Sains Malaysiana 53(3)(2024): 691-704
http://doi.org/10.17576/jsm-2024-5303-16

Investigation of Thermomechanical Analysis of Carbon/Epoxy Composite for Spacecraft Structure Material

(Penelitian Analisis Termomekanik Komposit Karbon/Epoksi untuk Bahan Struktur Kapal Angkasa)

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Received: 7 July 2023/Accepted: 15 February 2024

ABSTRACT

When building spacecraft structures, it is crucial to use lightweight and high-strength composite materials with the necessary characteristics. Aerospace applications benefit significantly from the exceptional properties of carbon/epoxy composite materials. As part of a study on composite materials, this work focuses on exploring the thermo-mechanical properties of carbon fiber. The matrix used in this research is LY-5052 epoxy, applied through a vacuum infusion technique. To achieve optimal composite properties, various tests are conducted to evaluate its thermo-mechanical behavior. These tests may include measuring Thermal Conductivity and performing thermogravimetric analysis (TGA). Most importantly, the composite is subjected to tensile testing at room temperature to 200 °C. This is done because most tensile tests on carbon/LY5052 composites are carried out at room temperature. The results obtained from the measurement of the thermal conductivity of the carbon/LY5052 composite were 0.419 W/mK; from the Thermogravimetric Analysis (TGA), the carbon/LY5052 composite began to decompose at a temperature of 365.63 °C and the tensile test was carried out simultaneously with variations in temperature from room temperature, 50 °C, 100 °C, 150 °C and 200 °C have tensile strengths of 553, 507, 340, 266, and 242 MPa, respectively. This trend confirms that strength decreases with higher temperature loads. Several image observations are also presented in this report to understand composite materials' failure behavior at these various temperatures.

Keywords: Carbon/epoxy composite; failure behavior; spacecraft structures; thermomechanical

ABSTRAK

Bahan komposit ringan dan berkekuatan tinggi adalah penting untuk struktur kapal angkasa yang memerlukan bahan dengan ciri yang dikehendaki. Bahan komposit karbon/epoksi mempamerkan sifat cemerlang untuk aplikasi ruang angkasa. Penelitian ini adalah sebahagian daripada kajian tentang sifat termo-mekanikal bahan komposit menggunakan gentian karbon, manakala matriks yang digunakan ialah epoksi LY-5052 yang dibuat melalui teknik infusi vakum. Untuk mendapatkan komposit terbaik dari segi sifat, tingkah laku termo-mekanikal dijalankan dengan melakukan beberapa ujian, antaranya pengukuran Kekonduksian Termal dan analisis termogravimetrik (TGA) dan yang paling penting ialah menjalankan ujian tegangan dengan variasi suhu daripada suhu bilik hingga 200 °C. Ini dilakukan kerana kebanyakan ujian tegangan pada komposit karbon/epoksi dijalankan pada keadaan suhu bilik. Keputusan yang diperoleh daripada pengukuran kekonduksian terma komposit karbon/epoksi ialah 0.419 W/mK daripada Analisis Termogravimetrik (TGA) komposit karbon/epoksi mula terurai pada suhu 365.63 °C dan ujian tegangan dijalankan, keluar serentak dengan variasi suhu daripada suhu bilik, 50 °C, 100 °C, 150 °C dan 200 °C masing-masing mempunyai kekuatan tegangan 553, 507, 340, 266 dan 242 MPa. Trend ini mengesahkan bahawa kekuatan berkurangan dengan beban suhu yang lebih tinggi. Beberapa pemerhatian imej juga dibentangkan dalam laporan ini untuk mendapatkan pemahaman tentang tingkah laku kegagalan bahan komposit pada pelbagai suhu ini.

Kata kunci: Komposit karbon/epoksi; struktur kapal angkasa; termomekanikal; tingkah laku kegagalan

Introduction

When selecting materials for spacecraft structures, their stiffness (elastic modulus or density) and strength (strength or density) are the primary factors. When considering materials, it is essential to consider various attributes such as ductility, fracture toughness, thermal conductivity, thermal expansion, corrosion resistance, volatility, ease of manufacturing, and ease of procurement. Although aluminum alloys are frequently employed in all structure areas, carbon/epoxy composite materials are also regularly used for both the primary and secondary structures to benefit from their superior mechanical qualities (Yasaka & Onoda 2003). In recent decades, carbon fiber laminated composites have undergone significant advancements in their structural design, components, and manufacturing processes. As a result, composite materials are now widely used in various applications. The aerospace industry, in particular, has extensively embraced the use of carbon fiber laminates due to their favorable strength-to-weight ratio compared to traditional metal alloys used in spacecraft structural elements. By replacing aluminum components with carbon fiber laminates, there has been a considerable increase in the efficiency of fuel use during spacecraft operations. It has been observed that any minor damage to the spacecraft's composite structure can be repaired quickly and easily (McKinnon et al. 2017; Thamizh Selvan et al. 2021).

Due to the high requirements on the structural material of the Spacecraft (high strength, low weight), a polymer matrix composite reinforced with carbon fiber is the most appropriate choice. This material has a low density, a high Young's modulus, and a higher tensile strength. Thus, the carbon fiber-reinforced polymer matrix composite material was suitable for the Spacecraft structural platform's design and development process (Grodzki & Łukaszewicz 2015; Parmar 2021).

