Mechanical and Thermal properties of Nanoclay/glass fiber/epoxy laminated composite

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Abstract - *In recent years, both industrial and academic world are focusing their attention towards the development of sustainable composites. In particular, among the composites, laminated composite are most interesting for their properties. The aim of this work is to illustrate the results of mechanical and thermal properties of unidirectional glass fibers with nanoclay as the fillers. Moreover, its main manufacturing technologies have been described. The major component of this cross-ply laminated composite is unidirectional glass fiber with Epoxy. Samples of laminated composite with varying compositions of 0% to 5% nanoclay have been prepared by applying the matrix on glass fiber by hand lay-up technique. The samples were tested on UTM to determine the flexural strength and tensile strength. The samples were also tested for hardness and Dynamic Mechanical Analysis (DMA). Further, the characterization of the fractured samples from tensile test were done using SEM.*

***Key Words*: Cross-Ply Laminated Composite, Glass Fiber, Epoxy, Nanoclay, DMA, Tensile Strength, Flexural Strength.**

1. INTRODUCTION

Composite materials are emerging as a great substitute for traditionally used metallic substance. Composites may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, race car bodies, shower stalls, bathtubs, and storage tanks. Strength, stiffness, thermal conductivity, wear resistance, weight etc. are some of the properties that can be improved by forming composites.

Composites have a property that they can be tailor-made; layer-by-layer, to meet specific functional requirements. Each layer can be engineered for the required properties. This one layer is called lamina and the stacked form of these laminas are called laminates. Laminates have become an attractive materials because they are cheap to produce compared with fiber composites, the volume fraction of components can be easily controlled, the fiber direction can be controlled, number of layers can be controlled, type of reinforcement and filler in each layer can be controlled and they have generally superior flexure properties. Some of the advantage of using laminated composite includes greater tensile and flexural strength, improved gas barrier properties for the same film thickness, reduced weight for the same performance, higher chemical resistant., improved optical clarity in comparison to conventionally filled polymers improved mechanical properties e.g. strength, modulus and dimensional stability, improved electrical conductivity [4-7].

Glass fiber has high ratio of surface area to weight ratio. It undergoes more elongation compared to other fibers. It is non-flammable, has a good corrosion resistance and has a great mechanical strength which makes its applications in mechanical components such as gear, crankshaft, connecting rod etc.

K. Kanny [1] prepared and studied laminates with varying quantities of nanoclays (0–5 wt %) and the effect of these Nanoclay on the epoxy resin flow characteristics. They found that the flow rate of resin continuously decreased as nanoclay content continuously increased. Ahmad Rafiq [2] studied the effect of nanoclay addition in Glass Fiber Reinforced Epoxy (GFRE) composites on impact response. They observed that the addition of nanoclay improved peak load and stiffness of GFRE. S. Helmy [3] investigated tensile fatigue behavior of tapered glass/epoxy laminates. They examined the effect of nanoclay addition into the epoxy resin. They showed that the relative orientation between the adjacent belt layer and the cut layer had important influence on the fatigue life. They explained that the fatigue crack starts at the resin pocket and propagates along the interface between the belt layer and the core layer in the thicker section of the laminate.

1.1 Materials

Unidirectional Glass Fiber Uniaxial glass fiber made of 220 gsm, containing diameter of 15 μm has been employed. The matrix system used is a medium viscosity epoxy resin

(LY556) and a room temperature curing polyamine hardener (HY951). The fillers that has been used is Nanoclay.

2. PREPARATION OF LAMINATES

The composition and designation of the composites prepared for this study are listed in Table 1. The matrix is poured on the glass fiber and spread homogenously with the help of a roller.

