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Effect of plastic waste shredding and its mixture formula on increasing the compressive strength of earth bricks

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Abstract: Plastic waste is a global problem that threatens the environment because it is difficult to decompose and can damage ecosystems. The large amount of plastic waste that has not been processed poses environmental risks as well as depletes local white soil resources, which are valuable for building materials. These factors strongly motivate the recycling of plastic waste and white soil into quality building products. This study aims to recycle and examine the effects of shredding four types of plastic waste and variations in mixture formulas with white soil and cement to improve the compressive strength of white soil brick building materials in Kupang, East Nusa Tenggara, Indonesia. White soil is a calcareous soil with different characteristics from the clay commonly used as a basic material for brick making. Ordinary soil materials are less capable of integrating with plastic waste without melting it first. In contrast, white soil is limestone-based, containing calcite, which can function as an adhesive. White soil makes up coral islands and limestone hills. In this study, four types of plastic waste were used: PET (Polyethylene Terephthalate), LDPE (Low-Density Polyethylene), PP (Polypropylene), and PS (Polystyrene), as part of the mixture for making white soil bricks. The method employed was an experimental approach involving the production of plastic waste-white soil bricks with three variations of mixture formulas combining plastic waste, white soil, and cement as an adhesive. The compressive strength test was conducted to observe the effects of the four types of plastic waste and the different formulas on the weight and compressive strength of the white soil bricks. Results showed that the use of plastic waste in manufacturing white soil bricks significantly affected compressive strength and reduced weight. All waste types contributed to increased compressive strength, especially LDPE waste, which reached a maximum of 100.3 kg/cm². The most effective formula was a mixture of 1 part cement, 1 part plastic waste, and 7 parts white soil. The compressive strength of these plastic waste-white soil bricks meets the requirements for concrete bricks according to Indonesian National Standard-03-0349-1989 and can be used as wall materials per Indonesian National Standard 03-6881.1-2000. The novelty of this research lies in demonstrating the ability of four types of plastic shreds without melting and identifying the most effective formula for producing lightweight, high-quality composite bricks from local white soil and plastic waste materials.

Keywords: *Compressive strength, Mix formula, Plastic waste type, Weighting.*

1. Introduction

The problem of plastic waste in the world and Indonesia is an important issue that must be faced. Indonesia is one of the largest producers of marine plastic waste in the world, with an estimated 1.29 million tons entering the sea each year, and still 58% of waste that has not been processed [1-3]. News from *Narasi Tv* https://narasi.tv/read/narasi-daily/daftar-negara-penghasil-polusi-plastik-terbesar?utm_source=copy_link&utm_medium=share, Indonesia is the world's number 3 waste producer, and can be seen in Table 1 Plastic waste has always been a major problem in environmental

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pollution, both land and marine pollution. The nature of plastic waste is not easily decomposed, the processing process causes toxins and is carcinogenic, and it takes up to hundreds of years if it decomposes naturally [1, 2].

Table 1.
Largest Plastic Waste Producing Countries in the World.

No.	Waste-producing countries	Total (tons/year)
1	India	9.275.777
2	Nigeria	3.532.479
3	Indonesia	3.352.229
4	China	2.808.179
5	Pakistan	2.567.461
6	Bangladesh	1.748.215
7	Russia	1.702.453
8	Brazil	1.444.824
9	Thailand	995.718
10	Congo	963.328

Source: https://narasi.tv/read/narasi-daily/daftar-negara-penghasil-polusi-plastik terbesar#google_vignette.

In the official website of the National Waste Management Information System (SIPSN) of the Ministry of Environment and Forestry (KLHK) https://sipsn.menlhk.go.id/sipsn/ in 2023, from 366 districts / cities in Indonesia, the amount of national waste has reached 38.3 million tons. Of this national waste, 61.75% (23.6 tons) can be managed, while the remaining 38.25% (14.6 tons) has not been managed. According to the latest news from RRI Kupang, waste generation in Kupang, East Nusa Tenggara reaches 233 tons/day. With so much plastic waste in Indonesia and Kupang, waste management is an urgent matter.

