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Research paper

Material Properties of Composite Materials for FSAE Car Body Panels

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Abstract

This paper presents the mechanical properties of selected composite materials for Formula Society of Automotive Engineers (FSAE) race car body panels. The objective is to present the best materials to be used as the body panels. Kevlar, Carbon and glass fibers were fabricated as specimens and underwent some mechanical tests to determine their tensile properties, fracture toughness and impact resistance. Results from the experimental works reveal that woven Carbon fiber scored the highest in two out of three tests (tensile and fracture properties), but has the lowest impact energy that is due to its lower density compared to the other two composite materials. On the other hand, the woven Kevlar fiber consistently showed a moderate result in all three tests, and the woven glass fibers only showed a better result in impact test. Considering all these results, the woven Kevlar fiber is chosen as the best materials to be used as the FSAE car's body panels, which is based on a trade-off between strength of the materials, fracture, weight, and impact resistance. The findings may be useful for the future design, fabrication and performance of the FSAE race cars.

Keywords: *FSAE, body panels, composite materials, Kevlar fiber, Carbon fiber, Glass fiber*

1. Introduction

FSAE is a special project organized by Society of Automotive Engineers (SAE) International, targeting engineering students to develop their own version of Formula One style car. This competition provides hands-on experience, where the students need to successfully integrate and develop an actual race car outside their classroom. To date, more than 120 universities around the world has participated in this FSAE worldwide event. The evaluation on the FSAE cars involves two main events, which are Statics and Dynamics. Low fuel consumption, acceleration and endurance of the car are some of the evaluated criteria. These criteria are strongly related to the right materials used for the car body panels.

In choosing the right materials for the body panels, the material strength is not the only requirement concerns, but also the body weight, impact resistance and the manufacturability [1]. The structure of the body must be rigid enough to bear the statics and dynamics loadings along the driving experience. At the same time, the body must provide forward acceleration through low body weight and aerodynamics body [2]. It is well understood that a lightweight materials can also improve fuel efficiency, thus providing more specifications of the right materials for the body panel. In term of safety, the ability to absorb impact energy or crashworthiness of the body panels is part of the selection criteria too [3]. When developing new materials for automotive parts, there will be questions of (1) whether the new material has an opportunity to be selected or not and (2) whether they meet all the requirements or not.

In automotive industries, normally in luxuries cars, composite materials are normally used as the body panels because composites can compensate a right proportion of the requirements [4]. Ferrari and Lamborghini are examples of car developers that have been using composite materials for their supercars. These top companies realized that composites are lighter, higher fuel efficiency and safer than the conventional materials [5]. The winner of 2017 FSAE competition, University of Waikato engineering students used carbon fiber as frame and body of their FSAE car.

While reducing the weight, composites can be tailored to a specific load bearing direction, so the fibers can be arranged in the direction of principles stresses [6]. It is well known that the carbon fiber can provide tremendous of weight saving feature and great structural rigidity. Similarly, Kevlar, the other type of carbon-fiber based composite also has a very high strength property, but this material is quite expensive and requires a lot of professional touch [7]. The past several years have seen steady in increases in the use of glass fiber. Use of glass fiber can potentially reduce the weight of the vehicle and easy to be shaped, but it has low impact energy absorption and the strength of the material is quite low compared to other types of composites [8].

Although many types of materials are available, the right material to be used for the specific FSAE car body panels need to be investigated properly. This year, Universiti Teknologi MARA (UiTM) is planned to join this worldwide event, and the urgency of finding the best suitable material is huge. Hence, the objective of this study is to find the best composite material for manufacturing the car body panel by understanding its material mechanical properties and its behavior. It is hoped that the findings may be useful for the future design, fabrication and performance of the FSAE race cars.

