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Development of Composite Plastic, Kenaf Fiber and Glass as Construction Material

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Abstract :

The problem of plastic waste has not been resolved since the attempts to reduce the amount through recycling are not optimally handled. There are several studies on the use of plastic as a construction material. Therefore, this study aims to obtain construction materials that use PET plastic waste. This type of waste does not have economic value, and in an experiment conducted, it was collected and chopped to pass a 2.75 mm sieve. Furthermore, it was made into particleboard composite with kenaf fiber and glass formed by the hand lay up and press mold methods. The specimens were made in 3 variations of layers for each composite material by taking PET plastic from the landfill (TPA) or other sites. The PET was then immediately chopped and used as specimens/ NTPA. The mechanical properties including MOR, MOE, shear strength, and compressive strength, and SEM test was conducted for the FPC composite. The results of mechanical testing showed that plastic composites with 1 layer and NTPA waste sources can be used as construction materials, especially in non-structural walls (insulating).

Keywords: plastic waste, PET, hand lay up, press mold, plastic composite

I. INTRODUCTION

Plastic waste is bad for the environment since it is not easily decomposed. This long process of decomposition results in a decrease in environmental quality [1], such as the emergence of chemical substances that can pollute the soil and reduce the level of benefits and fertility. Plastic waste has the potential to harm environmental ecosystems and human health when improperly disposed. Therefore, waste recycling has always been a topic of discussion when it comes to deal with the problem of plastic waste. According to the Indonesia Solid Waste Association (2013), this type of plastic waste was accumulated at 5.4 million tons per year and Indonesia is ranked second in the world as the producer of marine waste after China.
Currently, studies on the use of plastic waste as a construction material are increasingly conducted. Sojobi et al (2016) investigated the use of recycled plastic bottles (PET) in asphalt concrete for road construction [2], and the use of plastic waste as ceiling material. Furthermore, studies have been conducted on plastic materials as composite materials including Palm Oil [3]. In line with this, studies on the use of cultivated composites through natural fiber are increasing because consumers are environmentally conscious to preserve nature [4]. In its

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application, natural fibers are mixed with synthetic, which is man-made [5]. The PET plastic waste (Polyethylene Terephthalate) is easily obtained and it is the basic material in this study. Moreover, this material can melt at a temperature of 100°C - 180°C and can strongly stick together with other materials.
A study was conducted on mixed composites or hybridization of two natural fibers, synthetic and natural fibers, and two synthetic fibers in a single matrix [6]. The use of lignocellulosic in agriculture or as a filler and reinforcement in hybrid composites is also reported to improve the mechanical properties of composites [7].

Previous studies on composites showed the usage of kenaf fiber and fiber glass in the field of civil construction. These materials are used as an alternative home ceiling because its mechanical properties are better than the types made from plywood, calciboard, or gypsum [8]. This study raises the idea of alternative uses for other construction materials, such as a non-structural wall. Subsequently, the increasingly expensive raw construction materials for building walls such as gypsum, plywood, and asbestos then promotes manufacturers to obtain cheaper materials with physical and mechanical strength. Considering the sustainability and cost effectiveness, the materials used also should be obtained from nature, sourced from renewable energy, and locally available. The durability test of decent building materials is then needed to ensure the addition of recycled materials to reduce waste production is successfully achieved.

The types of plywood, gypsum, or asbestos are getting thinner, and their physical and mechanical strength is also reduced because of the limited raw materials. Therefore, the wood is made thinner allowing the public to reach the price of the product/material.
Plywood is not weather-resistant since it is easily damaged by rain when there is seepage. Furthermore, it is made up of flammable materials reinforced by polyester. Currently, the development of composites produces strong, low density, and renewable [9]. In terms of physical and mechanical strength, kenaf and glass fiber materials are superior to others besides being easier to obtain. Jones, R (1975) stated that fiber-reinforced composite materials are widely used because of their specific strength and stiffness. These materials are far above others and their properties are designed according to the requirements [10]. The results showed that kenaf and glass fiber are very good and should be used as an applied product. This study aims to find a new engineering product in the form of FPC (Fiber Plastic Composite) wall material as an alternative construction material.

