COMPARISON OF EPOXY *CARBON* FIBER *COMPOSITE* LAMINATION IN TERMS OF *BENDING* STRENGTH AND HARDNESS

Katon Bayu Rahmadewa[1], Ajeng Wulansari[2], Willy Artha Wirawan[3]

[1] *Program Studi Teknik Pesawat Udara, Politeknik Penerbangan Surabaya, Indonesia*
*Corresponding author. Email: katondewa@gmail.com

ABSTRACT

The purpose of this research is to examine how variations in the number of layers (2, 4, 6, and 8) influence the outcomes and fiber orientation (0°/90° and 45°/45°) in carbon fiber–epoxy composites on flexural strength and hardness. Specimens were manufactured using the vacuum bagging method based on ASTM D790 standards, resulting in dense laminates with minimal voids. The tests were conducted by applying the three-point bending technique to evaluate flexural strength and the Vickers hardness test to determine surface hardness levels.

The results show that the 45°/45° fiber orientation generally outperforms the 0°/90° orientation. The greatest resistance to flexural stress value of 1221.29 MPa was obtained from the 45°/45° orientation with 8 layers, while the lowest value of 467.83 MPa was recorded for the 0°/90° orientation with 2 layers. In the Vickers hardness test, the highest value of 95.6 HV was also achieved by the 45°/45° orientation with 8 layers, while the lowest value of 78.5 HV was recorded for the 0°/90° orientation with 2 layers. Overall, increasing layer count led to a notable enhancement in improved both the strength and hardness of the composite.

Based on these findings, the 45°/45° fiber orientation with more than four layers is recommended for usages that demand exceptional durability and strong resistance to mechanical stress to multidirectional loads. The vacuum bagging method proved effective in producing high-quality composites with consistent mechanical properties. It is anticipated that this research will contribute as a reference in the design process and manufacturing of composites, particularly in the aerospace, automotive, and other industries requiring lightweight, strong, and durable materials.

Keywords: Carbon fiber composite, fiber orientation, bending test, ASTM D790, mechanical strength.

1. INTRODUCTION

Global civilization continues to develop, leading to progress. This is no exception in the global technology sector, including the aerospace sector. This has encouraged the creation of new innovations in the development of new materials without compromising safety. Safety is very important and crucial in the world of aviation, and one example of such a material is *composite. Composite* has become a very important and rapidly developing material [1].

Theoretically, composites are materials formed from a combination of two or more types of materials, resulting in different characteristics and mechanical properties compared to their constituent materials [2]. Composites consist of two main elements, namely reinforcing materials and binders, each of which has different properties and characteristics. Compared to conventional substances, composites offer a number of advantages, including corrosion resistance, superior mechanical and physical properties, and relatively low production costs. In addition, composite materials can be modified according to construction needs, are lightweight, and retain their environmentally friendly characteristics [3].

Composites have various advantages, such as offering great strength with light mass and being able to withstand corrosion processes, thermal insulation capabilities, and flexibility in design. Because of these properties, composites are used in the manufacture of aircraft, spacecraft, race cars, sports equipment, and even infrastructure such as bridges and buildings. In the production of carbon fiber composites, the lamination method is often used to enhance mechanical performance, including hardness and bending properties.

Robiansyah's (2021) in his research entitled "The Effect of Fiber Orientation on the Tensile Strength and Bending Strength of Carbon Fiber Reinforced Epoxy Matrix Composites," the objective was to analyze the strength of carbon fiber reinforced composites, whereby the bending test group had several differences based on the average results of the composite bending test [4].

Firman Alhaffis (2019) in his study entitled "The Effect of Carbon Fiber/Epoxy Orientation on the Torsion Capacity of Composite Driveshafts" found that the effect of fiber orientation on tensile force of 120 N showed that a fiber orientation of 0° gave the best results. Equivalent stress: 1.20 MPa Total deformation: 0.07 mm. These results indicate that a fiber orientation of 0° is more suitable for applications involving tensile loads [5].

Abdi Setyo Wibowo (2023) in his research entitled "The Effect of Fiber Direction Variation and Number of Layers on the Tensile and Impact Testing of Carbon Fiber Composites". The results show that the fiber direction in carbon fiber composites affects their tensile strength. The highest tensile strength value for the two-layer composite was obtained in the 0° and 45° fiber configuration,which was 51.51 N/mm^2 ,while the maximum tensile strength value for the three-layer composite was recorded in the 0°, 90°, and 45° fiber configuration, which was 54.69 N/mm^2 .Meanwhile, in the impact, the two-layer composite with a fiber orientation of 0° and 90° showed the highest fracture energy of 7.36 Joules and toughness of 0.09 Joules/mm^2.The three-layer composite achieved the highest fracture energy in the 0°, 90°, 45° fiber configuration with a fracture energy value of 5.77 Joules and a toughness of 0.14 Joules/mm^2 [6].

Considering the description in the background, the author was interested in conducting research entitled "Comparison of Epoxy Carbon Fiber Composite Laminates in Terms of Bending Strength and Hardness," which aimed to analyze the comparison of the mechanical properties of bending and hardness of carbon fiber laminates made using fiber orientations of 0º/90 and 45º/45º using the Vacuum Bagging method with differences in layers of 2, 4, 6, and 8. This research also aims to evaluate the efficiency of this method in producing high-quality composites and to provide recommendations for the development of manufacturing techniques in the future.

