Evaluation of Tensile Properties of Composite Lycal/Epoxy Polymer Laminates Reinforced with E-Glass Fiber ±45º Woven Fabrics

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Abstract. Polymer matrix composite is mostly used as main material of UAV (Unmanned Aerial Vehicle) structure. The composite material that is usually used is polymer matrix composite using glass or carbon fiber with epoxy or polyester resin. E-glass, carbon, and aramid are the fibers that widely used in composite because of their high stiffness and strength, and they are lightweight. Therefore, in this study, the authors conducted a study of the mechanical properties of E-glass composite materials. We use E-glass fiber ±45°, this E-glass is woven type with fiber direction -45° and +45°. This E-glass will be tied with Lycal resin and epoxy. The purpose of this study is to determine the mechanical properties material such as tensile strength and stiffness of a composite material of E-glass fiber ±45° with Lycal resin and epoxy resin. Composite was compared between Lycal and epoxy ones. We manufactured the composite E-glass fiber ±45º/Lycal and E-glass fiber ±45º/epoxy with hand lay-up method, the cut specimen geometry refer to ASTM D3039 for tensile standard test. Tensile test was conducted with Tensilon Universal Testing Machine – AND RTF-2410 with a 100kN load cell, specimen shape and size according to standard size ASTMD 3039. The result shown that the matrix had an effect on tensile strengths of composite samples. The tensile strength of E-glass fiber ±45º/epoxy composite is 65.43 MPa, while the tensile strength of E-glass fiber ±45º/Lycal composite is 49.94 MPa, so that E-glass fiber ±45º/epoxy composite is stronger than E-glass fiber ±45º/Lycal composite.

INTRODUCTION

Due to considerations of costs and the final strain level that can be achieved, E-glass fibers are often preferred over carbon fiber even though the modulus is much lower and the vulnerability is higher for environmental degradation. In the same way, resin systems, such as polyester and vinylester, cured under ambient temperature conditions are often used, more preferably than improved high temperature epoxy healing systems, due to considerations of cost and ease of process. This is especially true in the rapidly developing field of aviation where reinforced fiber composites (FRP) are increasingly considered, and used, for airframe structural components and aircraft wing skins. Glass fiber-reinforced polyester composites have played a dominant role for a long time in a variety of applications for their high specific strength, stiffness and modulus.[1] V. Fiore *et al.*[2] evaluated the influence of uniaxial basalt fabric layers on the mechanical performances of a glass mat/epoxy composite used for marine applications. Polymer composites, reinforced by glass mat (GFRP), and hybrid ones, reinforced by glass mat and unidirectional basalt fabric, have been produced by vacuum bagging technique. Three points bending and tensile tests have been carried out to evaluate the effect of number and position of basalt layers on the mechanical properties of the investigated structures. The experimental tests have showed that the presence of two external layers of basalt involves the highest increase in mechanical properties of hybrid laminates compared to those of GFRP laminates.

The chemical compositions of glass fiber in wt% are shown in Table 1.

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TABLE 1. Chemical compositions of glass fibers in wt% type.[3]

Type	(SiO_2)	(Al_2O_3)	(TiO_2)	(B_2O_3)	(CaO)	(MgO)	(Na_2O)	(K_2O)	(Fe_2O_3)
E-glass	55.0	14.0	0.2	7.0	22.0	1.0	0.5	0.3	-
C-glass	64.6	4.1	-	5.0	13.4	3.3	9.6	0.5	-
S-glass	65.0	25.0	-	-	-	10.0	-	-	-
A-glass	67.5	3.5	-	1.5	6.5	4.5	13.5	3.0	-
D-glass	74.0	-	-	22.5	-	-	1.5	2.0	-
R-glass	60.0	24.0	-	-	9.0	6.0	0.5	0.1	-
EGR-glass	61.0	13.0	-	-	22.0	3.0	-	0.5	-
Basalt	52.0	17.2	1.0	-	8.6	5.2	5.0	1.0	5.0

