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The concept of sustainable prefab modular housing made of natural fiber reinforced polymer (NFRP)

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Abstract. This research aims to formulate the concept of public housing based on research results on natural fiber reinforced polymer (FRP) material which has been done in the road map of research. Research output is the public housing design and specifications of FRP made of water hyacinths and coconut fiber. Method used is descriptive review of the concept based on references and material test which consists of density, water absorption, modulus of rupture (MOR), tensile strength, absorption coefficient and Sound Transmission Loss (STL). The entire tests of material were carried out in the laboratory of materials and construction, while the acoustic tests carried out using the impedance tubes method. The test results concluded that the FRP material may have a density between 0.2481 – 0.2777 g/cm³, the absorption coefficient is average of 0.450 – 0.900, the Modulus of Elasticity is between 4061 – 15193 kg/cm², while the average of sound transmission loss is 52 – 59 dB. Furthermore, that the concept of public housing must be able to be the embryo of the concept of environment-friendly and low emissions housing.

1. Introduction

Technological developments increasingly rapidly identified one of them with the progress of the industry where material synthetic fibers began to be replaced by natural fibre (Pritchard,G, 2015). Building materials made of natural local fibers has been widely observed and implemented in construction. Natural fibers often used are the stem of banana, flax fiber, fiber of pineapple, coconut fibres and wood fiber. The past two year research have produced waffle acoustical material made of coconut fibers and sawdust which were produced using hot press machine with waffles matras. This Panel has a good acoustic performance, because the absorption coefficient have ranged between 0.6-0.8 and the Sound Transmission Loss is between 32-54 dB.

Road map of the research began from the innovation of materials made of waste and forest plantations (Setyowati, E, et.al, 2015a; Setyowati, E, et.al, 2015b). Coconut fibers and sawdust processed into composite absorber for the implementation of the housing in the noisy region (Setyowati, E, 2013; Setyowati, E and Sadwikasari, A.F, 2013; Setyowati, E and Trilistyo, H, 2013; Setyowati,E, 2015). The novelty in this research is the natural fiber composition system and technology with synthetic polymer that can be used for building wall panel. These Building materials are certainly very light compared to conventional wall panels that are often used in building construction. With its lightweight performance, then it secure the building against earthquake hazards. In addition, the cost for structural



components can be saved due to its performance. Climate change, pollution and environmental deterioration due to industry sparking much research related to how to make innovative, creative materials, reduce emissions and sustainable (Yan, L., et.al, 2016). In the automotive industry, the natural fiber is becoming increasingly popular and it replacing carbon (carbon fibre) and glass fiber (glass fibre). In the building industry, the use of natural fibers in concrete or polymer replace content of steel in concrete and it become a major step in the development of the sustainable building construction industries (Wei, J.Q and Meyer,C, 2015; Saba, N, et.al, 2015; Yan, L, et.al, 2014). As mentioned previously, that the industry had already begun abandon advanced synthetic fibers like glass fiber (glass fibre) and carbon fiber (carbon fibre) in manufacturing material. Even the car industry like Opel, Ford and Daimler-Chrysler have already used natural fibers on its component (Pritchard,G, 2015). In the building industry, natural fibre reinforced polymer had already been introduced, but haven't been popular yet. Hemp and some other bio fiber have a high hemiselulose content, so do the water hyacinth and coconut fibres (Staib,G., et.al, 2008; Kang, S, et.al, 2001). The following figure shows the concept of modular housing with wall panel made of Natural Fibre reinforced polymer (NFRP).

