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Synthesis and Characterization of Composite Materials with Enhanced Thermo-Mechanical Properties for Unmanned Aerial Vehicles (Uavs) and Aerospace Technologies

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ABSTRACT

Lightweight and high strength composite materials are vital for unmanned aerial vehicles (UAVs) and aerospace technologies with desired characteristics. Carbon composite materials exhibit extraordinary properties for UAVs and aerospace applications. This study aimed to discover the best-prepared composition of composites material having epoxy LY-5052 and carbon fibres laminate for UAVs. Besides, to develop a low cost with high specific strength composite material for aerospace application to replace metallic alloys. In this work, the vacuum bag technique is used to prepare rectangular strips of three different ratios of carbon fibre/epoxy laminates [(40:60), (50:50) and (60:40)] to obtain the best composite in terms of properties. The thermo-mechanical and viscoelastic behaviour of composite materials were evaluated using differential scanning calorimetry (DSC), universal testing machine (UTM) and dynamic mechanical analysis (DMA). The tensile strength of epoxy LY5052 composites with 60 wt% has enhanced to 986%, and glass transition temperature (Tg) was improved from 71°C to 110°C. Overall, 60 wt% carbon fibre exhibits better thermo-mechanical properties with lightweight, which may be a future composite material for aerospace, especially UAVs technologies.

Keywords: Aerospace and unmanned aerial vehicle, carbon fibres, composite materials, thermo-mechanical, vacuum bag technique

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INTRODUCTION

Currently, carbon fibre composites have broad applications in aerospace, for examples, Unmanned Aerial Vehicles (UAVs) used in military and routine applications (i.e., considering the air contamination, research, polar area observing, and animal calculations along with significant military field) (Schlothauer et al., 2020). The interest for more flexibility, successful payload UAVs is enlarging, where composite materials are assuming a basic function in the advancement of these new elite UAVs with exceptional composite material properties (lightweight and high quality) (Ramirez-Atencia et al., 2020). These composite materials are established by twice Young's modulus when contrasted with various types of metals and aluminium alloys with half low weight retention (Giones & Brem, 2017). In any argument, high stiffness, corrosion resistance, thermal and vibration damping characteristics are viewed as the most significant properties mulled over when working with UAV's composite materials (Ramirez-Atencia et al., 2020). The composite materials, the blending components, comprised of a few stages with various physicochemical properties. Composites are separated into reinforced filler and matrix following their capability. The most typically used matrix materials are metals, ceramics, and polymers. While, the reinforcement fillers are carbon, glass, boron, and aramid.

UAVs and aerospace technologies are manufactured mostly from aluminium, titanium, and steel, which reduced UAVs flight time due to heavyweight. The carbon fibre composites are exhibiting low density as compared to metals. However, mechanical damage is susceptible when composites being subjected to tension, flexural and impact loads (Shokrieh et al., 2013). Rahmani et al. (2014) investigated the effect of fibre orientation and fibre content in terms of mechanical properties by utilizing various epoxies. However, the prepared composites were brittle, elongation at break and impact strength was much lower while our research focuses on a different aspect of mechanical and thermal properties. Ridzuan & Jagan (2019) investigated the carbon fibres composite (CFC) for motorbikes' arms by utilizing hand layup process. However, there was no information regarding the epoxy used and curing time of epoxy was much longer to be 48 hours. Afshar et al. (2020) investigated the carbon fibre epoxy composite having different epoxy compared to us with the other motive. The motive of their research was the effect of environmental exposure with a metallic coating. The metallic coating increased the composite material's density and may not be suitable for various aerospace applications. Muralidhara et al. (2020) investigated the carbon fibres with boron carbide particles' insertion by utilizing LY1564 epoxy. The process adopted was much longer. Also, the information on tensile and flexural strength of the composite was not reported. Kaybal et al. (2020) were investigated the carbon fibres composites with a different epoxy. The researchers evaluated the effect of boron nitride reinforcement on the machinability of composite materials. The correlation of fibre orientation and resin, the effect of hardener over epoxy, inter-facial strength with respect to electrical, thermal, thermo-mechanical, inter-laminar fracture and vibration characteristics of composite with different types of the epoxy matrix were established by various researchers (Batabyal et al., 2018; Ashori et al., 2019; Kaybal et al., 2020; Ekşi & Genel, 2017; Kaleemulla & Siddeswarappa, 2010; Minty et al., 2018; Muralidhara et al., 2020; Ornaghi et al., 2010; Rahmani et al., 2014; Ridzuan & Jagan, 2019; Lee et al., 2018; Vasudevan et al., 2018). However, no one has used LY5052 epoxy for 40, 50 and 60 wt% of carbon fibre composites. Epoxy LY5052 exhibits outstanding mechanical and thermal properties besides lightweight. It can be best suited for replacing aluminium, titanium and steel if reinforced with carbon fabrics. This work is the continuation of work published by Khan et al. (2020) to explore further the mechanical and thermal-mechanical properties of epoxy LY-5052 and carbon fibres composites at various ratios.

