Evaluation of tensile properties of FRP composite laminates under varying strain rates and temperatures

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ABSTRACT. The present investigation deals with the characterization of tensile behavior of various Fiber Reinforced Polymer composites under Thermo-Mechanical loading. Five different types of Uni-Directional (UD) composites of Carbon, Glass, Carbon-Glass hybrid and Metal Laminates of Carbon and Glass were tested for tensile behavior. Tensile tests were performed at strain rates of 10^{-3}, 10^{-2}, and 10^{-1} s^{-1} at Room Temperature,250 ^{0}C and 450 ^{0}C. Stress-strain relations reveal the strain rate and temperature sensitive behavior of composites. Glass, Glass-Carbon, Glass-metal epoxy composites showed higher peak tensile stress under room temperature with varying strain rates as compared to neat carbon epoxy composites. Also, high strain rate tensile properties such as peak stress and peak strain of Glass-Carbon-Epoxy specimens were 26%, and 60% higher than that of the neat carbon epoxy composite. The failure mechanisms of both the composites were analyzed through scanning electron microscopy. The composites mainly failed due to matrix crack within elastic range under room temperature and failed with significant plastic deformation of matrix and fibers under test temperatures 250 ^{0}C and 450 ^{0}C. Finally, this study reveals that the continuous phase of metal layer embedded between Uni-Directional Glass and Carbon fiber, based composite system can be tailored to act as an energy-absorbing material system under both elastic and plastic stress strain regimes.

KEYWORDS. Carbon, Glass; High Strain Rate; Scanning Electron Microscopy; Tensile Test.

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INTRODUCTION

Many engineering structures in military applications such as, aircraft fuselage if explosives are carried and in industrial applications such as, high pressure vessels, may have to withstand internal blast loading in service. Traditionally, all internally blast loaded structures are covered with monolithic plates, made of steel. However, steel on burst or explosion, increases the risk of collateral damage by producing high velocity fragments which is may prove catastrophic in vicinity of blast site causing fatalities or serious injury to personnel or grave damage to structures. Reduction in collateral damage by use of lighter but not strength compromising materials for such structures is a novel concept. The Fiber Reinforced Polymers (FRP) composites and its variants like Hybrids, Sandwich Core and Fiber Metal Laminates offer the best solution as they disintegrate easily on blast, thereby reducing collateral damage. The use of composites in blast applications is best known as they provide high strength to weight benefits [1]. Blast loads typically produce very high strain rates in the range of 10^2 - 10^4 s^{-1}[2]. This high loading rate coupled with elevated temperature would alter the dynamic mechanical properties of structures. Under high strain tensile loading, the mechanical properties of FRP involving Young's Modulus, Tensile strength, tensile strain, Poisson's ratio etc. may suffer great changes [3-7]. The composite material has become more associated with FRP where a polymeric matrix (Epoxy, Vinyl-ester or polyurethane) is reinforced with strands of fiber or a combination of fibers (such as Glass, Carbon, Aramid etc.). Therefore, the investigation of the mechanical properties of FRP composites under dynamic loadings and different temperatures is essential to design the structures with this kind of materials.

Many testing methods have been developed for studying the dynamic response of materials under different strain rates. The screw drive load frame [8] is used for quasi-static testing of test specimens at a constant strain rate. Servo hydraulic machines are used for strain rates up to approximately 200 s^{-1} [9]. Even drop-weight impact systems can be used for this range of strain rates [10]. The Split Hopkinson Pressure Bar (SHPB), first introduced by Kolsky [11] is widely used for obtaining material properties at strain rates between 200 and 10^4 s^{-1}.

Pardo and Baptiste [12] carried out tests of unidirectional E-Glass/polyester composite specimens on a Schenck high strain rate hydraulic test machine to explore the effect of strain rate on tensile properties. The failure behavior of the pure unidirectional fibers was reported to be linear and brittle. Hayes and Adams [13] conducted various tests at various test speeds and load levels to characterize the tensile impact behavior and rate sensitive materials properties of unidirectional glass/epoxy and graphite/epoxy composites. The glass/epoxy material exhibited a considerable increase in the strength and modulus as the strain rates were increased but in case of the graphite/epoxy material system the results were opposite to that of glass/epoxy. The effects of strain rate on the mechanical behavior of Scotch ply type 1002 glass/epoxy angle-ply laminates were investigated by George and Gilat [14]. Tests were conducted at high strain rates of approximately $1000s^{-1}$ using direct tension split Hopkinson bar apparatus and quasi-static tests of strain rate approximately 0.0001 s^{-1} using servo-hydraulic testing machines. Authors reported that both fibers and matrix are sensitive to strain rates but fibers dominate the laminate properties in case of high-rate loadings. Lifshitz and Leber [15] investigated the inter-laminar tensile strength and modulus of two material systems namely E-glass/epoxy and Unidirectional Carbon fiber epoxy of 30-32 mm thick plates at high strain rates with SHPB. Results showed that both strength and modulus were rate sensitive and increased with the loading rates. The tensile behaviors of Carbon Fiber-Reinforced Polymers (CFRP) under different strain rates were studied by several researchers [8, 16-18]. It was reported that the tensile properties of CFRP are strain rate dependent, while the average transverse modulus is independent of strain rate. Barre et al. [19] determined the tensile behavior of Glass Fiber Reinforced Polymers (GFRP) using a drop-weight dynamic testing machine. The results revealed that dynamic elastic modulus and strength tend to increase with increasing strain rate. Shokrieh et al. [20] studied the tensile properties of unidirectional GFRP composites at quasi-static and intermediate strain rates of 0.001–100 s^{-1} by means of a servo-hydraulic testing apparatus. A significant increase of the tensile strength was observed with increasing strain rate. Ochola et al. [21] investigated the strain rate sensitivity of GFRP at strain rates of 10^{-3} and 450 s^{-1}. The experimental results reported that the dynamic material strength of GFRP increases with increasing strain rates.

Hawileh et al. [22] experimentally investigated the variation of mechanical properties in terms of the elastic modulus and tensile strength of composite glass (C), composite glass (G) sheets and their hybrid combinations (CG) when exposed to different temperatures, ranging from 25 to 300°C. Results showed that the elastic modulus and tensile strength reduced considerably at 250 ^{0}C in comparison to room temperature values. The hybrid combination was reported to have least value at elevated temperature. Reis et al. [7] conducted tensile tests on GFRP at different strain rates and temperatures. They reported that strain rate greatly affects the ultimate tensile strength while temperature only influences the modulus. Ou and Zhu [10] tested GFRP samples with single yarn at different strain rates from quasi-static up to 160 s^{-1} and temperatures ranging from 25 to 100°C to investigate any possible effects on their mechanical properties and failure patterns. The study found that tensile strength, maximum strain and toughness increase with increasing strain rates at room temperature, and the young's modulus, tensile strength and toughness decrease with increasing temperatures at the strain rate of 40 s^{-1}.

From the above, it is inferred that, the tensile behavior of composites especially the hybrids and FML at different strain rates and at elevated temperatures up to 450°C and their failure analysis through fractography is yet to be studied. Hence, in the present investigation three different strain rates of 10^{-3},10^{-2} and-10^{-1} s^{-1} and three different temperatures starting from room temperature, 250°C and 450°C are chosen to evaluate the tensile behavior. The fair mix of these chosen strain rate and temperatures would indicate the behavior of warhead casings in initial stages after detonation when temperature is rising in casing. The laminate samples of GFRP, CFRP, their hybrid and their metal laminates are tested under these strain rates and temperatures. The Room temperature on the day of the test was maintained at 25°C.

