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Artificial Neural Networks for Predicting the Tribological Behaviour of Al7075-SiC Metal Matrix Composites

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Abstract

Wear is a complex phenomenon and the most important reason for the damage and consequent failure of machine parts. The dry sliding wear performance of particulate reinforced aluminum metal matrix composites (Al-MMCs) are being investigated by numerous researchers during the last three decades. A lot of experiments have to be conducted in order to study the wear behavior. Artificial Neural Networks help in reducing the cost of experimentation when implemented with care and enough data. In this work, wear behavior of Al7075 aluminium matrix composites reinforced with particulates has been investigated. The Al7075-SiC metal matrix composites were fabricated through liquid metallurgy process containing 2-6 wt% SiC. The dry sliding wear tests were conducted using computerized pin on disc wear testing machine. The wear properties of the composites containing SiC were better than that of the matrix material and further, the composite containing 6 wt% SiC content exhibited superior wear resistance. An ANN model was developed to predict the tribological properties of the Al7075-SiC composites. The predicted values of tribological properties using a well trained ANN were found in good agreement with measured values.

Key words: Metal Matrix Composites, Sliding Wear, Artificial Neural Networks.

I. Introduction

Among several series of aluminum alloys Al7075 is much explored. Al7075 alloy possess very high strength, higher toughness and are preferred in aerospace and automobile sector [1]. However, aluminium alloys exhibit poor tribological properties. [2]. Dry sliding friction & wear behavior of material depend on several factors such as the properties of materials (chemical, physical and mechanical) sliding against each other and experimental conditions including environmental conditions, load, speed, etc., apart from contact configuration in different types of wear tester [4]. Alpas and Zhang [5] while investigating the effect of particulate reinforced MMCs under different applied load conditions identified three different wear regimes and the volume fraction of reinforcement (v_r) has the strongest effect on the wear resistance [5-9].

S Kumar et al, [10] while developing a mathematical model for dry sliding wear behaviour of Al7075-SiC composites reported that increased SiC in base alloy reduces the wear rate of the composites by restricting the flow or deformation of the matrix material against applied load. Rupa Dasgupta et al, [11] stated that the improvement in the hardness, mechanical property and wear resistance are attained by heat treating the composites. T. J. A. Doel et al, [12] in their study concluded that the 5 and 13 µm particle size SiC reinforced Al7075 exhibits improved tensile strength and lower ductility. K. Komai et al, [13] reported the superior mechanical properties of Al7075-SiC composites. Zongyi et al, [14] found the higher wear rate with composites containing SiC_w, than with those containing SiC_p. C. S. Ramesh et al, [15] concluded that Al6061–TiO_2 composite exhibited higher hardness, lower wear coefficient, when compared with the matrix alloy and Al6061–8 wt% TiO_2 possessed the lowest wear coefficient.

Artificial Neural Networks has found substantial applications in pattern recognition, classification, function approximation and signal processing and system identification [16]

It was reported that ANN network showed excellent performance in predicting wear volume loss, specific wear rate and friction coefficient as a function of sliding speed and load for different compositions of fiber and particulate reinforced composites [17,18].

Several researchers have developed ANN model using MATLab [19,20,21]. There are very few researchers who have attempted to study and develop

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the ANN model for the prediction of tribological properties of aluminium MMCs; hence the present work is undertaken. The objective of the present study is to fabricate Al7075-SiC composites, containing weight percentage of particulates from 2 to 6 wt% in the steps of 2. An artificial neural network technique is applied to predict the tribological behavior of Al7075-SiC MMCs using neural network toolbox of MATLab® and the experimental and ANN results were compared.

II. Experimentation

A. *Material Details*

The base matrix for the present studies selected was Al7075 alloy and The reinforcement material was Silicon Carbide (SiC) of size 150µm.

The fabrication of composites has been done through liquid metallurgy route via stir casting technique. Preheated SiC powder of laboratory grade purity of particle size 150µm was introduced into the vortex of the molten alloy after effective degassing with solid degasser hexachloroethane tablet. Mechanical stirring of the molten alloy for duration of 10 min was achieved by using ceramic-coated steel impeller. A speed of 400 rpm was maintained. A pouring temperature of 710^{o}C was maintained and the molten composite was poured into the preheated cast iron moulds. The extent of incorporation of SiC in the matrix alloy was varied from 2 to 6 wt% in the steps of 2. The cylinders of 22mm x 210mm cast composites of Al7075-SiC were obtained.

B. *Wear Tests*

The test specimens were in the form of pins of diameter 10 mm and height 25 mm, while the disc was high carbon EN31 steel having a hardness of HRC 60. The wear height loss of the pin in microns was recorded during each wear test using an LVDT transducer of accuracy 1.0 µm. The surface roughness of the test pin specimen and the disc were maintained at 0.1 µm *R*a.

