Mechanical and thermal behavior of nano-TiO_2 enhanced glass fibre reinforced polymeric composites at various crosshead speeds

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Abstract

Fibre reinforced polymeric (FRP) are used in different components of aerospace, space, marine, automobile and civil infrastructure. These materials are becoming prime choice of materials in the field of structural components. During their in-service period different structural components experience a wide range of loadings. The current investigation was focused on the assessment of mechanical and thermal behavior of glass FRP composite on the addition of nano-TiO_2 particles. The control glass/epoxy(GE) composites and nano-TiO_2 modified GE composites were tested at different crosshead speeds viz. 1, 10, 100, 500 and 1000 mm/min. Nano-TiO_2 was used as filler material and the epoxy matrix was processed with different nano-TiO_2 contents (0.1, 0.3 and 0.5 wt. %). Addition of 0.1 wt. % nano-TiO_2 particles exhibited an improvement in strength of nano-TiO_2 /GE composites at all crosshead speeds. Different failure patterns of nano-TiO_2 enhanced GE composite tested at 1, 10, 100, 500 and 1000 mm/min crosshead speeds were identified. Scanning electron microscopy (SEM) was carried out to know the main cause of failure that induced different morphologies. Furthermore, the viscoelastic behavior of the material was carried out using dynamic mechanical thermal analyzer which correlated the mechanical and thermo-mechanical behavior of the FRP composites.

Keywords: Nano-$TiO_{2;}$ glass fibre reinforced polymeric composites; Mechanical behavior; crosshead speeds; dynamic mechanical thermal analyzer

1. INTRODUCTION

Fibrous reinforced polymer composites are used in different components of aerospace, space, marine, automobile, and civil infrastructure. This is because of their lightweight, high specific strength, corrosion resistance, and competitive cost in comparison to metallic as well as nonmetallic materials [1,2]. However, environmental degradation of polymer matrix composites creates threat to the design engineer to select precisely the correct glass fiber-reinforced polymer (GFRP) composite material for hydrothermal, thermal, alkali, and corrosive media. However, the improvement depends on the nano fillers concentration, shape, size, and interlink between the matrix, fiber and nano fillers. Broadly nano fillers are carbon based (CNT, SWCNT, MWCNT, and graphene), inorganic (SiO2, SiC, etc.), metal (Fe, Al, etc.), metal oxide (TiO2, Al2O3, ZnO, etc.) and others (WS2, MoS2 nano clay, etc.) [3]. Addition of nano fillers into the polymer matrix composites enhances the mechanical properties, thermal stability and lowers the permeability as compared to that of neat epoxy GFRP composites [4,5]. Among different nano fillers, nano TiO_2 and Al2O3 are the most promising metal oxide fillers, because of their excellent mechanical, thermal, weathering properties, low density and low manufacturing cost as compared to carbon base nano fillers [6–7]. The current investigation was focused on the assessment of mechanical and thermal behavior of glass FRP composite on the addition of nano-TiO_2 particles. The control glass/epoxy(GE) composites and nano-TiO_2 modified GE composites were tested at different crosshead speeds viz. 1, 10, 100, 500 and 1000 mm/min.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in the experimental study was glass fibre and polymer matrix as epoxy. The fiber-reinforced polymer composites were fabricated by the combination of 60 wt% of woven roving glass fiber, 40 wt% of epoxy of diglycidyl ether of bisphenol A and hardener of triethylene tetra amine. Further nano-TiO_2 fillers were added at different weight percentage into the epoxy matrix before fabrication of nanocomposites. The nanoparticles were supplied by SRL Industries limited, Mumbai, India. It was observed that the shape of the nanoparticles is nearly spherical and the size of nano-TiO_2 particles is about <100 nm.

2.2 Manufacturing and testing of GFRP and nano filler enriched GFRP composites

The below flow chart shows the complete fabrication procedure of composites laminates. Composite laminates were fabricated by hand layup technique followed by hot press molding (10 kg/cm^2 pressure, 60°C and for 20 min). Each laminate contains 7 layers of glass fiber. Further, composites were cured for 6 h at 140°C. The composite laminates were cut as per the ASTM standard. The different composite is enhanced with 0, 0.1, 0.3 and 0.5 weight percent nano-TiO_2 enhanced glass/epoxy composites.