2. Methodology

2.1. Sample preparation

As shown in Fig. 1a, the woven-type Carbon, Kevlar and glass fibers are used as the specimens for the body panels. The fibers were individually mixed with epoxy resin and prepared by using hand lay-up technique. After the mixture, the laminates were left

to cure under room temperature. Each selected fibers has their own number of layers to be stacked in order to get a standard thickness which is set to 3mm. Hence, the numbers of layers for each specimen are as follows: 14-layer Carbon, 17-layer Kevlar and 9-layer glass fiber. As shown in Fig. 1, all specimens were cut to their required size by using a vertical bend saw.
Since the aim of the study was to find the material properties of the composite plate, the following standards were used: The ASTM D3039 for Tensile test, ASTM D6110 for Charpy Impact test and ASTM D5045 for Fracture test. The actual dimension of the specimens used were 210 mm x 25 mm x 3mm for tensile test, 126 mm x 12 mm x 3 mm for Charpy test and 30 mm x 8mm x 3mm for Fracture test. The mass, volume and density of each specimens were tabulated in Table 1.

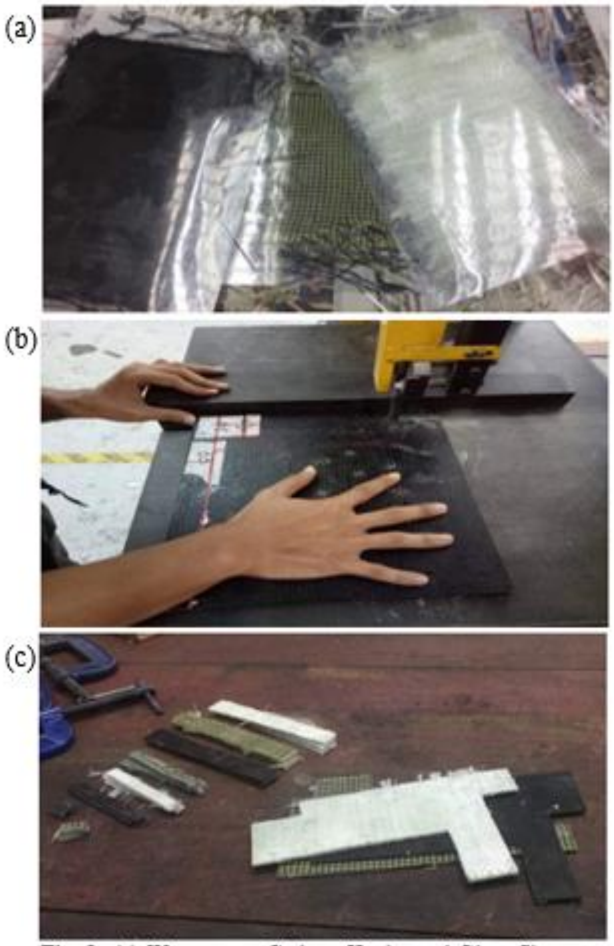

Fig. 1: (a) Woven-type Carbon, Kevlar and Glass fibers were used as specimens; (b) cutting specimens by vertical band saw; (c) small specimens for different mechanical tests.

Table 1: Density of each composite specimens

Type of Composite Fibers	Mass of the plate specimen (g)	Volume of the plate specimen (cm^3)	Density of the materials, ρ (g/cm^3)
Fiberglass Woven Fiber	364.8	189	1.9
Carbon Woven Fiber	264.6	189	1.4
Kevlar Fiber	311.9	189	1.6

2.2 Mechanical Tests

2.2.1 Tensile Test

To conduct the tensile test, the specimens were made according to ASTM 3039 standard, with the dimensions of 200 × 25 × 150 mm. The tensile test was conducted at room temperature with test speed of 5 mm/min using an INSTRON 3382 universal test machine. Tensile test was the method used to obtain the elastic modulus. For the Young Modulus of Elasticity, the value follows Equation 1:

$$\text{Young's Modulus} = \frac{\text{stress}}{\text{strain}} = \frac{FL_o}{A(L_n - L_o)} \tag{1}$$

If the composite material of cross sectional A is pulled by a force of F at each end, the composite material stretches from its original length, L_o to its new length, L_n.

