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STUDY ON EROSIVE WEAR BEHAVIOUR OF CARBON FIBER REINFORCED EPOXY COMPOSITES WITH AND WITHOUT FILLER – AN ANN APPROACH

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ABSTRACT

Fibre reinforced polymeric materials have been widely used due to their superior properties, low density, and manufacturing flexibility. Numerous applications have been allocated for these materials in aerospace and automotive industries such as gears, seals, bearings, cams etc. In order that these components satisfactorily perform under loading conditions, they should have good mechanical, tribological and machining properties.

In this paper, an experimental investigation was carried out to study the erosive wear behaviour of carbon fiber reinforced epoxy composites with and without MoS_2 filler. From the experimental result, it is very clear that MoS_2 filled composites showed optimum results when compared with unfilled one. The results from the experiments were analysed using artificial neural network.

Keywords: Artificial Neural Network (ANN), MoS_2 filler, Carbon fiber, Epoxy, Erosive wear

1. Introduction

Fibre reinforced polymeric materials have been widely used due to their superior properties, low density, and manufacturing flexibility. Numerous applications have been allocated for these materials in aerospace and automotive industries such as gears, seals, bearings, cams etc. In order that these components satisfactorily perform under loading conditions, they should have good mechanical, tribological and machining properties. Number of scientists and researchers are carrying out work to develop newer material system and characterize them for their various properties so that they can be selected for specific end use. A brief review of the literature is presented below throwing more light on the above.

B. Suresha et al. [1] carried out a study on three-body abrasive wear behaviour of carbon and glass fiber reinforced epoxy composites. From the study, they found that specific wear rate increased with applied load at lower abrading distance and decreased with increased abrading distance. Carbon epoxy composite showed better abrasion resistance as compared with that of glass fiber epoxy composites.

A study on Erosive wear behaviour of epoxy based composites at normal incidence was carried out by A.P. Harsha et al. [2]. They found that the bi-directional glass fibre reinforced epoxy composites showed better wear resistance than unidirectional reinforced composites. The erosion behaviour of epoxy composites is controlled by the type of fibre and its arrangement. They also reported that the epoxy composites have shown peak erosion rate at 60^0 impingement angle at a velocity of 25m/s.

J. Stabik et al. [3] conducted a study on electrical and tribological properties of gradient epoxy-graphite composites. They concluded that the surface resistivity increased significantly with decreasing content of filler in composite.

J.K. Lancaster et al. [4] conducted a study on the effect of carbon fiber reinforcement on the friction and wear of polymers. They found that the wear rate can be reduced by the addition of a third component, such as graphite or bronze, although only with small sacrifice on the bulk strength. However, they felt that further investigations are required to determine the most effective additives and their proportions to obtain an optimum compromise in strength and wear properties.

A study on solid particle erosion of glass fiber reinforced fly ash filled epoxy resin composites was carried out by V.K. Srivastava et al. [5]. From the experimental investigation, they found that the inclusion of fly ash filler in the GFRP composite decreased the hardness, tensile strength and density. They also reported that GFRP without any filler showed the highest erosion rate. The influence of impingement angle on erosive wear of all composites under consideration exhibited semi ductile wear behaviour with maximum wear rate at 60° impingement.

N. Mohan et al. [6] carried out a study for investigating two-body abrasive wear behaviour of silicon carbide filled glass fabric-epoxy composites. The wear loss of the composites was found increasing with the increase in abrading distances. A significant reduction in wear loss and specific wear rates were noticed after incorporation of SiC filler into GE composite.

B. Suresha et al. [7] carried out a study on Mechanical and tribological properties of glass-epoxy composites with and without graphite particulate filler. Their investigation revealed that the tensile strength and dimensional stability of G-E composite increased with increasing graphite content. The wear loss of the composites decreased with increasing weight fraction of graphite filler and increased with increasing sliding distance. On further investigation using SiC instead of graphite as the filler material in E-glass reinforced thermoset composites [8], they found that tensile strength, flexural strength and hardness of the glass reinforced thermoset composite increased with the inclusion of SiC filler.

Substantial research work has been carried out to investigate the mechanical and tribological behaviour of fiber reinforced polymeric matrix composite with and without addition of fillers. Though number of fillers has been tried out, the effect of adding MoS_2 filler on the mechanical and tribological behaviour of fiber reinforced polymeric composites is not much reported. In this context, the present work is to carried out with the main objective of studying erosive wear behaviour of carbon fiber reinforced epoxy composites with and without the addition of MoS_2 filler and the same has analysed using artificial neural network.

