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FIRE RESISTANCE MEASUREMENT OF OIL PALM EMPTY FRUIT BUNCH-PLASTIC COMPOSITES BY COMBUSTIBILITY TEST

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ABSTRACT

FIRE RESISTANCE MEASUREMENT OF OIL PALM EMPTY FRUIT BUNCH-PLASTIC COMPOSITES BY COMBUSTIBILITY TEST. This paper reports combustibility test of Oil Palm empty fruit bunch (EFB)-plastic composites to determine their fire resistance. Specimens were of several composite types with dimension of 40 x 40 x 50 mm^3. Combustibility test was done according to JIS A 1321-1975 by using small scale cylindrical furnace. Initial temperature of furnace was set at 750 ºC ± 1 ºC. Based on JIS A 1321-1975, all the composites tested were classified into combustible materials due to their temperature gradient higher than 50 ºC. The lowest temperature gradient was attained at 75 ºC for PE-EFB/GF/GF short fibers composite. However, the result showed that the temperature gradient of PE-EFB/GF/GF short fibers composite was lower compared to some solid woods and commercial wood-based panels. Weight loss has a strong relationships with density of the composites, shown by polynomial equation $y = -181.82\ x^2 + 452.36\ x - 205.5$, $R^2 = 0.9156$. The density of composites which formed EFB layers tended to decrease, conscequently increased their weight loss. Concerning the both factors, PE-EFB/GF/GF short fibers composite was recommended as the best fire resistance among the tested composites due to its lowest temperature gradient (75 ºC) and relatively lower weight loss (64.17 %).

Key words : Combustibility test, Empty fruit bunch, Composite, Temperature gradient, Weight loss.

ABSTRAK

PENGUKURAN KETAHANAN API KOMPOSIT TANDAN KOSONG KELAPA SAWIT-PLASTIK DENGAN PENGUJIAN SIFAT BAKAR. Makalah ini menguraikan hasil pengujian sifat bakar komposit tandan kosong kelapa sawit plastik untuk mengetahui ketahanannya terhadap api. Contoh uji dibuat menjadi beberapa jenis komposit dengan ukuran 40 mm x 40 mm x 50 mm. Pengujian sifat bakar dilakukan mengikuti JIS A 1321-1975 dengan menggunakan tungku silindris berukuran kecil. Suhu awal tungku dimulai pada 750 ºC ± 1 ºC. Berdasarkan JIS A 1321-1975, seluruh komposit yang diuji diklasifikasikan sebagai bahan yang mudah terbakar karena kenaikan suhu > 50 ºC. Kenaikan suhu terendah dicapai pada 75 ºC oleh contoh uji komposit *PE-EFB*/*GF*/*GF* serat pendek. Kenaikan suhu contoh uji komposit *PE-EFB*/*GF*/*GF* serat pendek tersebut masih lebih rendah dibandingkan dengan beberapa jenis kayu dan panel kayu. Kehilangan berat mempunyai hubungan yang sangat nyata dengan berat jenis komposit dan ditunjukkan oleh persamaan polinomial $y = -181{,}82\ x^2 + 452{,}36\ x - 205{,}55$, $R^2 = 0{,}9156$. Berat jenis komposit yang dibuat dengan pelapisan tandan kosong kelapa sawit (*EFB*) cenderung menurun, sehingga mengakibatkan meningkatnya kehilangan berat. Dengan mempertimbangkan kedua faktor tersebut, maka contoh uji *PE-EFB*/*GF*/*GF* serat pendek dapat direkomendasikan sebagai komposit yang paling baik sifat ketahanan apinya karena mengalami kenaikan suhu terendah (75 ºC) dan kehilangan berat yang relatif rendah (64,17 %).

Kata kunci : Pengujian sifat bakar, Tandan kosong kelapa sawit, Komposit, Kenaikan suhu, Kehilangan berat.

INTRODUCTION

Composites materials are usually concentrated to synthetic polymer and synthetic reinforcing fibers like glass, carbon and nylon. The most important disadvantage of such composite materials is the problem of convenient removal after the end of life time, which is not easily achieved because of the different natures of the various materials forming the composite and as the components are closely interconnected, relatively stable and therefore difficult to separate and recycle, then they are non biodegradable.

