Strength of polymeric foam composite reinforced oil palm empty fruit bunch fiber subjected to impact load

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Abstract. The subjects of this study were polymeric foam (PF) composites reinforced oil palm empty fruit bunches (OPEFB) fiber to dynamic load. OPEFB is waste of Palm Oil Mill which large number. This waste is seen has good potential to be harnessed and developed to become the engineering materials. This composite is processed with mixing of polyurethane (PU) and polyester resin. The paper aims to find the density of PF composite reinforced OPEFB fiber and to investigate the mechanical properties due to dynamic load. The specimens were prepared following the ASTM D1621-00 impact test standard. The method of making the test specimen is done by casting. The ratio of PU and mixing of polyester resin and OPEFB is 45%: 65%. The results are gotten density 630 kg/m³, at a level test of 0.5 m the magnitude of the tension that occurs is 226.68 kPa, the average energy absorbed is 75.20 Joule and at the level test of 1m, the magnitude of the tension is 261.43 kPa, the absorbed energy is 184, 68 Joule.

Keywords: OPEFB, impact load, composite, polymeric foam

1. Introduction
OPEFB is a waste of Crude Palm Oil (CPO) processing at palm oil mills with a considerable amount, reaching 1.9 million tons of dry weight per year or equivalent to about 4 million tons of wet weight per year in Indonesia. Conventionally, the OPEFB is mainly used as the burning fuel in boilers to supply electricity for the plantation mills. As one of the agricultural by-products with abundant quantity, the OPEFB also causes environmental problems due to its disposal issues. The potential of fiber originated from the OPEFB to be the alternative, natural composite material. However, this waste is considered to have good potential to be utilized and developed into alternative engineering materials.

The previous investigation about OPEFB has resulted panel board [1], alternative natural acoustic material [2], fire resistance panel [3], fertilizers, mulching material, and reinforcement materials in polymer composites [4][5]. Early development of research has been done on oil palm fiber on its potential as thermal insulating material in construction of buildings [6].

The aim of this study is to investigate obtain strength of polymeric foam composite reinforced oil palm empty fruit bunch fiber subjected to impact load. This pf composite could absorb impact energy. The impact method that applied is free fall. PF Composite reinforced OPEFB can be alternative materials to replace a synthetics polymer foam.
2. Literature Review

2.1. Composite Materials

Composite materials are defined as a mixture of two or more materials that produce new material with properties that are still dominated by the material properties of its formers [7].

Generally, composite materials are formed in two types of phases, namely the phase matrix and the reinforcing phase. The matrix phase is a material with a continuous phase that is always not rigid and weak while the reinforcement phase is always more rigid and strong, but more fragile. The density of composite materials is obtained from ratio of mass and volume. The combination of these two phases produces materials that can distribute the load received along the reinforcement so that the material becomes more resistant to the effect of the load.

Mechanical properties of the composite are influenced by fiber length, fiber orientation, and interfacial adhesion on polymeric alloys reinforced with short glass fiber [8]-[12].

2.2. Impact load on structure composite

Impact load [13]-[15] of the free-fall impact method is a test in which the batter moves down free of the stay condition and then moves and accelerates as the object falls. If the object falls to earth from a certain height is relatively small compared to the radius of the earth, then the object has increased the speed down at the same value every second. This means that the acceleration of the object decreases at the same value if an object is fired at a reduced speed at the same price every second and a constant upward slow down.

To determine the speed of falling objects every second will be obtained by the approach, as shown in Table 1.

| Time t (s) | 0 | 1 | 2 | 3 | 4 | 5 |
|-----------|---|---|---|---|---|---|
| Velocity v (m/s) | 0 | 9.8 | 19.6 | 29.4 | 39.2 | 49 |

The v-t graph corresponding to Table 1 shown in Figure 1 is a straight line so that the acceleration is uniform. If the air resistance is ignored the free-falling object motion can be calculated by constant acceleration to form a straight line, when the acceleration of a free-fall object equals the acceleration of gravity (g):

1) For downward movement $a = +g$
2. For upward motion $a = - g$; and
2) The acceleration of gravity (g), can be viewed as a vector in a straight downward direction toward the center of the earth.
The definition of displacement is a change in position; this is the vector quantity including distance and direction. Speed is the rate of change of position over time. It is also a vector quantity, including distance, direction and time. Whereas the uniform acceleration of the particles undergoing the same velocity change in the same time interval respectively regardless of the difference in time interval, as shown in equation 1.

\[ v = \sqrt{2gH} \]  

Then the equation 5 is the acceleration of the free-falling object depending on the distance or height of the falling object from the center of the earth, when a solid object falls with medium density, it can be assumed that the object undergoes a uniform acceleration of gravity, for a general sense the scientists take the acceleration rate of gravity g = 9.81 m/s².