2. RESEARCH METHOD

2.1 Research Design

This research was conducted from October 2024 to April 2025. This type of research is classified as experimental research. This research aims to determine the comparison of carbon fiber epoxy composite laminates in terms of bending strength and hardness. The initial stages involved preparing all the necessary materials, consisting of: 1) vacuum pump, 2) vacuum catch trap, 3) vacuum valve, 4) vacuum plastic, 5) strimin cloth, 6) peel ply cloth, 7) spiral hose, 8) pneumatic hose, 9) sealant tape, 10) release wax, 11) paper tape, 12) twill carbon fiber, 13) resin and hardener, 14) digital scale, 15) glass mold, 16) measuring cup, 17) thermometer, and 18) type D durometer. The specifications of the tools used include:

a. Range Kekerasan: 0 – 100 Shore D
b. Sudut Indenter: 30° (Cone Angle ±0,5°)
c. Gaya pegas (Spirng force): 44,5 Newton
d. Depth indentation range: 0–2,5 mm (kedalaman penetrasi jarum)
e. Ukuran Alat: 150 mm x 60 mm
f. Bobot: ± 200 gram – 500 gram

After that, the matrix proportion is determined, including the ratio of resin and catalyst. When the composition meets the specified standards, *the composite specimen* is manufactured using 2, 4, 6, and 8 layers of lamination and fiber orientation at angles of 0°/90° and 45°/45°. The reinforcement applied was carbon fiber, with the specimens formed using the vacuum bagging method. The specimens were then formed in accordance with ASTM standards. After the specimens met the specified standards, bending and Vickers tests were carried out on each specimen at a temperature of 25° to 31°.

The results were then analyzed in the discussion stage, where the data obtained was processed and compared to determine the best specimen based on the test results. The final step in this study involved drawing conclusions based on the entire process and the findings that had been collected.

2.2 Test Specimen Production

Test samples were prepared using the vacuum infusion method to obtain specimens that met testing standards. The types of tests to be performed included Bending tests in accordance with ASTM D790 standards and Vickers Hardness tests using Shore D based on ASTM D2240 standards. The stages carried out were as follows:

2.2.1 Specimen Preparation Process

This research used the vacuum bagging method with fiber directions of 0°/90° and 45°/45°. Each fiber strand was formed alternately using identical molds. The fiber thickness was adjusted to meet the specified requirements.

2.2.2 Vacuum Bagging Process

This process was carried out in 20 stages, starting from preparing the molds according to ASTM for each test for the composite material manufacturing process until the test material was ready for bending and hardness testing. The lamination results are shown in the following figure:

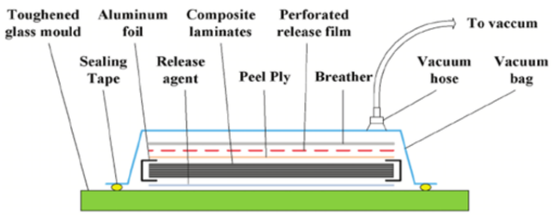

Figure 1. Proses Vacuum Bagging

2.2.3 Bending Test Standard

In this research, author applied the ASTM Standard D790 and used the three-point bending method.

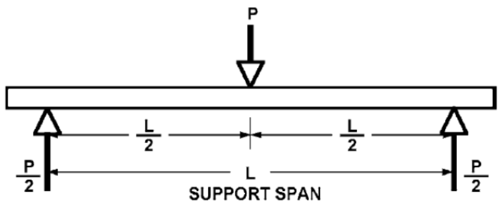

Figure 2. Three-point bending method

2.2.4 Vickers Shock D Testing Standard

In this test, the author used a type D Durometer test based on the ASTM D2240 standard, as shown in the figure below:

Figure 3. Type D durometer testing

2.3 Testing Techniques

2.3.1 Bending Test

Bending testing is carried out to assess how strong a material is in withstanding loads and the extent to which the material is elastic. The following are the steps for the bending testing process:

a. Prepare the specimen, measure its dimensions, then determine the center point and support point by marking them with lines.

b. Place the specimen on the bending machine and ensure it is positioned precisely on the support line that has been marked.

c. Adjust the pressure indenter until it touches the specimen.

d. Operate the bending machine while maintaining a stable pressing speed.

e. The test results will be displayed on the computer screen.

f. After the specimen breaks, gradually turn off the bending machine.

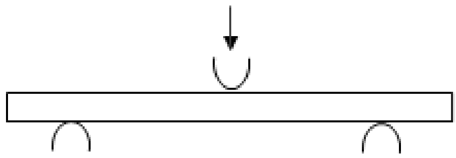

Figure 4. Three Point Bending Test

2.3.2 Vickers Hardness Testing

Vickers hardness testing is performed using a pyramid-shaped indenter made of diamond with a square base. In this test, the Vickers indenter is used in accordance with the ASTM E384 standard. The hardness of the material is obtained from the analysis of the indentation marks left on the specimen surface [7].

