# An Investigation on Failure and Fracture Behavior of Environmentally Conditioned Fibre Reinforced Polymeric Composites

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**Abstract**

At the present time, the use of composite materials for engineering applications has widely spread, replacing other more common and conventional materials (i.e. steel), thanks to their interesting weight ratios. Different composite materials have been developed; considering fibre reinforced polymer (FRP) composites. In light of their use as structural components, it is certainly very important to study their static and fatigue behavior. The components made up of FRP composites are exposed to temperature variations (thermal shock, thermal spike, low temperature environment, high and low temperature environment, humidity variations, UV radiation and often the combined exposure of these environments leads to more detrimental effect on the performance of the composites during fabrication, in-service time and storage. Further, the rate of loading has significant effects on the mechanical performance of FRP's. Another important aspect is to study the effect of addition of different nano fillers that alters the thermodynamic properties of the interface/interphase. The investigations in the study deals with mechanical behavior of the FRP composites exposed to aforesaid environments and loading rates. Also, different nano-fillers are used in the composites to enhance the strength and stiffness of the materials to better withstand in different harsh and hostile environments. Scanning electron microscope (SEM) was carried out to know the main cause of fractures that induces different morphologies. The in-service temperature of the FRP composite was measured using TMDSC (temperature modulated differential scanning calorimetry). Furthermore, dynamic mechanical thermal analyser (DMTA) was used to correlate the mechanical and thermo-mechanical response of the FRP composites. Furthermore, research is needed to characterize the interfaces in micro-scale and also by suitable modelling and simulation to explore the tailorability of the interfaces for making these composite materials sustainable and reliable at different service environments.

**Keywords:** Fibre reinforced polymeric (FRP) composite, Mechanical properties, Loading rate, Nano-fillers, Dynamic mechanical thermal analysis (DMTA)

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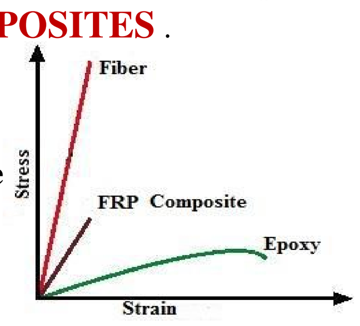
## Objectives

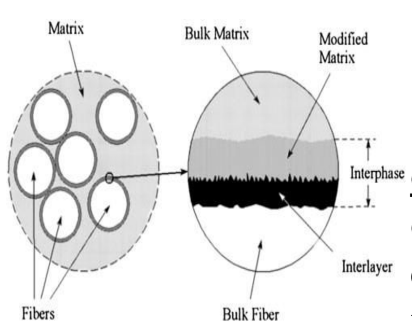
- Fabrication of different glass fibres reinforced polymer composite with different volume fractions.
- Different environmental conditionings such as high temperature and thermal shock.
- Assessment of mechanical behavior with different loading rates at room temperature, high temperature and also at thermal conditioning environment.
- To evaluate the effect of loading rates on the strengthening mechanisms and eventually the mechanical performance of glass-epoxy composite with multiwalled carbon nanotube (MWCNT) and nano- $Al_2O_3$.
- Micro-characterization using electron microscopy (SEM), differential scanning calorimeter (DSC) and dynamic mechanical thermal analyser (DMTA) to support the bulk material behavior obtained from aforesaid mechanical testings.

## Introduction

In the continuing quest for improved performance specified by various criteria including less weight, more strength , lower cost currently used materials reach the limit of their usefulness. So we are switching over to a new improved material called the **COMPOSITES** .

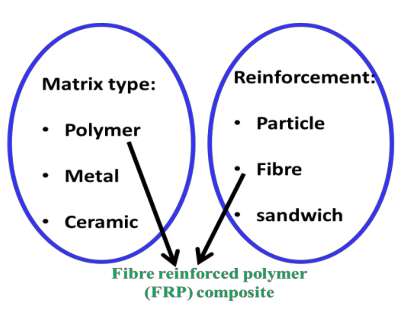
- Composite → Matrix + Reinforcement
- Matrix Phase → Soft, Ductile, Formable
- Reinforcement Phase → Strong, Stiff, Brittle
- Composite → Combination of properties of both matrix and reinforcement phase.