This study investigated the effect of laminated carbon fibres on epoxy LY5052 at three different ratios, i.e., A=40, B=50 and C=60 wt% [A=CF/Epoxy (40:60), B=CF/Epoxy (50:50), C= CF/Epoxy (60:40)] of composites properties in terms of tensile strength, tensile modulus, tensile strain, flexural strength, flexural modulus, storage modulus, tan§ and density with the simple and easy process. Where; CF stands for carbon fibres. The main objective was to compare the best suitable ratio of carbon fibres reinforced composite using a special epoxy for structural applications. The advantages include the processing method applied, low cost, ease of production and handling, lower safety requirements.

MATERIALS AND METHODS

Materials

Matrix resin Araldite LY-5052 and the release agent QZ-13 were bought from Huntsman Petrochemical Co. Table 1 presents the properties of Araldite LY-5052 provided by the manufacturer. Unidirectional carbon fabrics (6k) were imported from Boto Corp, Korea. Table 2 denotes the physical and chemical properties of carbon fabric as provided by the manufacturer. The remaining materials, such as vacuum bags, brushes and metal scrapers and gloves for the hand layup process, were purchased from the local market. Glass mould and vacuum pump were utilized to manufacture composites.

Preparation of Composites

The composite manufacturing details were obvious elsewhere (Hassan, 2012; Reddy et al., 2019). The composites having 1.5 mm thickness were prepared by hand layup vacuum bagging technique. Glass mould was coated with a releasing agent. Samples of the composites were prepared at ratios of 40, 50 and 60 wt% [A=CF/Epoxy (40:60), B=CF/Epoxy (50:50), C=CF/Epoxy (60:40)]. A brush and metal scraper were used to wet the fabrics properly, and the samples were sealed in a polyethylene sheet through sealant tape.

Table 1

Properties of Epoxy-LY5052

Properties	Values
Flashpoint	≥ 140°C
Cure cycles	1 day at room temperature
Glass transition temperature (Tg).	50 °C, at room temperature curing
Tensile strength	49-71 Mega Pascal (MPa)
Elongation	1.5 - 2.5 %
Tensile modulus	3350-3750 MPa
Flexural strength	130-140 MPa
Viscosity at 25^{o}C	1000 – 1500 centipoise [cps]
Poisson’s ratio	0.35

A vacuum pump pipe was inserted in polyethylene sheet through a sealed hole to create a vacuum. In the vacuum bagging unit, the vacuum of -27 mm of Hg was employed for 5 hours and left the laminates in the setup for 24 hours. All the samples were then shifted to a heat treatment furnace for post-curing at 80^{o}C for 2 hours. The physical and mechanical properties of carbon fabrics are mentioned in Table 2.

Table 2

Properties of carbon fabrics

Properties	Values
Fibre Diameter (µm)	8
Density ($10^{3}kgm^{-3}$)	1.75
Young’s modulus (GPa)	250
Tensile strength (GPa)	2.7
Elongation %	1
Coefficient of Thermal Expansion ($10^{-6}\,{}^{\circ}C^{-1}$)	-0.4
Thermal conductivity ($Wm^{-6}{}^{\circ}C^{-1}$)	24

Characterization

Mechanical Testing. The mechanical testing (stress-strain) of the composites was carried out using a universal testing machine (Zwick/Roell Z020). The tensile and flexural testing was performed according to ASTM standard D-3039 and D-3518, respectively, at room temperature.