Using LY-5052 epoxy as a matrix due to its essential mechanical qualities and excellent temperature resistance, LY-5052 is a frequently utilized Araldite epoxy resin system. Applications that need excellent dependability can use the system. Araldite® LY-5052 is a cross-linked epoxy resin that differs from traditional epoxy resins, comprising four parts. This unique feature enables it to provide different epoxy resin systems with various mechanical and thermal properties. Due to its capabilities, Araldite® LY-5052 is considered a potential material for spacecraft structures. Low viscosity, ease of impregnation, robust materials, lengthy working durations for the manufacture of tremendous things, and resilience to high temperatures are the key benefits of Araldite LY5052 epoxy resins (Jeyranpour, Alahyarizadeh & Minuchehr 2016).

Several studies have studied the mechanical properties of Araldite LY-5052 composites (Khan et al. 2021; Tilak et al. 2021; VenkateshwarReddy et al. 2020). According to the VenkateshwarReddy study, a composite of LY5052 and carbon fiber T700 can withstand 1500 MPa in UD laminates and 1900 MPa in ring specimens. Khan demonstrated in another investigation that a composite of 40% LY5052 and 60% carbon fiber yielded 550 MPa ultimate tensile strength. Tilak also investigated the flexural strength of hybrid polymer composite laminates reinforced with E-class fiber (32%), Kevlar fiber (38%), and LY 5052 (30%). At 3 mm thickness, this composite can bear 427 MPa flexural strength. However, earlier research mainly only evaluated mechanical strength at room temperature; finding the characterization at a higher temperature of 100 °C is difficult. In this paper, we explore the mechanical properties of composite material through experimentation at a range of temperatures, from room temperature to 200 °C. Understanding the composite›s behavior under high temperatures is crucial for analyzing its failure mechanisms when applied as a structure at high temperatures. The remaining strength of composite material at elevated temperatures will be determined so it can be a consideration when designing a structure using this material. We also investigate how the heat treatment during the composite›s formation may affect its behavior at elevated temperatures.

Materials and Methods

MATERIAL SELECTIONS

In our research, we employed carbon fiber grade Kyoto-carbon, purchased from CV. Kyoto Carbon Corp, Indonesia, is a type of carbon fiber with a plain weave pattern of 3Kx3K and a thickness of 0.27 mm. The mechanical properties of this material are detailed in Table 1. The matrix used in this study is the epoxy resin Araldite LY-5052 supplied by Huntsman Indonesia (Table 2). The mechanical properties of Epoxy LY-5052, Epoxy LY-5052 is a superior matrix option for various reasons. Its aerospace-grade quality, low viscosity, and long pot life make it easy to impregnate reinforcement materials and produce large-sized objects. Additionally, it boasts high-temperature resistance and impressive mechanical properties compared to other epoxy options.

TABLE 1. Carbon fiber technical data sheet

Properties	Value
Tensile strength	3310 MPa
Tensile modulus	240 GPa
Strain	1.6%
Density	1.78 g/cm^3
Weight of fiber	220 gsm

TABLE 2. Technical data sheet of LY-5052 epoxy resin

Properties	Value
Tensile strength	60 MPa
Tensile modulus	3.55 GPa
Strain	2.5%
Density at 25 °C	1.17 g/cm^3
Viscosity at 25 °C	1500 cP

PREPARATION OF CARBON/LY5052 COMPOSITE SPECIMENS

Because the type of carbon fiber used is plain weave (Figure 1), which has an orientation with the same angular direction, 0° or 90°, specimens require ten layers. The samples were created utilizing the vacuum infusion process, producing composites that use vacuum pressure to infuse resin into the laminate (fiber layers). Before the resin is poured, the fiber material is put into the mold and sucked out. After the vacuum condition has been established, the resin is sucked into the laminate through a pipe connected to the vacuum region (Ibadi et al. 2022). As shown in Figure 2, this vacuum infusion method's production plan for composites is available. The last step is the curing procedure, which entails storing it at room temperature for 24 h. The next step is to create a tensile test specimen with dimensions of 250 mm · 25 mm · 2.5 mm according to the ASTM D3039 standard for tensile testing of fiber-reinforced composites. The tensile test specimen's dimensions are displayed in Figure 3.

THERMAL ANALYSIS

THERMAL CONDUCTIVITY MEASUREMENT

Thermal conductivity measurements refer to the ASTM C1113 Standard Test Method for Thermal Conductivity of Refractories by Hot Wire. Using the QTM-500 Quick Thermal Conductivity Meter, the QTM-500 measuring instrument can measure thermal conductivity with results in the measurement range of 0.035 ~ 5.0 w/m K. The measurement process is carried out with a current of 1 ampere, and the temperature range at the time of measurement is 23 °C to 30 °C with a period of 60 s.

THERMOGRAVIMETRIC ANALYSIS (TGA)

The TGA test was performed using a Shimadzu DTG-60H. The working principle of this tool is to detect changes in sample mass as the temperature increases. Material degradation due to temperature changes can be studied from the results of this TGA test. TGA testing is carried out using parameters according to ASTM E1181 standards. The test temperature was carried out from room temperature to 850 °C, with the replacement of the gas for conditioning carried out at 600 °C. The inert gas used in this test is nitrogen. The heating rate used in this TGA test is 10 °C per min.

MECHANICAL CHARACTERIZATION

To determine the mechanical properties of a material, a test is needed, and one of the most frequently performed tests is the tensile test. This test has the function of determining a material's strength level and identifying its characteristics. Tensile testing was carried out with a Shimadzu AG-50KNX PLUS machine. Tensile testing refers to the ASTM D3039 standard for tensile testing of fiber-reinforced composites. During the tensile test process, the thermal load is also given simultaneously.

