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Comparative Study on Mechanical Properties of Waste Composite Materials for Bricks Application

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Abstract
This study discusses mechanical properties and analysis of composite materials to develop building bricks for structural lightweight concrete replacement applications made from three different waste materials, i.e. sawdust, polyethylene terephthalate (PET) plastic bottle, and used diaper. All waste materials are used to mixture composite, as cement replacement, with a mixture of 0%, 5%, 10%, 15%, and 20% of the total weight. This study uses a quantitative method with the sample used as cylindrical tube with 20 mm of diameter and 40 mm of height. Tests were carried out in the form of compressive and specific gravity tests to determine the mechanical and physical properties of the composite material. The use of waste materials as mixtures for composite manufacture with a water per cement ratio of 0.4 at the age of 28 days results in the best compressive strength of 20.70 MPa (5% sawdust), 33.04 MPa (5% PET), and 18.05 MPa (5% used diaper). The density value shows that the addition of waste materials tends to decrease the weight of the composite result. Based on these results, it can be concluded that the use of waste composite materials is a potential replacement for lightweight structural concrete as an effort to reduce the cement requirement for building material applications.
Keywords: Sawdust, PET, used diaper, composite, compressive strength.

1. Introduction

Cement is the most versatile, durable, and widely used construction material in the construction industry. Hence, large quantities of portland cement are required, and it is well known that the cement industry is considered a high emitter of carbon dioxide gas. The global production of cement has snowballed in recent years, and carbon dioxide emissions are the third largest source after fossil fuels and land-use change [1]–[4]. The environmental problems associated with the production of portland cement are usually well-known and closely monitored in terms of the amount of carbon dioxide released into the atmosphere during its production [5]. Since the current industrial growth is very high, the involvement and availability of building materials are increasing, so alternatives in industrial development are needed. Currently, research in building materials and construction is focused on designing alternative uses for cement.

Several studies even promote alternative construction materials to replace cement with 100% hydration content of non-cement, namely geopolymer, as an environmentally friendly material [6]–[9]. In addition to the cement problem, the subsequent environmental problem is the problem of utilizing production waste materials such from the wood industry, used drinking water bottles, and used diapers. The sawmill and plywood industry produces a lot of wood waste, which threatens environmental sustainability [10], [11]. The production capacity of sawn wood in Indonesia reaches 2.6 million m^3 with a waste of 1.4 million m^3 per year. Waste is generally in the form of logs, sawdust, veneer waste, and pieces of wood. Plastic water bottle usage impacts the environment, including overflowing landfills, requiring high amounts of fossil fuel for production, and covering the ocean surface with plastic products. It has created environmental threats, and thus it needs to be recycled [12]. Every year the Indonesian sea is estimated to receive 70–80 percent of plastic waste used for human consumption from land. The amount is between 480 thousand to 1.29 million tons of plastic waste from a total of 3.22 million tons of waste that enters the sea and coast.

At the same time, the global consumption rate of used diapers is increased exponentially. The global production of disposable diapers is expected to exceed US$ 71 billion per year by 2022. About 20 billion pieces of this waste materials are annually dumped in landfills requiring almost five-century to decompose fully. Disposing of used diaper waste causes several environmental and health issues [13]. The average baby wears 3–4 disposable diapers a day. In fact, every year, around 4.2 to 4.8 million babies are born in Indonesia. For these reasons, efforts are needed to reduce the amount of those waste materials by recycling them into other materials. Therefore, this study aimed to determine the effect of sawdust, polyethylene terephthalate (PET) plastic bottles, and used diapers on the compressive strength of mortar.

2. Method

This section consists of materials, preparation of mortar mixtures, and compressive strength of resulting composite material.

2.1. Materials

Type IV portland cement was used as binding material. Sand from the Cikarang building material store prepared in saturated surface dry (SSD) was used as an aggregate. The aggregates were passed through a sieve of 4.75 mm and retained on a sieve of 30 µm with requirements of ASTM C-33. Sawdust was obtained from the machining process of wood at construction sites around Cikarang, Indonesia. PET from used drinking water bottles was collected around Cikarang, Indonesia. The PET bottle was shredded manually in the previous study [14]–[15]. The used diaper was collected, shredded, and undergoes a purification chemical solution to remove the urine and toxic substances and then dried for further application. These waste materials can be seen in Figure 1.

(a) (b) (c)

Figure 1. Waste materials used in this study. (a) Sawdust, (b) PET, and (c) used diapers.

Table 1. Proportions of materials in mortar mixture.

Mixture Labels	Binder		Waste Type
	Cement (%)	Replacement (%)	
C	100	0	-
SD-5	95	5	saw dust
SD-10	90	10	
SD-15	85	15	
SD-20	80	20	
PET-5	95	5	PET
PET-10	90	10	
PET-15	85	15	
PET-20	80	20	
UD-5	95	5	used diapers
UD-10	90	10	
UD-15	85	15	
UD-20	80	20	

2.2. *Preparation of Mortar Mixtures*

Thirteen mixes were prepared by adding cement with 0%, 5%, 10%, 15%, and 20% replacement by mass to analyze the influence of waste replacement material on the compressive strength and density of the resulting composite mortar. The replacement materials are sawdust, PET, and used diapers. The mixed proportions of the studied mortars are listed in Table 1, where C (control) is mortar without cement replacement, SD is sawdust, PET is used drinking water bottle from PET material, and UD is used diaper.