MATERIALS AND METHODOLOGY

A. The materials used

1. PET waste plastic

The PET plastic waste used was obtained from Final Disposal Sites (TPA) and Non-TPA. Furthermore, non-TPA waste is not disposed of in a TPA, therefore bottles of mineral water used are immediately collected and chopped. The two types of waste are chopped and filtered to pass sieve 6 with a maximum diameter of 2.5 cm (1 inch).

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2. Kenaf fiber

The kenaf fiber used is obtained from the kenaf plant processed by the manufacturer to form sheets that are cut in the size of 50 cm x 50 cm.

3. Glass fiber

Two types of glass fibers commonly used in industrial fiber-reinforced plastics are E-glass and S-glass [11]. In this study, E-Glass was used, and the glass fiber is in the form of chopped strand math (CSM). The glass fiber used is cut according to the dimensions of the mold 50 cm x 50 cm.

4. Polyester resin

Polyester SHCP resin (Singapore High Chemical Polymer) was used as a matrix.

5. Catalyst

The catalyst used has MEKPO (Methyl Ethyl Ketone Peroxide) compound.

B. Methodology

1. Composite Preparation

The design of plastic composite constituent materials is based on the volume of the mold. In addition, the kenaf fiber was cut according to the composite mold and was fabricated using the hand lay up method by laying in layers (Figure 1) alternating between kenaf and glass fiber as well as shredded plastic. The variations of the layers used were 1, 2, and 3 layers with details of the volume fraction as shown in Table 1. The laying was manually conducted and coated with resin, and the process was repeated with each ingredient in 2 and 3 layers.

Table I . Formulation of Plastic composites

Sample Test		Composite Formulation				
Plastic Source		Plastic (gr)	Kenaf Fiber (gr)	Glass Fiber (gr)	Resin (gr)	Hardener (gr)
Landfill (TPA)	NTPA					
FPC 1 (1 layer)	FPC 1 (1 layer)	175.54	95.54	74.56	781	19
FPC 2 (2 layers)	FPC 2 (2 layers)	351.08	191.08	149.12	1562	38
FPC 3 (3 layers)	FPC 3 (3 layers)	526.62	286.62	223.68	2343	57

The process of making composites using the hand lay-up and press mold methods are:

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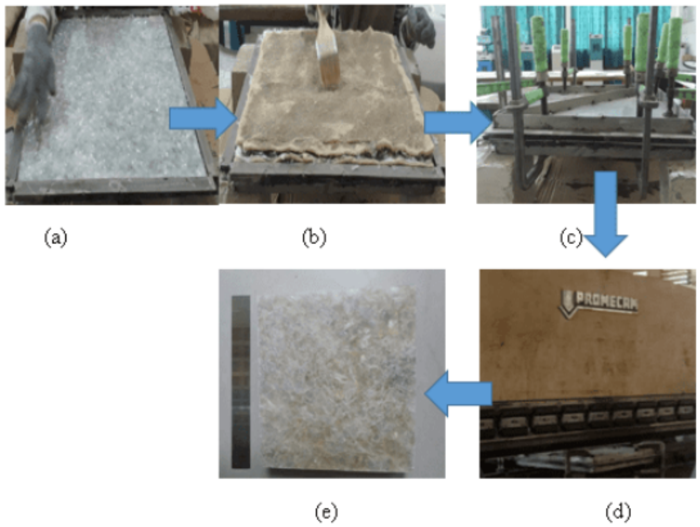

(a)Spreading plastic waste; (b) Overlaying of kenaf fiber; (c) Press Mold
(d) Pressed 200 kg/m^2; (e) FPC (Fiber plastic Composite)