Fibre Reinforced Polymer (FRP)

Composite = Polymer Matrix + Fibre




Common types of FRP Composites

CFRP(Carbon Fibre Reinforced Composite)

GFRP(Glass Fibre Reinforced Composite)

KFRP(Kevlar Fibre Reinforced Composite)

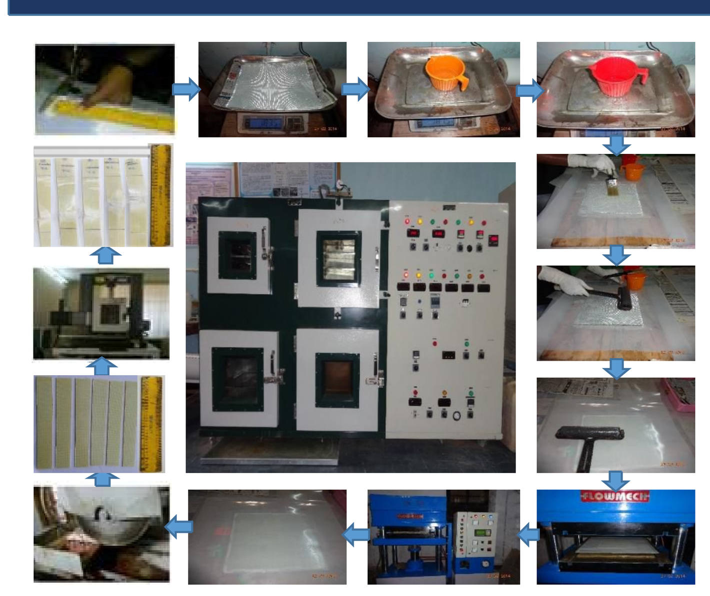
Service life of FRP composites – harsh environmental conditions (temperature, thermal spike. Thermal shock, humidity, UV)

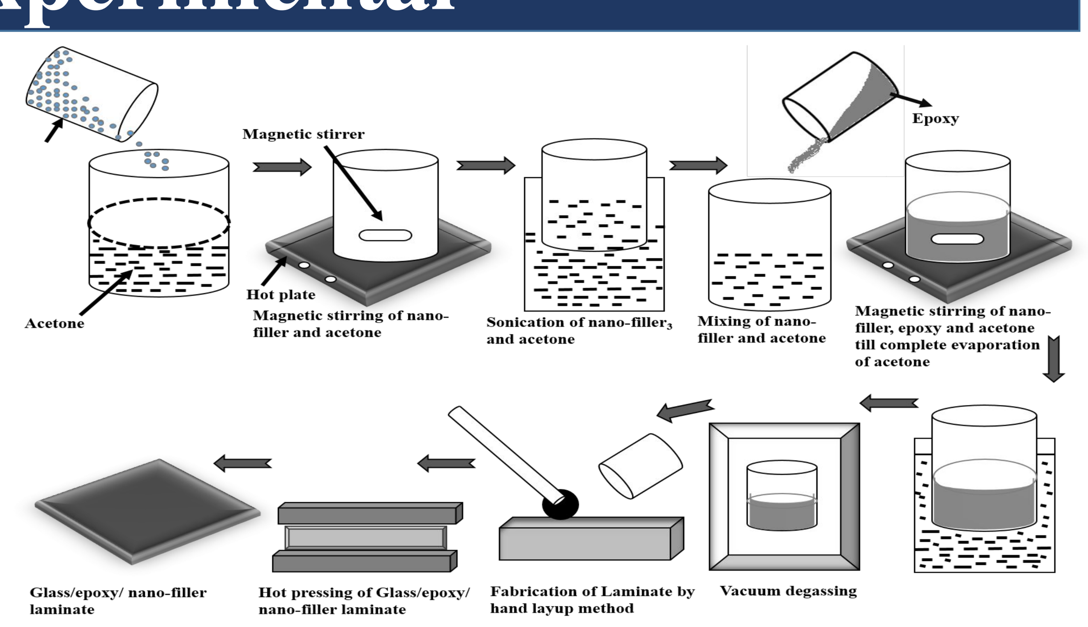
Major area of concern

Fiber Reinforced Composite – heterogeneous and anisotropic in nature - complex failure process.

