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Devolopment Eveluation and Performance Prediction by Ann of Nano Particles Treated Graphite Fabric Tribo Composites

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Abstract: **Increasing demands of fiber reinforced polymer composites (FRPCs) for structural applications, like aerospace, automobile and marine etc. is the topic of intensive research. FRPCs are self efficient in replacing their metallic counterparts, which have high costs of repair and maintenance of components damaged by corrosion and heavy loading conditions. Recently FRPCs are increasingly used in machine sliding components, which demands high performance and thermally stable tribo-materials under elevated operating and environmental conditions. Fiber - matrix adhesion in a composite is an important factor for efficient stress transfer from the matrix to the fiber during their usages. Graphite fibers due to their superior thermal and mechanical properties are best suited as reinforcement for specialty polymers. However, their chemical inertness and surface smoothness leads to less fiber- matrix adhesion. Efforts are hence continuously being made to enhance fiber surface reactivity towards matrix with newer and more efficient methods; either by surface roughening to enhance mechanical interlocking or by adding reactive chemical groups. The tribological characterization of any material is of great significance because these properties are neither intrinsic nor can be predicted a priori but depend on operating parameters, wear situations and environmental conditions.**

Keyword: **Graphite fibers, tribo-materials, matrix adhesion, Tribology, FRPC.**

1. INTRODUCTION

Polymers play an important part in materials and mechanical engineering, not just for their easein manufacturing and low unit cost, but also for their potentially excellent tribologicalperformance in engineered forms.Therefore, to deal with these effects and for better control of theresponses, polymers are modified by adding appropriate fillers to suit a particular application.The tribological characteristics of polymers are greatly influenced by the effects of temperature, relative speed of the interacting surfaces, normal load and the environment etc.A nanocomposite (NC) is as a multiphase solid material where one of the phases has one, two orthree dimensions of less than 100 nm, or structures having nano-scale repeat distances betweenthe different phases that make up the material. In mechanical terms, NCs differ fromconventional composites due to the exceptionally high surface to volume ratio of the reinforcingphase and/or its exceptionally high aspect ratio Carbon/Graphite fibers, though expensive are most favored for tailoring high performance composites and tribo-composites. Their surface, however, is chemically inert leading to the most potential problem of inadequate adhesion and hence weaker composite than the expected one. It is essential to treat them with proper treatment so as to explore their full potential in composites. Several types of reported surface treatments of carbon/graphite fibers are classified in two categories. First, improves the adhesion by physical means thereby enhancing the roughness resulting in more surface area and a large number of contact points, micro-pores or surface pits on already porous carbon/graphite fiber surface.