Fig 1. Fabricated Composite Plastic

The resin can be poured by hand into a mold measuring 50 cm x 50 cm on to the kenaf fiber in the form of a sheet. It was provided with a car kit to easily remove the composite from the mold. This is conducted with a certain amount while leveling it using a roller or brush. Smoothing or pressing is conducted to completely fuse the resin and fiber. The sprinkling is conducted with plastic waste that passes filter 6 with a maximum plastic size of 2.5 cm from the TPA. Furthermore, the resin is poured and the glass fiber is spread, and it is compressed with a compression pressure of 200 kg/cm^2. This is conducted with 3 variations including 1 layer with reinforcing material and matrix used 1 time each. Meanwhile, 2 layers were used with reinforcing material and matrix 2 times, and 3 layers were used with matrix and reinforcing material 3 times each. The process was repeated with non-TPA origin materials with the same layer variations until the desired thickness was achieved.

2. Modulus of Elasticity (MOE) testing

The MOE test was conducted to determine the elasticity properties of the composite material measuring 20 cm long and 5 cm wide for the 2 test objects. The modulus of elasticity is calculated by the formula:

$$MOE = \frac{\Delta PL^2}{4\Delta YBH^3} \qquad (1)$$

Where: MOE = Modulus of elasticity (kg/cm ^{2})
P = Big change in a load before proportion limit (kg)
L = Support distance (cm)
Y = The change in deflection due to changes in load P(cm)

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B = Width of the test sample (cm)
H = Thickness of the test sample (cm)

3. Modulus of Rupture (MOR) testing

The MOR test was conducted to determine the fracture properties of the composite material measuring 20 cm long and 5 cm wide for the 2 test objects. The modulus of rupture is calculated as follows:

$$MOR = \frac{3PL}{2BH^2} \quad \ldots\ldots (2)$$

Where: MOR = Modulus of rupture (kg/cm ^{2})
P = Maximum load (kgf)
L = Support distance (cm)
B = Width of the test sample (cm)
H = Thickness of the test sample (cm)
L = Width (cm)

4. Shear adhesive strength

The shear-adhesive strength test material was 5 x 5 cm in size, and the value of its firmness is calculated with the formula:

$$SA = \frac{P}{L} \quad \ldots\ldots (3)$$

SA = Bond shear strength (kg/cm ^{2})
P = Maximum load (Kg)
L = Surface area of adhesive (cm ^{2})

5. Compressive strength

The test material for testing the compressive strength is (5 x 10) cm, and the value is calculated using the formula:

$$CR = \frac{P}{L} \quad \ldots\ldots (4)$$

CR = Maximum compressive strength parallel to the fiber (kg/cm ^{2})
P = Maximum load (kg)
L = cross-sectional area (cm ^{2})

III. DATA ANALYSIS AND INTERPRETATION

The physical appearance of FPC composites from TPA and NTPA PET waste sources has a smooth texture. However, the color appearance of the printed results gives a slightly darker color for TPA PET FPC compared to the physical appearance of FPC composites from non-

TPA sources. This showed that the composite (a) contains dirt in the form of dust or soil originating from the landfill. As for the composite (b) the appearance of the formed print showed a lighter color than composite A as shown in Figure 2.

(a)TPA PET plastic composites

(b) Non TPA PET plastic composites

Fig 2. Composite physical appearance

A. Mechanical Properties of FPC Composite (Fiber Plastic Composite)

1. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

The MOR test was conducted to determine the fracture toughness of the TPA and NTPA FPC composites. Table II showed the results of the MOR and MOE testing of FPC composites with variations in specimen thickness.

