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The Influence of Matrix Shape and Resin Composition on Tensile and Bending Strength

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ABSTRACT

This study aims to determine the differences in tensile and bending strength caused by the use of 45° and 0° fiber orientations, to identify the ideal resin and catalyst composition, and to explain the mismatch between direct testing and ANSYS simulation results. The research used an experimental method. The specimen manufacturing process included preparation of tools and materials, mold preparation, resin-catalyst mixing, fiber preparation, vacuum infusion, cutting, and sanding. The specimens were manufactured using hand lay-up and vacuum infusion by arranging fibers on the mold and applying vacuum pressure at the end of the fabrication process. The results show that carbon composite laminates with 0° fiber orientation provide greater tensile and bending strength than those with 45° fiber orientation. The carbon composite had the highest tensile load when the resin and catalyst composition was 4:1, while the highest bending load was obtained for the 3:1 resin and catalyst composition. The difference between simulation and direct testing was caused by the assumption in ANSYS that the fiber-matrix bonding was perfect, while in actual specimens the resin distribution and bonding varied due to the vacuum infusion process

1 Introduction

Technological advances have resulted in discoveries in various areas of life, including in the field of materials. Composites have become an important innovation in materials engineering. The development of composite materials began in the manufacturing industry, and one of the composite materials widely used in industry is fiberglass and carbon fiber. Fiber-reinforced composites are widely used engineering materials because their specific strength and stiffness are higher than those of many conventional engineering materials, making them easy to design according to specific needs. In the automotive field, composite materials are also used as interior and exterior components [1].

A composite is a material made from a combination of two or more materials with different properties, resulting in a new material with unique properties. Composite materials generally consist of two elements, namely fibers as reinforcement and resin as a binding material. This combination produces composite materials with mechanical characteristics that differ from the original materials [2].

Carbon fiber is one of the commonly used composite reinforcements in industrial applications. Carbon fiber has the advantage of being lightweight while maintaining high strength compared with many metal materials. In addition, carbon fiber is relatively easy to obtain in the market [3]. Polyester resin was used in this study because it has sufficient strength and chemical resistance, as well as good electrical properties, low weight, acid resistance, water resistance, and a relatively fast processing time.

The strength of carbon composites is influenced by the arrangement of the reinforcing fiber and the resin composition used in the manufacturing process. Therefore, this study was carried out to determine the tensile and bending strength of carbon composites based on the carbon matrix shape and polyester resin mixture composition.

2 Method

This study used an experimental research method. Experimental research aims to determine whether a given factor has an effect on the subject under study by comparing one or more experimental groups with comparison groups. Experimental research focuses on testing cause-and-effect relationships through hypothesis testing using an analytical quantitative approach [4], [5].

The independent variables in this study were the variation of matrix arrangement and polyester resin composition. The dependent variables were tensile strength and bending strength of carbon composite materials. The control variable was the number of carbon fiber and fiberglass layers so that the effect of matrix arrangement and resin composition could be observed more clearly.

2.1 Composite arrangement and testing

The tensile specimens were manufactured with six layers, while the bending specimens were manufactured with eleven layers. The fiber used was woven carbon fiber type 3K twill 2/2 and E-glass fiberglass. The tensile testing referred to ASTM D3039 and the bending testing referred to ASTM D7264.

Table 1. Composite arrangement variations.

Code	Description
C0	Carbon fiber with 0° fiber orientation
F0	Fiberglass with 0° fiber orientation
C45	Carbon fiber with 45° fiber orientation
T1 tensile	C0 - F0 - C0 - F0 - F0 - C0
T2 tensile	C45 - F0 - C45 - F0 - F0 - C45
T1 bending	C0 - F0 - C0 - F0 - C0 - F0 - C0 - F0 - C0 - F0 - C0
T2 bending	C45 - F0 - C45 - F0 - C45 - F0 - C45 - F0 - C45 - F0 - C45
R1	Resin and catalyst ratio of 2:1
R2	Resin and catalyst ratio of 3:1
R3	Resin and catalyst ratio of 4:1

3 Result and discussion

The results and discussion section presents the tensile test results, bending test results, ANSYS simulation results, and the interpretation of the influence of matrix arrangement and resin composition on carbon composite performance.

3.1 Tensile test results

Based on the tensile testing, the data obtained are shown in Table 2. The tensile testing results show that the 0° composite arrangement has a higher load capacity than the 45° arrangement.

Table 2. Tensile test results.

