strength so that it can be used as a green material for building space partitions. Building space partitions have flexible properties so that they can separate the space into two spaces of different functions. Usually used by commercial high-rise buildings to reduce the burden on buildings. The partition material of building space is usually in the form of particleboards made of wood. Particleboards like this tend to have more weight, weak binding strength, and tend to crumble easily at the ends. Made from wood makes the need for wood increase, this is feared to damage nature.

Rammed earth has emerged as a sustainable building material and construction method. To make solid brick walls, it entails compacting unprocessed soil—often combined with water and additives—into makeshift molds (Marais et al., 2015). The flexibility of rammed earth to employ locally accessible resources lessens the environmental impact of conventional building materials like steel and concrete, making it an environmentally friendly option. Rammed earth's capacity to perform well in nearly any climate, provide passive thermal benefits, and last longer than most conventional buildings highlight its sustainable attributes (Narloch et al., 2015). However, there are still issues with rammed earth constructions' mechanical performance, especially when it comes to increasing their strength and longevity (Gomes et al., 2014). The lack of uniform regulations and the comparatively poor mechanical qualities of rammed earth in comparison to more traditional materials have impeded its use in contemporary building, despite its historical relevance (Kumar & Whittaker, 2018).

Recent research has investigated the use of cement, lime, and other stabilizers as well as other additives to stabilize rammed earth (Toufigh & Kianfar, 2019). According to these investigations, these additions increase the rammed earth buildings' compressive strength, which makes them more competitive with conventional materials. However, because of the environmental impact of cement production, these methods frequently come at the expense of sustainability (Rodríguez-Mariscal et al., 2021). Given the paucity of studies on using plastic trash as a reinforcing material for rammed earth, this points to a crucial gap in the literature. Closing this gap could result in the creation of novel, environmentally friendly building materials that also address the problem of plastic waste.

Many studies have been conducted on the incorporation of plastic trash into building materials, especially for use in asphalt and concrete (Biswas et al., 2021). Waste plastic, particularly high-density polyethylene (HDPE), has shown better tensile and flexural strength when utilized as a partial substitute for natural aggregates (Royani et al., 2014). The use of plastic aggregates in place of some of the natural particles in lightweight concrete has been the subject of numerous investigations. When added to concrete mixtures, a variety of plastics have been studied, including low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polyethylene terephthalate (PET), which is frequently used for bottles. PET aggregates were discovered to have the ability to both improve and decrease concrete's water absorption and strength. Because of its high density and corresponding strength, HDPE—one of the most widely produced plastic waste materials—is especially well suited as a replacement aggregate in concrete. However, little is known about using plastic trash in rammed earth. There are still issues with the consistency of plastic dispersion within the material and its bonding with other components, despite research showing that adding plastic waste can improve specific mechanical properties like compressive and tensile strength (Saikia & de Brito, 2013). In order to solve these issues, this study will assess how well plastic trash works as a reinforcing element in rammed earth, especially for usage in partition walls.

The simultaneous emphasis on waste management and sustainable building is what makes this study novel. This study investigates the possibility of using plastic waste as a stabilizing and reinforcing material in rammed earth technology, whereas earlier research has concentrated on conventional stabilizers. This method not only improves the rammed earth's mechanical qualities but also offers a creative way to address the world's plastic waste problem. The use of recycled plastic in building has expanded due to recent developments in plastic waste recycling technology (2019–2023), which provide a more environmentally friendly substitute for conventional stabilizers (Biswas et al., 2021).

Using rammed earth technology and plastic trash, the current work closes a large gap in the literature. Although plastic's use in concrete, bricks, and other construction materials has been studied in the past, little is known about how it can be used in rammed earth, especially for partition walls that are not load-bearing. By investigating the compressive and bending strengths of rammed earth reinforced with plastic trash, this study aims to close this gap. By doing this, it supports waste management initiatives as well as the sustainability objectives of the construction sector (Giuffrida et al., 2021).

Understanding how these advances fit into larger theoretical frameworks in sustainable construction is necessary in addition to the technical difficulties. The circular economy, which stresses material reuse and recycling to lessen environmental effect, is the foundation of this study (Pomponi & Moncaster, 2019; Adams et al., 2017; Yuan & Bi, 2006; Geissdoerfer et al., 2017). This study supports the circular economy by turning non-biodegradable garbage into a useful building material by incorporating plastic waste into rammed earth. Material science approaches that concentrate on improving the mechanical properties of building materials through creative reinforcing techniques also inform the theoretical underpinnings of this study. This dual theoretical approach offers a strong foundation for assessing the possibilities of plastic-reinforced rammed earth by fusing material science with the concepts of the circular economy.

