Applied Mechanics and Materials Vol. 391 (2013) pp 41-45
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.391.41

Utilization of Albizia Wood (Albizia Falcata) and Ramie Fibers as Wind Turbine Propeller Modification of NACA 4415 Standard Airfoil

Sudarsono[1,2,a], Purwanto[1,b], Johny W. Soedarsono[3,c] and Badrul Munir[3,d]

[1] Environmental Science Graduate Program, Universitas Diponegoro, Semarang, Indonesia

[2] Department of Mechanical Engineering, Institut Sains & Teknologi AKPRIND, Yogyakarta, Indonesia

[3] Department of Metallurgy and Materials Engineering, Universitas Indonesia, Depok, Indonesia

[a]sudarsono1574@gmail.com, [b]p.purwanto@gmail.com, [c]jwsono@metal.ui.ac.id, [d]bmunir@ui.ac.id

Keywords: Composite, propeller, airfoil, natural fiber, Albizia

Abstract. Ramie fibers and albizia wood, which are abundantly available in Indonesia, were used in fabricating hybrid sandwich composite for wind turbine propeller. A prototype was fabricated by modification of NACA 4415 standard airfoil, intended for low speed wind and environmental friendly operations. Hand lay-up method was applied for fabrication of this hybrid composite with one and two layers of ramie fiber. Mean volume fiber fraction (*vf*) of one-layer and two-layer composite are 47,12% and 44,82%, respectively. The highest measured bending stress is 30.88 MPa for two-layer composite with modulus of elasticity 2.02 GPa and bending strain 1,795%. Microstructure of this hybrid composite is unchanged significantly after 5.5 months operation. With ultimate simplicity and low manufacturing cost, hand lay-up method is suitable for small scale production.

Introduction

Nowadays, material for wind turbine propeller is being commonly replaced by glass fiber reinforced plastic (GFRP) composites. GFRP propeller is typically light and easily rotates, even in low speed wind. The wind turbine propeller from GFRP composite sandwich need to be developed in order to withstand greater external impact loads. Natural ramie fiber and Albizia wood should be used to reduce the use of imported synthetic materials. The aim of this research is to study the potential use of local genius materials in Indonesia, particularly natural fibers and natural wood to develop hybrid composite sandwich of ramie fiber with Albizia wood as a core. This hybrid composite is used as a material of wind turbine propeller. Prototype of this hybrid composite propeller is made by modify a model of NACA 4415 Standard Airfoil. This hybrids composite propeller is proposed for low wind speed and environmentally friendly operation.

Research of utilization natural fibers was started by the use of Kenaf fiber [1]. Randomly increasing of Kenaf fiber content can improve tensile strength and modulus. Kenaf composites-polyester shown a better tensile properties than composites of Kenaf – polypropylene [2]. A sandwich composite with Albizia has been developed as a composite core [3]. Xu, *et al*. studied the life cycle assessment of natural fibers in wood-fiber-reinforced polypropylene composites and introduced the term "material service density" (MSD), defined as the volume of material to meet the specific power requirements. When MSD is used as a functional unit, the wood fiber-reinforced composite is more environmentally friendly than polypropylene. For the same volume of material, the composite material has a density lower than polypropylene [4]. Strong composite material could be obtained by mixing a string of ramie fiber with high concentrations of alkali. Laminated ramie composites have twice impact strength greater than the composite without ramie [5].

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of TTP, www.ttp.net. (ID: 202.91.10.215-09/08/13,06:07:43)

Methodology

The materials used for the fabrication of wind turbine propeller prototype in this research consists of unsaturated polyester resin (Yukalak®) as a matrix and methyl ethyl ketone peroxide (MEKPo) as a hardener/curing agent. Meanwhile, Albizia and ramie fibers are used as the reinforcement of composite. Ramie fiber has specific gravity of 0.9 g/ml. NaOH 10% was used for soaking prior to the fabrication of composite resin in order to protect from delimitation between resin and Albizia. Vaseline was used to prevent the attachment of the resin on the mold surface. Hand lay-up method was implemented for fabrication of hybrid composite, with one-layer and two-layer ramie fibers. Prototype of wind turbine propeller was made based on modification of NACA 4415 standard airfoil, simulated using computational fluid dynamics, as shown in Figure 1 [6].

