Experimental Investigation on the Tensile and Flexural Strength of Nano-Polymer Composites

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***Abstract*— The prime aim of this investigation is to study the effect of Montmorillonite (MMT) nanoclay on the tensile and flexural strength of epoxy resin and GFRP. Two sets of composites viz., nanoclay as direct reinforcement (NCD) & nanoclay as filler material (NCF), were fabricated with varying weight percentage of nanoclay. In NCF, glass fiber weight percentage was also changed as 40 wt.% and 60 wt.%. NCD laminates were prepared by general casting technique where as NCF by hand lay-up technique. The specimens were prepared and tested for tensile strength, as per ASTM standard. The results reveled that increase in glass fiber weight percentage has enhanced tensile and flexural strength by 15 and 10%, respectively. Also, the nanoclay addition had positive influence on the tensile and flexural properties up to 13% and 15%, respectively.**

***Index Terms*— Nanoclay, GFRP, Tensile strength, Flexural Strength, Microstructure**

I. Introduction

In general, “composite” means “a material prepared by two or more different constituents” or “a combination of two or more different constituents, which are mixed at macroscopic level to get the best of their properties” [1-2]. “Glass-Fiber Reinforced Plastic” (GFRP) be made up of continuous glass-fiber and bulk polymer matrix, which is gradually being employed in many industries viz., aerospace, aircraft, marine and construction [3-4]. GFRPs provide inimitable mechanical properties blended with low specific weight and high endurance to degradation. GFRPs are capable substitutes for various applications, where orthodox materials viz., steel, aluminium and ceramics have been previously utilized. The properties of GFRP’s depend on the constituents and their interphase [5].

GRFP are broadly applied in many sectors to note few of them are hulls of boat, automobile, airplane body parts etc. In every application, an exclusive property viz., tensile, flexural and impact strength, plays a vital role. It’s a need of new era, to enhance the properties of GFRP, to make them more successful for many applications [6-7].

The fiber weight percentage of the GFRP intensely influence the properties of end products. GFRP’s strength relies up on the bonding strength amongst fiber and matrix (Interphase region), the robust the bond, steadier the GFRP. The fiber-matrix interphase area increases with increase fiber weight percentage, leads to increase in the bonding strength [8].

Throughout the decades, many researchers are investigating on utilizing various fillers i.e., microparticles or nanoparticles. Microparticles viz., cement, fly ash, asbestos etc., and Nanoparticles viz., nanoclay, carbon nanofiber and nanotubes etc., are used to elevate properties viz., tensile, flexural and impact strength of GFRP [9-11].

The use of nanoclay as filler in the polymer composites has pulled in extensive consideration due to its improved physical and mechanical properties. Nanoclay-polymer composite exhibit improved properties because of nanoscale size dispersion and high surface to volume ratio of nanoclay in polymer. Nanoclay acts as the load transfer medium in GFRP and also, it restricts the crack initiation and propagation.

Haque et al. [13] showed that mechanical properties of GFRP improved by adding organic silicate nanoparticles. Shear & flexural strength of the specimens improved by 44% and 24% respectively by adding 1% by weight nanosilicates. Also, they noted that enhancement in properties of the clay-epoxy nanocomposites was due to improved interfacial surface areas and bond characteristics.

Krushnamurty et al. [8] scrutinized the mechanical properties of GFRP-nanoclay nanocomposites. They added nanoclay (0 to 6 wt%) to resin using ultrasonication and abricated the composites. They reported that adding nanoclay up to 5 wt% had led to increase in mechanical properties of the hybrid composites.

Literature survey suggests that, adding nanoclay up to 5 wt.% gives better tensile properties. However, as the nanoclay wt.% increase in the resin, the propensity for the agglomeration turns out to be more articulated, which not only leads to decrease in the stress transfer but also acts as stress concentration [12-15].

The prime objective of this work is to experimental investigation of the tensile and flexural properties of nano-polymer composites, with varied weight percentage of glass fiber and nanoclay.

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II. Preparation of Nanocomposite

A. Selection of Materials

Table I. provides the details of the selected materials for this study.