## Applications


## Experimental






## Results and Discussion

### a) High temperature

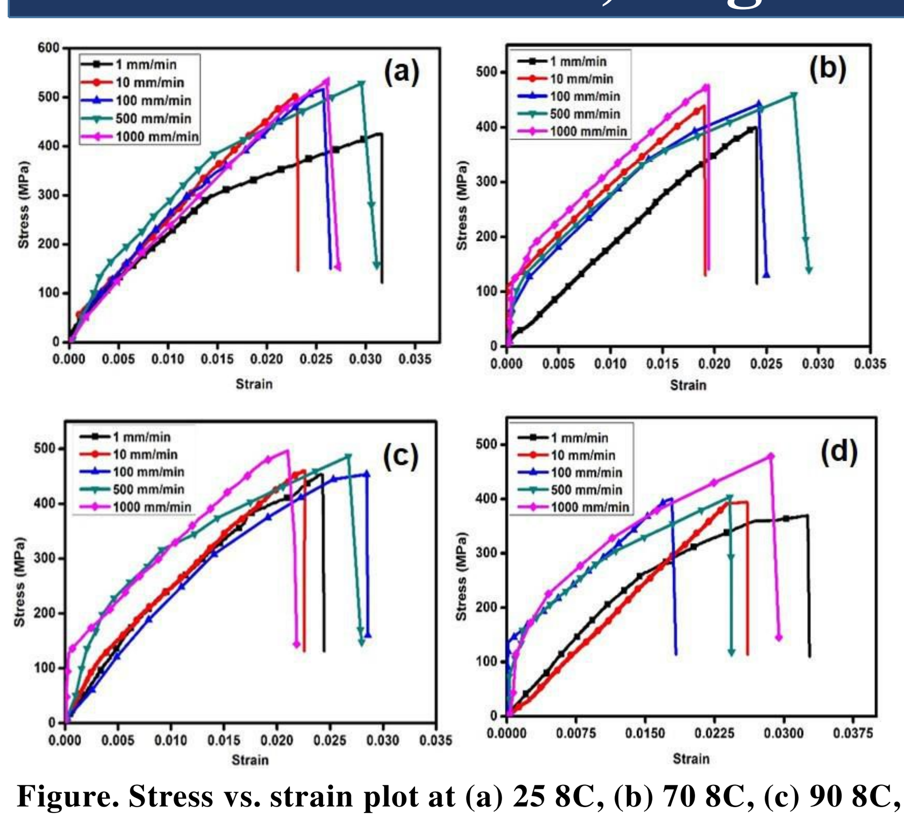


Figure. Stress vs. strain plot at (a) 25 8C, (b) 70 8C, (c) 90 8C, (d) 110 8C temperatures at 1, 10, 100, 500, 1000 mm/min loading rate with fiber volume fraction ($V_F$)=50%.

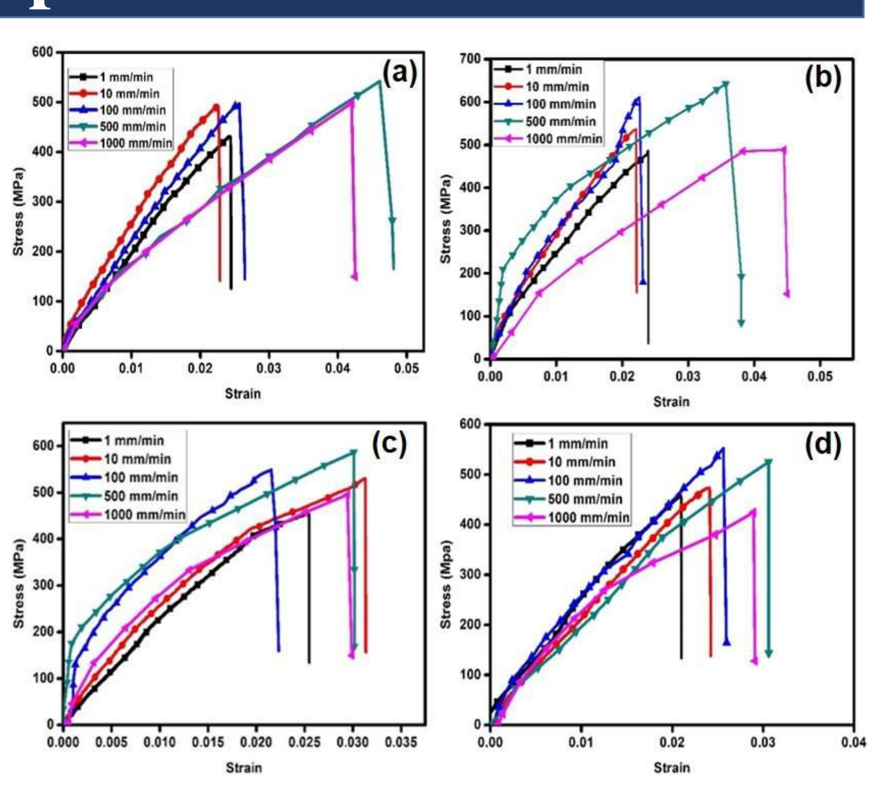


Figure. Stress vs strain plot at (a)25°C, (b)70°C, (c) 90°C, (d) 110°C temperatures at 1,10,100,500, 1000 mm/min loading rate with fibre volume fraction ($V_F$) = 70%