2.3. Energy mechanics
The mechanical energy in an object is fixed provided there is no external force acting on the object. The combined mechanical energy of potential energy and kinetic energy. Potential energy is the energy that an object possesses because of its level.

\[ Ep = mgh \]  

Kinetic energy is the energy that objects possess because of the motion that works on it.

\[ Ek = \frac{1}{2}mv^2 \]

3. Materials and Method

3.1. Materials

3.1.1. Polymer Composite Material
The technique of making polymeric composite materials generally does not involve the use of high temperature and impurities. This is due to this material easily being soft or melting [2]. The process of mixing the reinforce into the matrix is done when the matrix is in a liquid state.

The direct pouring method is carried out by attaching or touching the constituent materials to open mould and gradually flattened by using a grader or by outer impacting. This method is suitable for continuous and random fiber types as reinforce.

3.1.2. Unsaturated Polyester Resins
The unsaturated polyester resin is a type of thermosetting polymer having a long carbon chain structure. The mechanical data of the matrix material is shown in Table 2.

| No | Mechanical Properties | Unit | Amount |
|----|-----------------------|------|--------|
| 1  | Density (ρ)           | Mg.m⁻³| 1.2 s/d 1.5 |
| 2  | Young Modulus (E)     | GPa  | 2.0 s/d 4.5 |
| 3  | Tensile strength (σ₁) | MPa  | 40 s/d 90 |

Sources: YUKALAC, PT, Justus Indonesia Raya

3.1.3. OPEFB Fiber
OPEFB fiber is a natural fiber made from empty bunches of palm oil that is a waste in processing at a palm oil mill. The results of a research conducted by a commercial institution [10] on the chemical composition known that the material content of fiber in OPEFB is the maximum content as shown in Table 3.
### Table 3. Parameter of OPEFB per kg.

| No. | Materials Contains | Composition (%) |
|-----|--------------------|-----------------|
| 1.  | Vapour             | 5.40            |
| 2.  | Protein            | 3.00            |
| 3.  | Fiber              | 35.00           |
| 4.  | Oil                | 3.00            |
| 5.  | Water solution     | 16.20           |
| 6.  | Alkali solution 1% | 29.30           |
| 7.  | Dust               | 5.00            |
| 8.  | K                  | 1.71            |
| 9.  | Ca                 | 0.14            |
| 10. | Mg                 | 0.12            |
| 11. | P                  | 0.06            |
| 12. | Mn, Zn, Cu, Fe     | 1.07            |
|     | TOTAL              | 100.00          |

Figure 2 and 3 in a row is an OPEFB that has been minced into smaller parts and OPEFB fiber that have been mashed.

**Figure 2. Strips of OPEFB**  **Figure 3. OPEFB fiber**

Mechanical strength of OPEFB fiber with an average diameter of 0.4 mm has an average elasticity modulus value of 11.88 GPa with average maximum impact stress of 156.3 MPa [11]

#### 3.1.4. Blowing Agent

A blowing agent is a material used to produce a hollow structure on the composite formed. The type of blowing agent used in this study is polyurethane. The material formed from a mixture polyurethane and polymer is called polymeric foam material (PF). The shape of the polymeric foam structure formed is illustrated in Figure 4.