The water-to-cement ratio (w/c) was 0.52 by mass. The ratio of cement : aggregate was 1 : 2.75, conformed to SNI 03-6825-2002. Briefly, dry mixtures were placed and mixed to ensure the component mixed homogeneously. Afterward, the required amount of mixing water was poured into the dry mixture, followed by continuous mixing. Each specimen was then cast into 20 mm × 40 mm cylindrical molds. The specimens were left for 24 hours. Eventually, the specimens were released from the mold and cured at room temperature until the compressive test.

2.3. *Compressive Test*

The compressive strength test of the composites was examined according to the ASTM C-39 (Compressive Strength of Concrete Cylinders) [16]. Each mixture was evaluated at the age of 3, 7, and 28 days. The maximum compressive load was obtained using the RAT 100 Type Universal Testing Machine (UTM) in the Center of Infrastructure Built Environmental (CIBE), Institut Teknologi Bandung, and Laboratory of Structure of Civil Engineering Department, Institut Teknologi Sepuluh Nopember. The compressive strength (f_c) mortar was calculated by dividing the maximum compressive load received by the specimen during the test by surface area (Equation 1).

$$f_c(\text{MPa}) = \frac{\text{Max. Compressive Load (N)}}{\text{Surface Area (mm}^2)} \tag{1}$$

3. Result and Discussion

This section consists the resulting density and compressive strength of waste material based composites from this research.

3.1. *Density Result*

The density (ρ) of mortar was calculated by dividing the weight of hardened composite by the volume of material (Equation 2). The calculated density of composites are presented in Table 2 and Figure 2.

$$\rho\ (\text{kg/m}^3) = \frac{\text{Massa (kg)}}{\text{Volume (m}^3)} \tag{2}$$

Table 2. Density of waste material based composites.

Mixture Labels	Density (kg/m^3)
C	1860
SD-5	1110
SD-10	1090
SD-15	1070
SD-20	1060
PET-5	1840
PET-10	1820
PET-15	1800
PET-20	1780
UD-5	1800
UD-10	1770
UD-15	1600
UD-20	1130

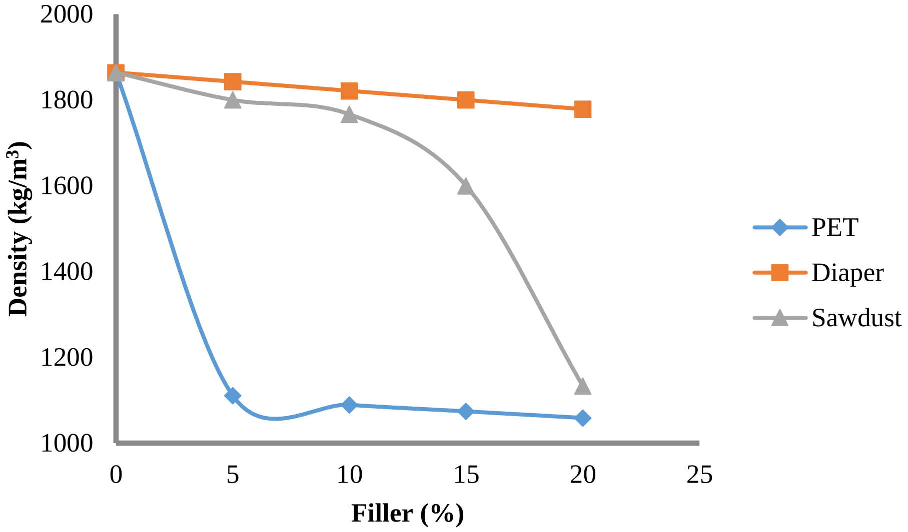

Figure 2. Density of waste material based composites influenced by filler weight.

Partial replacement of cement by sawdust, PET, and used diaper results in a decrease in composite densities. Used diaper slightly decreased the density because the diaper is made of sodium polyacrylate. This type of polymer has superabsorbent properties that absorb water heavily. When applied to a composite, it will retain some water and only slightly change the density value. Sawdust decreases the density significantly, starting at 15% weight. That is because sawdust is an organic material, and similar to used diaper, sawdust also has the ability to absorb water but not as much as diapers. The PET sharply reduces the density of composites, even though used at low content as low as 5%. This material does not absorb water, which decreases the density of composites.

3.2. Compressive Strength

Table 3 and Figure 3 show the compressive strength of sawdust, PET, and used diapers based composites. The addition of sawdust and used diaper decreased the compressive strength of composites, while 5–10% addition of PET increased the compressive strength of composites before decreasing after 15% addition or more. Both sawdust and used diaper are made of polymeric material that absorbs water. It makes the hardened composite have an excess amount of water, which explains the decrease in compressive strength of the composite because there are more capillary porosities present in the composite. Sawdust is an organic material containing carbon (C) elements, which delay water and cement's hydration. If the heating process activates this subsequent material, it can increase the early strength of cement mortars when used in a low amount [17].

