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Prediction of Coefficient Of Friction and Sliding Wear Rates of Cast Al6061-Si_3N_4 Composites using ANN Approach

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Abstract: ***This work focuses on the prediction of tribological behavior of cast Al6061-Si_3N_4 composites using ANN technique owing to its wide spread popularity in accurate predictions of material properties. The cast composites were developed by stir cast method and its tribological behavior were experimentally evaluated using a pin-on-disc tribometer adopting loads and sliding velocities ranging from 20-100N and 0.314-1.5740m/s respectively. The predictions of coefficient of friction and wear rates of matrix alloy and the developed cast composites by ANN approach do agree very closely with the experimental data.***

Keywords: coefficient of friction, wear rates, ANN, Composites, velocity, Metal Matrix Composites, pin on disc tribometer

1. Introduction

The use of Artificial Neural Networks (ANN) represents the new methodology in many different applications including material science and tool condition monitoring for machining of traditional engineering materials [3]. It is a promising field of research in predicting experimental trends and has become increasingly popular in last few years as they can often solve problems much faster when compared with other approaches with the additional ability to learn. ANN's are extensively used by many researchers to predict the mechanical, tribological and physical properties of Metal Matrix Composites (MMCs) which are currently the most promising material in space, aerospace, and automotive applications [2, 1]. These classes of materials possess high strength to weight ratio, high specific modulus coupled with excellent tribological behavior [5]. Among several MMC's, aluminum based composites are more popular and currently finds wide spread applications such as brake drum, brake disc where the tribological properties of the materials are of significant importance which dictate their performance.

Silicon nitride (Si_3N_4) possesses excellent anti-friction properties coupled with good hot hardness properties and is a good candidate as a reinforcement to develop aluminum based metal matrix composites for automotive applications. In the light of the above the present focuses on the development of silicon nitride reinforced Al-6061 composites by stir casting technique which is the most widely adopted processing routes to develop metal matrix composites on large scale production. The tribological behavior of the developed composites has been evaluated using pin-on-disc machine and their predictions are being carried out by ANN technique.

An ANN can be considered as black box that has a capacity to predict an output pattern when it recognizes given input pattern. Neural networks are basically connective systems in which various nodes called neurons are interconnected. A typical neuron receives one or more input signals and provides an output signal depending on the processing function of the neuron [6]. The neural network must be trained by processing a large number of input patterns and evaluating the output that results from each input pattern. Once trained, the neural network is able to recognize similarities when presented with new input patterns, and is able to predict an output pattern. In the past few years there has been a steady increase in neural network modeling in different fields of material science. However, no information is available as regards the prediction of sliding friction and wear behavior of cast Al6061-Si_3N_4 composites.

2. Methodology

Al 6061-Si_3N_4 composites were prepared by liquid metallurgy route as described in our earlier work [5]. The weight percent of silicon nitride in the composite was varied from 4-10 in the developed cast composites. Friction and wear tests were conducted using a pin-on-disc tribometer with the hardness of the counter disc maintained at HR_C-60. Pins of dimension 8 mm diameter and 20 mm height served as test samples. The initial surface roughness of the counter disc and the specimen were maintained at 1 µm and 5 µm respectively. Loads and sliding velocities were varied from 20-100 N and 0.314 to 1.574 m/s respectively. The frictional force was measured using a force transducer while the wear loss of the samples was measured in terms of height loss using LVDT of accuracy 1 µm. The co-efficient was calculated using the recorded normal and frictional forces while wear rates were calculated in terms of volumetric wear loss per unit slid distance and load from the height loss data.

The co-efficient of friction and the wear rates of the developed composites were predicted using ANN approach adopting back propagation neural network that uses a gradient descent learning algorithm. Fig.1 shows the schematic model of artificial neural network adopted in the present work. 110 sets of experimental data of co-efficient of friction and wear rates were used to train the ANN model. The model was developed using MATLAB 7.0. The input layer or the independent variables are weight fraction of Si_3N_4, load and sliding velocity. The output layer or the dependent layer is the co-efficient of friction and wear rates of the composites. The input neurons receive the input from the environment with the output neurons sending out outputs out of the system. The performance of the adopted ANN model was improved by training and testing. The sorted experimental data was then divided in 50:50 ratio so that 55 data sets were chosen for the training the network while the remaining 55 data sets were used for testing the generalization of the trained network. The number of hidden layers, the number of neurons in each layer and the transfer function of each layer of the adopted network plays a very important role in determining the functionality and generalization capability of the network. In this regard the present work has adopted a network consisting of two input neurons and five hidden neurons and one output neuron (2:5:1) for prediction of co-efficient of friction and wear rates of the composites.

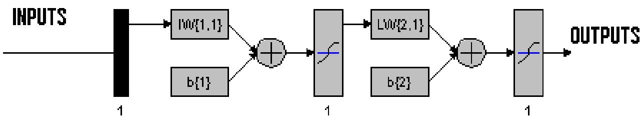

Figure 1: Schematic model of the adopted ANN

3. Results and Discussion

Coefficient of friction

Effect of reinforcement

The coefficient of friction decreases with increase content of Si_3N_4 in the composites due to its good lubricating property as shown in Fig.2. Si_3N_4 reacts with the moisture present in the environment and forms a stable oxide film. The formation of oxide film has been confirmed in our earlier works [5]. The predicted values are in close agreement with the experimentally measured values. The minimum and the maximum errors were observed to be in the range of 2%-5% respectively.

