Properties Comparison of Open Hole and Non-Hole Carbon UD-Lycal Composite with Vacuum Bagging Manufacturing Method

Lathifa Rusita Isna[1], Afid Nugroho[1], Rezky Agung P [1], Redha Akbar R[1]

[1]Aeronautic Technology Center, National Institute of Aeronautics and Space (LAPAN), Indonesia

e-mail: lathifa.rusita@gmail.com

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Abstract

Carbon fiber reinforced polymer is one of some composite materials that have high strength with lightweight material. To apply this composite to the amphibious airplane structure, it should through the experimental tensile test to know the tensile strength and modulus of elasticity of the composite. In this experiment, we use Carbon UD fiber and Lycal resin as the composite material manufactured with Vacuum Bagging Method. Specimens and testing process refer to ASTM D3039 for non-hole specimen and ASTM D5766 for the open-hole specimen of a tensile test standard for composite matrix polymers. The result of the experimental test shows that the tensile modulus of elasticity for non-hole composite is 34.92 ± 0.13 GPa, with the Ultimate Tensile Strength of this composite is 1081± 0.03 MPa, and the modulus of elasticity for open-hole composite is 41.87± 0.02 GPa, with the Ultimate Tensile Strength of this composite is 899.04± 0.02 MPa. The simulation yields nearly the same stress-strain graph as the result of an experiment. The result shows that the open hole composite has the ultimate tensile strength lower than non-hole composite, it's due to when the open hole composite tested with the tensile force, the stress will be concentrated in the hole area which becomes a trigger failure that may decrease the tensile strength value.

Keywords: *composite, carbon fiber, vacuum bagging, tensile testing, hole specimen.*

1. Introduction

Composite is the material that mostly uses for airplane structure. The composite development has increased significantly year by year. The advantages of composite material for the airplane structure are due to the high strength and the lightweight of this material that good for improving the structural performance. Carbon fiber generally has excellent tensile properties, low densities, high thermal and chemical stabilities in the absence of oxidizing agents (X. Huang, 2009). Carbon fiber reinforces polymer is one of some composite materials that have high strength with lightweight material. G Padhi et al say that aircraft structural design refers to the pyramidal structure of testing, ranging from specimen tests to full-scale structure tests (G. Padhi et.al, 2004). At the fundamental level, open-hole tension tests are a part of the qualification process for composite parts that need to be joined to other parts in aircraft structures (MIL-HDBK-17-F). In order to find the material selection data and develop the data allowable composite data, several mechanical tests were carried out on these composites.

The tensile test is used to know the tensile strength and modulus of elasticity of the composite. The previous research by R.M. O'Higgins and colleagues already determined the open hole tension (OHT) characteristics of carbon fiber reinforced plastic (CFRP) and high-strength S2-glass fiber reinforced plastic (GFRP), the result of both composite showed similar damage and failure sequence that consisted of matrix cracks in the ±45° and 90° plies followed by extensive delamination before failure (R.M. O'Higgins, 2008). More recently work by Go Yamamoto and colleagues showed the observations of the tensile test comparison of carbon UD/Epoxy composite with four different types of Epoxy, it was revealed that the extent of concentrated stress acting on the intact fiber surface can be changed by modifying the mechanical properties of the matrix polymer (G. Yamamoto, 2019)

In this experiment, we use Carbon UD fiber and Lycal resin as the composite material manufactured with Vacuum Bagging Method. Specimens and testing process refer to ASTM D3039 for non-hole specimen and ASTM D5766 for the open-hole specimen of a tensile test standard for composite matrix polymers. The tensile experimental test of these Carbon Fiber Reinforce Polymer (CFRP) composites have been done to compare.