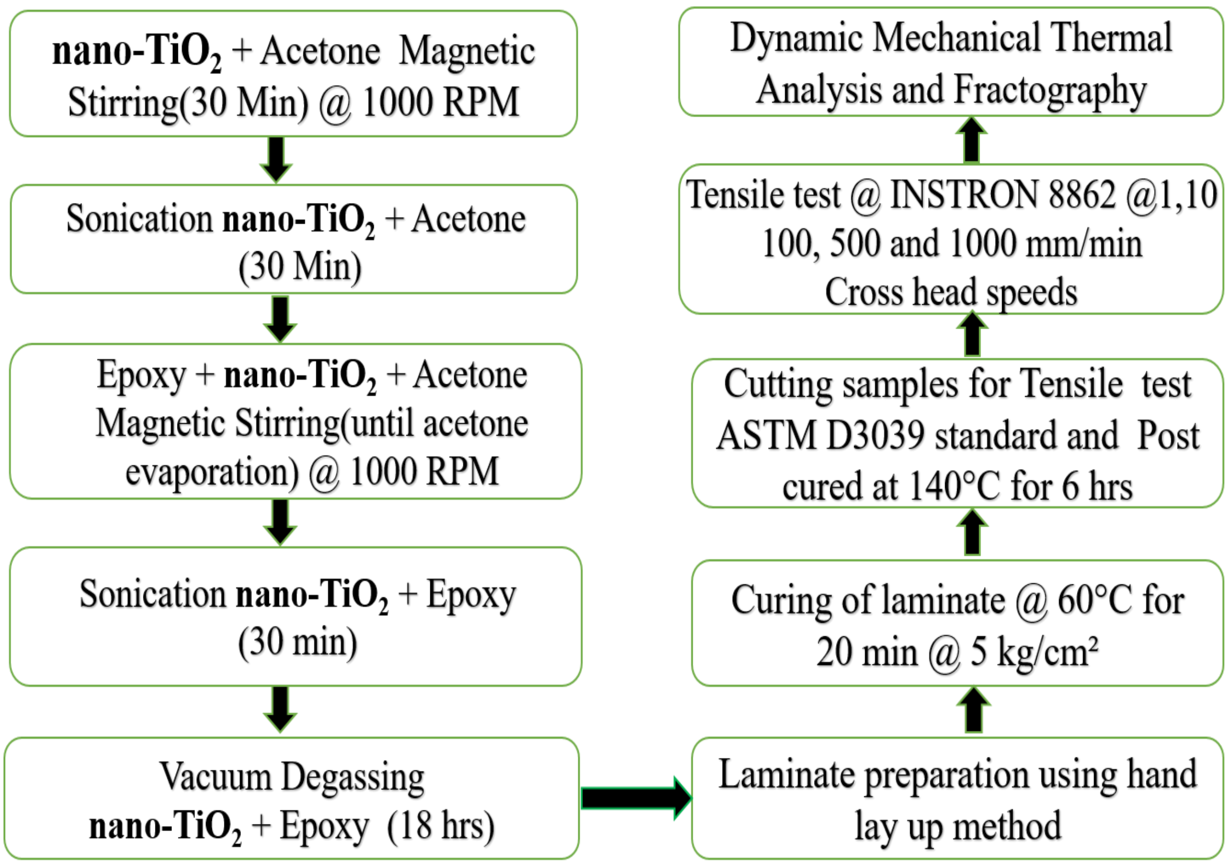


Figure 1: Outline of fabrication procedure of composites laminates

3. RESULTS AND DISCUSSION

3.1 Effect of tensile behavior of nano-TiO_2 enhanced glass/epoxy composite at various crosshead speeds

Figure 2. depicts the stress Vs strain plot for glass fiber polymer composite and nano-TiO_2 filled GE composite tested at 1,10, 100, 500 and 1000 mm/min crosshead speeds. Addition of 0.1 wt. % nano-TiO_2 particles exhibited an improvement in strength of nano-TiO_2 /GE composites at all crosshead speeds. The reason may be contributed to