Terbit online pada laman web jurnal
http://ejournal2.pnp.ac.id/index.php/jtm

JURNAL TEKNIK MESIN

POLITEKNIK NEGERI PADANG

Vol. 15 No. 1 (2022) 1 - 6 ISSN Media Elektronik: 2655-5670

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

Mahfud Ibadi[1], Yudan Whulanza[2*], Herry Purnomo[3], David N Vicarneltor [4], Tresna P Soemardi[5], Gatot Prayogo[6]

[1,2,5,6]Departemen Teknik Mesin, Fakultas Teknik, Universitas Indonesia

[3,4]Pusat Teknologi Roket, Badan Riset dan Inovasi Nasional (BRIN)

*yudan@eng.ui.ac

Abstract

Carbon Fiber Reinforced Epoxy is a material that is widely used in the manufacture of prosthesis structures. In this research, the carbon fiber used is plain weave-type carbon, while the matrix used is LY5052 epoxy, LY5052 epoxy has advantages such as low viscosity and long pot life making it possible to manufacture large-sized prostheses. The first step in this research is making specimens using the vacuum infusion method and then cutting the specimens with dimensions referring to ASTM D3039. Furthermore, tensile test experiments were carried out with the results obtained that the maximum stress () was 537.15 MPa. As an evaluation, a tensile test simulation was carried out with Finite element analysis using Abaqus software, the material properties used were the results of a tensile test experiment, in the process the mesh selection was carried out by input sizing control many times this was done to determine the accuracy of the results. The tensile test simulation results with abaqus software are 523.3 MPa when compared to the experimental, the difference is only 2.58%. based on experimental and simulation results, the mechanical properties of the Carbon Fiber Reinforced Epoxy LY5052 Composite material are almost the same, so that in the manufacture of prosthesis the mechanical properties data in this study can be used when performing numerical analysis in the prosthesis design process.

Keywords: LY5052, Prosthesis, Maximum stress, Simulation, Abaqus

Abstrak

Carbon Fiber Reinforced Epoxy merupakan salah satu material yang banyak digunakan dalam pembuatan struktur postesis. Dalam penelitian ini serat karbon yang digunakan adalah karbon-kyoto type *plain weave* sedangkan matriks yang digunakan adalah epoksi LY5052. Epoksi LY5052 mempunyai keunggulan diantaranya viskositas yang rendah dan *pot life* yang lama sehingga memungkinkan dalam pembuatan prostesis dengan ukuran besar. Langkah awal dalam penelitian ini yaitu pembuatan spesimen dengan metode *vacuum infusion* lalu spesimen dipotong dengan dimensi mengacu pada ASTM D3039. Selanjutnya dilakukan eksperimen uji Tarik dengan hasil yang didapatkan Tegangan maksimum () sebesar 537,15 MPa. Sebagai evaluasi dilakukan simulasi uji tarik dengan *Finite element analysis* menggunakan software Abaqus. Material propertis yang digunakan adalah hasil eksperimen uji Tarik, pada prosessnya pemilihan mesh dilakukan dengan cara *input sizing control* berkali-kali hal ini dilakukan untuk menentukan keakuratan hasil. Hasil simulasi uji Tarik dengan software abaqus sebesar 523,3 MPa jika dibandingkan dengan eksperimental selisihnya hanya sebesar 2,58%. Berdasarkan hasil eksperimental dan simulasi, karakter mekanikal properties dari material Carbon Fiber Reinforced Epoxy LY5052 Composite hampir sama, sehingga dalam pembuatan prosthesis data mekanikal propertis dalam penelitian ini dapat digunakan ketika melakukan *numerical analysis* dalam proses perancangan prostesis.

Kata kunci: LY5052, Prostesis, Tegangan maksimum, Simulasi, Abaqus

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.

