Mechanical Strength of Hybrid Laminate Composite Glass/Carbon Fibers on Savonius Blade Turbine Application

Niam Sukri, Ferriawan Yudhanto, Muhammad Abdus Shomad, Rinasa Agistya Anugrah
Department Mechanical Technology, Vocational Program, Universitas Muhammadiyah Yogyakarta, Daerah Istimewa Yogyakarta, 55183
Email: niam.sukri.d317@mail.umy.ac.id; ferriawan@umy.ac.id; abdusshomad@umy.ac.id; rinasaanugrah@umy.ac.id

ABSTRACT

Introduction – VI (Vacuum Infusion) method. The HLC consist of 1 ply carbon woven roving carbon 4 plies glass fiber woven roving (WR-WR), and another variation is 1 ply carbon woven roving and 4 plies glass fiber chopped strand mat (WR-CSM). The different types of glass fiber on the carbon woven roving of HLC is objecting to this research. The manufacture of HLC by VI using 0.8 Bar pressure to flow the polyester resin. The panel HLC cutting according to the ASTM (American Standard Testing and Material) D3039 for tensile strength and ASTM D790 for the flexural test of HLC. The HLC mechanical strength depends on the excellent bonding in the interfacial laminate stress. The direction of WR-WR gives a good effect against tensile load, and the fracture after the test is minor multiple cracks (ductile) and lowest delamination fracture. The WR-WR has the highest tensile stress and modulus by 162.9 MPa and 5.2 GPa, respectively. The flexural test has been resulted in the highest modulus by 8.8 GPa. These mechanical characteristics according to applicated on Savonius Blade Turbine.
Purpose – Knowing the mechanical strength of the Carbon/Glass-reinforced hybrid laminate composite, which is suitable for application to the savonius turbine blade
Methodology/Approach – We are composing one carbon fiber and four glass fibers in a WR-CSM and WR-WR arrangement. The process of making hybrid laminate composite with the Vacuum Infusion method.
Findings – The result of this research is to choose a fiber arrangement that has high mechanical strength and good bonding between fiber layers.
Originality/ Value/ Implication – The composite manufacture with vacuum infusion process produces a thin product which light and strong properties.

Keywords: hybrid laminate composite, glass fiber, carbon fiber, vacuum Infusion

INTRODUCTION

The use of wind turbines as an alternative source of electrical energy has been widely encountered. There are many different types of Savonius wind turbines. The kind of Savonius turbine designed is divided into a horizontal axis wind turbine (HAWT) and a vertical axis wind turbine (VAWT). The savonius blade design that will make is a vertical axis multi-blade type. The method of the vertical multi-blade Savonius turbine blade can be seen in Figure 1 (Schubel and Crossley, 2012).

The use of turbine material is the main object of this research. At first, wind turbine blades are made of thin metal plates coated with an anti-corrosion layer. This metal material is quite expensive so that currently, many composite materials are applied, which are much cheaper in terms of cost. The composites used are generally made of fiberglass. Fiberglass widely used is the E-Glass type because the price is relatively lower than the S-glass type, which is quite expensive. In addition, Thermosets matrix such as polyester, vinyl ester, and epoxies are widely used in turbine blade manufacturing. The advantages of polyester are that they can be applied at room temperature (27 ± 3 °C), low viscosity, so they are easy to use in vacuum infusion processes (Mishnaevsky et al., 2017).

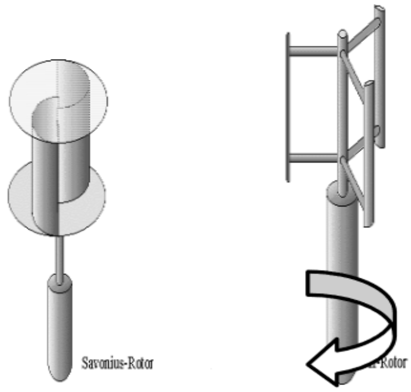

Figure 1. The Persian wind mill tipe vertical axis (Schubel and Crossley, 2012)

The use of fiberglass in wind turbines generally uses woven fiber (WR = woven roving) and random fiber (CSM = chopped strand mat). However, making blade turbines using the hand lay-up and press-mold methods often causes problems in its mechanical strength. In addition, the use of glass fiber with polyester resin in this composite has several weaknesses, such as brittleness and an easy cracking composite product (Yudhanto et al., 2016).