2. Methodology

2.1. Research Methodology

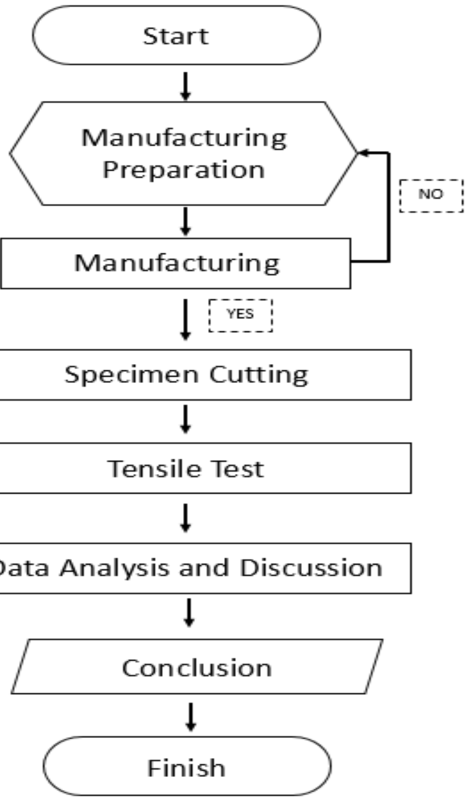


Figure 2-1: Research Methodology

2.2. Specimen Preparation

The specimens were made using Carbon UD, and Thermoset resin lycal GLR 1011 (N) with a hardener. The fiber volume fraction 40%. The manufacturing method using the vacuum bagging technique, Fig.2-2 shows the process of vacuum bagging technique (M. S. Ismail, 2019). The specimens were then cured at room temperature for 24 hours. Material cut with geometry as follows for tensile test non-hole specimen has thickness 1 mm, width: 15 mm, length: 250 mm, for tensile test hole specimen has thickness 1 mm, width: 15 mm, length: 250 mm, and diameter of the circular hole is manufactured by drilling at the center of the specimens 2.5 mm

2.3. Testing Method

All testing has been done using universal testing machine UTM RTF -2410 with capacity 100 kN and based on ASTM D3039 for tensile test non-hole specimen and ASTM D5766 for tensile test hole specimen. Fig.2-3. shows tensile and shear testing arrangement.

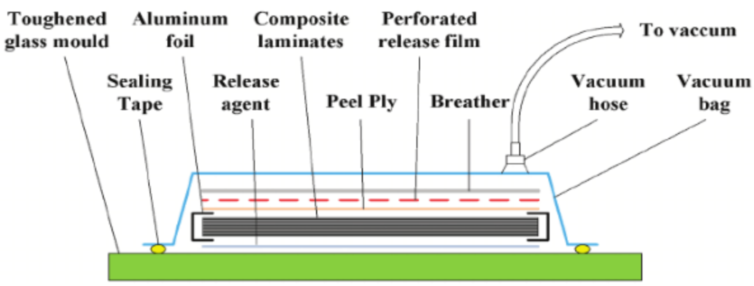


Figure 2-2: Vacuum Bagging Technique Process (M. S. Ismail, 2019)

Table 2-1: Composite Sample

Specimen Code	Specimen Content	Fiber Orientation
A	Carbon UD/Lycal	[0]
B	Carbon UD/Lycal with (Open Hole)	[0]

Figure 2-3: Testing Arrangement for Tensile Test Specimen

3. Result and Analysis

3.1. Data Analysis

The tensile test for non-hole specimens has been held using ASTM D3039 procedure standard. This test is used to obtain the composite tensile stiffness and strength. The maximum stress (σ) of the specimen can be determined by the following equation (ASTM D3039, 2017):

$$\sigma_i = P_i/A \tag{3-1}$$

The Maximum Strain (ε) on the mid-span of the specimen can be determined by the following equation:

$$\varepsilon_i = \delta_i/L_g \tag{3-2}$$

The Modulus of Elasticity E is a comparison between stress and strain which can be calculated by the following equation:

$$E^{chord} = \Delta\sigma/\Delta\varepsilon \tag{3-3}$$

The tensile test for hole specimen has been held using ASTM D5766 procedure standard ASTM D5766. The maximum ultimate open hole tensile strength (F_x^{OHTu}) of the specimen can be determined by the following equation:

$$F_x^{OHTu} = P^{max}/A \tag{3-4}$$

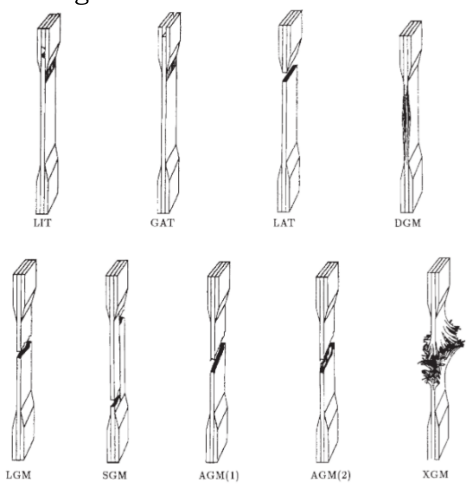
The Width to Diameter Ratio ($w/D\ ratio$) of the specimen can be determined by the following equation:

$$w/D\ ratio = \frac{w}{D} \tag{3-5}$$

The Diameter of Thickness Ratio of the specimen ($D/h\ ratio$) can be determined by the following equation:

$$D/h\ ratio = \frac{D}{h} \tag{3-6}$$

According to B. G. Green et .al, there are three types of failure mechanism category that occurs in the specimen after the test: first is pull-out, it occurred where the fiber dominated failure with extensive sub-critical damage; second is Brittle, it occurred where fiber dominated failure with little sub-critical damage, the fiber failure controls the laminate failure, and third is delamination that occurred when the matrix dominated failure along the entire gauge section that causes failure of the laminate (B.G. Green et.al, 2007).
To determine the failure typical modes of the composite after the tensile test, we refer to ASTM D3039, the typical mode of failure specimen can be determined by looking at the shape of failure as the following picture in figure 3-1.



First Character

Failure Type	Code
Angled	A
edge Delamination	D
Grip/tab	G
Lateral	L
Multi-mode	M(xyz)
long. Splitting	S
eXplosive	X
Other	O

Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
<1W from grip/tab	W
Gage	G
Multiple areas	M
Various	V
Unknown	U

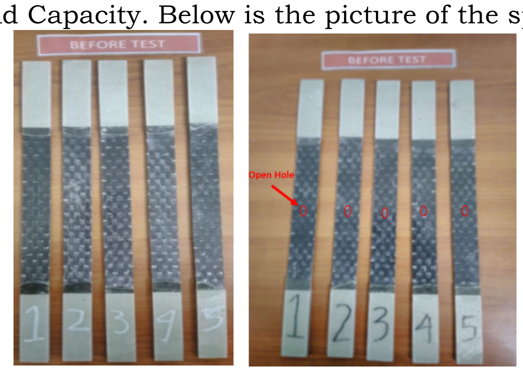
Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

Figure 3-1: Failure Typical Modes ASTM D3039

3.2. Result

Tensile test of Carbon UD/ Lycal composite non-hole and the open hole that manufactured by Vacuum Bagging method has tested. The test was held with Universal Testing Machine RTF 2410 with 100 kN load Capacity. Below is the picture of the specimen before the test:



(a) (b)

Figure 3-2: Composite Sample Before Test a) Non-Hole and b) Open Hole

Refer to ASTM D5766, the diameter of the hole was counted from w/D ratio that equal to 6. So, the diameter of the hole is 2.5 mm.

The specimen after test showed as below picture,

(a) (b)

Figure 3-3: Composite Sample After Test (a) Non-Hole Composite (b) Open Hole Composite

Figure 3-3 shows that there is no different failure mechanism between the non-hole and open hole specimens tensile test, both of them had a damage splitting and delamination between fiber and matric that occurred across the entire gauge length of the specimen and parallel along the fiber direction. In line with this failure mechanism, according to ASTM D3039, the typical mode of both specimens is XGM (explosive, gage, in the middle). This finding is also supported with the previous research by Waleed H et.al which found In all open-holed carbon/epoxy specimens, the crack initiated in the vicinity of the hole at low very stress and then propagated parallel to the fiber direction, i.e. fiber-matrix splitting, and parallel to the applied load due to the transmission of shear forces between fiber and matrix (Waleed H et.al, 2019). The tensile test result shows in table 3-1.