2.3.3 Bending Test Data Analysis Technique

This process is carried out to calculate the bending stress and flexural elastic modulus using the following equations:

Bending Stress:

$$\sigma_b = \frac{3PL}{2bd^2} \quad (1)$$

Modulus of Elasticity:

$$E_b = \frac{L^3 P}{4bd^3 \delta} \quad (2)$$

2.3.4 Vickers Hardness Test Data Analysis Technique

To determine the hardness level of the test sample, it is first necessary to measure the average diagonal length of the test mark using a microscope. The Vickers hardness value is then calculated by dividing the applied test load by the surface area of the mark using the following equation:

$$HV = \frac{P}{A}$$

Description:

HV = Vickers Hardness

P = Test load applied (kg)

A = Surface area of indentation (mm²)

If d is the average diagonal length of the indentation, then the surface area of the indentation can be calculated using the following formula:

$$HV = 1.854\left(\frac{P}{d^2}\right) \quad (3)$$

Formula for the relationship between Shore D value and penetration depth (ASTM D2240) :

$$S = 100 - \frac{h}{h_{max}}\ x\ 100 \quad (4)$$

3. RESULTS AND DISCUSSION

This study presents findings from flexural and hardness tests on carbon fiber composite materials produced using the vacuum bagging technique. Each variable was tested twice, and then the average value was taken. The following is an explanation of the test results that have been carried out, which are:

3.1 Vicker Test Results using a Durometer

This microhardness test used a *Vickers* Type D indenter, commonly known as *shore D*, as shown in Figure 3. The results of this microhardness test using a *Vickers* Type D indenter, commonly known as *shore D*, are as follows:

2.2.1 Specimen 2 layers 90° and 45°

a. Results obtained for the 2 layer 90° specimen

Table 1. Test data for 2 layers 90°

Specimen	Fiber Orientation 90°			Averege
	Point 1	Point 2	Point 3	
First	76	77	79	77.33
Second	78	78	80	78.67

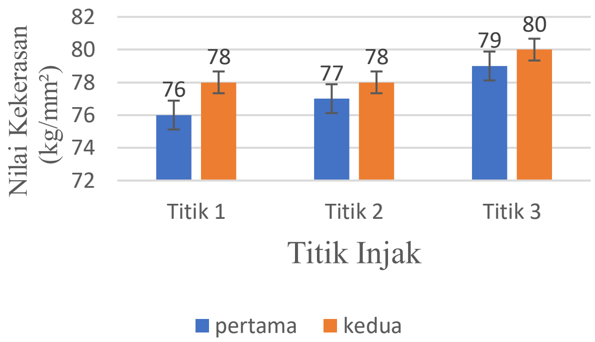

Figure 5. Graph 2 layer 90°

In general, Specimen 2 has a slightly higher hardness value than Specimen 1. This could be due to a better compression and resin impregnation process, resulting in a denser and more compact layer. When compared to specimens with more layers, such as 4 or 6 layers, this value is still moderate because the composite structure with only 2 layers tends to be thinner and not as dense as specimens with more layers.

b. Results obtained for the 2 layer 45° specimen

Table 2. Test data for 2 layers 45°

Specimen	Fiber Orientation 45°			Averege
	Point 1	Point 2	Point 3	
First	82	75	78	78.33
Second	73	73	70	72

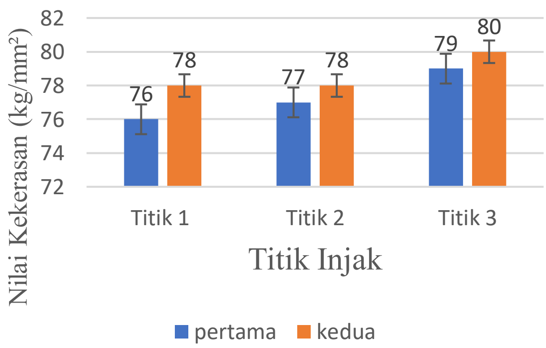

Figure 6. Graph 2 layer 45°

In generall, the average hardness of the two layers of 45° fibers is moderate, but still lower than that of the 90° direction, because the crossed fiber position causes the compressive force to be absorbed more by the resin rather than directly by the fibers.

2.2.2 Specimens with 4 layers at 90° and 45°

a. Results obtained from the data of the 4 layer 90° specimen

Table 3. Test data for 4 layers 90°

Specimen	Fiber Orietation 90°			Average
	Point 1	Point 2	Point 3	
First	83	83	82	82.67
Second	83	82	84	83

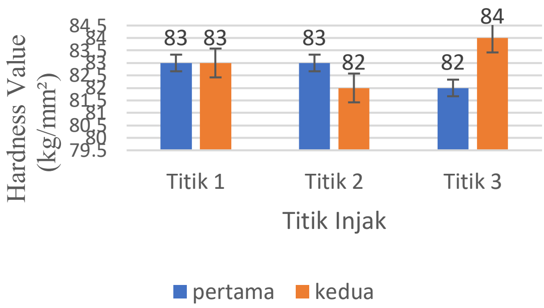

Figure 7. Graph 4 layer 90°

The hardness of the 4-layer 90° fiber specimen showed an increase compared to the 2-layer specimen. This is because the more layers used , the more dense and stronger the composite structure becomes, enabling it to better withstand the compressive force from the testing equipment. The difference in values between the first and second specimens was not too significant, which means that the lamination process was consistent. The average hardness value in the range of 82–83 indicates that the use of 4 layers is sufficient to increase the hardness of the material, but there is still potential for further improvement if the number of layers is increased to 6 or 8 layers.