Tensile testing at various temperatures was done with the help of a Shimadzu TCE-N300 thermal chamber, as shown in Figure 4. The tensile test jig was placed in the heating chamber during testing. Then, the chamber is heated until it reaches the desired temperature. When the chamber reached the determined temperature, the specimen was mounted in a testing jig and tested directly. Variations in thermal load include room temperature (RT), 50 °C, 100 °C, 150 °C, and 200 °C.

SCANNING ELECTRON MICROSCOPY (SEM) ANALYSIS

The carbon/LY5052 composites' microstructure was observed using scanning electron microscopy (Phenom Pro X by Phenom-World BV, Netherlands). The SEM was operated at an accelerating voltage of 10 kV, and with 600 magnifications, inspection focused on the fractured part of the tensile test results accompanied by temperature.

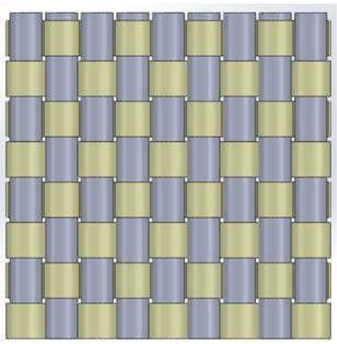

FIGURE 1. Plain weave type

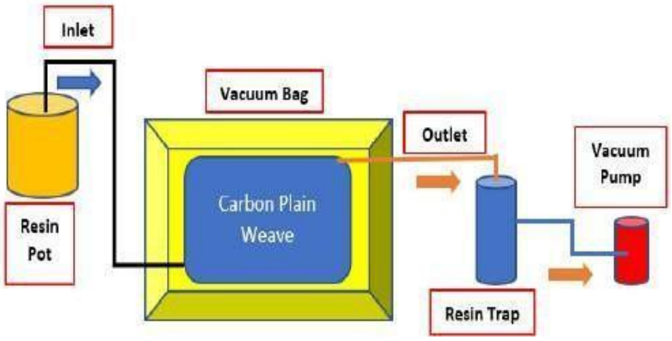

FIGURE 2. Vacuum infusion scheme

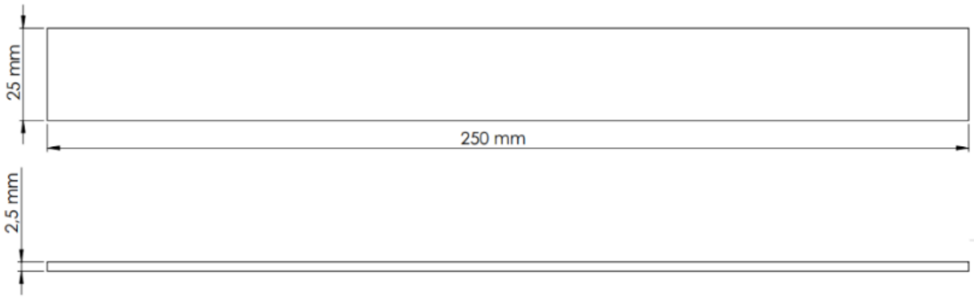

FIGURE 3. Dimensions of test specimens

Results and Discussion

CARBON/LY5052 COMPOSITE FABRICATION RESULTS

The results of the carbon/LY5052 composite fabrication process that was completed using the vacuum infusion method had a good surface finish and fiber-to-resin volume fraction. The fabrication process could affect composite mechanical and thermal properties. The vacuum infusion process was chosen because of its simplicity and good results. Carbon/LY5052 specimens are shown in Figure 5.

THERMAL CONDUCTIVITY ANALYSIS

Thermal conductivity is a value that expresses the ability of a material to conduct heat. The value of thermal conductivity for each material is different. The ratio of the value of thermal conductivity to thermal conductivity is comparable. This means that the higher the thermal conductivity value, the higher the capacity to conduct heat (Yao et al. 2023).

Table 3 is the result of measuring the thermal conductivity of carbon/LY5052 composites, which was repeated five times. Measurement of the thermal conductivity of the carbon/LY5052 composite with an average yield of 0.419 ± 0.034 W/mK. The value of thermal conductivity in each composite material has a value that is influenced by several parameters. The main parameters are the density and porosity of the material. The density parameter measures the material's density, so the higher the density, the greater the thermal conductivity value. The second is porosity.

FIGURE 4. (a) Shimadzu AG-50KNX UTM Machine with TCE-N300 Thermal Chamber (b) Inside of TCE-N300 Thermal Chamber

FIGURE 5. Carbon/LY5052 composite specimens from the vacuum infusion process

Porosity is the possibility of space in a material. Porosity is always inversely proportional to density, so the thermal conductivity value will also be inversely proportional. In addition, the fabrication method and the conditions for making composites play an essential role in their conductivity because they affect the distribution, orientation, and distance between fillers in the polymer matrix. Thermal conductivity values can vary depending on the circumstances (Gradiniar Rizkyta & Ardhyananta 2013).

THERMOGRAVIMETRIC ANALYSIS

TGA can be used to study the thermal stability (strength of a material at a specific temperature), oxidative stability (rate of absorption of oxygen in a material), and constitutive properties (e.g., fillers, polymer resins, solvents) of samples. In addition, weight gain or loss in the sample is related to various factors. In general, an increase in sample mass is associated with adsorption or oxidation, whereas a decrease in sample mass is associated with decomposition, desorption, dehydration, desolvation, or volatilization. The thermogravimetric analysis uses heat to force reactions and physical changes in materials. TGA quantitatively measures mass changes in materials associated with transitions and thermal degradation. The TGA records the mass change of dehydration, decomposition, and oxidation of the sample as a function of time and temperature (Bücheler, Kaiser & Henning 2016).