Specimen	Type	Resin ratio	Length (mm)	Width (mm)	Thickness (mm)	Load (kN)
T1R1	Type 1	2:1	250	25	2	12.833
T1R2	Type 1	3:1	250	25	2	12.866
T1R3	Type 1	4:1	250	25	2	13.654
T2R1	Type 2	2:1	250	25	2	6.409
T2R2	Type 2	3:1	250	25	2	5.323
T2R3	Type 2	4:1	250	25	2	5.396

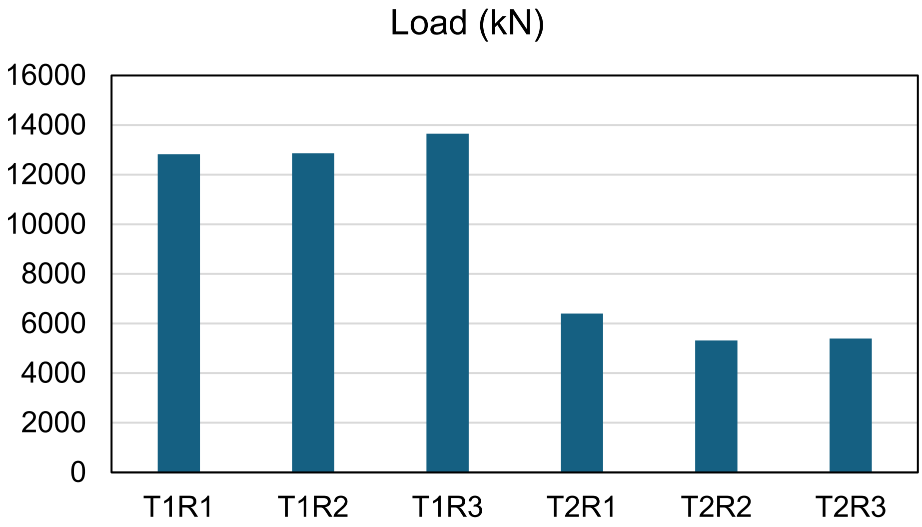

Figure 2. Tensile test load comparison.

The highest tensile load was obtained by the T1R3 specimen, with a load of 13.654 kN. In comparison, the Type 2 specimens had lower tensile loads, indicating that the 45° fiber orientation reduced the tensile load capacity. The influence of resin composition on tensile load was smaller than the influence of fiber orientation.

3.2 Bending test results

The bending test results are shown in Table 3. The bending data also indicate that the 0° composite arrangement provides a higher load capacity than the 45° composite arrangement.

Table 3. Bending test results.

Specimen	Type	Resin ratio	Length (mm)	Width (mm)	Thickness (mm)	Load (N)
T1R1	Type 1	2:1	128	13	4	488.17
T1R2	Type 1	3:1	128	13	4	500.74
T1R3	Type 1	4:1	128	13	4	465.15
T2R1	Type 2	2:1	128	13	4	353.84
T2R2	Type 2	3:1	128	13	4	267.34
T2R3	Type 2	4:1	128	13	4	318.53

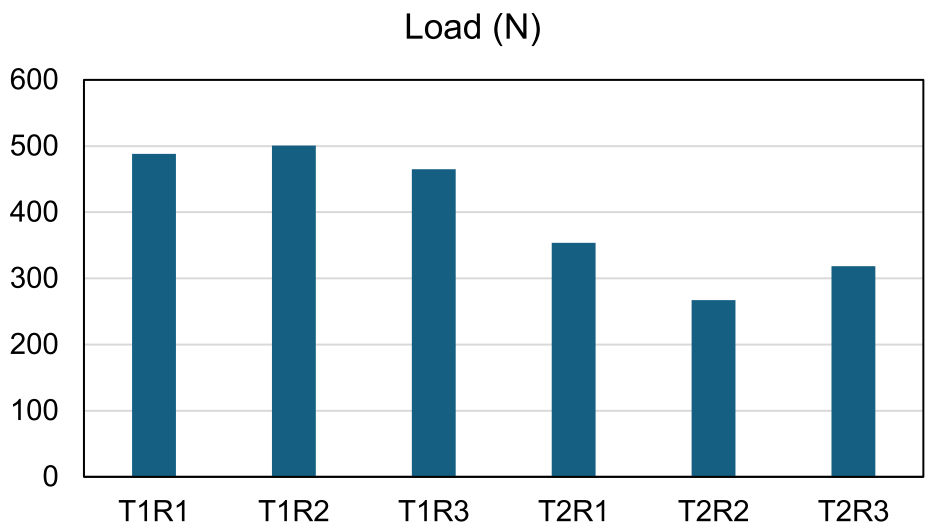

Figure 3. Bending test load comparison.

The highest bending load was obtained by the T1R2 specimen, with a load of 500.74 N, while the lowest bending load was obtained by the T2R2 specimen, with a load of 267.34 N. The 45° fiber orientation produced lower bending strength than the 0° orientation because the load direction was not aligned with the main reinforcing fiber direction.

3.3 ANSYS simulation results

The engineering data obtained from the direct tensile test were used as input for the ANSYS simulation. The engineering data are summarized in Table 4, while the comparison between simulation and testing results is presented in Table 5.

Table 4. Engineering data used in ANSYS simulation.

