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Effect of loading rate on tensile properties and failure behavior of glass fibre/epoxy composite

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Abstract. Fibre reinforced polymeric (FRP) composite materials are subjected to different range of loading rates during their service life. Present investigation is focused on to study the effects of variation of loading rates on mechanical behavior and various dominating failure modes of these potential materials when subjected to tensile loading. The results revealed that on the variation of loading rates the ultimate tensile strength varies but the tensile modulus is mostly unaffected. Furthermore, the strain to failure is also increasing with increase in loading rates. Different failure patterns of glass/epoxy composite tested at 1, 10,100, 500 and 1000 mm/min loading rates are identified. Scanning electron micrographs shows various dominating failures modes in the glass/epoxy composite.

1. Introduction

Combining with two or more constituents different from physical and mechanical properties, composite materials can obtain a desirable characteristic. Nowadays, the fibre reinforced polymeric (FRPs) composites are one among the highest used structural materials in the globe. Glass reinforced polymer matrix composite material has already evolved to be a kind of important engineering material due to its light- weight feature. Their superior favourable properties include high strength to weight ratio, high specific stiffness, low density, high corrosion resistance, high endurance limit, high fatigue resistance over traditional metallic materials. The FRP composites discovers a wide range of application in several fields such as automotive, aerospace, marine, sporting goods, low temperature application such as cryogenic fuel tanks, cryogenic fuel delivery lines, cryogenic wind tunnels and parts of the cryogenic side of turbo-pumps due to their easy usage, better mechanical properties and lower fabrication cost [1].

During the fabrication, in-service life and storage the FRP composite materials are exposed to various loading conditions ranging from quasi-static to dynamic loading. In many structural applications FRP's are subjected to high energy and high velocity dynamic loadings that can produce multi-axial dynamic states of stress [2]. FRP composites are anisotropic materials, so the damages due to these stresses are complex phenomenon involving various failure mechanisms (frequently interactive) in micro scale. Numerous methods have been suggested and discussed, including fracture mechanics, damage mechanics, nonlinear viscoplastic constitutive modelling, and macroscopic (global) failure criteria. For quasi-static loading conditions the latter are the commonly followed method in design and analysis of composite structures. Under certain biaxial states of stress and under dynamic loading conditions available failure criteria and design guidelines are still not promising and fully reliable [3]. These loadings are typically highly transient and the material and structural response occurs over very short (dynamic) time scales (of the order of milliseconds or microseconds).
Furthermore, in these composites the reasons for adding the fibres are often rather complex; for example, improvements may be sought in tensile, fatigue, creep, wear, fracture toughness, thermal

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stability. They are vulnerable to keep their performance effectively even in harsh space environments despite of having a lot of positive aspects of utilizing FRP's in space structures.

Type of fiber	Tensile strength (MPa)	Young's Modulus (GPa)	Density (g/cm^3)	Thermal Exp. Co-efficient (mm/^{o}C)
E-glass	2000	80	2.58	5.4
Epoxy	85	3.5	1.2	1.5-10

Table 1. Mechanical Properties of E-glass and epoxy.

The present investigation deals with the loading rate sensitivity of glass/epoxy composite at 1, 10, 100, 500 and 1000 loading rates at room temperature (30°C). The tensile behaviour of glass/epoxy composite was also evaluated in terms of ultimate tensile strength, modulus and strain at break.

2. Materials and Methods

2.1 Testing Materials

The current experimental investigation consists of fabrication of glass/epoxy composite and Diglycidyl Ether of Bisphenol A (DGEBA) based epoxy resin was used as matrix and triethylene tetra amine (TETA) was used as hardener. The woven fabric E-glass fibres used in the experimental program was supplied by Saint Gobin industries. Epoxy resin and hardener were obtained from Atul Industries Ltd, Gujarat having the trade name of Lapox L-12 and K-6 respectively. The epoxy to hardener weight ratio was taken as 10:1 as per the supplier's recommended standard.