TABLE I. Material Details

Material name	Details	Vendor	Properties
Glass fiber	Plain woven, bilateral, 360 GSM	Yuje Enterprises	Tensile strength (MPa) – 1950 Tensile modulus (GPa) – 76 Density (g/cm^3) - 2.52 Mat thickness (mm) - 0.3
Epoxy resin with hardener	Lapox L-12 with hardener K-6 (Mixing ratio 10:1)	Yuje Enterprises	Tensile strength (MPa) - 55 Tensile modulus (GPa) - 2.5 Density (g/cm^3) - 0.9
Nano Nanoclay	Montmorillonite clay - surface modified	Sigma Aldrich	Appearance (Form) - Powder Size - < 20 μm Density - 200 to 500 kg/m^3 (Bulk density)

B. Nanocomposites Constituents Details.

Table II gives the details of first set of nanocomposites, which were prepared by directly reinforcing nanoclay (NCD) in epoxy resin.

TABLE II. Constituents (wt.%) of Nanocomposites, Nanoclay as Direct Reinforcement (NCD)

Constituents (wt.%)	NCD I (Pure Epoxy)	NCD II	NCD III
Epoxy resin	100	98	96
Nanoclay	0	2	4

Second set of nanocomposites (NCF) laminates were fabricated using 0, 2 and 4 wt% of nanoclay, 40 and 60 wt.% glass fiber and the rest epoxy resin as shown in Table III.

TABLE III. Constituents (wt.%) of Nanocomposites, Nanoclay as Filler Material (NCF)

Constituents (wt.%)	NCF I	NCF II	NCF III	NCF IV	NCF V	NFC VI
Epoxy resin	60	58	56	40	38	36
Glass fiber reinforcement	40	40	40	60	60	60
Nanoclay	0	2	4	0	2	4

C. Laminate Preparation

Nanoclay with varied wt.%, added and mixed meticulously with epoxy resin by “mechanical stirrer” at 2000 rpm for 2 hours, followed by “sonication” at 50 kHz for 25 minutes. NCD laminates were prepared by general casting technique. After thorough mixing of nanoclay and epoxy, the mixture was cooled to room temperature. Once the mixture was cooled down, measured quantity of hardener was poured into the mixture which was then mixed thoroughly using a spatula. Then, the clay-epoxy mixture was pour down in the mould and left for curing overnight.

NCF laminates were prepared by hand lay-up technique. It is the modest technique used, to prepare GFRP. After sonication, hardener was mixed as per the standard ratio. The resin mixture was applied consistently to each ply of glass fiber sheet around 10-16 in numbers.. A roller was used to infuse the resin into the fibers. All the laminae stacked in sync and pressed consistently to eliminate air bubbles and excess resin mixture. Then nanocomposites were left aside for curing [16-17].

D. Specimen Preparation and Testing

Tensile and flexural tests were conducted using “Computerized Universal Testing Machine (UTM)” (ZWICK-ROELL Z020, LOADCELL 20 kN) according to the ASTM standard shown in table 4 and 5, with test speed of 2 mm/minute. Strain measured by video extensometer. Three specimens for each condition are used to minimize errors.

TABLE IV. Specimen Details for Tensile Test

Sl. No.	Particulars	ASTM Standard	Size (mm^3)
1	NCD	D 638	115 X 19 X 3
2	NCF	D 3039	250 X 25 X 3

TABLE V. Specimen Details for Flexural Test

Sl. No.	Particulars	ASTM Standard	Size (mm^3)
1	NCD	D 790	140 X 15 X 3
2	NCF	D 7264	175 X 13 X 3

III. Results and Discussion

A. Tensile Strength

Nanoclay as Direct Reinforcement (NCD)

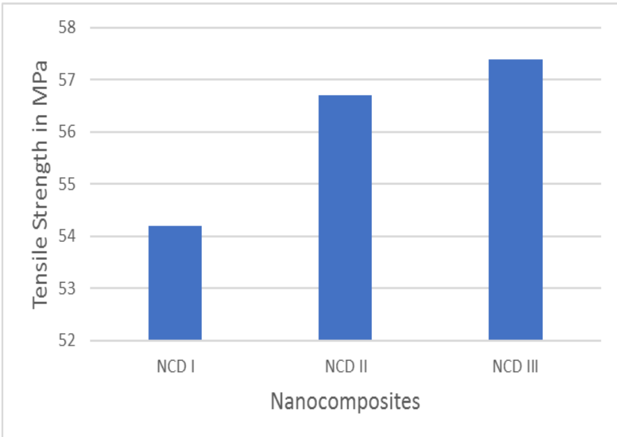
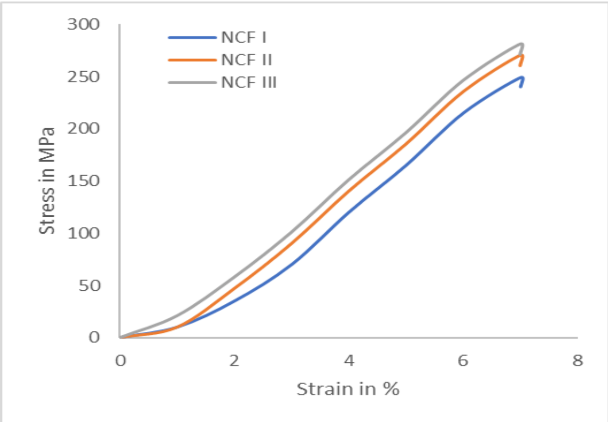