2.2.2 Fracture Test

The fracture toughness test is to determine the resistance of the material to the growth of cracks under increasing load. It is valuable in determining whether there is a danger of component failure when a flaw discovered in an existing structure. The fracture toughness test was performed according to the ASTM D5045 standard, using Single End Notch Bending (SENB) specimens. The machine used for the fracture toughness test is similar to the tensile test, an INSTRON 3382 universal test machine. The speed of the machine is set to 2 mm/min. The specimens are positioned among the jig and the measurements are reset to the initial condition. From the printed result the will be a plot, which is flexural load vs. flexural extension. The stress intensity factor, K_c was determined as the following equations Equation 2:

$$Kc = \frac{P}{BW^{\frac{1}{2}}} f(x) \tag{2}$$

K_c = stress intensity factor in Pa√m
P = applied load (N);
B = thickness of the specimen (m) = 3mm
W = width of the specimen (m) = 10 mm.

$$f(x) = 6x^{1/2} \left\{ \frac{[1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2)]}{(1+2x)(1-x)^{\frac{3}{2}}} \right\} \tag{3}$$

x = ratio of pre-crack over the width = a/w = 5 mm /10 mm = 0.5.

Based on the x value, the f(x) can also be obtained from ASTM D5045 Table 1. In order for a result to be considered valid according to these test methods, the following size criteria (Equation 4) must be satisfied. The criteria require that B must be sufficient to ensure plane strain and that (W−a) be sufficient to avoid excessive plasticity in the ligament. If (W−a) is too small and non-linearity in loading occurs, then increasing the W/B ratio to a maximum of 4 is permitted for SENB specimens.

$$B,\ w\text{-}a,\ a \ \geq 2.5 \left(\frac{Kc}{\sigma y}\right)^2 \tag{4}$$

a = crack length
K_c = conditional or trial K_c value
σ_y = yield stress of the material

When a material of unknown fracture toughness is tested, a specimen of high material phase thickness tested need to be used, or its specimen size can be based on its prediction of the fracture toughness. The test must be repeated using a thicker specimen if the fracture toughness value resulting from the previous test does not satisfy the requirement of the above equation. When a test fails, another test with a different thickness is required to ensure plane strain condition, if satisfied, the fracture toughness values, Kc, corresponding to the successful thickness can be accepted. It is not possible to produce a constantly perfect set of specimen that meets the thickness requirement. For example, a sample with excessive thickness may impose a difficulty in producing a crack tip in the sample, while, a sample that is too thin, less than 3mm, may produce Kc value that is invalid. Due to this restriction, a regular test for each sample is compulsory to maintain the validity of the Kc. Thus, the value of Kc of each material can be compared and the highest value of fracture toughness shows the ability of a material containing a crack to resist fracture.

2.2.3 Charpy Impact Test

The purpose of impact testing is to determine the nature and extent of material deformation under rapid loading conditions. The test measures the impact energy, or the energy absorbed prior to fracture, using Izod and Charpy Universal Impact testing machine. V-notched specimens were prepared according to the ASTM D6110 standard, with a required length of 126 mm and width of 12.7 mm. The notch should have a depth of 2 mm, included angle of 45°, and a root radius of 0.25 mm. The Charpy impact test method works by placing a notched specimen (with the notch facing away from the point of contact) into a large machine with a pendulum of determined weight. The weight of the pendulum was set by using an R4 pendulum (3.624 kg) at an angle of 90°. The energy absorbed at fracture, E, can be determined using Equation 6:

$$E = mg(h_o - h_f) \qquad (5)$$

The load is applied as an impact blow from a weighted pendulum hammer that is released from a position at a fixed height h. The specimen is positioned at the base and with the release of pendulum, which has a knife edge, strikes and fractures the specimen at the notch. The pendulum continues its swing, rising a maximum height h_f which should be lower than h_o naturally. The energy absorbed at fracture E can be obtained by simply calculating the difference in potential energy of the pendulum before and after the test such as in Equation 5, where m is the mass of pendulum and g is the gravitational acceleration.

