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SYNTHESIS AND CHARACTERIZATION OF HYBRID GLASS FIBER REINFORCED EPOXY/TiO_2 NANOCOMPOSITES

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Abstract

Advancements in the nanotechnology industry promise to offer improvements in capabilities across a spectrum of applications. This is of immense strategic importance to the high performance sector which has historically leveraged technological advances. The polymer nanocomposites are widely used in marine, aerospace, automotive and construction industries due to light weight with high strength. In this present research work, synthesis of hybrid S-glass fiber reinforced with epoxy/TiO_2 nanoparticles were carried out and characterized by tensile and impact tests. Glass fibers of woven roving mat (WRM) and chopped stranded mat (CSM) were used as reinforcements. The composite laminates were prepared by hand layup technique with varying weight percentages of TiO_2 nanoparticles such as 0, 1, 2, 3, 4 and 5 wt. % respectively. Scanning electron microscope (SEM) is employed to investigate the structural morphology and distribution of TiO_2 nanoparticles in the polymer matrix. The mechanical properties of the prepared nanocomposites laminates were characterized in terms of tensile and impact (Izod) tests as per ASTM standards. At addition of 3 wt. % of TiO_2 nanoparticles the tensile strength was improved by 44% and impact strength by 64.7% when compared with neat polymer nanocomposites. The reason for the enhancement was good interfacial bonding with fiber and polymer matrix.The fractured surfaces of the nanocomposites were examined by using scanning electron microscope (SEM) to characterize the damage progressions.

Keywords: Glass fiber, TiO_2 nanoparticles, Impact test, Interfacial bonding, Scanning electron microscope (SEM).

I. Introduction

Hybrid S-glass fibre reinforced polymer based composites have been drastically improving owing to their reduced weight, improved mechanical properties making them equivalent to those of metallic materials. The dispersion of nanoparticles in the polymer matrix influences its physical properties. Moreover hybridization of glass fibres induces the binding strength of fibres of both woven roving and chopped strand types. Mechanical properties play a vital role in studying the behaviour of the materials under application of pressure or load. Fiber rein-forced polymers are either used for the substitution of metals in many weight-critical components in aerospace, automotive, and marine applications. Holger Ruckdasche etal. reported a fundamental overview of comprehensive research regarding carbon nanofiber polymer composites for demanding tribological applications [1]. Feng-Hua Su et al. studied the Tribological behaviour of hybrid glass/PTFE fabric composites with phenolic resin binder and nano TiO_2 filler and found that The improved tribological performance of 4% TiO_2 filled hybrid glass/PTFE fabric composites can be attributed to the improved structural integrity of the composites, the character of transfer film and the special anti-wear action of TiO_2 during friction process [2]. A.Ikram et al. investigated the flexural behaviour of micro and nano TiO_2/epoxy composites and also characterized the fractured surfaces at maximum deflection. The stiffness (Young's modulus) of samples increase with increase of filler addition, it's because of nanoparticles restrictions to the chains, decreasing in chains length and increasing in complicating the crosslink between polymer chains [3]. Epoxy/nanocomposites have many positively characteristics such as mechanical performance, dielectric behaviours, thermal stability, and also have many advantages of good corrosion resistance, adhesion to most substrate, good scratch resistance, and excellent tribological properties. Several potential applications was leading to wide interest in this type of nanocomposites such as using in sealants, paints, coatings [4]-[7]. The properties of nanocomposites were greatly influenced by the size scale of its component phases and the degree of mixing between the two phases. Depending on the nature of the components used and the method of preparation, significant differences in composite properties may be obtained [8]. Nanoparticles filled polymers are attracting considerable attention since they can produce property enhancement that are sometimes even higher than the conventional filled polymers at low volume fraction range [6].

In the present investigation, the hybrid glass fiber reinforced with epoxy/TiO_2 nanoparticles were synthesized and their mechanical properties such as tensile and impact tests are carried out to examine the strength, stiffness and nature of failure. The fractured surfaces were employed under scanning electron microscope (SEM) for characterization of the delaminated fibers and load distribution.

II. Materials and Methods

A. *Materials Used*

S-Glass is generally used for polymer matrix composites that require improved mechanical properties compared to E-glass based composites. In this research work, S-glass fiber of woven roving mat (WRM) and chopped stranded mat (CSM) were used in order to improve the load bearing property on both the directions. Epoxy resin of trade name LY556 mixed with TiO_2 nanoparticles was used as matrix materials. TiO_2 nanoparticles are used as a filler material to prepare the polymer nanocomposites laminates. Polyvinyl alcohol (PVA) is a water soluble synthetic polymer applied on the mould before the hand layup process for the easy removal of prepared laminates after curing.