Table II. MOR and MOE of FPC composites

Specimen Code	Pressure Load (kg/cm^2)	Layer variations	Composite Mechanical Properties	
			MOR (Mpa)	MOE (Mpa)
FPC 1 (TPA)	200	1 layer	33.25	3249.33
FPC 2 (TPA)	200	2 layers	23.47	1461.90
FPC 3 (TPA)	200	3 layers	13.57	345.71
FPC 1 (NTPA)	200	1 layer	72.14	4954.06
FPC 2 (NTPA)	200	2 layers	45.97	2756.88
FPC 3 (NTPA)	200	3 layers	30.69	1306.42
ASTM D 143 2005 control			Min 25.30	Min 4206.30

The mechanical properties test in Table II showed that the values of two specimen variables meet the required standards and ASTM D 143-2005 is FPC 1 NTPA. For the MOR value, the specimen with additional layers has a lower value with the increase in the number of composite layers. Furthermore, all FPC variations with NTPA plastic sources have MOR values greater than 25.30 Mpa. This showed that the thickness of the composite specimen greatly affects the

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value of flexural strength and elasticity. The epoxy resin adhesive also has an important role as a binder for fiber particles in the specimen. Maloney (1993) stated that the fiber content, type of adhesive, adhesive bonding power, fiber length and type used affect MOE value [13]. Figures 3 and 4 showed the MOR and MOE of all specimens.

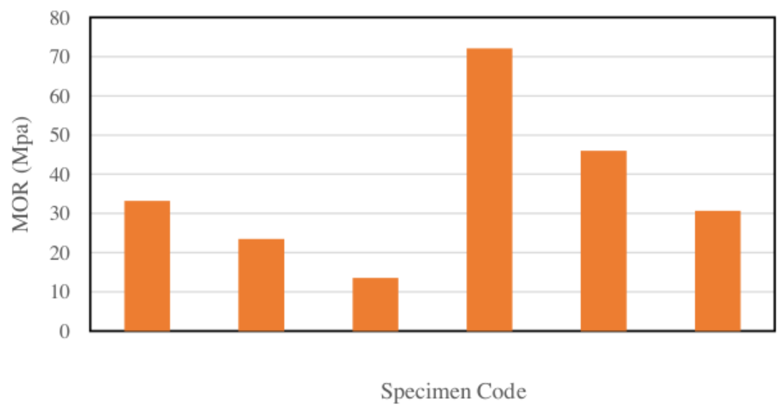

Fig 3. MOR test results

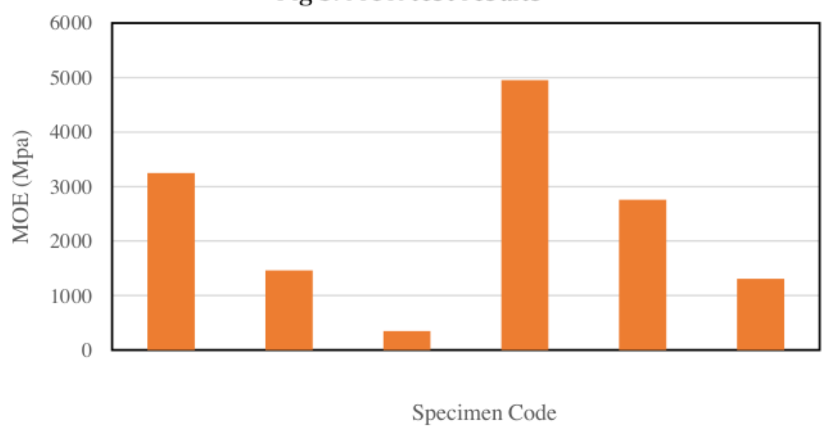

Fig 4. MOE test results

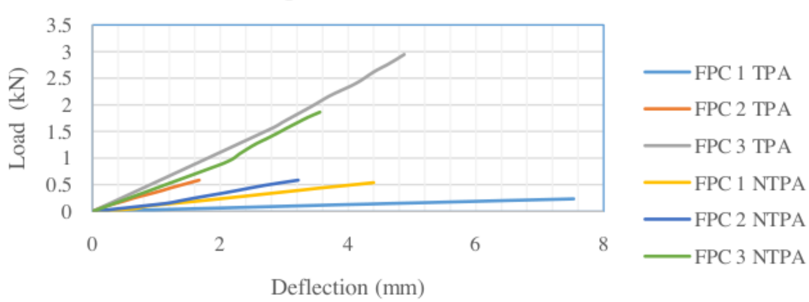

Fig 5. Load-Deflection of FPC

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2. Shear Strength Test

The shear strength is used to determine the level of adhesion between the FPC constituent materials. Table III showed the value of the shear-adhesive strength obtained from the test results.