3. Results and Discussion

3.1 Tensile Properties

The stress-strain curves and the trend bars (yield strength and elasticity modulus) for the tensile properties of three composite specimens are presented in Fig. 2, Fig. 3 Fig. 4. The tensile properties of woven Carbon fiber specimen are higher than the woven Kevlar and glass fiber specimens. From Fig. 2, a shorter elongation and a higher area under stress-stress curve in Carbon fiber specimen can be observed. These two features reflect that the woven Carbon fiber specimen has a shorter plastic deformation, absorb higher energy and a tougher material, compared to the other two specimens. On the other hand, the woven glass fiber specimens have the lowest tensile properties. For Kevlar specimens, it shows moderate tensile properties (25% lower than Carbon fiber), but exhibiting the highest elongation compared to other specimens, which means it takes time for the specimen to break. However, the area under the stress-strain curve is still smaller than one in Carbon fiber specimen. This is some trade off in finding a new material for FSAE body panels, whether to use a material with high modulus or a material with lower modulus but tend not to break easily or quickly. A material with higher modulus normally used to support or distribute structural load, but for this FSAE car, the material will be used as body panels not as the chassis structure. So, it might be safe to say that the strength of the material could be sacrificed a bit in order to accommodate a longer deformation before the final failure stage.

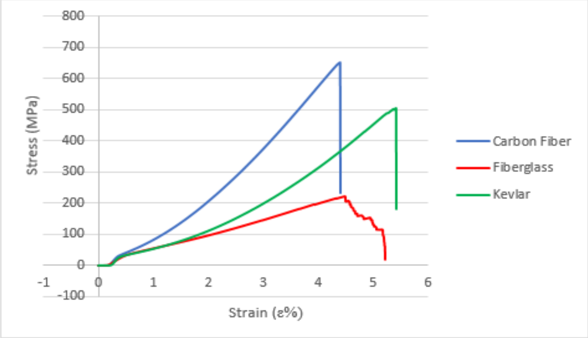

Fig. 2: Experimental tensile stress-strain curve for three types of composite specimens

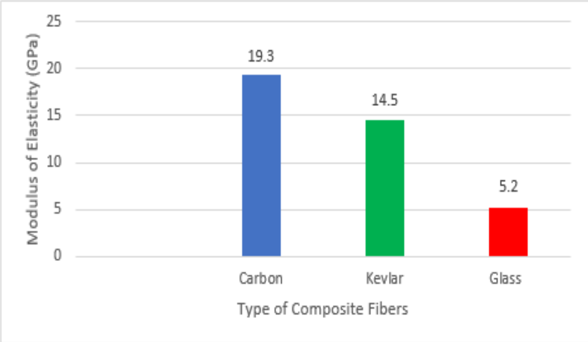

Fig. 3: Modulus of Elasticity of each composite specimens

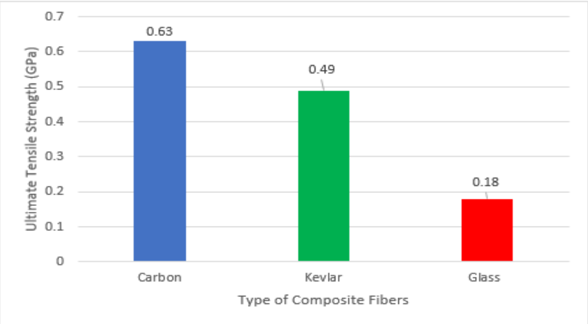

Fig. 4: Ultimate Tensile Strength of each composite specimens.

3.2 Fracture Toughness

Fig. 5 shows the curves of the flexural load versus flexural displacement for the three composite specimens under three-point bending test. It can be seen that the flexural load increases with increasing flexural displacement, but for the woven carbon fiber, the flexural load started to decreased when the displacement is lower than 3.5 mm. Also can be seen, the average flexural load of the woven Carbon Fiber specimens is the highest (570 N) followed by the woven Kevlar (290 N), then the woven glass fiber (82 N). From the flexural test, the fracture toughness value is calculated using Equation 2 and Equation 3, all valid under condition verified using Equation 4. Carbon fiber toughness values are significantly higher, compared to the other two composite specimens, with an extraordinary value of 20 MPam$^{1/2}$. It should be noted that the K_c was calculated from the maximum recorded load and the corresponding crack length determined by the compliance formula. Based on these findings, it clearly demonstrates that the Carbon fiber has the highest ability to resist fracture and it needs a high energy to break the specimen. This property is considered as one of the most important properties for any design applications.