The possibility of replacing manmade reinforcements with natural fibers is currently of interest, attract the attention of scientists and technologists. Natural fibers reinforced composites combine good mechanical properties with a low density. Such composites offered a number of well known advantages include low cost, availability of renewable natural resources and biodegradability. The use of natural fibers such as filler in polymer has been done elsewhere.

The bast fiber of flax and hemp are commonly quoted as being among the strongest and the stiffest of the available natural fibers [1]. Fibers from bamboo also appear to compare favorably. Kenaf fiber is a potentially an outstanding reinforcing filler in thermoplastic composites [2]. Study on the use of straw [3], jute, ramie, and flax [4-6] as well as wood [7] has been done previously. Thermo-set resins such as epoxy, polyester, and vinyl ester are most commonly used with those natural fibers to produce low strength materials. These resins have good dimensional stability, are easily manufactured, and limit moisture absorption. The major drawback of thermo set is the fact that they cannot be recycled or reshaped after being cured. Thermoplastics are more attractive due to their potential recycle ability. Affordable manufacturing processes such as injection molding or compression, in turn, allow for high volume production. However, thermoplastic use could be limited by their high melting point.

Oil Palm (*Elaeis guineensis)* is one of the major plantation commodities in Indonesia, which has a great contribution for national income. Crude Palm Oil (CPO) as the main product of Oil Palm fruit can be used in many different industries. In Indonesia, the Oil Palm plantation has been increasing by about 118% from 1992 to 2002. The planted area by the end of 2002 reached about 3.2 million hectares. It is estimated that in 2010 Indonesia will lead the world CPO production. The CPO production has also been increasing from 3.2 million tons in 1992 to 6 million tons in 2002. In the line with the development of CPO production, Oil Palm empty fruit bunch (EFB) as one of the solid wastes produced by Palm oil mill is readily available in large amount throughout the year. The Palm oil industry must dispose about 1.1 ton of EFB for every ton of CPO produced. In 2002, the availability of this waste was estimated about 6 million tons [8].

These EFB consists of high cellulose content and is a potential natural fiber re-sources. However, its applications account for a small percentage of the total potential production. Effect of Oil Palm EFB fibers on the physical and mechanical properties of fiber glass reinforced polyester resin composites has been studied [9]. The addition of EFB fibers volume fraction around 40~70 % increases flexural strength of polyester composites by about 350%. The addition of 40% volume fraction EFB fibers resulted in the similar flexural properties with glass fiber/polyester composites but showed lower density. This suggests that EFB fibers have a potential ability to replace glass in many applications that do not require very high load bearing capabilities. Several works have been done on the physical and mechanical properties of EFB filled/ reinforced-polymer composites. However, its fire resistance is not discussed yet. The application of such products needs to be assessed for their fire resistance for the life-safety point of view.

Fire retardant properties of wood depend on several factors, i.e. density, thermal conductivity, moisture content, gas permeability, ring orientation, thickness of the specimen, charring temperature, the combustible volatile content and the char layer characteristics [10]. Since the wood-based composites have no fiber orientation, the above factors affect to wood-based composites, except ring orientation. Among the factors, density is considered to have the great influence on the fire retardant properties. Indicating parameters for the fire performance of wood and wood-based composites are also many, such as ignition time, Mass Loss Rate (MLR), char depth, heat release rate, heat of combustion, heat flux and charring rate (CR). Trans and White (1992) used a Cone Calorimeter, and proposed to calculate the MLR and CR. They presented the equation that MLR = CR x density. The equation showed a strong relation between MLR, CR, and density. Also reported that the increasing of density and surface hardness of compressed wood affected ignition time and MLR [11]. However, MLR parameter could not exactly determine the fire retardant levels. The observation indicated that temperature elevation at the opposite side of fire exposing surface could classified the fire retardant levels of wood and wood-based panels [12].

