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Experimental and Numerical Evaluation of Mechanical Properties for Carbon Fiber Reinforced Epoxy LY5052 Composite for Prosthesis Structures

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ABSTRACT. Carbon Fiber Reinforced Epoxy is one of the materials that is widely used in the manufacture of phosthesis structures. In this study, the carbon fiber used carbon-kyoto type plain weave while the epoxy matrix was LY5052. The maximum stress (σ) from the tensile test is 537.15 MPa. Furthermore, tensile test simulation with Finite element analysis simulation using Abaqus software, in the process the selection of mesh through input sizing control determines the accuracy of the results. The simulation results are 523.3 MPa when compared to the experiment the difference is 2.58%

Keywords: Carbon fiber, Phrostesis, maximum stress

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1. INTRODUCTION

The prosthesis is a medical device designed to obtain certain body parts to assist patients in certain functions after the body part has been severely affected by an accident or disease [1]. Most prostheses are used to restore function to body parts that have been removed. The most popular prosthesis used is on the hands and feet. The prosthesis for the hand may consist of a hand and forearm prosthesis, or an upper arm, which is recommended when the elbow joint is also missing.

Composites of carbon fiber and epoxy are excellent materials for orthotic prosthetics. Carbon fiber / epoxy composites stand out as the material of choice for prosthetics manufacture for a variety of reasons, including its tensile and compressive strength, modulus, impact resistance, fatigue resistance, specific weight, simplicity of manufacturing, cleanliness, and aesthetic aspects. Carbon composite prostheses have helped tens of thousands of individuals all around the world live a better and more happy life [2].

2. EXPERIMENTAL AND NUMERICAL

2.1 Experimental

2.1.1 Materials

Text The material used in this study as a fiber using carbon fiber (Kyoto – carbon) with a plain weave type of 3K × 3K 220GSM and a thickness of 0.27 mm, plain weave type is shown in Fig. 1. As the matrix are Epoxy resin Araldite LY5052 and hardener Aradur 5052 supplied by Huntsman, with a mix ratio based on weight of 100:38

2.1.2 Fabrication Method

In making specimens referring to ASTM D3039 requires 10 layers with all orientations at the same angle, namely 0° or 90° because the carbon fiber used is plain weave type, this is done to obtain the initial mechanical properties of CFRP. The specimens were made using the vacuum infusion method which is a composite manufacturing technique using vacuum pressure to flow the resin into the laminate (fiber layers). The fiber material is placed into the mold and vacuumed before the resin is flowed. When the vacuum condition has been reached, the resin is sucked into the laminate through a pipe attached to the vacuum area [4]. The scheme of composite manufacturing by this method can be seen in Fig. 2. The final stage is the curing process by leaving it at room temperature for 24 hours.

The next step is to prepare a tensile test specimen referring to ASTM D3039 standard of tensile testing of fiber reinforced composites with dimensions of 250 mm × 25 mm × 2.5 mm, Fig 3 shows the dimensions of the tensile test specimen.

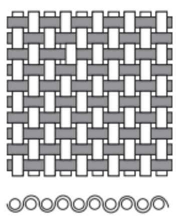

Fig. 1 Plain weave type

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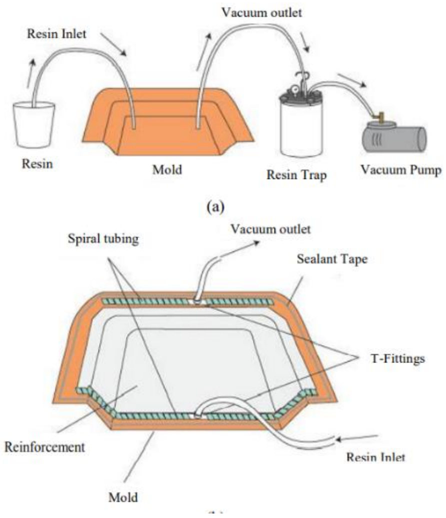

Fig.2 vacuum infusion scheme [4]