3. Research Methods

Materials

The major components for this study are local soil and plastic garbage. The soil was selected because it is suitable for rammed earth construction, which necessitates a particular sand, gravel, and silt mixture to guarantee mechanical performance and adequate compaction. As per the guidelines presented by Krahn (2019) in "Essential Rammed Earth," the soil needs to fulfill particular gradation and particle size distribution specifications in order to function at its best in rammed earth constructions. With particle sizes ranging from fine sand to medium gravel, the soil utilized in this study was carefully chosen using these parameters. To make sure the soil was suitable for rammed earth building, its qualities were examined using ASTM standards.

Plastic garbage was chosen as a reinforcing material because of its widespread availability and environmental benefits. Because of its advantageous mechanical qualities, including high tensile strength and resistance to degradation, high-density polyethylene (HDPE) was mainly utilized. HDPE is a great option for reinforcing rammed earth since it can increase the tensile and flexural strength of construction materials, according to studies by Saikia & de Brito (2013) and Biswas et al. (2021). In addition to addressing material performance and environmental concerns, the choice to employ plastic waste is consistent with sustainable building and waste management principles.

Sample preparation

Four types of rammed earth samples were created with varying percentages of plastic waste (0%, 1%, 3%, and 5%) by weight of cement. Preliminary research and recommendations from pertinent literature on the integration of plastic waste into building materials were used to determine the percentages (Biswas et al., 2021). The objective was to assess how different plastic contents affected the rammed earth's bending and compressive strengths.

Compressive Strength Samples: For the purpose of testing compressive strength, upright beams measuring 50 mm by 50 mm by 200 mm were constructed. Samples of Bending Strength: For the purpose of testing bending strength, wall-like samples measuring 200 mm by 50 mm by 200 mm were made.

The dirt, cement, water, and plastic garbage were combined in the designated ratios to create each sample. A manual rammer was used to compact the mixture in layers, making sure that each layer was completely compressed to reach the highest density possible.

Instrument Used

Compressive and bending strength tests were conducted using the Universal Testing Machine (UTM). The UTM ensures accuracy in evaluating the mechanical properties of the material by precisely measuring the force applied to the samples. The UTM was selected because it provides accurate measurements of both compressive and bending strength, which are essential for assessing the performance of rammed earth materials. The choice of soil and plastic waste as materials was informed by existing research (Biswas et al., 2021; Saikia & de Brito, 2013) demonstrating the potential benefits of using these materials in sustainable construction. In order to verify that the soil utilized satisfies the gradation requirements for rammed earth building, sieves and sieve shakers are employed for particle size analysis. ASTM standards (No. 4, 8, 16, 30, 50, 100, 200) were adhered to by the sieves. To guarantee that the moisture level was regulated and constant across all samples, the soil was dried in the oven prior to mixing an oven was used in this study.

Data analysis techniques

For each test (compressive and bending strength), 24 samples were created, 6 for each variation in plastic waste content. In order to guarantee statistical reliability and provide a solid dataset for the compressive and bending strength tests, this sample size was used. Following 30 days of curing—a typical amount of time for the material to acquire its maximum strength—testing was carried out in accordance with SNI 03-4431-2011 and EN 12390-3:2001 specifications.

Compressive Strength Testing: To ascertain the samples' maximum compressive strength, a Universal Testing Machine (UTM) was used. Each sample's compressive force was measured, and the findings were averaged for each variation across the six samples. Compressive strength is the ability to withstand or carry a load (resistance to pressure). Rammed earth compressive strength testing was performed on 30-day-old test objects using the EN 12390-3:2001 method.

$$fc = \frac{F}{A_c} \tag{1}$$

Where:
f c = Compressive force (Mpa)
F = Maximum load (N)
Ac = Cross-sectional area of the test piece

Bending Strength Testing: In a similar manner, a UTM was used to test the samples' bending strength under a two-point loading system. The data were averaged, and the maximum load applied prior to the sample failing was noted.

Rammed earth bending strength testing was carried out on test objects aged 30 days using the SNI method 03-4431-2011.

$$Fr = \frac{P \ x \ L}{b \ x \ h^2} \tag{2}$$

Where:
Fr = Bending Strength (Mpa)
P = Maximum load (N)
L = Span length (mm)
b = Width of the test piece (mm)
h = Height of the test object (mm)

The data obtained from the test results of compressive strength and bending strength of *rammed earth* as the dividing wall of the room were further analyzed. The data will be analyzed by performing a simple linear regression analysis, which is an analysis that is useda n to measure the influence of plastic waste (free variable / X) on the strength of *rammed earth* (bound variable / Y). Used model simple linear regression according to (Sugiyono, 2013).

$$Y = a + bX \tag{3}$$

Where:
X = Free Variable
Y = Bound Variable
a = Constant
b = Regression Coefficient

Then the F Test was carried out to see whether or not the free variable free variables (independent) were significantly measured together against the bound (dependent) variables. This test is carried out by comparing the calculated F with the table F, the conditions for declaring the F significant test are as follows:

a. If Fcount ≤ Ftable or the significant value of the test F > 0.005 then Ho is accepted, meaning that the free (independent) variables simultaneously have no effect on the bound (dependent) variables.
b. If Fcount > Ftable or the significant value of the F test < 0.005 then Ho is rejected, meaning that the free (independent) variables simultaneously affect the bound variables (dependents).