Figure 6 is a thermogravimetric analysis curve of the carbon/LY5052 composite material. In this curve, we can find the T_{onset} of the carbon/LY5052 composite material. The T_{onset} is the temperature at which decomposition begins. Since samples may contain different amounts of adsorbed water and the rate of weight loss differs from sample to sample, T_{onset} is taken as the temperature at which the sample loses 7% of its initial weight (Zárate, Aranguren & Reboredo 2008) - carbon/LY5052 composite T_{onset} at 365.63 °C. Furthermore, the TGA results, which refer to the ASTM E1131-08 standard (Table 4), explain general techniques regarding thermogravimetric analysis to determine highly volatile matter, medium volatile matter, combustible materials, and residues. Highly volatile matter, very volatile materials such as moisture, additives, residual solvents, or other components with low boiling points (200 °C or less), causes material degradation when highly volatile matter is present in carbon/LY5052 composites (1.433%).

Furthermore, for volatile matter mediums, such as oil content and polymer degradation products, the recommended temperature range is 200 °C to 550 °C, and the material degradation that occurs in the carbon/LY5052 composite is 32,284%. Next, the combustible material stage is a material that can be oxidized at a temperature of 750 °C; at this stage, the degradation of the material that occurs for the carbon/LY5052 composite material is 28.528%. Mass loss is generally caused by chemical reactions, such as thermal degradation, water loss, crystallization, and combustion, and by physical transformations, such as vaporization, evaporation, sublimation, drying, and desorption (de Souza, da Silva & de Souza 2020; Raof et al. 2019). Residues, namely the remaining non-volatile material in the oxidation process, may be due to the type of content in the material, including metal components, filler content, or inert reinforcing materials.

TABLE 3. Results of thermal conductivity measurements on carbon/LY5052 composite

	Thermal conductivity (W/mK)
Test-1	0.390
Test-2	0.424
Test-3	0.380
Test-4	0.438
Test-5	0.462
Average	0.419
SD	0.034

The residue on the carbon/LY5052 composite material is 9.977%. Based on the results of the TGA, it can be concluded that the incorporation of materials into the composite can significantly reduce the decomposition rate, with the leading role being the formation and retention of charcoal on the composite surface. This also applies to resins with the addition of particulates, which can reduce composite ablation (Shaheryar et al. 2017).

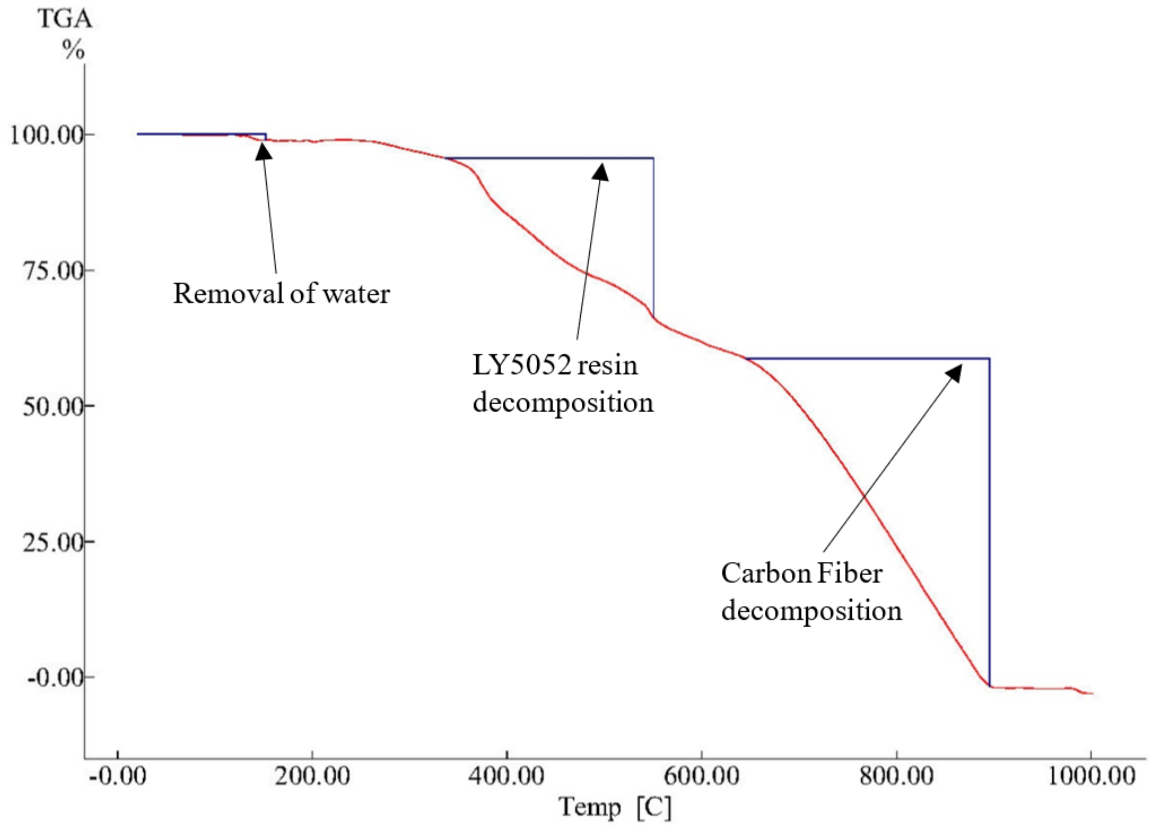

FIGURE 6. Carbon/LY5052 composite thermogravimetric analysis result's curve

TABLE 4. Analysis of thermogravimetric results of carbon/LY5052 composite

Characteristics	Degradation (%)
Highly volatile	1.433
Medium volatile	32.284
Combustible	28.528
Residue at 850 °C	9,977

