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Strain Rate Dependent Behavior of Glass/Nano Clay Filled Epoxy Resin Composite

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ABSTRACT

It is believed that addition of small amount of nanoclays in the neat epoxy and fiber reinforced epoxy composite system can improve the mechanical properties. The mechanical properties of most of polymer matrix composites are sensitive to testing rate. However, most of the researches were concentrated on the behavior of the polymer matrix composites at high strain rates. The present research work is to investigate the role of clay on neat epoxy and glass–fiber reinforced epoxy composites, at low strain rates. The clay in terms of 1.5 wt%, 3 wt%, and 5 wt% are dispersed in the epoxy resin using mechanical stirring followed by sonication process. The corresponding glass/epoxy nanocomposites are prepared by impregnating the clay epoxy mixture by hand lay-up process. Characterization of the nanoclay is done by X-ray diffraction and Scanning Electron Microscopy. Tensile stress-strain curves are obtained at strain rates of 10^{-4} s^{-1}, 10^{-3} s^{-1}, 10^{-2} s^{-1}, and 10^{-1} s^{-1} by a hydraulic machine reporting that, even at low strain rates, the longitudinal strength and stiffness increase as strain rate increases for all clay loadings. It is observed that the tensile modulus increases as the clay loading increases for both epoxy and glass/epoxy nanocomposites. It is also noticed that the longitudinal tensile strength decreases as the clay loading increases. The failed specimens show marked changes in the fracture surface with increased strain rate. Scanning electron microscopy is used to study the fiber/matrix/clay adhesion in fracture surfaces.

Keywords: Hybrid composites, nano clays, mechanical properties, fractography, scanning electron microscopy

1. INTRODUCTION

Epoxy resin based fibre reinforced polymer composites and their sandwich structures find wide applications in engineering fields[1,2]. However, with the advent of nanotechnology, there are many reports on nanocomposites for various applications[3,4]. The mechanical properties of silicate/nylon-6 nanocomposites synthesized by in-situ polymerization were first demonstrated by researchers at the Toyota Central Research Laboratories. The incorporation of nanoceramics such as layered silicate clays, calcium carbonate or silica nanoparticles into polymers improve their mechanical performances significantly. The increase in modulus is believed to be directly related to the high aspect ratio of silicate layers as well as the ultimate nanostructure. Zerda[5], *et al.* studied the mechanical behavior of intercalated nanocomposites of modified montmorillonite clays in a glassy epoxy and observed increase in tensile modulus with reductions in both ultimate strength and strain at break, resulting in loss of ductility. Isik[6], *et al.* investigated the nanocomposites of layered silicate/epoxy prepared by in-situ intercalation method and observed that tensile strength decreased with increasing amount of MMT. The authors also concluded that the tensile modulus of the nanocomposite increased with increasing amount of MMT. Lin[7], *et al.* examined the effect of exfoliated nanoparticles on the mechanical behavior and low-velocity impact behavior of epoxy matrix. The experimental results imply that the degree of exfoliation may exhibit a maximum with respect to tensile strength, but show a minimum with respective to impact strength. Similar studies were made by many researchers[8-10] Liu[11], *et al.* studied organosilicate-modified high performance epoxy nanocomposites with a direct-mixing method (DMM) and high pressure mixing method (HPMM). The nanocomposites made with the HPMM showed dramatic improvement in fracture toughness at very low clay loading. Velmurugan[12], *et al.* processed the nanocomposites of epoxy resin system DGEBA with garamite as nanoparticle using triethylene tetramine (TETA) curing agent and observed good improvement in elastic modulus and reduction in tensile strength.

It is revealed from the literature that so far, the information related to the effect of organoclay on the mechanical responses of fiber/epoxy composites is lacking. Hence there is a need to explore further investigation. Haque[13], *et al.* fabricated glass/epoxy nanocomposites through an affordable vacuum assisted resin infusion method (VARIM). They showed that significant improvements in mechanical and thermal properties of conventional fiber reinforced composites with low loading of organo silicate nanoparticles. Chowdhury[14], *et al.* investigated the effects of nanoclay particles on flexural and thermal properties of woven carbon fiber reinforced polymer matrix composites and found good improvement. Kornmann[15,

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et al. fabricated epoxy-layered silicates nanocomposites where dynamic mechanical analyses showed a systematic glass transition temperature decrease of the nanocomposite based materials. Daud[16], *et al.* investigated the mechanical and thermo mechanical properties on three-phase glass fiber reinforced composites (GFRP) consisting of traditional woven glass fiber and polyamide-6 (PA6) matrix dispersed with organically modified layered silicates. They observed improvement in both flexural strength and compressive strength at elevated temperatures. The in-plane shear properties measured from $[\pm45]_s$ laminates revealed that the layered silicates help improved both the in-plane shear strength and modulus. Velmurugan[17], *et al.* studied the effect of clay addition on improving the mechanical properties of epoxy polymer and glass fiber-reinforced epoxy-clay hybrid composites.