b. Results obtained from the data of the 4 layer 45° specimen

Table 4. Test data for 4 layers 45°

Specimen	Fiber Orientation 45°			Everage
	Point 1	Point 2	Points 3	
Pertama	83	81	83	82.33
Kedua	83	85	84	84

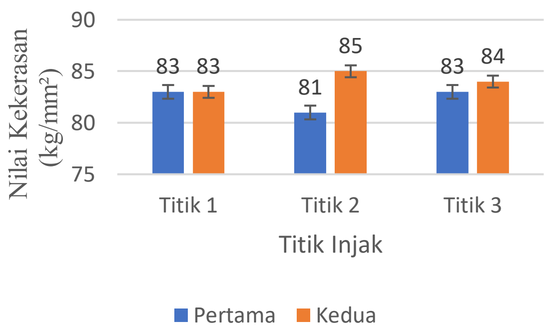

Figure 8. Graph 4 layer 45°

In *the* 4-layer *Specimen* with a fiber orientation of 45°, it can be seen that the hardness value increases when compared to *the* 2-layer 45° *Specimen*. This is because the greater number of layers makes the material thicker and more compact, resulting in better resistance to pressure. The average hardness value of *the* second *specimen* is higher than that *of the* first *specimen*, indicating that the lamination process on *the* second *specimen* is more even and dense

2.2.3 Specimen 6 layers 90° and 45°

a. Results obtained from the data of the 6 layer 90° specimen

Table 4. Test data for 6 layers 90°

Specimen	Fiber Orientation 90°			Average
	Point 1	Point 2	Point 3	
First	80	81	81	80.67
Second	85	83	85	84.33

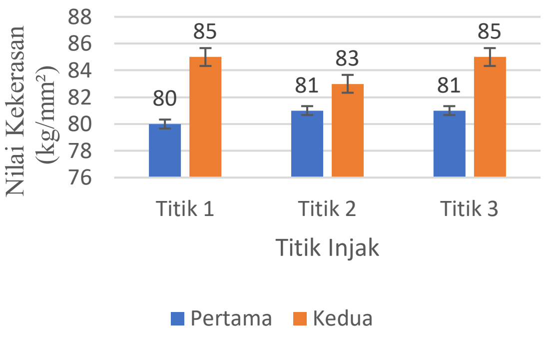

Figure 9. Graph 6 layer 90°

With the addition of 6 layers of 90° fibers, the hardness value increased significantly when compared to *Specimens* 2 and 4 layers. This shows that the more layers used, the stronger, denser, and more resistant to compressive forces from the testing device the composite structure becomes. Overall, the 90° fiber orientation in the 6-layer composite proved to be very effective in increasing the hardness of the material. The results also show a tendency that the more fiber layers there are, the greater the material hardness will be.

b. Results obtained from the data of the 6 layer 45° specimen

Table 5. Test data for 6 layers 45°

Specimen	Fiber Orientation 45°			Average
	Point 1	Point 2	Point 3	
First	86	84	84	84.67
Second	83	84	84	83.67

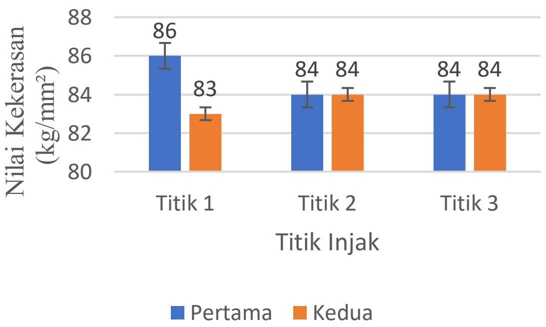

Figure 10. Graph 6 layer 45°

When compared to 4 layers of 45° fibers, the hardness of 6 layers shows a significant increase. The addition of layers makes the composite thicker and more homogeneous, enabling it to respond better to pressure during Vickers testing. In general, the 45° fiber orientation in 6 layers provides a fairly good increase in hardness and is almost equal to the 90° fiber orientation at the same thickness. This means that even though the fibers are arranged crosswise, when there are enough layers, the material is still able to withstand compressive forces well.