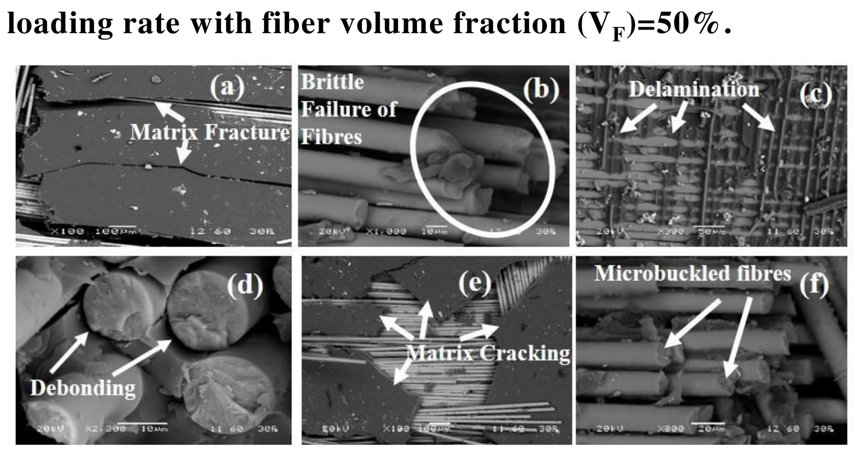



Fig. SEM images fractured GFRP composites tested at 1 mm/min at different temperatures and different volume fractions of fibres (a) 25°C, $V_F$ =50% (b) 25°C, $V_F$ =70% (c) 70°C, $V_F$ =50% (d) 70°C, $V_F$ =70% (e) 110°C, $V_F$ =50% (f) 110°C, $V_F$ =70%

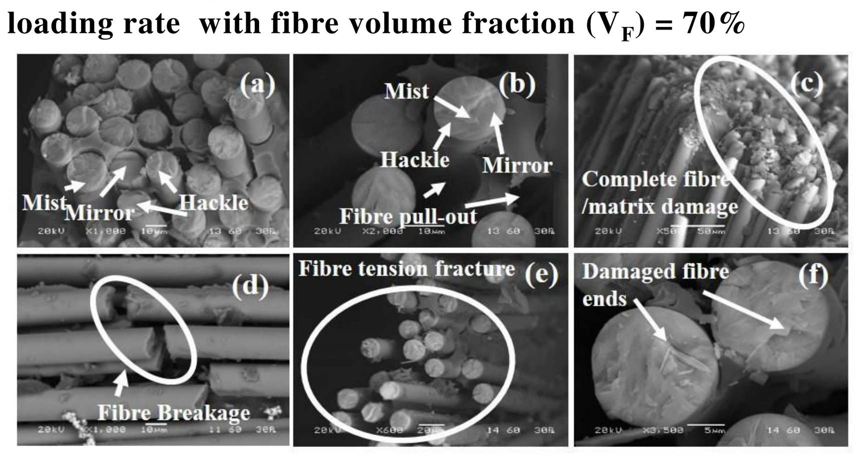



Fig. SEM of GFRP composites tested at 1000 mm/min at different temperatures and different volume fractions of fibres 25°C, $V_F$ =50% (b) 25°C, $V_F$ =70% (c) 70°C, $V_F$ =50% (d) 70°C, $V_F$ =70% (e) 110°C, $V_F$ =50% (f) 110°C, $V_F$ =70%