One solution to handling plastic waste is to process it into building materials, especially for brick making. Brick making with additional plastic waste is an interesting solution to reduce plastic waste while improving the quality of brick building materials. Brick is a wall building material that is commonly used in Indonesia and the world and is based on soil, including local white soil material.

Tanah putih is the local name in Kupang NTT for limestone/calcium carbonate (CaCO3). It is a material derived from crushed limestone and coral, and contains 35-60% sand. White soil has several characteristics that differ from clay and other soils, including; it can be a substitute for coarse and fine aggregates [4] as a substitute for some adhesive materials because it contains Calsit [5] and is the basic ingredient of kupang cement and is white in color. Bricks produced from white soil tend to have weaknesses in compressive strength [6] , so other materials with strong and tough properties must be added in order to improve their strength [7, 8]. The lightweight, tough, strong, rigid, and corrosion resistant properties of plastic waste are expected to improve the strength of white soil bricks [9] ... By adding plastic to the brick composition, the quality and mechanical properties of the brick in this case its compressive strength are expected to improve.

Based on research, the compressive strength of *HDPE (High Density Polyethylene)* 950 kg/cm², *PP (PolyPropylene)* 905 kg/cm², *LDPE (Low Density Polyethylene)* 920 kg/cm² and *PET (Polyethylene terephthalate*) 1455 kg/cm² [10]. With this high compressive strength potential of plastic, it is expected to increase the compressive strength of bricks. In previous studies, plastic waste added to the soil tends to separate and in order to adhere well, the plastic is melted first. The melted PET plastic liquid serves as a soil/sand adhesive, and the maximum compressive strength is at a ratio of sand to PET plastic waste of 1: 3 [11]. In another study, plastic waste of various types that were melted and added to sand with a percentage of 15% plastic waste gave maximum compressive strength [12]. In another study, plastic bottles were filled with sand, then used as construction materials casted with aggregate [13].

There is also PET plastic waste from the beach chopped into small pieces or shredded then mixed with cement and fly ash and sand in the manufacture of concrete bricks, the maximum compressive strength when adding 1% plastic waste [14]. Some plastic waste is also melted, then molded into plastic panels that are reinforced with natural fibers to study the aesthetic value and strength. Thin panels of melted plastic waste can be used for walls and ceilings [15]. PS plastic waste, which is added to bricks to make them lighter, but its compressive strength is lower than bricks without PS plastic waste [16]. Comparative research on the compressive strength of bricks from 3 types of plastic waste, namely PET, PP and HDPE which plastic through the process of melting / melting first, the highest compressive strength is brick denngan plastic type PP [17]. The use of LDPE waste for brick making with a composition of 6.5 sand, 1 cement and 1.5 LDPE produces a lower compressive strength than ordinary bricks, namely 18kg / cm [18]. In Figure 1 can be seen the form of using plastic waste for wall materials.