Table III. Shear Strength of FPC

Specimen Code	Pressure Load (kg/cm^2)	Layer variations	Max load (kN)	Shear strength (kg/cm^2)
FPC 1 (TPA)	200	1 layer	20.52	4.24
FPC 2 (TPA)	200	2 layers	18.00	3.52
FPC 3 (TPA)	200	3 layers	36.44	7.13
FPC 1 (NTPA)	200	1 layer	27.30	5.42
FPC 2 (NTPA)	200	2 layers	34.65	6.24
FPC 3 (NTPA)	200	3 layers	36.01	7.56
ASTM D 143 2005 control				3.5 - 7

The highest shear strength value is shown by specimens with a variation of 3 layers from TPA and NTPA plastic sources. For 3 layers FPC (TPA) the shear strength value is 7.13 and for 3-layer FPC (NTPA) the shear strength value is 7.56 above the standard ASTM D 143 2005. Meanwhile, the value of shear strength of variation 1 and 2 layers meet the standard of ASTM D 143 2005. During the shear-adhesive testing process, the sample experienced cracks in the lamina cleavage, especially the 3-layer. This is due to the thickness of the sample, which has not experienced a sufficiently dense density and it is still possible to have pores with cracks. However, for 1-layer and 2-layer FPC from PET TPA and NTPA, the average value of the adhesive shear strength has met the ASTM D 143 2005 standard. Figure 6 showed the graph of the results of the shear strength test.

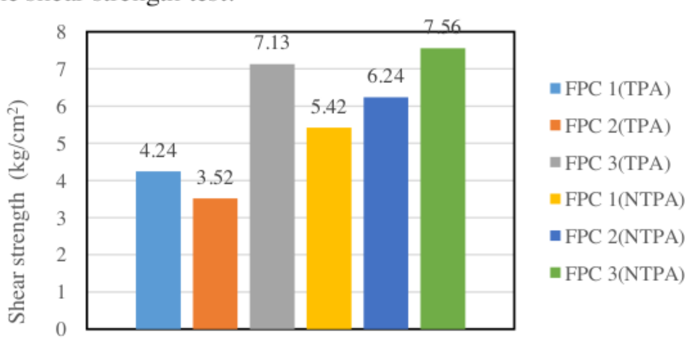

Fig 6. Shear Strength FPC

3. Compressive Strength Test

A compressive strength test was conducted to determine the effect of the layer variations. Table IV showed the results of the compressive strength test of the FPC composite specimen. NTPA FPC has a high firmness value of all FPC specimens compared to TPA FPC, and this showed the effect on plastic waste. The presence of dirt and dust attached to the plastic waste reduces the

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compressive strength, and 1 layer FPC has the lowest results compared to others. The compressive strength values of all FPC samples from TPA and NTPA increased with increasing layer thickness. However, the average compressive strength test results have met the standards required by ASTM D 143 2005, and the graph is represented in Figure 7.