**Figure 4. Illustration of polymeric foam material.**

The catalyst is a chemical material used to speed up the polymerization reaction of the composite structure at room temperature conditions and atmospheric impurities. Administration of the catalyst may serve to regulate the formation time of BA bubbles, so as not to over-expand, or to harden too quickly, which may result in inhibition of bubble formation.
3.2. Manufacturing Processes

The manufacturing of dynamic impact test specimens is adjusted to ASTM 1621-00 standard for composite materials as shown in Figure 5. The process of manufacture is as follows:

1) Apply a separator layer on the inside of the mould with mould release wax to easily remove the product from the mould.
2) Preparation of necessary materials is OPEFB fiber, BQTN 157-EX type resin which is unsaturated polyester resin then weighed following the weight of the mixture set.
3) Combine the unsaturated polyester resin and OPEFB fiber and stir thoroughly for ± 2 minutes with an indication that all the fiber are immersed in the resin and coded C1.
4) Mix the catalyst into a mixture of fiber and resins and mix thoroughly for ± 2 minutes with the indicative color of this mixture is dark brown and give C2 code. Do not let C2 be more than 15 minutes, because it will harden.
5) Combine polyurethane-forming material with polyol and isocyanate compositions, and mix thoroughly for ± 0.5 minutes with the indication of polyurethane being formed is cream-colored foam and give C3 code.
6) Insert the C3 mixture into the resin mixture and OPEFB fiber, and stir it evenly over ± 0.5, then mix it with the catalyst and stir until the mixture is evenly distributed for ± 0.5 with indicative of this mixture color light brown and give C4 code.
7) Pour the C4 mixture into the mould as shown in Figure 5 and leave it for 24 hours until it is completely hardened and dry. Then the specimen removes from the mould. The shape of the specimen is shown in Figure 6.

![Figure 5. Manufacturing of composite](image)

![Figure 6. The impact test specimen of PF composite](image)

The results of specimens of impact test according to ASTM 1621-00 standard with ratio polyurethane and composite reinforced OPEFB fiber 45%; 65% are shown in Figure 7 and density $\rho = 630$ kg/m$^3$
3.3. Impact Test
Impact test of the specimen with impact load with the free-fall method and samples were taken with 3 samples of each height variation 0.5 m and 1 m. The impactor mass 6.8 kg is above specimen. Set up impact tests shown in Figures 7 and 8.

![Figure 7. Set up Impact Test](image)

![Figure 8. Impact Test Apparatus](image)

4. Results and Discussion
The result of the impact test shown in Figure 9. Variant height of impact load is from 0.5, 1 and 1.5 m. The impact load increase if the impactor is higher. It becomes potential energy bigger.

![Figure 9. Fracture of the specimen after impact load, variant height 0.5, 1 and 1.5m](image)

(a) (b)

The force-time graph of the free-fall method at 0.5 meter height is shown in Figure 10.
In the composite graph shown in figure 10 where the impact test results at 1 meter height are all large forces, dynamic timing and muted wave propagation vary. In sample 1 the force and dynamic time were 25.22 kgf and 31 ms, in sample 2 were 25.83 kgf and 47 ms and sample 3 were 25.83 kgf and 47 ms so that the average force and dynamic time is 25.63 kgf and 41.67 ms.

In the loading area, the surface area is 961.62 mm². A comparison between the force with the cross-sectional area will be generated stress. Whereas energy is obtained from the product of dynamic force with height, the result of this calculation is tabulated in table 4.

From the result of the dynamic impact test of the free-fall method to all samples, it is found that the force is 22.22 kgf (217.97 N). Thus to calculate the magnitude of the stress that occurs in the sample at the loading area is based on the stress equation is the force divided by the area. The area is obtained on the cross-sectional surface of the sample that is 961.62 mm². So the magnitude of the stress that occurs is 226.68 kPa. The stress causes plastic deformation in the sample.

The total impact energy that occurs on an experimental basis is the measured force multiplied by the height. The mean experimental dynamic impact energy is 108.55 Joules. The theoretical dynamic impact energy is the multiplication of mass with the acceleration of gravity and the height of the test. The mean of theoretical dynamic impact is 33.35 Joule. Moreover, the energy absorbed by the sample is the difference in total dynamic impact energy based on experimental and theoretical energies. The average energy absorbed is 75.20 Joules. The data of the three samples are tabulated in Table 5.