A four layered cross-ply laminated composite is prepared. The fiber material is mixed with Epoxy LY556 resin in different percentages. The fabrication of the laminated composite is done by conventional hand-layup technique followed by light compression molding technique.The fibers are mixed thoroughly in the epoxy resin. The low temperature curing epoxy resin and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. The samples are then left for curing for 24 hrs. After this the samples are post cured in furnace heated at 70°C for 24 hours for hardening. The cast of each composite is cured under a load of about 100 kg for 24 hours before it is removed from the mould. Specimens of suitable dimensions are cut using a diamond cutter for thermal and mechanical characterization. Utmost care has been taken to maintain uniformity and homogeneity of the composites

Table -1: Samples Prepared and Representation

S.N.	Sample Representation	% Epoxy	% Nanoclay
1	A	100	0
2	B	99	1
3	C	98	2
4	D	97	3
5	E	96	4
6	F	95	5

3. RESULTS AND DISCUSSION

The samples were tested for their flexural, tensile and hardness. The failed samples from tensile test were characterized under SEM. The samples were also studied for their thermal properties using Dynamic Mechanical Analysis (DMA).

The specimens had been cut and prepared as per the ASTM standards D3037 and D3039 for tensile and bending. The testing samples were cut with the help of hacksaw. The dimensions of specimens are shown below.

Table-2: Dimensions for test samples

Parameters for Specimen	Specimen for Tensile Test	Specimen for Flexural Rigidity Test	Specimen For DMA
Length	127 mm	127 mm	28 mm
Width	12.7 mm	12.7 mm	9 mm
Thickness	1.35 mm	1.35 mm	1.35 mm

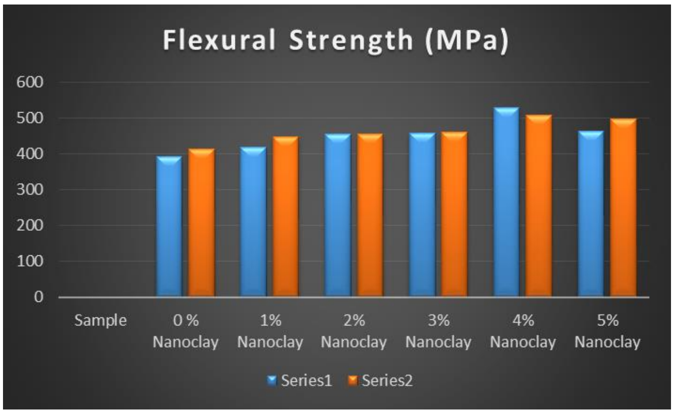

Chart -1: Flexural Strength

It was observed that with the inclusion of nanoclay the flexural strength increased and saw a maximum at 4% nanoclay concentration sample. An increase in flexural strength to about 28% for 4% nanoclay was observed.

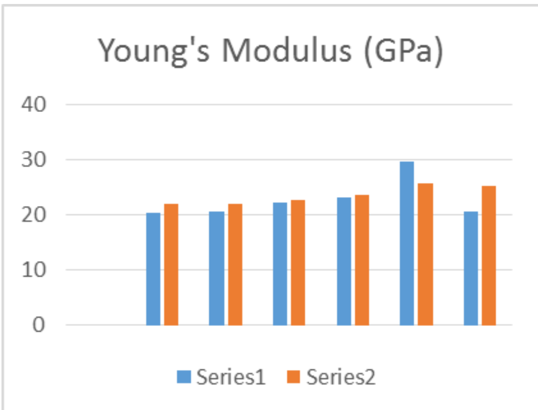

Chart -2: Young's Modulus obtained from three point bending test

It was observed that with the inclusion of nanoclay the Young's Modulus increased and saw a maximum at 4% nanoclay concentration sample. An increase in flexural strength to about 39% for 4% nanoclay was observed.