2.2.4 Specimen 8 layers 90° and 45°

a. Results obtained from the data of the 8 layer 90° specimen

Table 6. Test data for 8 layers 90°

Specimen	Fiber Orientation 90°			Average
	Point 1	Point 2	Point 3	
First	85	84	84	84.33
Second	84	85	82	83.67

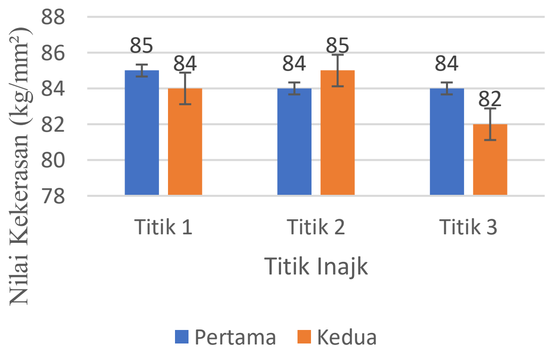

Figure 11. Graph 8 layer 90°

In the 8-layer specimen with a 90° orientation, the hardness value increased consistently compared to the previous number of layers. Although the difference in values between the first and second specimens was not significant, it can be seen that almost all test points showed a hardness value above 83 kg/mm². This indicates that the 8-layer material has good lamination quality. The highest number (85) indicates the area where the fibers and resin are optimally bonded together.

b. Results obtained from the data of the 8 layer 45° specimen

Table 6. Test data for 8 layers 45°

Specimen	Fiber Orientation 45°			Average
	Point 1	Point 2	Point 3	
Pertama	85	85	82	84
Kedua	85	86	87	86

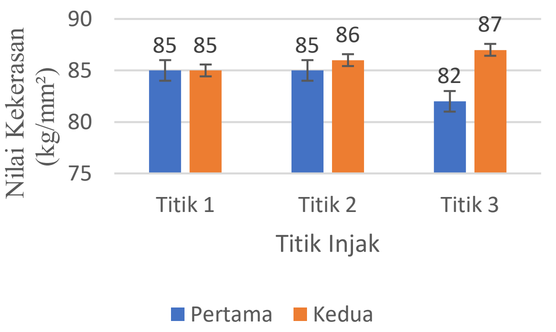

Figure 12. Graph 8 layer 45°

In *the* 8 layer *specimen* with a 45° fiber direction, the hardness value increased significantly compared to the previous 4- and 6-layer *specimens*. The addition of layers made the material much denser and stronger, even though the fibers were positioned at a 45° angle. The highest value at point 3 *of the* second *specimen* (87) indicates that this part has a very solid fiber resin bond.

3.2 Hardness Test Results

Based on a series of tests, it can be concluded that an increase in the number of carbon fiber layers directly affects the increase in the hardness value of the epoxy-carbon composite material. At a 90° orientation, an increase in the number of layers from 2, 4, 6 to 8 layers was always followed by an increase in hardness. This phenomenon occurs because the growth in the number of layers affects the composite structure, making it denser, with the fibers arranged more tightly, and able to withstand pressure from the indenter more optimally.

At a fiber orientation of 45°, the initial hardness value at 2 layers is still lower because the diagonal fiber position is less able to withstand direct compressive forces. However, when the number of layers increases to 4, 6, and 8 layers, there is a significant increase in hardness. This means that adding layer thickness can compensate for the limitations of the diagonal orientation.

In general, the trend shows that the more fiber layers used, the greater the composite hardness value, both for 90° and 45° orientations. The 90° fiber orientation still produces the highest value at all layer levels, but the 45° orientation also shows a significant increase, especially from 4 layers and above. The overall results indicate that the combination of fiber orientation and number of layers significantly determines the mechanical properties of the composite, with the 8 layer configuration using 90° fibers being the most optimal for enhancing hardness.

3.3 Bending Test Results

After the Vickers test on the composite specimens, the bending test was conducted. Each fiber direction had 2 specimens to be tested, and the test data was processed to compare the strength of the fiber count. The following are the bending test results obtained:

3.3.1 Specimen 2 layers at 90° and 45°

a. Test results for the specimen with 2 layers of 90° fiber orientation

The test conducted on *the* first *specimen* involved mixing 2 layers of *carbon fiber* with a 90° fiber orientation, epoxy resin, and a catalyst (*hardener*).

Table 7. Specifications 2 layers 90° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Tekanan Lentur (Mpa)
1	17	0,93	11,81	9,12	13,41
2	17	1	12,7	9,81	12,11

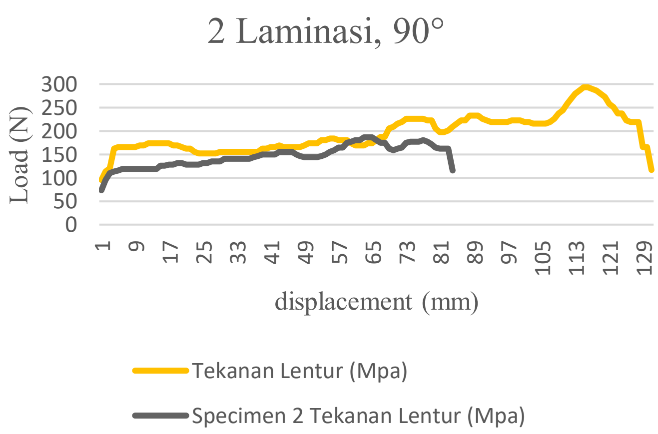

Figure 13. Graph specimen 2 layer 90°

In the load vs. displacement graph above, the curve shows a slow and unstable increase, then a sharp drop indicating brittle fracture. This occurs because there are only two layers and the fibers are unidirectional, so the specimen's ability to withstand bending forces is very limited. In general, this specimen is mechanically weak and prone to fracture.