Lembaga Penerbangan dan Antariksa Nasional (LAPAN) has developed unmanned aircraft called LAPAN Surveillance UAV (Unmanned Aerial Vehicle – LSU). There were some kind of UAVs developed by LAPAN, such as LSU-01, LSU-02, LSU-03, and LSU-05. They have some missions, such as aerial photography or mapping of certain region. The main materials used for LSU-02, LSU-03, and LSU-05 are polymer matrix composite using glass or carbon fiber and epoxy or polyester resin. The fiber is synthetic fiber type, such as glass, carbon, and aramid that is widely used in composite because of its high stiffness, strength, and light weight.[4] Glass fiber-reinforced polymer composites (GRPC) reduce weight.[5] Lathifa *et al.*[6] conducted a study of the tensile strength of E-glass fiber ±45º composite with polyester resin matrix, E-glass fiber ±45º stress strain obtained ultimate tensile strength 104.72 ± 12.28 MPa, average elastic modulus 9587.3 ± 1714.79 MPa, and the Poisson's ratio value is 0.80 ± 0.16. The average value of ultimate strength and modulus of elasticity in this study is lower than previous studies with WR 185 fiber, which shows that the tensile strength of E-glass fiber ±45º is lower but its elasticity is higher than WR185. Caitlin O'Brien and Arash E. Zaghi[7] studied woven glass fabrics in ±45º orientation were hybridized with unidirectional stainless steel fabrics in 0º and 90º orientations. This put the glass and steel layers in in-plane shear and normal stresses, respectively. The nonlinear stress–strain relationship, residual plastic strains, energy dissipation capability, and failure mechanisms of hybrid and nonhybrid composite type were compared. The hybrid composites presented improved energy dissipation, tensile strength, and stiffness when compared to nonhybrid ones. Bambang K. Hadi and Bima K. Rofa[8] studied effect central circular hole to tensile strength of woven-glass/epoxy composite plates. Lay-up configuration of (0º/90º)s gives the highest strength, while the (±45º)s gives the weakest strength. The lay-up configuration of (0º/90º/±45º)s is between the other lay-up configurations. The (±45º)s specimens failed in 45º failure direction, while the other two lay-up failed in 0º direction. This coincides with the maximum stresses occurred in the adjacent to the hole. Therefore in structural application where hole is necessary, it is recommended to use more (0º/90º)s lay-up configuration.

Therefore, in this study the authors conducted a study of the mechanical properties of E-glass composite materials. E-glass fiber (GF) used is type ±45° (GF±45°), where the type is different from E-glass fiber used so far (woven roving), ie E-glass fibers are woven with fiber direction -45° and + 45° and thicker than E-glass woven roving, E-glass fiber ±45º in this study will be tied with Lycal resin and epoxy. The purpose of this study was to determine the tensile strength and stiffness of a composite material of E-glass fiber ±45° with Lycal resin and epoxy. Composite will be compared between Lycal and epoxy ones.

METHOD

The testing method was all referred to ASTM D3039 standard tensile test of composite material. The test has done using Universal Testing Machine (UTM) Tensilon RTF – 2410 with crosshead speed of 2.0 mm/min. Figure 1 shows the research methodology.

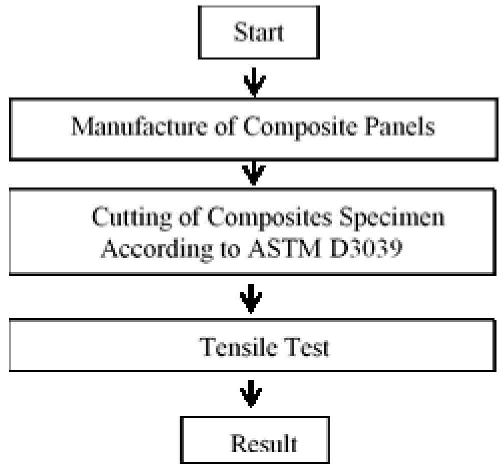


FIGURE 1. Research methodology

A study was conducted to investigate the ability to model the mechanical performance of composites containing E-glass fibers ±45° lay-up with Lycal resin matrix. Mechanical properties of the composites were determined using universal electro-mechanical testing machine Tensilon. Sample set consisted of nine specimens. Average strength and stiffness values of the tensile test were taken as the results. Since the physical properties of many materials can vary depending on ambient temperature, tests were carried out according to the standards for room temperature. A universal electro-mechanical testing machine Tensilon with a 100 kN load cell at a fixed loading rate of 2 mm/min was used tensile tests. We can define the maximum normal stress σ_i [MPa] in the tensile test as

$$\sigma_i = \frac{P_i}{A} \quad (1)$$

where P is load at i^{th} data point [N], A is average cross-sectional area [mm^2], tensile modulus or ultimate tensile strain was to calculated as follows

$$\varepsilon = \frac{\delta i}{L_g} \quad (2)$$

where δ is the extensometer displacement i th data point [mm], L_g is extensometer gage length [mm]. The tensile modulus of elasticity E_f [MPa] is the ratio of stress to the corresponding strain at a given point on the stress–strain curve. Hence, it can be calculated as

$$E^{chord} = \frac{\Delta\sigma}{\Delta\varepsilon} \quad (3)$$

The standard specimen is shown in Fig. 2 below.