Commercially, carbon fiber has several advantages, namely having a low density of 1.2 g/cm^3, very high tensile strength, and modulus of elasticity of 3500 MPa and 230 GPa (Gulgunje et al., 2015). Therefore, combining the two types of fiber, namely glass fiber and carbon fiber, is expected to improve the mechanical properties of the hybrid laminate composite (HLC).

LITERATURE REVIEW

In the previous research by Shomad et al. (2020), there are two layers of glass fiber as reinforcement for hybrid composites with a polyester matrix: CSM (chopped strand mat) and WR (woven roving). Manufacturing of five laminate composites using a vacuum infusion process. The results obtained are high tensile strength is WR (150 MPa) compared to CSM (129 MPa). In addition, the fiber's direction of 90^o and 0^o is dominated by the woven fiber's characteristics so that the focus of tensile strength towards unidirectional is greater than CSM.

Research on Jute/Glass hybrid fiber as HLC (hybrid laminate composite) was studied by Ahmed and Vijayarangan (2008) using 10 layers of fiber for HLC products. The combination is woven jute fabric (J) and glass fibers (G). The results obtained are variations of JJJJJJJJ (100% jute fibers), which have the lowest tensile and flexural strength values of 80 MPa and 120 MPa. On the other hand, the high mechanical strength is the arrangement of HLC GGGJJJJGGG (60% Glass-40% Jute fibers) with a tensile value of 125 MPa and flexural strength of 160 MPa. It indicates that the addition of glass fiber has an impact on increasing the tensile and compressive strength.

MATERIALS AND METHODS

Materials

The primary materials used are two types of fiber and polyester resin. The fibers used are CSM (chopped strand mat) and WR (woven roving glass fibers), and WR (woven roving carbon fibers). The combination used is the use of different glass fibers, namely random and woven.

The material for the VI manufacturing process is bagging film, sealant tape, spiral tube, flow tube, T connector, flow media, and peel ply.

Figure 2. Glass fibers (a) CSM 450 and (b) WR 200

Figure 3. Woven roving carbon fiber (90º/0º)

Laminate Fabrication

HLC manufacturing uses the Vacuum Infusion method. It is considered better than the hand lay-up and press-mold process because the pressure difference between the bagging film and the outside air could perfectly decrease voids in the HLC product. Component VI includes sealant tape, spiral tube, bagging film, flow media, peel ply, and fiber. The main tool components are a resin trap and a 1 HP vacuum pump.

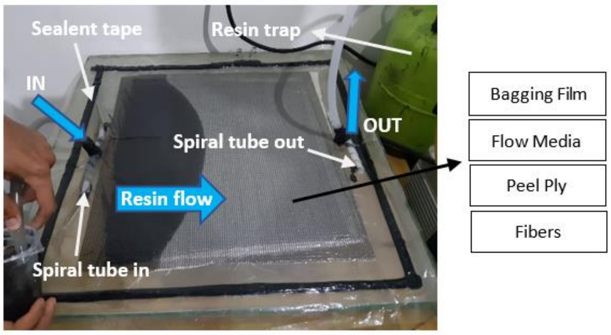

Figure 4. VI process of HLC

The composition of MEKPO (Methyl Ethyl Ketone Peroxide) polyester resin and hardener are 100:1. The resin and hardener are mixed by stirring and put into bagging film with a pressure of 0.8 bar. The curing process takes 15 minutes.

Table 1. Stacking Sequence of HLC

Symbol	Stacking squence	Wt.% of Fibers		V_f (%)	Thickness (mm)
		Carbon	Glass		
WR-CSM	CGGGG	20	80	31.2	1,4
WR-WR	CGGGG	20	80	29.4	1,1
• C = Carbon Fiber; G = Glass Fiber					

The fiber volume fraction can be found using the approximation of equation 1.