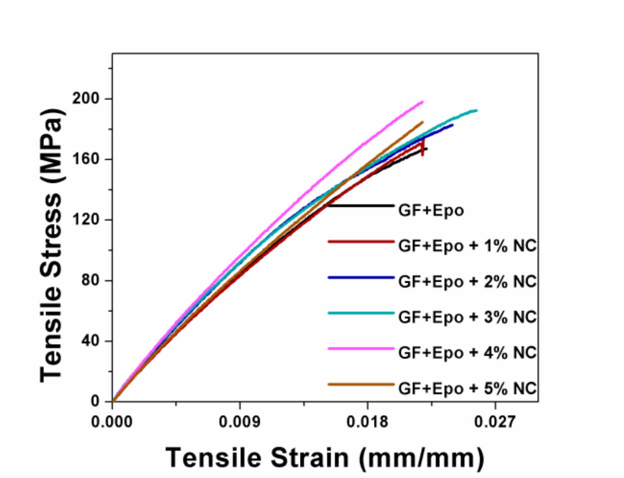

Chart -3: Tensile properties obtained from tensile test

Results of the tensile test are shown by the Chart-3 which shows the increase in tensile strength of the laminated composite with the inclusion of nanoclay.
This can be explained by the fact that as nanoclay is added it provides higher surface area for the bond formation which increases the strength. We observed that the strength increases upto 4%. This can be explained by the fact that as the concentration of nanoclay increases agglomeration will play an important role thereby restricting the increase in strength and mixing.

Hardness test were carried out using Rockwell Hardness. The scale used was HRB. The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a minor load (10 kgf) is applied to a sample using a steel indenter. This load represents the reference position that initially breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, is applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. In our case the dwell time was of 10 seconds. This major load (100 kgf) is then released and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number.

Table 3 Results of Rockwell Hardness Test

S.No	Sample	Average HRB
1	A	25.23
2	B	27.93
3	C	31.93
4	D	27.67
5	E	27.43
6	F	26.86

Though the hardness tend to increase but not a significant amount of change is observed amongst the samples. There is increase in hardness for the 2 % nanoclay samples with respect to the 0 % nanoclay sample and a further decline is observed. It can be explained by the fact that by adding nanoclay into the epoxy resin it enhances its hardness. But there is an optimal value depending upon the processing conditions and choice of material. It can be speculated and a conclusion can be made that as the concentration of nanoclay increases it slows down the chemical reaction which causes incomplete curing of the laminate. As the nanoclay's content increased the matrix might not have fully cured which explains the decline in the hardness.

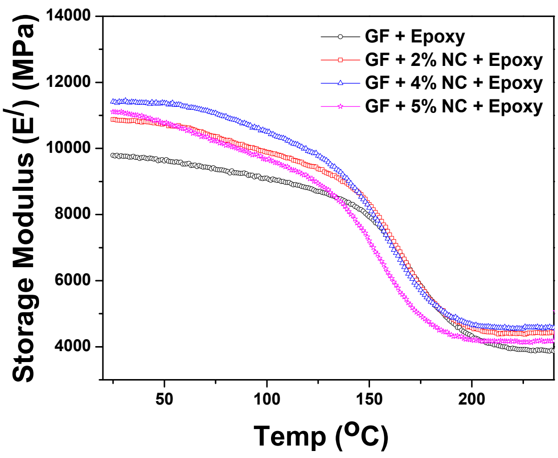

Chart -4: Storage modulus of glass fiber epoxy laminated composites with variation of Nanoclay

The storage modulus (E′) of GF/epoxy and GF/Nanoclay/epoxy are presented in Chart-4. In this Chart, it has been observed that the GF/epoxy shows a lower storage modulus than GF/Nanoclay/epoxy composites over the entire range of temperatures i.e., 30 to 250^{o}C. The storage moduli of GF/Nanoclay/epoxy composites are enhanced by more than 15% when compared to the GF/epoxy composite sample. The modulus is increased due to the Nanoclay. Besides this the improvement is also due to the good interaction between the Nanoclay and epoxy; and glass fiber and epoxy. It was also reported that between these samples storage modulus was greater for 4 % nanoclay concentration. The value increased and had its maximum at 4 % nanoclay and again decreased at 5 % nanoclay.

