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Evaluation of Reuse and Recycling Disaster Waste Materials for Post-disaster Shelter with Compressive Strength Testing and Case Study in Cianjur, Indonesia

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Abstract. Earthquake activity in Indonesia increases annually, causing more victims to require shelter and a rise in disaster waste. This waste can pose health risks and safety threats to humans, making careful management essential. One way to address this issue is recycling or reusing disaster waste materials to construct shelter. Therefore, this study aimed to investigate the performance of earthquake waste materials, recycled or reused as post-disaster shelter. To achieve this objective, a case study was conducted in Cianjur, Indonesia, where a recent earthquake occurred, and waste material samples (red brick, ceramic tile and roof tile) were collected for testing. Moreover, the compressive strength of the materials was measured in comparison with new building materials. The results shows that ceramic tile and roof tiles meet the compressive strength standards and can be reuse for post-disaster shelters, with compressive strengths of 17.7 MPa and 21.8 MPa.

Keywords: Compressive strength; Disaster waste material; Post-Disaster shelter

1. Introduction

1.1. General Background

Indonesia is situated along the Asia-Pacific Ring of Fire, a region characterized by frequent volcanic and seismic activity (BNPB, 2023). This "active zone" experiences numerous earthquakes annually, with 22 out of 10,792 major earthquakes recorded in 2022 (Dandy, 2023). Increased earthquake activity can lead to greater damage, displacing victims whose homes are destroyed and requiring safe shelter. In 2023, approximately 104.226 disaster victims required shelter (BPS, 2024). Effective shelter should provide security, comfort, protection, clean water, and proximity to essential facilities (UN/OCHA, 2008). In addition to causing displacement, earthquakes generate significant amounts of waste. For example, Lombok earthquake produced an estimated 15-20 kg of waste per day (Wibowo and Anugrah, 2017), and the 2021 East Flores in East Nusa Tenggara earthquake left 2,587 out of 85,755 houses heavily damaged (BNPB, 2021). Accumulated disaster waste poses health risks, and hazardous materials can increase safety threats, necessitating proper waste management. Recycling or reusing disaster waste materials to construct shelter is one viable solution to mitigate these challenges (UNEP, 2008).

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1.2. Related Studies

The United Nations Environment Programme (UNEP, 2008) defines disaster waste as accumulated construction debris and sediment from landslides caused by seismic activity. This waste poses health hazards due to the presence of chemical and biological contaminants, necessitating effective waste management. Managing natural disaster requires the implementation of effective policy, timely response, and appropriate preparedness measures (Berawi, 2018). Earthquake waste management practices vary across countries, but the Joint UNEP/OCHA Environment Unit outlines a guideline with three stages, namely emergency, early recovery, recovery, and contingency planning (MSB and JEU, 2011). According to (UNEP, 2008), in Indonesia, there are two stages in managing earthquake waste materials, namely pre-disaster and post-disaster. Pre-disaster focuses on mitigation measures, such as securing land leases or permits and developing programs to handle building debris effectively during emergencies. Meanwhile, post-disaster addresses recovery or reconstruction. It includes identifying waste at the disaster site, assessing its characteristics and capacity, evaluating risks, and determining priorities. Separating waste materials can increase the percentage of recyclable materials and raise public awareness (Kristanto, Gusniani, and Ratna, 2015). Disaster waste materials are categorized into plant debris, soil and sediment, domestic waste, and construction materials, such as bricks, wood, and concrete. Construction materials can be recycled or reused as aggregates or building materials for constructing shelter.

Shelter is essential for improving health, supporting families, ensuring security, providing protection from weather, and saving lives during crisis or post-disaster recovery (Sphere Association, 2018). Furthermore, it is defined as a place that offers comfort, access to clean water, and proximity to essential facilities including workplaces, educational institutions, and healthcare centers (UN/OCHA, 2008). Shelter can also be understood as a space equipped for human habitation (Sinclair, 2006). According to (Krimgold, Davis, and Thompson, 2015), and (IFRC, 2013), (Sinclair, 2006), post-disaster shelter includes transitional stages before victims move to permanent housing. These stages include emergency, temporary/transitional, and progressive/core shelter. Emergency shelter is a short-term solution that provides basic support immediately after a disaster. It is constructed using materials that can be quickly dismantled and reassembled, such as plastic sheets with wooden poles and ropes. Progressive/core shelter is designed with materials that allow for transformation into permanent housing. It typically includes one or two rooms and may also serve as transitional shelter when recovery efforts take longer.