The mechanical properties of most of polymer matrix composites (PMCs) are strain rate sensitive. For this reason, many researchers have conducted investigations to obtain the variations of strength and stiffness of these composites with strain rate. However, most of the researches were concentrated on the behavior of the PMCs at high strain rates. Szu-Hui Lim[18], *et al.* studied the effect of loading rate and temperature on nylon 6/organoclay nanocomposites, with and without POE-g-MA rubber particles. Bao[19], *et al.* found that polypropylene nanocomposites reinforced with multi-walled carbon nanotubes are strain rate and temperature dependence. Zebarjad[20], *et al.* studied the role of both nano-sized calcium carbonate and strain rate on the tensile properties of HDPE. They concluded that dependency of pure HDPE to strain rate is higher than for its nanocomposites. Fereshteh-Saniee[21], *et al.* investigated the rate dependency of glass/epoxy composites at low strain rates. They observed the longitudinal strength and stiffness have increased to 24.7% and 4.2%, respectively, by increasing the strain rate from 0.0001 s^{-1} to 0.11 s^{-1}. Shokrieh[22], *et al.* investigated the behavior of unidirectional glass fiber reinforced polymeric composites under uni-axial loading at quasi-static and intermediate strain rates and found significant increase on tensile properties by increasing the strain rate. Kallimanis[23], *et al.* studied the tensile behavior of unidirectional glass-fiber polymer composites at three different strain rates. They described the strain rate-dependent behavior through a scaling law, assuming that a model parameter is a function of the imposed strain rate. Berezhnyts'kyi[24], *et al.* studied the influence of the strain rate and temperature on the physicomechanical properties of polymeric composite materials. They proposed new empirical formulae's for the strain rate and temperature dependences of the composites. Okoli[25], *et al.* performed tensile and shear tests at increasing rates of strain and showed that the effect of the logarithm of the rate of strain on the material properties can be regarded as linear and extrapolated to provide the data at high strain rates. Ray[26] studied the effect of thermal ageing on the mechanical behavior of glass fiber/epoxy composites and found that change in loading rate may result in variation of failure modes.

The present research work is to investigate the role of clay on neat epoxy and glass–fiber reinforced epoxy composites, at low strain rates.

2. EXPERIMENTAL

2.1 Materials

Glass Fiber, 610 GSM Woven Roving Mat was procured from Sakthi Fibers, India. Epoxy resin, diglycidyl ether of bisphenol A (DGEBA), and the curing agent triethylenetetramine (TETA) were supplied by Huntsman Ltd, India. Clay, GARAMITE® 1958 (Alkyl quaternary ammonium clay) was sourced from Southern Clay Products, Inc., USA.

2.2 Sample Preparation

Nanocomposites containing the organo-montmorillonites were prepared at clay mineral levels of 1.5 wt.%, 3 wt.%, and 5 wt.%. The mould used for preparing nanocomposites was made from two rectangular steel plates having dimensions of 300 mm × 300 mm. Rubber beadings were used to maintain a 3 mm thickness all around the mould plates. Releasing agent was used to coat the surface of the plate. The epoxy resin was preheated at 85 °C in order to reduce the viscosity. The required amount of clay was added slowly while stirring with a mechanical stirrer. The mixture was further stirred for 2 h. The curing agent TETA was added and the mixture was gently stirred in order to avoid the formation of bubbles. After degassing, the mixture was cast in the mold.

The glass fiber/epoxy composites were prepared by mechanical stirring and compression moulding technique. The epoxy organo-montmorillonites compound at clay mineral levels of 1.5 wt.%, 3 wt.%, and 5 wt.% were fabricated by mechanical stirring. After adding required amount of curing agent, a thin layer of epoxy/organoclay mixture was applied with a brush on the plate coated with a releasing agent. Then the epoxy/organoclay mixture was impregnated into the WRM glass fiber with the assistance of hand roller to ensure all fibers are wetted. The laminates were cured at room temperature and kept in the compression moulding machine at room temperature for 24h for complete curing.

2.3 X-ray Diffraction

X-ray diffraction was performed on nanocomposites by Philips PW-1730 (CuKα radiation at a scan rate of 1°/min in 2θ range from 3 to 15°). The results (Fig. 1) showed that the nanocomposites at 1.5 wt.% and 3 wt.% clay loadings exhibited no observable peaks, indicating that most of the clay particles in the nanocomposites were exfoliated or, the clay's interlayer distance (d-spacing) was more than 7 nm. Only the highest clay concentration (5%) shows a small peak correlating to a reduced exfoliated structure.

2.4 SEM Micrographs

The dispersion of clay in the epoxy resin was observed with a Hitachi S-4800 scanning electron microscope (SEM) at 5 kV accelerating voltage equipped with energy dispersive spectroscopy (EDS) to identify the clay particles in the composites. The surfaces were coated with a thin gold film to increase their conductance for SEM observation.

The SEM micrograph in Fig. 2 shows the microstructure of layered silicate. Figure 3 shows the dispersion of clay in epoxy at 5 wt.% which shows the dispersion of clay.

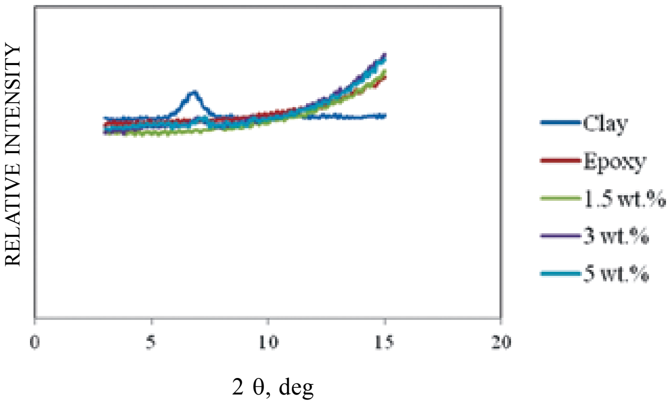

Figure 1. XRD patterns of pure nanoclay and epoxy nanocomposites.