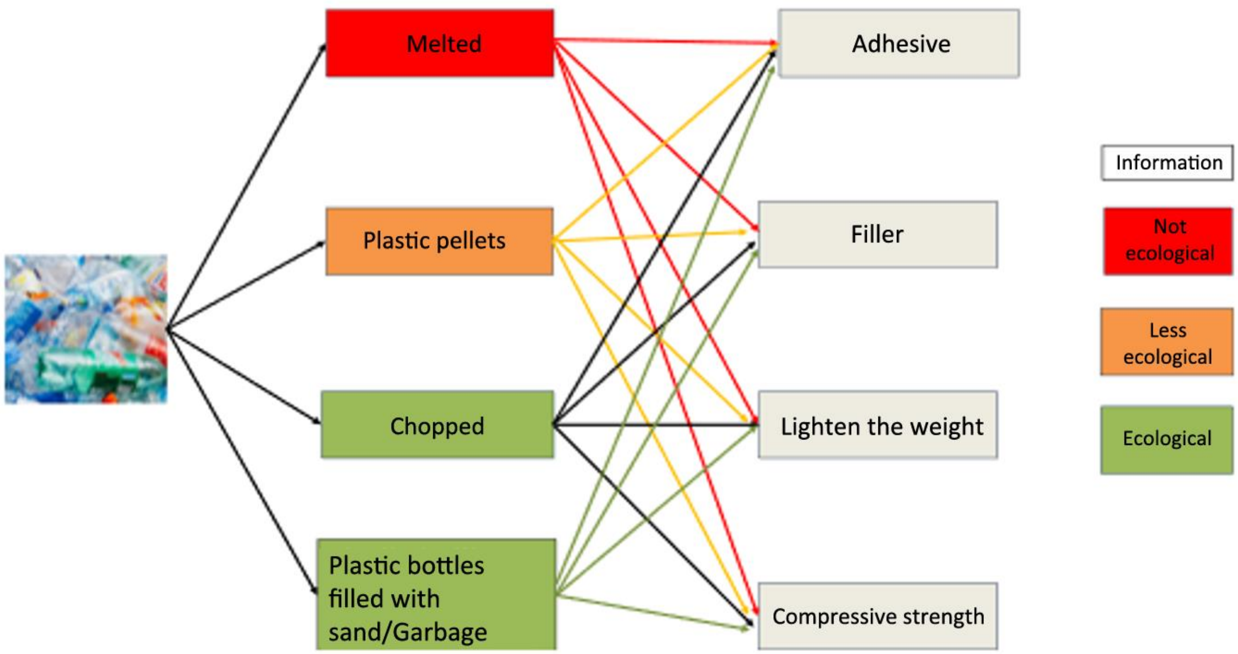

Figure 1.
Use of plastic waste for wall materials.

Previous research has widely discussed the utilization of plastic waste as an additional material in brick making, namely when mixed with soil plastic waste is melted first and of course melting plastic waste is not environmentally friendly. When mixed with sand in concrete brick making, some are melted while others use cement and fly ash as adhesive materials. However, a specific study exploring the effect of shredding 4 types of plastic waste (PET. PP, LDPE and PS) without melting on the compressive strength of bricks made from white soil has not been conducted. In addition, the ideal composition/formula between white soil, cement and plastic waste has also not been studied. Therefore, this research will fill the void by exploring the variation of 4 types of plastic waste and the composition of materials in making quality and more environmentally friendly white soil plastic waste bricks.

2. Material and Method

This research was conducted in several main stages:

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3. Research Design

3.1. Materials and Equipment

Brick-making materials such as plastic waste, white soil and cement and water were prepared first. The white soil was sieved first with a 5 mm perforated sieve which can be observed in Figure 2. Each plastic waste was separated based on its type, then made shreds with a size of 2-3cm wide and 3-5cm long. The chopped waste is separated according to its type as shown in Figure 3.

Figure 2.
Sifting white soil.

Figure 3.
Shredded *PET*, *PP*, *LDPE* and *PS* plastic waste.

The brick-making equipment consists of a brick press, bucket, shovel, iron and cement scoop. Initially, the brick molding tool was in a form that produced interlocking bricks, but the molding process encountered problems due to wet dough, making it difficult to form interlocking. The molding tool used is a manual wooden molding tool with a size of 60 cm long, 24 cm wide and 12 cm high. One molding can produce 5 bricks at a time. The equipment used is shown in Figure 4.

Figure 4.
Brick making equipment.

3.2. Mixed Formula

Composition 1: 7 white soil 1 cement
Composition 2: 1 plastic waste 7 white soil 1 cement
Composition 3: 2 plastic waste 7 white soil 1 cement
Composition 4: 3 plastic waste 7 white soil 1 cement
In detail, it can be observed in Table 2.

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Table 2.
Mixture Formula.