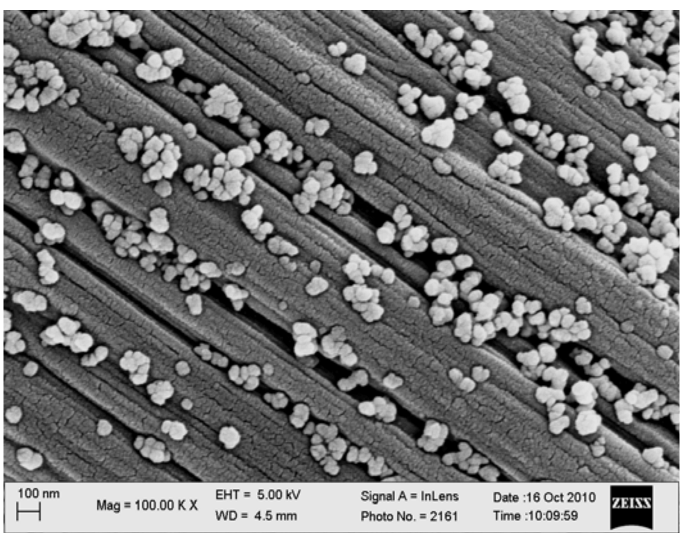
2. LITERATURE REVIEW

Carbon fibers are chemically inert in nature and hence have poor wettability and adsorption withmost of the matrices. There have been various reported attempts to improve upon low shearstrength values of carbon fiber reinforced composites. The surface may be treated so as toproduce a chemical bond between resin and fibre, Alternatively, the fibre surface may beroughened so as to increase mechanical keying between resin and fiber or by attacking the fibrewith oxidising agents the surface can be etched, and provided the etching is uniform the shearstrength can be improved.Zhanget al. predicted the specific wear rate and frictional coefficient based on a measured database for short fiber reinforced polyamide using a multiple-layer feed-forward artificial neural network (ANN), and showed the predicted data is well acceptable when comparing them to the real test values.Bayesian regularization training function was used to improve the predictive capabilities of the artificial neural network and to avoid early stopping of training of network.Higher is the value of B better is the performance of network. Coefficient of determination (B) was utilized to evaluate the network and found B ranging from 0.54 to 0.97 depending upon architecture of network Zhang et al. predicted mechanical properties of waste polypropylene/waste ground rubber tire powder blends using artificial neural networks and optimized network by genetic algorithmsand optimized concentration of ingredients for tensile strength and % elongation at break.Veltanetalused artificial neural network techniques to predict and analyze the wear behaviour of short fibre reinforced polymeric bearing materials in freeting wear mode for 72 data sets.

3. DEVELOPMENT AND CHARACTERIZATION OF COMPOSITES –MATERIALS, METHODOLOGY AND RESULT

3.1 Selection of Treatment for Graphite Fabric

Rare earth compound Ytterbium fluoride (YbF3) was used for treatment of graphite fabric which was supplied by Nano-Amor, USA in the 40-80 nm size. The size was verified with the use of FESEM micrograph**(Fig. 3.1)** taken for carbon fiber after YbF3 treatment



Treatment of Graphite Fabric

Fiber - matrix adhesion in a composite is an important factor for efficient stress transfer from the matrix to the fiber during wearing so that fiber (which has very high wear resistance as compared to the matrix) wear preferentially. Graphite fibers due to their superior thermal and mechanical properties are best suited as reinforcement for specialty polymers. However, their chemical inertness and surface smoothness lead to less fiber- matrix adhesion and hence weaker composites. The extent of fiber-matrix adhesion can be enhanced by employing various surface treatments. Graphite Fibers were treated with nano sized YbF3 in the solution of ethyl alcohol for 1hour at 80ºC.

Fig. 3.3: Experimental set up for YbF3 treatment of graphite fabric

3.2 Formulation of Composites

3.2.1. Composites Development

Various techniques are available for development of bidirectional (BD) composites, such as handlayup, impregnation technique, resin transfer, film technique and powder prepreg etc. Whileconsidering the complexity involved in BD reinforcement, efficient method of impregnationtechnique was adopted to develop of GF-PES composites for the present research work.

3.2.2. Impregnation technique for GF-PES composites

Treated and untreated carbon fabric plies were sealed from all the sides with PTFE coated glassfabric to avoid misalignment in fabric weave. Dicloromethane (DCM) was used as a solvent toprepare the solution of PES (20 wt %). Twelve fabric plies were then immersed for 8 hrs in asteel container filled with viscous solution of PES in DCM. The container was sealed to avoidevaporation of solvent, which was required for wetting of fiber strands with the PES solution.

A mould release agent, PTFE coated glass fabric, was placed on the top andbottom of the stacked prepregs. The mould was then heated in a compression molding machineto a temperature of 300-3100C and compressed for 20 minutes under a pressure of 4 MPa.The prepregs were taken out carefully to avoid the disturbance in weave and dried in oven for 1hour at 1000C in a stretched condition. Prepregs were then stacked in the mould carefully toavoid misalignment.