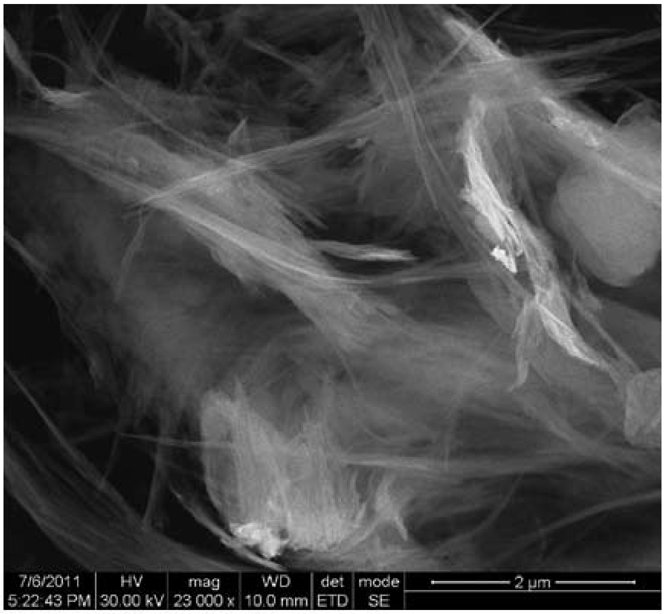

Figure 2. SEM micrograph of layered silicate.

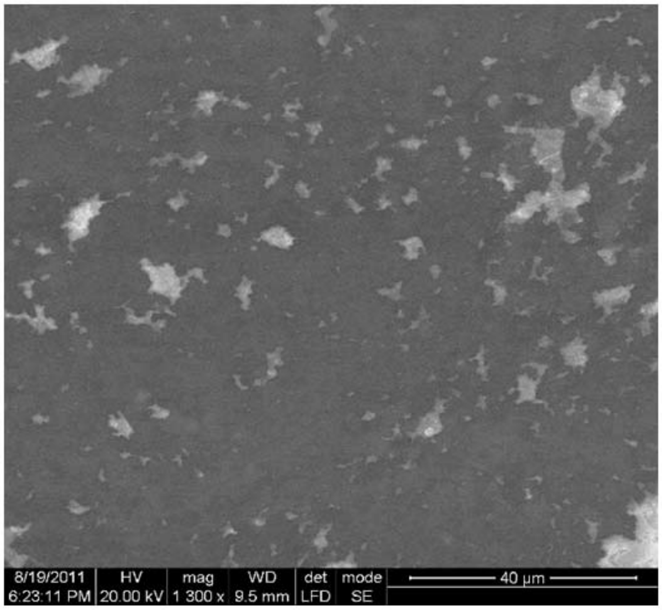

Figure 3. SEM micrograph of 5 wt.% epoxy clay nanocomposite.

2.5 Tensile Testing

Tensile modulus, tensile strength, and elongation at break values were evaluated for both epoxy clay nanocomposites and glass fiber/epoxy nanocomposites as per ASTM D638-10 in a universal testing machine. Clay filled glass epoxy composites were fabricated, giving 3 mm in thickness with 50 mm gauge length. Thin laminate composed of woven roving plies of reinforcement with epoxy resin were fabricated, giving a laminate approximately 1 mm in thickness. Woven glass/ epoxy tabs 2.5 mm thick and 35 mm long with tapered ends were locally bonded on each side of the specimens. These tabs allowed a smooth load transfer from the grip to the specimen and reduce stress concentration. The gauge length of the composite specimens was 12.7 mm. The fiber volume fraction of the composites was 50 per cent.

Automatic calibration of the testing machine was carried out. The specimen was then positioned into the grips of the hydraulic press. Afterwards, various dimensions of the test sample and the velocity of the ram were given as input to the software. Tensile tests were conducted on five cross-head stroke rates of 0.5 mm/min, 5 mm/min, 50 mm/min, and 500 mm/min on epoxy clay nanocomposite specimens. These stroke rates provide nominal strain rates of 0.0001 s^{-1}, 0.001 s^{-1}, 0.01 s^{-1}, and 0.1 s^{-1} on the specimens. The nominal strain rates were calculated by dividing of the stroke rate of the cross-head of the machine by the gauge length of the specimen. Different results obtained from the experiments are presented in the following section.

3. RESULTS AND DISCUSSION

3.1 Epoxy Clay Nanocomposites

3.1.1 Stress – Strain Curves

Figures 4-7 illustrate the stress–strain curves at different strain rates for neat, 1.5 wt.%, 3 wt.%, and 5 wt.% clay loadings in epoxy nanocomposites respectively. It is not possible to describe the mechanical behavior of the composites in terms of mean, or average, stress-strain curve at a given strain rate. Instead, the results have been characterized by determining, for each test, the initial slope (elastic modulus), the maximum stress, and the strain to failure defined as the strain corresponding to the maximum stress.