Equation 1;

$$V_f = \frac{\left(\frac{W_C}{\rho_C}\right) + \left(\frac{W_G}{\rho_G}\right)}{\left(\frac{W_C}{\rho_C}\right) + \left(\frac{W_G}{\rho_G}\right) + \left(\frac{W_R}{\rho_R}\right)}$$

dimana nilai densitas serat carbon adalah (ρ_C = 1.2 g/cm^3), serat gelas (ρ_G = 2.55 g/cm^3), dan nilai berat jenis resin polyester (ρ_R=1.21 g/cm^3).

Tensile Test

The tensile test follows the ASTM D3039 standard with 15 mm width and 250 mm length (Figure 5). Specimen Thickness adjusts from HLC. The tensile test produces tensile strength, strain, and tensile modulus values obtained by equation 2,

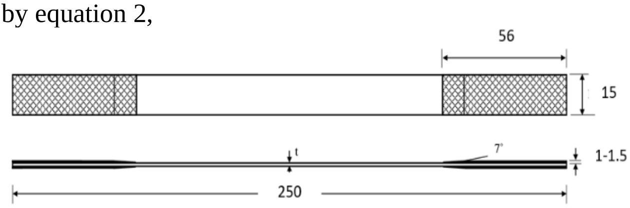

Figure 5. Tensile speciment of HLC (ASTM D3039)

Equation 2;

$$\sigma = \frac{F}{A_o}$$

$$\varepsilon = \frac{L_i - L_o}{L_o} \ x \ 100\%$$

$$E = \frac{\sigma}{\varepsilon}$$

Where σ is tensile strength (MPa), F is the load at a given point on the load-deflection (N). A0 is an initial area (mm), Lo is the initial length (mm), Li is the length after the tensile test. ε is elongation (%), E is the modulus of elasticity (mm). The cross-head speed rate for the tensile test set at 5 mm/minutes.

Flexural Test

The flexural test follows the ASTM D790 standard with 15 mm width and 75 mm length (Figure 6). Specimen thickness adjusts from HLC. The flexural test obtained produces compressive strength and compressive modulus values obtained from equation 3. The mechanical strength values are then adjusted to the macro fracture results after the test to determine the damage to the HLC material.

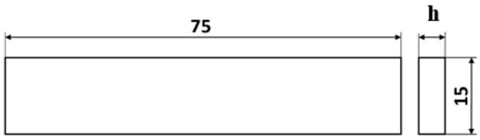

Figure 6. Flexural specimen of HLC (ASTM D790)

Equation 3;

$$\sigma_f = \frac{3.P.L}{2.b.h^2}$$

$$E = \frac{F.L^3}{48.\Delta y.I}$$

$$I = \frac{1}{12} b.h^3$$

Where σf is tensile strength (MPa), P is the load at a given point on the load-deflection (N), L has supported span length (30 mm), b is the width of beam tested (15 mm). E is the modulus of elasticity, I is the moment of inertia, and h is the thickness of the specimen tested (mm). The speed rate for the flexural test was set at 2 mm/minutes.

RESULT AND DISCUSSION

Analysis material HLC (hybrid laminate composite) for small wind turbine depend on testing material results. The important for selection of HLC is excellent bonding with minimum delamination on interfacial laminate between glass and carbon fibers for selection Savonius blade turbine.

Analysis of Tensile Test

Figure 4 shows that the highest tensile strength (σ) and elasticity modulus (E) is 162.9 MPa and 5 GPa, respectively, on the WR-WR variation. In the previous research from Shomad *et al.* (2020), the five (5) laminate fabric woven roving (WR 200) have a tensile strength of 150 MPa and 3 GPa, respectively. It indicates that the additional one (1) ply carbon woven roving increases the tensile strength by 8.6 % and 73% elasticity modulus. Thus, the addition of one-ply woven roving carbon fiber significantly increases the elasticity modulus of HLC.