Dynamic Mechanical Analysis (DMA). A dynamic mechanical analyzer (Perkin-Elmer DMA7e) was utilized to evaluate storage modulus, loss modulus and tan delta (δ) of the composite materials. Dynamic mechanical analysis (DMA) tests were carried out according to ASTM D-4065. The size of the DMA samples was 50x12 mm^2. Each type of test was done five times, and the average was taken.

Differential Scanning Calorimetry (DSC). Differential scanning calorimetry of the composite materials was performed through the DSC analysis instrument Model: TA 2920. DSC of all the samples was done at the rate of 10^{o}C per minute heating. A nitrogen atmosphere was applied during the DSC testing of samples.

Density. The density of the sample was checked according to the GB-1033 test method for density standard so that the density of the composites can be compared with the known density of aluminium, titanium, and steel.

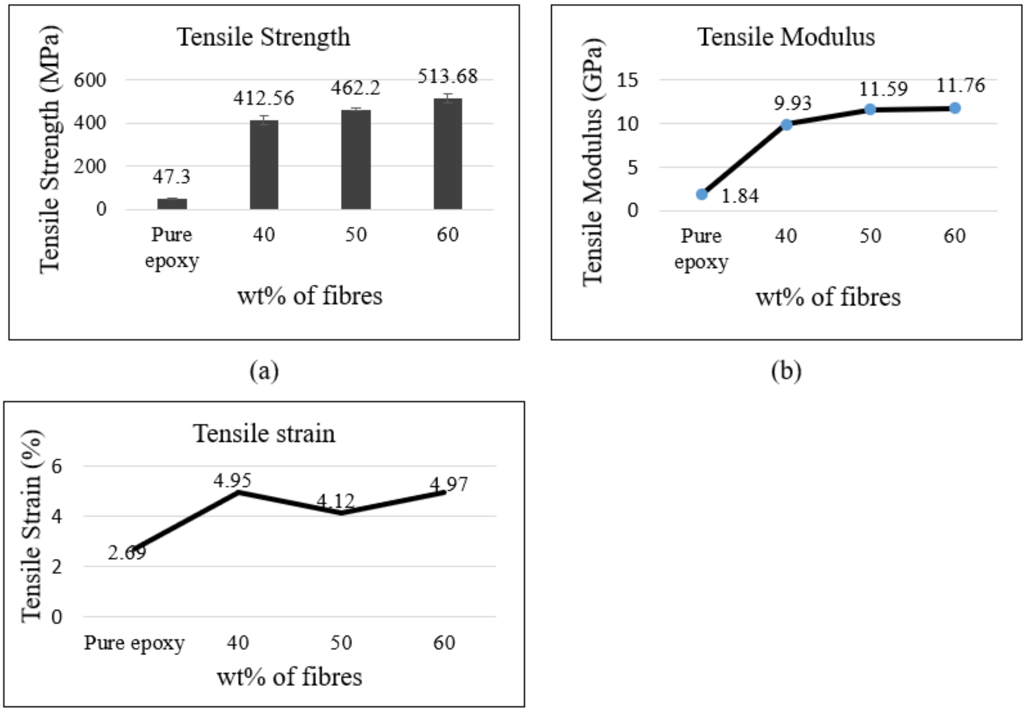
RESULTS AND DISCUSSION

Mechanical Properties

Figure 1 demonstrates tensile strength, tensile modulus and strain% for pure epoxy and carbon fibres composites (CFC). In Figure 1a the tensile strength of pure epoxy was 47.3 MPa. The tensile strength of epoxy LY-5052 was increased in all proportions after the incorporation of fibres. i.e., 412.56, 462.2 & 513.68 MPa for 40,50 and 60 wt% of carbon fibers respectively. The difference in tensile strength in pure epoxy and CFC was mainly because of the tensile strength of carbon fabrics. The increase in tensile strength was attributed to the constraining effect of fibres on the movement of polymer chains of epoxy.