The stress–strain response is approximately linear elastic up to the maximum stress point followed by abrupt failure at a strain of 1.94% under quasi static loading and increased to

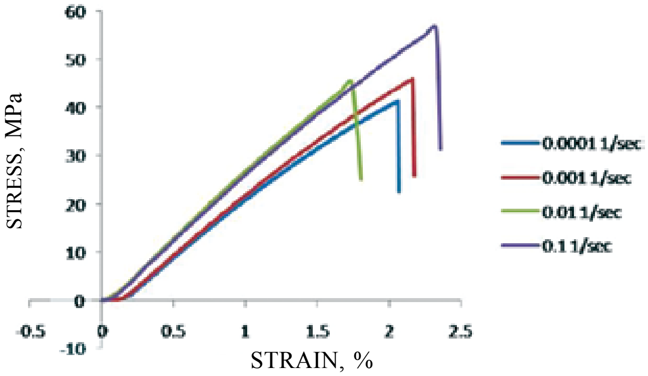

Figure 4. Stress – strain curves of neat epoxy at different strain rates.

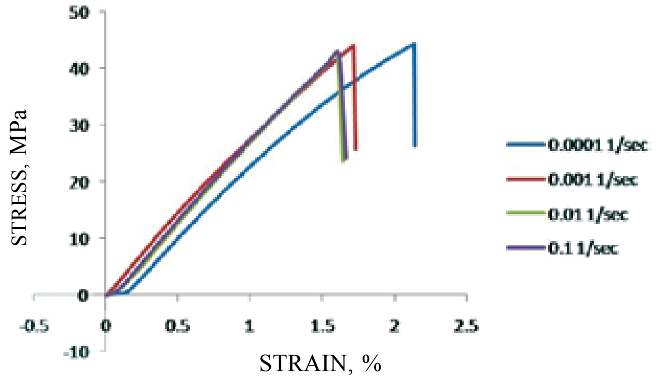

Figure 5. Stress–strain curves of 1.5 wt.% clay epoxy nanocomposite at different strain rates.

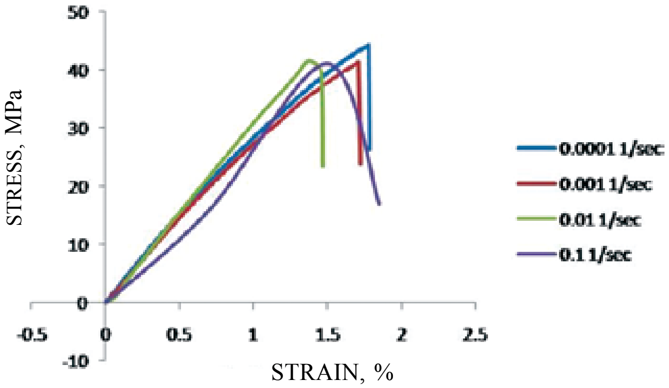

Figure 6. Stress – strain curves of 3 wt.% clay epoxy nanocomposite at different strain rates.

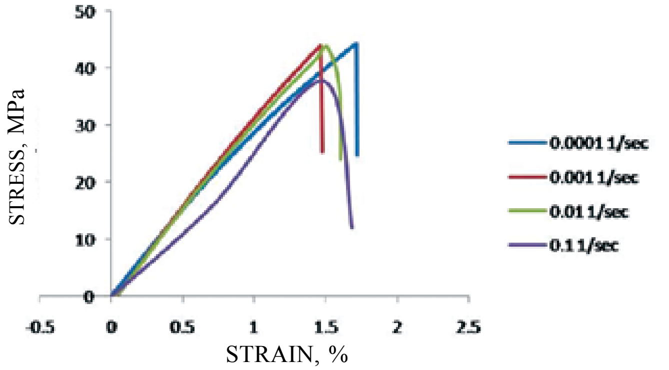

Figure 7. Stress – strain curves of 5 wt.% clay epoxy nanocomposite at different strain rates.

2.43% under highest strain rate (0.1 1/s) for neat epoxy system. For 1.5 wt.% clay loading, the stress-strain response is linear elastic and failed at a strain of 1.79% under quasi static and decreased to 1.52% at highest strain rate. Similarly, for 5 wt.% clay loading, the specimen failed at a strain of 1.67% under quasi static and decreased to 1.48% at highest strain rate. Neat epoxy system is more sensitive to strain rate than epoxy clay nanocomposites.

3.1.2 The Tensile Strength and the Stiffness

The extracted data for different strain rates are summarized in Table 1. To determine the stiffness (slope of stress–strain curve), initial linear portion of the curve has been fitted with a linear curve. To determine the tensile strength, the peak load is divided by original cross-sectional area.

Table 1. Mechanical properties of neat epoxy at different strain rates

Cross head velocity (mm/min)	Tensile modulus (GPa)	Tensile strength (MPa)	Strain rate (S^{-1})
0.5	2.57± 0.10	45.57± 5.91	0.0001
5	2.76± 0.13	45.31± 0.91	0.001
50	2.81± 0.10	43.53± 2.37	0.01
500	2.97± 0.01	56.51± 0.07	0.1

The effect of strain rate on the tensile modulus is shown in Fig. 8. The stiffness of epoxy clay nanocomposites tends to slightly increase as strain rate increased by 12.89 %, 7.14 %, 4.95 % and 2.06 % at the highest strain rate (0.1 1/sec) for neat epoxy, 1.5 wt.%. 3 wt.% and 5 wt.% clay loadings, respectively. It is observed that neat epoxy is more testing speed sensitive when compared to epoxy nanocomposites. Increasing strain-rate will decrease the molecular mobility of the polymer chains, consequently leading to a value apparently a stiffer and more brittle material.