MECHANICAL CHARACTERISTICS OF CARBON/LY5052 COMPOSITES

Figure 7 is the results of the tensile test on the carbon/LY5052 composite with varying temperature loads from room temperature (RT), 50 °C, 100 °C, 150 °C, and 200 °C. Figure 7 shows the stress-strain curve of the results of tensile testing of carbon/LY5052 composites with various temperature variations, including room temperature (RT), 50 °C, 100 °C, 150 °C, and 200 °C. The curve at room temperature (RT) has the highest tensile strength (553.092 MPa) with a strain of 4.837%, so the RT conditions are the best for carbon/LY5052 composite materials. The trend of decreasing strength in carbon/LY5052 composite materials immediately occurs when the temperature increases by 50 °C, resulting in 506,540 MPa with a strain of 5,417%. The decrease in material strength, as seen from the results of the stress-strain curve, begins to occur significantly when the temperature is 100 °C, when the stress is 340.199 MPa, and the strain is 4.664%. The decrease continued at temperatures of 150 °C and 200 °C, with resulting tensile strengths of 265,775 MPa and 241,829 MPa, respectively.

In Table 5, there is a decreasing trend in the elastic modulus value of the Carbon/LY5052 composite sample from RT to a temperature of 150 °C, but an increase at a temperature of 200 °C. Guangyong Sun reported the same thing in previous research, but there is no explanation for the source of this event.

Figure 8 shows that the higher the temperature during the tensile test, the more the resulting tensile strength value decreases. The red dotted line in Figure 8 illustrates the possible behavior of the carbon/LY5052 composite stress value in the tensile test with variations in temperature from room temperature up to 200 °C. The results show that the higher the temperature load during the tensile test, the stronger the carbon/LY5052 composite decreases, as well as the lower the strain value when the temperature is higher. The tensile strength was decreased 8.42% when the temperature was increased to 50 °C. The highest tensile strength decline happened at 100 °C that is 32.84%. The lowering of tensile strength still happened at 150 °C with a value of 21.88%. A small reduction of 9.01% tensile strength occurs at 200 °C.

This is influenced by several factors that can affect the strength and performance of the composite, including bonding on the interface between the resin and the fiber, as well as the mechanical properties of the resin and the fiber, which significantly affect the performance of the composite. Fiber length, orientation, fiber-to-resin ratio, and the fabrication method used to make the composite also affect the performance of the composite (Irawan et al. 2011). Specifically, for the tensile test along with temperature on carbon/LY5052 composites, the strength of the composite gradually decreases with increasing temperature. This is because the epoxy resin matrix is

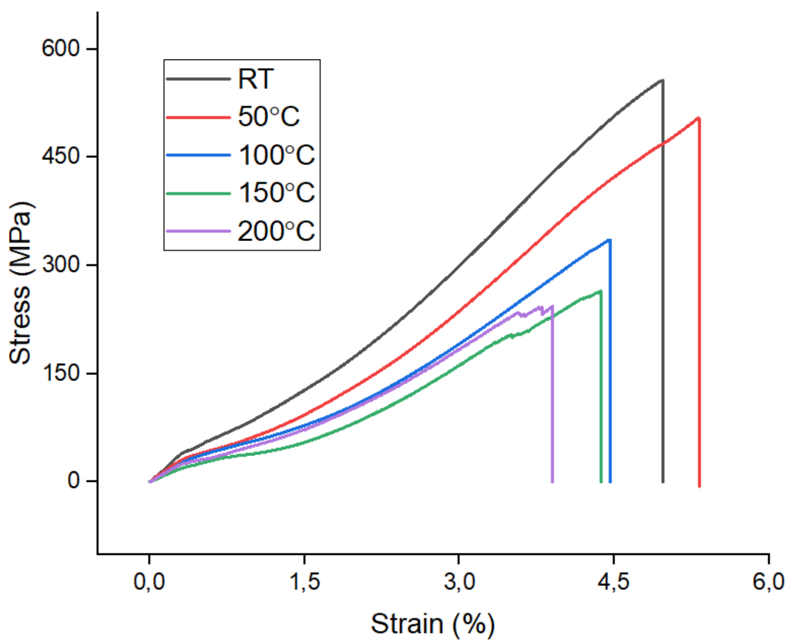

FIGURE 7. Carbon/LY5052 composite stress-strain curve from tensile test at various temperatures

already in a soft and highly elastic state and has a low Young's modulus and more significant elastic deformation when the chain bonds begin to loosen due to melting at high temperatures (Li et al. 2016). These results indicate that the higher the temperature during the tensile test on the carbon/LY5052 composite, the more it contributes to the stability of the composite's strength at high temperatures (Cao, Wu & Wang 2009).