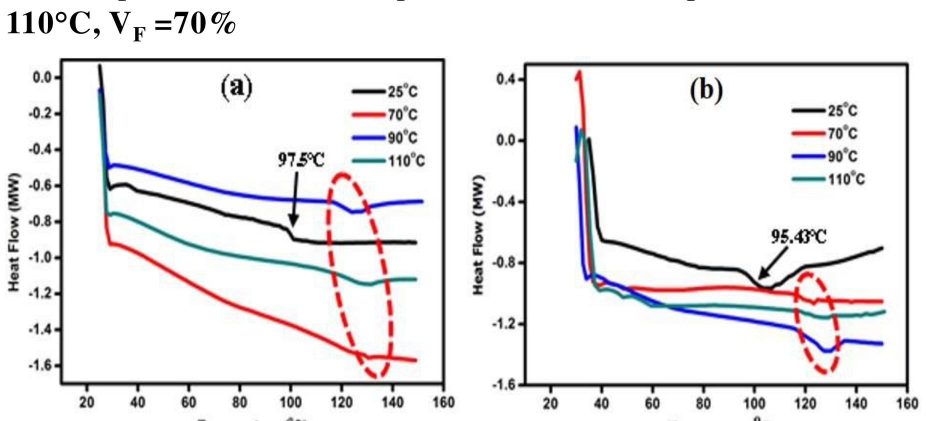



Figure. Glass transition temperature ($T_g$) plot of GFRP composites at 25°C, 70°C, 90°C and 110°C temperatures for 50% and 70% volume fractions of fibres respectively.

The dotted marks in Figure (a) and (b) represents the $T_g$ of conditioned samples which is near to 120°C in all conditioning temperatures. This may be attributed to the closeness of the transition temperature of the polymer phase in the GFRP composite and due to no more further crosslink between the polymeric chains in the PMCs.

### b) Loading rate & Thermal shock

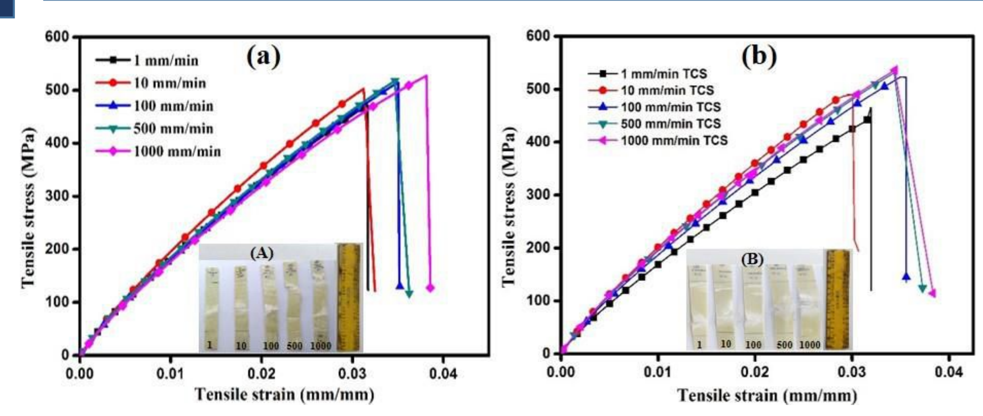



Figure. Tensile stress Vs Tensile strain curve with 1, 10, 100, 500 and 1000 mm/min loading rates tested at (a) RT (30°C) (b) Thermal-shock conditioned specimen

- The GE composites of both the system is found to be loading rate sensitive. As the loading rate increases the UTS of thermal-shock conditioned composite is increasing and the stress value is higher at each loading rate as compared with the RT specimens.
- The TCS specimens exhibits better fiber/matrix interfacial bonding by mechanical keying factor imparting better strengthening of the GE composites.
- The tensile modulus of both the composites system is found to be loading rate in-sensitive. The thermal-shock conditioned specimens exhibit more modulus value than room temperature.