MATERIALS AND METHODS

Testing materials

Plain woven Uni-Directional composites are used in these tests. The UD E Glass woven fabric and Carbon fabrics were supplied by Mark Tech Limited, Bangalore, India, in areal weights of 200 g/m^2 and 204 g/m^2 respectively. Ply thicknesses of this plain weave fabrics were approximately 0.19 mm and 0.31 mm respectively. Liquid Diglycidyl Ether of Bisphenol-A (DGEBA) Epoxy resin, Araldite® LY 556 manufactured by M/s Ciba Performance Polymers, USA was used for fabrication of composite plies. Fig. 1 shows schematic representation of weave pattern for these UD Glass and Carbon fabrics.

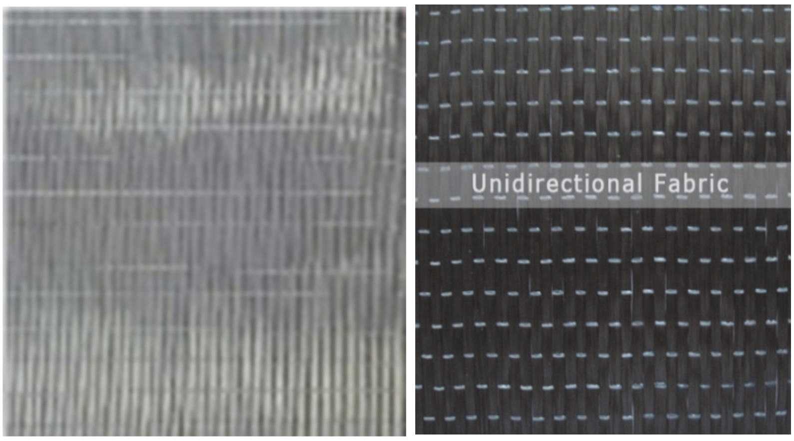


Figure 1: Schematic representation of weave pattern. (a) Plain-woven UD Glass fabric (Left) and (b) UD Carbon fabric (Right).

Laminate construction

The FRP Laminates used for tensile tests were manufactured by the aid of a Hot-press compression molding machine with pre-set temperature of 130 ^{0}C for about 10 minutes. The weight percent of fibers and matrix materials used for making laminates are given in Tab. 1.

	Laminate code	Fiber and Epoxy in weight percentage				Thickness of Laminate in mm	No.of Layers
		UD Glass fiber	UD Carbon fiber	Metal	Epoxy Matrix		
Glass Epoxy-Laminate	**GE**	55%	-	-	45%	1.79	14
Carbon Epoxy Laminate	**CE**	-	42%	-	58%	1.71	09
Glass-Carbon-Epoxy-Laminate	**GCE**	32%	18%	-	50%	1.77	12
Glass-Metal-Epoxy Laminate	**GME**	34%-	-	1%	65%	2.00	08
Carbon-Metal-Epoxy Laminate	**CME**	-	39%	1%	60%	1.89	06

Table 1: Laminate codes and weight percentages of Glass, Carbon, Metal and Matrix materials.

Tensile test specimen preparation

The specimen dimensions as shown in Fig. 2, were chosen in accordance with ASTM D 638 standards.

Specimen as shown in Fig. 3 were machined to get the required dimension as per the ASTM D 638 using water jet cutting method from cured laminates of 250 x 250 x 2mm for tensile test.

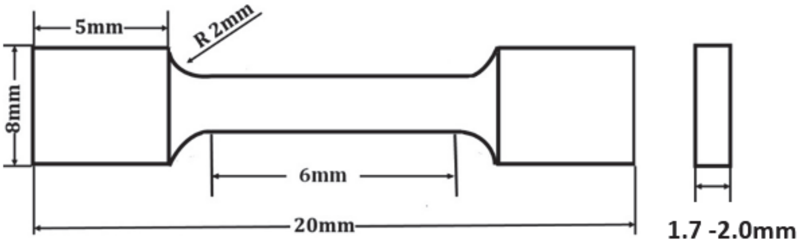


Figure 2: Tensile test specimen dimensions.

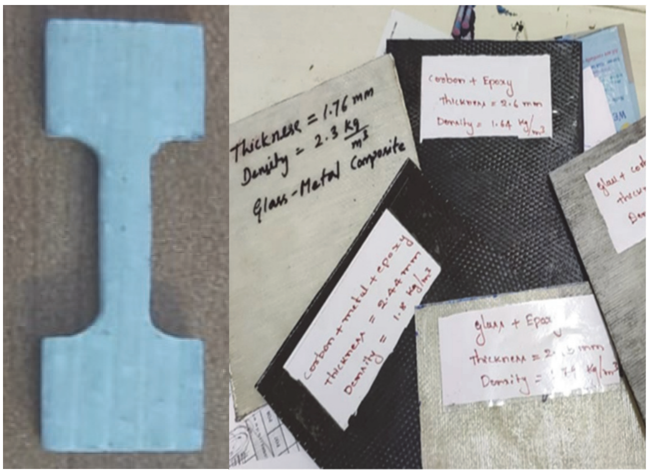


Figure 3: Images showing (a) Tensile test specimen – Left side and (b) Laminates of varying Fiber reinforcements -Right side

METHODS

Tensile Test

The tensile tests were carried out as per procedure prescribed in ASTM D 638 [23]. Testing was performed using a 30 KN Instron 5967 Universal Testing Machine (UTM) installed at Material Engineering Department of Indian Institute of Science, Bengaluru. The machine (Fig. 4) has a speed range of 0.001–1000 mm/min and load measurement accuracy of ±0.5%. In this work, load cell of 10 KN was used for testing. The UTM was coupled with an electrical heating chamber manufactured by Max Heat Furnaces, Bengaluru. The chamber was set for heating rate of 10°C/min The tests were performed at a varying cross-head speeds of 0.36, 3.6 and 36 mm/min depending on the strain rates. The test speed was controlled with strain rates of 10^{-3}, 10^{-2} and 10^{-1} s^{-1} at temperatures of Room Temperature, 250 ^{0}C and 450 ^{0}C. A total of 9 sets of readings were obtained for each type of laminate specimen and the statistical analysis of the experimental data was done by calculating standard deviations for all the experimental results discussed under the results and discussions. The strain measurement was done by Linear Variable Differential Transformer with optical encoder. The heating chamber was switched on after placing the specimen in between the upper and lower grips. A settling time of five minutes was allowed after the chamber reaches the desired temperature and then subsequently load was applied till fracture. The maximum load carried before failure is the ultimate failure strength of the material. The results as indicated by BlueHill 3 software were plotted for further analysis.

Fractography studies

Scanning Electron Microscopy (SEM) was carried out on tensile test fractured specimens of various fiber reinforcements using Tescan Mira system. Subsequently, a detailed examination was conducted to know the fiber matrix failure upon chosen temperatures and test speeds during experimentation. The discussions with proper justifications for the failure patterns of each of the composite laminates are also presented subsequently after tensile behavior of specimens under the following sections.