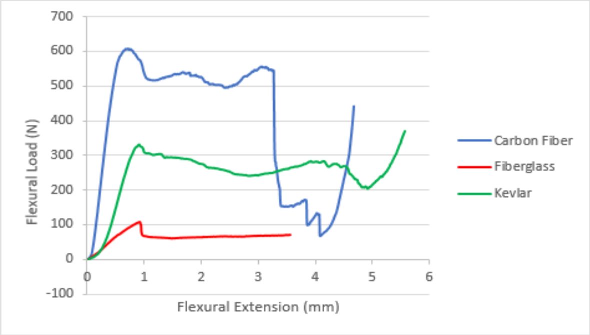

Fig. 5: Experimental flexural load-displacement curve for three types of composite specimens

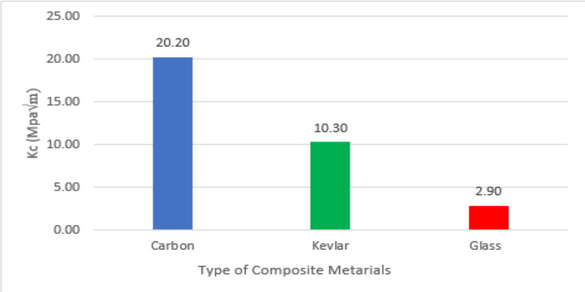

Fig. 6: Fracture toughness of each composite specimens

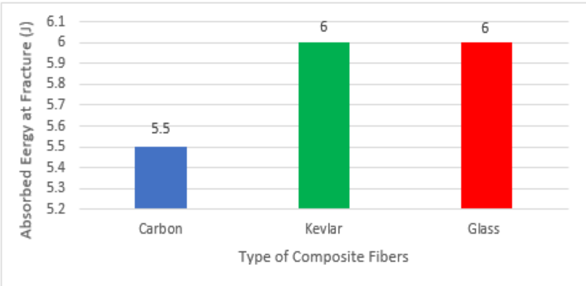

Fig. 7: Impact energy of each composite specimens

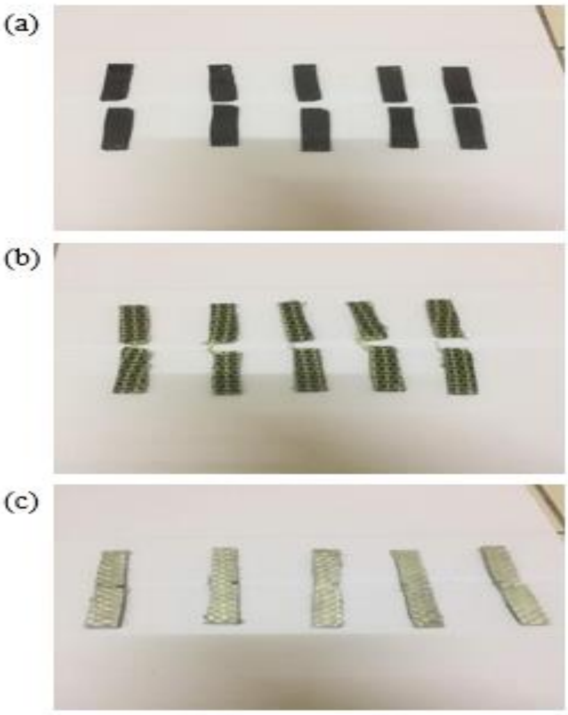

Fig. 8: Sample of three composite specimens after impact test; (a) woven carbon fiber, (b) woven Kevlar and (c) woven glass fiber