Table 3. Compressive strength of waste material based composites.

Mixture Labels	Compressive Strength (MPa)	
	7 days	28 days
C	15.99	24.61
SD-5	13.45	20.70
SD-10	12.74	19.59
SD-15	12.59	19.36
SD-20	6.49	9.98
PET-5	31.65	33.04
PET-10	27.56	26.96
PET-15	5.23	20.89
PET-20	3.54	14.81
UD-5	11.73	18.05
UD-10	6.57	10.11
UD-15	1.40	2.16
UD-20	0.10	0.16

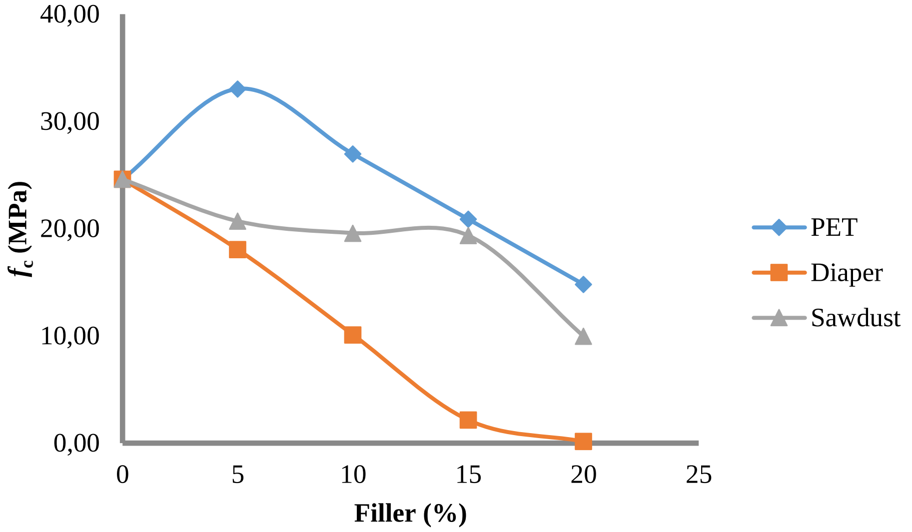

Figure 3. Compressive strength of composites influenced by filler weight.

The diaper can be used as a self-cure agent to improve concrete performance when used in a low amount [18]. PET, when used at 5-10% weight, increases the material's compressive strength because it does not absorb water and makes the composite more compact. PET particle as cement replacement in mortar has good sulfate resistance and mechanical properties while also solving the solid waste problem generated by plastics [19]. When melted and mixed with granular material (aggregates), plastic binders have the potential structural application [20].

3.3. *Composite Potential as Structural Lightweight Concrete*

To analyze the potential of waste material-based composites as structural low-density (lightweight) concrete replacement, the resulting density and 28 days compressive strength were referred to ACI 213R-14: Guide for Structural Lightweight-Aggregate Concrete. Structural lightweight concrete has an air-dried density of not more than 1850 kg/m^3 and compressive strength of more than 17 MPa. Table 4 represents the density and compressive strength value of composites in this study according to ACI 213R-14. Columns marked by bold highlight indicate that the density and compressive strength of resulting composites are in accordance with ACI 213R-14. Sawdust and PET can be used up to 15% replacement of cement, while used diapers can be used only up to 5%. That is because the high absorbent properties of diapers will increase the water content in resulting composites and decrease the compressive strength even though the density is in accordance with the standard.

Table 4. Density and compressive test of composites in accordance to ACI 213R-14.

Mixture Labels	Density (kg/m^3)	f_c (MPa)	Density	f_c
C	1860	24.61	No	Yes
SD-5	1800	20.70	**Yes**	**Yes**
SD-10	1770	19.59	**Yes**	**Yes**
SD-15	1600	19.36	**Yes**	**Yes**
SD-20	1130	9.98	Yes	No
PET-5	1110	33.04	**Yes**	**Yes**
PET-10	1090	26.96	**Yes**	**Yes**
PET-15	1070	20.89	**Yes**	**Yes**
PET-20	1060	14.81	Yes	No
UD-5	1840	18.05	**Yes**	**Yes**
UD-10	1820	10.11	Yes	No
UD-15	1800	2.16	Yes	No
UD-20	1780	0.16	Yes	No

4. Conclusion

This study developed composites based on sawdust, PET, and used diapers. The raw material of the composite affects the resulting density and compressive strength. The addition of waste materials tends to decrease the density of hardened composites. The highest compressive strength of 5% sawdust, PET, and used diapers as cement replacement are 20.70 MPa, 33.04 MPa, and 18.05 MPa, respectively. Sawdust and PET can be used as up to 15% replacement of cement, while used diapers can be used only up to 5% as a potential structural lightweight concrete replacement.

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