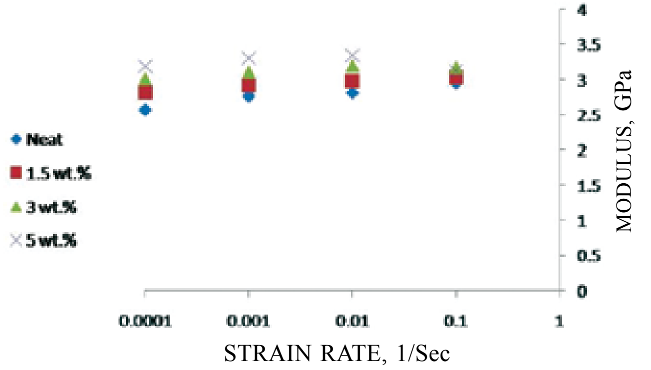

Figure 8. Effect of strain rate on tensile modulus of epoxy clay nanocomposites.

The effect of strain rate on the tensile strength of composites is shown in Fig. 9. The extracted longitudinal tensile strength response tends to have significant decrease with increasing strain rate. The increase is 23.99% for neat epoxy and decrease is 14.77%, 12.18% and 20.72% at the highest strain rate (0.1 1/sec) for 1.5 wt.%, 3 wt.% and 5 wt.% clay loadings of epoxy clay nanocomposites respectively. At higher clay loadings drastic decline in tensile strength is noticed with the increasing strain rate.

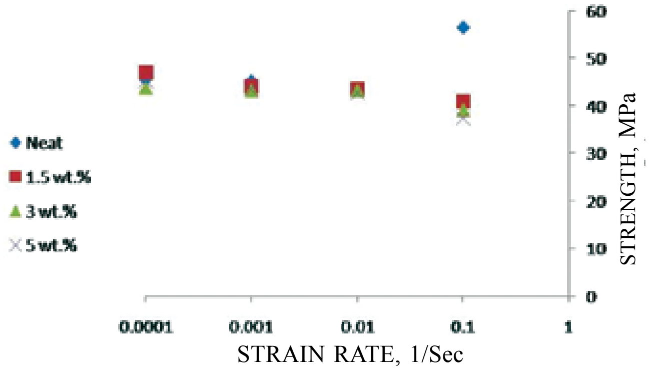

Figure 9. Effect of strain rate on tensile strength of epoxy clay nanocomposites.

The strain to failure tends to increase for neat epoxy system and decrease for 1.5 wt.%, 3 wt.% and 5 wt.% clay loadings as strain rate increased. The increase is 20.31% at the highest strain rate for neat epoxy and decrease is 17.98%, 14.68% and 12.45% at the highest strain rate (0.1 1/sec) for 1.5 wt.%, 3 wt.% and 5 wt.% clay loadings of epoxy clay nanocomposites respectively. Decrement in failure strain is observed for higher loadings with the increasing strain rate.

3.1.3 Effect of Clay on Tensile Properties

The failure stresses are declining as the organoclay loading increases. The decrease in strength at higher clay loading is believed to be a direct result of the aforementioned weak interfacial bond between the filler and the matrix. Also, the presence of minor agglomerations in the 3 wt% and 5 wt% specimens could be a reason for decrement in strength. With properties such as the ones tested in this section, the ability of the strong bond to transfer load from the weak matrix to the rigid filler is crucial. If such a bond does not exist or is weak, the load is borne primarily by the weak matrix causing the material to fail prematurely.

The larger the surface area of the filler in contact with the polymer, the greater will be the reinforcing effect. This could partly explain why layered silicates, having an extremely high specific surface area (on the order of 800 m^2/g) impart dramatic improvements of modulus even when present in very small amounts in a polymer. It is found that the modulus of the nanocomposites increases monotonically with increasing clay content. In general, the improvement in elastic modulus is attributed to the good dispersion of nanosize clay particles and good interfacial adhesion between the particles and the matrix so that the mobility of polymer chains is restricted under loading.

3.2 Glass Fiber Epoxy Hybrid Nanocomposites

3.2.1 Stress – strain curves

Tensile test were conducted on five cross-head stroke rates of 0.5 mm/min, 5 mm/min, 50 mm/min, and 500 mm/min on glass/epoxy/clay nanocomposite specimens. These stroke rates applied nominal strain rates of 0.00066 1/s, 0.0066 1/s, 0.066 1/s, and 0.66 1/s on the specimens. Figures 10-13 illustrate the stress–strain curves at different strain rates for neat, 1.5 wt.%, 3 wt.% and 5 wt.% clay loadings of glass epoxy clay hybrid nanocomposites respectively. The stress – strain curves were similar and the behavior was consistent at different strain rates.