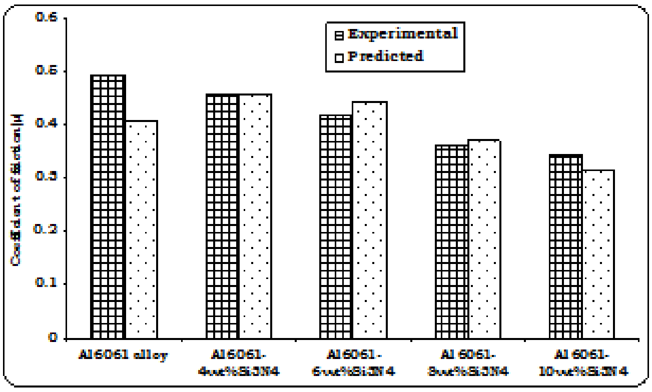

Figure 2: Comparison plot for experimental and predicted values of COF for varying weight fraction of Si_3N_4

Effect of load

The performance of neural network in comparison with the experimentally measured values of coefficient of friction with change in load is shown in Fig.3. It is observed that the increase in load results in the decrease of COF of both composites and alloy. The COF tends to decrease more in case of composites compared to that of alloy.

This can be attributed to higher extent of squeezing out of Si_3N_4 from the composite with increased load leading to larger extent of tribofilm formation resulting in lowering of COF at higher loads. The error between the predicted and experimental values of COF with increase in load ranges between1%-7%.

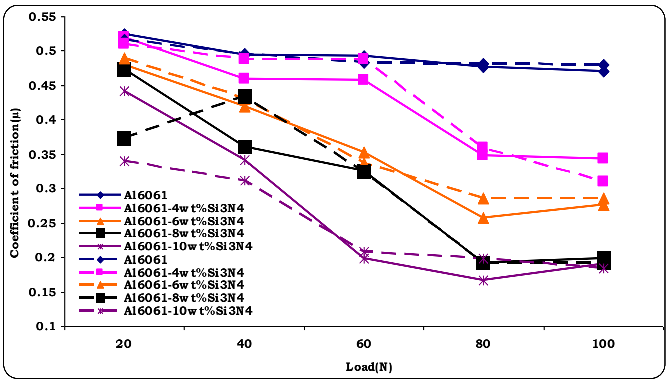

Figure 3: Comparison plot for experimental and predicted values of COF for varying loads

Effect of Sliding Velocity

Fig.4 shows the ANN values and experimental values of COF with increased sliding velocities for both matrix alloy and its composites. The minimum and maximum errors were 1%and13% respectively. The increase in the sliding velocity results in the increase in the surface temperature and beneficial oxides that are formed gets fragmented at higher sliding velocities. This leads to higher probability of the contact of fresh surfaces during sliding which results in higher coefficient of friction.

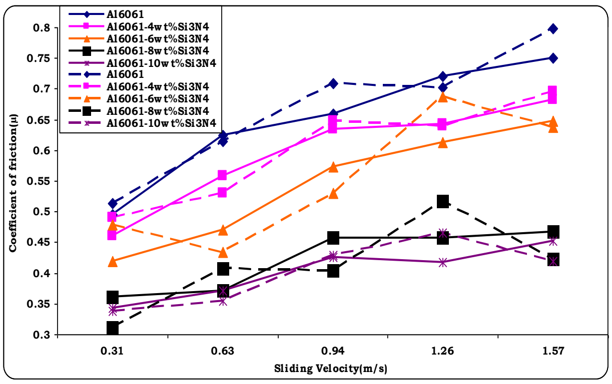

Figure 4: Comparison plot for experimental & predicted values of COF for varying sliding velocity

Wear Rate

Effect of reinforcement

There is a decrease in the wear rates of the composite with increase content of Si_3N_4 as shown in Fig.5. This can be attributed to the improved mechanical properties such as

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hardness and strength of the composites as discussed in our earlier works [5], improved hardness and strength results in lesser extent of plastic deformation of the composites during the sliding process leading to lesser material removal.