4. Results and Discussions

Test Objects

The design of the test object mixture begins with preliminary testing activities. In this study, preliminary testing is intended to see the characteristics of the constituent materials before making the test object, so that the constituent materials to be mixed are in accordance with the standard mixture of rammed earth materials. The preliminary tests that need to be done include:

1) Destruction of soil material
The initial stage, the soil material taken from the quarry must be destroyed first to obtain the desired grain size.
1) Soil drying process
If the condition of the soil obtained is wet or humid, then the soil material must be dried by drying it in the sun or by putting the material in the oven (Rodríguez-Mariscal et a., 2021).
2) Cleaning of plastic waste:
Plastic waste obtained from various sources, must be cleaned first to remove traces of food or drink attached to the plastic packaging. Cleaning is done by soaking plastic waste in soapy water for 24 hours then rinsing thoroughly.
3) Sieve Analysis (after gradation recommended by Krahn, 2019)
This examination is carried out to determine the size of the soil grains used as the main material in making *rammed earth*, according to the size of the soil grains based on Krahn standards. The results of the sieve analysis tests that have been carried out can be seen in the figure 1.

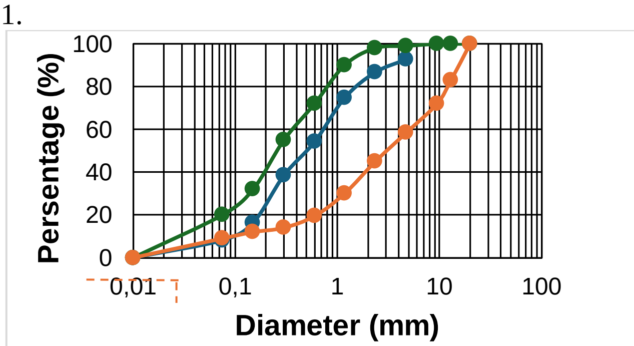

Fig. 1. Soil grain size

The graphic results also show that the soil grain size obtained from the results of sieve analysis tests that have been carried out in this study previously met the soil grain size requirements for rammed earth based on Krahn standards, (2019). Based on figure 1, about

5.3 g of soil radiation that escapes is between the maximum and minimum grain sizes (Table 1).

Table 1 - Soil Gradation Examination Results

Sieve Number	Diameter sieve holes (mm)	Retained weight (grams)	Percentage held (%)	Percentage of compulsive restrained (%)	Percentage of escaped granules
4	4.75	35.5	7.41	7.14	92.7
8	2.36	29.2	6.09	13.49	86.7
16	1.18	58.6	12.23	25.72	74.7
30	0.6	99.7	20.80	46.53	54.2
50	0.3	76.2	15.9	62.42	38.5
100	0.15	107.3	22.39	84.81	16.4
200	0.075	32.2	6.718	91.53	8.2
Pan	-	40.6	8.47	100	0

4) Soil Water Content

This examination is carried out to determine the condition of the soil levels that will be used as the main material in making *rammed earth*. Testing of soil moisture content in this study using the ASTM D-2216-71 method reference (Table 2).

Table 2 - Soil Water Content Test Results

Information	Unit	Sample 1	Sample 2	Average
Saucer weight, WI	Gram	13.7	13	
Weight (saucer + wet soil), W2	Gram	63.7	69	
Oven Weight (saucer + dry soil), W3	Gram	57.1	61.6	
Water Weight (W2-W3), Ww	Gram	6.6	7.4	
Dry soil weight (W3-W1), Ws	Gram	43.4	48.6	
Groundwater content (Ww/Ws x 100), W (%)	%	15.20	15.23	15.22

Composition of Rammed Earth and Plastic Rebar Mixture

Furthermore, mixed planning is the process of determining the portion of mixtures in the manufacture of *rammed earth* mortar. The needs of the materials that will be planned for the *rammed earth* mixture in this study are, 75% soil, 25% cement, PP plastic addition with variations of 0%, 1%, 3%, and 5% of the cement weight. The need for water in the rammed earth mixture is 13% of the weight of the soil. The mixed planning applied in this study is also based on the guidebook of *rammed earth* construction methods by Krahn, (2019) entitled "*Essential Rammed Earth"*.