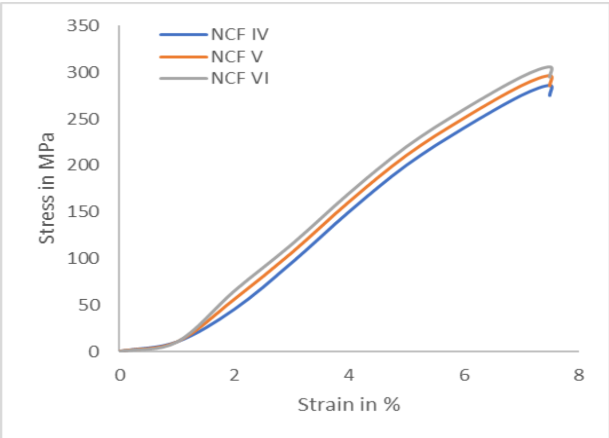
Figure 1. Tensile strength of NCD.

Fig. 1 depicts that, addition of 2 (NCD II) and 4 (NCD III) wt.% of nanoclay results in enhanced tensile strength as compared to NCD I. Nanoclay improves the tensile strength of epoxy resin, due to synergy of load transfer from the matrix to reinforcement. Also, nanoclay has excellent strength to weight ratio and got large surface area, which crafts it to be chemically more active and aids to have better bonding with the epoxy resin[19-20].

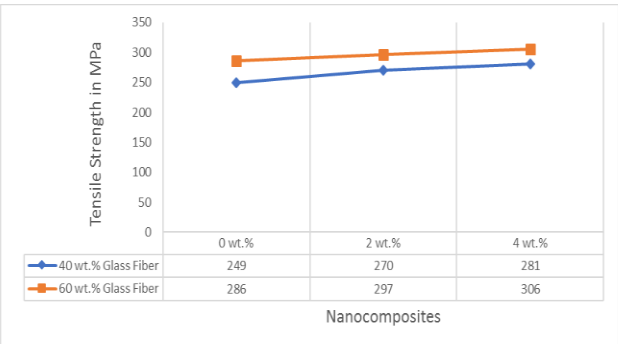
Nanoclay as filler materials in GFRP (NCF)



(a)



(b)



(c)

Figure 2. (a) Stress strain curves of 40 wt.% NCF (b) Stress strain curves of 60 wt.% (c) Tensile strength of NCF.

The results of tensile strength for each type of specimen are shown in Fig. 2. It is noticed that, increase in the glass fiber weight percentage from 40 to 60, in the composite increases the tensile strength by 15% at 0 wt.% of nanoclay (NCF I & IV). It is also observed that adding 2 and 4 wt.% nanoclay enhances the tensile strength by 4 to 13%. With addition of nanoclay, higher increase in tensile strength is observed for 40 wt.% glass fiber nanocomposites compared to 60 wt.% glass fiber nanocomposites. An increase of 13% in tensile strength is observed for 40 wt.% glass fiber nanocomposites and 8% for 60 wt.% glass fiber nanocomposites, with the addition of 4 wt.% nanoclay.

From Fig. 4 (a & b), it is observed that, the failure of NCF is brittle in nature, due to rupture of epoxy resin and increase in interphase bonding between fiber and matrix. It is also noticed that, nanoclay addition had more effect on 40 wt.% NCF as compared to 60 wt.% NCF.

Nanoclay is not the load bearing reinforcement in these nanocomposites. Still, nanoclay addition into epoxy resin has improved the tensile strength. It indicates that, adding nanoclay ensures more load transfer to glass fiber by enhancing the interfacial bonding and resisting the interfacial crack propagation [21-25].