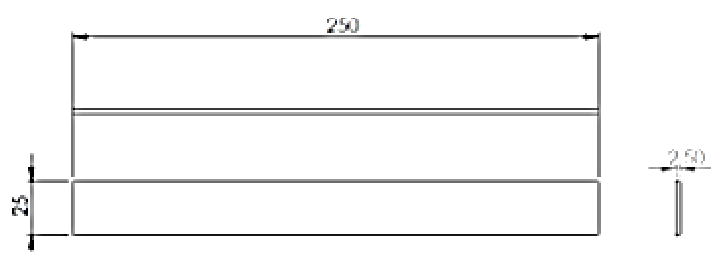


FIGURE 2. Standard specimen for tensile test[10]

The tensile tests were performed following the ASTM D3039 procedure 9 using a tensile test fixture which is shown in Fig. 3 below.

FIGURE 3. Tensile test

RESULT AND DISCUSSIONS

The test results of the maximum load (P), maximum strengths (σ_f) and stiffness (E_f) for the composite Lycal/epoxy polymer laminates reinforced with E-glass fiber ±45º woven fabrics samples are tabulated in Table 2. The result shows that the tensile strength of E-glass fiber ±45º/epoxy is 31.02% higher than E-glass fiber ±45º/Lycal, but the modulus of elasticity of E-glass fiber ±45º/epoxy is 36.63% lower than E-glass fiber ±45º/Lycal.

TABLE 2. Tensile test results of E-glass fiber ±45º/Lycal and E-glass fiber ±45º/epoxy composites.

Data	**E-Glass Fiber ±45º/Lycal**	**E-Glass Fiber ±45º/Epoxy**
	Average	**Average**
Load (N)	3014.7	4174.2
Stress (Mpa)	49.94	65.43
Elastic Modulus (Mpa)	3252	2061.1

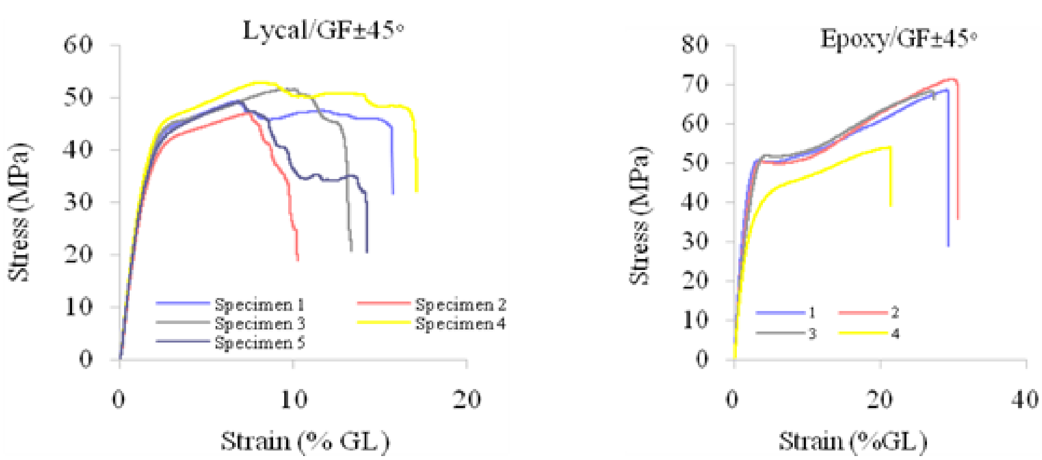


FIGURE 4. Graphical comparison of stress-strain for the tensile specimens

Figure 4 shows tensile stress versus tensile strain of composite type. From this curve we can know the stress value at each strain point. Stress-strain curves indicate that the composite material is very brittle as indicated by the maximum strain of the specimens, which is in the range of 10-20 strain values (% GL) for Lycal / E-Glass Fiber ±45º and 20-40 strain values (% GL) for Epoxy/ E-Glass Fiber ±45º. Composites Lycal / E-Glass Fiber ±45º type tend to have a bond between resin and fiber that is lower than Epoxy/ E-Glass Fiber ±45º. Lycal matrix which is a type of polyester has a lower mechanical than epoxy matrix. It was observed that tensile strength is maximum at 71.24 MPa for Epoxy/ E-Glass Fiber ±45º and tensile strength was lower for Lycal/ E-Glass Fiber ±45º The value of ultimate strength and modulus of elasticity in this study is lower than previous studies of E-Glass Fiber ±45º composite with polyester resin matrix, E-Glass Fiber ±45º stress strain obtained ultimate tensile strength 104.72 ± 12.28 MPa, average elastic modulus 9587.3 ± 1714.79 MPa. But this process is with vacuum infusion so it is better than hand lay up process.[6] Tensile properties of the composites are mostly affected by the materials, method, specimen condition and preparation and also by percentage of the reinforced. The tensile strength of the fabricated composite depends to a large extent on the interfacial bonding strength between the matrix reinforcement and also on the inherent properties of the composite ingredients.[1]