Designation	Matrix Material	Fabric	Treatment	Size of YbF_3	Medium
U0	PES	Graphite Fabric	Untreated	-----------	Ethyl Alcohol
T2	PES	Graphite Fabric	0.2% YbF_3 Treated	40-80nm	Ethyl Alcohol
T3	PES	Graphite Fabric	0.3% YbF_3 Treated	40-80nm	Ethyl Alcohol
T4	PES	Graphite Fabric	0.4% YbF_3 Treated	40-80nm	Ethyl Alcohol

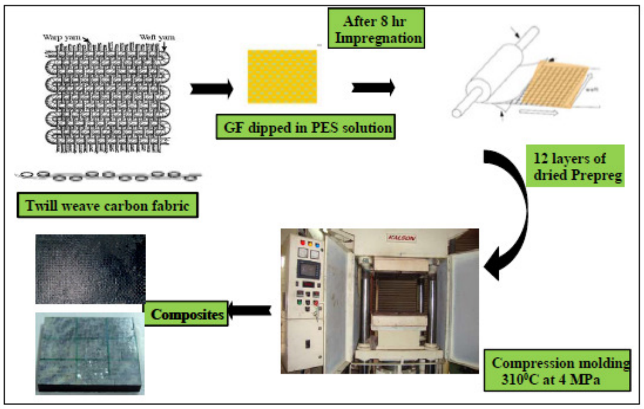


Figure 3.4: Schematic of fabrication of composites using compression moulding

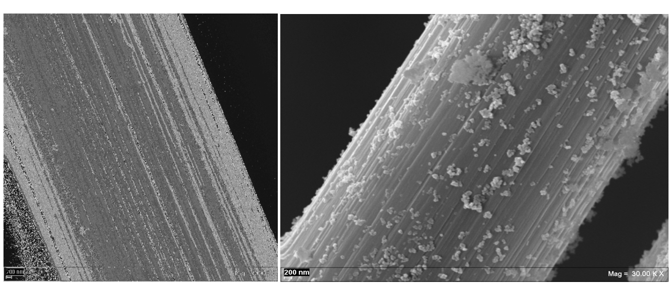
4. CHARACTERIZATION OF MATERIALS AND DEVELOPED COMPOSITES

4.1. Graphite Fabric Surface studies

Various surface characterization techniques were adopted to analyze the effect of YbF3 treatment on GF surface.

4.2 Scanning Electron Microscopy (SEM)

SEM (ZEISS, EVO-MA10) was used to study the surfaces of treated and untreated graphite fibers. For the sample preparation, these were gold coated using ion sputtering (Cressington sputter coater -108) method.

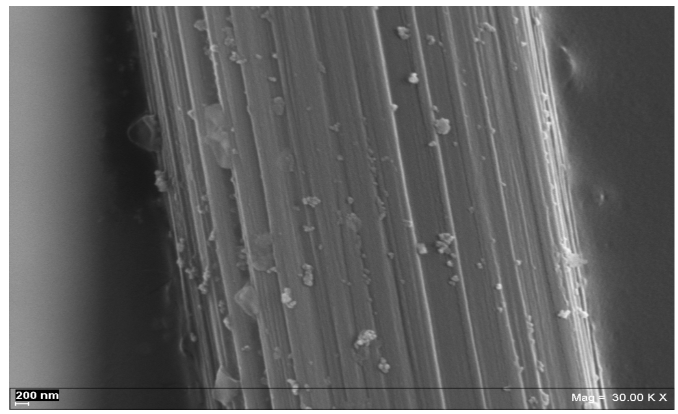


SEM micrographs

It isalso evident from the SEM micrographs that the grooves on the fibers led to an increase in the roughness of fiber surface and provided active sites on the fiber surface for better mechanical interlocking between the carbon fiber and matrix.

