OPTIMIZATION DESIGN OF NATURAL COMPOSITE PROPELLER OF WIND TURBINE FOR COASTAL AREA PANDANSIMO, YOGYAKARTA, INDONESIA

Sudarsono[1*], Purwanto[2], Johny W Soedarsono[3]
[1]Jurusan Teknik Mesin, Fakultas Teknologi Industri, Institut Sains & Teknologi AKPRIND, Yogyakarta
[1]Jl. Kalisahak 28 Kompleks Balapan Yogyakarta
[2]Program Studi Ilmu Lingkungan, Universitas Diponegoro, Semarang
[2] Jl. Imam Barjo No. 5 Semarang
[3]Departemen Metalurgi & Teknik Material, Universitas Indonesia
[3] Kota Depok Jawa Barat
[*]*sudarsono1574@gmail.com*

ABSTRACT

The objective of this research is to study a feasibility of potential local genius material in Indonesia, particularly ramie fiber (Boehmerianivea) and Albizia wood (Albiziafalcata) as modified NACA 4415 based propellers.Modified NACA 4415 is fluid dynamic modeled with FLUENT software and experimental validated. The optimum design of blades is found to be 1.625 m in length with 20 elements blade with chord length from 0.08 to 0.28 m and twist angle of 24,8^0 and -4,7^0 at hub and tip, respectively. Propeller has a maximum Betz coefficient of 0.4 at Tip Speed Ratio of 4. At average wind speed of 3-5 m/s in Indonesia, this wind turbine can generate power output, torque, and power coefficient of 50-240 watts, 25 Nm-75 Nm, 0.35-0.40, respectively. The coefficient of aerodynamic of modified NACA 4415 has good performance at Reynolds number of 41000- 250000. Fabrication with hand lay-up method gives the highest bending stress of 30.881 MPain 2 layers composite. The modulus elasticity and and bending strain of 2 layers composite are 2.018GPaand1.795%.

Kata kunci*: optimization, NACA 4415 propeller, natural composite,performance*

1. INTRODUCTION

Due to depletion of fossil fuel worldwide, it is been developed and utilized alternative form of energy. Indonesia, one of the world largest archipelago countries, has potential wind energy to produce electricity by means of wind turbine power plant. However, only 800 kW of energy demand in Indonesia is generated form wind energy. Less wind energy conversion system applied is still a problem facing in Indonesia. It is because the cost of wind turbine unit is costly, mainly the cost of wind turbine propeller.

Many researchers have been worked on utilization of natural material as composite material. Diharjo*et al*.,2005, 2007 developed theuse ofKenaffiber as composite materials. Randomly increasing of Kenaffiber contentcan improve itstensilestrength andmodulus. Atvf= 32%, tensilestrength andmodulus ofKenaffiber composite-polyester was 59.03MPaand8.75GPa, respectively. Boththe mechanical propertiesincreased with value of 107.8% and51.91% compared with therandomKenaf-polyester compositesatvf=13,18%. Furthermore,Diharjo et al. [3] have also developed a sandwich composite with Albizia as a composite core. Comparison between Kenaf-polyester and Kenaf-PP composite has been studied by Karnani, *et al*.Kenaf-Polyester composite hadbettertensile propertiesthan Kenaf-PPbeing thecomposites.

Meanwhile, Suizu, *et al*.has investigated the useof naturalfiberreinforcedmaterialsto produceeco-friendly andstrong material. Strong material could be obtained by mixing astringof ramie fiberwithhigh concentrations ofalkali. The results of tensile test indicatedthatramiecompositeshave greater tensile strength up to two tothreetimes without decreasing instrengthcompared to thecompositewithout ramie fiber. Laminated ramie compositeshave twice impact strengthgreater thanthe composite withoutramie.

In order to minimize design cost and to optimize propeller design, it is common to used simulation tool in designing work. Rooijand Timmer focused on ratio of lift force to drag force of airfoil characteristic for wind turbine propeller.