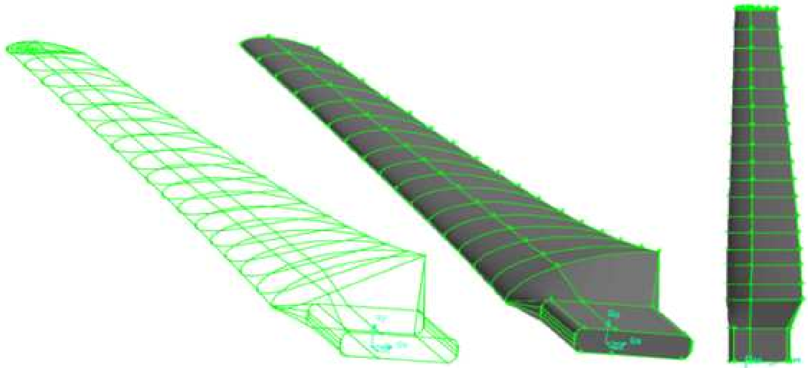

Fig.1. Design of blade of wind turbine based on modified NACA 4415 airfoil

Several characterization works were conducted on the specimen, including relative error measurement, volume fraction measurement, bending test, and Scanning Electron Microscopy (SEM), both on two-layer composite laboratory specimens and after 5.5 months operation at the coastal area of Kwaru, Bantul, Yogyakarta, Indonesia.

Relative Error. Relative error of weight measurement is defined by comparing a specimen weight with theoretical weight as:

$$\%\text{error} = \frac{\text{Weight}_{\text{theoretical}} - \text{Weight}_{\text{fabrication}}}{\text{Weight}_{\text{theoretical}}} \tag{1}$$

Theoretical weight is defined as the total weight of Albizia wood, ramie fibers and resin used for this sandwich composite. Calculation of the mean weight relative error is aimed to determine the concentration of ramie fibers in composites.

Volume Fraction. One important factor that determines the characteristics of the composite is the comparison of matrix and reinforced fiber. This comparison can be shown in the form of fiber volume fraction (Vf) or fiber weight fraction (Wf). However, the composite strength formulation is used more often. Fiber volume fraction can be calculated using the following equation:

$$V_f = \frac{\left| V_c - \frac{M_c - M_f}{QM} \right|}{V_c} \tag{2}$$

where *QM* is matrix density (gram/ ml), *Vc* is composite volume (ml), *Mc* and *Mf* are weight of matrix composites and fibers.The mean fiber volume fraction of one-layer composite and two-layer composite is observed on flexural specimen with mold volume of 204 ml.

Bending Test. A standard procedure of ASTM D790 is adopted for bending test, which measures the force required to bend a plastic board at a given load. The data is often used to select a suitable material that able to support the applied load without any bending on the material. Bending modulus indicates the stiffness of the material when bent. Values obtained from bending tests are bending stress, bending strain and modulus elasticity.
Maximum bending stress is determined with equation:

$$\sigma_f = \frac{3PL}{2bd^2} \tag{3}$$

Value of strain is calculated using equation:

$$\varepsilon_f = \frac{6Dd}{L^2} \tag{4}$$

Highest the value of modulus elasticity, lower the elastic strain that means stiffer the material. Modulus elasticity is calculated using equation:

$$E_B = \frac{L^3 m}{4bd^3} \tag{5}$$

where σ_f is bending srength (MPa), L is support span (mm), P is load, b is specimen width, d is specimen thickness, ε_f is bending strain (MPa), D is maximum deformation at the mid span , and m is slope of stress-strain curve

Results and Discussion

Hybrid composite of ramie fiber and Albizia wood are shown in Figure 2. The ramie alignment is smoother and denser in two-layer composite. The mean weight relative error of one-layer and two-layer composite are 7.18% and 6.88%, respectively. This result indicates that the composite fabrication process by hand lay-up method is done well, either on one-layer composite or two-layer composite.

Fiber volume fraction (reinforce, ramie fiber and Albizia) in two-layer composite is 44.82%. This fraction is smaller than one-layer fabricated composite which volume fraction of 47.12%. Decreasing fiber volume fraction increases mechanical strength of composite. Increasing bending stress in two-layer composite is found to be 56,36%. This situation may occur due to the matrix have enough strength and good ability for load distribution during bending test.