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**Table 4. Results of testing the sample with dynamic free fall at 0.5 m**

| No. | A (mm²) | F (kgf or N) | σ (kPa) | E (Joule) | I (Ns) |
|-----|---------|--------------|---------|-----------|--------|
| 1   | 961.62  | 22.23(216.11)| 224.74  | 108.06    | 10.16  |
| 2   | 961.62  | 22.02(218.07)| 226.78  | 109.04    | 9.05   |
| 3   | 961.62  | 22.40(219.14)| 228.51  | 109.87    | 7.03   |
| Av. | 961.62  | 22.22(217.97)| 226.68  | 108.55    | 9.60   |

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**Table 5. Results of calculation of the dynamic impact energy of the sample at the height of 0.5 meters**

| No. | h (m) | M test rig (kg) | Transfer energy (Joule) | Potential energy (Joule) | Absorbed energy (Joule) |
|-----|-------|-----------------|-------------------------|--------------------------|-------------------------|
| 1   | 0.5   | 6.8             | 33.35                   | 108.06                   | 74.71                   |
| 2   | 0.5   | 6.8             | 33.35                   | 109.04                   | 75.69                   |
| 3   | 0.5   | 6.8             | 33.35                   | 109.87                   | 76.52                   |
| Av. | 0.5   | 6.8             | 33.35                   | 108.55                   | 75.20                   |
The combination of the three force-time graphs of the free-fall method at the height of the 1 meter test is shown in Figure 11.

![Force-time graph](image)

**Figure 11.** Force-time graph at 1 m

In the composite graph shown in Figure 11 where the dynamic impact test results at 1 meter height are all large forces, dynamic timing and muted wave propagation vary. In sample 1 the force and dynamic time were 25.22 kgf and 31 ms, in sample 2 were 25.83 kgf and 47 ms and sample 3 were 25.83 kgf and 47 ms. So that the average force and dynamic time is 25.63 kgf and 41.67 ms.

From the result of the impact test, the free-fall method to the sample obtained data that the force is 25.63 kgf (251.39 N). So that the average tension is 261.43 kPa. The impulse that occurs due to the dynamic impact is the multiplication between force and time. At the height of the 1 meter sample test the mean impulse was 9.79 N.s.

| No. | A (mm$^2$) | F (kgf or N) | $\sigma$ (kPa) | E (Joule) | I (Ns) |
|-----|------------|-------------|--------------|----------|-------|
| 1   | 961.62     | 25.22(247.41)| 257.28      | 247.41   | 7.67  |
| 2   | 961.62     | 25.83(253.39)| 263.61      | 253.39   | 11.91 |
| 3   | 961.62     | 25.83(253.39)| 263.61      | 253.39   | 11.91 |
| Av  | 961.62     | 25.63(251.39)| 261.43      | 251.39   | 9.79  |

From the result of the dynamic impact test of the free-fall method to all samples, it is found that the force is 25.63 kgf (251.39 N). Thus to calculate the magnitude of stress that occurs in the sample in the dynamic area based on the stress equation is the force divided by the area. The area is obtained on the cross-sectional surface of the sample that is 961.62 mm$^2$. So the magnitude of the stress that occurs is 261.43 kPa. The resulting stress causes plastic deformation in the sample.

The total dynamic impact energy that occurs on an experimental basis is the measured force multiplied by the height of the test. The average of experimental dynamic impact impediment is 251.39 Joule. The impact energy of theoretical dynamics is the multiplication of mass with the acceleration of gravity and altitude. The mean of theoretical dynamic energy is 66.71 Joule. Also, the energy absorbed by the sample is the difference in total dynamic impact energy based on experimental and theoretical energies. The average energy absorbed is 184.68 Joule. The data of the three samples are tabulated in Table 7.
Table 7. Results of energy calculations of samples at the height of 1 meter

| No | h (m) | Mass of a test rig (kg) | Transfer Energy (Joule) | Potential Energy (Joule) | Absorbed Energy (Joule) |
|----|-------|------------------------|-------------------------|--------------------------|-------------------------|
| 1  | 1     | 6.8                    | 66.71                   | 247.41                   | 180.70                  |
| 2  | 1     | 6.8                    | 66.71                   | 253.39                   | 186.68                  |
| 3  | 1     | 6.8                    | 66.71                   | 253.39                   | 186.68                  |
| Av | 1     | 6.8                    | 66.71                   | 251.39                   | 184.68                  |

5. Conclusion
Preparation of dynamic impact test specimen based on standard ASTM D1621-00, made by casting method, and has a density of $\rho_{av}$ 630 kg/m$^3$. At the height of the dynamic load test of 0.5 m, the magnitude of the stress that occurs is 226.68 kPa, the average energy absorbed is 75.20 Joules, and at the height of the test 1m, the magnitude of the stress that occurs is 261.43 kPa, absorbed is 184.68 Joule.

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