2. Introduction to artificial neural network

2.1 Introduction

Artificial Neural Networks, also known as “Artificial neural nets”, “neural nets” or ANN for short, are a computational tool modeled on the interconnection of the neuron in the nervous systems of human brain. Biological Neural Nets (BNN) is the naturally occurring which are equivalent of the ANN. Both BNN and ANN are network systems constructed from atomic components known as “neurons”. Artificial neural networks are very different from biological networks, although many of the concepts and characteristics of biological systems are faithfully reproduced in the artificial systems. Artificial neural nets are a type of non-linear processing system that is ideally suited for a wide range of tasks, especially tasks where there is no existing algorithm for task completion. ANN can be trained to solve certain problems using a teaching method and sample data. In this way, identically constructed ANN can be used to perform different tasks depending on the training received. With proper training, ANN is capable of generalization, the ability to recognize similarities among different input patterns, especially patterns that have been corrupted by noise.

2.2 Neural nets

The term “Neural Net” refers to both biological and artificial variants, although typically the term is used to refer to artificial systems only. Mathematically, neural nets are nonlinear. Each neuron is a multiple-input, multiple-output (MIMO) system that receives signals from the inputs, produces a resultant signal, and transmits that signal to all outputs. Practically, neurons in an ANN are arranged into layers. The first layer that interacts with the environment to receive input is known as the input layer. The final layer that interacts with the output to present the processed data is known as the output layer. Layers between the input and the output layer that do not have any interaction with the environment are known as hidden layers. Increasing the complexity of an ANN, and thus its computational capacity, requires the addition of more hidden layers, and more neurons per layer. Biological neurons are connected in very complicated networks. Some regions of the human brain such as the cerebellum are composed of very regular patterns of neurons.

Other regions of the brain, such as the cerebrum have less regular arrangements. A typical biological neural system has millions of cells, each with thousands of interconnections with other neurons. Current artificial systems cannot achieve this level of complexity, and so cannot be used to reproduce the behavior of biological systems exactly.

2.3 Present study using ANN

For materials research, a certain amount of experimental results is always needed first to develop a well performing neural network, including its architecture, training functions, training algorithms and other parameters, followed by the training process and evaluation method. After the network has learnt to solve the problems based on these datasets, new data from the same knowledge domain can then be put into the trained neural network, in order to output realistic solutions. The process of creating ANNs for materials research can, therefore, be summarized in terms of the following stages:

1. Database collection: analysis and pre-processing of the data.
2. Training of the neural network: this includes the choice of its architecture, training functions, training algorithms and parameters of the network.
3. Test of the trained network: to evaluate the network performance.
4. Use of the trained ANNs for simulation and prediction

The greatest advantage of ANNs is its ability to model complex non-linear, multi-dimensional functional relationships without any prior assumption about the nature of the relationships and the network is built directly from experimental data by its self-organizing capabilities. However, the limitations of the ANN method are as follows:

1. Training data of the database should have a close relationship with the predicting parameters.
2. Sufficient training data for complex ANNs are necessary.
3. ANNs are purely phenomenological and does not inherently produce a mechanistic understanding of the process being modeled. Nevertheless, well trained ANNs may contribute to the development of a mechanistic understanding of the problem considered

2.4 Use of artificial neural network

Artificial neural network is used to determine the predictive value for the experiment conducted. The module simulink of MATLAB is used in the present work for modeling. The said software is utilized to predict the output values and the steps involved are as follows.

STEP 1: Open MATLAB 7.5 software. Type "nftool;" in the command prompt.

STEP 2: Artificial neural network tool is seen. Enter the input and target file. Input file represents the parameters that are varied during the conduction of experiment (for example: In air jet erosion test, impinging angles are the input parameters). Target file represents the output value after experimentation (for example: In air jet erosion tests, erosive wear or weight loss could be the target value).

STEP 3: After selecting the input and target data, the next step is Validation and Testing. In this step out of 15 samples available from the present experiment on airjetr test, five datasets are used for testing, five for validation and remaining dataset for training.

STEP 4: After validation and testing, the next step is to train the network. This step is used to fit the input and target data.

STEP 5: Using Levenberg – Marquardt optimization, network was trained to get the regression graph and output file (predictive value).

STEP 6: After obtaining the results as described in step 5, a comparison graph is plotted for the actual and predicted values.