This study aims to evaluate the effect of (1) composite types, (2) density, and (3) EFB fiber length on the fire resistance of glass fiber reinforced polyester resin composites. Besides Cone Calorimeter Test, ISO 5660, there are some fire testing that can be done to measure the fire resistance of a material, such as: Fire Rating Test-Full Scale, SNI 03-1741-1989/JIS A 1304-1994, specimen size 106 x 105 cm^3; Spread of Flame Test, ISO 5658-2-1996/ASTM D 3806-1979, specimen size 16.5 x 16.5 x 0.6 cm^3; and Thermal Conductivity Test, TC-32, specimen size 20 x 10 x 5 cm^3. In this experiment, fire resistance of composites was detected by Combustibility Test, SNI 03-1740-2000/JIS A 1321-1975, due to the test can be conducted for a small specimen with the size of 40 x 40 x 50 mm^3. This test only classifies specimen into un-combustible or combustible material based on its temperature gradient. If the specimen reaches temperature gradient higher than 50 ºC, specimen will be classified into combustible materials. Therefore, the temperature gradient and weight loss of the tested composites were compared with some other materials.

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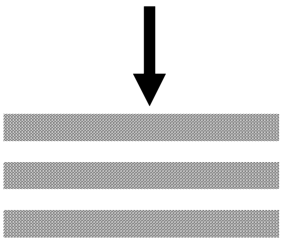
EXPERIMENTAL METHOD

Materials

Empty fruit bunch (EFB) of Oil Palm (*Elaeis guineensis*)**,** was kindly supplied by PT. Condong Garut Estate Crop, Garut, West Java. General-purpose polyester resin (PE) used as the matrix and glass fiber (GF) mat (density = 2.59 g/cc) were obtained from local supplier. PE resin density was determined by Picnometer. The resin density was found to be 1.36 g/cc.

Fiber Preparation Methods

All EFBs were manually dismantled into bundles of virgin fiber. The bundled fibers were air dried at room temperature before being cut to 2~5 cm as shorter fiber and 8~10 cm of length as longer fiber, respectively using a carding. Fibers were then soaked in 2 % sodium hydroxide solution at 100 ^{o}C for 30 min and dried at 60 ^{o}C for 24 h. Each of longer and shorter EFB fibers were then set on the aluminum sheet randomly and pressed at 1 MPa to give thin EFB fibers sheet crossing one another. Weight of inner, middle, and outer layers are based on the weight of commercial glass fiber layers used in composites (Figure 1), namely 19.6, 26.1, and 45.2 g [13].



Fiber layer 1, (inner layer, 19,6 g)
Fiber layer 2, (middle, 26,1 g)
Fiber layer 3, (outer layer, 45.2 g)

Figure 1. Position of fiber layers in composite.

Composite Preparation

EFB fiber mats and GF mats were stacked together with PE resin using closed aluminum mold size of 270 x 270 x 4 mm^2 by hand lay up method. Composites having a different volume fraction of EFB fibers and GF were stacked together. PE resin composites and GF composites were made as control specimens.

The mold is first polished and then a mold releasing agent is applied on the surface. General purpose PE resin is mixed with 0.4 wt% methyl ethyl ketone peroxide solution in dimethylphtalate as catalyst and 2 wt% of synthetic hydrophilic amorphous silica (Wacker HDK N20). The resin mixture then poured on the mats placed in the mold. When the mats are completely wet by the resin, the mold is closed and placed on the lower movable platen of the hydraulic press. The mold is then pressed at 7.4 MPa and cured at room temperature for 24 h.

Combustibility Test

The testing was done according to JIS A 1321-1975 by using small scale cylindrical furnace powered by electric. The apparatus was made of refractory materials with 10~13 mm in thickness, 75 mm in diameter and 150 mm in height. It was covered by a thick resistance sheet to isolate the wire heat elements surrounding the apparatus (Figure 2). The specimen was placed vertically in a wire case and put into the furnace.

Figure 2. Small scale cylindrical furnace apparatus.

Typical curve of combustibility tested specimen is shown in Figure 3. Initial temperature of furnace was set at 750 °C ± 1 °C (time axis). Temperature once decreased when specimen was put into the furnace due to moisture content of the specimen; then it gradually increased to a maximum peak. Temperature gradient was calculated as the increasing temperature from 750 °C to a maximum peak. The time required to a maximum peak for each specimen was more or less than 30 minutes.