Figure 13. Results of the 2 layer 90° bending test

b. Test results for the specimen with 2 layers of 45° fiber orientation

The next test was conducted on *a specimen* made by mixing two layers of *carbon fiber* with a 45° fiber orientation, epoxy resin, and a catalyst (*hardener*).

Table 8. Specifications 2 layers 45° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Kekuatan Tekanan (Mpa)
1	17	1,24	2,10	12,16	9,75
2	17	1,25	2,12	12,26	9,70

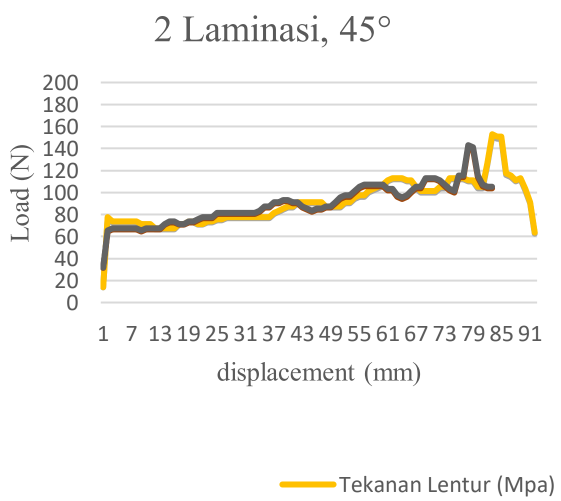

Figure 15. Graph specimen 2 layer 45°

The 2-layer 45° specimen was able to withstand loads more stably than the 90° angle. The graph shows that the load increased to around 200 N before dropping sharply due to fracture. Overall, the 45° orientation was stronger than 90°, but still limited because it only had two layers.

Figure 14. Results of the 2 layer 45° bending test

3.3.2 Specimen 4 layers at 90° and 45°

a. Test results for the specimen with 4 layers of 90° fiber orientation

The first test conducted on the specimen involved mixing 4 layers of carbon fiber with a 90° fiber orientation, epoxy resin, and a catalyst (hardener).

Table 9. Specifications 4 layers 90° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Kekuatan Tekanan (Mpa)
1	17	1,36	2,31	13,34	8,95
2	17	1,50	2,55	1,47	0,80

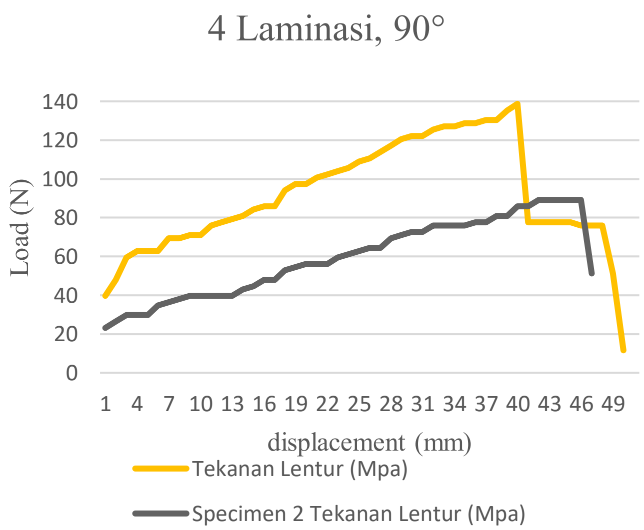

Figure 16. Graph specimen 4 layer 90°

In the 4-layer specimen with a 90° fiber direction, the load increase was more stable than in the 2-layer specimen. The graph shows that the load continued to increase until it reached around 150 N before experiencing a sudden decrease. This indicates that the specimen was able to withstand a greater load because it had more fiber layers. However, after reaching its peak, the sample broke quite quickly. The graph pattern for specimen 2 is slightly lower than that of specimen 1, but both show a significant increase in strength compared to the two-layer configuration.

Figure 17. Results of the 4 layer 90° bending test

b. Test results for the specimen with 4 layers of 45° fiber orientation

The test conducted on the first specimen involved mixing 4 layers of carbon fiber with a 45° fiber direction, epoxy resin, and a catalyst (hardener).

Table 10. Specifications 4 layers 45° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Kekuatan Tekanan (Mpa)
1	17	1,30	2,21	12,75	9,31
2	17	1,17	1,98	11,47	10,35

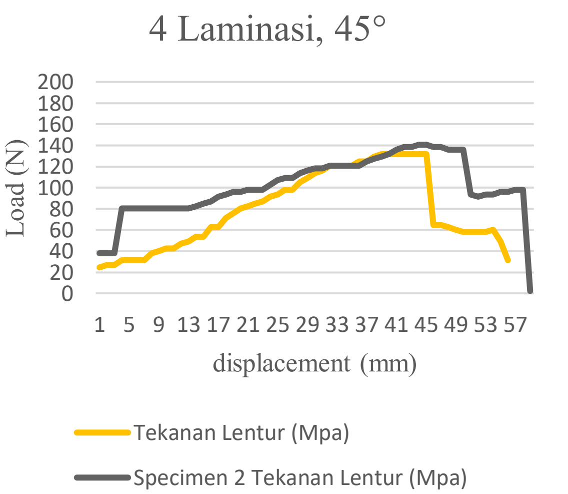

Figure 18. Graph specimen 4 layer 45°

In the 4-layer specimen with a 45° fiber orientation, the load increased gradually and was more stable than in the two-layer configuration. The graph shows that the load was able to reach approximately 150 N before a sharp decline occurred, indicating material failure. This shows that with the addition of layers, the material becomes stronger and able to withstand bending forces for longer. Overall, the 4-layer 45° specimen is stronger than the 2-layer specimen and has a more even load distribution due to the intersecting fiber angles.