Type	Ex (MPa)	Ey=Ez (MPa)	vxy	vyz	vxz	Gxy (MPa)	Gyz (MPa)	Gxz (MPa)
T1R1	16.388	4.012	0.22	0.30	0.22	6716.4	1543.1	1644.3
T1R2	17.864	12.029	0.22	0.30	0.22	7321.3	4626.5	4929.9
T1R3	17.621	11.911	0.22	0.30	0.22	7221.7	4581.1	4881.5
T2R1	10.241	10.266	0.22	0.30	0.22	4197.1	3948.5	4207.4
T2R2	9.802	7.004	0.22	0.30	0.22	4017.2	2693.8	2870.5
T2R3	9.886	10.340	0.22	0.30	0.22	4051.6	3976.9	4237.7

Table 5. ANSYS simulation nonconformity with direct testing.

Resin	Type 1 (T1)	Type 2 (T2)
R1	5.02%	5.33%
R2	3.86%	3.66%
R3	8.85%	5.66%

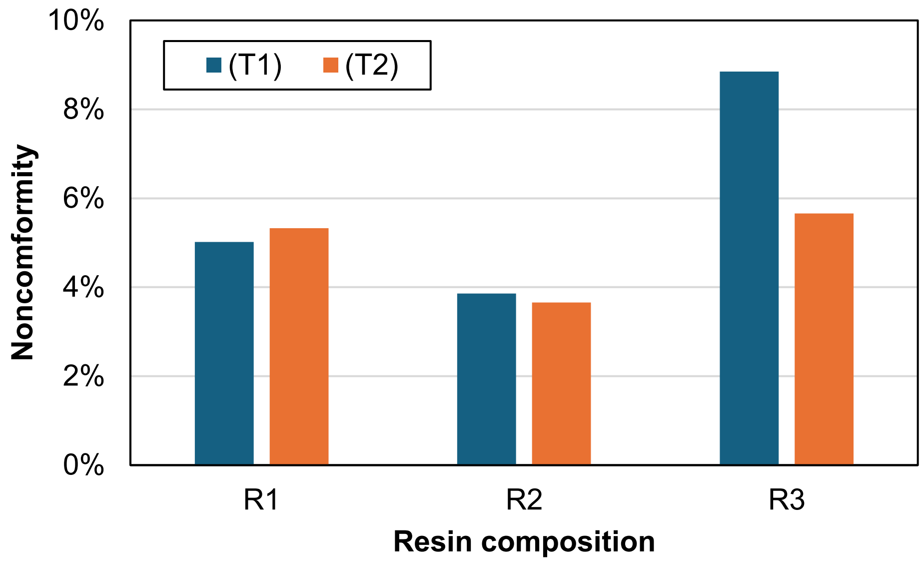

Figure 4. ANSYS simulation nonconformity with direct testing.

The difference between simulation and direct testing is related to the assumption in ANSYS that the bond between the fiber and the matrix is perfect. In real conditions, the fiber-matrix bond depends on resin distribution within the composite. During vacuum infusion, resin may accumulate around the inlet port and decrease in composite layers located farther from the port. Therefore, the actual specimen may have nonuniform resin distribution, whereas the simulation assumes a constant resin percentage in each part of the specimen [6].

3.4 Discussion

The specimens were produced using hand lay-up and vacuum infusion to reduce trapped air bubbles that could initiate cracks. Tensile specimens consisted of six layers, with three layers of carbon fiber and three layers of fiberglass. Bending specimens consisted of eleven layers, with six layers of carbon fiber and five layers of fiberglass.

The test results demonstrate that the matrix arrangement and resin composition affect the strength of the carbon composite. The Type 1 arrangement, which used 0° carbon fiber orientation, consistently produced higher tensile and bending loads than the Type 2 arrangement, which used 45° carbon fiber orientation.

For tensile loading, the highest value was observed in the T1R3 specimen, while the lowest value was observed in the T2R2 specimen. For bending loading, the highest value was observed in the T1R2 specimen, while the lowest value was observed in the T2R2 specimen. These results indicate that fiber orientation has a dominant effect on the mechanical performance of the composite.

The resin ratio also affected the test results, although its influence was lower than that of fiber orientation. A higher catalyst content in the resin mixture can accelerate hardening and may increase brittleness. Therefore, the ideal resin and catalyst composition should be evaluated further using resin-only

4 Conclusion

Based on the experimental study of carbon fiber composite specimens with variations in matrix arrangement and resin composition, it can be concluded that the 0° carbon fiber composite arrangement has greater tensile and bending strength than the 45° carbon fiber arrangement. The highest tensile load was obtained for the Type 1 specimen with a 4:1 resin composition, while the highest bending load was obtained for the Type 1 specimen with a 3:1 resin composition based on the measured bending load. The difference between ANSYS simulation and direct testing results was caused by the simulation assumption that fiber-matrix bonding was perfect, whereas in actual specimens the resin distribution and fiber-matrix bonding varied due to the vacuum infusion process. Future research should focus on improving fiber-matrix bonding and testing resin-catalyst specimens without fiber reinforcement to evaluate the influence of resin composition more accurately.

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Conflicts of Interest

The authors declare no conflict of interest.

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