The calculation of c ampuran is based on the volume used for the manufacture of one test object. Where the overall percentage of the material is taken from the total specific gravity of *rammed earth*. The composition of the *rammed earth* mixture for every 1 m³ is presented in the following table 3 and table 4.

Table 3 - Composition of Rammed Earth Mixture for 1 m³ (Upright Beam)

No	Composition	Unit	*Rammed Earth*			
			0%	1%	3%	5%
1	Soil	gram	658.44	659.9	662.8	665.8
2	Content	gram	265.5	266.1	267.3	268.4
3	Water	gram	138.06	138.3	138.98	139.6
4	Plastic	gram	-	10.7	32.1	53.7

Table 4 Composition of Rammed Earth Mixture for 1 m³ (Wall)

No	Composition	Unit	*Rammed Earth*			
			0%	1%	3%	5%
1	Soil	gram	2633.76	2639.3	2651.3	2663.1
2	Content	gram	1062	1064.4	1069.1	1073.8
3	Water	gram	552.24	553.5	555.9	558.4
4	Plastic	gram	-	42.6	128.3	214.8

Analysis of the composition of the mixture in m³:

a) Soil requirement

= 62% of the specific gravity of *rammed earth* = Bj. *Rammed earth* x Percent material

= 2,124 x 62%
= 1316.88 kg/m³

b) Cement Requirement = 25% of the specific gravity of *rammed earth*
= Bj. *Rammed earth* x Percent material
= 2,124 x 25%
= 531 kg/m³

c) Water requirement = 13% of the specific gravity of *rammed earth*
= Bj. *Rammed earth* x Percent material
= 1316.88 x 13%
= 276.12 liters/m³

d) Plastic Needs
Here arethe variations of plastic as an added material
Specific gravity of plastic 473 kg/m³
Plastic 1% = 473 x 1% = 4.73
Plastic 3% = 473 x 3% = 14.19
Plastic 5% = 473 x 5% = 23.65

Then the need for plastic:

a) Variation of 0% plastic = 0% of the specific gravity of *rammed earth*
= Bj. *Rammed earth* + plastic 0%
= (2,124 + 0) x 0
= 0 kg/m³

b) Variation of 1% plastic = 1% of the specific gravity of *rammed earth*
= Bj. *Rammed earth* + plastic 1%
= (2,124 + 4.73) x 1%
= 21.2873 kg/m³

c) Variation of 3% plastic = 3% of the specific gravity of *rammed earth*
= Bj. *Rammed earth* + plastic 3%
= (2,124 x 14.19) x 3%
= 64.1457 kg/m³

d) Variation of 3% plastic = 5% of the specific gravity of *rammed earth*
= Bj. *Rammed earth* + plastic 5%
= (2,124 x 23.65) x 5%
= 107.3825 kg/m³

Composition Mixture *rammed earth* for 1 upright beam object. Upright beam molds with an area of 50 mm x 50 mm and a height of 200 mm.

Volume 1 of the test piece
= 50 x 50 x 200
= 0.0005 m³

An example of material calculation for one test object is as follows:

For Variation 1%

a. *Soil = Number of soils* x *vol.* 1 *test piece*
= 1316.88 x 0.005
= 658.44 gr

b. *Cement= Amount of cement* x *vol.* 1 *test piece*
= 531 x 0.0 005 gr
= 265.5 gr

c. Water= *Amount of water* x *vol.* 1 *test piece*
= 276.12 x 0.0 0 0 5
= 138.06 gr

d. Plastic= *Amount of plastic* x *vol. 1 test piece*
= 0 x 0. 0005
= 0 gr

Komposition *Rammed earth* mixture for 1 wall test piece. Used wall molds with a size of 20 cm x 5 cm x 20 cm.

Volume of the one test piece = 0.002 m³
An example of material calculation for one test object is as follows:
For 0% variation

a. *Soil = Number of soils* x *vol.* 1 *test piece*
   = 1316.88 x 0.002
   = 2633.76 gr
b. *Cement = Amount of cement* x *vol.* 1 *test piece*
   = 531 x 0.0135
   = 1062 gr
c. Water = *Amount of water* x *vol.* 1 *test piece*
   = 276.12 x 0. 002
   = 552.24 gr
d. Plastic = *Number of plastics* x *vol.* 1 *test piece*
   = 0 x 0.002
   = 0 gr

Manufacture of Test Objects

The process of making mortar carried out in this study includes the following:

1. Prepare the main materials to make rammed earth materials, namely soil, cement and water. Where each of these materials has been weighed according to the required proportions.
2. Prepare additional materials in the form of plastic according to the percentage of plastic to be used including 0%; 1%; 3%; and 5%).
3. After all the materials needed to make the rammed earth specimen mortar are available, then start making rammed earth mortar by mixing all the ingredients.
4. If the mortar has been mixed well, before the mixture is printed first the mortar is tested by the method of dropping the ball, with the aim of knowing whether the mixture made has an appropriate moisture content to compact.