No.	Brick Sample	S	TP	CSP	Age (days)	Quantity (pieces)	Size p x l x t (cm)
1	BTPCSP0	1	7	0	28	3	24 x 12 x 12
2	BTPCSP11	1	7	1	28	3	24 x 12 x 12
	BTPCSP12	1	7	2	28	3	
	BTPCSP13	1	7	3	28	3	
3	BTPCSP21	1	7	1	28	3	24 x 12 x 12
	BTPCSP22	1	7	2	28	3	
	BTPCSP23	1	7	3	28	3	
4	BTPCSP31	1	7	1	28	3	24 x 12 x 12
	BTPCSP32	1	7	2	28	3	
	BTPCSP33	1	7	3	28	3	
5	BTPCSP41	1	7	1	28	3	24 x 12 x 12
	BTPCSP42	1	7	2	28	3	
	BTPCSP43	1	7	3	28	3	

Description:
TP=White Land,
S = cement,
CSP = Shredded Plastic Waste (Types 1,2,3 and 4)
BTPCSP0 = White earth brick without plastic waste mixture
BTPCSP11 = White soil brick mixed with plastic waste type 1 (PET) formula 1
BTPCSP12 = White soil brick mixed with plastic waste type 1 (PET) formula 2
BTPCSP13 = White soil brick mixed with plastic waste type 1 (PET) formula 3
BTPCSP21 = White earth brick mixed with plastic waste type 2 (PP) formula 1
BTPCSP22 = White earth brick mixed with plastic waste type 2 (PP) formula 2
BTPCSP23 = White earth brick mixed with plastic waste type 2 (PP) formula 3
BTPCSP31 = White earth brick mixed with plastic waste type 3 (LDPE) formula 1
BTPCSP32 = White earth brick mixed with plastic waste type 3 (LDPE) formula2
BTPCSP33 = White earth brick mixed with plastic waste type 3 (LDPE) formula 3
BTPCSP41 = White soil brick mixed plastic waste type 4 (PS) formula 1
BTPCSP42 = White earth brick mixed with plastic waste type 4 (PS) formula 2
BTPCSP43 = White earth brick mixed with plastic waste type 4 (PS) formula 3

3.3. Brick Making

After the white soil is mixed with cement and chopped plastic waste, water is added to approximately 25% of the total mixture until it thickens, and mixed evenly using a shovel and cement spoon. This mixture is then molded in a mold placed on a flat and watertight base. The mixture is inserted while being compacted. After 10 minutes, the mold is removed. The process of mixing materials to molding bricks with the addition of one type of plastic waste can be seen in Figure 5.

The wet bricks were left under the roof until they were 28 days old or older, then observed for physical properties, labeled according to plastic type and mix formula and ready for testing.

Figure 5.
Process of mixing materials to molding bricks.

4. Result

4.1. Compressive Strength Test and Brick Weight Measurement

The compressive strength test was carried out using a press test machine to determine the compressive strength of the brick sample as shown in Figure 6. This test was carried out at the material testing laboratory of the PUPR Office of NTT Province on September 17, 2024, with details of the results in Table 3

Table 3.
Weight and compressive strength test results.

No.	Brick sample	Size Pxlxt	Weight (grams)	Compressive strength (KN)	Compressive strength (kg/cm²)
1	BTPCSP0	24 x 12 x 12	6330	118	41.4
2	BTPCSP0	24 x 12 x 12	6360	125	43.8
3	BTPCSP0	24 x 12 x 12	6310	119	41.7
4	BTPCSP11	24 x 12 x 12	6150	196	68.7
5	BTPCSP11	24 x 12 x 12	6145	185	64.9
6	BTPCSP11	24 x 12 x 12	6140	190	66.6
7	BTPCSP12	24 x 12 x 12	6010	132	46.3
8	BTPCSP12	24 x 12 x 12	6050	138	48.4
9	BTPCSP12	24 x 12 x 12	6020	137	48.1
10	BTPCSP13	24 x 12 x 12	5040	130	45.6
11	BTPCSP13	24 x 12 x 12	5035	125	43.8
12	BTPCSP13	24 x 12 x 12	5050	130	45.6
13	BTPCSP21	24 x 12 x 12	6220	223	78.2
14	BTPCSP21	24 x 12 x 12	6200	231	81.0
15	BTPCSP21	24 x 12 x 12	6210	264	92.6
16	BTPCSP22	24 x 12 x 12	6100	124	43.5
17	BTPCSP22	24 x 12 x 12	6120	122	42.8
18	BTPCSP22	24 x 12 x 12	6120	126	44.2
19	BTPCSP23	24 x 12 x 12	5065	94	33.0
20	BTPCSP23	24 x 12 x 12	5055	107	37.5
21	BTPCSP23	24 x 12 x 12	5060	101	35.4
22	BTPCSP31	24 x 12 x 12	6130	286	100.3
23	BTPCSP31	24 x 12 x 12	6140	268	94.0
24	BTPCSP31	24 x 12 x 12	6130	279	97.8
25	BTPCSP32	24 x 12 x 12	6020	172	60.3
26	BTPCSP32	24 x 12 x 12	6000	181	63.5
27	BTPCSP32	24 x 12 x 12	6020	176	61.7

