Journal of Material Sciences & Engineering

Research Article Open Access

Study on the Mechanical Characterization of Composite Materials for Automotive Wheel Application

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Abstract

Nowadays the development of using fiber-reinforced polymer composites in the field of aviation, defense, automotive, and marine industry is growing due to their lower density as compared with conventional materials. In the automotive industry, the requirements of reduction of weight and fuel consumption have become an essential study without losing any mechanical strength.

Fiber-reinforced polymer composite materials are an alternative automotive wheel materials having outstanding mechanical properties via lower density, high fatigue resistance, flexibility of design, stability of dimension, better resistance of corrosion, the resistance of high temperature, high mechanical strength and light in weight, etc.

To determine the mechanical properties of fiber-reinforced carbon epoxy composite material using quasi-isotropic orientation having [45/0/0/0/0/-45/90/90/90/90/-45/0/0/0/0/45]s stacking sequences with a total number of 32 plies was prepared and mechanical characterization was performed. To quantify this analysis tensile and compression tests were performed by fabricating the samples through hand layup as per ASTM standards. From the result, fiber-reinforced carbon epoxy composite material has excellent tensile strength in the longitudinal direction and moderate compressive strength in the transversal direction.

Keywords: Composite material; Automotive; Carbon fiber

Introduction

A composite material is defined as a composition of different materials having significantly different chemical and physical properties when combined together produce new materials that have the characteristics different from the individual components with the required engineering properties [1,2]. A suitable engineering material to build a designed system, component, device or equipment is still a challenge for design engineers. But, composite materials are becoming alternative materials for the application of automotive parts. This is mainly because of composites are lighter and stronger than the frequently used metallic materials. Additionally, they offer the flexibility of design, the stability of dimension, better resistance of corrosion, the resistance of high temperature, high mechanical strength and light in weight, etc. [3,4].

Previous Research on Composite Wheel

Different researchers are trying to get the best combination of composites for the application of the automotive wheel, and those researchers are trying to compare the existing materials and composite materials for the application of the automotive wheel.

Firstly, Jyothi [5] studied "Advanced vehicle performance by replacing a conventional vehicle wheel with a carbon fiber reinforced composite". In this study, he considers reducing the weight of the wheel, vehicles unsprung mass, and rotational inertia. Using carbon/epoxy resin the reduction in the weight was up to 40%-50% compared with the conventional. Finally, he concludes that using CFRP material wheel has the potential to improve the performance of the vehicle by lowering the unsprung mass and rotational inertia of wheel assembly.

Similarly, Choudhury DR (2015) conducted "Design and analysis of composite wheel rim" [6]. For greater control and suspension, Aluminium alloy wheel was compared with carbon/epoxy composite material. In the study, the numerical analysis was presented in ANSYS workbench pre-post. From the analysis using CFRP wheel rim has the potential to improve the performance of FSAE vehicles by lowering the unsprung mass and the rotational speed of the wheel assembly.

Additionally, Karan V, et al. (2016) studied on "Fatigue and static structural analysis of car wheel using the finite element method" [7]. The analysis was carried out in ANSYS by considering two different materials namely Alumunium alloy and carbon-reinforced fiber. Form their study, carbon fiber wheel has more life and the weight reduction 40% less than the Al alloy wheel.

Furthermore, Bao Y, et al. conducted "Research of lightweight composite automobile wheel" [8]. In this study, they consider the radial, bending and impact load using carbon/epoxy (T300/5222) composite materials. In their study composite carbon/epoxy automotive wheel was compared with Aluminium wheel having the same dimension. Finally, weight reduction is 11.3% while using carbon/epoxy composite material.

Finally, Jakubczak, et al. investigated "carbon fiber reinforced wheel for ultra-efficient vehicle" [9]. In their study, the research concerning the innovative design, manufacturing method and the test of the wheel for such a vehicle are considered. From the result, using carbon fiber material shows a weight reduction of up to 40%.

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Received September 17, 2019; **Accepted** November 29, 2019; **Published** December 06, 2019

Citation: Gardie E, Alemu N (2019) Study on the Mechanical Characterization of Composite Materials for Automotive Wheel Application. J Material Sci Eng 8: 548.

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Analytical Analysis

To know the effect of fiber orientation efficiency factor (Krenchel factor) was used [10].