Composite materials have allowed for significant advancements in the design and performance of current orthopedics and prosthetic devices. Composites with underlying polymer matrix currently make up the bulk of upper and lower limb prostheses. Carbon fiber reinforced epoxy matrix composites are now the most widely utilized multi-phase materials in orthopedics, owing to their superior strength-to- weight ratios and high biocompatibility. Epoxy-matrix composites have good mechanical and tribological qualities, as well as good chemical and corrosion resistance and dimensional stability [2].

The mechanical characteristics of fiber/polymer matrix composites dominated by the matrix [2]. The matrix composite material has a great influence in binding the reinforcing material in addition to functioning to distribute the load and provide protection from environmental influences. The matrix itself functions to form a coherent bond, distribute stresses, protect the fiber, and contribute to several properties such as stiffness, toughness and electrical resistance [3]. There is still space for improvement in matrix-dominated parameters such as in-plane and interlaminar shear properties, as well as matrix stiffness, toughness, and hardness [4].

In this study try to use epoxy LY5052 as a matrix because this resin is Low viscosity (easy impregnation of reinforcement materials), long potlife (2 hours for 100 ml at ambient): ample processing time allows production of big objects, high temperature resistance (glass transition temperature) after ambient cure: 60 °C, after post-cure at 100:120 °C, excellent mechanical and dynamic properties after ambient cure with potential for even higher properties after post- cure at elevated temperatures, also laminates show outstanding mechanical and dynamic properties [5,6].

In this study, we examine the experimental results of the tensile test of carbon fiber with epoxy LY5052 matrix, the experimental results obtained are used as input in the use of Abaqus simulation software, so that it can be seen how far the differences in the mechanical properties of the experimental and simulation results are. and in the end the mechanical properties of Carbon Fiber Reinforced Epoxy LY5052 Composite can be used as one of the materials of choice in designing prosthesis components.

2. Experimental and Numerical

2.1. Experimental

2.2. Material

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 Figure 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.

2.2.1 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 [8]. The scheme of composite manufacturing by this method can be seen in Figure 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 250mm □ 25mm □ 2.5mm, Figure 3 shows the dimensions of the tensile test specimen.

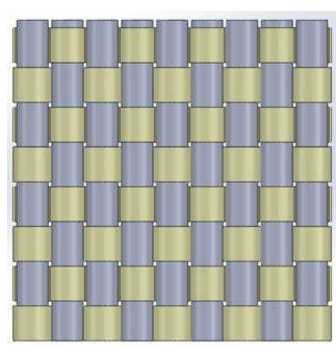

Figure. 1. Plain weave type

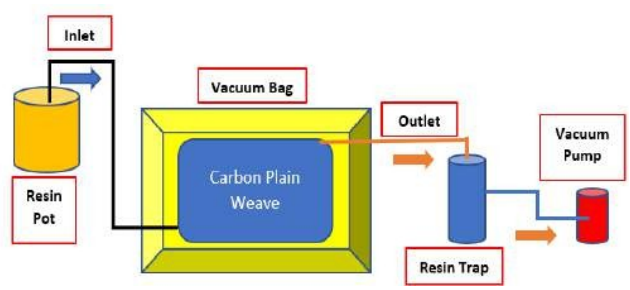

Figure 2. Vacuum infusion scheme

Figure 3. Dimensions of test specimens (ASTM D3039)

2.3. 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 250mm □ 25mm standard displacement rate of 2 mm/min according to ASTM D3039

2.4. 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 250mm × 25mm.
- In second step, in the module part, select the partition face to define the grip and gauge length shown in Figure 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 [9].
- 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 Figure 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 Figure 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 Figure 7
- In the next step of mesh selection, the selected mesh element is a Quad shape mesh as shown in Figure 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)