B. Flexural Strength

Nanoclay as direct reinforcement (NCD)

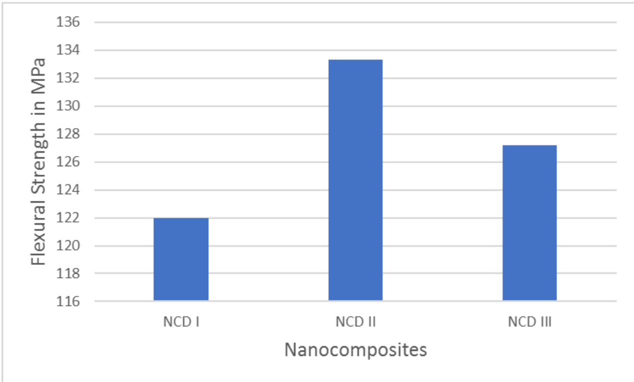


Figure 3. Flexural strength of NCD.

As shown in Fig.3, addition of 2 (NCD II) and 4 (NCD III) weight percentage of nanoclay increased the flexural strength as compared NCD I. But NCD III has poorer flexural strength, as compared to NCD II. The cross-linking reactions between resin and nanoclay at 2 wt.%, enhanced flexural strength.

Further accumulation of nanoclay (4 wt.%) lead to decrease the values flexural strength because of “inhomogeneity” or “agglomerates” in nanocomposites [19-20].

Nanoclay as filler materials in GFRP (NCF)

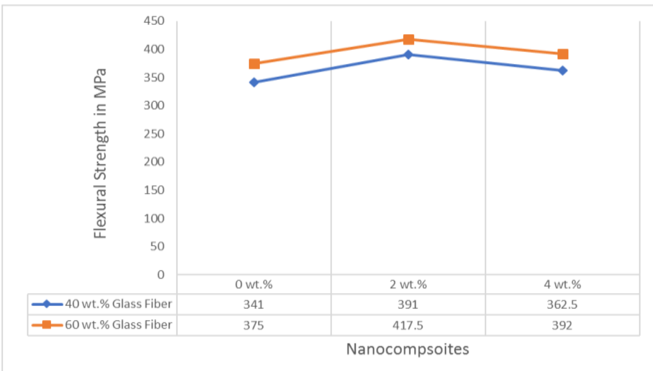


Figure 4. Flexural strength of NCF.

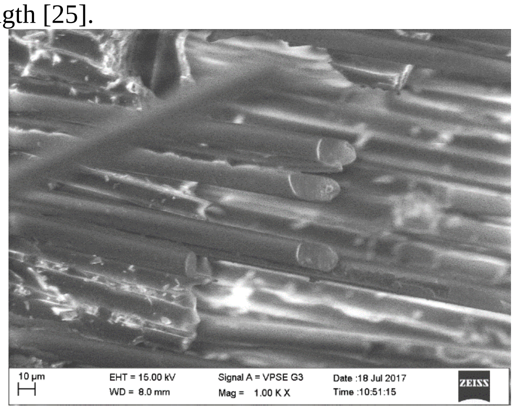
It is noticed that from Fig. 4, increase in the glass fiber weight percentage in the composite increases the flexural strength by 10% at 0 wt.% of nanoclay. It is also observed that adding 2 (NCF II & V) and 4 (NCF III & VI) wt.% nanoclay enhances the flexural strength by 6 to 15%, due to improved properties of nanoclay-epoxy composites and improved interfacial bonding properties, which might have effectively resisted bending loads. But, NCF III & VI have poorer flexural strength as compared to NCF II & V, due to “embrittlement” of epoxy resin, heading to the untimely failure of fibers, hence resulting in hasty failure of the nanocomposite [21-25].

Microstructure analysis of Specimens

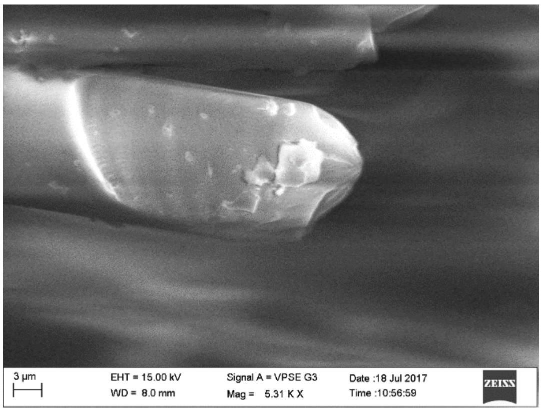
The micrograph of the fractured specimen is shown in Fig.5. Fig.5 (a) shows the arrangement of glass fiber in the bidirectional woven fiber mat. Fig.5 (b) shows the failure of specimen due to rupture and pulling out of the glass fiber, under tensile load. The de-bonded fiber surface has not shown any trace of matrix attached to it. Fig.5 (c) shows broken fiber end, which reveals the de-bonding of glass fiber and epoxy resin. Also, glass fiber has broken at an angle, it might be due to glass woven format, which might have led to shear failure.