According to (PMI, 2019), (Krimgold, Davis, and Thompson, 2015), and (Wilson, 2011), several criteria should be considered when reusing and recycling disaster waste materials for shelter, including security, comfort, long-term planning, and adherence to basic construction standards. Ensuring the quality of materials is crucial for constructing a shelter that is durable, environmentally friendly, affordable, and accepted by the local community. These objectives can be achieved by using high-quality materials, maintaining proper construction practices, and engaging experts and local communities. Shelter construction criteria are particularly relevant to this study, with a specific focus on the reuse and recycling of disaster waste. Furthermore, the strength of waste materials is a key consideration, specifically in disaster-prone areas where safety and durability are paramount.

Several studies have investigated the reuse and recycling of disaster waste materials. For instance, (Al-Zaid, 2020), (Parura and Rahardyan, 2020), and (Sunoko, Prijotomo, and Noerwasito, 2016) examined disaster waste management techniques, structural methods, straw systems, beam systems, and manufacturing processes. Although these studies offered practical solutions for post-disaster shelter construction, there is no extensive testing of material properties to ensure quality. (Pradani *et al.,* 2023) also investigated the recycling of disaster waste into flexible pavement materials such as aggregates, asphalt, and bitumen. Therefore, this current study aimed to evaluate the reuse and recycling of disaster waste materials through a case study in Cianjur, Indonesia, and material strength tests. Strength is defined as the maximum stress a material can withstand under an external force (load) without failure (Zhang, 2011). Strong materials resist deformation under high stress (ASM International, 2010). Strength is categorized into tensile, compressive, bending, and shear strength (Zhang, 2011). Due to resource limitations, this study focused on compressive strength, which is the ability of a material to withstand compressive forces without deforming (Betaubun and Hairulla, 2018). It is calculated using the formula:

$$\mathrm{P} = \frac{F}{A} \tag{1}$$

Where F is the maximum load (in Newtons) and A is the total surface area (in mm^2).

According to (Zhang, 2011), the strength of a material depends on its composition and structure. Even with the same composition, materials with different structures have varying strengths. Other factors include testing conditions, size, shape, surface characteristics, water content, loading speed, ambient temperature, and the accuracy of testing equipment. Therefore, materials are expected to meet specified standards, such as the Indonesian National Standard (SNI) or equivalent benchmarks, to be deemed suitable for use (BSN, 2019).

2. Methods

Case study and material testing were conducted to achieve the study objective. Case study was specifically conducted to examine the location, earthquake characteristics, building conditions in the affected area, the types and quantities of remaining earthquake waste materials, and the state of temporary housing structures at the site. Meanwhile, material testing included selecting samples for examination, identifying new materials for comparison, adjusting sample sizes for testing, and conducting compressive strength tests (Figure 1).