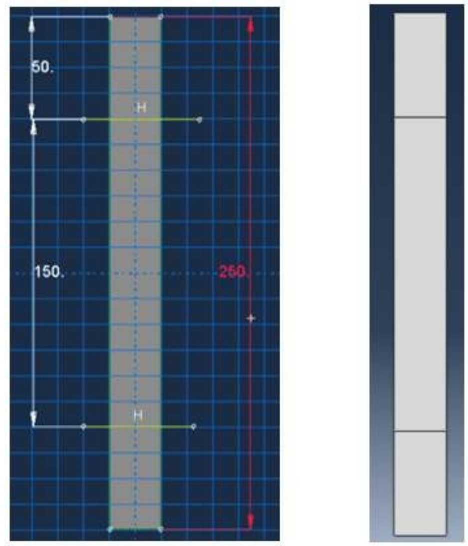

Figure 4. Partition face

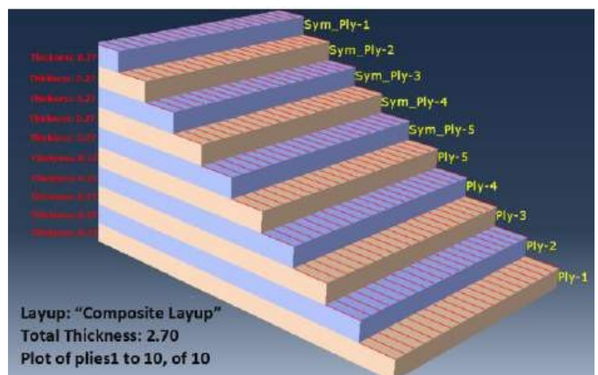

Figure. 5. Ply stack plot

Figure 6. Reference point of upper and lower grip

Figure 7. Boundary condition and load

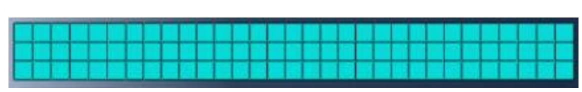
Figure 8. Quad shape mesh

3. RESULTS AND DISCUSSION

3.1 Specimen (ASTM D3039)

Figure 9 describes the process of making specimens through the vacuum infusion method, after curing they are cut with dimensions of 250mm □ 25mm.

Figure 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.

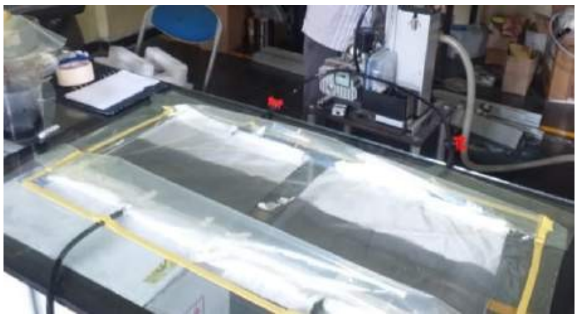

Figure 9. Vacuum infusion process

(a)

(b)

Figure 10. Specimen (ASTM D3039): (a) before tensile test;
(b) after tensile test

3.2. Tensile Properties

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 □: 537 MPa, and strain □ : 4.77%. Thus, the mechanical properties of the tensile test results can be used as a reference when designing the prosthesis components as needed. Table 2 also shows the results of the tensile test both Elasticity modulus, Max Stress, and strain, the percentage of Standard Deviation can be said that the smaller the standard deviation, the more similar the values on the item or the more accurate the mean (16).

Table 2. Tensile test results (Elasticity modulus E, Max Stress □, and strain ε)

Specimen Code	E (GPA)	□ (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	12.14%	4.37%	0.28

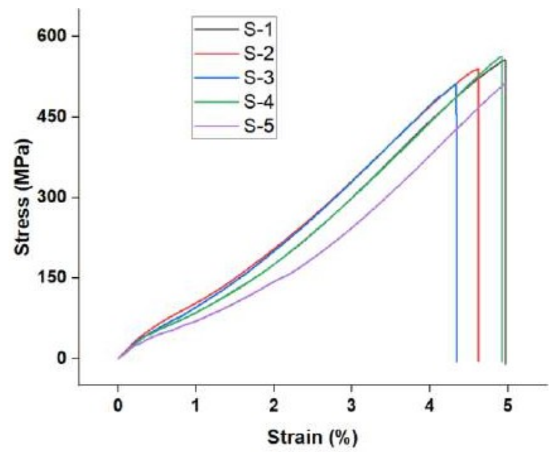

Figure 11. Stress-strain diagrams for tensile test

To see the comparison between stress and strain from the tensile test on these five specimens, we can also look at Figure 11. In the tensile stress-strain curve shown in Figure 11, it shows that the composite material used is included in the brittle material because there is no yield point (yield point), and the test will suddenly break (Breaking) without any addition or extension occurring (17).