Dry-sliding wear experiments were conducted using a DUCOM computer aided pin-on-disc wear-testing machine at constant sliding velocity (V=2.62 ms^{-1}), 10-60 N normal load applied in the steps of 10 N while the sliding distance of 6 km and 50 mm track radius was maintained. The wear tests were conducted in accordance with ASTM G99 standard. During wear testing, height loss experienced by the pin specimen is measured in microns.

III. Results and Discussions

A. *ANN Model*

In the present investigation Back propagation (BP) learning algorithm is used for ANN modeling. As shown in the Figure 1, for the present work 4 – $[5 – 9]_2$ – 1 ANN configuration was selected (the network includes four input, one output and 2 hidden layers with 14 hidden nodes, 5 neurons in the first and 9 neurons in the second hidden layers), with two material and two testing parameters as input and wear height loss as output as shown in Figure 1.

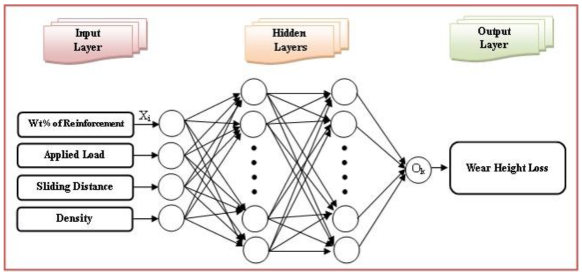

Figure 1. An artificial neural network with input, output and hidden layers.

An ANN was modeled using NN tool box of MATLab® (MATLAB 7.7). The obtained experimental wear data was further divided into training and testing set. The data was collected by conducting 24 experiments. A total of 960 data was collected out of which 816 was selected as training data and the remaining was used as testing data for verification. A nonlinear tan-sigmoid transfer function served between the layers (except the output layer), and a linear transfer function was used between the last hidden layer and the output layer to avoid limiting the output value to a small range. This model was used to predict wear-height loss. The feed forward back propagation network was trained by using LMBP algorithm with Mean Square Error (MSE) as the performance measuring parameter. The optimization process was obtained by using a TRAINLM function which is available inside the neural network toolbox. TRAINLM is a network training function based on Levenberg–Marquardt algorithm that updates weights and bias values in a back propagation algorithm.

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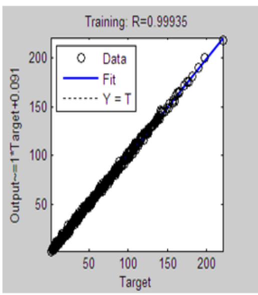
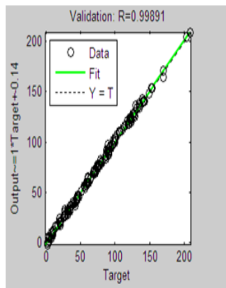
B. *Implementation*

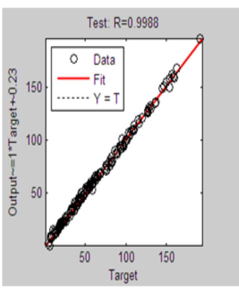
This section presents the details of the ANN model training, testing and validation. The Figures 2 (a) – (d) presents the results of regression plots of training, testing, validation and average of all. The plots show an average regression value of R=0.99915 i.e. a regression value close to 1 which means that the predicted values are in close relationship with the output as the data in the graphs lie on the fit. Same can be appreciated for training, testing and validation individually.



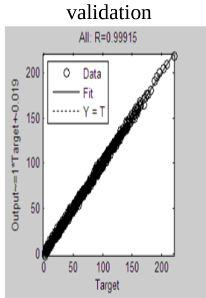
(a). Regression plot for training



(b). Regression plot for validation



(c). Regression plot for testing



(d). Overall regression plot

Figure 2 a-d. The regression plots of training, testing, validation and average of all sets.

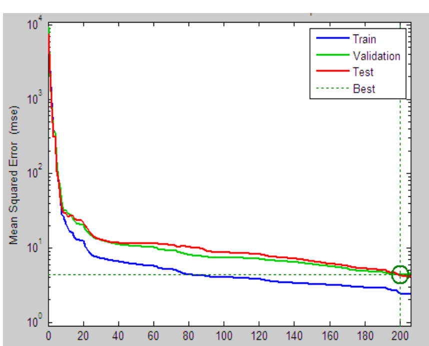


Figure 3. The Mean squared error (MSE) performance plot of ANN.