2. METHODOLOGY

Prior to manufacturing process, computational fluid dynamics analysis is done on modified NACA 4415 model using FLUENT. Spallart-Almaras model performed on FLUENT simulation [Sudarsono*et al*., 2013]. The simulation is done at Reynoldnumber from41000 to 250000. and angle of attack in the range of -12^0 to 20^0. The simulation is used to predict the coefficient of aerodynamic, Betz coefficient, torque, power output and power coefficient of wind turbine propeller. The two model of natural composite propellers, namely one layer and two layer of ramie fiber composite are also tested on its mechanical properties.

2.1. Bending Test

A standard procedure of ASTMD790 is adopted. Bending testmeasures theforcerequired tobendaplastic boards at a givenload. The data isoftenused to select a suitable material that able to support the applied load without any bending on the material. Material bending modulus indicates thestiffness of the materialwhen bent. From bending test, it is obtained 3 parameters, namely bendingstress, bending strain and modulus elasticity [Sudarsono*et al*., 2013]

Maximum bending stress is determined with equation:

$$\sigma_f = \frac{3PL}{2bd^2} \qquad (1)$$

Value of strain is calculated using equation:

$$\varepsilon_f = \frac{6Dd}{L^2} \qquad (2)$$

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

$$E_B = \frac{L^3 m}{4bd^3} \qquad (3)$$

whereσ_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

3. DISCUSSION

Based on Fluent simulation, the optimum design of propeller is obtained by modification of standard NACA 4415 airfoil. Modification is done on lower side of leading edge and upper side of trailing edge. Lift coefficient increase with this modification, hence able to produce higher torque.

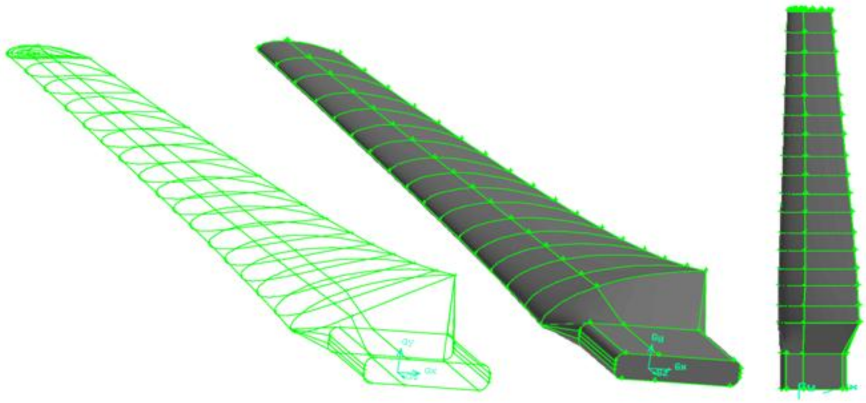

Fig.1. Modified NACA 4415 airfoil

Ratio of lift coefficient to drag coefficient of NACA 4415 airfoil and modified NACA 4415 airfoil at different Reynold numbers are shown on Figure 2 to Figure 7.