the transfer of stress from matrix to fiber at lower crosshead speeds was minimal. In the other hand the transfer of stress at higher crosshead speeds was higher due to lack of time availability. Which in turn, stress is carried by the fibers only not the matrix exhibiting higher stress at higher loading rates. This shows the composites system are loading rate sensitive.

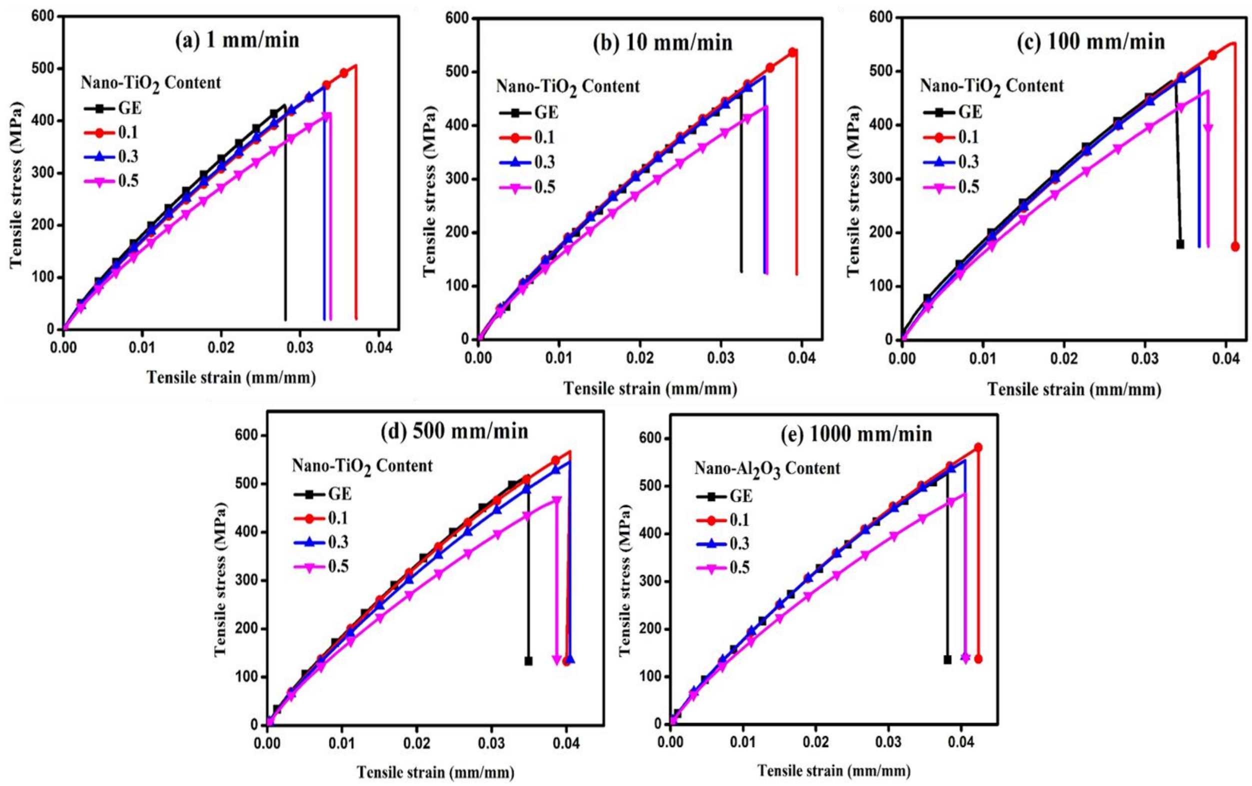


Figure 2: Stress Vs Strain plot for glass fiber polymer composite and nano-Al_2O_3 filled GE composite tested at 1,10, 100, 500 and 1000 mm/min crosshead speeds.