B. *Sample Preparation*

Hand layup technique is used to prepare the nanocomposites laminates of size 320 x 320mm in a mould of size 400 x 400mm. Before casting the mould was cleaned and free from dust particles. 6 layers of fiber mats where laid as a whole to get single hybrid laminate which consist of 3 layers of WRM and 3 layers of CSM. Mechanical stirrer is used for mixing the epoxy resin and TiO_2 nano particles at a constant speed of 800rpm for controlled dispersion of TiO_2 particles in the epoxy resin. The laminates were let to cure at room temperature for 48 hours and remoulded after curing. The specimens are cut as per ASTM standards for tensile and impact tests. According to the ASTM D3039 with a dimension of 250 x 25 x 4 mm specimens were cut from prepared laminates for tensile test [10]. In accordance to the ASTM D256 with a specimen size of 64 x 12.7 x 4 mm laminates were cut and prepared for Izod impact test [11].

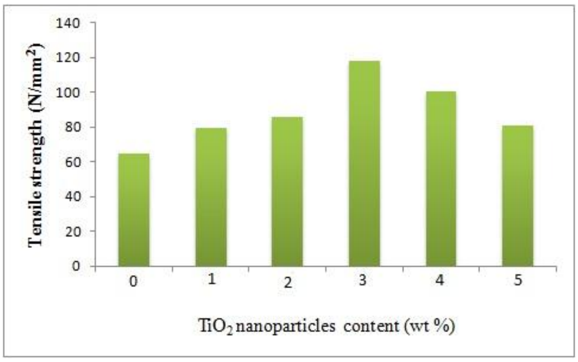
III. Results and Discussions

A. *Tensile Test*

The parameters such as ultimate strength, maximum elongation, poison`s ratio and yield strength were obtained by the stress – strain curve drawn for the tensile test of prepared laminates. Tensile tests were carried out by using INSTRON universal testing machine 3382 model under a static load of 1kN. The tensile strength and modulus values of hybrid glass fiber reinforced epoxy /TiO_2 nano composite is presented in table.1.

Table. 1. Tensile properties of hybrid glass fiber /epoxy TiO_2 nanocomposites.

TiO_2 nanoparticles content (wt. %)	**Maximum load (N)**	**Tensile strength (N/mm^2)**	**Tensile modulus (GPa)**
0	7765.77	64.98	2.91
1	9525.38	79.71	3.19
2	10291.45	86.12	3.32
3	14087.61	117.89	4.04
4	9508.89	100.89	3.92
5	8899.44	80.90	3.78



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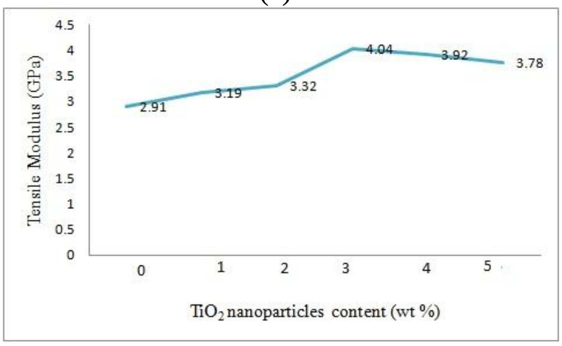


(b)

Fig. 1. TiO_2 nanoparticles content (wt. %) vs. tensile strength (N/mm^2) and tensile modulus (GPa).

The graphical representation of tensile strength and tensile modulus values are sown in fig.1. It indicates that the tensile strength was increased by 44% at addition of 3wt % of TiO_2 nano particles when compared with neat polymer matrix composites. This enhancement is due to the presence of exfoliated nanocomposites structure i.e. well dispersion of TiO_2 nano particles in the polymer matrix composite. A similar trend was observed in tensile modulus properties which increased by 8% and 27% with addition of 1wt % and 3wt % of TiO_2 particles respectively. But during higher concentration of TiO_2 particles, it did not improve the tensile properties. This phenomenon might be due to the comparatively poor dispersion of TiO_2 nanoparticles in epoxy and more possibly of the existence of voids and colloidal form in the composites.

B. Impact Test

Low velocity impact test of the composite laminates could occur in the range of 1-10m/s depending on the target stiffness, material properties and projectile mass and stiffness. Izod impact test is a low velocity impact testing process that used pendulum type impact tester. The impact strength of the polymer nanocomposites laminates was measured in accordance to the ASTM standard D256 and impacted upon by energy of 1kN. 6 pair of specimens were used to get average values from the obtained of six results. The low velocity impact strength values of hybrid glass fiber reinforced epoxy/TiO_2 nanocomposites were presented in table 2. The obtained results showed that there was a gradual increase in impact strength from 33.52kJ/m^2 for neat epoxy to 95.21kJ/m^2 for 3wt. % of TiO_2 nanoparticles infused samples.

Table. 2. Impact properties of hybrid glass fiber /epoxy TiO_2 nanocomposites.

TiO_2 nanoparticles content (wt. %)	**Impact meter reading (J)**	**Impact strength (kJ/m^2)**
0	4.04	33.52
1	4.11	37.44
2	5.03	64.3
3	5.58	95.21
4	5.28	79
5	4.23	65.25

The graphical representation of impact strength was shown in fig.2. The fiber reinforced polymer laminates give rise to four major modes of failure, matrix mode, delamination mode fiber mode and penetration in low velocity impact [11]. Graphical representation of impact strength is shown in fig 2. It indicates that the impact strength was increased by 64.7% at addition of 3 wt. % of TiO_2 when compared with neat epoxy nanocomposites laminate. This result was obtained due to the uniform dispersion of nano TiO_2 particles among the hybrid glass fibers.