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28	BTPCSP33	24 x 12 x 12	5030	97	34.0
29	BTPCSP33	24 x 12 x 12	5020	106	37.2
30	BTPCSP33	24 x 12 x 12	5000	99	34.7
31	BTPCSP41	24 x 12 x 12	6010	157	55.1
32	BTPCSP41	24 x 12 x 12	6000	148	52.0
33	BTPCSP41	24 x 12 x 12	6105	152	53.3
34	BTPCSP42	24 x 12 x 12	5040	105	36.8
35	BTPCSP42	24 x 12 x 12	5050	108	37.9
36	BTPCSP42	24 x 12 x 12	5045	101	35.4
37	BTPCSP43	24 x 12 x 12	5000	77	27.0
38	BTPCSP43	24 x 12 x 12	4890	80	28.1
39	BTPCSP43	24 x 12 x 12	4900	85	29.8

Source: The results of compressive strength measurements at the Lab.Testing materials PUPR Office of NTT Province.

Figure 6.
Compressive strength testing.

The following is the average brick weight in Table 4 and the average brick compressive strength in Table 5 processed from measurement data at the material testing laboratory of the PUPR Office of NTT Province.

Table 4.
Average Weight of Brick.

No.	Brick sample	Type plastic	Weight (grams)
1	BTPCSP0	_	6333
2	BTPCSP11	PET	6145
3	BTPCSP12	PET	6027
4	BTPCSP13	PET	5042
5	BTPCSP21	PP	6210
6	BTPCSP22	PP	6013
7	BTPCSP23	PP	5060
8	BTPCSP31	LDPE	6133
9	BTPCSP32	LDPE	6023
10	BTPCSP33	LDPE	5017
11	BTPCSP41	PS	6020
12	BTPCSP42	PS	5045
13	BTPCSP43	PS	4930

Source: Data processing results of brick weight from the NTT PUPR Office.

The following is a diagram of the average measurement of brick weight from the NTT PUPR Office testing laboratory which can be seen in Figure 7.