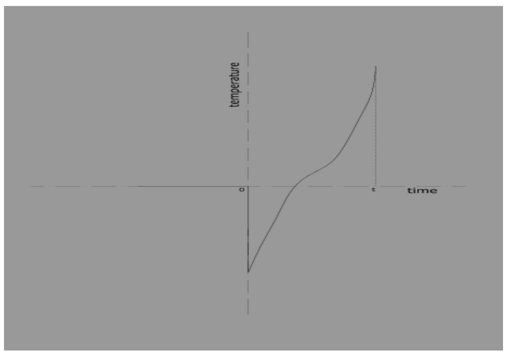


Figure 3. Typical curve of combustibility tested specimen.

Table 1. Composite types of Oil Palm empty fruit bunch-glass fiber reinforced polyester resin composites.

Composite Type	Density g/cc		Final Temperature (ºC)		Temperature Gradient (ºC)		Initial Weight g		Final Weight g		Weight Loss %	
	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short
PE	1.368		870		120		111.8		29.8		73.35	
PE-GF/GF/GF	1.559		868		118		122.1		50		59.05	
PE-EFB/GF/GF	1.512	1.501	860	825	110	75	112.1	118.9	43.3	42.6	61.37	64.17
PE-EFB/EFB/GF	1.451	1.424	870	844	120	94	116.2	117.2	39.3	38.3	66.18	67.32
PE-EFB	1.365	1.406	880	845	130	95	106.3	112.3	27.7	29	73.94	74.18
PE-EFB/EFB	1.333	1.362	841	865	91	115	104.4	108.1	25.2	27.8	75.86	74.28
PE-EFB/EFB/EFB	1.311	1.306	860	832	110	82	106.3	106.1	27.1	28.5	74.51	73.14

Notes:
Initial temperature = 750ºC.
PE = Polyester resin
GF = Glass fiber
EFB = Empty fruit bunch

RESULTS AND DISCUSSIONS

The measurement results of density, temperature and weight for all the specimens are shown in Table 1. Polyester resin (PE) and glass fiber (GF) composites were tested as control specimens. Fiber length of which formed empty fruit bunch (EFB) sheet was separated into long and short fibers.

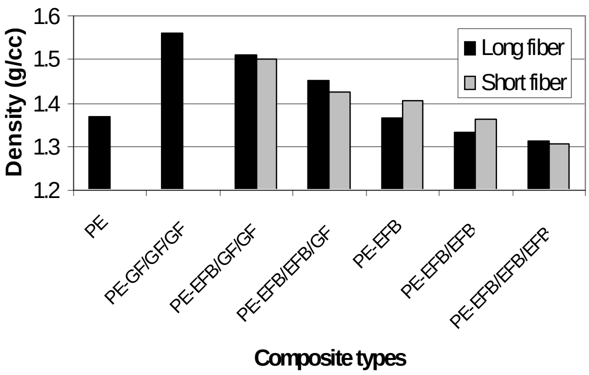


Figure 4. Density of the composites.

Figure 4 shows that PE control specimen has relatively the same density with its initial density, i.e. 1.368 g/cc (initial density = 1.360 g/cc). The highest density was attained for PE-GF/GF/GF composite, i.e. 1.559 g/cc, because initial density of GF was high (2.59 g/cc). On the other hand, PE-EFB/EFB/EFB composite has the lowest density (density of EFB long fibers = 1.311 g/cc; EFB short fibers = 1.306 g/cc). The formation of EFB layers tended to decrease density of the composites. These results were in agreement with the previous study that the addition of 40 % volume fraction EFB fibers resulted in the similar flexural properties with PE/GF composites but showed lower density [9].

Temperature gradient of all the specimens was between 75~130 ºC (Figure 5). PE and PE-GF/GF/GF as control specimens have almost the same temperature gradient, i.e. 118~120 ºC. The addition of EFB long fiber layers on the composites did not decrease their temperature gradient; PE-EFB long fiber composite even reached the highest temperature gradient, i.e. 130 ºC. However, the temperature gradient of composites which formed by EFB short fiber layers was generally lower than that of EFB long fiber layers. These results were probably in relation with their thermal conductivity and surface roughness, which EFB long fibers have a higher thermal conductivity and rougher surface than EFB short fiber, consequently increased the temperature gradient.