Figure 1b illustrates the tensile modulus of pure epoxy and its composites with carbon fibres. The tensile modulus of pure epoxy was recorded as 1.8 GPa. The upsurge of 9.93, 11.59 and 11.76 GPa in tensile modulus was observed with the incorporation of 40, 50 and 60% carbon fibres. Figure 1c illustrates the strain percentage of epoxy and its composites at ratios of 40,50 and 60 wt%. The strain percentage of pure epoxy was improved amazingly with the incorporation of carbon fabrics. There was an increase of 84.75 % in strain% with the incorporation of 60 wt% of fibres, as presented in Figure 1c. The simultaneous increase in tensile strength and strain% at 60 wt% of fibres compared to other ratios was the sign of higher impact toughness. The tensile results are in accord with the work of Rahmani et al. (2014) and Cai et al. (2016).

Table 3 demonstrates the flexural strength of pure epoxy and its composites. The flexural strength of epoxy was recorded as 70 MPa. The upsurge of 515, 552 and 609 MPa was noticed for 40, 50 and 60 wt% of carbon composites. The rise in flexural strength with increasing fibres content resulted from the restricted movement of polymer chains of epoxy and the pinning effect of embedded fibres. The flexural modulus of laminates has also been shown in Table 3. It has been observed that with the incorporation of carbon fibres in epoxy LY 5052, the flexural modulus enhanced greatly. The higher properties exhibited by CF/Epoxy laminates are due to the better integral characteristics of carbon fibres, as reflected in Table 3. The flexural results are in accordance with the work of Barkoula et al. (2005) and Turla et al. (2014).



(a) (b)

(c)

Figure 1. (a) Tensile strength of CFC (b) Tensile modulus of epoxy CFC (c) Tensile strain of CFC

Table 3

Flexural strength and modulus of all the carbon fibres composites

Formulations (Carbon fibres/epoxy)	Flexural Strength (MPa)	Flexural Modulus (GPa)
Pure epoxy LY5052	70 ± (11.94)	0.73 ± (0.02)
40:60	515 ± (8.71)	10.53 ± (0.52)
50:50	552 ± (6.44)	10.62 ± (0.11)
60:50	609 ± (16.73)	10.77 ± (0.17)

Thermal Properties of Laminates

Figure 2 represents the Differential Scanning Calorimetry (DSC) curves for epoxy and its composites. The glass transition (Tg) of epoxy was improved at all proportions. The Tg of epoxy-LY5052 was recorded 71^{o}C. The Tg was increased to 110^{o}C with CFC at 40 wt% of carbon fibres (CF/Epoxy 40:60), as shown in Figure 2. The rise for Tg in 50 wt% and 60 wt% (CF/Epoxy (50:50) and CF/Epoxy (60:40) was up to 39^{o}C. The increase in Tg was due to the restricted movement of polymer chains. The DSC results were in accordance with the results of Vasudevan et al. (2018) & Ekşi and Genel (2017).

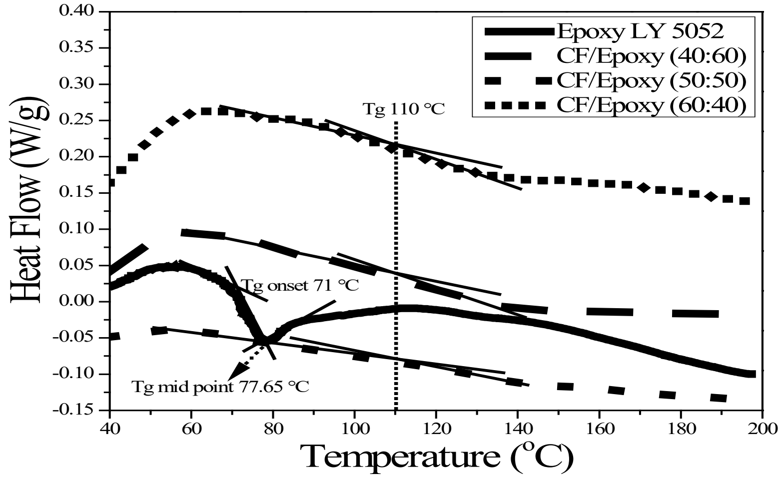


Figure 2. Heat flow vs transition temperature of carbon fibre composites

Dynamic Mechanical Analysis (DMA)

Loss Modulus. Figure 3 shows the loss modulus of epoxy and its composites. The loss modulus of epoxy was improved with the addition of carbon fibres. The peaks were shifted towards higher temperature with the incorporation of fibres, as shown in Figure 3. Broadening and shifting of peaks toward increasing temperatures was the confirmation of increment in the Tg. It may be attributed to the immobilization of the matrix chain with fibres. The results were in agreement with the study of Ornaghi et al. (2010).