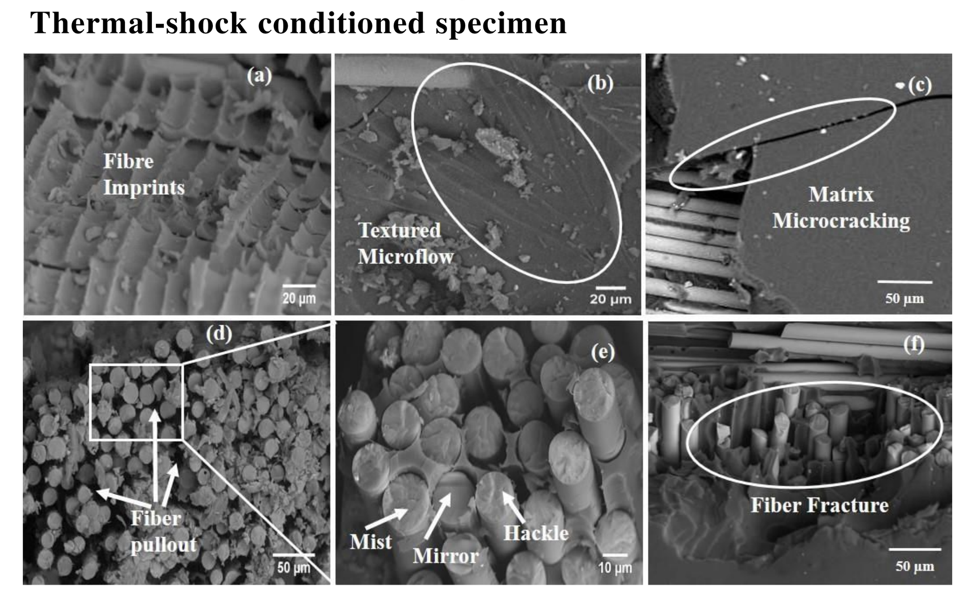



Figure. Scanning electron micrographs of thermal-shock conditioned GE composites tested at (a) 1mm/min, (b) 1mm/min, (c) 1 mm/min (d) 1000 mm/min (e) 1000 mm/min and (f) 1000 mm/min loading rates respectively

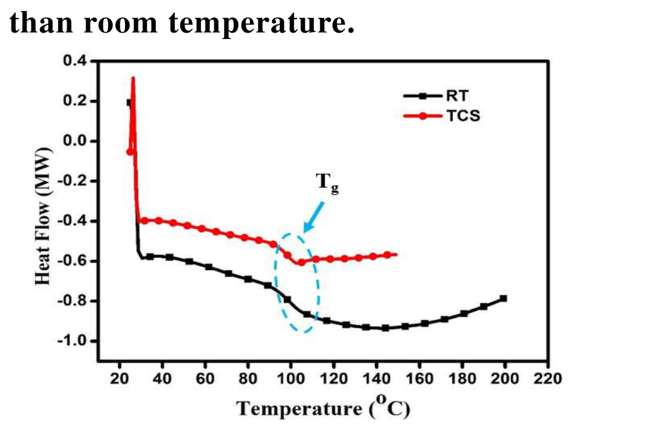



Figure . TMDSC graphs of GE composites at room temperature and at thermal-shock condition.

In-service temperature of the polymer phase of the composite i.e. the glass transition temperature at the room temperature and thermal-shock conditioned temperature were found to be nearly same.

### c) MWCNT & nano-$Al_2O_3$

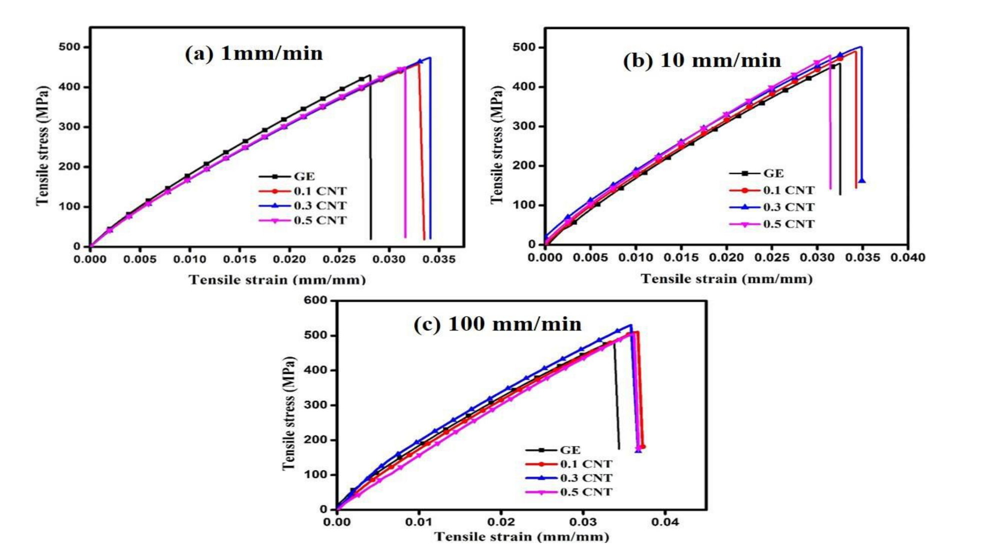



Figure. Stress–strain curves for GFRP composites at various MWCNT contents at room temperature with different loading rate (a) 1 mm/min, (b) 10 mm/min and (c) 100 mm/min.