4.3 Attenuated Total Reflectance Fourier transform infrared (ATR-FTIR)

YbF3 is from rare earth family and rare earths are known for increased surface energy. In order to investigate the possible changes in chemical composition of graphite fibers by YbF3 treatment, ATR– FTIR analysis was done on Perkin Elmer SPECTRUM BX in mid infrared range (4, 000–600 cm-1). ATR spectra for composites U0, T2, T3 and T4 are as shown in figures 3.6 to 3.9 respectively.



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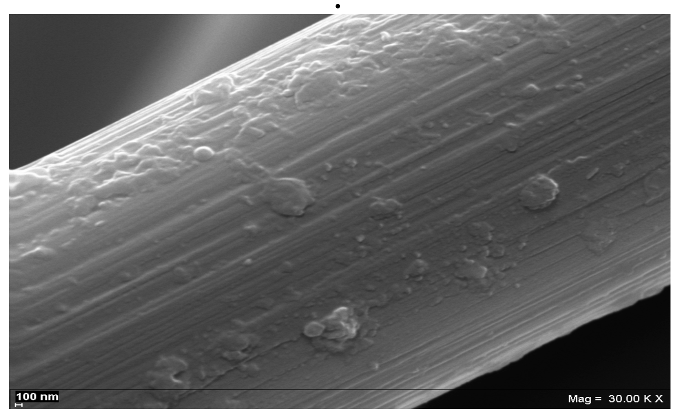

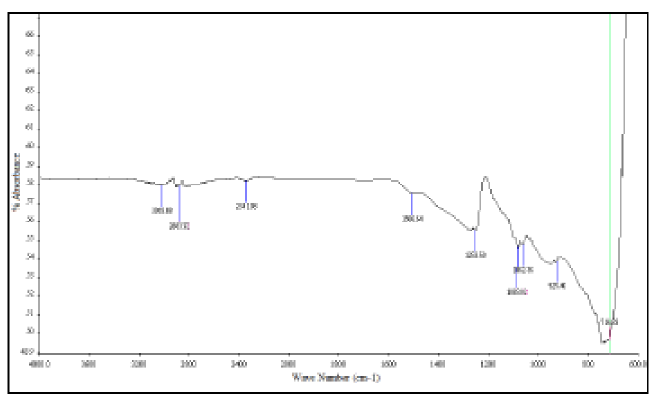

Figure 3.6: FTIR-ATR spectra of U0 fabric.

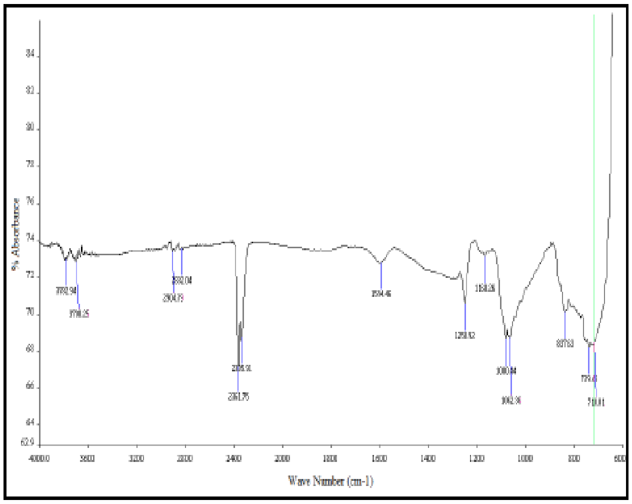

Figure 3.8: FTIR-ATR spectra of T3 fabric.

4.4Characterization of Pristine Polymers andComposites

4.4.1 Fiber- matrix Adhesion test

100×100 mm graphite fabric separately dipped in the solutions of PES (in DCM 20 wt %) toanalyze the effect of polymer viscosity on fiber matrix adhesion. After 10 minutes the fabricwere carefully taken out from the solutions at the same time and allowed to dry in identicalconditions. It is clear from **Fig. 3.11** treated fabrics have better adhesion with the matrix ascompare to untreated fabric and there is significant improvement in matrix adhesion withtreatment.