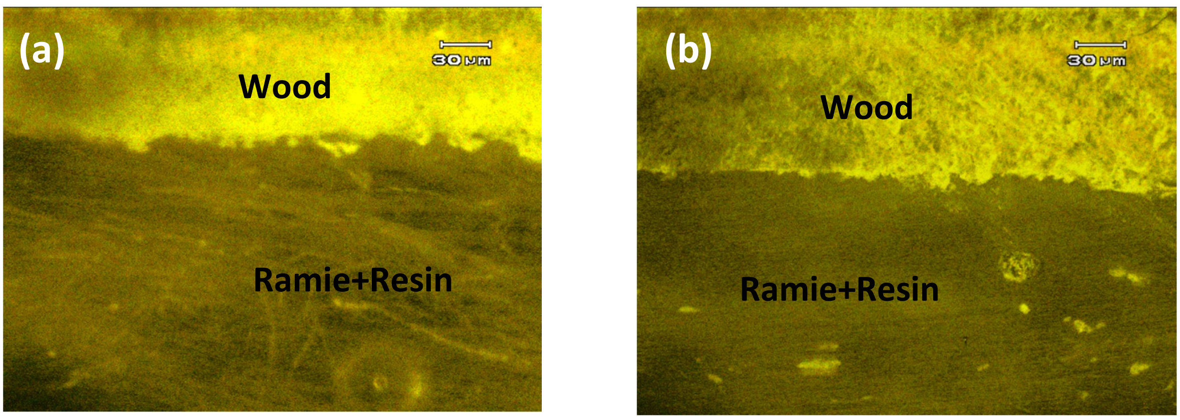

Fig.2. Composite of ramie fibers and Albizia wood (a) one-layer, (b) two-layer

Bending test result of the hybrid composite is shown in Table 1 and Figure 3. Specimens were made in one-layer and two-layer ramie fibers and one-core of Albizia wood. Bending stress, bending strain, and modulus elasticity of one-layer composite are 19.013 MPa, 2.313% and 0.776 GPa. Meanwhile, for two-layer composites are 30.881 MPa, 1.795% and 2.018 GPa, respectively. The addition of one-layer ramie fiber increases the composite bending strength as about 62.42% with relatively small increasing in weight. Due to this reason, the prototype of wind turbine propeller was made using the two-layer composite lay-up. The prototype shows a good bending strength and also light, hence suitable for low wind speed.

Table 1. Test results for bending stress, bending strains and modulus elasticity

Samples	Average Bending Stress σ_f (MPa)	Average Bending Strain ε (%)	Average Modulus Elasticity E (GPa)
1 Layer	19.013	2.313	0.776
2 Layers	30.881	1.795	2.018