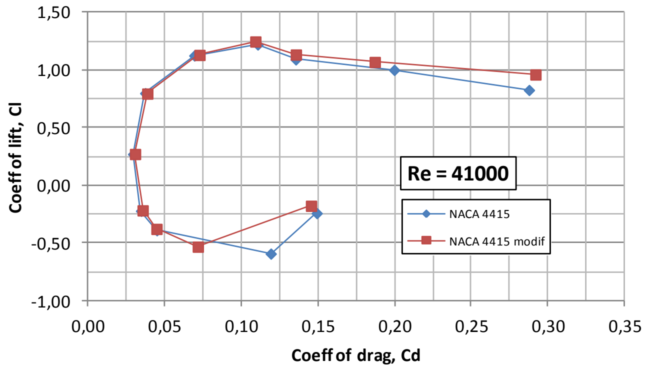

Fig.2. Lift coeff. to drag coeff. at Re=41000

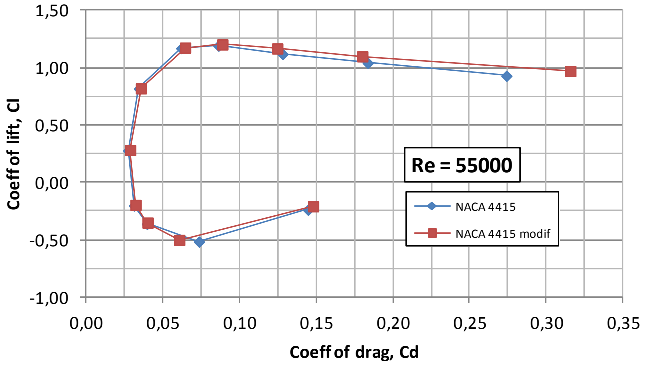

Fig.3. Lift coeff. to drag coeff. at Re=55000

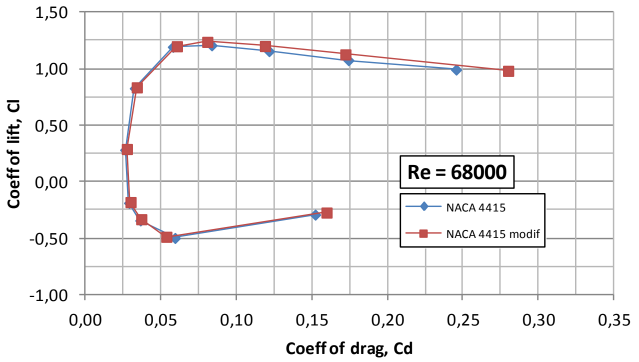

Fig.4. Lift coeff. to drag coeff. at Re=68000

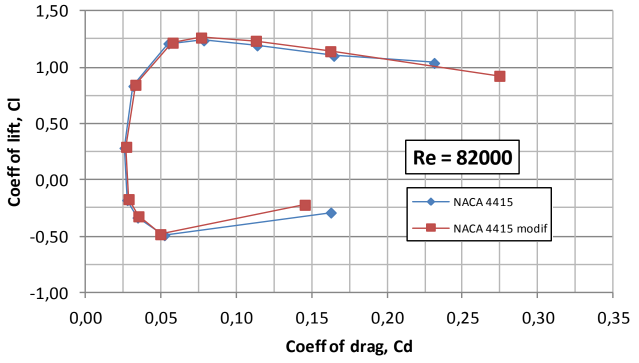

Fig.5. Lift coeff. to drag coeff. at Re=82000

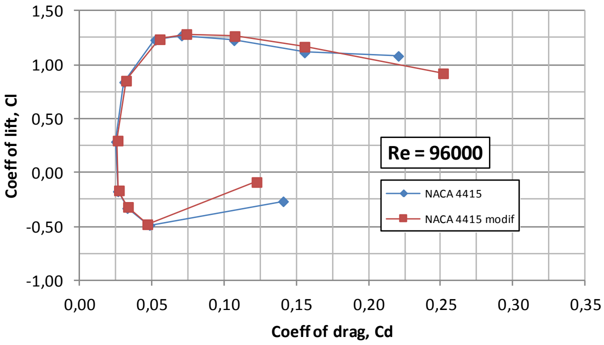

Fig.6. Lift coeff. to drag coeff. at Re=96000

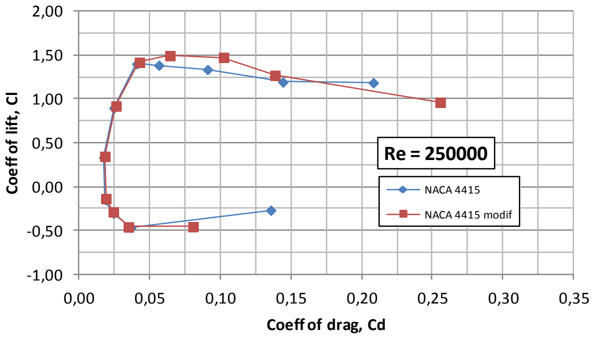

Fig.7. Lift coeff. to drag coeff. at Re=250000

Meanwhile, bendingtest resultof thehybrid compositefor the prototype of modified propellerNACA4415airfoilis shownin Figure 5. Specimens are made in1 layerand2 layersramie fiber and 1 core of Albizia wood. Bending stress, bending strain, and modulus elasticity of 2 layer composite are found to be 30.881MPa, 1.795% and 2.018GPa, respectively. Meanwhile, for 1 layer composite are 19.013MPa, 2.313% and 0.776GPa. Additional of 1 layer increases bending strength on composite as about 38,43% with relatively small increasing in weight. Due to this reason, prototype of wind turbine propeller is made from 2 layers composite. Propeller has good bending strength and also light, hence suitable for low wind speed.

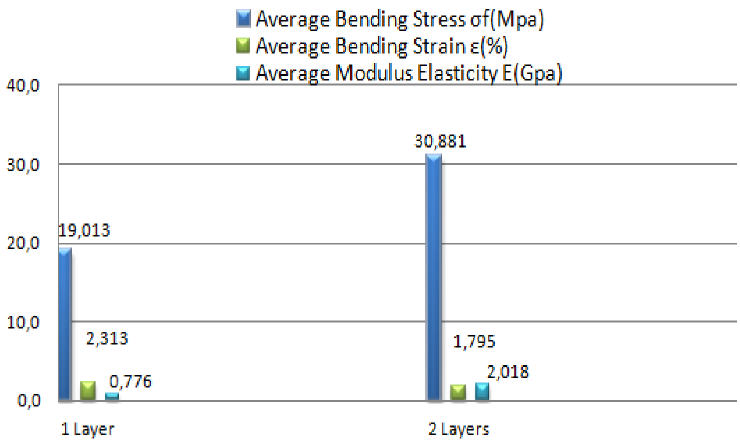

Fig.8. Bending test results

4. Conclusion