Specimen printed on molds of beams and walls. There are 3 specimens each for each percentage of plastic.

Rammed earth printing is carried out after the mortar is thoroughly mixed according to the desired conditions. The printing stages carried out in this study include the following:

a. Gradually insert the rammed earth mortar into the mold.
b. The mortar is gradually ground on each side using a pounding rod. Each specimen is manually compacted with a pounding rod.
c. For compaction specimens consist of three layers with as many as 50 each carried out in the circumference of each mold area for every one layer.
d. After the insertion and mortar stage inside the mold is completed, then the specimen is opened from the mold then the wet mass of the specimen is weighed.
e. Put a mark with a colored marker on the specimen.

Test Object Care

The treatment of specimens in the study was carried out on the basis of the method carried out by Koutous Hilali, as follows:

1) Specimens that have been removed from the mold are marked using markers, this is intended to facilitate the process of identifying rammed earth specimens.
2) Weigh the marked specimen to see its wet mass.
3) Then carry out the treatment by drying the specimen at an air temperature of 20˚C to 25˚C.
4) Do this drying process repeatedly every day, until you reach the desired age plan.
5) After 30 days the weight of each specimen is re-weighed, then the specimens are tested. Where cylindrical specimens to be tested for compressive strength and beam specimens to be tested for bending strength.

Compressive Strength Test Results

Compressive strength testing on rammed earth material aims to determine the ability of rammed earth material to withstand maximum compressive load before collapsing. Rammed earth specimens are made in the form of upright beams with a height of 20 cm; width 5 cm; and 5cm thick. In the test press, the test object is pressed using a CTM (Concrete Testing Machine) tool until it is destroyed. Hacel testing of rammed earth compressive strength is known to be compressive strength through a straight ratio between the maximum load and the compressive plane area expressed in N/mm² or MPa. Data on the results of compressive strength testing at the age of 30 days based on the results of calculating the average compressive strength of all variations can be seen in table 5.

Table 5 - Rammed Earth Compressive Strength Test Results with Plastic Waste

Test Object Code	Cross-sectional Area (mm^2)	Upright Beam	Max load		Compressive Strength (MPa)	Average Compressive (MPa)
			(kN)	(N/mm^2)		
		A	20.57	20570	4.57	
RE PP 5%	4500	B	19.8	19800	4.40	4.26
		C	17.18	17180	3.82	
		A	25.56	25560	5.68	
RE PP 5%	4500	B	18.86	18860	4.19	4.63
		C	18.07	18070	4.02	
		A	25.55	25550	5.68	
RE PP 5%	4500	B	19.23	19230	4.27	5.17
		C	25.08	25080	5.57	
RE PP 5%	4500	A	21.12	21120	4.69	1.56

*RE = Rammed earth

The compressive strength test results in Table 5 and Figure 2 show data on the average compressive strength test results of rammed earth with the addition of plastic waste at the age of 30 days, namely in RE PP0% specimens obtained an average compressive strength about 4.26 MPa. In the RE PP1% specimen, an average compressive strength about 4.63 MPa was obtained. In the RE PP3% specimen, an average compressive strength about 5.17 MPa was obtained. In RE PP5% specimens, an average compressive strength about 1.57 MPa was obtained. Based on the data of the specimen compressive strength test results, the optimum compressive strength value occurs in the variation of the RE PP3% specimen. While the minimum compressive strength occurs in variations in RE PP5% specimens. Based on the test results obtained, it shows that the greater the percentage of plastic waste used, the higher the compressive strength. This pattern of data implies that including plastic trash up to a particular percentage (3%) can improve the compressive strength of rammed earth, as seen in studies by Araki et al., (2016). In line with our findings for the RE PP3% specimen, discovered that adding more LDPE plastic trash to concrete increased compressive strength. However, strength decreases above 3%, which is consistent with findings from Royani et al., (2014), who found that increasing plastic content could degrade material qualities due to poor binding characteristics. Similar to how Jiang et al., (2022) showed that mixes with a higher moisture content decreased tensile strength because they had less suction, our investigation suggests that too much plastic waste impairs the overall structural integrity by creating voids. A threshold for the usefulness of plastic waste as a reinforcing material is indicated by the linear regression analysis in Figure 2, which shows a good connection (R2 = 0.673) between plastic content and compressive strength up to 3%. After that, the correlation becomes less.