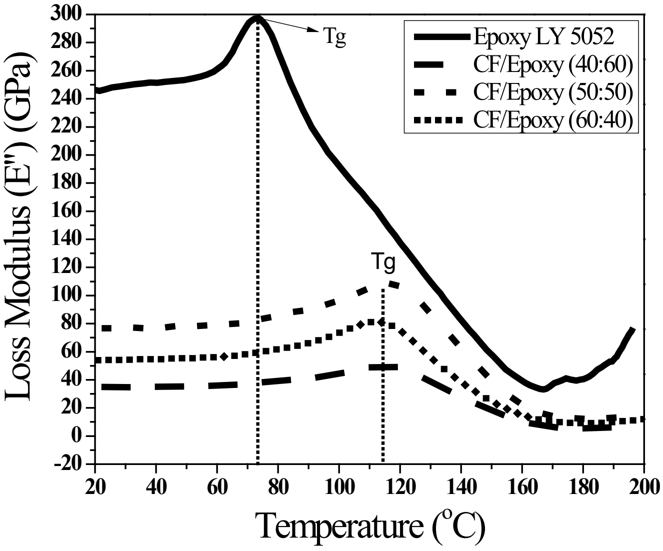


Figure 3. Loss modulus vs temperature (°C) of carbon fibres composites

Storage Modulus. Figure 4 shows the storage modulus of epoxy and its composites. The storage modulus of epoxy was increased at all proportions with the incorporation of carbon fibres. The storage modulus of epoxy was recorded to be 4.7 GPa. The storage modulus was increased to 8 GPa with the incorporation of 40 wt% of continuous carbon fibres. An increase up to 21 GPa was noticed with 50 wt% fibres. However, in the case of 60 wt% of fibres, the storage modulus was reduced to 18 GPa. It was slightly lower than the composite with 50 wt% fibres. This is expected due to the reduce interfacial bonding at the higher carbon fibre content.

The reduce interfacial bonding can be supported by the reduce Tg value from storage modulus (Figure 3) and damping (Figure 5) curves for CFC with 60 wt% carbon fibre then 50 wt% carbon fibre. DMA analysis is known to characterize fibre and matrix composites interfacial bonding at the molecular level (Dong & Gauvin, 1993). The Tg of CFC is related to the matrix chain mobility that increases with increased interfacial bonding and chain entanglement in composites. The higher value of storage modulus was reflecting the higher stiffness of composites. Apart from comparing the storage modulus values, it was established that composites viscoelastic behaviour revealed from the storage modulus decreases with increasing temperature. The drop-in modulus for epoxy was observed in the range of 70-100°C, while it was improved to the range of 100-140°C for composites, as shown in Figure 4. It happened plausibly due to the restriction in molecular mobility of polymer chains of epoxy. These results were confirmed the significant increase in Tg of composites at all proportions and coincide with the work of Backes et al. (2018).