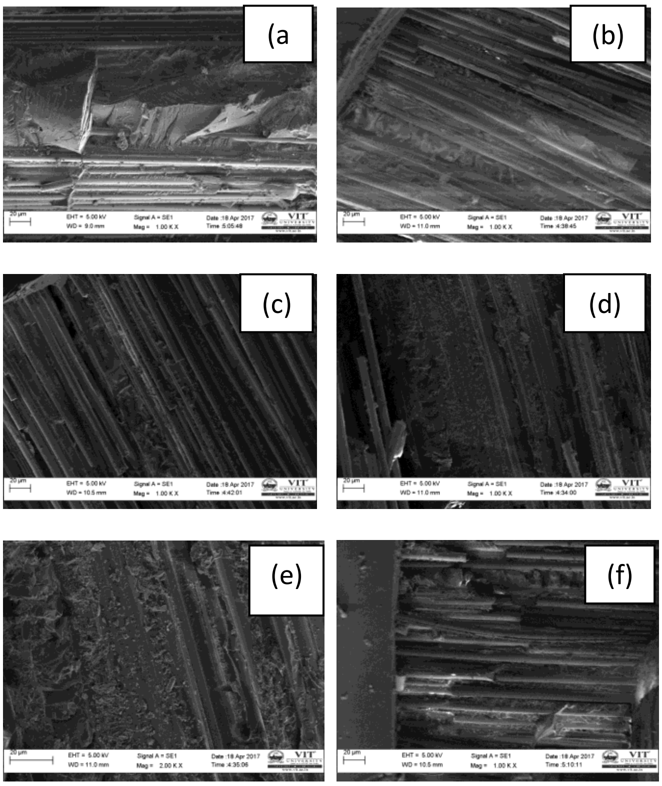

Fig -1: SEM images of Fracture specimens (a) glass fiber/ epoxy, (b) 1 % nanoclay +glass fiber/epoxy, (c) 2 % nanoclay +glass fiber/epoxy, (d) 3 % nanoclay +glass fiber/epoxy, (e) 4 % nanoclay +glass fiber/epoxy, and (f) 5 % nanoclay +glass fiber/epoxy

The SEM of the fractured surfaces of the glass fiber reinforced epoxy composite has been done to investigate the glass fiber-epoxy interaction and the microstructural changes involved on the incorporation of the nanoclay into the epoxy matrix. From the micrograph of the fractured surface of the glass fiber epoxy specimen (Figure 1 (a)), it has been observed that the fracture is brittle in nature. There is smoothness in the fractured surface with very little roughness. The SEM micrographs of the nanoclay/glass fiber/epoxy composite reveal that nanoclay have the good contact with epoxy matrix (Figure 1 (b, c, d, e, f)). With introducing nanoclay content there is a remarkable difference in the surface morphology of the fractured surface. The smoothness of the fractured surface goes on decreasing in presence of nanoclay suggesting a brittle to ductile transformation in the composite material.

4. CONCLUSIONS

Laminated composite made of glass fiber and epoxy with varying amounts of nanoclay was studied for mechanical and thermal properties. Samples of laminated composite with varying compositions of 0% to 5% nanoclay were prepared by applying the matrix on glass fiber by hand lay-up technique.The samples were tested on UTMmachine to determine the flexural strength and tensile strength. The samples were also tested for hardness and Dynamic Mechanical Analysis (DMA). Further, the characterization of the fractured samples from tensile test were done using SEM. Both tensile strength and flexural strength increased with the addition of nanoclay. It increased to a maximum value at 4 % nanoclay in both tensile and flexural test. Hardness also increased as the nanoclay concentration increased upto 2 % of nanoclay. At this value hardness was maximum but it then decreased as the nanoclay concentration increased. The results of DMA showed an increase in storage modulus as high as 15 % as compared to no nanoclay laminated composite.

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