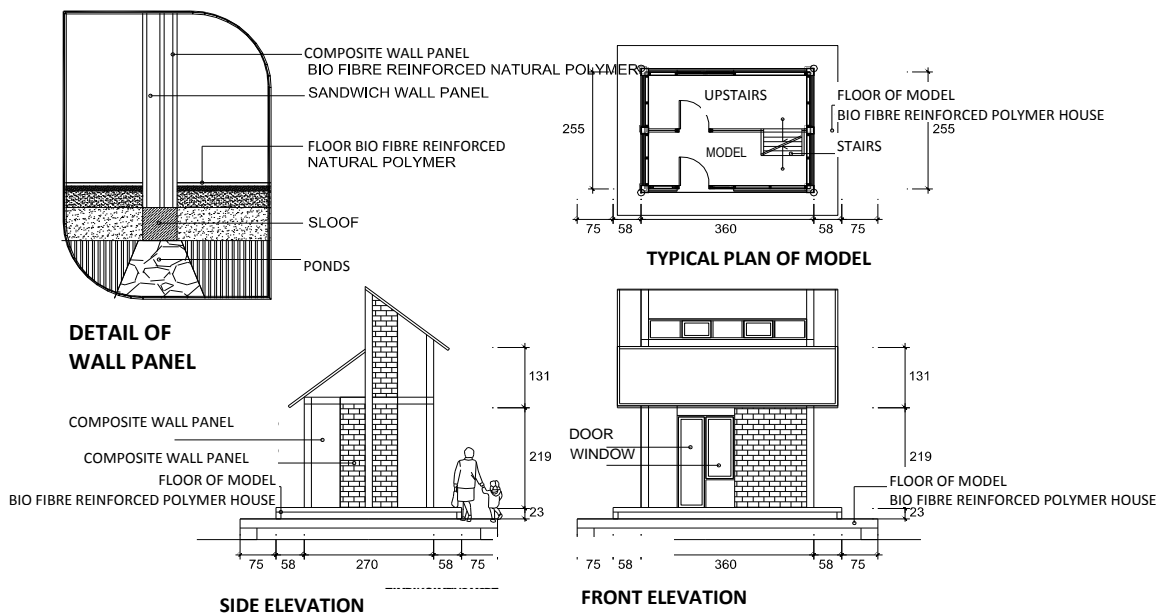


Figure 1. The Concept of Modular housing made of NFRP

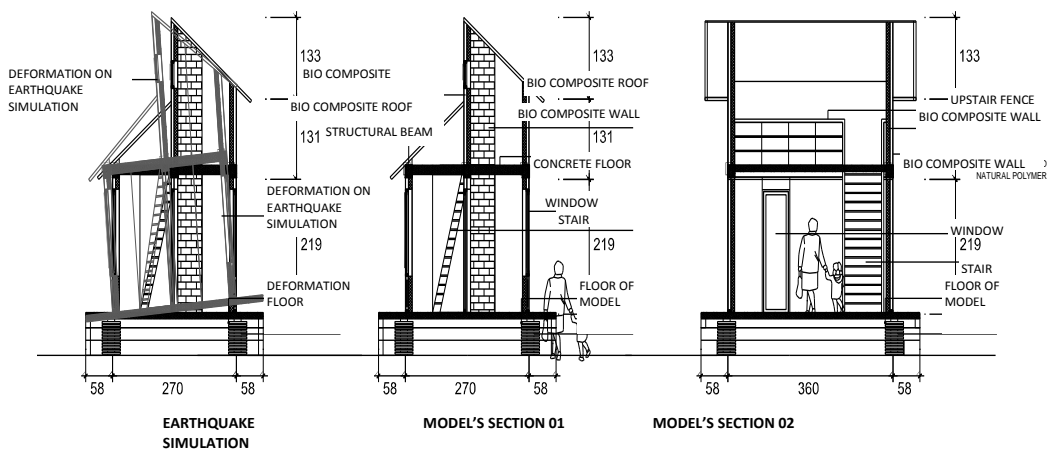


Figure 2 The Section of Modular Housing Concept

Figure 1 shows the concept of modular housing with wall panel made of natural fibre reinforced polymer (NFRP). Natural fibers used are water hyacinth and coconut fibers. Wall Panels made of NFRP used to baffle interior and exterior wall panel. Because it is made from polymer, then the wall panel is highly resistant to weather constraints. Figure 2 shows the elasticity of modular housing in the earthquake vibrations withstand that will probably arise. Due to the lightweight performance, then the modular housing model is reliable as earthquake resistant housing. Observing the process of manufacturing wall panel made of natural fiber reinforced polymer (NFRP), then on the next parts are methodology, results and discussions.