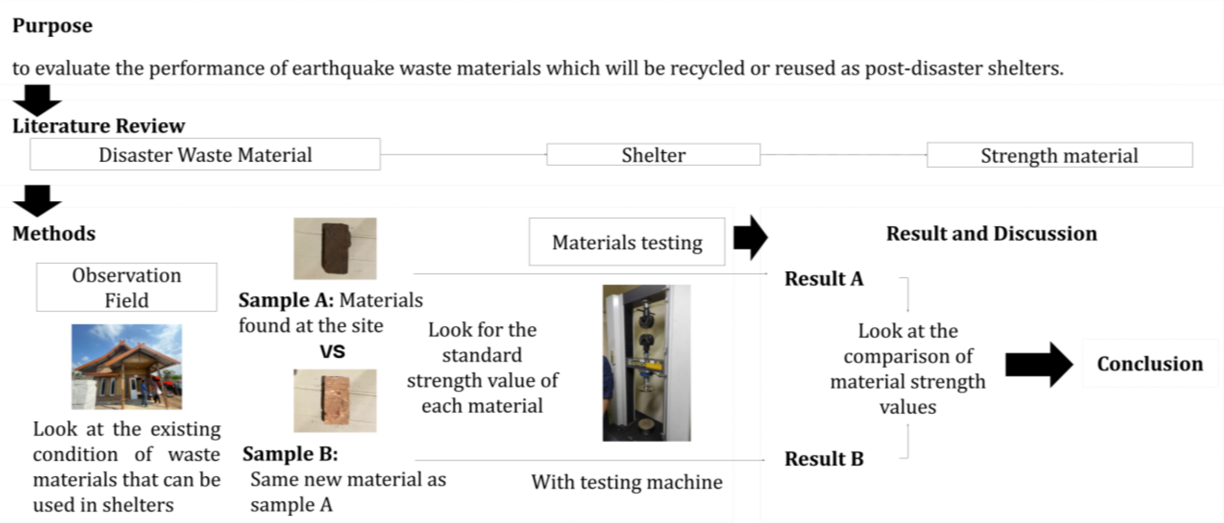


Figure 1 Workflow of the study

Data collection for material measurement and testing was carried out using specific tools, including a meter for measuring dimensions and a compressive test machine for determining compressive strength values (Table 1).

Table 1 Measurement Framework

No.	Tools	Type	Data to retrieved	Photo
1.	Meter	Self-Lock 7.5 m	Determine the dimension of specimen and recycle house case study	
2.	Compressive Testing Machine	Go-tech Testing Machine A1 7000	Determine the compressive strength value	

2.1. *Case Study*

The case study location was the earthquake epicenter in Cianjur, specifically Sarampad Village, Cugenang District, Cianjur Regency, West Java. This region was highly earthquake-prone, with an MMI scale greater than VIII, showing the potential for ground cracks, slope movement, and land shifts (PVMBG, 2014). The earthquake occurred on November 21, 2022, with a magnitude of 5.6 and a damage intensity of VIII on MMI scale (Putratama, 2022). After a year of recovery, various facilities were constructed in the affected area. This site currently includes a nearby post and a 3,546.82 m^2 landfill designated for disaster waste disposal (Figure 2). Other facilities, such as schools and mosques, had also been established. The earthquake caused significant damage and loss of life. According to (Asmarini, 2022), 268 people died, 1,083 were injured, and 58,362 were displaced due to structural damage. Moreover, the destruction spanned three regions and sub districts, with 21,282 houses damaged, including 6,570 suffering severe destruction. To aid disaster victims, several shelters, mosque facilities, and schools have been rebuilt. Recycle House Program (RHP), led by Mr. Sunaryo Adhiatmoko, was selected as the focus of this case study. The program conceptualized house reconstruction post-earthquake using recycled materials (Figure 3).

Figure 2 Landfill for disposing disaster waste

Figure 3 Recycle House in Sarampad Village

RHP had constructed 352 units in the disaster-affected area. These structures used coconut wood sourced from West Sumatra, bamboo walls made by craftsmen, spandex roofs, GRC list planks, and brick walls (Figure 4). Disaster waste materials, such as wood and concrete shards, were also repurposed for doors, window frames, brick walls, and foundations. In total, 3,546.82 m^2 of disaster waste was collected in an open field, forming a pile approximately 1 meter high. This abundance of waste prompted the village community to reuse 50% of the discarded materials for home reconstruction. Table 2 and Figure 5 present the types of disaster waste materials found and utilized in the case study.