Figure 19. Results of the 4 layer 45° bending test

3.3.3 Specimen 6 layers at 90° and 45°

a. Test results for the specimen with 6 layers of 90° fiber orientation

The first test conducted on the specimen involved mixing 6 layers of carbon fiber with a 90° fiber orientation, epoxy resin, and a catalyst (hardener).

Table 11. Specifications 6 layers 90° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Kekuatan Tekanan (Mpa)
1	17	2,53	4,30	24,81	4,78
2	17	2,27	3,85	22,26	5,33

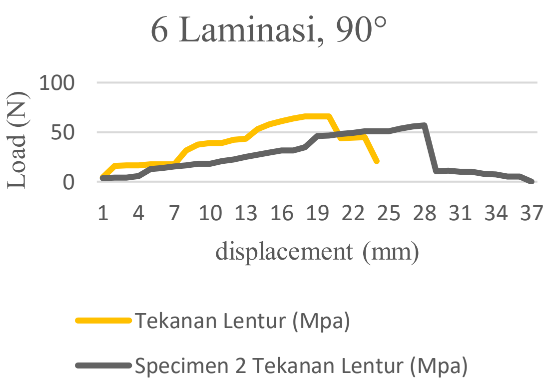

Figure 20. Graph specimen 6 layer 90°

For the 6-layer specimen with a 90° orientation, the test piece width was 17 mm with a thickness of 2.53 mm and 2.27 mm for each specimen. The normal load that the first specimen could withstand reached 24.81 N with a compressive strength of 4.78 MPa. Meanwhile, the second specimen was able to withstand a load of 22.26 N with a higher compressive strength of 5.33 MPa because its cross-sectional area was smaller. This shows that the smaller the cross-sectional area, the greater the stress generated even though the load received is lower.

Figure 21. Results of the 6 layer 90° bending test

b. Test results for the specimen with 6 layers of 45° fiber orientation
The test conducted on *the* first *specimen* involved mixing 6 layers of *carbon fiber* with a 45° fiber direction, epoxy resin, and a catalyst (*hardener*).

Table 12. Specifications 6 layers 45° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Kekuatan Tekanan (Mpa)
1	17	1,87	3,18	18,34	6,48
2	17	1,99	3,38	19,52	6,09

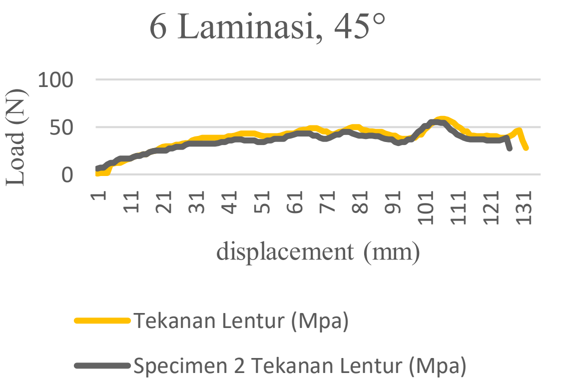

Figure 22. Graph specimen 6 layer 45°

In the testing of 6-layer specimens with a fiber orientation of 45°, each specimen was 17 mm wide with a thickness of 1.87 mm and 1.99 mm. The normal load that the first specimen could withstand was 18.34 N, producing a compressive strength of 6.48 MPa. Meanwhile, the second specimen withstood a higher load of 19.52 N but produced a slightly lower compressive strength of 6.09 MPa because its cross-sectional area was larger. This shows that cross-sectional area greatly affects the magnitude of bending stress.

Figure 23. Results of the 6 layer 45° bending test

3.3.4 Specimen 8 layers at 90° and 45°

a. Test results for the specimen with 8 layers of 90° fiber orientation

The test conducted on the first specimen involved mixing 8 layers of carbon fiber with a 90° fiber orientation, epoxy resin, and a catalyst (hardener).

Table 12. Specifications 8 layers 90° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Kekuatan Tekanan (Mpa)
1	17	2,07	3,51	20,30	5,85
2	17	2,52	4,28	24,72	4,80

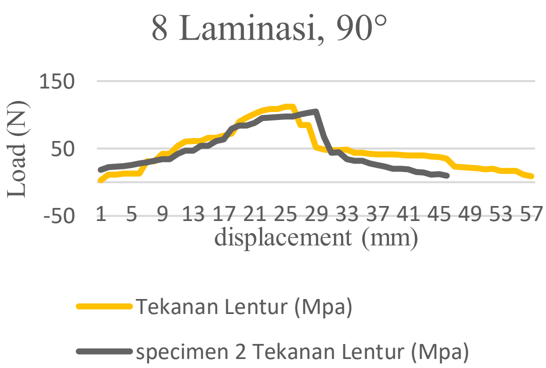

Figure 24. Graph specimen 8 layer 90°

Based on the data from the 8-layer 90° fiber specimen, specimen 1 has a thickness of 2.07 mm with a compressive strength of 5.85 MPa, while specimen 2 is thicker (2.52 mm) but has a compressive strength of only 4.80 MPa. This indicates that increasing thickness does not necessarily increase compressive strength per cross-sectional area. Therefore, it can be concluded that specimens with smaller thicknesses have better specific compressive strength at a 90° fiber orientation.