3. Material and methods

3.1 Specimen preparation

The steps involved in preparation of carbon fiber reinforced epoxy composites laminates by layup technique is as follows:

Step 1

The rectangular box of dimension 100mm×170mm is cleaned with soft brush using acetone to remove the dust. A layer of releasing agent is coated on the cleaned surface for the easy removal of the laminate after curing. Carbon fiber strand is cut to fit rectangular box.

Step 2

The epoxy resin is weighed to a ratio of 3:2 with that of weight of reinforcement material taken and is poured in to a bowl. Hardener HY 951, which is 2%-6% of the weight of epoxy resin is added to the bowl containing epoxy and stirred uniformly

Step 3

The first layer of epoxy resin is coated on the releasing agent, on which a single strand of carbon fiber is placed. Again a layer of epoxy is coated on which the carbon fiber strands is placed. To clean away the entrapped air and to obtain uniform distribution of epoxy over the carbon fibers of the mat, hand operated rollers are rolled under constant pressure throughout the mat surface. Same procedure is repeated until the desired thickness is obtained. Alternate layers of epoxy and carbon fiber are placed.

Step 4

On the top most surface of the carbon fiber a flat plate with same dimensions of laminate is placed. The pressure is applied manually for the extra epoxy resin to squeeze out from sides of the laminates.

Step 5

The laminate is cured under light pressure for 2 hrs, followed by curing at room temperature for 24 hrs. By following the same procedure as said above, composite laminates having filler composition of 4% and 8% is prepared. The erosive wear behavior of all the composite laminates are tested subsequently.

Table 3.1. Composite selected for study

Material	Matrix	Filler
Carbon –Epoxy (C-E)	40	-
MoS_2 Filled(C-E1)	36	4
MoS_2 Filled(C-E2)	32	8

3.2 Air jet erosion test:

Solid particle erosion test rig used in the present study. The rig consists of an air compressor, a particle feeder, an air particle mixing and accelerating chamber. Dry compressed air is mixed with sand particles, which are fed at a constant rate from a conveyor belt type feeder in to the mixing chamber and then accelerated by passing the mixture through a tungsten carbide (WC) converging nozzle of 4-mm diameter. These accelerated particles impact the specimen, which can be held at various angles with respect to the impacting particles using an adjustable sample holder. The feed rate of the particles can be controlled by monitoring the distance between the particle feeding hopper and belt drive carrying the particles to the mixing chamber. The impact velocity of the particles can be varied by varying the pressure of the compressed air. Square samples of size 50mm×50mm×3mm are cut from the plaque for erosion tests (fig 3.1). A standard test procedure has been employed for each erosion test in accordance with ASTM G76. The samples have been cleaned and weighed to an accuracy of 0.1mg using an electronic balance, they eroded in the test rig for 4 min and weighed again to determine weight loss. The ratio of this weight loss to the weight of the eroding particles causing the loss (i.e. testing time x particle feed rate) is then computed as the dimensionless incremental erosion rate. The test conditions are represented below.

a. Nozzle diameter (mm) = 3
b. Erodent velocity (m/s) = 30
c. Erodent feed rate (g/min) = 4.56
d. Abrasives = silica
e. Abrasive size (μ) = 200
f. Time period (mins) = 4
g. Impinging angle (ά) = 0°,15°, 30°, 45°, 60°

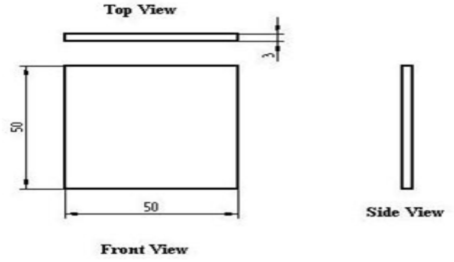

Fig 3.1. Air Jet Erosion Test Specimen

4. Results and discussions

Air jet erosion tests were conducted using solid particle erosion test rig for carbon fiber reinforced epoxy composites with and without MoS_2 filler at different impinging angle in accordance with ASTM G76. The results are shown in table 4.1

Table.4.1. Results of air jet erosion test

	IMPINGING ANGLE (α)				
COMPOSITION	α -0	α -15	α -30	α -45	α -60
	Weight Loss (g)	Weight Loss (g)	Weight Loss (g)	Weight Loss (g)	Weight Loss (g)
C-E	0.0312	0.0301	0.0298	0.0268	0.0248
C-E + 4% MoS_2	0.0058	0.0056	0.0053	0.005	0.0046
C-E + 8% MoS_2	0.0198	0.0178	0.0165	0.0132	0.0099