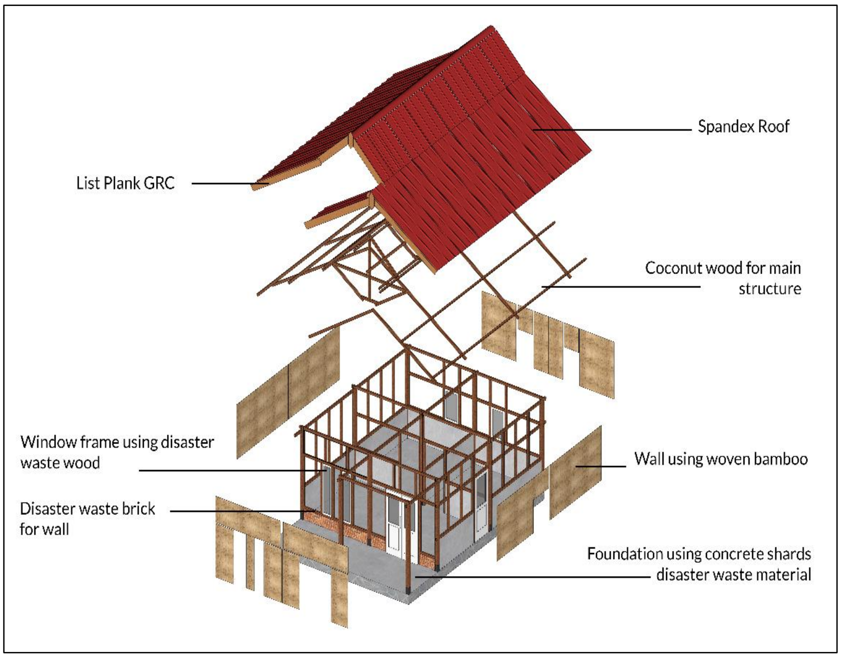


Figure 4 Exploded Axonometric of Recycle House Program Materials Component

Table 2 provides an overview of disaster waste materials that can be repurposed for shelter based on case study and theoretical investigations. Meanwhile, Figure 5 presents the practical application of these materials in RHP case study. Examples include mixed ceramic shards and bricks used for walls, repurposed wooden window and door frames, and reused roof tiles. Based on the types of materials identified at the site, specific waste materials were selected for testing. The selection process considered the application in RHP, use in residents' houses incorporating disaster waste, the availability of comparative materials, and the accessibility of testing equipment. The selected materials for testing included red bricks, roof tiles, and ceramic tiles.

Table 2 Comparison of Waste Material Application at Location and Theoretical Study

Material Type	Source			
	(PMI, 2019)	(MSB and JEU, 2011)	(UNEP, 2008)	RHP shelter Case Study
Vegetation	-	As compost	-	Vegetation
Wood	Reused as construction	Reused as furniture or fuel for cooking	Reused as construction	Reused as window frame
Bricks	Reused as construction	Reused as walls	Bricks	Reused as construction
Concrete	-	-	-	Reused as walls or foundation
Plastic	-	Sorted and sold. Cannot be reused	Recycle	Collected and transferred
Sand & Gravel	As aggregate			
Roof tile	Reused as roof	-	-	Reused as roof
Steel	Reused as joints	Recycle as metal strap	Cannot be reused. Not friendly to victims	Steel
PVC pipe	Reused as water Pipes	-	-	-
Glass	-	Recycled		-
Alumunium	-	-	Recycled	
Ceramic tile	-	-	Reused as construction	Reused as floor tiles

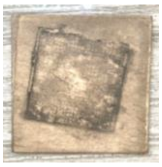
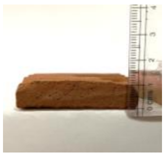
*Note: - not mentioned

Figure 5 Application of Disaster Waste Material in Recycle House Program and Residents Houses

2.2. *Material Testing*

The material testing method was designed to determine the compressive strength of each type of disaster waste material. In addition, comparative materials were included in the analysis, categorizing the samples into two groups, namely disaster waste and new building materials. Compressive tests were conducted using Go-tech Testing Machine A1 7000 to evaluate the load-bearing strength of the samples (Figure 6). The materials were prepared as 5 x 5 cm samples, with one sample tested for each material category (Table 3). Subsequently, the test results were compared against the standards outlined in section 3.4.

Table 3 The Tested Materials

	BML	BMB	GKL	GKB	KL	KB
Sample before cutting						
Material Sample Size L x W = 5 x 5 cm						
Sample height						
	5 cm	4 cm	1,5 cm	1 cm	1 cm	0,5 cm

*Note: BML = bricks from disaster waste material; BMB = bricks from new building material; GKL = roof tile from disaster waste material; GKB = roof tile from new building material; KB = Ceramic tile from disaster waste material; KL = Ceramic tile from new building material.