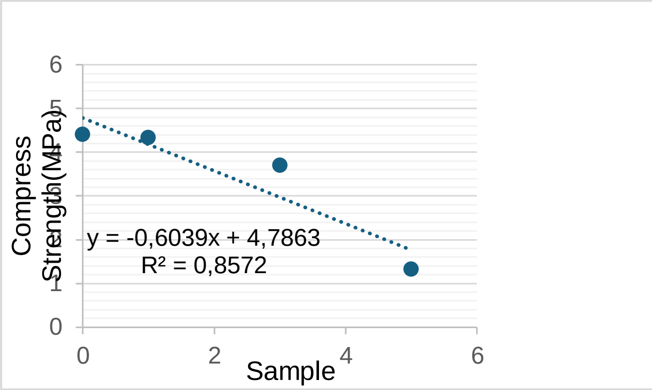

Fig. 2. Compress Strength

The results of the regression analysis obtained; the similarity of the regression model can be written Y = – 4.866x + 5.0024. The maximum correlation value between x (Variation of test objects) and y (Compressive strength) is 0.673 this value is between 0.60 – 0.799, which is a strong correlation category. There is a crucial limit to the beneficial benefits of plastic waste on compressive strength, though, as the link becomes weaker after this. This implies that although discarded plastic can be useful, its use in rammed earth needs to be carefully managed to avoid sacrificing the integrity of the material. It is explained that the magnitude of the percentage of influence of variable x (Variation of test objects) on variable y (Compressive strength) called the coefficient of determination is 0.453 or 45.3%. While the rest is influenced by other factors beyond the variable x. The significant value of F obtained is 0.327 and the value of F count = 1.659, where the condition of the significant value f < alpha 0.005 or F count > F table. It defines that the variation of the test object (x) to the compressive strength (y) has no simultaneous/significant effect not.

Compairing these findings to Jiang et al. (2022), which examined the tensile strength of rammed earth with different water contents, shows a similar pattern to ours: the material's strength increases under ideal conditions (plastic content in our study, water content in theirs), but excessive modification results in a decrease in performance. Their findings demonstrated that strength was enhanced by increased suction brought on by a decreased water content, whereas our findings imply that the ideal plastic content increases compressive strength before causing structural flaws.

The tensile strength of the layer interfaces inside the rammed earth specimens that were the weakest should be assessed using a direct tension test. Although the tensile stress is mobilized inside the compaction layers, a splitting test assesses the strength associated with the tensile strength inside the layers (Araki et al., 2016). According to Xu et al. (2018), shear behaviour of rammed earth under various clay content and relative humidity circumstances was shown to be more ductile under higher relative humidity levels and more brittle under lower relative humidity levels. At higher clay levels, this tendency was more pronounced. At the same stress level, there was a clear increase in residual strain concurrent with the rise in relative humidity. - At constant relative humidity and confining pressure circumstances, shear strength fc increased as clay content rose (within the range of values studied). The amplitude of this amplification reduced with increasing relative humidity because of the softening effect of water on clay.

Bending Strength Test Results

Testing the bending strength of rammed earth with the addition of plastic waste as a substitution of cement aims to determine the maximum bending strength value that occurs before the rammed earth material collapses. This bending test loading method uses 2 loading points.

The results indicate a varied pattern in terms of bending strength. The RE PP5% specimen had the lowest bending strength (1.31 MPa), whereas the RE PP0% specimen had the highest (4.39 MPa), as shown in Table 6. The inadequate bonding between the plastic particles and the surrounding soil-cement mixture may be the reason for the steady decline in bending strength that occurred as the amount of plastic rose. This is consistent with research by Saikia and de Brito (2013), who found that weak spots under tensile or bending stress are frequently caused by plastic waste in building materials because of inadequate bonding.

Table 6 - Bending Strength

Test Object Code	Wall	I(mm)	b(mm)	h(mm)	P		Strong Bending (MPa)	Average Bending Strength (MPa)
					(kN)	(N/mm^2)		
	A	200	200	50	9.18	9180	3.67	
RE PP 5%	B	200	200	50	10.63	10630	4.25	4.29
	C	200	200	50	13.11	13110	5.24	
	A	200	200	50	11.33	11330	4.53	
RE PP 5%	B	200	200	50	10.77	10770	4.31	4.31
	C	200	200	50	10.26	10260	4.10	
	A	200	200	50	10.1	10100	4.04	
RE PP 5%	B	200	200	50	8.9	8900	3.56	3.69
	C	200	200	50	8.69	8690	3.48	
RE PP 5%	1	200	200	50	9.85	9850	3.94	1.31