2.2 Preparation of glass/epoxy laminates

The glass/epoxy composite laminated was fabricated with 10 layers of woven fabric E-glass fibres having 60:40 weight fraction of glass fibres and epoxy respectively. The fabrication was done using hand layup method. The glass/epoxy laminates were cured in hot press compression moulding machine at 60°C temperature for 20 minutes at a pressure of 5 kgf/cm^2. Then the glass/epoxy laminates were dried in an oven at 60°C for 2 hours to remove moisture and volatile substances. As per the ASTM D3039 standard the samples were cut using diamond cutter as shown in figure 1(a). After that the samples were post cured in an oven at 140°C for 6 hours [4].

2.3 Testing Method of glass/epoxy composite

2.3.1 Tensile Test

The test was performed with tension fixture in Instron 8862 Universal testing machine (UTM) shown in figure 1(b) in accordance to the ASTM D3039 standard samples to evaluate the tensile properties. The samples were tested at room temperature with different loading rates viz. 1, 10, 100, 500 and 1000 mm/min.

2.3.2 *Scanning Electron Microscopy (SEM) Analysis.* The fractured surfaces of the tested specimens were further analysed using scanning electron microscope (SEM) for determining the various dominating modes failure mechanisms using JEOL-JSM 6480 LVSEM at 20KV.

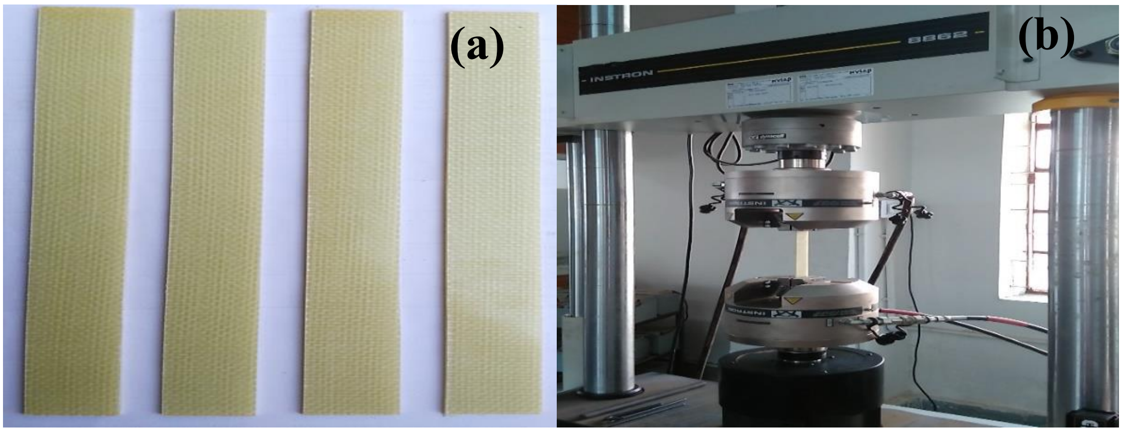

Figure 1. (a) Glass/epoxy standard tensile samples and (b) Instron 8862 UTM with tension fixture.

3. Results and Discussions

3.1 Effect of loading rates on tensile behaviour of Glass/Epoxy composite

The samples were tested at room temperature (30°C) with different loading rates viz. 1, 10, 100, 500 and 1000 mm/min.

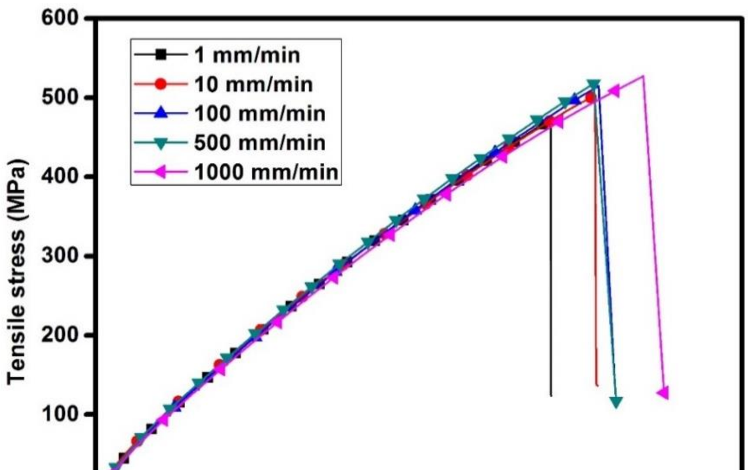

Figure 2. Tensile stress Vs Tensile strain curve with 1, 10, 100, 500 and 1000 loading rates tested at room temperature (30°C).