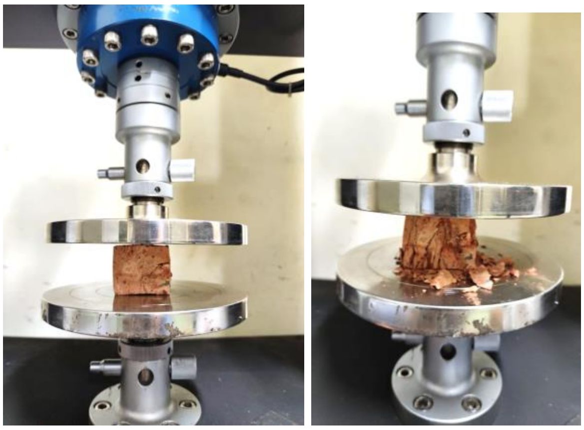


Figure 6 Documentation of Compressive Strength Test

3. Results and Discussion

The compressive strength results required data processing. Therefore, force measurements obtained were converted into newtons (N), and the materials area into square millimeters (mm^2). Using Equation 1, compressive force (F) was calculated and expressed in megapascals (MPa) or (N/mm^2). Furthermore, Table 4 presents GKB's fractured texture compared to GKL's more robust composition, contributing to the observed strength disparity.

Table 4 The Condition of Material Test Results

BML	BMB	GKL	GKB	KL	KB
					

3.1. BML and BMB Red Bricks Results

Figure 7(a) presents the compressive stress-strain results for bricks. During the fracturing process of both BMB and BML samples, pressure increased until cracks formed. The force curve for BMB was steeper, confirming greater hardness than BML. This was supported by Figure 7(b), where BML showed a compressive strength of 12.94 Mpa, significantly higher than BML's 3.44 Mpa. The materials' height had an effect on the compressive strength, with taller materials typically showing lower compressive strength values (Fodi, 2011). Table 5 shows BML with a height of 5 cm compared to BMB's 4 cm, contributing to the strength difference. For example, the load for BML was 9,100 N, lower than BMB's load, as shown in Table 4. Other factors, such as materials composition and load capacity, also affected compressive strength (Zhang, 2011). BML's texture after testing was softer and more crushed, while BMB maintained a more solid texture. The quality and number of holes in bricks, as well as the forming process, further influenced compressive strength (Foytong *et al*., 2016). (Panennungi and Bakhrani, n.d.) considered firing duration as another significant factor, with longer firing duration resulting in higher compressive strength. As BMB represents new building materials, its hardness is naturally greater than BML, which consists of long-used disaster waste bricks.

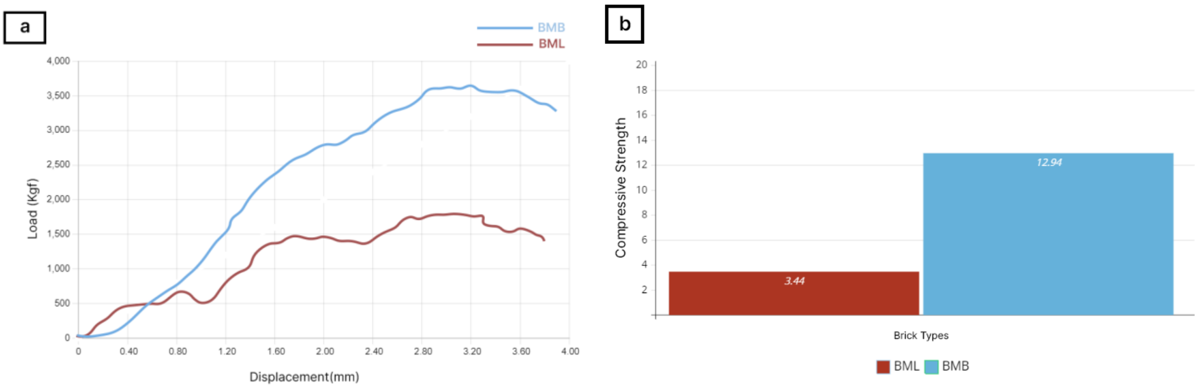


Figure 7 BML and BMB Compressive Test Results: Compressive stress–strain curve (a), Compressive strength value (b)

Table 5 BMB and BML Red Bricks Compressive Strength Results

Bricks Type	Method	Test Speed (mm/min)	Shape	Width (mm)	Length (mm)	Area (mm2)	Load (N)	Height (cm)
BML	Flattening	20.00000	plate	52.8	50	2640	9100.57	5
BMB	Flattening	20.00000	plate	51.3	52.2	2678	34656.7	4

3.2. GKL and GKB Roof Tile Results

Figure 8(b) shows the compressive strength results for roof tiles, showing significant differences between samples. Roof tiles made from disaster waste materials (GKL) showed a compressive strength of 21.8 Mpa, much higher than that of new roof tiles (GKB) at 1.16 Mpa. This phenomenon could be attributed to load differences. Table 6 shows GKL with a load value of 55.809 N, significantly greater than GKB's load, resulting in higher compressive strength for GKL. Figure 8(a) further explains this phenomenon, as GKB's force curve was smaller and had a faster crack than GKL. However, the cause of the very different compressive strength values needs further investigated.