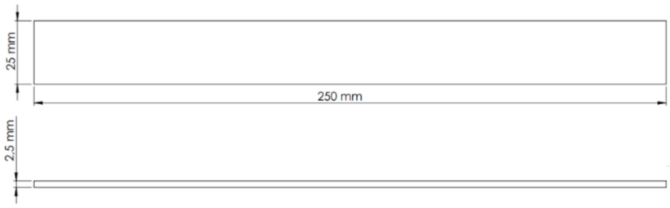

Fig. 3 dimensions of test specimens (ASTM D3039)

2.1.3 Mechanical study

The tensile test was carried out using the Shimadzu AG-50KNX PLUS Machine located at the Polymer Technology Center (BRIN) laboratory. Tensile test was carried out at room temperature 21.8 C with 58% humidity. Specimen dimensions are 250 mm × 25 mm standard displacement rate of 2 mm/min according to ASTM D3039

2.2 Numerical analysis

ABAQUS Software is used for numerical modeling of tensile test specimens. The steps taken include the following:

– In first step, the part is modeled as a 3D deformable, in the base feature section select the shell, then make a specimen with dimensions of 250 mm × 25 mm.
– In second step, in the module part, select the partition face to define the grip and gauge length shown in Fig. 4
– In the third step, the elastic properties of the carbon/epoxy lamina were determined as reported in Table 1. For the characterization of E1, E2 and v12 the plain weave properties were taken from the literature [5].
– In the fourth step, In composite layup manager, a composite stacking sequence was created by allocating thicknesses of 0.27 to carbon plies, shown in Fig. 5
– In the fifth step, In the assembly module, the dependent mesh type was chosen.
– Furthermore, the analysis step was defned in which type of analysis was declared to be static general. The time period refers to ASTM D3039 with a standard displacement rate of 2 mm/min
– In the sixth step, coupling interaction was defined between reference point of upper grip and lower grips nodal region as shown in Fig. 6.
– Create boundary conditions, category mechanical, types Encastre (U1 = U2 = U3 = UR1 = UR2 = UR3 = 0). The load is a displacement of 2 mm/min which refers to ASTM D3039 as shown in Fig. 7
– In the next step of mesh selection, the selected mesh element is a Quad shape mesh as shown in Fig. 8
– Finally, Job submitted. So that the visualization of the results from the simulation can be obtained

Table 1
Lamina properties for numerical simulation

Physical property	Carbon/epoxy Lamina	Source
$E_1 = E_2$ (MPa)	13180	Experimentally
G_{12} (MPa)	2231.34	Analytically (rule of mixture)
$G_{23} = G_{13}$	1142.38	Analytically (rule of mixture)
ν_{12}	0.21	Analytically (rule of mixture)