Figure 2 shows the curve between tensile stress and tensile strain. It is evident from the figure that with increase in loading rate i.e. from 1 mm/min to 1000 mm/min the value of tensile stress is also increasing.

The UTS Vs Loading rate curve is shown in figure 3 and it is evident from the figure that the tensile strength of the glass/epoxy composite increases with increase in the loading rate. Its shows the load carrying capacity of the glass/epoxy composite is better at higher loading rate. It is due to the better cohesive bonding between the fibre/matrix interfaces and also due to proper post curing between fibre/matrix.

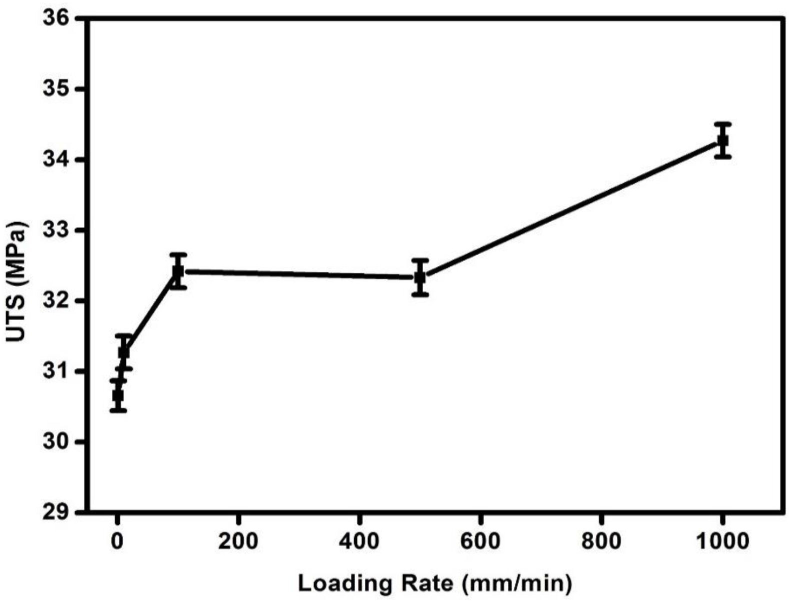

Figure 3. UTS Vs Loading rate curve with 1, 10, 100, 500 and 1000 mm/min loading rates tested at room temperature (30°C).

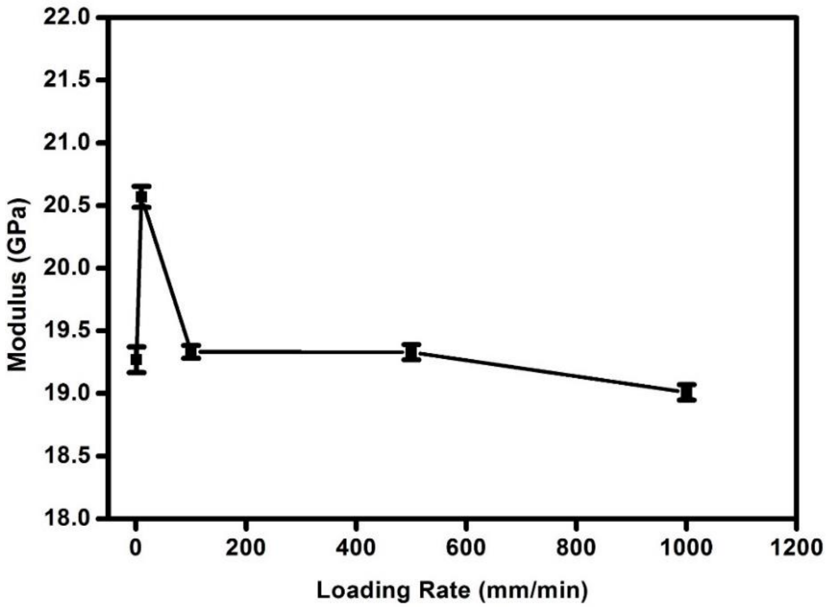

Figure 4. Modulus Vs Loading rate curve with 1, 10, 100, 500 and 1000 mm/min loading rates tested at room temperature (30°C).