In Fig. 10, it can be seen that the stress-strain curves for glass epoxy composite show characteristics similar to those of pure epoxy. The curves for glass epoxy composite also exhibit relatively greater linearity than those for pure epoxy, suggesting that stiffening is due to the reinforcing fibres. The stress–strain response is approximately linear elastic up to the maximum stress point followed by abrupt failure at a strain of 10.23% under quasi static loading and increased to 13.90% under highest strain rate (0.66 1/s) for neat epoxy glass epoxy composite.

For 1.5 wt.% clay loading, the stress–strain response is linear elastic and failed at a strain of 9.99% under quasi static

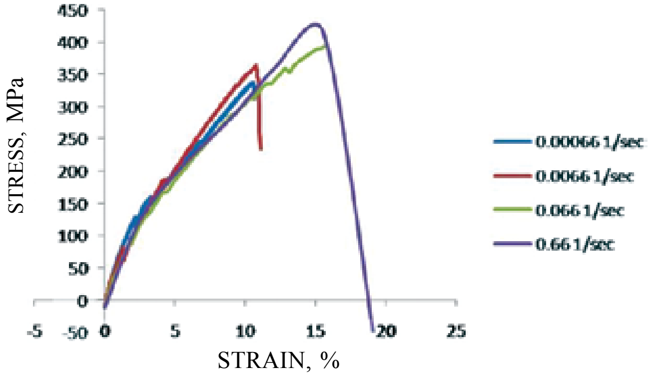

Figure 10. **Stress – strain curves of glass epoxy composite at different strain rates.**

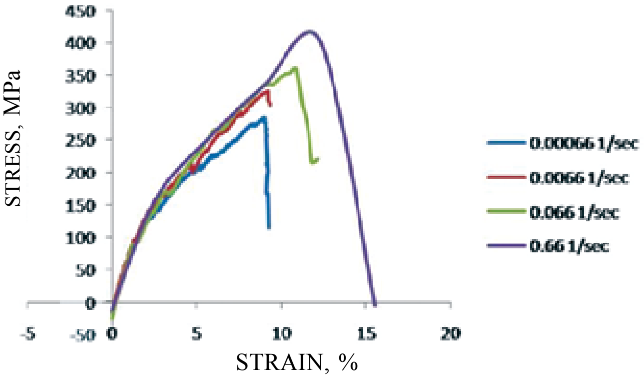

Figure 11. **Stress – strain curves of 1.5 wt.% clay glass epoxy hybrid nanocomposite at different strain rates.**

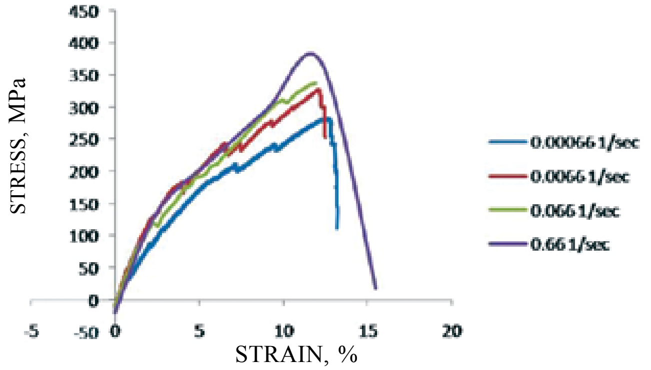

Figure 12. **Stress – strain curves of 3 wt.% clay glass epoxy hybrid nanocomposite at different strain rates.**

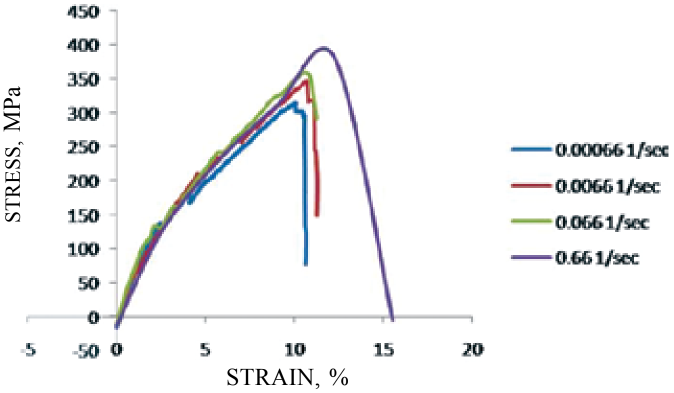

Figure 13. **Stress – strain curves of 5 wt.% clay glass epoxy hybrid nanocomposite at different strain rates.**

loading and increased to 13.32% at highest strain rate (0.66 1/s) and the failure strain is reduced with the addition of clay.

For 5 wt.% clay loading, the specimen failed at a strain of 9.97% under quasi static loading and decreased to 9.68% at highest strain rate. At higher strain rate, the initial stress–strain response leading up to the peak stress is almost similar to the quasi-static results. On the other hand, comparing the figures, it can be understood that when the strain rate is increased, the ultimate strength of the composite under consideration is increased.

3.2.2 *The Tensile Strength and the Stiffness*

The extracted data for different strain rates are summarized in Table 2, which gives modulus and tensile strength. To determine the stiffness (slope of load-dispalcement curve), initial linear portion of the curve was fitted with a linear curve. To determine the tensile strength, the peak load was divided by original cross-sectional area.