Table IV. Compressive Strength FPC

Specimen Code	Pressure Load (kg/cm^2)	Layer variations	Compressive Strength MPa
FPC 1 (TPA)	200	1 layer	5.84
FPC 2 (TPA)	200	2 layers	9.50
FPC 3 (TPA)	200	3 layers	13.90
FPC 1 (NTPA)	200	1 layer	9.52
FPC 2 (NTPA)	200	2 layers	12.50
FPC 3 (NTPA)	200	3 layers	20.08
ASTM D 143 2005 control			Min 0.608

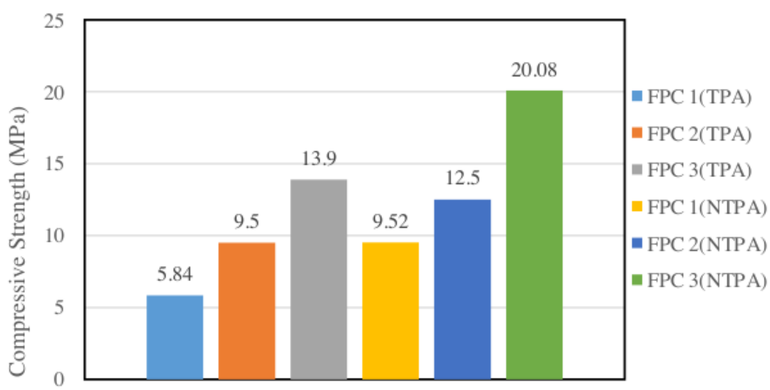

Fig 7. Compressive strength FPC

B. Morphological Characteristics of FPC

Observation of the microstructure at the point of the matrix and the interface of the reinforcement area was conducted on the elements of the composite. Some of the information that supports the properties of the composite is obtained from the microstructure.

The trapped air formed during the molding or the composite manufacturing process causes microscopic damage and also air voids, matrix cracks, debonding, and delamination, from the observation of the microstructure. Therefore, there is a difference in tensile stress between one point and another or between one layer and another, resulting in damage such as micro-cracks of the matrix. The presence of shear stresses between the laminae results in debonding, and it is the

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arrangement of fibers in an inclined position. The brittle cross-section is conducted by the composite with the fiber orientation angle of 0^0 to reduce the strength.

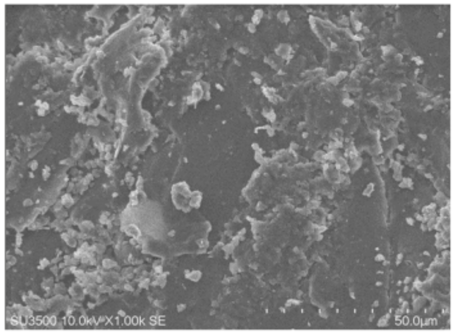

Fig 8. FPC 1 (TPA) SEM Morphology

The SEM results showed that the 1-layer FPC (TPA) specimen has dirt attached to the material and appears to be scattered as shown in Figure 8. In contrast to the results of the morphological characteristics for FPC (NTPA), there are no scattered particles due to the direct origin of PET from NTPA. In addition, the PET was directly chopped and it had a denser texture and fewer cavities. The density and mechanical properties such as MOR, MOE, Shear strength and the compressive test produced is higher than that of FPC (TPA) specimens. The morphology of the two composites has a solid form.

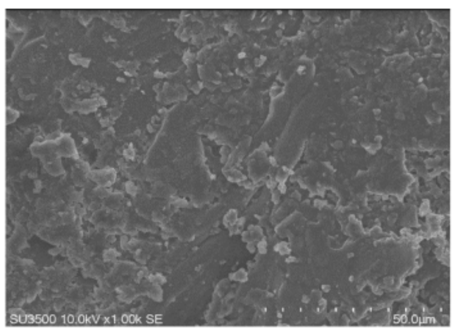

Fig 9. FPC 1 (NTPA) SEM Morphology

IV.CONCLUSION

1. The results of FPC fabrication showed a smooth texture and in terms of physical appearance, the source of plastic used was strongly affected following the SEM test. Furthermore, the NTPA FPC showed a brighter appearance than TPA FPC.
2. Mechanical behavior in the form of MOR, MOE, shear strength, and compressive strength of FPC 1 layer of NTPA met the requirements of ASTM D 143 2015 standard.

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Therefore, 1- layer variation of FPC is an environmentally friendly construction material for the non-structural wall.

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