For the elastic modulus, as in Table 5, the decrease occurs from RT to 150 °C. The glass transition temperature (Tg) plays an important role in this phenomenon, which can change from a hard/glassy state to a soft/leathery state. Based on data sheet LY5052, Tg for the curing process of 23 °C for 8 days is in the range 63 °C - 68 °C (Huntsman 2012). Higher curing temperature can increase the Tg of LY5052, as can be seen in Table 6. This Tg value corresponds to the elastic modulus value which decreases when passing Tg. There is an increase in the modulus value at 200 °C, this phenomenon is assumed due to carbon fiber being reoriented because the matrix had been softened. The fiber orientation became more homogenous and increased the tensile resistance.

TABLE 5. Elastic modulus of carbon/LY5052 composites

Temperature	Elastic modulus (GPa)	
	Average	Standard deviation
RT	13.731	1.241
50 °C	10.399	0.807
100 °C	8.682	0.698
150 °C	6.831	0.689
200 °C	7.528	1.099

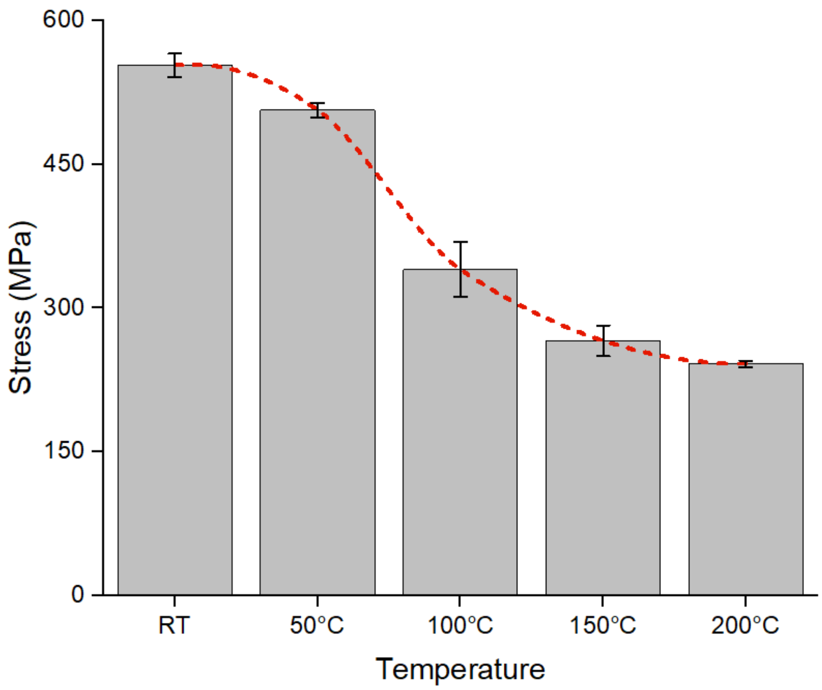

FIGURE 8. Tensile test behavior of carbon/LY5052 composites at various temperatures

TABLE 6. Glass transition temperature of LY5052 at several curing conditions based on the technical datasheet

Curing condition	Tg (°C)
2 days 25 °C	52-55
8 days 25 °C	62-66
4 months 2 °C	67-71
1 day 23 °C + 10 h 40 °C	70-76
1 day 23 °C + 20 h 40 °C	74-80
1 day 23 °C + 10 h 50 °C	80-85
1 day 23 °C + 20 h 50 °C	82-88
1 day 23 °C + 10 h 60 °C	94-104
1 day 23 °C + 15 h 60 °C	96-106
1 day 23 °C + 2 h 80 °C	108-114
1 day 23 °C + 8 h 80 °C	114-122
1 day 23°C + 1 h 90 °C	108-118
1 day 23 °C + 4 h 90 °C	116-126
1 day 23 °C + 1 h 100 °C	118-130
1 day 23 °C + 4 h 100 °C	120-134
4 months 23 °C + 4 h 130 °C	120-132

CARBON/LY5052 COMPOSITE FAILURE MODES

Figures 9 and 10 show the failure modes of the carbon/LY5052 composite specimens after the tensile test was carried out with temperature variations of (RT), 50 °C, 100 °C, 150 °C, and 200 °C. From the following figure, it can be seen that the failure modes of several specimens after tensile testing. The failure mode of the tensile test at room temperature (Figure 9(a)) and at 50 °C (Figure 9(b)) is that the fiber and matrix are broken together because the resin bonds are still firmly attached between the fibers. When the temperature is increased by 100 °C, the failure mode that occurs (Figure 9(c)) is that apart from the fiber and matrix breaking together, there are parts that experience debonding due to the low bond strength of the fiber and matrix interface (Johnson, Hayes & Jones 2012). Due to this debonding, a delamination failure mode occurs in the carbon/LY5052 composite specimen.

Fiber debonding due to increased temperature breaks down the chemical bonds between the fibers and the adjacent matrix, creating a new surface. Increased debonding of fibers causes strain energy to create new surfaces; increased debonding of the laminate due to lower interfacial strength will encourage delamination (Garrett 2016). This is very clearly seen in the failure modes of the carbon/LY5052 composite specimens at 150 °C (Figure 9(d)) and 200 °C (Figure 9(e)). The failure modes that occur are almost similar when viewed from the specimen's top surface; it looks intact; only fiber debonding occurs, but when viewed from the side view, it is clear that it has experienced delamination. This delamination is caused by the epoxy's inability to withstand high temperatures. This is because the epoxy resin softens in this temperature range, so the specimen fails with the loss of some of the epoxy matrix, resulting in separation between the laminations on the composite (Hawileh et al. 2015, Sun et al 2021).