Table 2. Mechanical properties of neat GFRP at different strain rates

Cross head velocity (mm/min)	Tensile modulus (GPa)	Tensile strength (MPa)	Strain rate (S^{-1})
0.5	7.52± 0.77	325.9± 13.61	0.00066
5	8.26± 0.18	339.4± 18.13	0.0066
50	8.98± 0.27	387.1± 7.04	0.066
500	6.13± 0.55	401.9± 19.04	0.66

The effect of strain rate on the tensile strength of composites is shown in Fig. 14. The extracted longitudinal tensile strength response tends to significantly increase with increasing the strain rate. The increase is 23.33%, 27.99%, 27.82% and 13.03% at the highest strain rate (0.66 1/s) for neat glass fiber epoxy, 1.5 wt.%, 3 wt.% and 5 wt.% clay loadings of glass epoxy clay hybrid nanocomposites respectively. The stiffness of glass/epoxy hybrid nanocomposites tends to slightly increase as strain rate increased by 19.4%, 23.66%, 15.07% and 12.6% for neat epoxy, 1.5 wt.%. 3 wt.% and 5 wt.% clay loadings respectively. The maximum increase in elastic modulus and tensile strength is observed for 1.5 wt.% clay loading at highest strain rate (0.66 1/s).

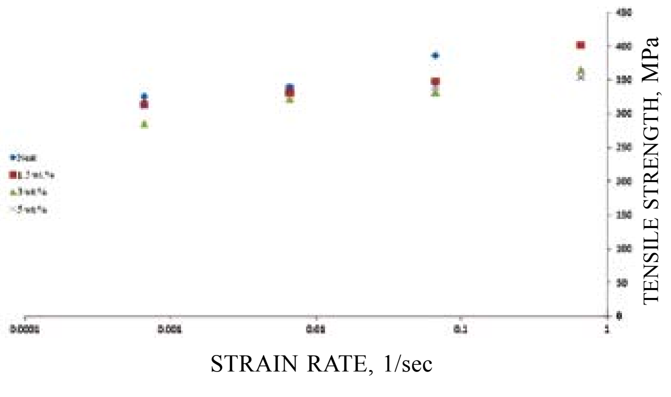

Figure 14. **Effect of strain rate on tensile strength of hybrid nanocomposites.**

The increase in tensile modulus and strength is generally explained by a combination of several factors including the viscoelastic nature of the polymeric matrix, i.e. stiffening with increased rate of loading, the woven structure and geometry of the composite. Furthermore, the rate sensitivity of the tensile strength can also be attributed to the rate dependence of the glass fibres in fibre dominated loading mode, as suggested by Okoli[21]. Therefore, compared with the elastic modulus, the longitudinal tensile strength is highly affected by the strain rate.

The increment in failure strain is observed for glass epoxy clay hybrid nanocomposites with the increasing strain rate. The increase is 36.75%, 33.84%, 23.60% and 6.62% at the highest strain rate (0.66 1/s) for neat glass fiber epoxy, 1.5 wt.%, 3 wt.% and 5 wt.% clay loadings of glass epoxy clay hybrid nanocomposites respectively.

3.2.3 *Effect of Clay on Tensile Properties*

In general, the tensile strength is fiber dominated property, the stress-strain curve is linear and sudden failure occurs as the ultimate strength is reached. The failure stresses are declining as the organoclay loading increases. Since, the tensile strength is fiber dominant property and should not be much influenced by the matrix, but when the epoxy matrix is modified with the organoclay, the stiff silicate particles make the matrix brittle, which could be responsible for the decrease in the tensile strength of nanocomposites. Apparently, the silicate layers constrain the matrix so that plastic deformations are prevented in the nanocomposite.

The tensile modulus increases by adding montmorillonite organoclay. It is noted that an increase of about 10% is achieved with addition of only 1.5 wt% organoclay. It should be recalled that for the nanocomposites with 1.5 wt% organoclay, XRD showed no peak, indicating that the exfoliated clay morphology dominates. Thus, it indicates that the exfoliated structure contributes more significantly to the improvement of the tensile modulus. It is also reported that the increase in modulus is directly related to the high aspect ratio of silicate layers.

A sudden drop in failure strain is observed with the addition of clay in glass epoxy composites. The decrease in strain to failure at higher clay loading is believed to be due to the stiff silicate particles.

3.3 SEM Fractography

From the visual inspection a marked change could be observed in the fracture surface at different cross-head speed. At lower strain rates, less damage in the fracture surface and matrix crack were observed. On the other hand, with increasing strain rate, fracture path covered the entire gauge region. An extensive debonding of fibers from the matrix was observed with increasing strain rate.

The SEM micrographs of clay–GFRP hybrid composite specimens tested at lowest strain rate are shown in Fig. 15. The neat GFRP samples showed smooth surfaces of homogenous matrix material flow in the form of shear lips, leads to brittle failure. The fiber surfaces were very clean without any trace of attached resin particles. The clay nanocomposite matrix between the reinforcing fibers showed rough surfaces and shear