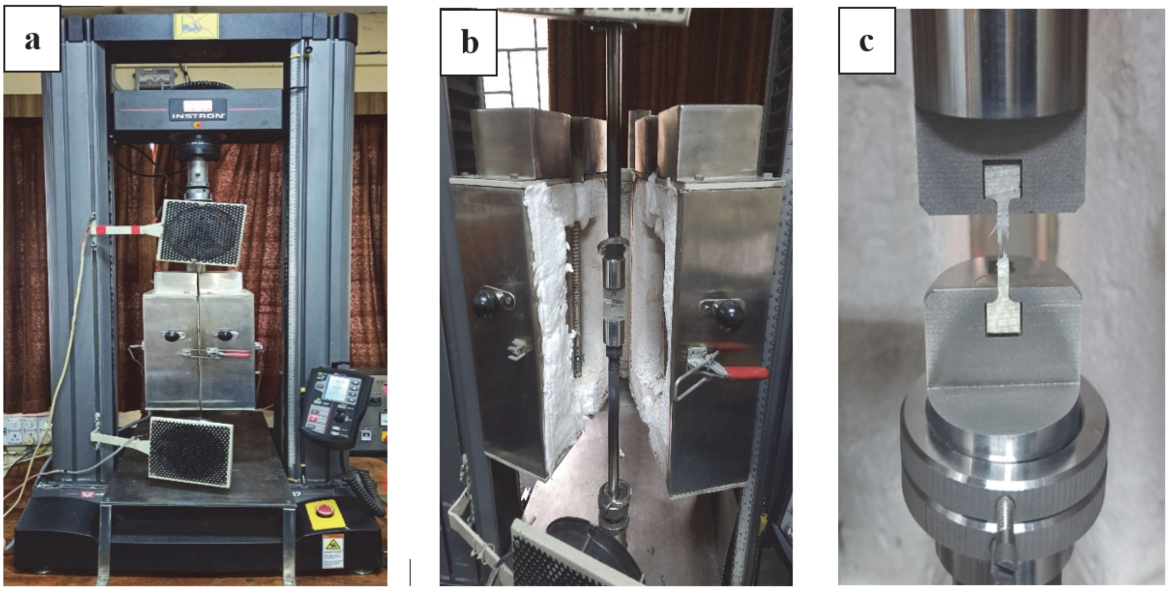


Figure 4: Tensile test setup (a) Test machine (b) Temperature controlled chamber and (c) Specimen fixed in upper and lower grips.

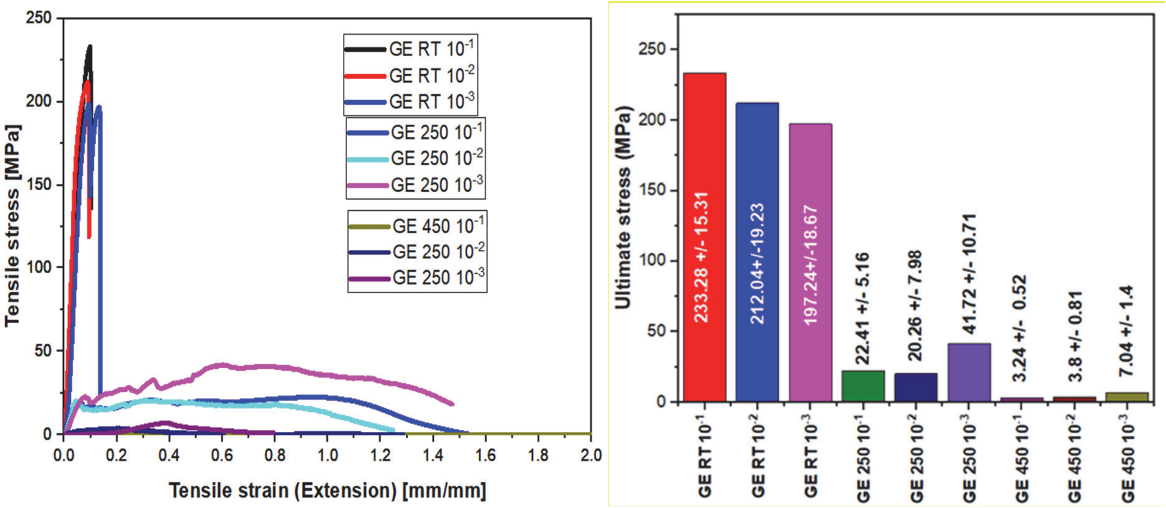


Figure 5: High speed tensile test results for (a) Tensile stress versus Tensile strain (Left) and (b) Ultimate stresses for GE laminates (Right) under varying strain rate and temperature.

RESULTS AND DISCUSSION

Temperature and strain rate response - Response of glass epoxy (GE) specimens

The stress-strain behavior for Glass Epoxy (GE) specimen is shown in Fig. 5 for all the tested strain rates and temperatures. Fig. 5 (a) indicates that the GE specimens under room Temperature (RT) exhibited a linear response until failure for all the three strain rates 10^{-1}, 10^{-2} and 10^{-3} s^{-1} with no damage up to highest tested strain rate of 10^{-1} s^{-1}. Beyond this strain rate, the tensile strength suddenly dropped indicating brittle failure in GE specimens. But for the highest tested strain rate of 10^{-1} s^{-1}, the GE specimen has taken higher load, hence higher tensile and ultimate strengths as shown in Fig. 5 (b) when compared other two strain rates used in this research investigations. Further, the test was continued by exposing GE specimens to 250^0 C keeping strain rates same as that under RT conditions. The results indicate onset of plastic deformation followed by a non-linear stress strain response. The primary cause of strain growth at this point was matrix deformation due to rise in temperature. The tensile strength dropped to 88 % of RT value due to plastic deformation when GE specimen was exposed to 250^0 C. However, the drop of both tensile and ultimate strengths) is much higher when exposed to 450 ^{0}C as shown in Fig. 5(b). Finally, it was seen that the tensile and ultimate strengths of GE specimens do not have significant effect with rise in strain rates but rise in temperature contributes significantly in lowering strength of GE specimens. It was also observed that the GE specimens are strain rate sensitive with average of 8% increase in magnitude of the ultimate tensile strength over the given strain rate change under RT.

Response of Carbon Epoxy (CE) specimens

Analyzing the tensile stress versus strain curves and ultimate stress values against varying strain rates and temperatures of CE specimens is presented in Fig. 6. Because of less elongated and high stiffened carbon fibers, the CE specimens produced lower strain values as shown in Fig. 6 (a) in comparison to GE specimens for same strain rates. For lowest strain rate of 10^{-3} s^{-1} under RT and 250 ^{0} C temperature, the CE specimens exhibited higher ultimate tensile strength with respect to other strain rates chosen in this study. By exposing CE specimens to 450 ^{0}C, there exists huge plastic deformation in the matrix, which causes significant drop in tensile strengths values as shown in Fig. 6(b).

