Morphological Study of the Flexural Behaviour of Nanoclay Filled Jute/Kevlar Reinforced Epoxy Hybrid Composite

Bhanupratap R1, H C Chittappa2
1Research Scholar, Department of Mechanical Engineering, UVCE, Bengaluru, Karnataka, India.
2Associate Professor, Department of Mechanical Engineering, UVCE, Bengaluru, Karnataka, India

Corresponding author: bhanurpratap@yahoo.in

Abstract: Composites are occupying the place of conventional materials by meeting the requirements of industries of not only in aerospace sector but in automotive, mechanical, space, construction industries and biomedical applications, but the desire of achieving the higher modulus to density ratio always remains starved as it requires the maximum output in minimal consumption with better life expectancy to find the economical means of utilizing the technology for different applications. Hybrid composites are one of the most prominent materials that are being extensively used and is gaining momentum due to factors like flexibility in design and higher strength to weight ratio. Natural fibre composite like jute has became more attractive due to its improvement in properties. Mixing of the jute with kevlar is finding its way for the new sort of research. In view of this, the new polymer hybrid composite is developed in which the jute and kevlar fibre is reinforced to the epoxy resin with the application of nanoclay at 1%wt, 2%wt, 3%wt, 4%wt which are fabricated by simple hand lay up technique. The interfacial properties, internal cracks and internal structure of the fractured surfaces are evaluated using the Scanning Electron Microscope(SEM). The results indicate that the incorporation of 3%wt nanoclay to the jute/kevlar has led to the improvement in bending property.

Keywords: Nanoclay, jute, kevlar, epoxy, hybrid polymer composites, flexural property

1. Introduction

Fiber Reinforced Polymer (FRP) is a composite material made of a polymer matrix reinforced with fibers. The most widely used synthetic fibers till date are glass, carbon, aramid and Kevlar. Over the recent years, FRP composites have become increasingly popular for its structural applications in aerospace, marine, automobile and construction industries due to their higher mechanical performance. In the aerospace industry, applications are being from wall, floor panels to the fuselage [1, 2]. Now a days natural fibres such as jute reinforced composites are replacing the glass and carbon fibres due to their ease of availability and ease of cost[3]. The use of natural fibres has improved day by day due to the fact that the field of application is in use especially in automotive industries. Silva et al [4] developed the natural fibre / castor oil polyurethane composites and tested for the fracture toughness which led to the best out of performance[4]. Cicala et al [5] have studied the properties of various hybrid glass/ natural fibre composites for the application in curved pipes. Most of the studies on
natural fibres deal only with single reinforcement. The addition of natural fibre to the kevlar fibre can make the composite hybrid by improving the properties. Panthapullakkal and sain[6] studied the mechanical properties of hemp/glass fibre polypropylene composite materials. They observed improvement by the use of hybrid composite material by increasing the flexural and impact properties. They also observed the addition of glass fibre into Hemp-PP composites resulted in improvement in thermal properties and the water resistance of the composites. The addition of natural fibre with GFRP improves the flexural strength of the materials[7] and keeping the GFRP layers at the end possess very good mechanical strength[8]. AC Albuquerque et al[9] worked on the mechanical properties of uniaxially oriented jute roving reinforced polymer composites. It was found that the flexural strength and modulus of longitudinal composites increased with the fibre content. De Rosa et al [10] concluded that using the basalt fiber at the top and bottom of the glass laminate improves the post-flexural strength of the hybrid composite. However, it finds difficult to arrive at the conclusion from one hybrid to the other, as there is no theoretical framework available to assess the various material parameters. The flexure strength of the glass fibre reinforced polymer composite can be enhanced by incorporating it with E Glass epoxy laminates and making it hybrid polymer composite[11]. Very less research have been conducted in the field of synthetic fibre and natural fibre reinforced composite materials[12].

Nano particles are presently considered to be high potential filler materials for the improvement of the mechanical and physical properties. The nanometric size, leading to the huge specific surface areas (SSA) of up to more than 1000 m$^2$/g, and their unique properties have caused intensive research activities in the field of natural and engineering sciences [13]. Their mechanical properties with electrical and thermal properties make them interesting materials for the use as fillers in polymers and open up new perspectives for multi-functional materials. An efficient exploitation of the properties of the nanoparticles in order to improve the material performance are generally related to the degree of dispersion, impregnation with matrix and to the interfacial adhesion [14]. The advantage of the nano scaled particles compared to the micro scaled fillers is their enormous surface area, which can act as interface for stress-transfer. However, a high SSA causes the formation of agglomerates. The agglomerates of the nanocomposite are difficult to separate and to infiltrate with the matrix [15].

The purpose of present study is to evaluate the utilisation of kevlar to the jute by adding the nanoclay as filler and the effect of nanoclay to the jute/kevlar content on the flexural behaviour of the composites will be investigated by means of morphological study.