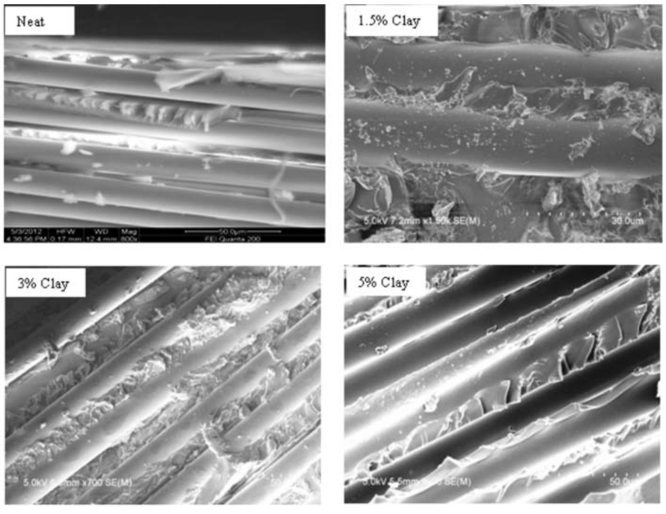

Figure 15. **SEM micrographs of fiber matrix interaction at different clay loadings.**

lips became smaller in size, deeper and dense with increasing clay content. The clay-modified epoxy matrix shows good wetting to the glass fibers than the neat matrix. It is noted that only good fiber–matrix adhesion allows good load transmission between glass fibers and polymer matrix.

From SEM micrographs it is clear that the failure modes change with changing loading rate. Figure 16 revealing matrix cracking, matrix damage and fiber break for clay- GFRP hybrid composites at lower strain rates (0.5 mm/min and 5 mm/min). Micro voids (~1 µm dia) and matrix cavity were observed for 5 wt.% clay loading (Fig. 17)

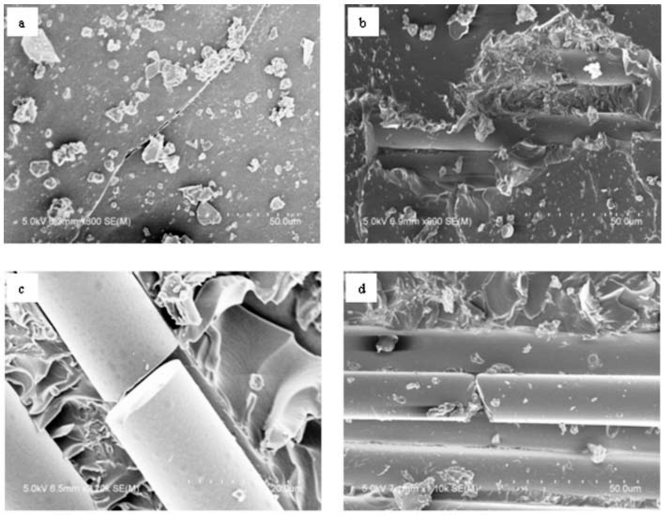

Figure 16. **SEM images of quasi static fractured surfaces of clay-GFRP hybrid (a) matrix cracking, (b) matrix damage, (c) and d) fiber breakage.**

It is observed that the failure mode changes from fiber brittle failure to brittle failure with considerable matrix damage preceding final fracture as the strain rate increases. At higher strain rates, total loss of adhesion at the fiber/polymer interface were observed for clay-GFRP hybrid composites (Fig. 18)

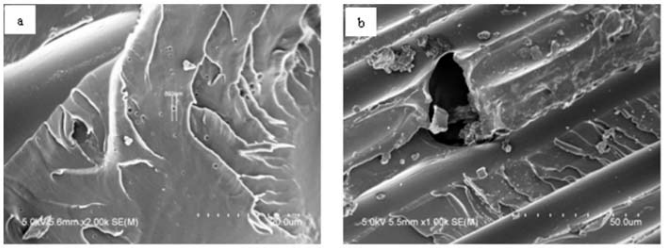

Figure 17. **SEM images of 5 wt.% clay-GFRP hybrid composites (a) micro voids and (b) matrix cavity.**

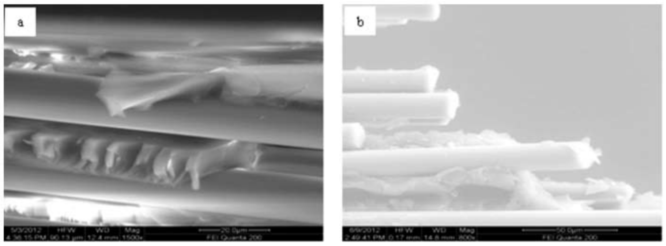

Figure 18. **SEM images of tensile fractured surfaces at loading rate of 500 mm/min (a) matrix debonding and (b) fiber pullout.**

4. CONCLUSIONS

In the current study, the role of both clay and strain rate on the tensile properties of neat epoxy and glass epoxy hybrid nanocomposites were studied. The tests were conducted for strain rates ranging from 0.5 mm/min to 500 mm/min with samples possessing different clay loadings. The performance of the composites depends on loading rates and the dispersion of nano particle in the matrix. The strain rate effect plays a dominate role in the stress–strain behavior of this composites. The mechanical properties of both epoxy and glass/epoxy composite are strain rate sensitive, even at low range of strain rate. The experimental findings show that the longitudinal tensile strength is more rate sensitive than its longitudinal stiffness. The visual inspection of the failed specimens shows significant changes in the fracture surface with increased strain rate. At low strain rates, damage regions cover a small portion of the fracture surface while with increasing strain rate the damage path covers the entire gauge section where extensive debonding between the fibers and the matrix is also observed. The presence of nano clay has a significant effect on mechanical properties; even at low weight fraction, an increase in modulus is observed in epoxy and glass/ epoxy composites.

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