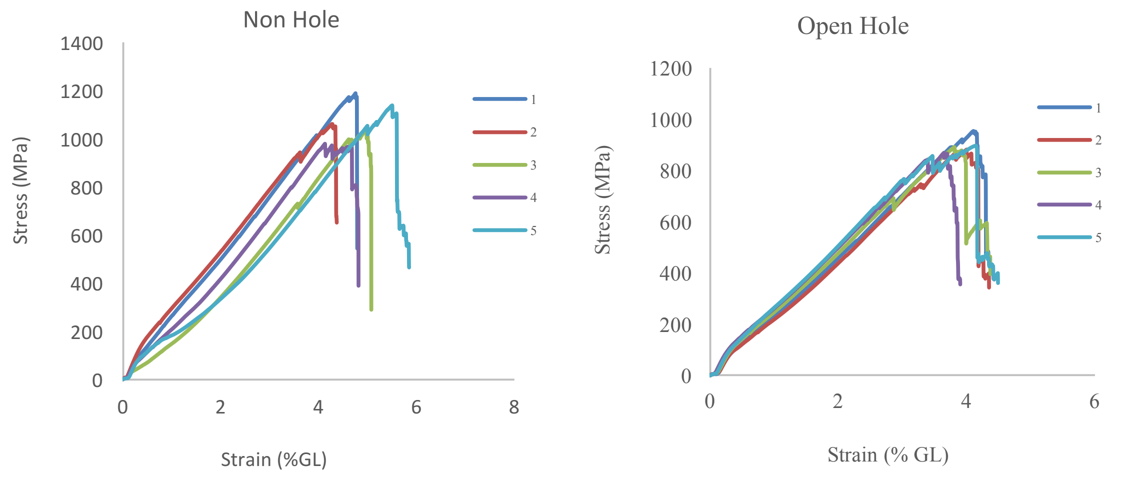
Table 3-1: Tensile Test Result

Data	A	B
	Average	Average
Stress (MPa)	1081,00 ± 0.03	899.04 ± 0.02
Elastic Modulus (GPa)	34.92 ± 0.45	41.87 ± 0.02
Break Point Strain (%GL)	0.45 ± 0.37	0.28 ± 0.5

The measured average value of the tensile strength of the non-hole composite is 1081,00 ± 0.03 MPa and the Elastic modulus is 34.92 ± 0.45 GPa, while the open hole composite has the average tensile strength value 899.04 ± 0.02 MPa and the modulus of elasticity 41.87 ± 0.02 GPa. This present value for the non-hole specimen is still lower than previous research by Waleed H et.al with the sample Carbon/Epoxy composite that has a strength value of 2.9 GPa and modulus of elasticity 155 GPa. In contrast, the stress value of the open-hole specimen is much higher than the Waleed H result which was only 358 MPa. The difference in the strength value is due to the dissimilar resin and kind of fiber we used so the compatibility of resin to the fiber is also divergent. The actual size of diameter and specimens have also affected the results.

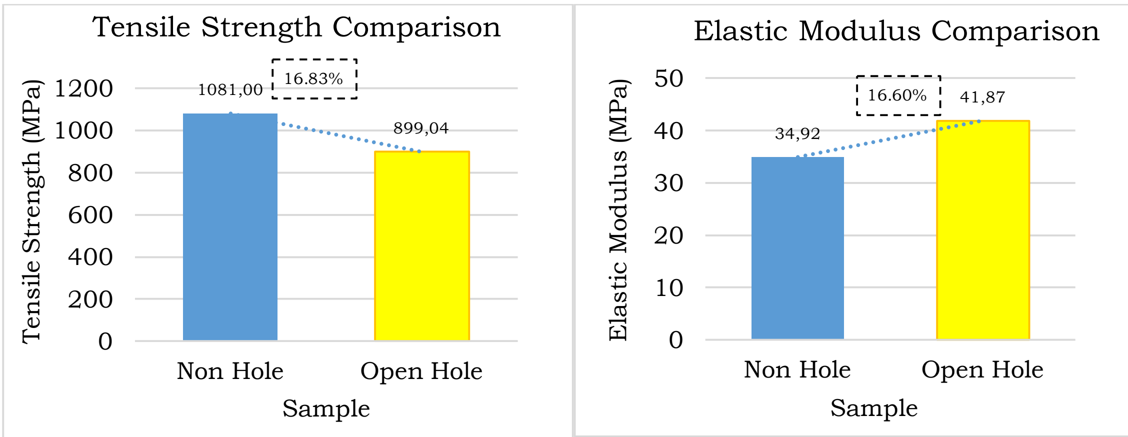
A comparison of both sample's laminate stress-strain and modulus reduction curves is presented in Figures 3-4.