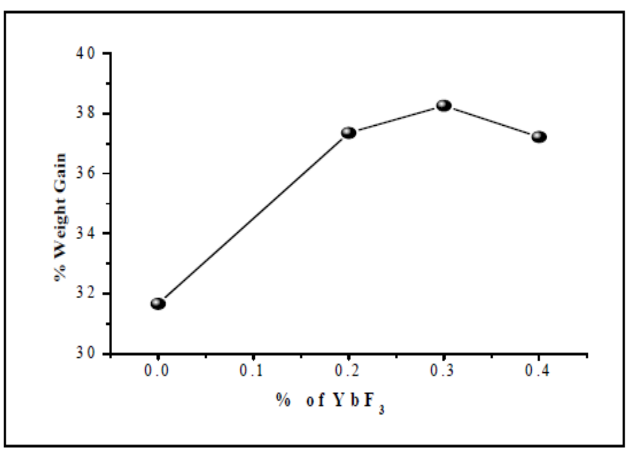

Figure 3.11: Variation of matrix adhesion with dose of YbF_3.

The reason of improvement is YbF3 particles are adsorbed on the carbon fiber surface throughchemical bonding, which increases the concentration of reactive functional groups due to thechemical activity of rare earth elements. As per literature RE is first adsorbed onto thecarbon fiber surface and then strongly attracts the electrons in C-C bond of carbon fiber, resulting in the excursion of the electron cloud of C-C bond and weakening the C-C bond.These have big effective nuclear charge and strongability to attract electrons of other atoms around it. Therefore, it is easier for functional groups to react with carbon fiber, and more functionalgroups are introduced on the fiber surfaces increase compatibility and reaction of fiber andmatrix. Increased number of particles on graphite fiber with increase in dose concentration wasalso confirmed by SEM.

4.5 Fiber tow tension test

In order to investigate effect of treatments on graphite fiber tensile testing was done in instronuniversal testing machine. A tow (3k) of fabric was glued on the abrasive paper at a distance of150 mm. Before starting the tension test, paper was cut from the mid portion to allow the load tocome on the tow only. Testing speed was 0.5 mm/sec. Maximum force taken by the fabric towwas observed. As seen in **Fig. 3.10** tensile load taken by fabric tows was reduced with dosing

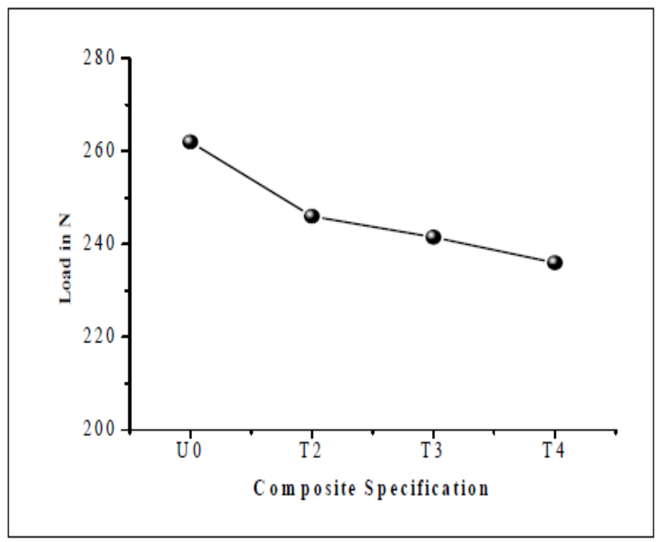

Figure 3.10: Variation of load taken by untreated and treated fiber tows.

5. MECHANICAL CHARACTERIZATIONS

5.1 A Tensile Properties

Tensile strength and tensile modulus, toughness and % strain to failure were calculated as per thespecification of ASTM D638 on Instron 3365 universal testing machine. For this test cross headspeed during the test was 2 mm/min. To avoid slippage of samples during testing, 2mm thickaluminum tabs were used to grip the samples from both the side.