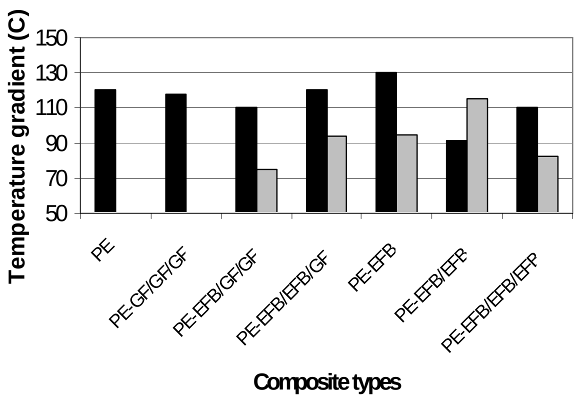


Figure 5. Temperature gradient of the composites (Legend, see Fig. 4).

The lowest temperature gradient was attained at 75 °C for PE-EFB/GF/GF short fibers composite. However, based on JIS A 1321-1975, all the composites tested were classified into combustible materials due to their temperature gradient of higher than 50 ºC. To know

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the fire resistance level, composites were compared with several woods, wood-based panels, and other structure materials. It shows in Table 2 that Terentang, Borneo and Kamper woods, commercial plywood, wood-wool panel, and UF/MF particleboards were also classified into combustible materials; and aluminum sheet, red-brick, cement-glass fiber, gypsum, concrete roof-tile, asbestos panel and cement-pulp board were classified into non combustible materials. The result showed the temperature gradient of PE-EFB/GF/GF short fibers composite was lower than that of some solid woods and commercial wood based panels.

Table 2. Temperature gradient of other structure materials.

Combustible materials		Non-combustible materials	
Specimens	Temperature gradient (> 50°C)	Specimens	Temperature gradient (< 50°C)
Terentang wood	88	Aluminium sheet	0
Borneo wood	112	Red-brick	0
Camphor wood	238	Cement-glass fiber	0
Commercial plywood	88	Gypsum	17
Wood-wool panel	149	Concrete roof-tile	18
UF-particleboard	227	Asbestos panel	34
MF-particleboard	239	Cement-pulp board	39

Source: R & D Center for Settlement, Bandung, Indonesia.

Figure 6 show that temperature gradient has no relationships with density of the composites. PE-EFB/GF/GF short fibers composite with density of 1.512 g/cc attained the lowest temperature gradient; on the other hand, PE-GF/GF/GF composite with the highest density (1.559 g/cc) attained the temperature gradient of 118 ºC.

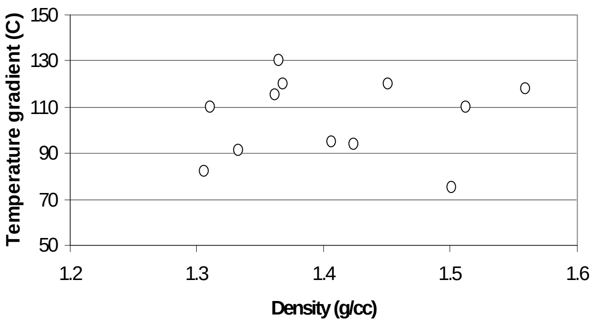

Figure 6. Relationship between density and temperature gradient of composite

Another factor to indicate fire resistance of materials is their weight loss due to fire test. Weight loss of each composites is shown in Figure 7. The lowest weight loss was attained at 59.05 % for PE-GF/GF/GF composite. The addition of EFB either long or short fiber layers tended to increase weight loss of the composites. These results indicated GF has better fire resistance than EFB due to its higher initial density (2.59 g/cc). It was also suggested that the both materials have different thermal conductivity, gas permeability, charring temperature, and the combustible volatile content [10].