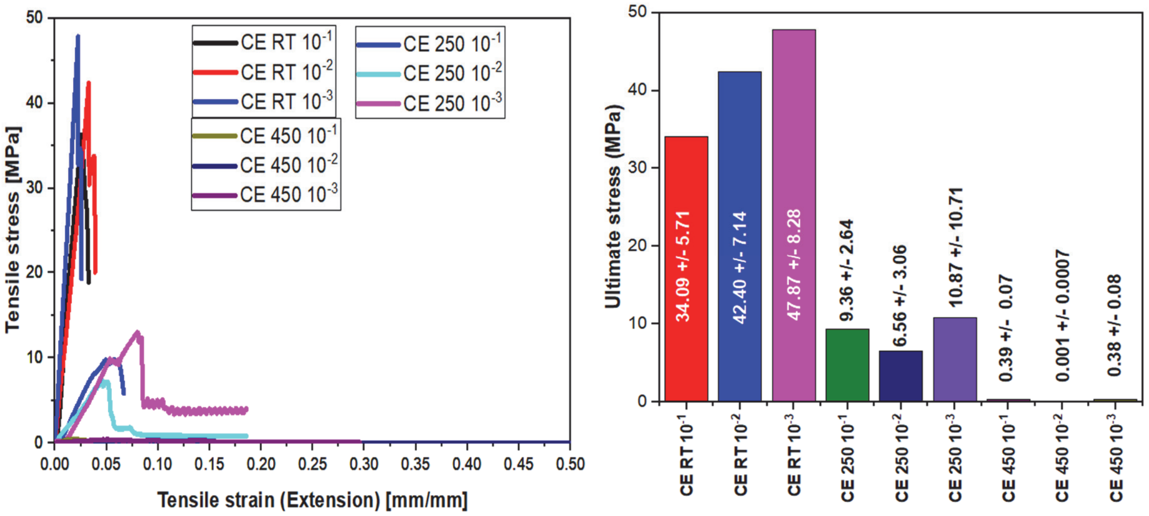


Figure 6: Plots showing tensile test results for (a) Tensile stress versus Tensile strain (Left) and (b) Ultimate stresses for CE laminates (Right) under varying strain rate and temperature.

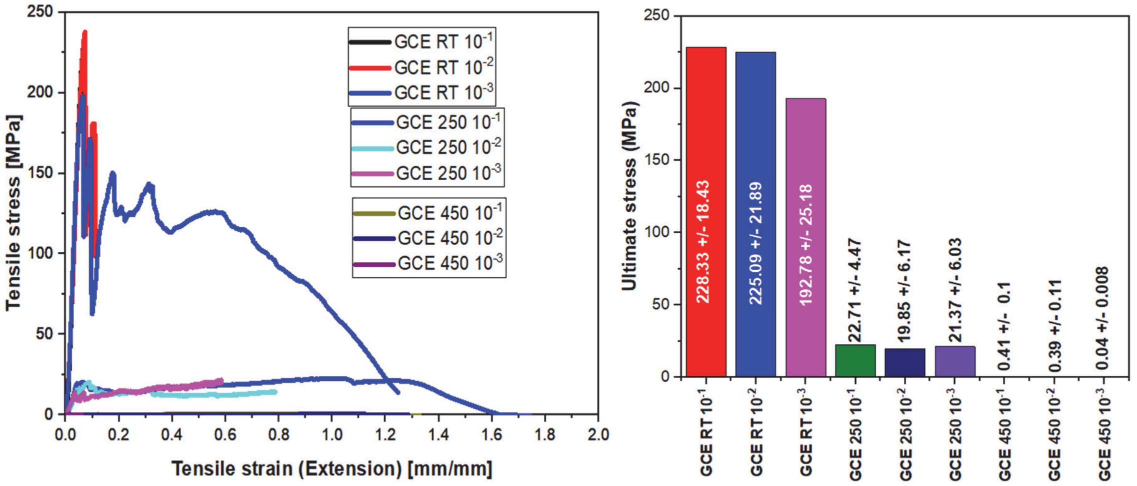


Figure 7: Plots showing tensile test results for (a) Tensile stress versus Tensile strain (Left) and (b) Ultimate stresses for GCE laminates (Right) under varying strain rate and temperature.

Response of Glass-Carbon Epoxy (GCE) specimens

The response of GCE composite specimens to changes in strain rate and temperatures is illustrated in Fig. 7. A linear stress-strain growth was observed as shown in Fig. 7(a) up to the ultimate failure strength in GCE specimens under temperatures range of RT to 250 ^{0}C for chosen test speeds. But the linear stress growth was followed by a non-linear growth in GCE-RT with strain rate 10^{-3} s^{-1}, resulting in plastic deformation up to a strain of ~0.6. Further, the significant drop in stress and stiffness with increased strain was noticed at temperature of 250 ^{0}C for all the strain rates, indicating a stable plastic deformation as a function of induced strain until fracture. For the given test speeds with increase in temperature from 250 ^{0}C to 450 ^{0}C indicates a huge plastic deformation with invisible stress strain behavior and ultimate strength values as shown in Fig. 7(b).

Response of Carbon Metal Epoxy (CME) specimens

The various types of FRP composites prepared in this investigation are further hybridized by reinforcing metals sheet as a continues phase at the mid-section of laminate to enhance the ultimate tensile strength at high strain rate with varying elevated temperatures. This type of composite system may resist high explosive blast loads before complete collapse/burst of the explosive components. The CME specimens exhibited higher tensile strength as shown in Fig. 8 (a) with no significant plastic deformation in RT conditions. It was also observed that there is a huge drop in tensile strength with slightly better and stable plastic deformation seen in these specimens at 250 ^{0}C. The ultimate strength values shown in Fig. 8 (b) did not vary much for 250 ^{0}C and 450 ^{0}C operating temperatures during test, which indicates stable performance at elevated temperatures.

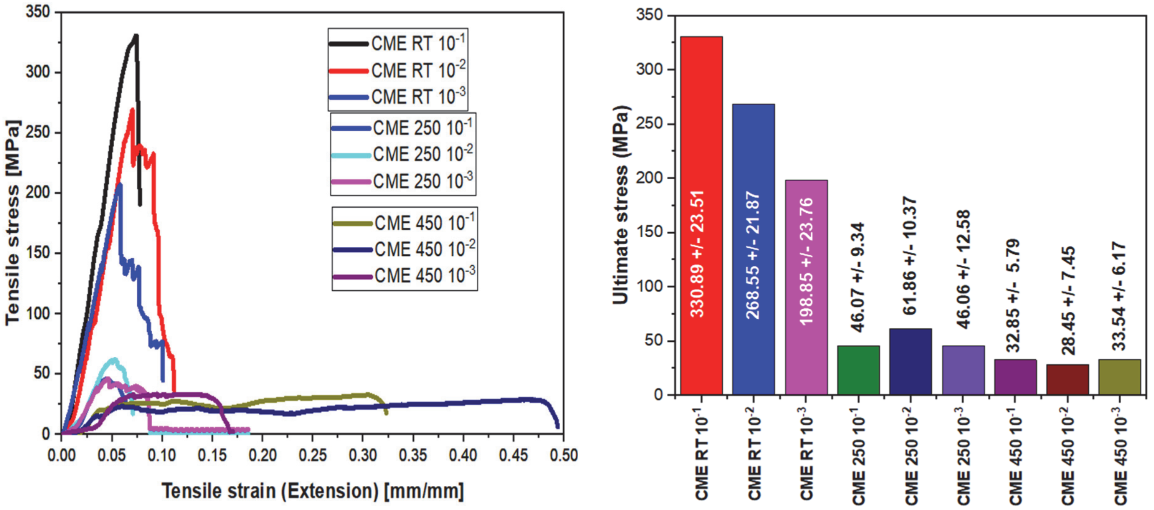


Figure 8: Plots showing tensile test results for (a) Tensile stress versus Tensile strain (Left) and (b) Ultimate stresses for CME laminates (Right) under varying strain rate and temperature.