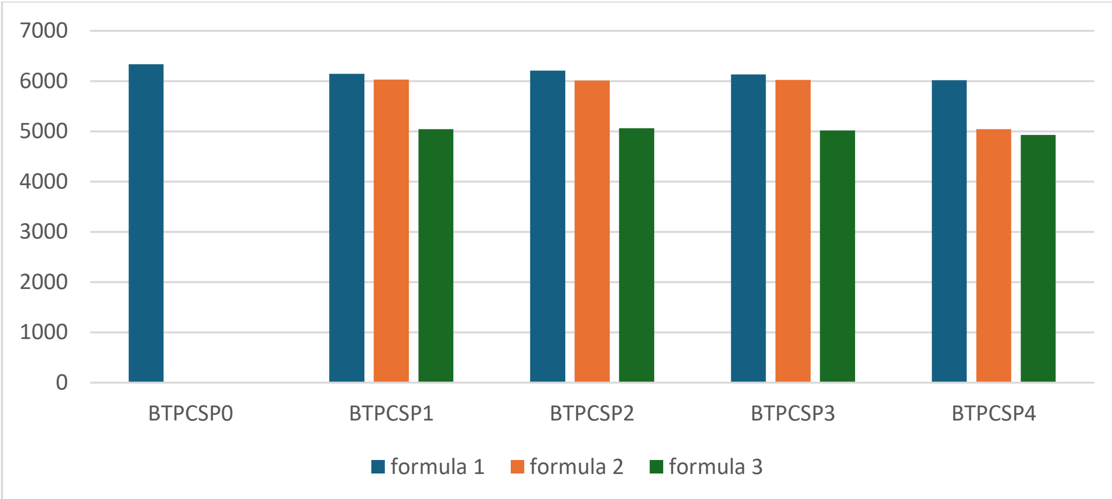

Figure 7.
Average weight diagram of bricks.

Table 5.
Average compressive strength.

No.	Brick sample	Type plastic	Compressive strength (kg/cm²)
1	BTPCSP0	_	42.3
2	BTPCSP11	PET	66.7
3	BTPCSP12	PET	47.6
4	BTPCSP13	PET	45.0
5	BTPCSP21	PP	83.9
6	BTPCSP22	PP	43.5
7	BTPCSP23	PP	35.3
8	BTPCSP31	LDPE	97.4
9	BTPCSP32	LDPE	61.8
10	BTPCSP33	LDPE	35.3
11	BTPCSP41	PS	53.5
12	BTPCSP42	PS	36.7
13	BTPCSP43	PS	28.3

Source: Data processing results of compressive strength from the NTT PUPR Office.

The average compressive strength of the bricks can be observed in diagram 4 below.

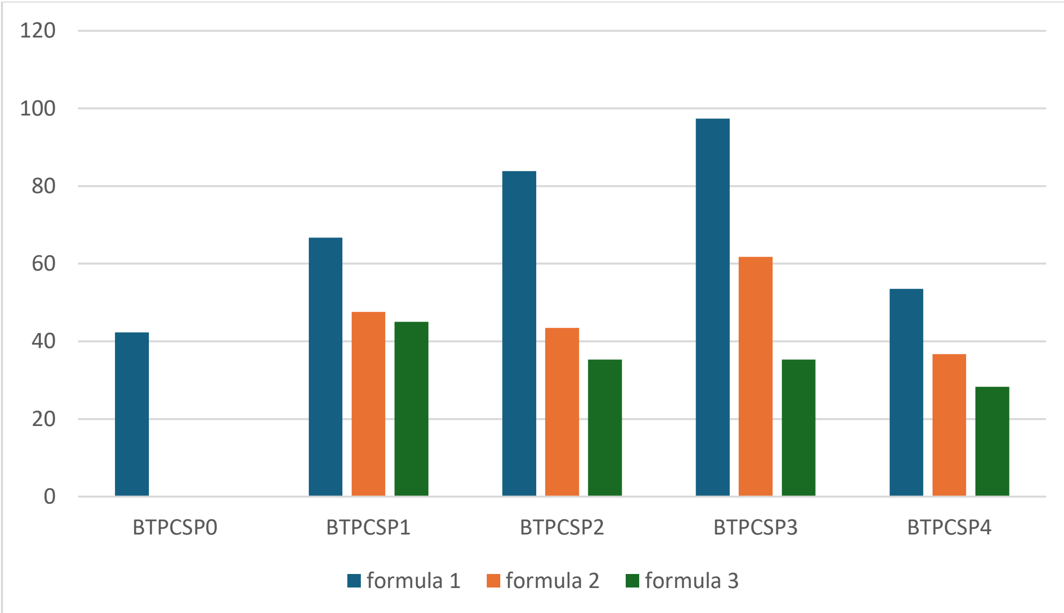

Figure 8.
Diagram of average compressive strength of bricks.