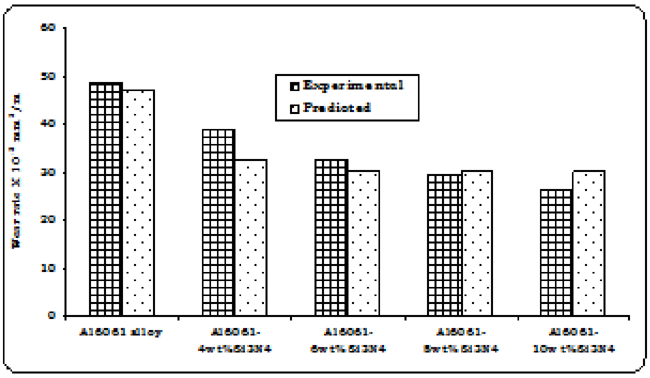

Figure 5: Variation of wear rates of matrix alloy and its composites

Effect of load

The superior wear behavior can also be attributed to the uniform distribution of Si_3N_4 particles within the matrix alloy as shown in Fig.6. The predicted wear rates from the developed ANN matches closely with the experimental ones. The minimum and maximum error is in the range of 2%-15%.Fig.7 shows the effect of load on wear rates of matrix alloy and its composites. It is observed that the wear rate increases with load linearly up to 40N for both the matrix alloy and the composites. However, at loads higher than 40n the wear rates of matrix alloy is significantly higher compared with the composites. Increased load leads to higher extent of plastic deformation at the sliding surfaces and sub surfaces leading to initiation of cracking and eventually resulting in larger material removal and hence higher wear rate at high loads. The predicted wear rates from the developed ANN matches closely with the experimental ones. The error range is 1%-9%.

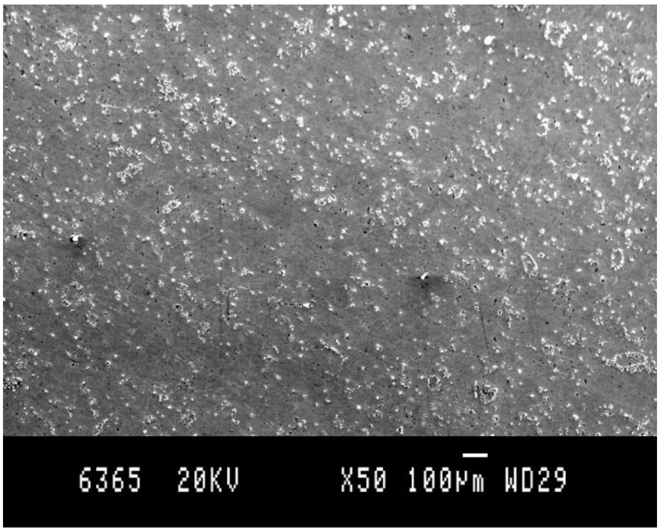

Figure 6: SEM photograph of Al6061- 10wt% Si_3N_4 composite

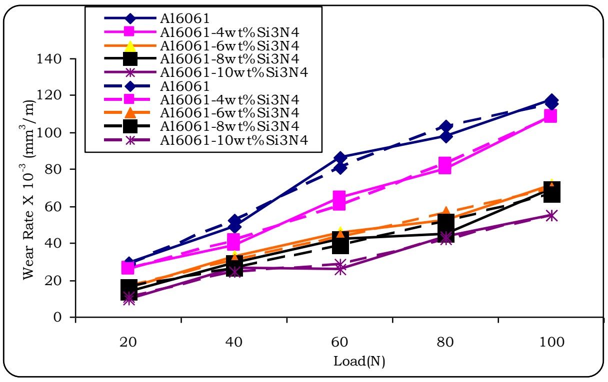

Figure 7: Variation of wear rates of matrix alloy and its composites with load

Effect of Sliding Velocity

The variation of wear rates with sliding velocity is shown in Fig.8. It is observed that for the matrix alloy there is a linear increase in wear rates with increase in sliding velocity up to 0.944 beyond which a steep rise in the wear rates are observed this can be attributed to the fact that higher sliding velocities the surface temperatures during the sliding process increases leading to softening of the sliding surfaces which in turn leads to larger extent of plastic deformation and there is a possibility of gouging of softened surfaces. This phenomenon will result in larger material removal. At all the sliding velocities composites exhibits lower wear rates when compared with the matrix alloy. The predicted wear rates from the developed ANN matches closely with the experimental ones. The error range is 1.5%-8%.

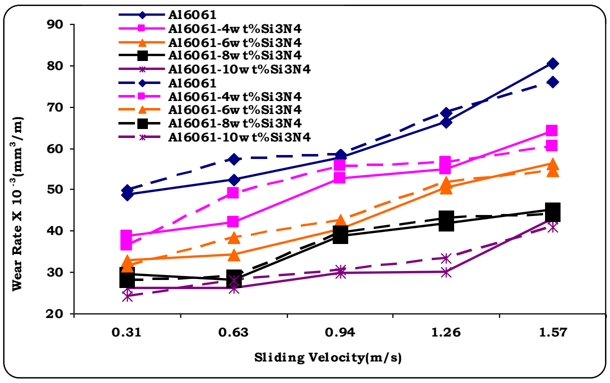

Figure 8: Variation of wear rates of matrix alloy and its composites with sliding velocity

4. Future Scopes

More different percentages of Si_3N_4 with Al6061 can be used to find their co-efficient of friction, wear rate of matrix alloy and sliding distance at different loads and velocities.

5. Conclusions

ANN predicted values of coefficient of friction and wear rates of Al6061 and Al6061-Si_3N_4 composites under all the sliding conditions studied agrees very closely with the experimental data.

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