The maximum stress was carried by 0.1 wt. % nano-filler enhanced GFRP composites at all the loading rates. This shows the optimal content of nanofillers in the epoxy matrix. As the content goes on increasing from 0.1 to higher (0.3 and 0.5) the strength of the composites goes on decreasing. This decrement in strength may be attributed to the agglomeration of the nano- filler particles in the polymer matrix.

3.2 Different failure patterns of glass/epoxy composite

The various failure behavior of the GFRP composites tested at different crosshead speeds are shown in figure.3. Generally, at lower crosshead speeds the failure of the GFRP composites is not quite significant. But at higher crosshead speeds the failure of the composites occurred at several regions. This indicates the complete failure behavior of the composites at higher loading speeds.

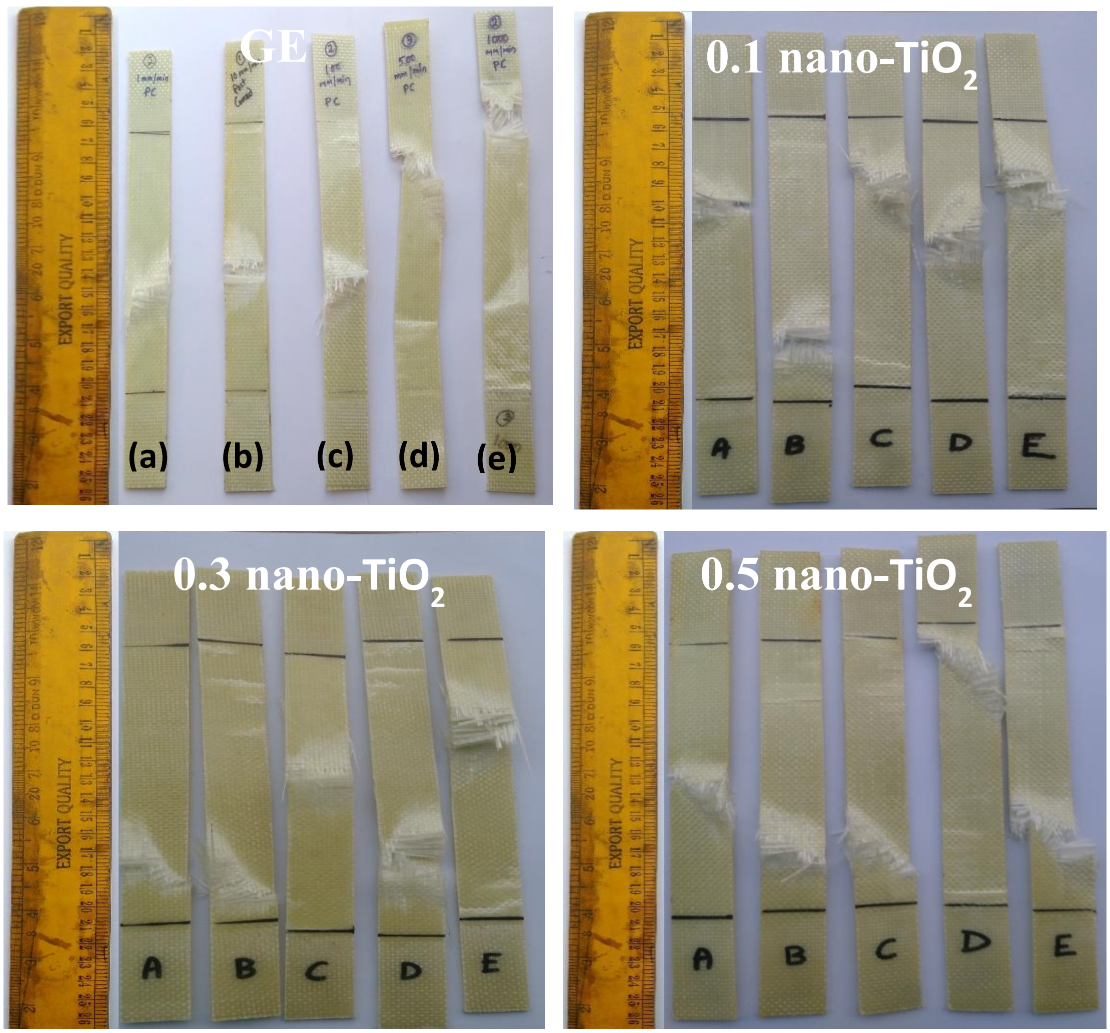
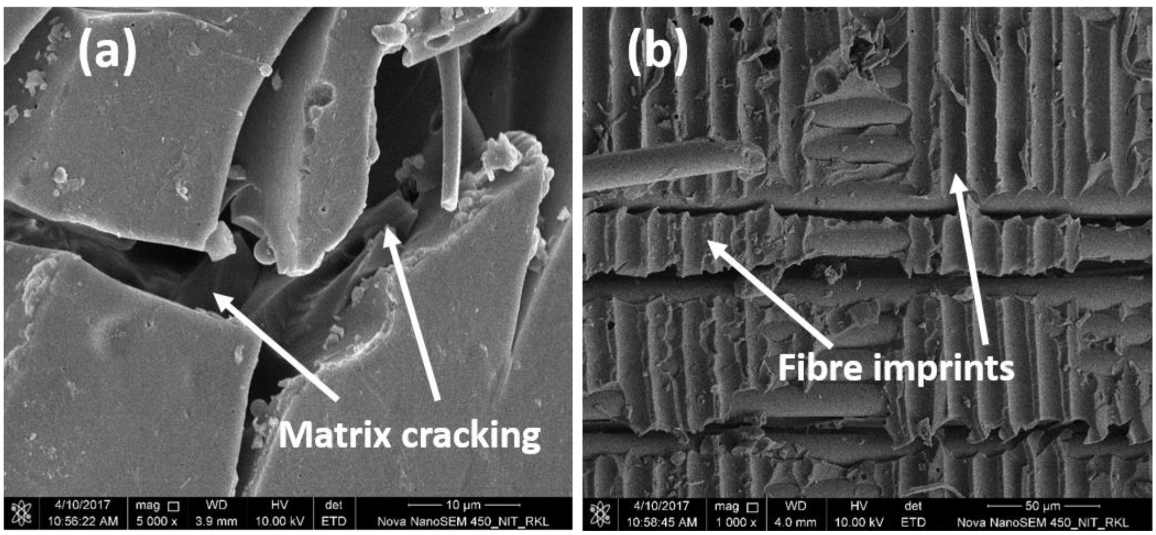