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 Figure 12 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.

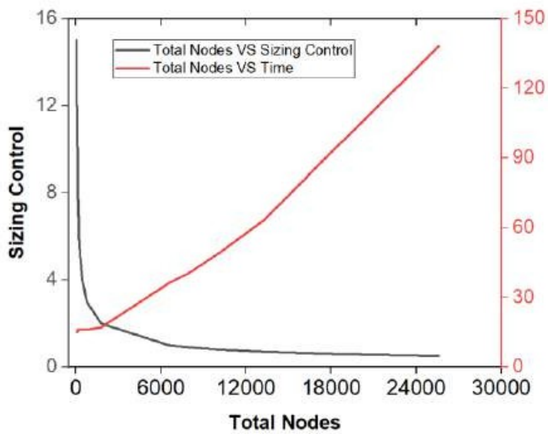

Figure 12. Total nodes vs sizing control and total nodes vs time

Furthermore, the simulation uses composite lamina properties with E1 = E2 derived from the experimental results, for v12, G12, and G23 = G13 using the calculation (rule of mixture), see table.1.

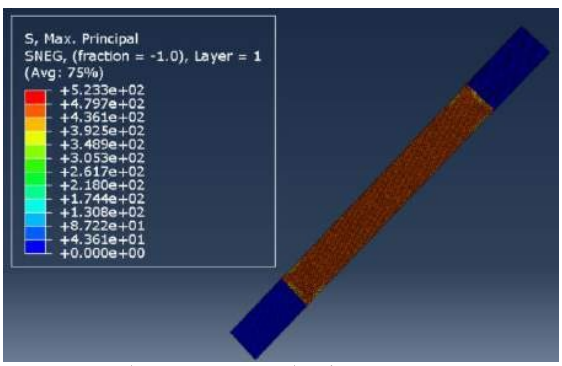

Figure 13. Contour plots for stress max

From the properties that have been entered in the simulation work process, the results obtained can be seen in Figure 13, stress max is shown on the red contour plot and this area is the gauge length area which is simulated with Abaqus experiencing the most stress, when compared to the experimental Tensile test, the fractured specimen area can be seen in Figure 10 (b). So it can be interpreted that between the simulation and the experimental area the stress max is in the same area, in a simulation using the Abaqus software the stress max is 523.3 MPa (Fig. 12), 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.

Finally, based on experimental and simulation results, the mechanical properties of the Carbon Fiber Reinforced Epoxy LY5052 Composite material are almost the same, so that in the manufacture of prosthesis the mechanical properties data in this study can be used when performing numerical analysis in the prosthesis design process.

4. Conclusion

Conclusions that can be obtained based on experiments and simulations on carbon/epoxy as a prosthesis material include: The experimental results of tensile test of carbon fiber reinforced epoxy LY5052 composite average Max Stress σ = 537.15 MPa. Mesh settings with the selection of sizing control greatly determine the accuracy of the simulation work. Stress max simulation results using abaqus software obtained 523.3 MPa, when compared with the experimental results the percentage difference is only 2.58%. Mechanical properties of experimental results that have been obtained are used as input in using simulation software, so that when we design a prosthesis component, the material properties data in this case carbon fiber reinforced epoxy LY5052 can be used according to the needs of the designed prosthesis component.

Furthermore, the mechanical properties that have been obtained can be used when designing the prosthesis while still paying attention to the load requirements or dimensions of the prosthesis

Acknowledgments

Many thanks and gratitude to Saintek BRIN scholarship for the financial support of this study.