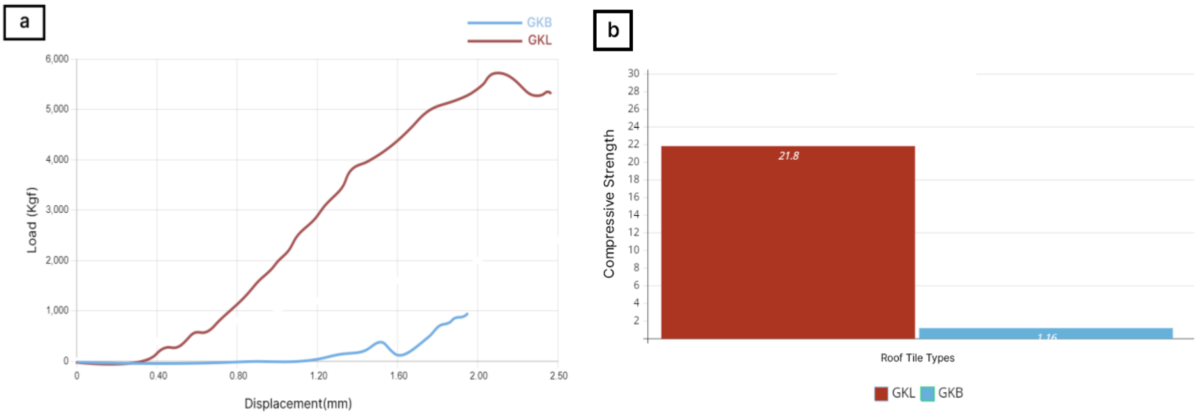


Figure 8 GKL and GKB Compressive Test Results: Compressive stress–strain curve (a), Compressive strength value (b)

Table 6 GKL and GKB Roof Tile Compressive Strength Results

Bricks Type	Method	Test Speed (mm/min)	Shape	Width (mm)	Length (mm)	Area (mm2)	Load (N)	Height (cm)
GKL	Flattening	20.00000	plate	49.4	51.7	2554	55809.6	1.5
GKB	Flattening	20.00000	plate	50.6	55.4	2803	3255.81	1

3.3. KL and KB Ceramic Tile Results

Based on Figure 9(b), the compressive strength values of the two ceramic materials differed slightly. Ceramics derived from disaster waste (KL) showed lower compressive strength than new ceramic materials (KB), with values of 17.7 Mpa and 27.8 Mpa, respectively. Differences in compressive strength could be influenced by the height of the material during testing. As shown in Table 7, KL had a thickness of 1 cm, which was greater than KB's thickness of 0.5 cm. This difference could affect compressive strength, as taller materials generally had lower compressive strength. The load applied to the material also impacted its compressive strength. KB experienced a higher load of 76,933 N, compared to KL, contributing to its greater strength. As observed in Table 4, KL had more extensive fractures than KB, reflecting its lower compressive strength. Figure 9(a) further showed that KB had a larger force curve, confirming greater hardness than KL.