2. Methodology of Experimental Research

In this research, the concept of modular housing from the NFRP was based on the availability of natural resources in abundance, ease the process of manufacture material and technology that are beneficial to the development of housing in Indonesia. To apply the material made of natural fibre, then the NFRP needs to get a series of test materials which are carried out at the materials and construction laboratory

2.1. Density Test

Example of test measuring 10 cm x 10 cm material with electric scales weighed and recorded as the initial weight (m). Length (p), width (l) and thickness (t). Then the volume is calculated using the formula as below:

$$V = p \times l \times t \quad (1)$$

V is the volume (cm³), p is the length (cm), l is the width (cm) and t is the thickness (cm).

After obtaining the value of the volume, then the magnitude of the density can be obtained by the formula:

$$\rho = \frac{m}{V} \quad (2)$$

with ρ is density (g/cm³), m is the weight of the initial sample test (g) and V is the volume of the test of sample (cm³)

2.2. Modulus of Elasticity Test

Modulus of Elasticity test used UTM Instron MOE. This test used one point loading, the point of imposition on the middle of the length of sample. Loading executed until the limit of the elastic point of sample. The length of the span is 15 times the nominal thickness, but not less than 7.5 cm. MOE values obtained using the formula

$$MOE = \frac{\Delta PL^3}{4\Delta ybh^3} \quad (3)$$

with MOE is Modulus of Elasticity (kg/cm²), P is the difference in the burden under the limit of proportion (kg), L is the length of the span (cm), y is the change in deflection under the limit of proportion (cm), b is the width of the test sample (cm), and h is the test sample thickness (cm)

2.3. Modulus of Rupture

The static bending strength or Modulus of Rupture (MOR) is one of the very important mechanical properties. The strength of bending fracture or Modulus of Rupture (MOR) is the

mechanical properties of wood related to the strength of the wood that is the size of the wood's ability to withstand loads or style beyond the work and tend to change the shape and size of the wood. Modulus of Rupture (MOR) is calculated from the maximum load (the load at the time of broken) in the test using the pliable constancy the same test for MOE (Bowyer et al. 2003).

2.4. Absorption Coefficient Test

The Absorption coefficients of materials can be observed and thoroughly calculated using impedance tubes. The sound absorption coefficient (α_0) was calculated by comparing the sound pressure that falls on the surface of the material and reflects. Testing against the absorption on a material refers to standard of JIS a 1405 1963. This coefficient can be calculated using the following equation (ASTM E 413)

$$\alpha_0 = \frac{4}{n + \left(\frac{1}{n}\right) + 2} \quad (4)$$

with α_0 is the Sound absorption (dB) and n is the ratio of the standing wave. Standing wave ratio (n) is calculated by substituting it value prisoner/sound attenuation, while for determining equations, the standing wave ratio are used by the following equation (ASTM D 790):

$$n = 10^{\left(\frac{L}{20}\right)} \quad (5)$$

Where n is the ratio of the standing wave and L is the difference in sound intensity level. On the process of the absorption Coefficient Test (α), the lab has used the device namely the Impedance tube equipped with 1 unit of microphone to transmit sound frequencies in the low frequency range up to high frequency (ASTM D 790).

2.5. Sound Transmission Loss Test

Unlike the absorption coefficient Test, the transmissions loss (STL) used the impedance tube equipped with four microphones that have the sensitivity to high frequency sounds with. STL voice transmission value partition is defined as the ratio between logarithm of transmitted sound pressure (W_t) and sound pressure comes on the surface material/material partitions (W_i). In general the STL definition above can be formulated as (ASTM E 2611-09):

$$TL = 10 \log \frac{W_t}{W_i} \quad (6)$$

$$TL = 10 \log \frac{1}{r} \quad (7)$$

The value of r is the transmission coefficient of sound material in question, namely the value of the ratio between the powerful voice that is transferred through a material with a sound that falls on the surface of the material. Based on the ASTM E 413-2004, measurement of STL in the tubes is carried out using impedance frequency which have range between 125 Hz up to 4000 Hz in 1/3 octave filter (ASTM E 2611-09).