Response of Glass Metal Epoxy specimens

The stress-strain response of GME hybrid laminates under given strain rate with varying temperature is shown in Fig. 9. The ultimate strength values which are shown Fig. 9(b) indicate quite impressive results even under elevated temperatures like 250 ^{0}C and 450 ^{0}C with low strain rate to high strain rate chosen in this investigation. It was also observed that there is no loss of stiffness in GME laminates for chosen test parameters. The presence of metal layer embedded between Glass layers in GME laminates indicates better linear stress strain behavior with elastic region up to the strain 0.025 for all the composites tested under chosen test speed and temperatures. Further, it was also seen that these hybrid laminates have stable plastic deformation beyond the strain 0.025 with non-linear stress strain response which will be most suited for making casing for internally blast loaded structures.

Comparison of tensile behavior of all tested specimens

The comparison of tensile behaviors of various specimens that were tested at three different strain rates and temperatures is presented in Fig. 10. It is clearly noticed from test results that the GME composites perform significantly better than GE, CE, GCE, and CME composites. The ultimate tensile stress values are reported to be slightly higher than neat CE specimens and also performance of GME composites is more stable under elevated temperature and across all strain rates tested. Further, GME composite as performed better under higher temperatures with higher strain rate. But CME composite gave good strength under low and moderate strain rates under lower temperature. Finally, it was concluded that GME has better strength under the chosen test parameters. This makes GME laminates most suited for Internal blast applications where reduction of collateral damage is objective.

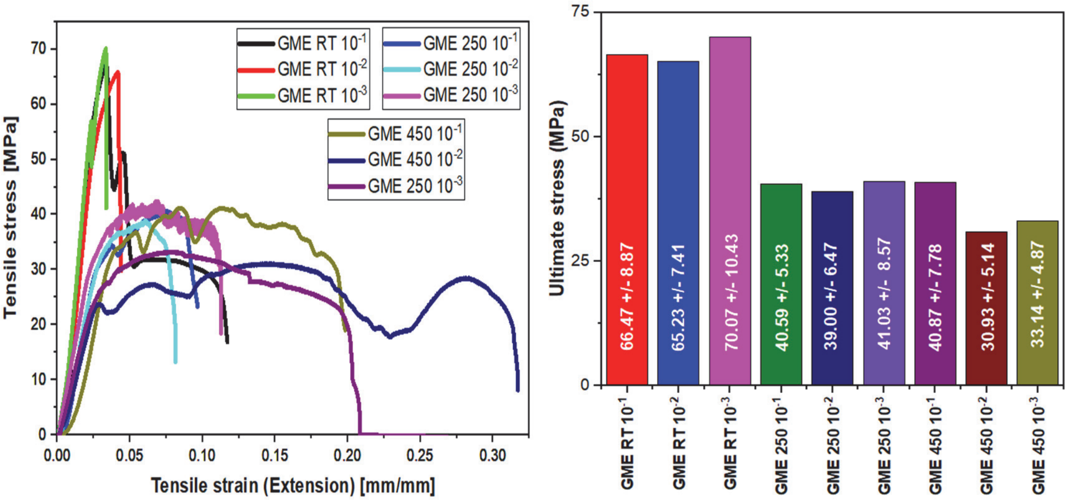
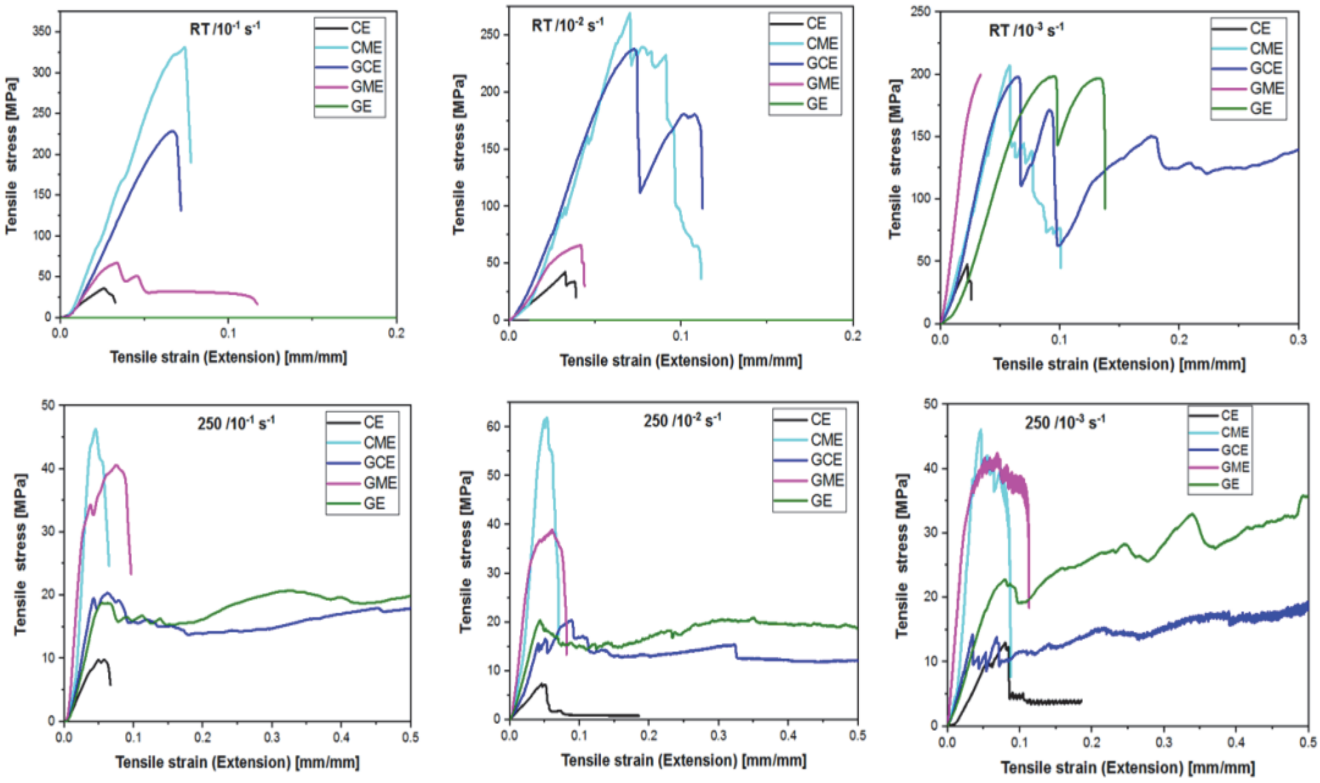


Figure 9: Plots showing tensile test results for (a) Tensile stress versus Tensile strain (Left) and (b) Ultimate stresses for GME laminates (Right) under varying strain rate and temperature.