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Fig.4.1 shows the erosive weight loss of C-E composites as a function of impinging angle. It is observed that erosive weight loss is decreased with increase in impinging angle for all the composites. C-E composite with 4% MoS_2 additive resulted in least erosive when compared with other two. The erosive wear for C-E composite with 4% MoS_2 filler remained more or less same with increased impinging angle. This suggesting that this composite has stable erosive wear characteristics

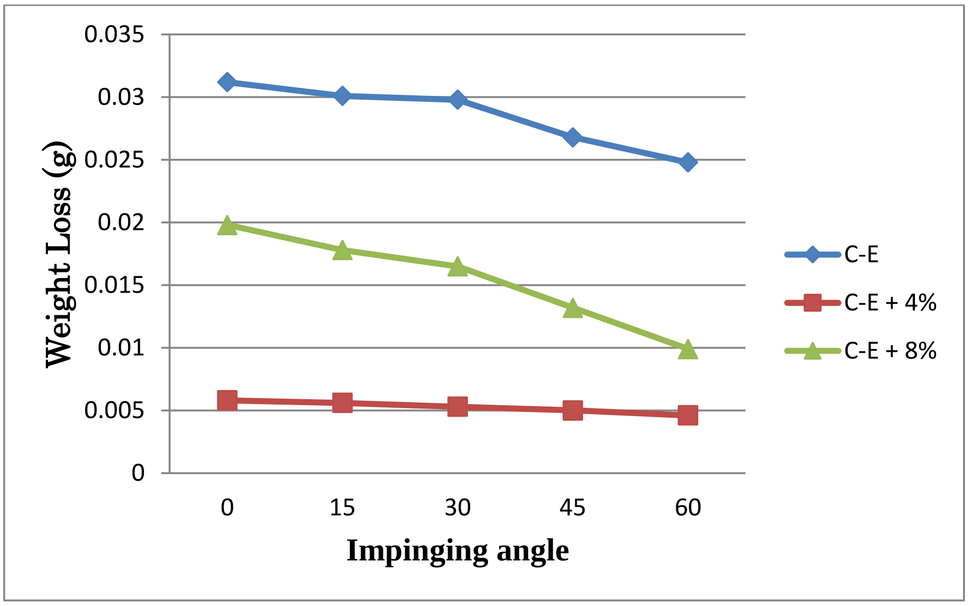

Fig 4.1: Weight loss Vs Impinging angle for C-E composites – Without ageing

4.2 ANN modelling air jet erosion test data

A total dataset of 15 independent wear parameters used in air jet erosion testing were used to train and test the neural network. These dataset include wear data obtained at different impinging angles and composition of work material. An automated ''Bayesian'' regularization of a back propagation algorithm was selected, which has the capability of automatically identifying the optimal size of the artificial neural network in its hidden layers. The training of the neural network was performed using the 'Neural Network Toolbox' of MATLAB. A randomly chosen test dataset was used in the quality evaluation.

Figure 4.2 show the regression graph. It is seen that the data points which were used as input to network fits into a liner fit.