3.3 Impact Energy Value

A graph comparing three different types of composite materials is shown in the following Fig. 7. This impact value can be used as a rule of thumb for determining the load bearing capacity of a material against stresses from impact and fracture conditions. Surprisingly, it can be observed that the woven glass fiber and woven Kevlar specimens effectively absorbed energy at fracture with 6J, 8% higher compared to the woven carbon fiber specimen that absorb the impact energy at 5.5 J. For a given material, it is expected that the impact energy will be decreased if the yield strength is increased, and in this case, the carbon fiber has the highest yield strength. If the material undergoes some process that makes it more brittle and less able to undergo plastic deformation. The impact resistance (toughness) of a composite depends on many factors, such as molecular structure, molecular weight, cohesive energy and crystal structure. It has been demonstrated so far that the glass fiber has the lowest stiffness properties and fracture toughness, but highest impact energy. This could be related to its density, which is the highest amongst the other two specimens (shown in Table 1). It is expected that a high molecular weight and narrow molecular weight distribution generally improves impact resistance, hence, the result shows a very good impact resistance of glass fiber specimens. Examples of post fracture Charpy impact specimens are shown in Fig. 8. It can be observed that the glass fiber specimens still intact and did not break during (Fig. 8c) the impact test, meanwhile the other two composite specimens were broken into two. Looking at the materials, it is convinced that both woven carbon and Kevlar specimens (Fig. 8a and 8b) have more voids in the fabric arrangement compared to the glass fiber, which in turns lower the impact resistance.

4. Conclusion

This project successfully investigated the mechanical properties of three different composite materials that will be used as the bod panels of UiTM FSAE race car. The objective is to present the best materials to be used as the body panels. From the results, the tensile properties and fracture toughness value of woven Carbon fiber specimen is higher than the woven Kevlar and glass fiber specimens. But also can be observed, the carbon fiber exhibits the lowest impact resistance and but has the lowest elongation, which means it takes a shorter time for the material to break. On the other hand, the woven Kevlar specimen consistently showed a moderate results (in terms of tensile, fracture and impact properties) compared to the woven Carbon and glass fiber specimens. Hence, a trade-off between the very high tensile or high impact properties is needed. Since the materials will be used as the body panels of the FSAE car, which is not as the load bearer structure, it could be safe to decide to choose the woven Kevlar material to be used as the FSAE car body panels. Although woven Kevlar is not a common material to be used as a body panel, this study has successfully characterized its material properties that is better than the woven Carbon and glass fiber materials. However, in the future, more dynamic tests should be conducted in order to represent a real condition of a race car's body panels. It is hoped that this study is useful in finding a better composite material to be used as the body panels of a FSAE race car.

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References

[1] R. Zaripov and P. Gavrilovs, "Research Opportunities to Improve Technical and Economic Performance of Freight Car through the Introduction of Lightweight Materials in their Construction," Procedia Eng., vol. 187, pp. 22–29, 2017.

[2] R. G. Tornero, "Composite materials are more present today than ever before in cars," Reinf. Plast., vol. 59, no. 3, p. 3617, 2015.

[3] G. Marsh, "Carbon composite car body panels gain traction with Gurit Automotive," Reinf. Plast., vol. 55, no. 5, pp. 24–27, 2011. Jacob, "Carbon fibre and cars – 2013 in review," Reinf. Plast., vol. 58, no. 1, pp. 18–19, 2014.

[4] Jacob, "BMW counts on carbon fibre for its Megacity Vehicle," Reinf. Plast., vol. 54, no. 5, pp. 38–41, 2010.

[5] J. Wang et al., "Design and experimental verification of composite impact attenuator for racing vehicles," Compos. Struct., vol. 141, pp. 39–49, 2016.

[6] T. J. Singh and S. Samanta, "Characterization of Kevlar Fiber and Its Composites: A Review," Mater. Today Proc., vol. 2, no. 4–5, pp. 1381–1387, 2015.

[7] M. R. Ricciardi, I. Papa, A. Langella, T. Langella, V. Lopresto, and V. Antonucci, "Mechanical properties of glass fibre composites based on nitrile rubber toughened modified epoxy resin," Compos. Part B Eng., vol. 139, no. January 2017, pp. 259– 267, 2018.