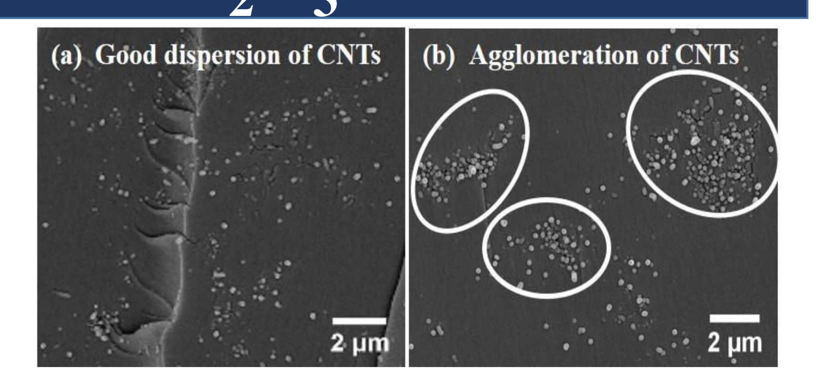



Figure 5. FESEM images of (a) 0.1% CNT/GFRP and (b) 0.5 % CNT/GFRP composites.

Increase in the CNT content upto 0.3% the tensile strength increasing for all the crosshead speeds as compared to the control GFRP composite. The tensile strength are dependent on the CNT content in GFRP composite. It has been observed that addition of 0.1% CNT and 0.3% CNT enhanced the tensile strength by 6.11% and 9.28% respectively than control GFRP composite.

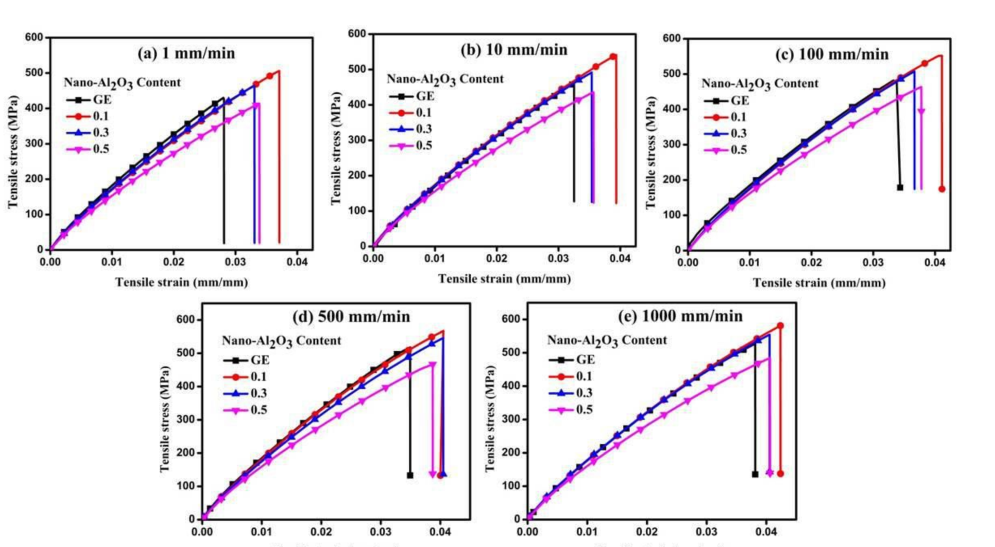



Figure. Tensile stress–strain curves for GE composites at various nano-$Al_2O_3$ contents tested at room temperature with different crosshead speeds.