When the temperature is below Tg, the failure mode is brittle, and fibers are still surrounded by the resin matrix. In this case, the temperature has an insignificant effect on the tensile behavior and failure mode of FRP laminates/sheets. When the temperature reaches the resin

Tg, the resin softens and causes the separate fibers to fracture. In other words, the laminates fail due to the resin softening and gasification followed by fiber rupture. In this case, considerable mechanical properties degradation will occur, and part of the epoxy will also be lost. When the temperature reaches Td, almost no resin will be left since the resin reaches its self-ignition temperature. This will let the specimen bend freely after the tensile test.

SCANNING ELECTRON MICROSCOPIC (SEM) ANALYSIS

Microstructural observations were carried out on carbon/LY5052 composite specimens using scanning electron microscopy (SEM). SEM was used to carry out microstructural observations of composite damage. Figure 10(a) is a carbon/LY5052 composite specimen before tensile testing; from SEM observations, there are no voids. The process is carried out under a vacuum so that the gases in the mold have been removed, and indirectly, atmospheric pressure will reduce the porosity in the sample (Abdurohman et al. 2018). When seen from the SEM results of the tensile test at room temperature (RT), the resin content is intact throughout the fiber (Figure 10(b)).

Compared to the tensile test at 50 °C (Figure 10(c)), parts of the fiber began to reduce the resin content. Besides that, the composite at 50 °C also showed fiber imprints. This condition showed that the composite with epoxy resin was very sensitive to temperature. When the temperature is increased to 100 °C, as shown in Figure 10(d), the carbon/LY5052 composite specimen's condition is degraded in the matrix characterized by broken fibers without resin. This indicates poor adhesion between the fiber and resin due to temperature and the appearance of many cracks as a cause of delamination. For the results of the tensile test at temperatures of 150 °C and 200 °C, analysis was not carried out using SEM because there was no fracture between the fiber and the matrix. The SEM in this study focuses on explaining the fracture in the fiber and matrix due to the tensile test, which occurs at temperatures of 150 °C and 200 °C, the specimens that have been eliminated and did not break during the tensile test.

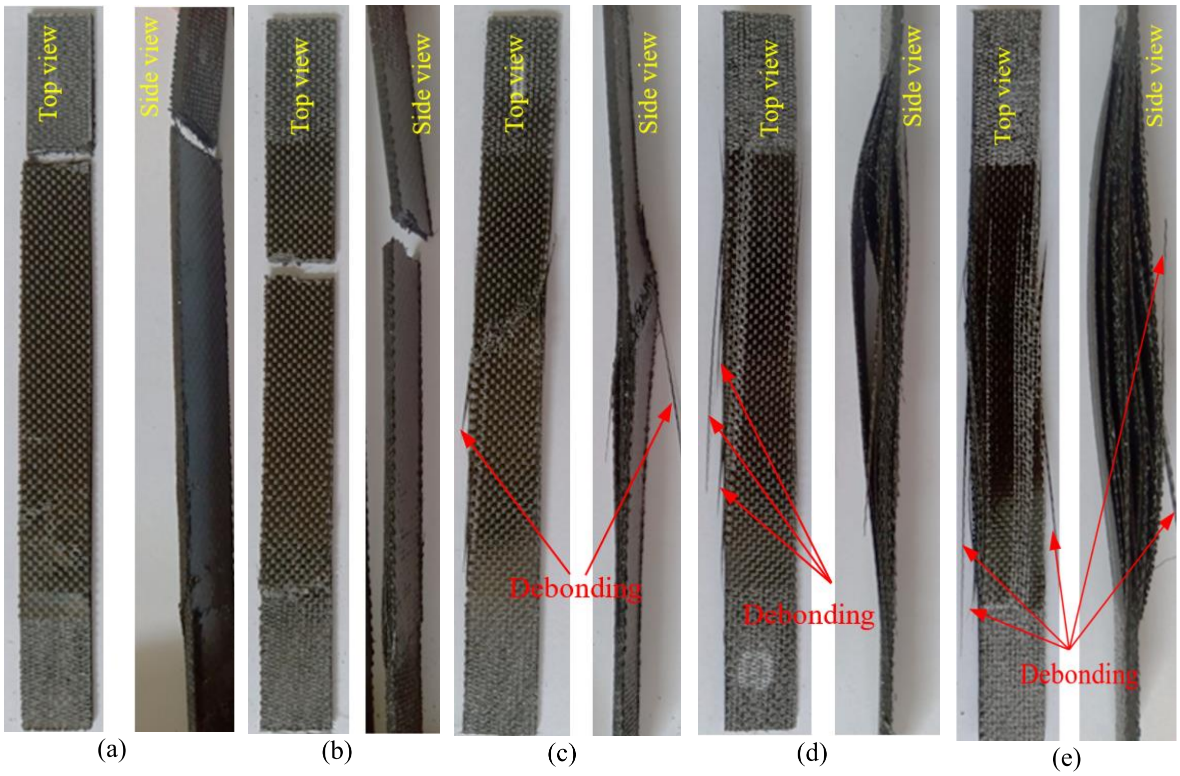

FIGURE 9. Carbon/LY5052 composite failure modes: (a) RT, (b) 50 °C, (c) 100 °C, (d) 150 °C, and (e) 200 °C