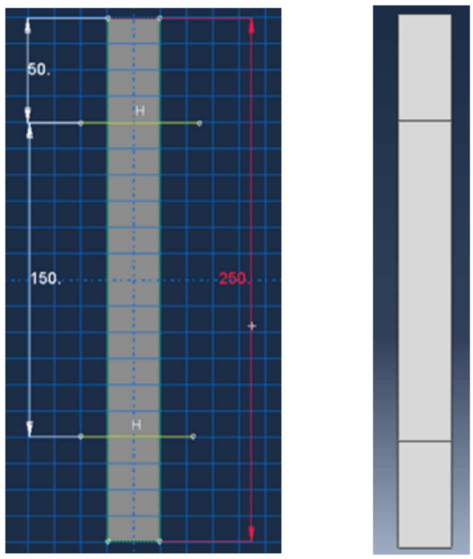

Fig. 4 partition face

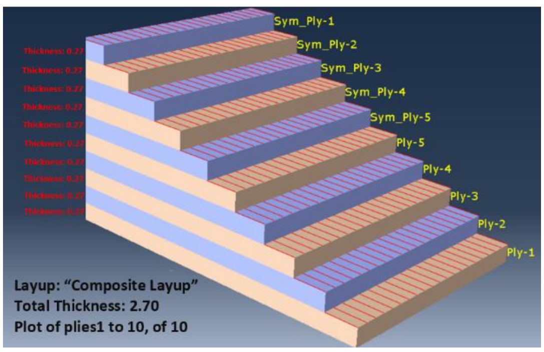

Fig. 5 ply stack plot

Fig. 6 reference point of upper and lower grip

Fig. 7 boundary condition and load

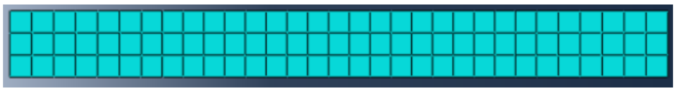

Fig. 8 quad shape mesh

3. Results and Discussion

3.1 Specimen (ASTM D3039)

Fig. 9 describes the process of making specimens through the vacuum infusion method, after curing they are cut with dimensions of 250 mm × 25 mm. Fig. 10 shows the specimen cut which refers to ASTM D3039 and the specimen after tensile test. Tensile testing uses the same specimen five times with the same treatment, the specimens are coded S-1, S-2, S-3, S-4 and S-5.

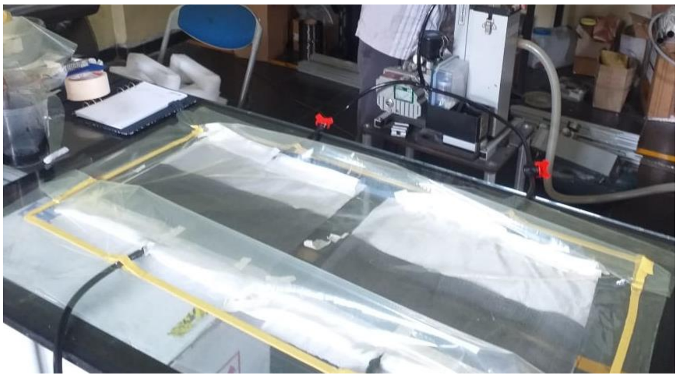

Fig 9. Vacuum infusion process

(a)

(b)

Fig.10 specimen (ASTM D3039): (a) before tensile test; (b) after tensile test

3.2 Tensile Properties

Table Table. 2 shows the complete results of the Tensile test on 5 specimens at room temperature of 21.8°C with 58% humidity, so that plain weave carbon fiber with LY5052 epoxy matrix 10 layers at an angle of 0° or 90° by looking at the average Modulus of elasticity E: 13.18 GPa, Stress Max σ: 537 MPa, and strain ε : 4.77%. Thus, the mechanical properties of the tensile test results can be used as a reference when designing the prosthesis components as needed. To see the comparison between stress and strain from the tensile test on these five specimens, we can also look at Fig. 11

Table. 2

Tensile test results (Elasticity modulus E, Max Stress σ, and strain ε)

Specimen Code	E (GPA)	σ (MPa)	ε (%)
S-1	13.14	556.76	4.97
S-2	15.15	539.50	4.63
S-3	13.93	512.57	4.34
S-4	12.90	563.02	4.92
S-5	10.78	513.90	4.98
Average	13.18	537.15	4.77
SD	1.60	23.47	0.28