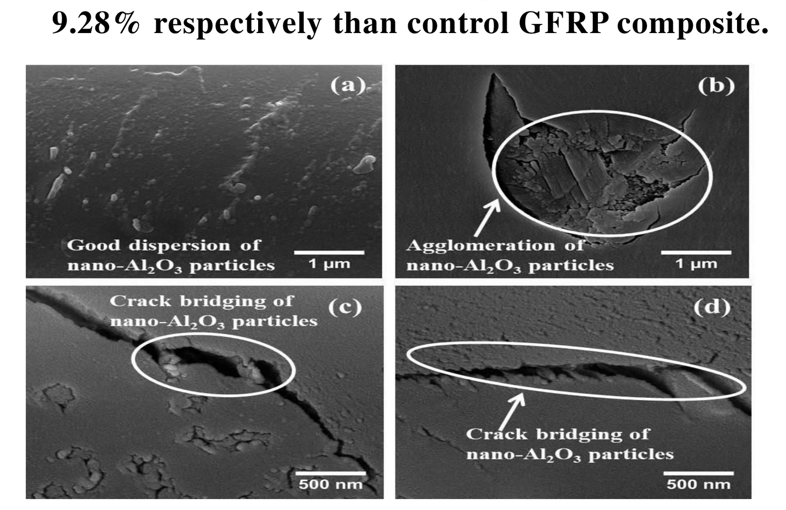



Figure. FESEM images ofnano-Al2O3-GE (a) 0.1wt. % (b) 0.5 wt. % (c) 0.1 wt. at 1mm/min and (d) 0.1 wt. % at 1000 mm/min composites.

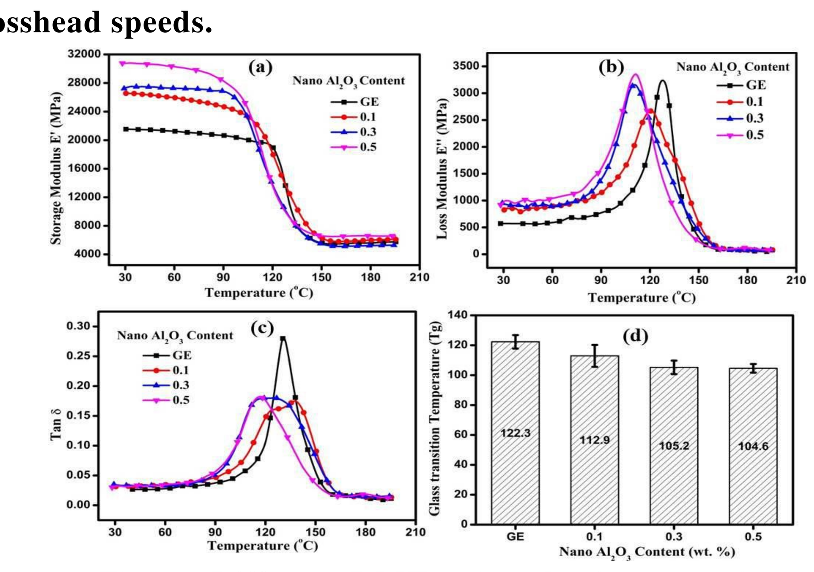



Figure. Different DMTA viscoelastic properties

- Addition of 0.1 wt. % nano- $Al_2O_3$ enhanced the tensile strength by 15.01% than control GE composite at 1 mm/min crosshead speed. Similarly at 10, 100, 500 and 1000 mm/min crosshead speeds the increase in tensile strength was observed to be 15.92 %, 12.86 %, 8.84%, and 9.29% of that of control GE composites respectively.
- The viscoelastic behavior of the control GE and nano-$Al_2O_3$/GE enhanced composites was evaluated. With increase in the nano-$Al_2O_3$ content the storage modulus increases. While, the glass transition temperature (Tg) of 0.5 wt. % nano-$Al_2O_3$enhanced GE composites is found to be decreasing from 122.3 °C to 104.6 °C as compared control GE.

## Conclusions

- The values of tensile strength of the investigated GFRP composites increase with the increase in crosshead speed at all test temperatures. At higher crosshead speed the response of the composite is primarily governed from the fibre phase and increase in load carrying capacity can be attributed to fibre dominated mechanical response.
- The tensile fracture surfaces indicated various dominating failure modes for the investigated GFRP composite specimens. Matrix fracture was predominant at lower crosshead speeds while in case of higher crosshead speeds fractures were of complex nature by means of fibre/matrix debonding, fibre pullout, both fibre and matrix cracking..
- Increase in the CNT content upto 0.3% the tensile strength increasing for all the crosshead speeds as compared to the control GFRP composite.
- Increase in the nano-$Al_2O_3$ content upto 0.1 wt. % increases the tensile strength for all the crosshead speeds as compared to the control GE composite.
- The viscoelastic behavior of the control GE and nano$Al_2O_3$/GE enhanced composites was evaluated. With increase in the nano-$Al_2O_3$ content the storage modulus increases. While, the glass transition temperature (Tg) of 0.5 wt. % nano-$Al_2O_3$enhanced GE composites is found to be decreasing from 122.3 °C to 104.6 °C as compared control GE.

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