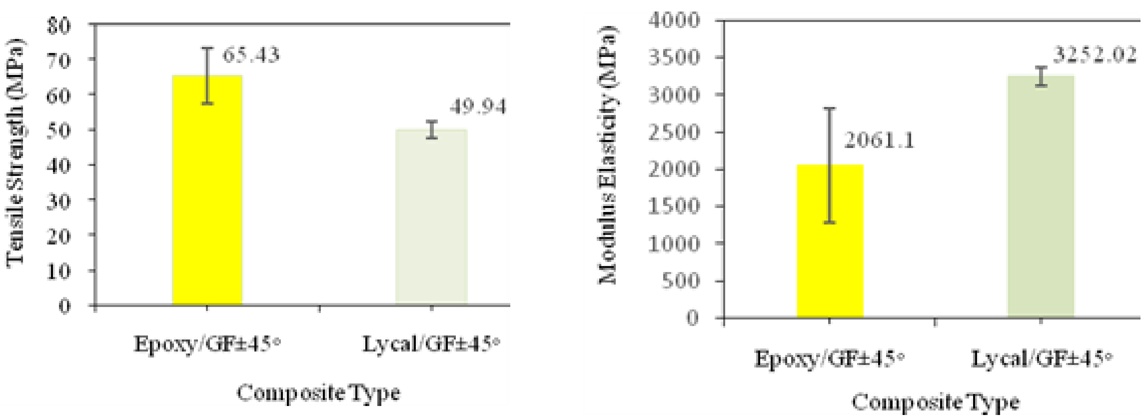
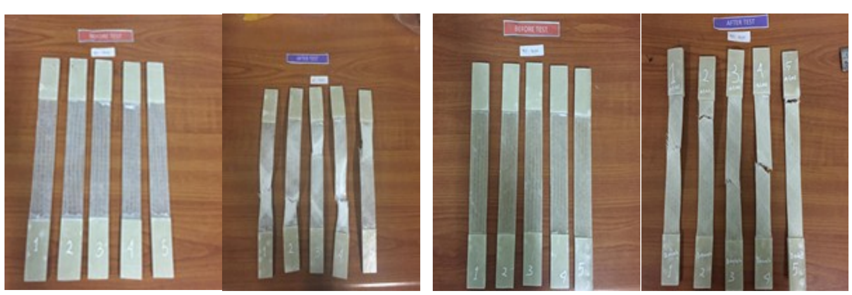


FIGURE 5. Graphical comparison of tensile strength for the tensile specimens

Figure 6 shows tensile strength for composite type. The tensile strength average of composite E-glass fiber ±45º/epoxy is higher than composite E-glass fiber ±45º/Lycal. But the elastic modulus of composite epoxy/E-glass fiber ±45º is lower than composite Lycal/E-glass fiber ±45º. We can conclude that the E-glass fiber ±45º/Lycal is stiffer than E-glass fiber ±45º/epoxy. The fracture result specimen after test can be seen at Fig. 7.



a b

FIGURE 6. Specimens before and after test: (a) Lycal/GF±45º, and (b) epoxy/GF±45º

As shown by Fig. 7, failure type of the specimen after test are dominated by Angle Gage Middle (AGM), but there is also specimen with Lateral At grip/tab Top (LAT) failure type.[9]

CONCLUSIONS

The result shown that the matrix had an effect on tensile strengths of composite samples. According to the test result, tensile strength of E-glass fiber ±45º/epoxy composite is 65.43MPa, which is higher 31.02% compared with Lycal, which is 49.94 MPa. However, the elastic modulus composite laminate reinforced E-glass fiber ±45º woven fabrics with epoxy matrix is 2061.1 MPa, is lower 36.63% compared with Lycal 3252 MPa. We can conclude that the E-glass fiber ±45º/Lycal is stiffer than E-glass fiber ±45º/epoxy.

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