*RE = Rammed earth

Table 6 and Figure 3 present the average findings of the compressive strength test conducted on rammed earth with plastic waste added at the 30-day mark. Specifically, the 0% RE PP specimen yielded an average compressive strength of 4.39 MPa. An average compressive strength of 4.32 MPa was found in the RE PP1% specimen. An average compressive strength of 3.69 MPa was found in RE PP3% specimens. An average compressive strength of 1.31 MPa was found in the RE PP5% specimen. Using information from the specimen bending strength test findings, the optimum bending value occurs in the variation of the RE PP0% specimen. While the minimum compressive strength occurs in variations of RE PP5% specimens. This implies that plastic trash is less effective—and even harmful—when it comes to strengthening tensile attributes like bending strength, even while it may make a minor contribution to compressive strength.

The inadequate bonding between the plastic particles and the other ingredients of the rammed earth combination, which impairs the material's resistance to tensile stresses, is probably the cause of this drop in bending strength. Plastic waste can cause weak spots in the construction, especially when subjected to tensile or bending stress (Royani et al, 2014). One of the main causes of the decrease in bending strength is the weakening of the bonds that hold the aggregate and cement paste together. Additionally, in their investigation of rammed earth reinforced with textile meshes, Eudave et al. (2022) emphasized the significance of bonding, pointing out that inadequate bonding results in reduced mechanical performance. Similar patterns found in our research emphasize how crucial material bonding is in determining the strength properties of rammed earth.

Plastic content and bending strength have a very significant link (R2 = 0.857), according to the regression analysis in Figure 3. The conclusion that plastic trash is less successful in reinforcing rammed earth in terms of bending strength compared to compressive strength is supported by the regression model, which indicates that bending strength falls as plastic content increases.

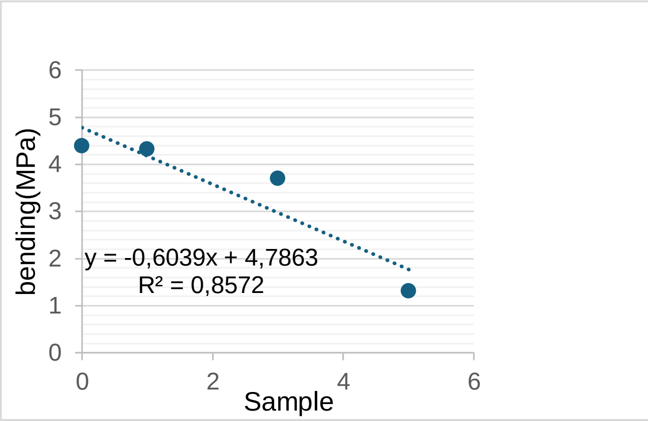

Fig. 3. Bending Strength

The results of the regression analysis produced, regression model Y = – 0.6039x + 4.7863. The correlation value between x (variation of the test object) and y is 0.857 this value is between 0.80 – 1.00, which is a very strong correlation category. It is explained that the magnitude of the percentage effect of variable x (Variation of the test object) on the variable y (bending level) called the coefficient of determination is 0.786 or 78.6%. While the rest is influenced by other factors beyond the variable x. The significant value of F obtained is 0.074 and obtained F count = 12.001 where the condition of the significant value f < alpha 0.005 or $F_{count} > F_{table}$. It defines that the variation of the test object (x) to the bending strength (y) has no effect simultaneously / globally.

The study's findings indicate that, up to a certain amount, plastic waste can be utilized as a reinforcing element in rammed earth. The study's findings are consistent with current developments in sustainable building, especially when it comes to enhancing building materials with waste resources. According to earlier research, enhancing the tensile and compressive strength of rammed earth necessitates meticulous material composition control (Araki et al., 2016). Moreover, with more general patterns in recycling plastic trash and sustainable building, especially those investigated by Xu et al. (2018), show the potential of waste materials to improve the mechanical qualities of sustainable building materials. Furthermore, this study's wider ramifications highlight the possibility of employing plastic waste as a partial reinforcement in non-load-bearing applications, such as partition walls. Although the results show that plastic waste can, in modest amounts, increase compressive strength, they also point out that plastic waste's weak bonding properties, particularly in tensile and bending applications, limit its use as a complete reinforcement material. These results are consistent with research by Biswas et al. (2021), which indicates that recycled plastic may work well in some situations but has to be improved upon to maximize its use in building materials.