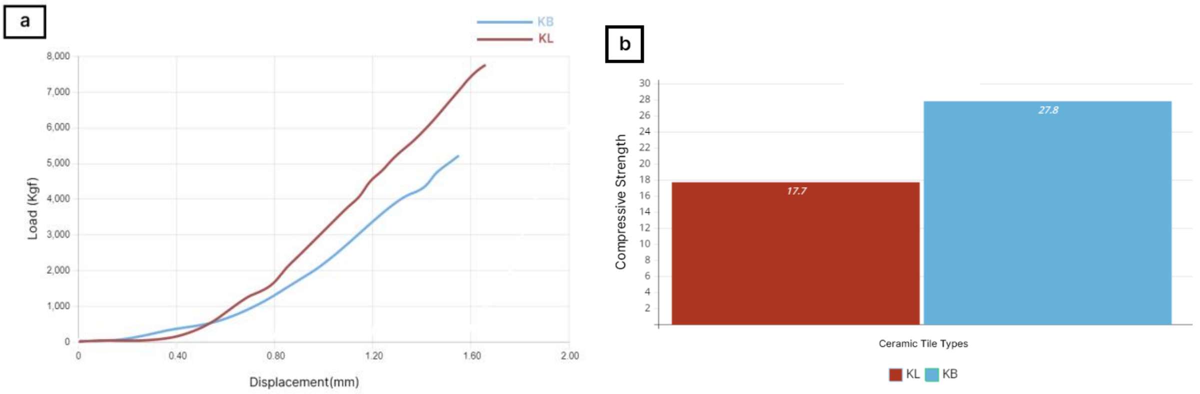


Figure 9 KL and KB Compressive Test Results: Compressive stress-strain curve (a), Compressive strength value (b)

Table 7 KL and KB Ceramic Tile Compressive Strength Results

Bricks Type	Method	Test Speed (mm/min)	Shape	Width (mm)	Length (mm)	Area (mm^2)	Load (N)	Height (cm)
KL	Flattening	20.00000	plate	53.20	53,10	2825	50190.4	1
KB	Flattening	20.00000	plate	52.5	52,6	2762	76933.2	0.5

3.4. Comparison of Compressive Strength Test Results with Standard

The test results were compared with the compressive strength standards, as shown in Tables 8, 9, and 10. The comparison showed that BML did not meet the standards outlined in (SNI-15-2094, 2000) and (ASTM C62, 2018), while BMB did. GKL satisfied the standards provided by (Akinwande *et al.*, 2021) and (Rajalakshmi R., 2020) but GKB did not. KL did not meet the standards from (CES Edu Pack Software, 2013) but complied with (ASTM C 1424, 2019). Lastly, KB met the compressive strength standards specified in both references. Based on this analysis, disaster waste materials deemed suitable for shelter construction were KL and GKL. However, further investigation was required to address materials that did not meet the standards.

Table 8 Comparison of BML and BMB Compressive Strength Results with Standards

Red Bricks Type	Compressive Strength Test Value	Source		
		(CES Edu Pack Software, 2013)	(SNI-15-2094, 2000)	(ASTM C62, 2018)
		20 - 50 Mpa	5-15 Mpa	8.6 - 20 Mpa
BML	3.44 Mpa	Not qualify	Not qualify	Not qualify
BMB	12.94 Mpa	Not qualify	Qualify	Qualify

Table 9 Comparison of GKL and GKB Compressive Strength Results with Standards

Roof Tile Type	Compressive Strength Test Value	Source	
		(Akinwande *et al.*, 2021)	(Rajalakshmi R., 2020)
		18.3 Mpa	8-10 Mpa
GKL	21.8 Mpa	Qualify	Qualify
GKB	1.16 Mpa	Not qualify	Not qualify

Table 10 Comparison of GKL and GKB Compressive Strength Results with Standards

Ceramic Tile Type	Compressive Strength Test Value	Source	
		(CES Edu Pack Software, 2013)	(ASTM C 1424, 2019)
		20 - 50 Mpa	3.49-6.4 Mpa
KL	17.7 Mpa	Not qualify	Qualify
KB	27.8 Mpa	Qualify	Qualify

4. Conclusions

In conclusion, evaluating disaster waste materials for reuse and recycling into shelter required careful consideration. Therefore, waste materials should be categorized into groups such as plant materials, soil, domestic waste, and construction materials. At earthquake sites, the remaining materials often included building debris, sediment, plants, and hazardous substances like asbestos. Materials suitable for shelter included bricks for walls, concrete for walls and foundations, wood for furniture and window frames, ceramic tiles for roofing and flooring, as well as sand and gravel for aggregates. One important parameter for reusing disaster waste as shelter material was strength. Compressive strength tests showed that GKL and KL met the required standards with values of 21.8 MPa and 17.7 MPa, respectively. However, BML did not meet the standards, with a value of 3.44 Mpa. These results showed disaster waste materials could be reused for shelter construction, provided the required material and structural standards were met. This experiment was limited to testing compressive strength. Therefore, further investigations were required to explore the broader use of disaster waste materials, specifically for shelter, and to evaluate other types of disaster waste materials other than the three materials tested. Other parameters besides compressive strength should also be examined to ensure a comprehensive assessment of materials suitability.

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