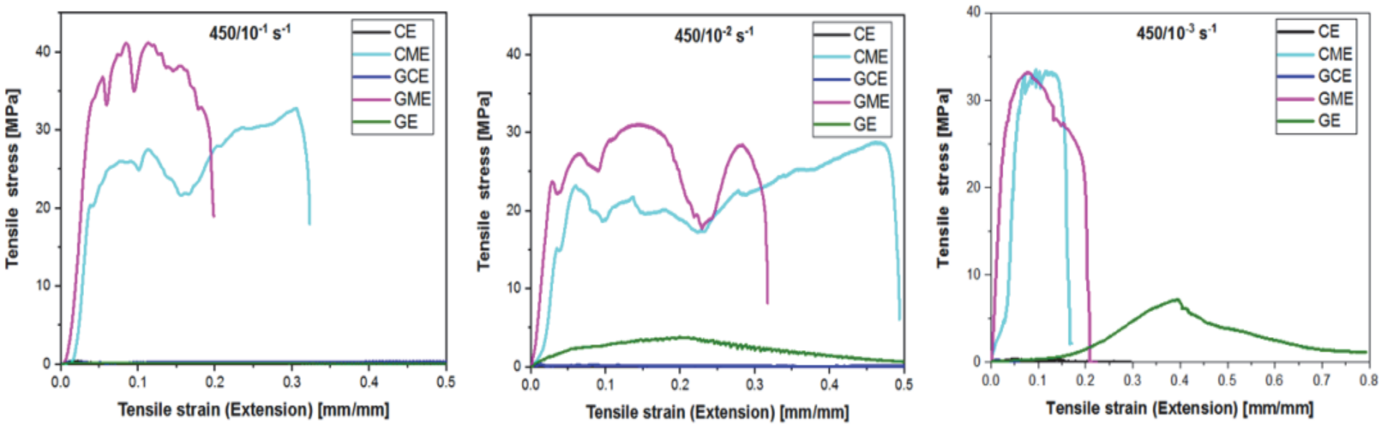


Figure 10: Tensile test results of different composites at three different strain rates and temperatures

SCANNING ELECTRON MICROSCOPY ANALYSIS

Fibre-Matrix failure analysis was examined microscopically. Microscopic analysis was performed by assessing fractured laminate images using Scanning Electron Microscope (SEM).

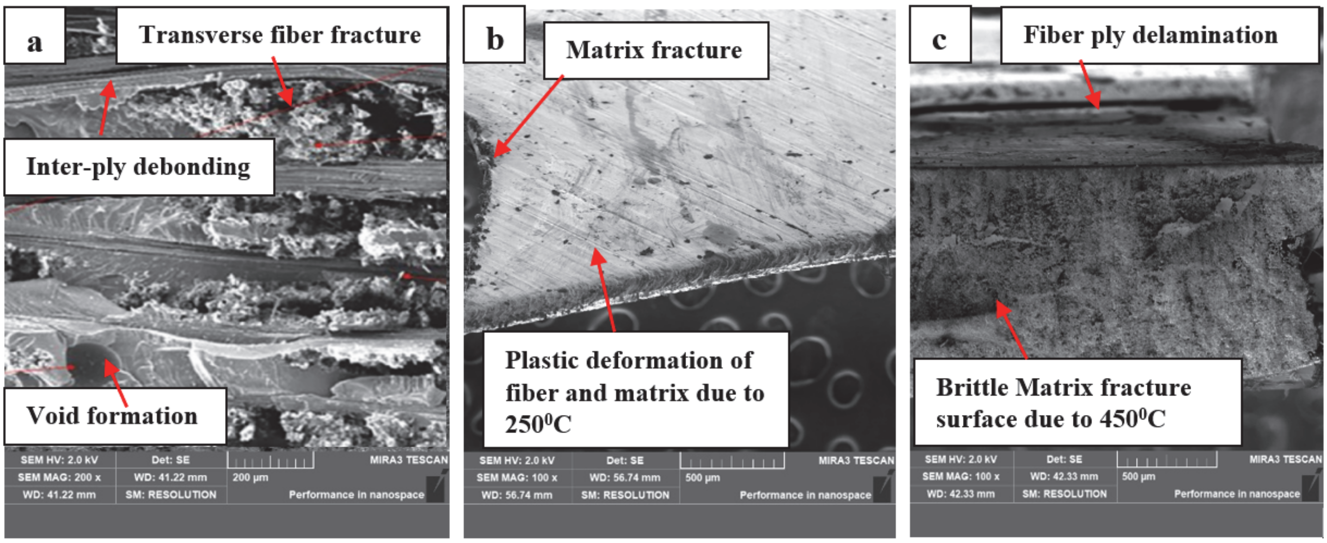


Figure 11: SEM micrographs of fractured GE laminates for (a) GE-RT, 10^{-1} s^{-1}, (b)GE-250 ^{0}C, 10^{-2} s^{-1} and (c) GE-450 ^{0}C,10^{-3} s^{-1}.

SEM analysis of GE specimens

Fig. 11 shows SEM micrographs of the GE specimen failing at a strain rate of 10^{-1}, 10^{-2} and 10^{-3} s^{-1} under room temperature (RT), 250 °C and 450°C. The GE composites under three strain rates with chosen temperatures indicating three distinct zones of fracture for a better understanding of the damage pattern. The microscopic failure primarily consisted of inter-ply debonding, cracking, and fracture under plastic deformation of the fibre and matrix with fibre-matrix debonding, fibre pull-out and local delamination. The cross-sectional area normal to tensile load with higher strain rate receives the stress wave travelling through the specimen along the fibre direction with several internal fibre–matrix failure in the form of inter-ply de-bonding and fibre fracture in transverse direction as shown in Fig. 11(a). This results into the rise in the ultimate tensile strength with brittle failure. Fig. 11 (b) depicts the edge fracture which was an outcome of dislocation of the matrix due to rise in temperature to 250°C with reduced strain rate. The moderate plastic deformation of matrix and fibers leading to huge reduction in ultimate tensile strength values, there by the composite could sustain applied loads within the non-liner region of the stress strain spectrum. With reduction in strain rate to 10^{-3} s-^{1} and increase in temperature to 450°C, the matrix phase within the GE composite system is over cured beyond its melting point temperature of the matrix and fiber leading to huge plastic deformation eventually failing to resist applied loads during the test as shown in Fig. 10 (c).

SEM analysis of CE specimens

Fig. 12 displays the SEM micrographs of fracture of CE composite at chosen strain rates and temperatures. At a strain rate of 10^{-1} s^{-1} under RT, the failure of fibers was observed through SEM after reaching maximum load, the CE composite has exhibited only inter-ply de-lamination which is seen in Fig. 12 (a). Beyond this strain rate (10^{-2} s^{-1}) by raising the test temperature to 250 ^{0}C, the CE composite was seen to be subjected to reasonably good plastic deformation (Fig. 12(b)) which is witnessed by stress strain response displayed in Fig. 6(a). At lower strain rate of10^{-3} s^{-1} and increased temperature of 450 ^{0}C, the CE composite microscopically disintegrated into multiple failed pieces with huge plastic deformation causing cracks induced shear planes. As an outcome, the broken fibers melted along with separated matrix lump which is noticeable in Fig. 12(c). This type of fiber matrix failure mechanism causes the specimen to no longer resist the applied loads, indicating no load taking capacity of CE composites. Similar failure phenomenon resulting in matrix damage induced inter-ply delamination followed by fiber failure has been reported in the literature by high-speed rate testing [24, 25, 26] and for projectile impact [27].