2. Experimental
2.1. Materials
In present investigation, the jute and kevlar fibres are used for fabricating the composite specimen with epoxy as the matrix and nanoclay as filler. The jute is obtained from Jute cottage, Indiranagara, Bengaluru. Kevlar is obtained from Hindoostan composites, Mumbai. Epoxy resin i.e Diglycidyl ether of bisphenol is obtained from local source and the type used is Araldite LY556, nanoclay(montmorillolite) is obtained from sigma aldrich company, Bengaluru.

2.1.1. Epoxy resin
Epoxy resins are the mostly used resins. They are a low molecular weight organic liquids which contains epoxide groups. Epoxide has two members in its ring they are carbon and oxygen atoms. The reactions of epichlorohydrin eith aromatic amines or phenols amines make most epoxies. Filler, hardeners and plasticisers are also added to produce epoxies with a wide range of properties of impact, viscosity, degradation etc. Although epoxy is a costlier one than other polymer matrices, polymer matrix composites is mostly used. More than two thirds of the polymer matrices which is used is epoxy based type. Its chemical name is Diglycidyl ether of bisphenol and the type used is Araldite LY556[19].
Table 1: Properties of epoxy

| Description               | Properties       |
|---------------------------|------------------|
| Specific gravity          | 1.2 kg/m$^3$    |
| Tensile strength          | 35-130 MPa       |
| Poisson’s ratio           | 0.37             |
| Compressive strength      | 100-200 MPa      |
| Elongation                | 1-8.5%           |
| Co-efficient of Thermal Expansion | 45-70*10$^6$/°C |
| Water absorption          | 0.1-0.4%         |

2.1.2 Natural fibre
In the last two decades, there has been an increase in the use of natural fibres in terms of fibre extraction from sisal, jute, coir, hemp etc for making new environmental friendly composites which is termed as green composites. Recent studies in natural fibre composites offer remarkable improvement in materials with enhanced support for global existence. These natural fibre possess high strength, thermal stability when they are recyclable, but the problems of using pure biodegradable polymers are their low strength and glass transition temperature[13].

2.1.3 Jute fibre
Jute usually takes three months, to grow to certain height of 12-15ft, during season. Then cut, bundled and kept immersed in water for “RETTING PROCESS”, where the inner and outer stem, gets separated out and the outer plant will move apart, to form a fibre. Then the plant gets separated to remove the dust from the plant. The fibre is taken to jute mills after drying for getting converted to jute yarn and hessian. From the jute various lifestyle products are being produced and it is diversified into various forms, due to R&D support and also from government organizations[13]. The table shows the physical properties of jute fibres.

Table 2: Properties of jute fibre

| Description               | Properties       |
|---------------------------|------------------|
| Specific gravity          | 1460 kg/m$^3$    |
| Tensile strength          | 400-800 MPa       |
| Elongation at break       | 1.7-1.8%          |
| Youngs Modulus            | 7.6 MPa           |
| Stiffness                 | 10-30KN/mm$^2$    |
| Water absorption          | 13 %              |

2.1.4 Kevlar fibre
Kevlar fibre reinforced composite materials are increasingly popular over the years. Its application is considerably vast due to its superior mechanical properties like lighter weight, unique flexibility, corrosion resistant etc compared to metallic materials. Kevlar fibre possess unique properties. In order to increase the stiffness, it can be viewed as nylon with extra benzene rings in the polymer chain. It is mainly popular for its applications in industrial and advanced technologies like ballistic armor, helicopter blades, pneumatic devices, sporting goods etc. Compared to other synthetic fibres, it possess significantly lesser fibre elongation and higher tensile strength and modulus[14].

Table 3: Properties of kevlar fibre

| Description               | Properties       |
|---------------------------|------------------|
| Density                   | 1.45 g/cm$^3$    |
| Filament diameter         | 12nm             |
| Tensile strength          | 3176 MPa          |
2.1.5 Preparation of composite specimen:
The base resin was heated in the oil bath, maintained at a constant temperature of 60ºc. Nanoclay at different proportions was added slowly to the resin and then stirring was done mechanically for 2 hours. After stirring, modified epoxy solution was mixed with the hardener and stirring up to 20 mins was done. Finally the mixture was applied to the fibre sheet on both sides using hand lay up and left over night for drying. The laminas were cured under ambient temperature to get the shape as that of the mould cavity. Finally the samples were cut as per ASTM standards.

| Laminate Designations | Nanoclay | Compositions       |
|-----------------------|----------|--------------------|
| L1                    | 3%       | J+J+J+J            |
| L2                    | 3%       | J+K+J+J+J          |
| L3                    | 3%       | J+K+J+K+J+K+J      |
| L4                    | 3%       | J+K+K+J+K+J+K+K+J |