5.2 Sample Specification

Length of Specimen= 165 mm
Gauge Length =100mm
Width = 19 mm

Thickness= 4mm

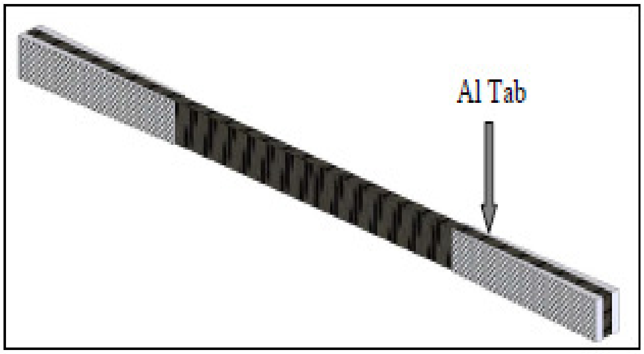

Figure 3.12: Schematic representation of tensile test specimen

The net strength of such composite is governed by two factors; first increase in fiber-matrix adhesion and second, decrease in the strength of fiber due to the treatment. Up to 0.3 % dosing, combination of these two factors still was in the positive direction and hence the final strength ofthe composite increased. Beyond that, however, reduction in the strength of fiber dominated andstarted over powering gains endowed by the first factor viz. enhanced fiber-matrix adhesion. Thedecline in the curves after showing maxima indicated that excess treatment causes deteriorationin the properties.

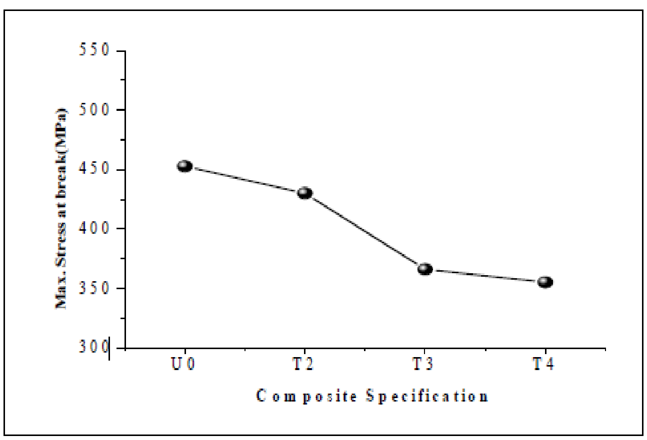

Figure 3.16: Variation of maximum stress at break of untreated and treated fabric composites.

Artificial Neural Network Analysis on compositesArtificial neural networks are computational systems that simulate the microstructure (neurons)of a biological nervous system. The most basic components of ANNs are modeled after thestructure of the brain, and therefore even the terminology is borrowed from neuroscience. Themost basic element of the human brain is a specific type of cell, which provides us with theabilities to remember, think, and apply previous experiences to our every action. These cells areknown as neurons, and each of these neurons can connect with up to 200, 000 other neurons.The power of the brain comes from the numbers of these basic components and the multipleconnections between them. All natural neurons have four basic components as shown in **Fig 5.1,** which are dendrites, soma, axons, and synapses.

6. FEED FORWARD BACK PROPAGATION LEARNING

The hidden neurons extract important features contained in the input data and output is generated by taking information from hidden neurons. This is known as feeding in forward direction and such networks are known as feed forward networks. The back-propagation algorithm has emerged as the workhorse for the design of a special class of layered feed forward networks known as *multilayer perceptrons*(MLP).

The training of an MLP is usually accomplished by using a *back-propagation (BP) algorithm* that involves two phases.

- ***Forward Phase.*** During this phase the free parameters of the network are fixed, and the input signal is propagated through the network of Fig. 5.2 layer by layer. The forward phase finishes with the computation of an error signal ei = di-yi ……................... (eq. 5.3)

  Where *di* is the desired response and *yi*is the actual output produced by the network in response to the input **x***i*.