Figure 3: Failure outlines of glass fiber polymer composite and nano-Al_2O_3 filled GE composite tested at (a) 1mm/min, (b) 10 mm/min (c) 100 mm/min (d) 500 mm/min (e) 1000 mm/min crosshead speeds.

3.3 Fractography analysis

After, mechanical testing fractured surfaces of the composites were seen in scanning electron microscope to know the different failure morphology of the composites. The dominant modes of failures identified after the mechanical testing were matrix cracking and fibre imprints. Usually at low loading speeds, due to the time available for crack propagation is higher that establishes transfer of stress from matrix to fiber. This transfer of stress comes with cracking of matrix phase. But in case of higher crosshead speeds the time available for crack propagation is lower that creates complete removal of matrix phase showing imprints of fibres



4. CONCLUSIONS

The experimental investigation comprises the following conclusions

- Addition of 0.1 wt. % nano-TiO_2 particles exhibited an improvement in strength of nano-TiO_2 /GE composites at all crosshead speeds. Its shows the composites are loading rate sensitive.
- Different failure patterns of nano-TiO_2 enhanced GE composite tested at 1, 10, 100, 500 and 1000 mm/min crosshead speeds were identified.
- Scanning electron microscopy (SEM) was carried out to know the main cause of failure that induced different morphologies such as matrix cracking and fiber imprints.

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