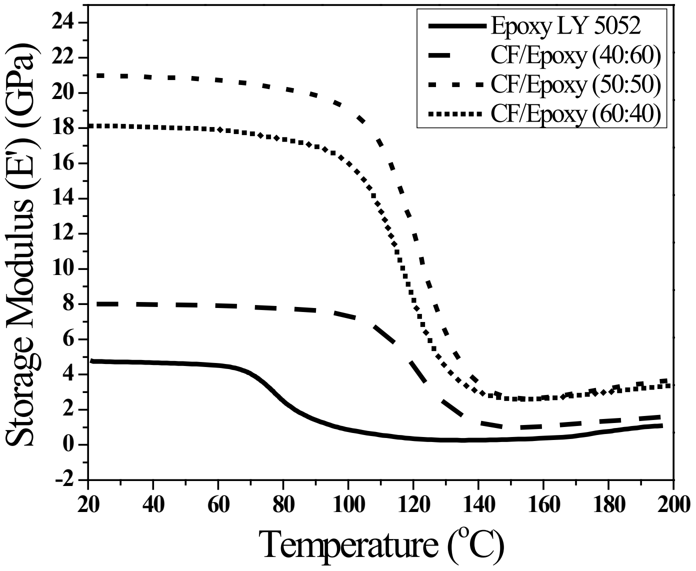


Figure 4. The storage modulus of carbon fibre composites

Tan δ. Figure 5 is showing the tan δ results of epoxy and carbon fibres composites. Tan δ can be obtained from DMA results and can be defined as storage modulus/loss modulus. This property usually represents the damping factor of the materials, which was improved by incorporating carbon fibres. Figure 5 shows that the peaks were shifted in the right direction, which confirms the increase of glass transition temperature (Tg). An increase in Tg is related to the increased in interfacial bonding in the composites material. At higher carbon fibre content (60 wt%), the Tg is slightly reduced revealed that the interfacial bonding is reduced at the higher fibre content. The results were in agreement with the study of Ornaghi et al. (2010).

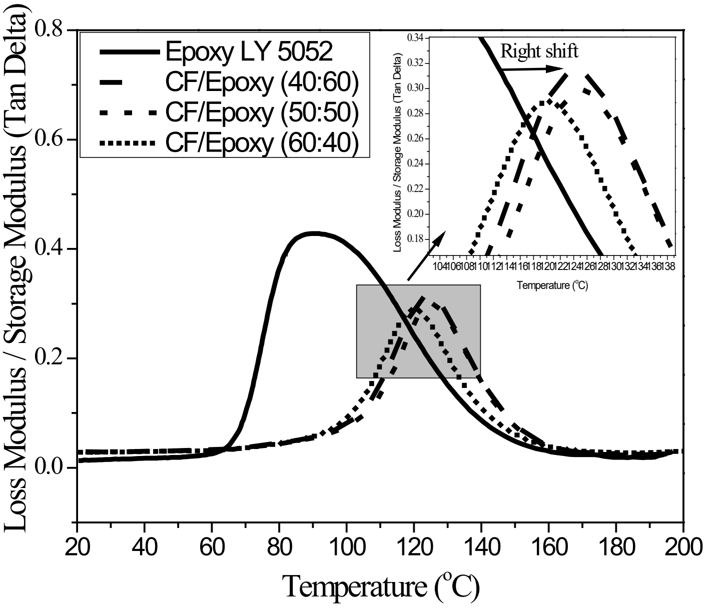


Figure 5. Tan Delta of carbon fibre composites

Density

Table 4 represents the density of epoxy and its composites. Densities of the composites were found much lower than known densities of aluminium (2.7 g/cm^3), titanium (4.5 g/cm^3) and steel (8.05 g/cm^3). The density of the composites shown in Table 4 confirmed the composite's lightweight compared to aluminium.

Table 4

The density of carbon fibres composites

Samples	Density g/cm^3
Resin LY 5052	1.16 ± (0.01)
Carbon Fibre /Epoxy Composite 40:60	1.33 ± (0.015)
Carbon Fibre /Epoxy Composite 50:50	1.31 ± (0.005)
Carbon Fibre /Epoxy Composite 60:40	1.53 ± (0.051)

CONCLUSIONS

The study's objective was to investigate thermo-mechanical properties of epoxy LY-5052 in lightweight carbon fibres composites to replace the heavy metal in UAVs and aerospace applications. The results indicated that mechanical, thermal, and thermo-mechanical properties of special structural epoxy LY5052 upsurged with fibre laminate at all proportions. However, the tensile strength, flexural strength, and CFC thermal properties at 60 wt% were highest and superior. Furthermore, the increase of fibres beyond this ratio would create wettability issues associated with the bonding interaction between CF/Epoxy, resulting in lower properties. The glass transition temperature of composites, irrespective of their mixing ratios, was much higher than epoxy. The increase was 54.92% for CFC. The decrease in loss modulus was noticed with the rise of carbon fibres in composites, which is beneficial and represents the better damping factor. Conversely, the storage modulus amplified significantly with increasing fibre content in composites. Overall, the epoxy LY-5052 and carbon fibre composites exhibit superior properties for structure application of UAVs and aerospace in terms of lightness, stiffness, and strength compared to Al, Ti and steel.

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