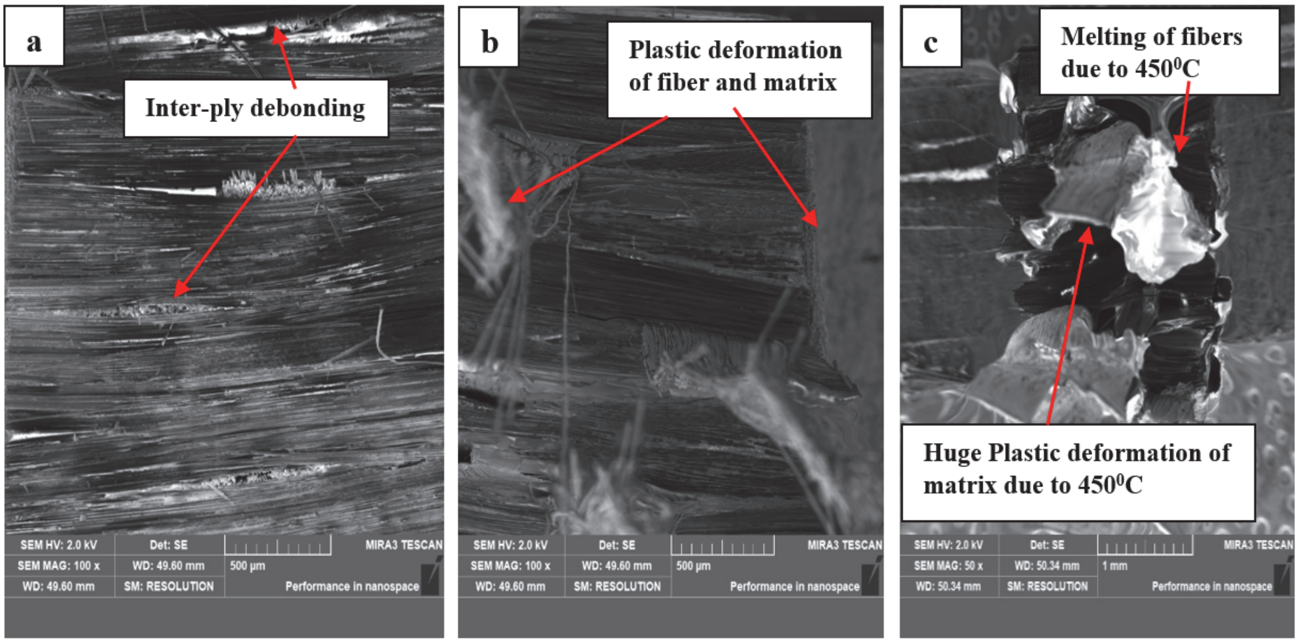


Figure 12: SEM micrographs of fractured CE laminates for (a) CE-RT, 10^{-1} s^{-1}, (b) CE-250 ^{0}C, 10^{-2} s^{-1} and (c) CE-450 ^{0}C,10^{-3} s^{-1}.

SEM analysis of GCE specimens

The fiber matrix failure mechanism for GCE composite is shown in Fig. 13**.** At strain rate of 10^{-1} s^{-1} under RT conditions, the GCE composite has failed through matrix crack as shown in Fig. 13 (a) with tensile pull induced voids and flaws. Due to this failure pattern, a linear stress strain response up to ultimate load was seen in Fig. 7(a)**.** With reduction in strain rate to 10^{-2} s^{-1} and increase in test temperature to 250 ^{0}C, the GCE composite is seen to be subjected to tensile fracture of carbon fibers by withstanding higher loads up to ultimate loads. Thereafter, the load has been resisted by high elongation and low stiffened glass fibers indicating better plastic deformation as seen in Fig. 13 (b). Further reduction in strain rate to 10^{-3} s^{-1} and increase in temperature to 450 ^{0}C, the GCE composite was not able to withstand any further tensile loads indicating huge fiber and matrix plastic deformation which is seen in SEM micro graphs of Fig. 13(c)**.**

SEM analysis of CME specimens

The micrographs of CME specimens at RT and 10 s-1 shown in Fig. 14(a) reveal a clear fracture of fibers, metal and matrix with no plastic deformation until ultimate strength limits, thereafter a catastrophic failure of CME composites is noticed.

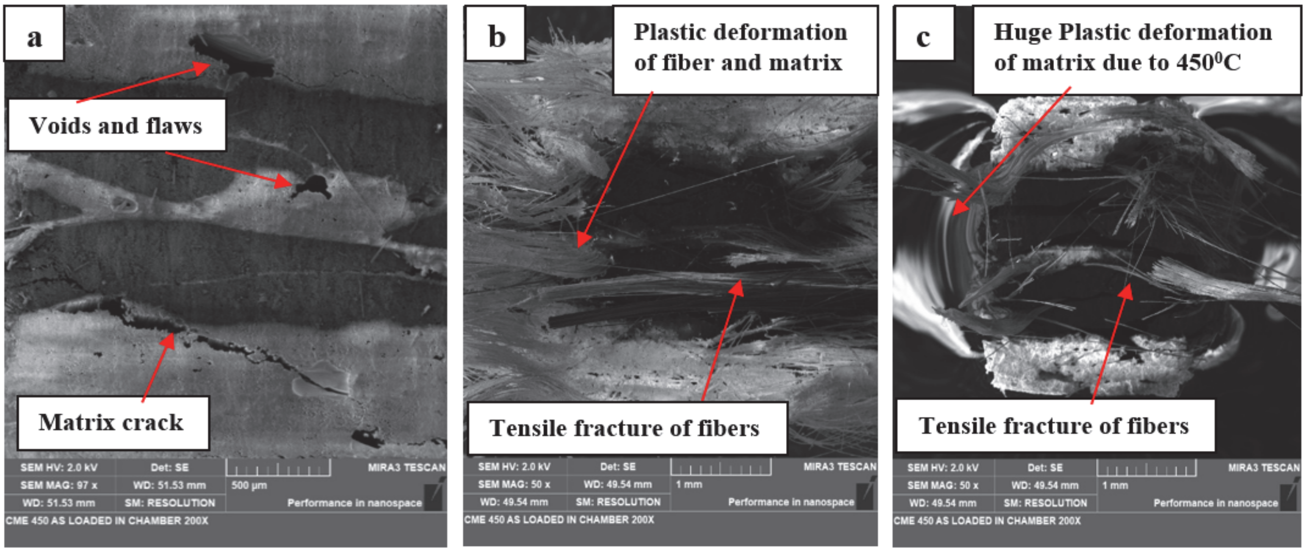


Figure 13: SEM Images of fractured GCE laminates for (a) GCE-RT, 10^{-1} s^{-1}, (b) GCE-250 ^{0}C, 10^{-2} s^{-1} and (c) GCE-450 ^{0}C, 10^{-3} s^{-1}.