Figure 25. Results of the 8 layer 90° bending test

b. Test results for the specimen with layers of 45° fiber orientation
The test conducted on the first specimen involved mixing 8 layers of carbon fiber with a 45° fiber direction, epoxy resin, and catalyst (hardener).

Table 12. Specifications 8 layers 45° specimen

Specimen	Lebar (mm)	Tebal (mm)	Luas (mm²)	Beban Normal (N)	Kekuatan Tekanan (Mpa)
1	17	3,81	6,47	37,37	3,18
2	17	3,76	6,39	36,89	3,22

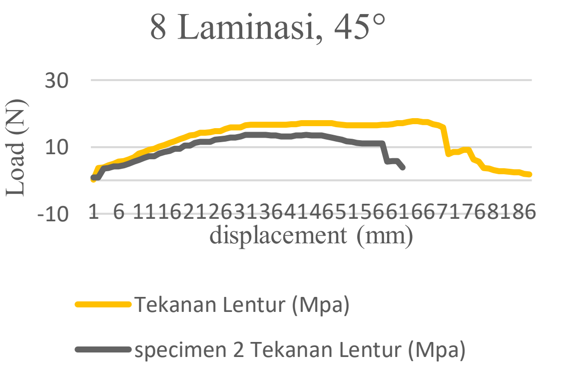

Figure 26. Graph specimen 8 layer 45°

Based on the specifications in the table, both 8-layer specimens with a 45° angle have almost the same size and are able to withstand a load of around 36–37 N with a compressive strength ranging from 3.18–3.22 MPa. This shows that the 45° fiber orientation produces a relatively low compressive strength value. Overall, the 45° fiber orientation shows poorer performance in withstanding compressive loads compared to the 90° orientation, as the material experiences a faster load reduction at small displacements.

Figure 27. Results of the 8 layer 45° bending test

The flexural strength test shows that the fiber direction and number of layers play an important role in the composite's ability to withstand loads. Specimens with a 45°/45° orientation consistently had higher bending strength values than those with a 0°/90° orientation with the same number of layers. Thus, the combination of a 45°/45° orientation and a greater number of layers proved to provide optimum flexural strength in epoxy carbon fiber composites.

3.4 Results and Discussion of Bending Tests

From the bending test results on all *specimen* variations, it can be seen that the number of layers and fiber orientation greatly affect the composite's ability to withstand bending loads. In *the* 2-layer *specimen*, both 90° and 45° orientations still have low bending strength. *The* 90° *Specimen* was only able to withstand loads below 10 N, with a sharp and brittle load vs. displacement curve. Meanwhile, the 45° orientation was able to withstand loads of up to around 200 N with a slightly more stable curve.

In the 4 layer configuration, there was a significant increase in flexural strength. *The* 4-layer 90° *specimen* was able to withstand loads of up to ±150 N, while the 45° orientation produced similar but more stable performance. This shows that the addition of layers makes the material stiffer and more resistant to bending forces, as well as providing a more even distribution of fibers. However, the fractures that occurred were still brittle after reaching the peak load.

In *the* 6 layer 90° *specimen*, although the maximum load was only around 22–25 N due to the small cross-sectional area, the bending stress (MPa) showed an increase. This proves that the cross-sectional area greatly affects the magnitude of stress. The smaller the cross-sectional area, the greater the stress generated. This trend is also seen in the 6-layer 45° specimen, where the bending stress increases when the cross-section is smaller, even though the load received is not much different.

In *the* 8 layer 90° fiber *specimen*, the maximum load that can be withstood is greater overall. However, the compressive strength (MPa) is actually higher in specimens that are slightly thinner because the cross-section is smaller. This shows that increasing the thickness does not automatically increase the strength per cross-section. At a 45° orientation with 8 layers, the maximum load is only around 36–37 N and the stress is around 3 MPa, indicating that the flexural performance is still low compared to the 90° orientation in the same layer.

4. CONCLUSION

Based on the results of the research conducted, it can be concluded that the use of more layers with a fiber orientation of 0°/90° has been proven to increase the flexural strength of the material. Specimens with 6 and 8 layers showed the highest bending resistance compared to specimens with 2 and 4 layers, especially in the 0°/90° fiber arrangement. In addition, a greater number of layers with a 0°/90° fiber orientation also had a positive effect on the Vickers hardness value, where specimens with 6 and 8 layers had higher hardness than those with a 45°/45° orientation. The tightly packed and dense fiber structure made the material harder when tested.

5. AUTHORS' CONTRIBUTIONS

The author, Katon Bayu Rahmadewa, is fully responsible for all stages of the research, from conceptualization and formulation of the research problem, development of the theoretical framework and literature review, research method design, as well as data collection, processing, and analysis. In addition, the author is also responsible for drawing conclusion

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