3. Results and Discussion

This research focused on the innovation of natural fibre material processed into material Fiber Reinforced Polymer (FRP). To be able to produce materials FRP as intended, then this study uses polymer (polyester) mixed with fibers of nature: water hyacinth and coconut fibers. The catalyst used was methyl ethyl ketone peroxide composition material comparison: natural fibres: polyester catalyst = 200 ml: 200 ml: 100 ml: 20 ml respectively. The results of the Test weight and density is as follows:

Table 1. Density Test

Sample	thickness (mm)	weight (gram)	Ø (mm)	T (gram)	Volume (cm ³)	density
A	15	11	29	1.5	39.6111	0.2777
B	30	19	29	2.8	73.9407	0.2570
C	15	10	29	1.5	39.6111	0.2525
D	30	19	29	2.9	76.5815	0.2481

with A and B are 15 mm and 30 mm thickness of water hyacinth composite respectively; C and D are 15 mm and 30 mm thickness of coconut fibre composite respectively. From the 4 samples tested, then it can be inferred that the FRP material density is 0.2481 – 0.2777 g/cm³. Based on the category of composite material, then this material can be concluded the Low-density Composite. Because the value of the density of the material affected by the dimensions of the components forming the material. According to T.M. Maloney (1998), that based on its density, particle board can be divided into three groups (Maloney, t. m., 1998):

- Low density particleboard*, i.e. the particle board that has a density less than 0.59 g/cm³.
- Medium density particleboard*, i.e. the particle board that has a density between 0.59 – 0.8 g/cm³.
- High density particleboard*, i.e. the particle board that has a density more than 0.8 g/cm³.

To test the Modulus of Elasticity and the Modulus of Rupture is obtained the following results:

Table 2. Modulus of Elasticity and Modulus of Rupture

Natural Fibre Reinforced Polymer	MOE (kg/cm ³)	MOR (kg/cm ³)
15 mm thickness water hyacinth	4,061	29
30 mm thickness water hyacinth	12,280	126
15 mm thickness coconut fibre	4,534	59
30 mm thickness coconut fibre	15,174	138

The nature of stiffness is a measure of the ability of an object to resist changing incurred as a result of loading. This trait is expressed with a Modulus of Elasticity (MOE) and applies only to the limit of proportion (Bowyer et al. 2003). Based on the testing that has been done is obtained value ranges between MOE 4,061 – 10,238 kg/cm² on particle board also 0.4 g/cm³,

while MOE values between 12,280 – 15,193 kg/cm² on the NFRP water hyacinths 0.6 g/cm³ density. Increased density can increase MOE about 46.18 – 235%. This is in accordance with statement of Bowyer et al. 2003, that the higher the level of density of the material produced, the higher nature of power supply. Meanwhile, the larger the particle size the more increases the power supply.

Modulus of Rupture (MOR) or broken modulus is the ability of the Board to hold a load of bending up to maximum limit (broken constancy). Based on the testing that has been done is obtained a value of MOR ranges between 29 – 74 kg/cm² on the material also 0.4 g/cm³, while the value of MOR between 116 – 167 kg/cm² on material density 0.6 g/cm³. Increased density can increase MOR about 125 – 300%. This is in accordance with statement of Bowyer et al. (2003) that the higher level of density of the material, it will be the higher nature of supply..

On the process of the absorption Coefficient Test (α) laboratory is using the device Impedance tube equipped with 1 unit of microphone to transmit sound frequencies in the range of low to high. The results of absorption coefficient tests are:

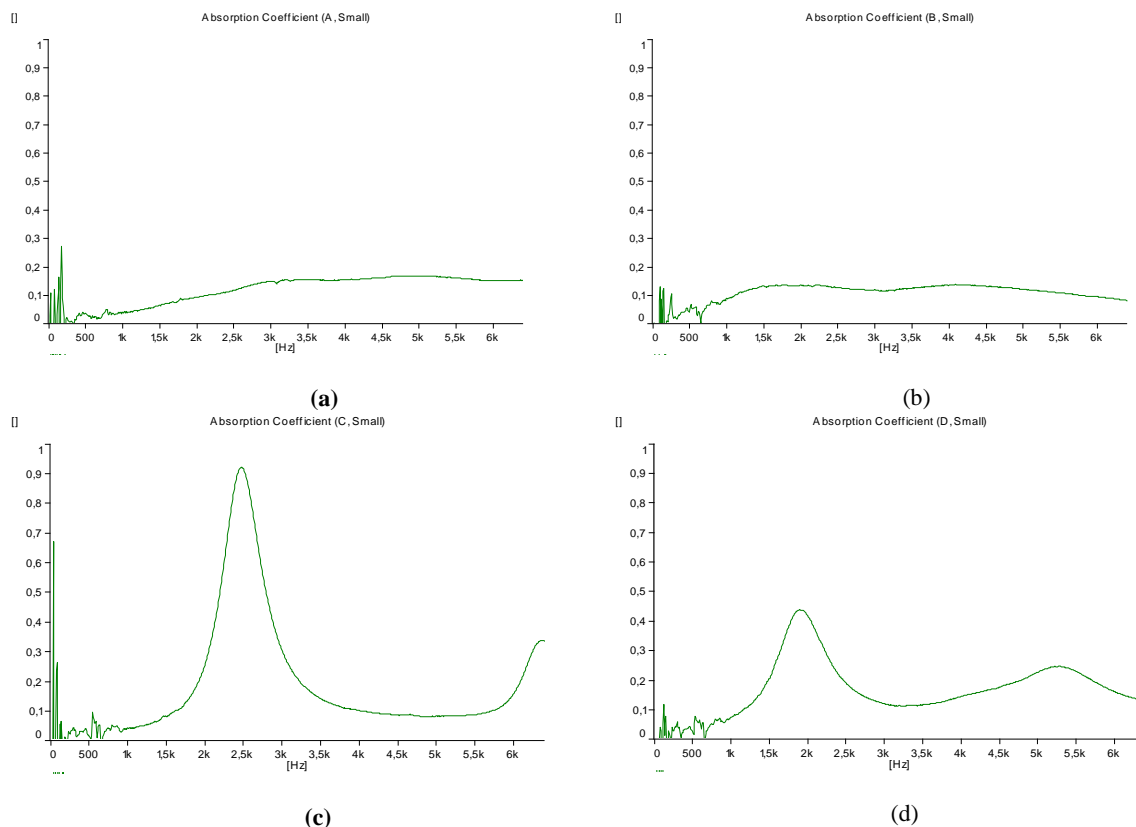


Figure 3. The results of Absorption Coefficient Tests

In contrast to materials FRP (composite) water hyacinth, then materials FRP (composite) coconut fibers have a better acoustic performance. Coconut fibers in composite materials with 15 mm thick, it looks that the material has a coefficient of absorption between 0.500 – 0.900. This material can also be categorized into the absorber is good, especially in the 2000 Hz frequency – 3250 Hz. highest Coefficient (peak) recorded at 2500 Hz frequency (2.5 k).

Materials FRP (composite) coconut fibers with thickness 30 mm also has a better acoustic performance than the material water hyacinth, although not as good as FRP (Composite thick coconut fibers 15 mm). Material has a coefficient of absorption between 0.050 – 0.450. Two thousand Hz is the frequency of the peak absorption coefficient of the material performance of FRP coconut fibers. From the graph, it can be concluded that the coconut fibre composite material thickness 30 mm has the ability as the absorber is primarily on the frequency-frequency: 1500 – 2500 Hz and 4500 – 5500 Hz. In contrast with the methods implemented in Test coefficient of absorption, then test the Sound Transmission Loss (STL) using impedance tube equipped with a microphone that has 4 units voice sensitivity is high. The results of Sound Transmission Loss Tests are as below:

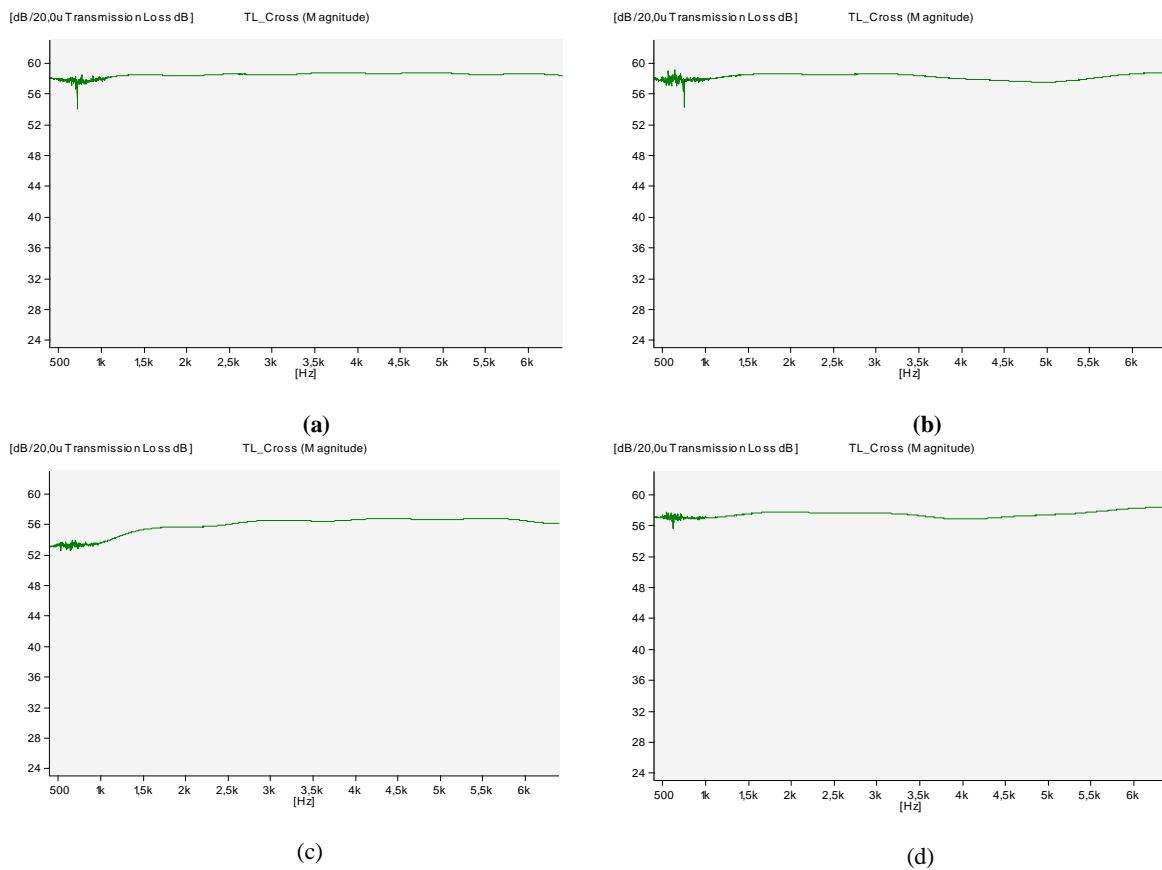


Figure 4. The Results of Sound Transmission Loss Tests

Test results showed the STL an average rating of 59 dB, it means that the material can absorb sound coming towards the surface up to 59 dB (fig. 4a). Similar to the results, the composite of water hyacinth with 15 mm thickness has Transmission Loss which is quite high, i.e. in the range of 57-59 dB comparing the 3.0 cm material. The conclusion is that the material could be used as absorber (fig. 4b).

Coconut fibers composite STL performance was lower compared with the FRP water hyacinth. Test results showed the value of STL ranged between 52 – 56 dB (figure 4 c). Performance of FRP material STL (composite) 30 mm thick coconut fibers resemble the performance shown by FRP materials water hyacinth. The value of the STL this material ranges between 56 – 58 dB. The conclusion is that this material can be used as a reliable sound reducing on the building (figure 4 d). The buildings in an area prone to such noisy

airport region, industry, railroads and highways are advised to use this material as an attempt to reduce the sound on the components of the wall of the building.

4. Conclusion

Natural fibre material has quite a good performance in the development of materials for housing low income communities. Because the material is easy to find, then this would be very appropriate material for housing in Indonesia. NFRP material from water hyacinth and coconut fibers proved to have a good acoustic power, so it can be used for housing in the area is prone to noise. The power supple and its elasticity can withstand vibrations or earthquakes in areas prone to disasters.

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