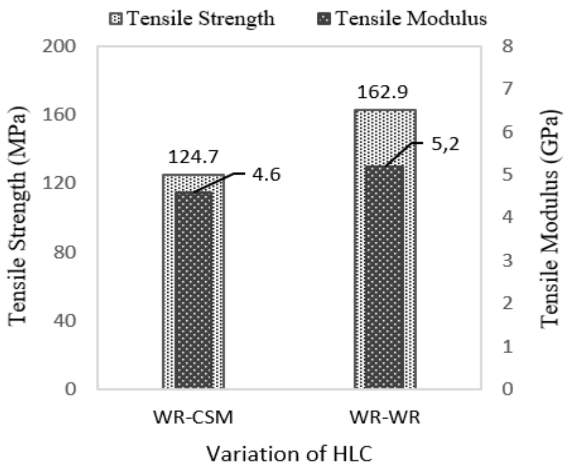

Figure 7. Tensile strength-modulus of HLC

Figures 8 shows that WR-CSM's fracture variation is brittle, and fibers pull out after the tensile test. It indicated that CSM glass fiber is lower tensile strength and elasticity modulus than WR glass fibers. Figure 9 shows that the substitution of CSM to WR glass fibers on the HLC increases the tensile strength and elasticity modulus by 30% and 60% and results the diagonal multiple crack

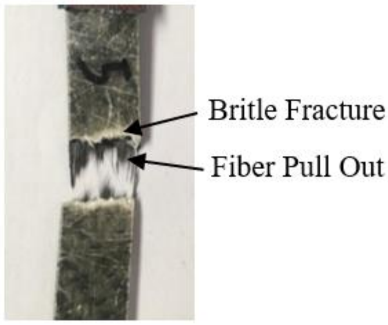

Figure 8. WR-CSM tensile test fracture

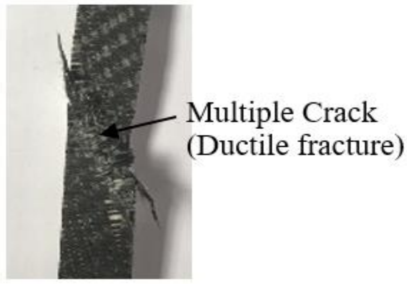

Figure 9. WR-WR tensile test fracture

Analysis of Flexural Test

Figure 10 shows the flexural test graph, which results in the highest flexural strength of WR-CSM by 187.5 MPa but the lowest flexural modulus by 6.2 GPa. Conversely, the highest flexural modulus is WR-WR by 8.8 GPa but the slight flexural strength by 149.7 MPa.

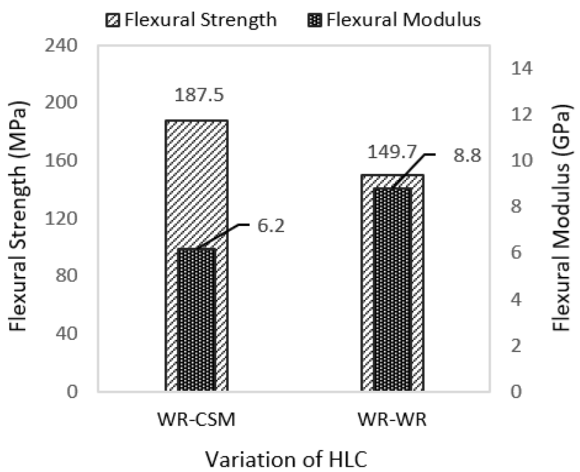

Figure 10. Flexural strength-modulus of HLC

Figure 11 that the WR-CSM specimen after flexural test occurs the delamination fracture and brittle fracture. Figure 12 shows that the WR-WR specimen test occurs ductile fracture. It is due to the excellent mechanical interfacial locking between carbon woven roving and glass woven roving.

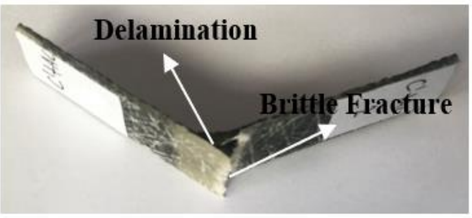

Figure 11. WR-CSM flexural test fracture

Figure 12. WR-WR flexural test fracture

CONCLUSION

The selected material for the Savonius blade turbine is WR-WR has a lightweight and highest elasticity modulus. The WR-WR variation has a tensile strength of 162.9 MPa. The tensile and flexural elasticity modulus are 5.2 GPa and 8.8 Gpa, respectively higher than WR-CSM variation. The fracture of WR-WR did not occur in the delamination interfacial skin of HLC (ductile fracture).

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