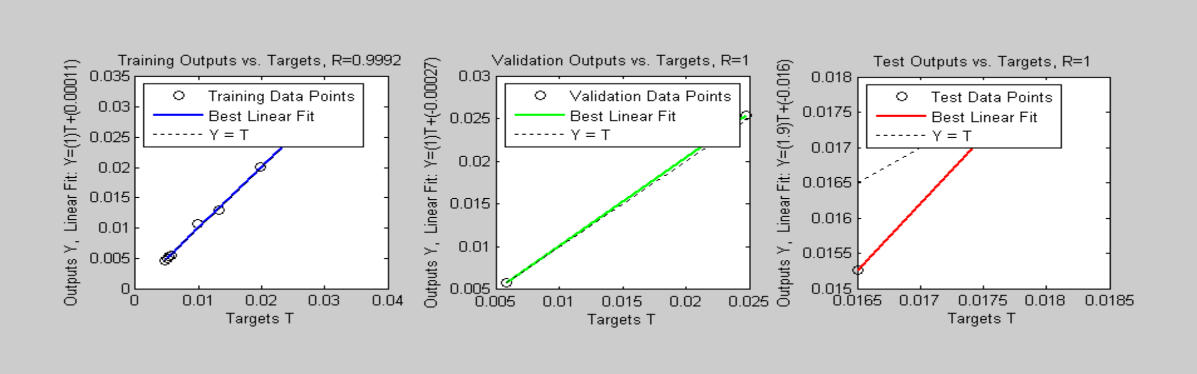

Fig 4.2. Regression graph – Air jet erosion test

Figure 4.3 and 4.4 shows the comparison between actual and predicted value from ANN for air jet erosion test. From the figures, it can be clearly seen that the actual value and the predicted values are more or less same and in graphs, they almost match with each other. From figure 4.4, it is seen that the actual value and predicted values are same for 10 datasets out of 15. In the remaining data samples, the actual value is slightly greater than that of the predicted value. The results obtained from ANN validate the data obtained from the present air jet erosion test experimentation. The above steps were followed to model the data through ANN for the air jet erosion test conducted on C-E composites with ageing.

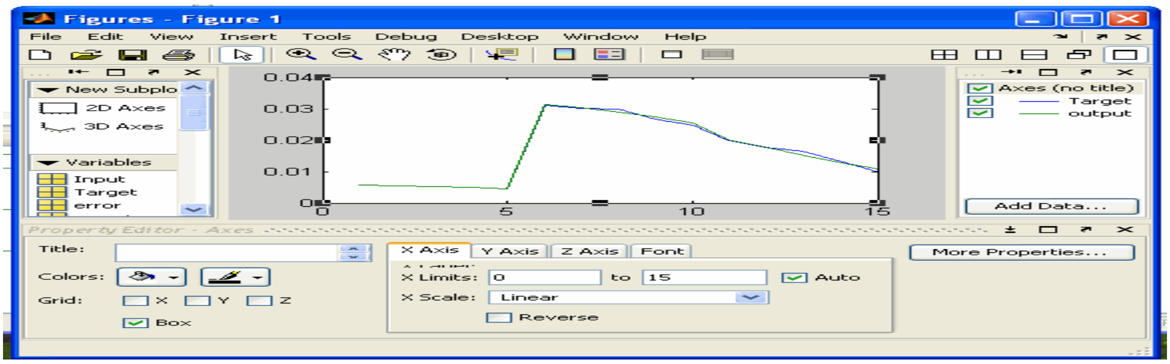

Fig 4.3. Comparison between actual and predictive value

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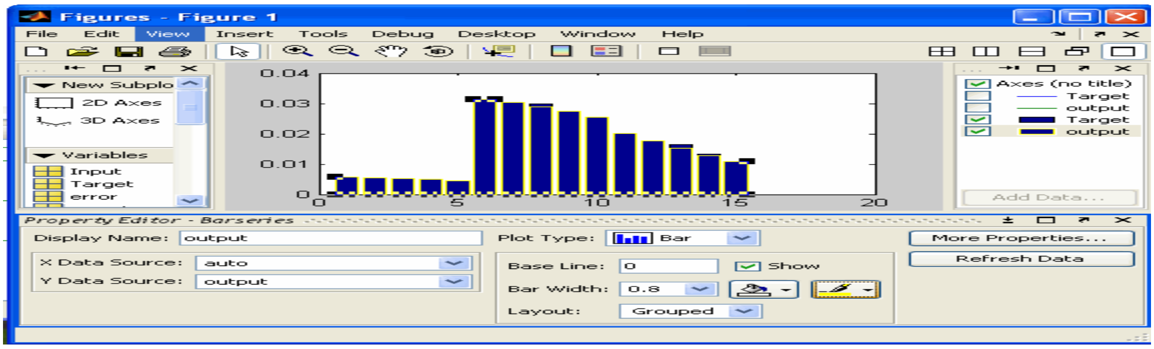

Fig 4.4. Comparison between actual and predictive value – bar graph

5. Conclusion

- The primary reason for reinforcing fibers and adding fillers to polymer are to improve their erosive characteristics.
- An experimental study of air jet erosion tests on carbon fiber reinforced epoxy composite with and without MoS_2 filler at different impinging angle was carried out and the following conclusions are drawn:
- Weight loss of C-E composite during abrasion test was strongly dependant on the test parameter namely impinging angle. Comparative erosive wear performance of all the composites showed that wear loss decreased with increased impinging angle. C-E composites with filler showed better erosion resistance. Best erosive wear performance were seen for C-E composite with 4% MoS_2 filler.

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