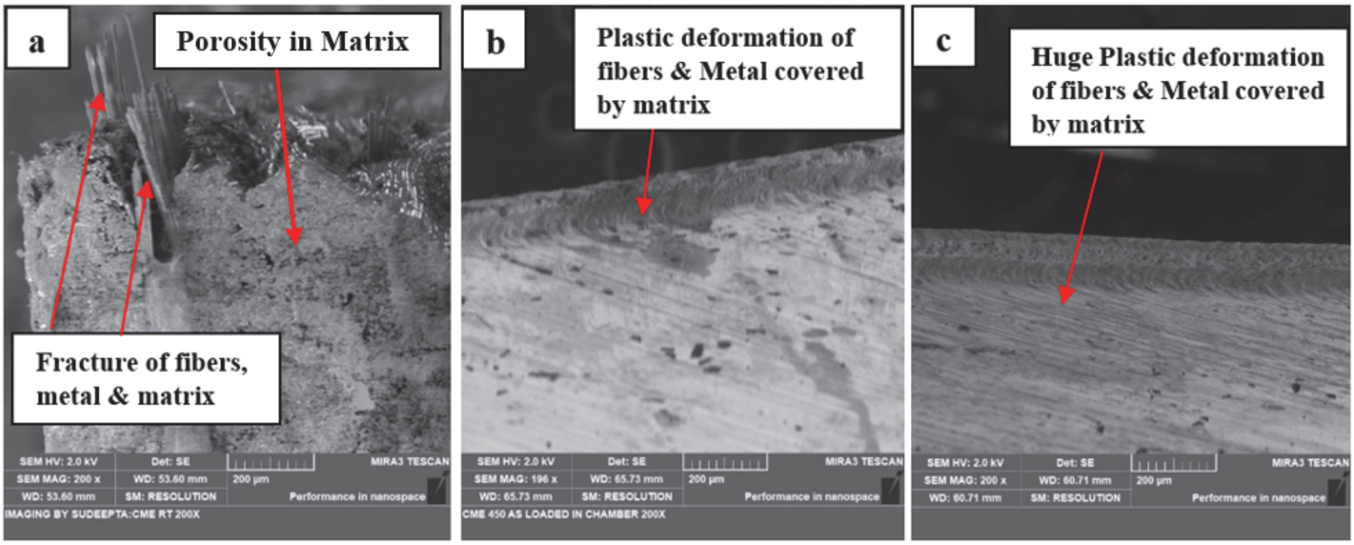


Figure 14: SEM Images of fractured CME laminates for (a) CME-RT, 10^{-1} s^{-1}, (b) CME-250^{0}C, 10^{-2} s^{-1} and (c) CME-450^{0}C, 10^{-3} s^{-1}.

But from Fig. 14(b) and 14(c) it is seen that there exists a plastic deformation followed by fracture of reinforcements and matrix leading to huge reduction in tensile strengths within the linear and non-linear regions of the CME stress strain response which is shown in Fig. 8(a).

SEM analysis of GME specimens

After the test, the fractured surface seen in Fig. 15(a), indicates that the GME with initial strain rate of 10^{-1} s^{-1} under RT, exhibits rough fiber surface and inter-ply debonding with induced voids and flaws. This nature of fracture morphology has resulted higher tensile strength and better stiffness until elastic yield limit stress, there after the GME will have catastrophic failure with non-plastic deformation. The same test performed by increasing test temperature to 250 ^{0}C with strain rate of 10^{-2} s^{-1} indicates, moderate plastic deformation of fibers, metal and matrix as shown in Fig. 15(b). The GME composite under this test parameters sustained loads even in nonlinear region of the stress-strain spectra which is displayed in Fig. 9. By further increase in test temperature to 450^{0}C with strain rates 10^{-3} S, the specimens were seen to fracture with higher plastic deformation of reinforcements and as well as matrix as shown in Fig. 15(c) leading to significant reduction in tensile strength values.

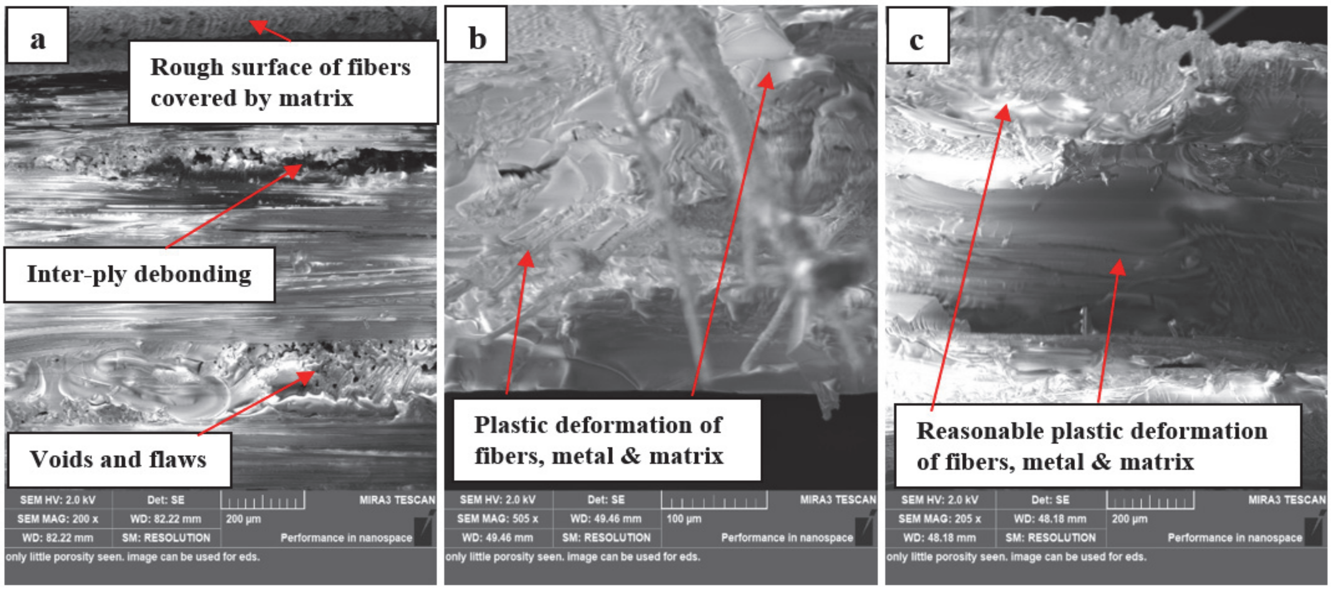


Figure 15: SEM Images of fractured GME laminates for (a) GME-RT, 10^{-1} s^{-1}, (b) GME-250 ^{0}C, 10^{-2} s^{-1} and (c) GME-450 ^{0}C, 10^{-3} s^{-1}.

CONCLUSIONS

This experimental study focuses on the tensile characterization and failure pattern of five types of composite specimens under three types of strain rates and temperatures. The effects on tensile behavior and fracture morphologies are investigated and discussed comparatively. The following conclusions can be drawn from this study:

- The tensile strengths were significantly higher under RT condition for all types of Glass fiber reinforced Hybrid and non-Hybrid fiber composites under strain rate of 10^{-1} s^{-1}.
- Interestingly, all types of composites tested under elevated temperature in this study could perform better within the non-linear region of the stress strain response under the dynamic tensile loading for identical specimen dimensions. The peak ultimate tensile stress of GE, GCE, CME and GME composites with strain rate 10^{-1} S under room temperature was 75–86% higher than the CE composites.
- The elastic modulus and tensile strength reduced considerably at higher temperatures in comparison to room temperature values. The drop was reported almost 80-85% of RT value. The hybrid combination was reported to have least value at elevated temperatures.
- It is reported that strain rate greatly affects the ultimate tensile strength while temperature only influences the modulus as seen from the tensile behavior of all composite specimens.
- Tensile strength and Maximum strain increase with increasing strain rates at room temperature, and the Modulus and tensile strength decrease with increasing temperatures at strain rate of 10^{-3} $s^{-1.}$
- The SEM photo micrographs gave clear fiber matrix failure mechanisms which is in agreement with all the tensile test results obtained under varying strain rates and test temperatures.

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