The fracture took place across the interphase of fiber-matrix, is due to stronger interphase bonding between glass fiber and epoxy resin, triggered the GFRP to collapse in “brittle mode” as shown in Fig. 5 (d).

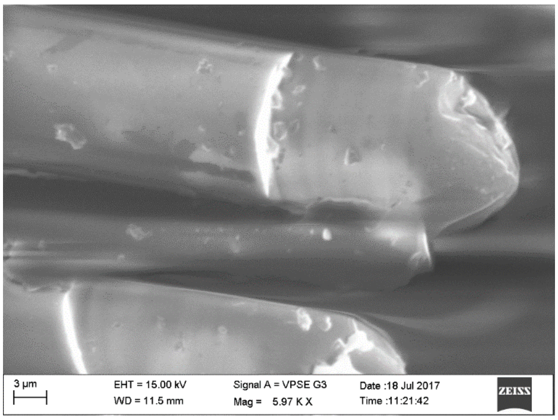
Fig. 5 (e) shows the glass fiber and nanoclay-epoxy interphase, which indicates addition of nanoclay have altered the failure mechanism with increase in interfacial bonding, which is an evidence for increase in tensile strength [25].



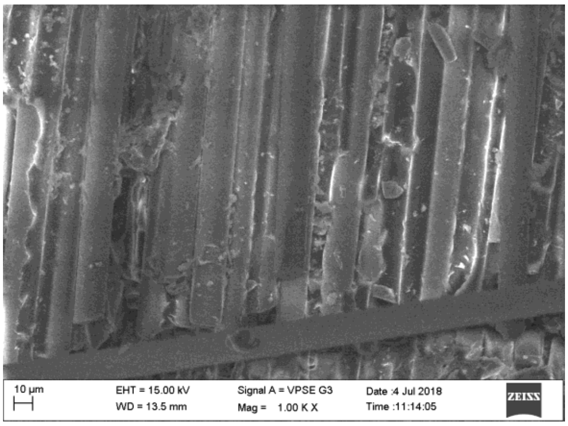
(a) Bidirectional woven fiber mat



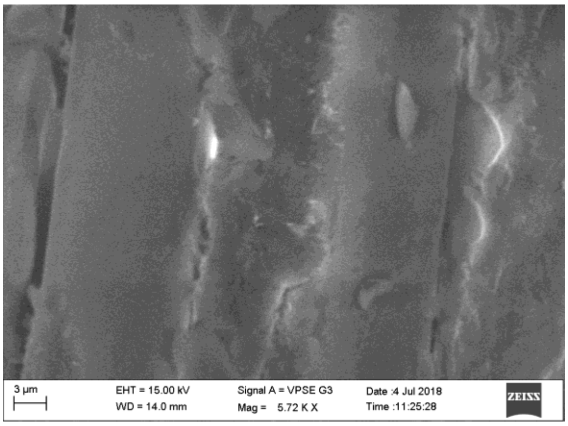
(b) Rupture and pulling out of the glass fiber



(c) Broker glass fiber end



(d) Interphase of fiber-matrix



(e) Interphase of glass fiber and nanoclay-epoxy

Figure 5. Micrographs of fractured tensile test specimen.

IV. Conclusion

1. Increase in the glass fiber weight percentage in the composite without nanoclay increases the tensile and flexural strengths by 15 and 10% respectively.
2. Nanoclay addition improves the tensile and flexural strengths of GFRP. At lower fiber quantity (40 wt.%), nanoclay has higher influence on the properties.
3. Addition of 2 and 4 wt.% nanoclay enhances both tensile (4-13%) and flexural (6-15%) strengths.
4. In tensile loading, the failure of specimen is due to rupture and pulling out of the glass fibers.

5. As future work, NCD & NCF could be tested for impact strength and fire retardant tests. Also, this work could be compared with work with other nanoparticles and weight percentage of glass fiber.

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