The efficiency factor of the laminate in the X-direction,

$$\left(\frac{No.of\ 0^0\ plies}{Total\ no.of\ plies}\times\eta\ factor\ of\ 0^0\right)+\left(\frac{No.of\ 45^0\ plies}{Total\ no.of\ plies}\times\eta\ factor\ of\ 45^0\right) \quad (1)$$

The efficiency factor of the laminate in the Y-direction

$$\left(\frac{No.of\ 90^0\ plies}{Total\ no.of\ plies}\times\eta\ factor\ of\ 90^0\right)+\left(\frac{No.of\ 45^0\ plies}{Total\ no.of\ plies}\times\eta\ factor\ of\ 45^0\right) \quad (2)$$

To calculate the strength of the composite;

$$\left(\frac{No.\ of\ 0^0\ plies}{Total\ no.of\ plies}\times tensile\ strength\ of\ 0^0\right)+\left(\frac{No.\ of\ 45^0\ plies}{Total\ no.of\ plies}\times strenth\ of\ 45^0\right) \quad (3)$$

Table 1 shows the values obtained from the analytical analysis of carbon epoxy composite materials with 60% fiber and 40% resin.

Sample Preparation

Hand layup is one of the simplest techniques of the composite material manufacturing process. Due to smaller requirements of infrastructure for manufacturing the component. Hand layup is suitable for manufacturing any complex shapes (Figure 1) [11,12].

No.	Material properties	Symbol	Value	Unit
1	Density	ρ	1.524	g/cm³
2	Compressive strength in x-direction	σ_{cx}	0.568	Gpa
3	Compressive strength in y-direction	σ_{cy}	0.264	Gpa
4	Compressive strength in z-direction	σ_{cz}	0.568	Gpa
5	Tensile strength in x-direction	σ_{tx}	1.118	Gpa
6	Tensile strength in y-direction	σ_{ty}	0.220	Gpa
7	Tensile strength in z-direction	σ_{tz}	1.118	Gpa
8	Young's modulus in x-direction	E_x	71.518	Gpa
9	Young's modulus in the y-direction	E_y	4.237	Gpa
10	Young's modulus in the z-direction	E_z	71.518	Gpa
11	Shear modulus in the x-direction	G_{12x}	16.704	Gpa
12	Shear modulus in the y-direction	G_{12y}	2.944	Gpa
13	Shear modulus in the z-direction	G_{12z}	16.704	Gpa
14	Strain	ε	0.0175	-
15	Major poisons ratio	v_{12}	0.264	-

Table 1: Calculated property of fiber-reinforced carbon/epoxy composite materials.

Figure 1: Sample preparation of laminated carbon/epoxy composite material.

Results

Tensile test

As shown in Figure 2 the stress-strain behavior of tensile testing specimens was linearly increases and final failure occurs catastrophically. Also from the standard deviation value, it's noticed that the tensile testing graph of the specimens has a little different from each other, the reason is that the mechanical and material factors, specimen preparation (hand layup process) and measurement errors.

Figures 2-4 show stress-strain (E%) for the specimens, average force-displacement and average stress-strain for longitudinal tensile tests respectively.

From the graphs, for the same size, orientation (quasi-isotropic), and material (carbon/epoxy) the force-displacement and stress stain relation increases linearly until failure occurs. Typical stress-strain curves for tensile loading was presented in Figure 4. In this figure, tensile stress increased linearly with an increase in strain until the point of ultimate load under uniaxial tensile loading. From Figures 2-4 the maximum load applied on the specimen was 59.99 KN, modulus of elasticity 69.995 Gpa and the maximum tensile strength is 999.83 Mpa. Figure 5 shows the comparison of the modulus of elasticity for both experimental and analytical results.

Compressive test

As shown in Figure 6 stress-strain curve of the compression test;

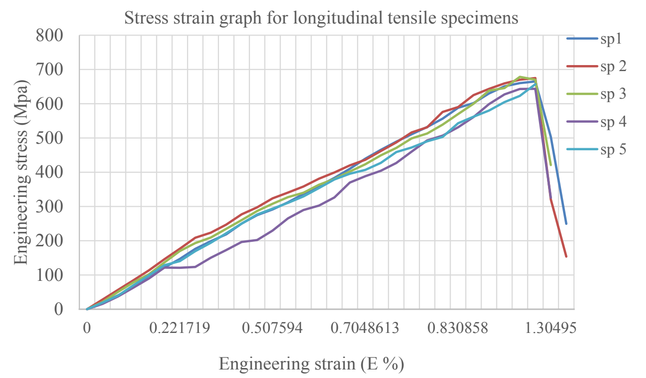

Figure 2: Engineering stress-strain graph for longitudinal tensile specimens.