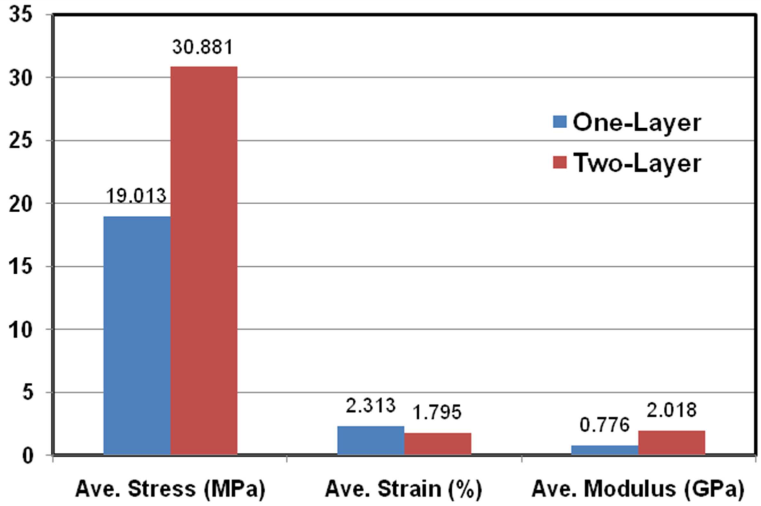

Fig.3. Bending test results

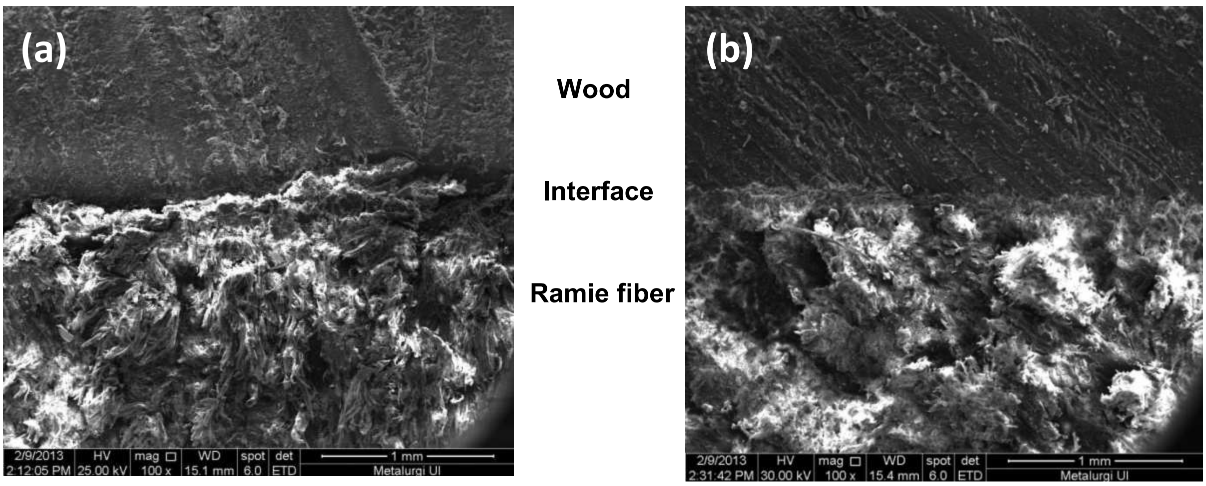

Fig.4. Cross sectional SEM image of two-layer composite, (a) before, (b) after 5.5 months operation

Figure 4 shows the cross-sectional SEM images of two-layer composite. The samples were taken from laboratory specimen before operation and the airfoil prototype after 5,5 months operation in coastal area of Kwaru, Bantul. The SEM image indicates that the propeller prototype shows no significant degradation in the structure after operation. The interface between the core and resin with ramie fiber reinforcement after operation also remains tight enough. These properties can be attributed to the polarity of the resin which make easier to produce a mixed well components of the composites.

Conclusions

Ramie fiber composite with Albizia core was manufactured by hand lay-up method with mean weight relative error of fabricated composite is 7.18% in two-layer and 6.88% in one-layer. Mean fiber volume fraction (*vf*) for one-layer and two-layer composite are 47.118% and 44.820%, respectively. The highest bending stress is found to be 30.881 MPa in two-layer composite. The modulus elasticity and bending strain of two-layer composite are 2.018 GPa and 1.795%. The prototype of propeller made from two-layer composite of ramie fibers and Albizia remains unchanged in structure and interface after 5.5 months utilization as wind turbine propeller at coastal area in Kwaru, Bantul, Yogyakarta, Indonesia. Furthermore, with ultimate simplicity and low manufacturing cost hand lay-up is a suitable method to manufacture the modified NACA 4415 airfoil.

References

[1] K. Diharjo, Jamasri, Soekrisno and H. S. B. Rochardjo: *Tensile Properties of Unidirectional Continuous Kenaf Fiber Reinforced Polyester Composite,* International Proceeding, Kentingan Physics Forum, Sebelas Maret University, Indonesia (2005)

[2] R. Karnani, M. Krishnan and R. Narayan: Polymer Engineering and Science, Vol. 37 Issue 2 (1997), p. 476 – 483

[3] K. Diharjo, Jamasri, Soekrisno and H. S. B. Rochardjo: *Effect of Faces Thickness on Impact Properties of Kenaf-Polyester Sandwich Composite With Albizzia Wood Core*, Proceeding of The Malaysia-Japan International Symposium On Advanced Technology (MJISAT 2007), 12th – 15th November, Kuala Lumpur, Malaysia.

[4] X. Xu, K. Jayaraman, C. Morin and N. Pecquex: Journal of Materials Processing Technology, Vol. 198 Issue 1 (2008), p. 168-177

[5] N. Suizu, T. Uno, K. Goda and J. Ohgi: Journal of Materials Science, Vol 44 Issue 10 (2009), p. 2477-2482

[6] Sudarsono, Purwanto and J. W. Soedarsono: accepted for publication at Advanced Materials Research (2013)