The open hole in the middle of the specimen becomes an initial failure while it took the tensile load. The stress concentration at the hole was an increase that causes the initiation and propagation in the region around the hole. From the result, we calculated that the Ultimate Tensile Strength (UTS) of the open-hole composite decreased 16.83% from the non-hole composite, and the modulus elasticity increased 16.60 %. The illustration of the different percentages shown in Figures 3-5.



(a) (b)

Figure 3-4: Stress- Strain Graph of (a) Non-Hole Composite (b) Open Hole Composite



(a) (b)

Figure 3-5: Comparison Graph of (a) Tensile Strength (b) Elastic Modulus

The simulation for the tensile test was done in FE software Abaqus. Specimen size and ply stacking configuration follow the experiment. Material properties for simulation were taken from the result of the experiment and parametric studies of another similar material. The Stress-strain graph comparing the results of simulation and experiment is shown below.

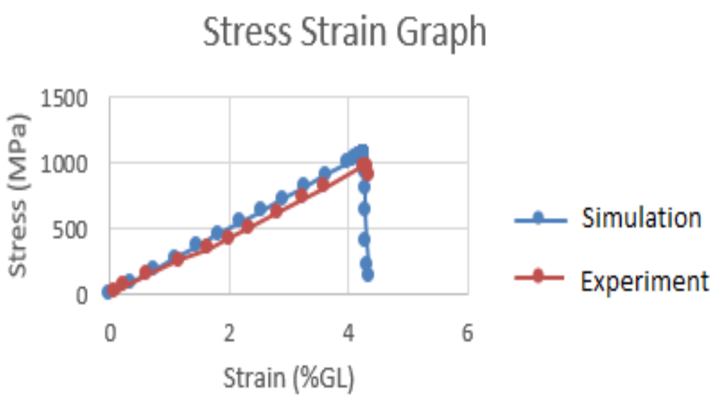
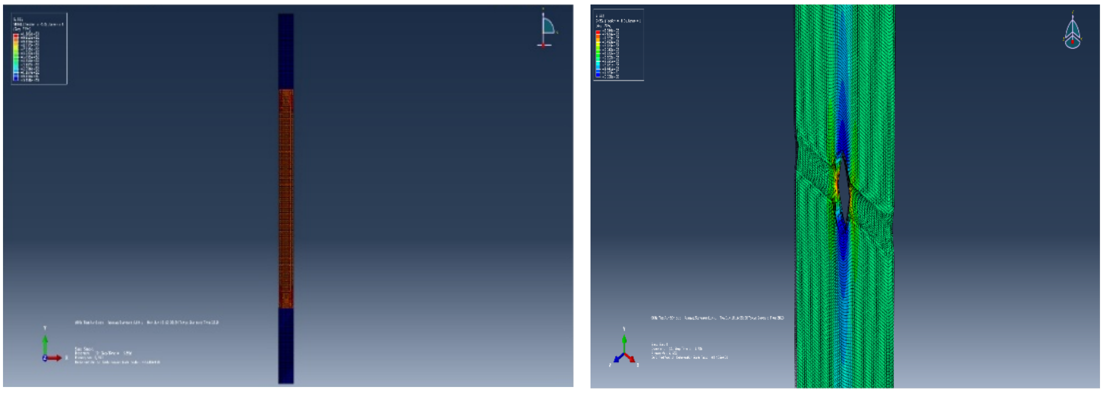