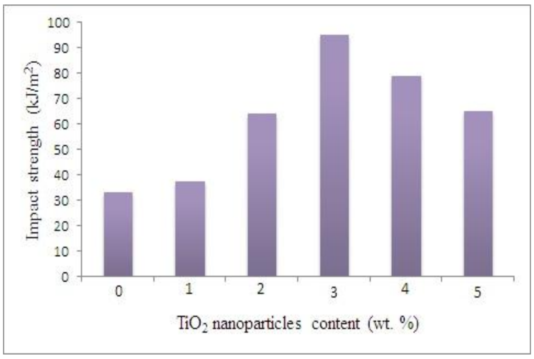
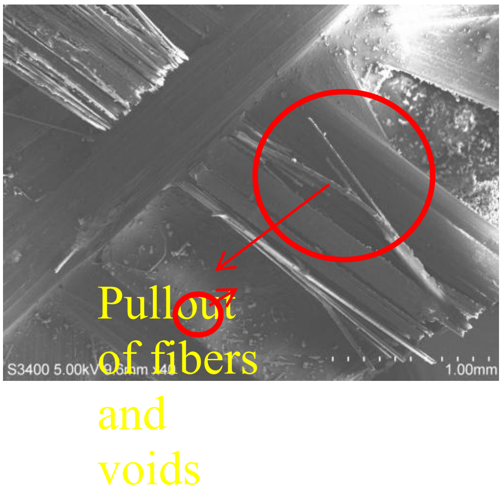


Fig. 2.TiO_2 nanoparticles content (wt. %) vs. impact strength (kJ/m^2).

C. SEM analysis of fractured surfaces



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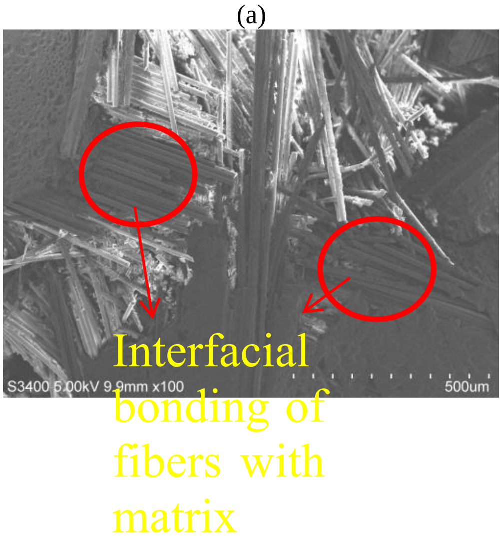

(b)

Fig. 3. SEM microstructure of polymer matrix nanocomposites and fractured surfaces at 1wt % and 3wt % of TiO_2 nanocomposite laminates.

The morphology of epoxy nanocomposites of 1wt % and 3wt % of TiO_2 nanoparticles were imaged using scanning electron microscope (SEM) to find out the bonding between fibers and resin. Fig. 3 presents the SEM microstructure of a interfacial bonding and uniform dispersion of TiO_2 nanoparticles at 1wt % and 3wt % in the polymer matrix laminates respectively. The impact failure surfaces of laminates were examined and it detailed that the resistance to crack propagation is high due to the influence of TiO_2 nanoparticles and excellent interfacial bonding between the fiber and matrix. It showed that at 3wt % of nanoparticles significant matrix cracking, delamination and debonding at the interface the fibers are adhere with the matrix material. At 1wt % and higher concentration of nanoparticles the formation of pores and voids were observed it causes delamination and pullout of fibers from the matrix material. Thus the reason for lowered impact damage progression and also controlling the fiber failures.

IV. Conclusion

In this study, the effects of TiO_2 nanoparticles on the hybrid glass fiber/epoxy composite laminates were investigated under tensile and low velocity impact tests. The failure mechanism and various damage processes are examined by using SEM. The following conclusions can be drawn from the tests,

- The hybrid glass fiber/epoxy TiO_2nanocomposite laminates were successfully prepared by varying wt. % of 0, 1, 2, 3, 4, and 5 respectively.
- Scanning electron microscope observation proven that the TiO_2 particles are uniformly dispersed into the epoxy and fiber laminates and the obtained morphology is intercalated structures.
- There is a gradual increase in tensile strength and maximum tensile strength of 117.89N/mm^2 is obtained at addition of 3wt % of TiO_2 nanoparticles. Also maximum impact strength of 95.21kJ/m^2 is observed due to the uniform load distribution on the polymer nanocomposite laminates.
- By adding higher concentration of TiO_2 nanoparticles, it did not improve the tensile properties. This phenomenon might be due to the comparatively poor dispersion and agglomeration of nanoparticles in epoxy and more possibly of the existence of voids in composites.
- Good interfacial bonding between the fibers and matrix due to excellent influence of TiO_2 nanoparticles is the main reason for the enhancement in the mechanical properties. The fractures surfaces of 3wt % of TiO_2 nanocomposites show considerably different fractographic features in SEM images.

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