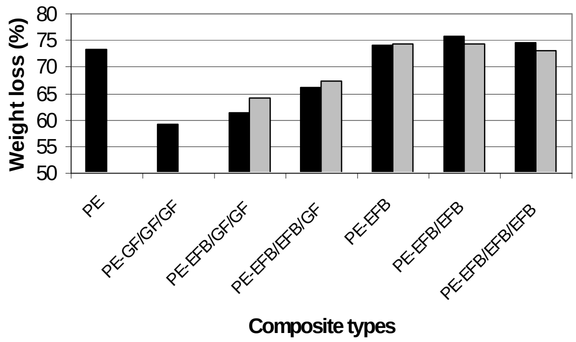

Figure 7. Weight loss of the composites (Legend, see Fig. 4).

It is shown in Figure 8 that weight loss decreased with the increasing of density and followed polynomial regression $y = -181.82\ x^2 + 452.36\ x - 205.55$; $R^2 = 0.9156$, regardless of the composite types. The result indicated that density of the composites has strong influence to their fire resistance.

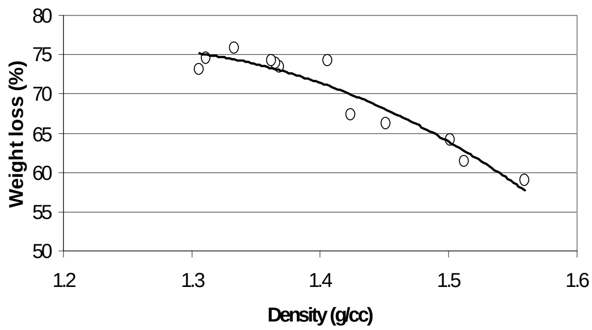

Figure 8. Relationships between density and weight loss of the composites.

To determine the best fire resistance among the composite types in concern with their temperature gradient and weight loss, the relationships between the both factors was observed.

Figure 9 shows that temperature gradient has no relationships with weight loss of the composites, as well as no relationships with density (Figure 6). As also shown in Figure 7 previously, the lowest weight loss was attained at 59.05 % for PE-GF/GF/GF composite and subsequetly followed by PE-EFB/GF/GF long fibers (61.37%) and PE-EFB/GF/GF short fibers composites (64.17%). However, the temperature gradient of PE-GF/GF/GF and PE-EFB/GF/GF long fibers composites

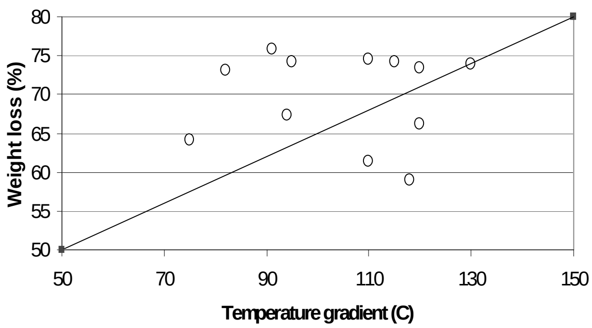

Figure 9. Relationships between temperature gradient and weight loss of the composites.

was higher than that of PE-EFB/GF/GF short fibers composites (Figure 5). Therefore, concerning the both factors, PE-EFB/GF/GF short fibers composite was recommended as the best fire resistance among the tested composites due to its lowest temperature gradient (75 ºC) and relatively lower weight loss (64.17 %).

CONCLUSIONS

Temperature gradient has no relationships with density of the composites. The temperature gradient of composites which formed by EFB short fiber layers was generally lower than that of EFB long fiber layers. The lowest temperature gradient was attained at 75 ºC for PE-EFB/GF/GF short fibers composite. Based on JIS A 1321-1975, all the composites tested were classified into combustible materials due to their temperature gradient of > 50ºC. However, the temperature gradient of PE-EFB/GF/GF short fibers composite was lower than that of some solid woods and commercial wood based panels.

The formation of EFB long or short fiber layers tended to decrease density of the composites, and subsequently increased their weight loss. Weight loss decreased with the increasing of density which followed polynomial regression $y = -181.82 x^2 + 452.36 x - 205.55$, $R^2 = 0.9156$, regardless of the composite types.

Concerning the both factors, PE-EFB/GF/GF short fibers composite was recommended as the best fire resistance among the tested composites due to its lowest temperature gradient (75 ºC) and relatively lower weight loss (64.17 %).

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