Reference

[1] https://www.docdoc.com/id/info/condition/prostesis. accessed on April 28, 2022

[2] Baptista, R., Mendão, A., Guedes, M., & Marat-Mendes, R. 2016. An experimental study on mechanical properties of epoxy-matrix composites containing graphite filler. Procedia Structural Integrity, 1, 74-81.

[3] Oktaviameta, A., Kardiman, K., & Suci, F. 2021. Pengaruh Fraksi Volume Serat Jerami Terhadap Kekuatan Material Komposit Aplikasi Kayu Lapis. Jurnal Teknik Mesin, 14(2), 70-74. https://doi.org/10.30630/jtm.14.2.568

[4] Cho, J., Chen, J.Y. and Daniel, I.M., 2007. Mechanical enhancement of carbon fiber/epoxy composites by graphite nanoplatelet reinforcement. Scripta Materialia 56,685–688

[5] S. Saseendran, M. Wysocki and Janis Varna., 2017 "Cure- state dependent viscoelastic Poisson's ratio of LY5052 epoxy resin, Advanced Manufacturing: Polymer & Composites Science, 3:3, 92-100, DOI: 10.1080/20550340.2017.1348002

[6] Technical Data Sheet epoxy LY5052 https://www.generaladhesivos.com/proveedor-pegamento/909hoja-tecnica-Araldite%20LY%205052 accessed on June 02, 2022

[7] ASTM D3039 / D7264M-15, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International, West Conshohocken, PA 19428-2959, 2002

[8] FiberGlast., 2015. "Vacuum Infusion - The Equipment and Process of Resin Infusion Introduction.

[9] Autar K Kaw., 2006. Mechanics of Composite Materials second Edition. CRC Press Taylor & Francis Group.

[10] A. F. Istiqomah, et al., 2021. "Design and Analysis of The Energy Storage and Return (ESAR) Foot Prosthesis Using Finite Element Method," Journal of Biomedical Science and Bioengineering (JBIOMES) 1 (2), page 59–64.

[11] M. Y. Khalid, et al., 2020. "Experimental and numerical characterization of tensile property of jute/carbon fabric reinforced epoxy hybrid composites." SN Applied Sciences, 2(4). doi:10.1007/s42452-020-2403-2.

[12] K. Karthik, D. Rajamani, T. Raja et al., 2022. Experimental investigation on the mechanical properties of Carbon/Kevlar fibre reinforced epoxy LY556 composites, Materials Today:

Proceedings, https://doi.org/10.1016/j.matpr.2021.10.077

[13] Nirbhay, M., Dixit, A., Misra, R. K., & Mali, H. S., 2014. Tensile Test Simulation of CFRP Test Specimen Using Finite Elements. Procedia Materials Science, 5, 267–273. doi:10.1016/j.mspro.2014.07.266.

[14] Krucinska, and Stypka., 1991. Direct measurement of the Axial Poisson's Ratio of Single Carbon Fibres. Composites Science and Technology, 41(1), 1–12. doi:10.1016/0266-3538(91)90049-u.

[15] A. P. Kurniawan, T. P. Soemardi, Widjajalaksmi, 2009. Komposit Laminate Rami Epoksi Sebagai Bahan Alternatif Socket Prosthesis. JURNAL TEKNIK MESIN Vol. 11, No. 1, April 2009: 41–45

[16] Memahami Nilai Standard Deviation (Standar Deviasi) Dalam Penelitian Ilmiah. https://accounting.binus.ac.id/2021/08/12/memahami-nilai-standard-deviation-standar-deviasi-dalam-penelitian-ilmiah/. accessed on April 29, 2022

[17] Kurva Tegangan Regangan (Stress-Strain Curve) Pada Uji Tarik. https://www.etsworlds.id/2020/01/kurva-tegangan-regangan- stress-strain.html accessed on April 29, 2022