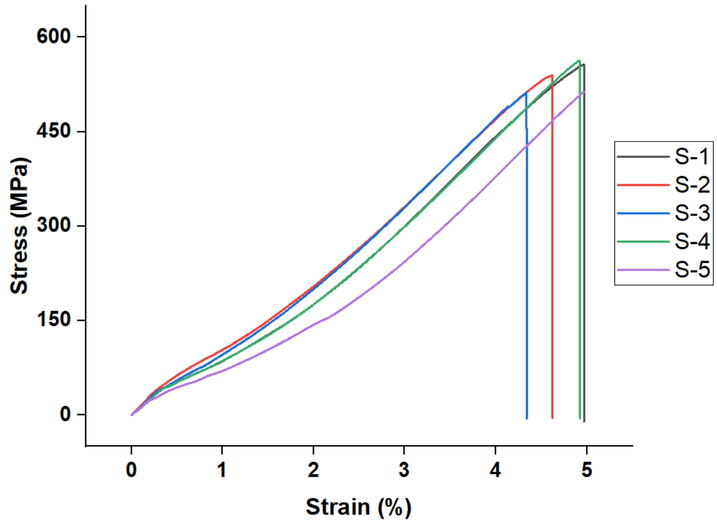

Fig.10 Stress-strain diagrams for tensile test

3.3 Numerical analysis

In numerical analysis using abaqus software in the meshing process sizing control needs to be done, which means that the dimensions of the specimen design that are made automatically are divided by the number input that we input in the sizing control option, the smaller the number entered in the sizing control menu, the smoother the mesh shape will be, this is shown in the number of nodes formed, this causes the length of time needed to complete the simulation work process that is made, more details in Fig. 11 can be seen the comparison between the total nodes formed when choosing the sizing control, the smaller the input sizing control, the more total nodes, so that in the end the more nodes the graph formed will be more sloping, this indicates the simulation results are getting more convergent, which means the more

accurate the results obtained. However, the more nodes that are formed, of course it takes more time, it is clearly seen in the red graph the comparison between the total nodes and the running time.
Furthermore, the simulation uses composite lamina properties with $E_1 = E_2$ derived from the experimental results, for v_{12}, G_{12}, and $G_{23} = G_{13}$ using the calculation (rule of mixture), see table.1. on Fig. 12 stress max simulation results using Abaqus software obtained is 523.3 MPa. From the simulation results can be compared with the experimental stress tensile test results, see table. 2 using the average stress data from carbon/epoxy of 537.15 MPa so that the results of simulation work using abaqus software are not much different.

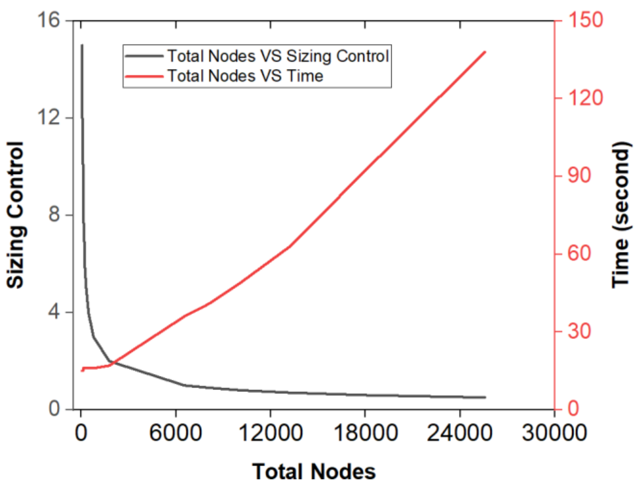

Fig. 11 total nodes vs sizing control and total nodes vs time

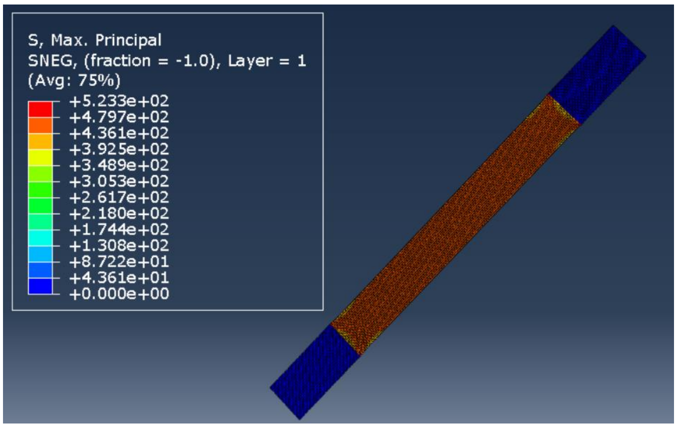

Fig. 12 Contour plots for stress max

4. Conclusion

Conclusions that can be obtained based on experiments and simulations on carbon/epoxy as a prosthesis material include:

1. The experimental results of tensile test of carbon fiber reinforced epoxy LY5052 composite average Max Stress σ = 537.15 MPa
2. Mesh settings with the selection of sizing control greatly determine the accuracy of the simulation work.
3. Stress max simulation results using abaqus software obtained 523.3 MPa, when compared with the experimental results the percentage difference is only 2.58%

Acknowledgments

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