Practically, using plastic waste in rammed earth construction is a viable approach for decreasing plastic waste while promoting eco-friendly building practices. However, this result indicates, the use of plastic waste needs to be carefully controlled to guarantee that the material's performance is not jeopardized, particularly in structures like partition walls that are subjected to tensile forces.

Furthermore, this result adds to the expanding corpus of information on the circular economy in the building industry. As Geissdoerfer et al. (2017) highlight, we provide a real-world implementation of circular economy concepts by repurposing plastic trash as a reinforcing material. However, further study is required to improve the use of plastic waste in rammed earth, especially with regard to its long-term durability and behavior in various environmental settings.

According to Eudave et al. (2022), Recently, a pertinent and creative solution to this issue has been suggested: strengthening using inexpensive textile meshes embedded in a mortar matrix (LC-TRM). This solution serves as an externally bonded reinforcement, much as the fiber reinforced polymer (FRP) systems found in masonry constructions. However, elements made of materials that have weak mechanical qualities, including rammed earth and adobe, are the focus of LC-TRM. However, study by Serrano et al. (2012) found that improving the proportion of lime and straw—which are utilized as physical and physicochemical stabilizers—improves the material's compressive strength (within the range of percentages examined in this paper). Furthermore, a modest improvement in compressive strength is shown when the percentage of Phase Change Materials (PCM) is increased.

According to Marais et al. (2015) that utilized PSE foundations for reduced CO_2 emissions, this construction method was satisfactory, economical, and resulted in a 46% reduction in CO_2 emissions. Within the first year, the polymer earth foundations functioned as intended, showing no signs of movement or settlement in the early examinations. The DCP testing technique, which was adapted from the road construction industry, was a successful test technique that made it possible to swiftly, cheaply, and simply test the material's strength on location (Marais et al. 2015).

Furthermore, according to Narloch et al (2015), The flexural tensile strength is increased by the gravel factions' content, according to laboratory test results. The flexural tensile strength of the mixed samples had an average value that was 137% more than the average value obtained from the mixture. It should be highlighted that the greater moisture content of the mixture—this mixture had a higher optimal moisture content—could be the cause of the differences in the results. Experiments and parameter studies will be used to validate the setup and optimize it in order to improve this assessment. In addition, both experimentally and statistically, the dynamic methodology will be further refined in the future. Lastly, the inverse characterization approach for ascertaining the hygrothermal material properties will employ the results of the dynamic trials (Indekeu et al., 2017). Although cement and other additives are also utilized, natural or synthetic fibers are frequently the best option when tensile, flexural, or shear strength needs to be improved.

Although rammed earth has low values for these characteristics, rammed earth elements' behavior and failure depend on them. Rammed earth walls are typically constructed with local earth, which may contain large grains, as opposed to other materials like compressed earth blocks, where the earth is sieved, or concrete, where the grading is known and uniform. Therefore, it is necessary to eliminate those large grains and occasionally sift the material before creating samples in order to streamline the laboratory manufacturing process and reduce result variability. Nevertheless, the earth's granularity is altered throughout the screening process, making the samples unrepresentative of the earth used in on-site operations. It was necessary to create a unique testing protocol to address this problem (Pele-Peltier et al., 2022).

5. Conclusion

With an emphasis on compressive and bending strength, this study investigated the impacts of incorporating plastic trash into rammed earth for use in partition walls. With the RE PP3% specimen exhibiting the maximum strength at 5.17 MPa, the results reveal that adding plastic waste up to 3% can greatly increase the compressive strength of rammed earth. But after this point, the compressive strength starts to decrease, as shown by the RE PP5% specimen's notable strength decline. On the other hand, bending strength consistently decreased when plastic trash was added, underscoring the difficulties caused by inadequate bonding between plastic particles and the soil-cement matrix.

The findings of this study highlight plastic-reinforced rammed earth as a viable environmentally friendly substitute for non-load-bearing applications such partition walls, adding to the expanding corpus of information on sustainable building materials. The limitations of employing plastic waste are also highlighted in the study, especially in applications where tensile strength is crucial. These results highlight the need for additional study to enhance the bonding properties of waste plastic in building materials, perhaps with the use of surface treatments or chemical additions.

The research's implications go beyond rammed earth's mechanical performance because it offers a workable way to cut down on plastic waste in the building sector. This study provides a workable solution to the global plastic waste problem by incorporating recycled plastic into construction materials, which is consistent with the circular economy's tenets. Furthermore, the results may help direct future advancements in environmentally friendly building techniques, especially in areas with difficulties managing plastic trash.

Acknowledgement

We express our gratitude to Universitas Negeri Medan for providing research funding support through the PNBP Grant of Universitas Negeri Medan for the 2022 Fiscal Year with contract number 0013/UN33.8/PPKM/PIT/2022.

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