Ramiefiber composite with Albizia core can be utilized as natural composite material of wind turbine propeller. The natural composite is manufatured by hand lay-up method with two layers ramie fibers. In order to obtain optimum design of wind turbine propeller, computational fluid Dynamics simulation is very helpful to minimize designing cost and time.

REFERENCES

Diharjo K., Jamasri, Soekrisno, Rochardjo H. S. B., 2005. *Tensile Properties of Unidirectional Continuous Kenaf Fiber Reinforced Polyester Composite*

Diharjo K., Jamasri, Soekrisno, Rochardjo H. S. B., 2007. 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)*, 12^{TH} – 15^{TH} November, 2007a, Hotel Seri Pacific, Kuala Lumpur, Malaysia.

Karnani R., Krishnan M., and Narayan R, 1997, Biofiber-Reinforced Polypropylene Composites, *Polymer Engineering and science*, Vol. 37 No. 2, pp. 476 – 483

Rooij V.R and Timmer N., 2004, Design of Airfoils for Wind Turbine Blades, Delft University of Technology, The Netherlands

Suizu N., Uno T., Goda K., Ohgi J., 2009, Tensile and impact properties of fully green composites reinforced with mercerized ramie fibers, Journal of Materials Science, May 2009, Volume 44, Issue 10, pp 2477-2482

Sudarsono, Purwanto, Soedarsono J.W, Computational Fluid Dynamics Performance Analysis of Ramie-Albizia Composited for Wind Turbine Rotor, *Advanced Materials Research Vol. 772 (2013) pp 735-73.*

Sudarsono, Purwanto, Soedarsono J.W., Munir, B., Utilization OfAlbizia Wood (*AlbiziaFalcata*) And Ramie Fiber As Wind Turbine Propellers Of Naca 4415 Standard Airfoil, *Applied Mechanics and Materials Vol. 391 (2013) pp 41-45*