5. Discussion

5.1. Discussion of Compressive Strength Results

The test results show a significant difference in the compressive strength of bricks made without plastic waste and those made with plastic waste.

a. Composition 1 or formula 1 cement and 7 white soil (BTPCSP0) showed a stable compressive strength, in accordance with the standard of ordinary brick from white soil without plastic waste mixture, which is 42.3 kg/cm².
b. Composition 2 or formula 1, namely 1 cement 7 white soil and 1 plastic waste, bricks with a mixture of PET waste (BTCSP11) experienced an increase in compressive strength of 57.7%, PP (BTPCSP21) 98.3%, LDPE (BTPCSP31) 130.3% and PS (BTPCSP41) 26.5% compared to without plastic waste. This shows that plastic waste increases the compressive strength of bricks significantly according to the type of plastic waste. In Formula 1 plastic waste 7 white soil and 1 cement, LDPE waste has the highest compressive strength. The elasticity properties possessed by LDPE helps to increase the ***toughness*** and durability of the composite material against compressive loads [19]. Meanwhile, PP waste also has a great influence on the increase in compressive strength due to its structure and great hardness [20]. In addition, the irregular shape of the shreds in the PP waste treatment allows PP waste as an aggregate that strengthens the brick. PET waste also increased the compressive strength of this formula, although not as high as LDPE and PP. PET waste, which is quite hard in small elongated pieces, is enough to be a fiber material that can strengthen the bricks but is not as elastic as LDPE waste [21]. PS waste also increases the compressive strength although slightly. The hollow structure of PS plastic and its low density affect the compressive strength of bricks. In this formula, PS is enough to reinforce the bricks [22].
c. Composition 3 or formula 2, namely 1 cement 7 white soil and 2 plastic waste, showed an increase in compressive strength in bricks with a mixture of plastic waste PET (BTPCSP12) 12.5%, PP (BTPCSP22) 2.8%, LDPE (BTPCSP32) 46.1% while PS (BTPCSP41) decreased 13.2% compared to bricks without plastic. In formula 1 cement 7 white soil and 2 plastic waste, LDPE waste still increased the compressive strength by 46.1%. This is due to the elasticity of LDPE and the thin,

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elongated shape of the shreds that function as reinforcing fibers, [23]. PET and PP also still influence the compressive strength although not too high, namely 12.5% and 2.8%. This means that PET waste still functions as a reinforcement and PP, although slightly reinforcing, still functions as an aggregate to lighten the brick. Meanwhile, PS in this formula has experienced a 26.5% decrease in compressive strength, namely 36.7kg/cm². The hollow structure of PS and its brittle mechanical properties affect the decrease in the compressive strength of the bricks [24].

d. Composition 4 or formula 3, namely 1 cement 7 white soil and 3 plastic waste, bricks with a mixture of PET waste (BTPCSP13) showed an increase of 6.4%, PP (BTPCSP23) and LDPE (BTPCSP33) decreased by 16.5% while PS (BTPCSP43) decreased by 33.1%. In this formula, LDPE waste, although more plastic, and in formula 2 increased the compressive strength of bricks, but in formula 3 it was not able to increase the compressive strength of bricks [25]. PET waste still increased the compressive strength slightly by 6.5%. The stronger and more stable structure of PET makes it still increase the compressive strength [26].
e. Comparison of plastic types showed that LDPE gave slightly higher compressive strength results than PET, and PP while PS was lower than the others at the same composition.
f. All experimental bricks meet the minimum compressive strength of *SNI 03-0349-1989* which is 20kg/cm².

These results show that the addition of plastic waste to bricks gives mixed results, depending on the type of plastic and the formula/mixture used. The compressive strength of LDPE bricks was highest than PP. PET and PS. The elasticity property of LDPE helps to increase the **toughness** and durability of the composite material against compressive load [19].

The elasticity of LDPE allows the bricks to better withstand stresses before breaking, contributing to higher compressive strength and improved dimensional stability. This is because LDPE can improve the cohesion between particles in the mix, even though it is not chemically bonded directly to the cement [27, 28].