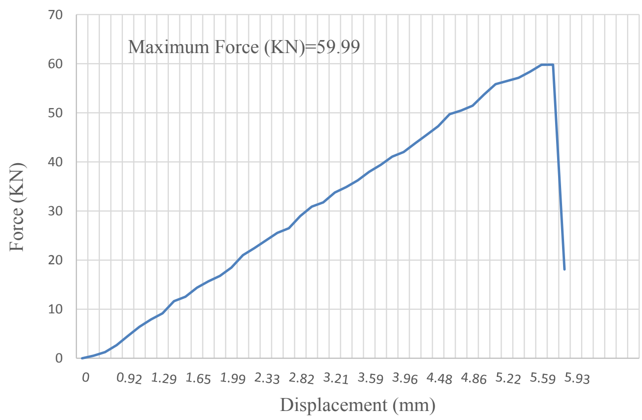

Figure 3: Average force-displacement graph for longitudinal tensile specimens.

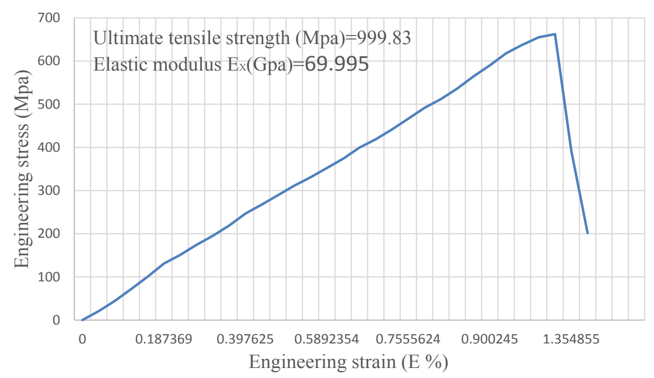

Figure 4: Average engineering stress-strain graph for longitudinal tensile testing specimens.

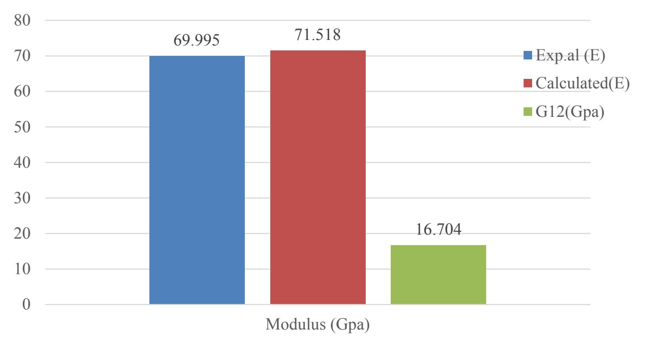

Figure 5: Modulus of elasticity for experimental and analytical results.

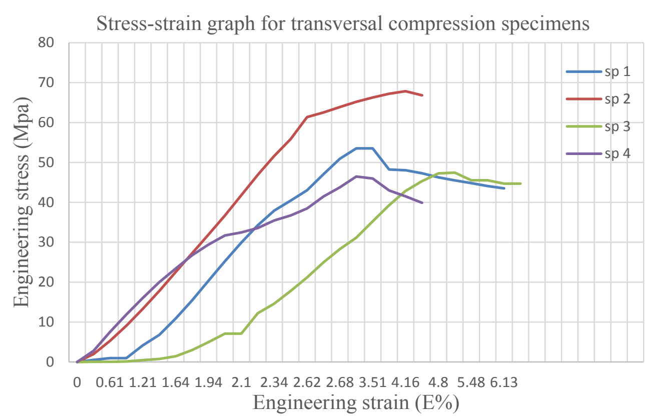

Figure 6: Engineering stress-strain graph for transversal compressive specimens.

the compressive strength increased with increasing the load until it reaches their ultimate compressive strength and then finally fail catastrophically.