3. Testing and Evaluation
In this study, the flexural property of jute and kevlar reinforced polymer hybrid composite will be investigated by machining the specimens by means of water jet cutter to the required dimension as per ASTM: D790 standard (sample dimension is 80 × 8 × 3 mm³). The flexure test for the hybrid composite is obtained using tensometer. The speed of the cross head was 5mm/min. The specimens are loaded step by step until failure under flexural loading along the longitudinal axis. A continuous record of load and deflection is obtained by a digital data acquisition system. The flexural strength and modulus were calculated using the following equations:

- Flexural strength \( \sigma_f = (3PL) / (2bd^2) \),
- Flexural modulus, \( E = L^2m/4bd^3 \),

where, 
\( P \) = Load at a given point on the load deflection curve in Newton (Peak load)  
\( L \) = support span in mm  
\( b \) =width of the samples in mm  
\( d \) = thickness of the samples in mm  
\( m \) = slope of the tangent

The table 4 shows the flexural properties that were determined from each laminate.

| Laminate Designations | Flexural strength (MPa) | Flexural modulus (GPa) |
|-----------------------|-------------------------|------------------------|
| L1                    | 84.91                   | 6480.04                |
| L2                    | 103.883                 | 8366.83                |
| L3                    | 165.935                 | 14186.9                |
| L4                    | 140.663                 | 9544.98                |
**Fig 1:** Sample graph obtained from tensometer for load vs displacement (Flexural test)

**Fig 2:** Load vs Displacement

**Fig 3:** Flexural strength vs laminates
4. Scanning Electron Microscopy (SEM) Analysis
The surface characteristics of the composite material used for the investigation is studied through Scanning electron microscopy. The cross sectional view of the fabricated composite material consisting of jute, kevlar, nanoclay composite are presented in Fig 5a. Scanning electron microscopy (SEM) images are taken to observe the interfacial properties, internal cracks and internal structure of the fractured surfaces of the composite materials. All the specimens are coated with conducting material before observing the surfaces through SEM. The scanning electron image observed for jute, kevlar composite material of 3wt% nanoclay subjected to flexure test is presented in Fig 5b. It is often not possible to see the individual nanoclay particles mixed in polymer matrix using SEM. However the surface properties observed in specimens is an indication of the uniformity of the nanoclay dispersion. It can be seen that for a laminated composite with nanoparticles of 3wt% nanoclay showed rough fracture as the matrix is completely stacked to the fibres at the failure surface, which represents the improvement of adhesion between the matrix and the fibres at the presence of nanoparticles. The issue can increase the toughness and strength of fibre reinforced resin. However the brittle nature of the resin can reduce the mobility and increase the modulus and strength. But it will not be the case for more than 4 wt% as they tend to break apart before the peak, which meant they will be brittle. It was because when the nanoclay weight percentage increases, the mixture itself becomes too viscous, sluggish and more void formations in the samples of high wt%. The more the nanoclay the more viscous of the clay-resin mixture. Thus the nanoclay particles with 3 wt% improve the nanocomposite by acting as rigid connector between the fibre and matrix.

Fig 4: Flexural modulus vs laminates
5. Results and Discussion
The composite laminates L1, L2, L3, L4 are tested in tensometer and properties obtained are shown in Table 4. The sample graph of load vs displacement obtained from tensometer after flexure test is shown in fig 1. The load vs displacement graph is shown in fig 2. The variation in flexure strength and flexure modulus of composite with increase in fibre content is shown in fig 3 and fig 4 respectively. It is very much evident that the laminate L4 having 3wt% nanoclay composite showed considerable increase in the flexural properties. It has been suggested that clay-resin interactions leads to this. It can be seen that the laminate L1 which consists of pure jute layers shows lower flexure strength as the layers of kevlar is not been placed. The kevlar fibre inclusion enhances the load bearing capacity to the jute epoxy composite and the ability to withstand the bending strength. Thus from the
results, it can be asserted that the laminate L4 is performing well as compared to the other type of fibres used.

6. Conclusion:
This work proves successful fabrication of the nanoclay filled bidirectional jute kevlar reinforced epoxy hybrid composite that is obtained by simple hand lay up technique for different proportions. It is proved that when nanoclay is incremented in small percent, the flexural strength is greatly influenced by the different fibre proportions. The proper transmission and distribution of the applied stress by the epoxy resin results in higher strength of the hybrid composite. The flexural properties of the nanoclay filled bidirectional jute kevlar reinforced epoxy hybrid composite has the highest strength at 3 wt% which is due to the strong bonding of the filler with the matrix and reinforcement and the load carried by them. In this study it is observed that the thickness of the composite enhances the flexural strength due the addition of kevlar which is required for the dynamic loading applications.

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