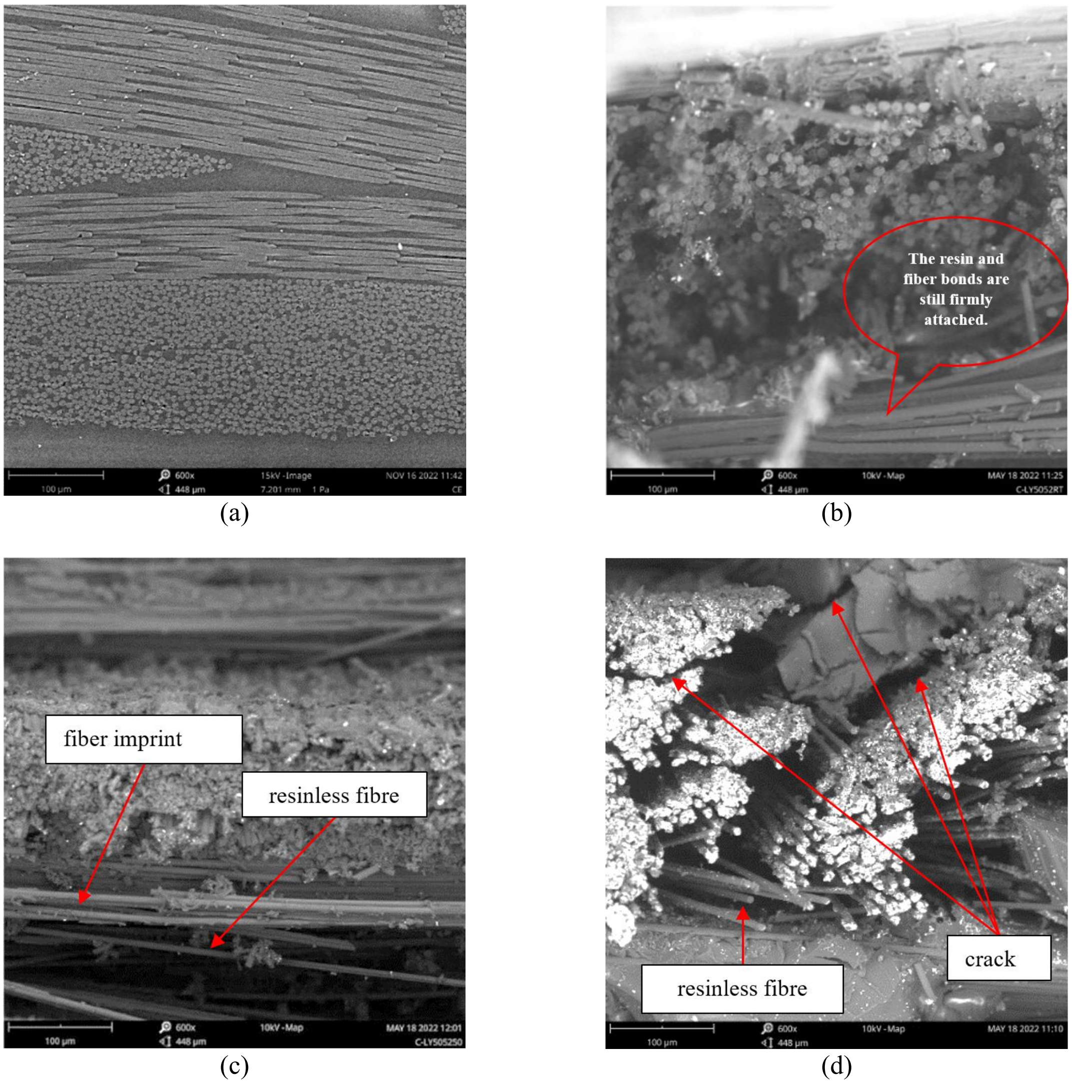

FIGURE 10. SEM of carbon/LY5052 composite cross-section: (a) before the tensile test, (b) RT, (c) 50 °C and (d) 100 °C

CONCLUSION

Based on experimental results, the reference material for spacecraft structure materials can be made from carbon/LY5052 composite materials that have undergone several tests, including thermal conductivity, Thermogravimetric Analysis (TGA), and tensile strength with temperature fluctuations. The results obtained from the thermal conductivity measurement of 0.419 W/mK, based on Thermogravimetric Analysis (TGA), showed that carbon/LY5052 composites began to decompose at 365.63 °C. The results of the tensile test with temperature loads showed the tensile strength values of the composites at room temperature, 50 °C, 100 °C, 150 °C, and 200 °C, with values of 553, 507, 340, 266, and 242 MPa, respectively. Following tensile testing, failure analysis of carbon/LY5052 composites reveals that delamination occurs at high temperatures, whereas fiber and matrix breaking occurs at low temperatures. LY5052 Tg affected the mechanical properties at high temperatures and LY 5052 Tg can be modified by modifying the curing condition. Tensile strength was decreased after surpassing the Tg, besides, that fiber reorientation could improve elastic modulus at high temperatures. These research results can be considered when designing spacecraft components that operate at high temperatures. The reduction of mechanical properties should be the main consideration when using carbon/LY5052 material to avoid fatal failure. LY5052 epoxy resin is a potential material for spacecraft structures, offering benefits like ease of impregnation, robustness, and resilience to high temperatures.

ACKNOWLEDGEMENTS

The authors acknowledge Research Organization for Aeronautics and Space, National Research and Innovation Agency (BRIN) for supporting of this research through Rumah Program Research Organization for Aeronautics and Space 2024.

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