PP and PET plastic waste also considerably influence the increase in compressive strength. Where in this study. The addition of PS in the brick mix did not increase the compressive strength significantly due to its brittle mechanical properties [24] its inability to bond with the cement matrix, poor stress distribution, and low toughness [29]. Although PS has a low density, which may be useful for reducing brick weight, it does not provide the structural reinforcement required to improve mechanical properties such as compressive strength [22].

5.2. Discussion of Compressive Strength Results in Relation to Concrete Brick Quality Requirements

Based on the quality requirements of concrete bricks SNI 03-0349-1989 [30]. The experimental results of white earth bricks mixed with 4 types of plastic waste meet several quality categories, as can be seen in Table 6. No brick samples do not meet the minimum compressive strength requirements.

Table 6.
Concrete brick quality requirements.

No.	Quality	Compressive strength (kg/cm²)	Brick sample
1	I	80-100	BTPCSP31, BTPCSP21
2	II	60-70	BTPCSP11, BTPCSP32
3	III	35-40	BTPCSP41 BTPCSP12, BTPCSP13 BTPCSP22, BTPCSP23 BTPCSP33, BTPCSP42 BTPCSP0
4	IV	21-25	BTPCSSP43

Source: Results of analysis of compressive strength test results and requirements for compressive strength of concrete bricks SNI 03-0349-1989.

Based on the requirements for use as wall material SNI 03-6881.1-2000 [30] the experimental bricks can be categorized as in Table 7.

Table 7.
Requirements for the use of bricks as walls.

No.	Brick Usage	Compressive strength (kg/cm²)	Sample Brick
1	Unprotected, load-bearing walls	80-100	BTPCSP31, BTPCSP21
2	Load-bearing and protected walls	60-70	BTPCSP11, BTPCSP32 BTPCSP41
3	Non-load-bearing and unprotected walls	35-40	BTPCSP22, BTPCSP23 BTPCSP33, BTPCSP42 BTPCSP0
4	Non-load-bearing and protected walls	20-25	BTPCSP43

Source: results of compressive strength analysis adjusted to brick quality requirements and their use in buildings SNI 03-6881.1-2000.

In general, in accordance with the demands of brick quality requirements of SNI 03-0349-1989 and SNI 03-6881,1-2000, it is concluded that;

1. All samples of white earth bricks mixed with 4 types of plastic waste, meet the requirements of compressive strength based on *SNI 03-0349-1989 and can be used as a wall material based on SNI 03-6881.1-2000.*
2. White soil bricks mixed with LDPE and PP plastic waste in formula 1, namely 1 cement, 7 white soil and 1 LDPE and PP plastic waste (BTPCSP31, BTPCSP21) are of quality 1 and can be used as load-bearing and unprotected walls.
3. White earth bricks mixed with PP plastic waste formulas 2 and 3 and white earth bricks mixed with PET plastic waste formula 1 (BTPCSP11), LDPE formula 2 (BTPCSP32) and PS formula 1 (BTPCSP41) are categorized as quality 2 and are used for load-bearing and protected walls.
4. PET plastic waste white earth bricks formula 2 and 3 (BTPCSP12, BTPCSP13), LDPE formula 3 (BTPCSP33) and PS formula 2 (BTPCSP42) and white earth bricks without plastic waste (TPCSP0) are grade 3 and are for non-load bearing and unprotected walls.
5. For white earth bricks mixed with PS plastic waste formula 3 (BTPCSP43), it is grade 4 and is used for non-load-bearing and protected walls.

These results show that the addition of plastic waste to white earth bricks gives mixed results, depending on the type of plastic and the proportion used.

5. Conclusion

This study concluded that the utilization of plastic waste in the manufacture of white soil bricks in Kupang, NTT, can increase the compressive strength of bricks, especially at the right composition, namely 7 white soil, 1 cement and 1 plastic waste. LDPE, PP and PET are more effective than PS in improving brick quality. However, excessive use of plastic waste reduces the compressive strength of bricks. These findings can serve as a basis for further development in the utilization of waste plastic for more sustainable building materials in NTT.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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