Figures 6-8 show that stress-strain (E%) for the specimens, average force-displacement and average stress-strain for transversal compression tests respectively. As shown in Figure 8 the average compressive stress-strain increases linearly until the point of ultimate stress under the compressive load. From these figures the maximum compressive load was 20 KN, the maximum compressive transversal strength was 0.250 Gpa and the calculated strength was 0.304 Gpa. Figure 9 below shows the ultimate strength results of the tensile and compressive test modes for the experimental and calculated values.

Failures modes

During the mechanical testing process, the failures are different from specimen to specimen. The tensile and compression specimens before testing and after testing are depicted in Figure 10.

From Figure 10, it's noticed that most of the specimen's failure occurs at the gauge length sections. Also, it was observed that some specimens are failed at out of the gauge length such as at grips or at multimode types. However, such testing specimens that failed out of the

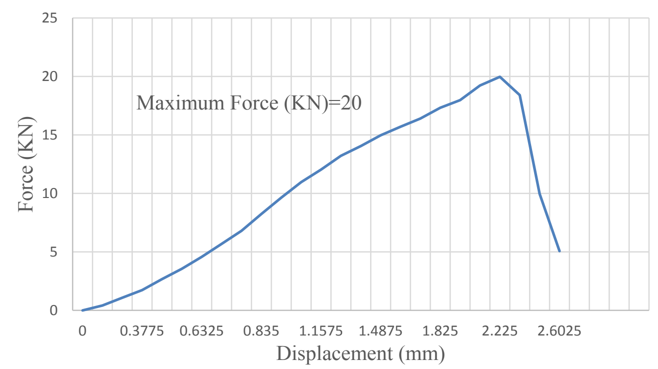

Figure 7: Average force-displacement curve of the transverse compression specimens.

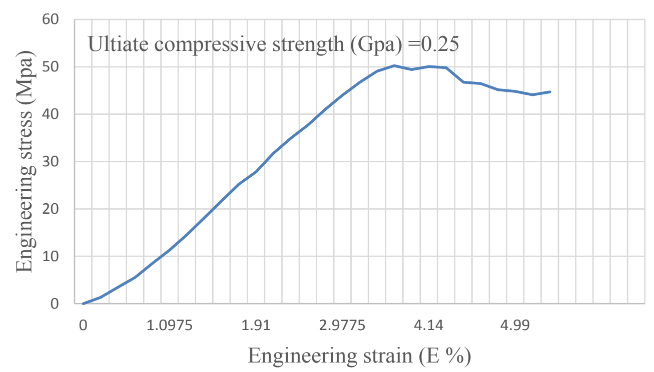

Figure 8: Average engineering stress-strain curve for transverse compression specimens.

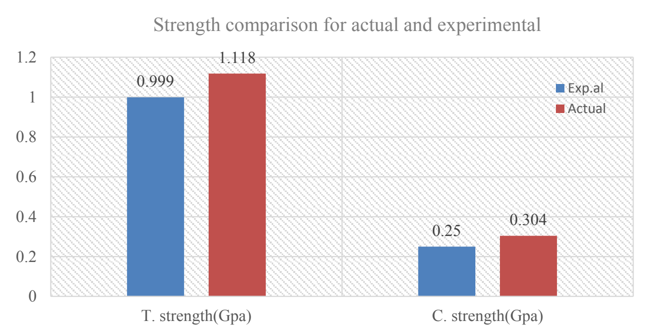

Figure 9: Ultimate strengths for tensile and compression testing modes.

Figure 10: Tensile specimen and compression specimen before and after test respectively.

gauge section was omitted from the data. From all testing specimens, it was observed that the matrix damage first occurred and then followed by fibers failure through then fracture propagate spontaneously starting from the first layer to the next layers.

Conclusion

The carbon-reinforced epoxy resin (laminated carbon/epoxy) composite material was successfully manufactured using hand Layup process and mechanical property characterization was done from UTM records. From the mechanical characterization results, the carbon fiber reinforced composite material has a good tensile strength basically in the longitudinal direction. However, it has moderate compressive mechanical strength in the transversal directions.

From the analysis, the strength of the composite material depends on the fiber orientation and the thickness of the fibers. When the number of layers of the laminate increases the mechanical properties of the laminated carbon/epoxy increases.

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