- ***Backward Phase***

Back-propagation learning may be implemented in one of two basic ways, as summarized here:

1. *Sequential mode* (also referred to as the on-line mode or stochastic mode): In this mode of BP learning, adjustments are made to the free parameters of the network.
2. *Batch mode*: In this second mode of BP learning, adjustments are made to the free parameters of the network on an epoch-by-epoch basis, where each epoch consists of the entire set of training examples. The batch mode is best suited for nonlinear regression.

   The back-propagation learning algorithm is simple to implement and computationally efficient in that its complexity is linear in the synaptic weights of the network. However, a major limitation of the algorithm is that it does not always converge and can be excruciatingly slow, particularly when we have to deal with a difficult learning task that requires the use of large network.

6.1 Advantages of ANN

- Its ability to model complex nonlinear, multidirectional function relationship without any prior assumptions about the nature of the relationships.

- The network is built directly from experimental data by its self organizing capabilities.

6.2 Applications of ANN

ANN is commonly used when:

1. A large database is available.
2. It is difficult to find an accurate solution to the problem by existing mathematical approaches.
3. The dataset is incomplete, noisy or complex.

An artificial neural network (ANN) approach is a fascinating mathematical tool, which can be used to simulate a wide variety of complex scientific and engineering problems.

ANN is utilized in tribology to predict specific wearand coefficient of friction behavior of composites. There is aa view to improve the fiber- matrix adhesion essential for stronger composites, Graphite fabric (GF) will weave was treated nano sized particles of rare earth compound (YbF3) with varying doses. Based on these GF four composites were developed based on Polyethersulphone (PES) keeping following parameters constant so that the performance of all the composites could be compared.

- Type of fabric (PAN based-twill weave)
- Matrix –PES
- Amount of fiber and matrix (55-60 % vol)
- Processing technique and parameters
- Orientation of GF with respect to loading direction

Effect of surface treatment on the fiber surface was analyzed with SEM, FTIR-ATR, adhesion test and fiber tow tension test. The GF-PES composites were characterized and tribo-evaluated in adhesive wear mode. Tribological properties of composites viz. specific wear rate and coefficient of friction were predicted using artificial neural network.

7. CONCLUSIONS

1. Effect of treatment on GF properties and mechanical performance of composites

- There was a substantial improvement in the fiber-matrix adhesion which was supported by the matrix-pick up test developed indigenously in this research work.
- Treatments led to an inclusion of polar functional groups on the fiber surface as supported by by FTIR-ATR analysis. Ester, carboxyl and carbonyl groups were observed on the surface. Thus increased surface roughness and inclusion of polar groups as a consequence of treatment to GF were found to be responsible for increased adhesion with the matrixThis enhanced adhesion led to the improvement in mechanical properties such asstrength ILSS and tensile modulus. The enhancement was maximum for ILSS.

2. Effect of treatment on tribological performance of composites

Following are the conclusions drawn based on tribological studies on the composites developed from treated fabrics.
This enhanced adhesion led to the improvement in tribological properties in adhesive wear modes. Significant improvement in specific wear rate and coefficient of friction properties were observed for treated GF composites. The extent of improvement depended on the type of treatment and selected dose. Following are the trends in improvement in specific wear rate and friction coefficient

3. Scope for Future Work

- Rare earth treatment proved beneficial in improvement of performance properties of composites. Potential of other rare earth element in micro and nano size should beexplored.
- Combination of treatment methods should be explored to get the best mechanical and tribological properties of composites..
- Treatment dose should be optimized by various tools like ANN, Fuzzy logy andcomposites for this optimized dose should be fabricated.
- Quantification of surface roughening with AFM should be tried.
- Effect of treatment of GF on fretting, erosive wear properties should be explored

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