Figure 4 shows the curve between Modulus Vs Loading rate and it reveals that at 10 mm/ min the modulus of the composite is higher and after that with increase in the loading rate the modulus of glass/epoxy composite decreases and least modulus was observed at 1000 mm/min. But the modulus value is found to be unaffected with loading rate. Therefore in glass/epoxy composite the modulus value is found to be loading rate is in-sensitive.

The Strain at break Vs Loading rate is shown in figure 5 and it is evident from the figure that as load carrying capacity of the composite system increases the strain value of the glass/epoxy composite is also increasing.

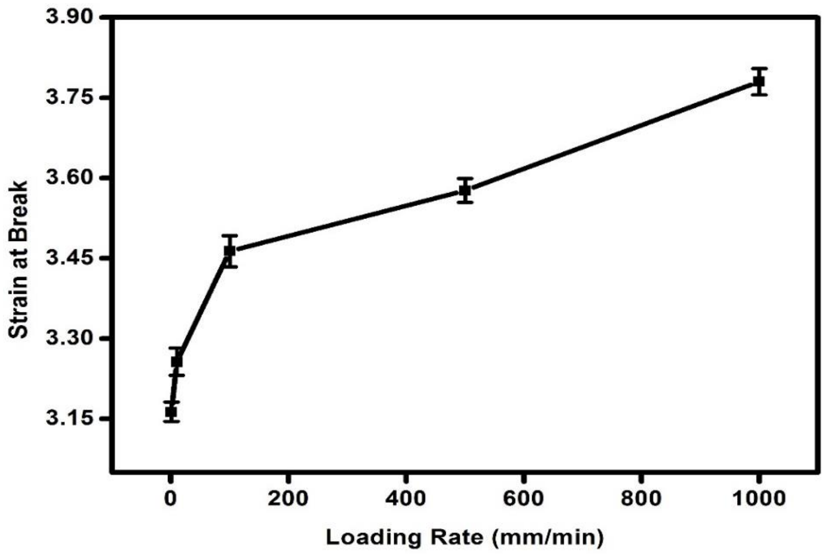

Figure 5. Strain at break Vs Loading rate curve with 1, 10, 100, 500 and 1000 mm/min loading rates tested at room temperature (30°C).

3.2 *Fractography Analysis*

After the tensile testing, fractured samples were analysed using scanning electron microscope (SEM). The Figure 6(a) and 6(b) shows scanning electron micrographs of glass/epoxy composite tested at 1 mm/min loading rate at room temperature. The various dominating modes of failures modes obtained in the composite are matrix fracture, and delaminations of fibres and matrix.