Figure 3-6: Stress-Strain Graph Comparison of Simulation and Experiment



(a) (b)

Figure 3-7: Finite Element Simulation Result of (a) Non-Hole Composite (b) Open Hole Composite

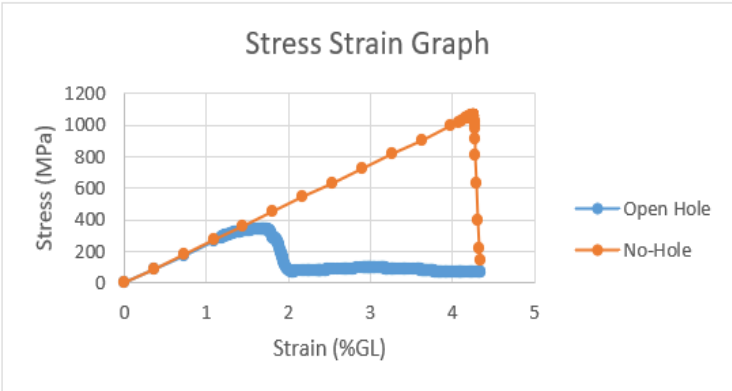


Figure 3-8: Stress-Strain Graph Comparison of Non-Hole and Open Hole Simulation

The simulation yields nearly the same stress-strain graph as the result of the experiment. The maximum stress in the experiment is 1081 MPa, while the simulation result yields 1064.98 MPa for non-hole specimens. Basse on the simulation results of the maximum stress value, when compared with the simulation, has a difference of 1.5%. Open hole simulation shows a significant reduction in maximum stress. The maximum stress on an open-hole specimen is 342.61 MPa, while in a non-hole specimen the maximum stress is 1064.98 MPa. There is approximately a 65% reduction of maximum stress in open hole specimens, compared to the non-hole specimen. High-stress concentration was observed in the hole sides, while the highest stress in the non-hole specimen was observed near tab edges. If we compare the results of simulations and experiments on open hole specimens, the maximum stress value has a difference of 61.9%. The simulation can be used to predict the result of the tensile test simulation. But when comparing it should be noted that the properties of carbon UD fiber and lycal resin, defined in the finite element model, have been determined experimentally, which could affect the accuracy of the calculation. it should be also taken into account that experimental data may differ slightly from the actual properties of the composites. Further research to find the proper material properties is needed, so the simulation can predict the experiment result accurately.

4. Conclusions

The result of the experimental test shows that the tensile modulus of elasticity for non-hole composite is 34.92 ± 0.13 GPa, with the Ultimate Tensile Strength of this composite is 1081± 0.03 MPa, and the modulus of elasticity for open-hole composite is 41.87± 0.02 GPa, with the Ultimate Tensile Strength of this composite is 899.04± 0.02 MPa. The UTS difference is 16.83% with the non-hole composite higher than an open hole and the modulus elasticity difference is 16.60% with the open hole specimen higher than the non-hole specimen. There is no different failure mechanism between the non-hole and open hole specimens tensile test, both of them had a damage splitting and delamination between fiber and matric that occurred across the entire gage length of the specimen and parallel along the fiber direction. The simulation yields nearly the same stress-strain graph as the result of the experiment. The maximum stress in the experiment is 1081 MPa, while the simulation result yields 1064.98 MPa for non-hole specimens. This data will be used for the N219 Amphibious aircraft material database.

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Contributorship Statement

LRI acts as main idea provider, prepared the specimen, tested the specimen, analyzed the results of test, and prepared the manuscript. AN prepared the specimen, tested the specimen, analyzed the results of test and simulation. RAP prepared the specimen, tested the specimen, analyzed the results of specimen, and prepare the specimen. RAR designed the simulation, simulated the test, analyzed the simulation results, and prepared the manuscript.

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