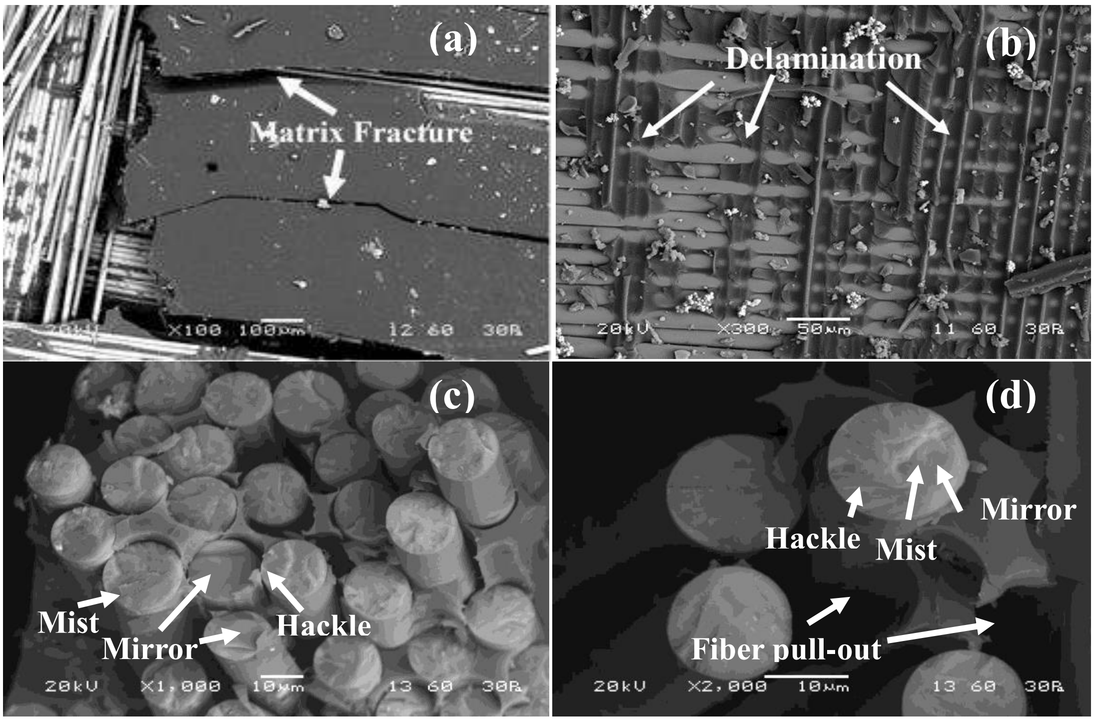

Figure 6. Scanning electron micrographs of glass/epoxy composite tested at (a) 1mm/min, (b) 1mm/min (c) 1000 mm/min (d) 1000 mm/min loading rates respectively.

The Figure 6(c) and 6(d) shows scanning electron micrographs of glass/epoxy composite tested at 1000 mm/min loading rate at room temperature (30°C). The various dominating modes of failures modes obtained in the composite are mirror, mist and hackle and fibre pullout.

3.3 Failure patterns of glass/epoxy composite

Figure 7 shows the bulk images of glass/epoxy composite with different failure pattern tested at (a) 1mm/min, (b) 10 mm/min (c) 100 mm/min (d) 500 mm/min and (e) 1000 mm/min loading rates. At lower loading rates the initiation of crack generates at the middle portion of the specimens. But at higher loading rates multiple numbers of cracks are generating throughout the samples i.e. at middle portions as well as at the tab portions.

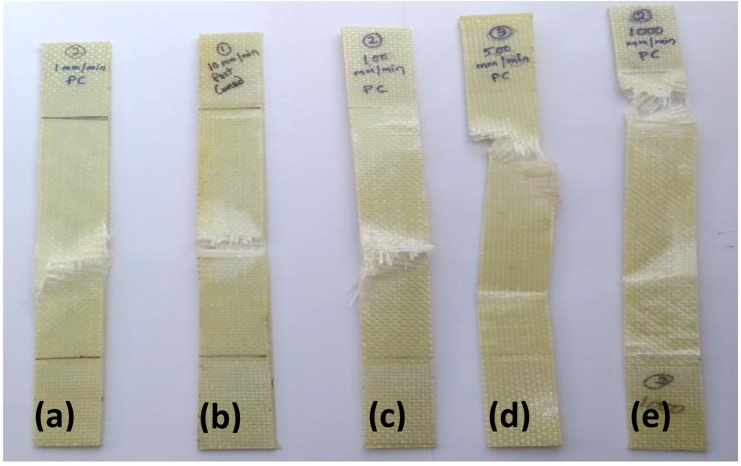

Figure 7. Different failure patterns of glass/epoxy composite tested at (a) 1mm/min, (b) 10 mm/min (c) 100 mm/min (d) 500 mm/min and 1000 mm/min loading rates.

4. Conclusions

The investigation on the effect of tensile properties and failure behavior of glass/epoxy composite comprises the following conclusions

- The glass/epoxy composite is found to be loading rate sensitive. As the loading rate increases the ultimate tensile strength of the composite is also increasing.
- The tensile modulus of the composite is found to be loading rate in-sensitive.
- The strain to failure of the glass/epoxy composite is also increasing as the loading rate increases.
- At bulk level different failure patterns of the glass/epoxy composite is observed. At lower loading rates failure generates from the middle portion of the glass/epoxy composite, but at higher loading rates it is throughout the glass/epoxy composite.

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