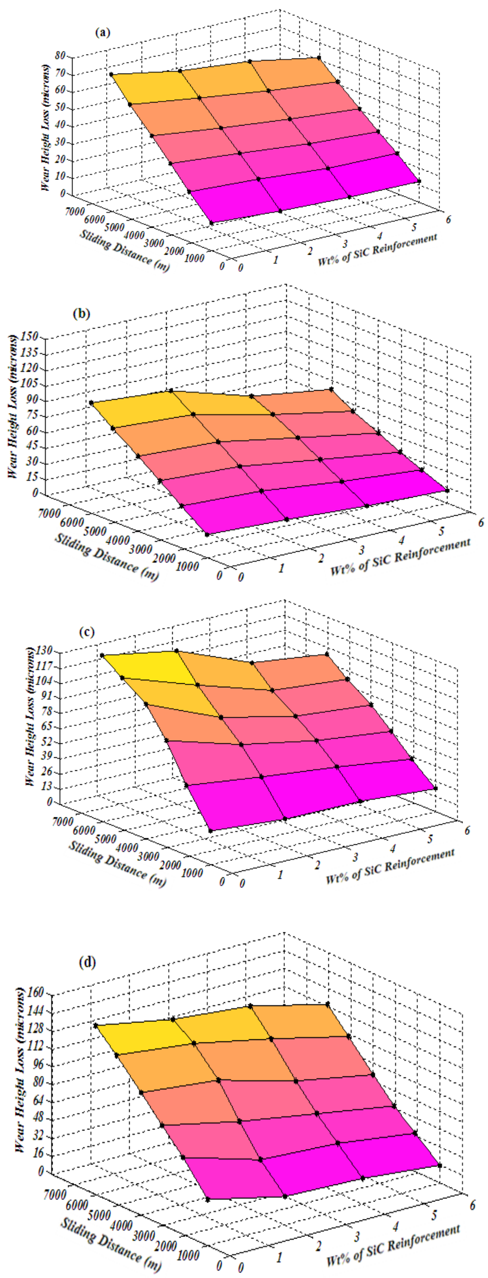
The performance of the network shown in Figure 3, is measured using MSE over the epochs i.e. the number of iterations carried out by the network in order to achieve generalization. The ANN achieved stable state after 200 cycles of training. The error curve of training is shown Figure 3. Figure shows the decrease of error over the epochs or iterations carried out by the network during training, validation and testing. Generalization was stopped at the 206th epoch as there was no improvement. The best performance was obtained at the 200th epoch at which the MSE during training and validation was found to be 4.3438.

C. *Prediction by ANN*

Once the neural network is successfully trained, it can be used to predict new results in the same knowledge domain. New input data sets are constructed according to the experimental results which were provided to the network for the prediction of wear characteristics. Figures 4 (a) to (f), were drawn by making the use of the stored domain knowledge in the neural network, which show the relationship between the different tribological properties (percentage weight of reinforcement, applied load, sliding distance and wear height loss).

The prediction of wear height loss of the Al7075-SiC reinforced MMCs as a function of sliding distance and percentage weight of reinforcement are shown in the Figures 4 (a) to (f), at different applied loads (10 to 60 N). At a constant applied load (10N), Figure 4 (a), show that the wear height loss decreases as the SiC wt% reinforcement increases from 0 to 6% and the wear height loss increases gradually as the sliding distance increases. A similar trend can be observed in the Figures 4 (b) to (f). From the above figures, it can be concluded that as the sliding distance increases the wear height loss increases and decreases with the increase in the SiC content in the Al7075 base material. At larger sliding distance, increase of temperature of the sliding surfaces is unavoidable. This results in softening of the matrix and composite pin surfaces leading to heavy deformation at higher sliding distances. Further the Al7075-6 wt% SiC composite shows lower wear height loss. This improvement in the wear resistance can be attributed to the presence of hard SiC particulates.

Figures 5 (a) to (d), show wear height loss of the Al7075 base material and its SiC filled composites as a function of sliding distance and applied load. From the Figures, it is observed that as the applied load increases from 10 to 60 N, the wear height loss increases rapidly. At higher sliding loads for all the composites studied, at all sliding distances, the wear height loss increases. From the above discussion the applied load, sliding distance and wt% of reinforcement material have the significant effect on the wear height loss of the Al7075 base material and its SiC filled composites. Further, the Al7075-6 wt% SiC composite showed excellent wear resistance than the other composites studied. This improvement in the wear resistance of the Al7075-SiC filled composites is mainly attributed to the better bonding between the matrix and the reinforcement material and hence better load transfer from the matrix to the reinforcement material. Similar results were obtained by other researchers [18-20].



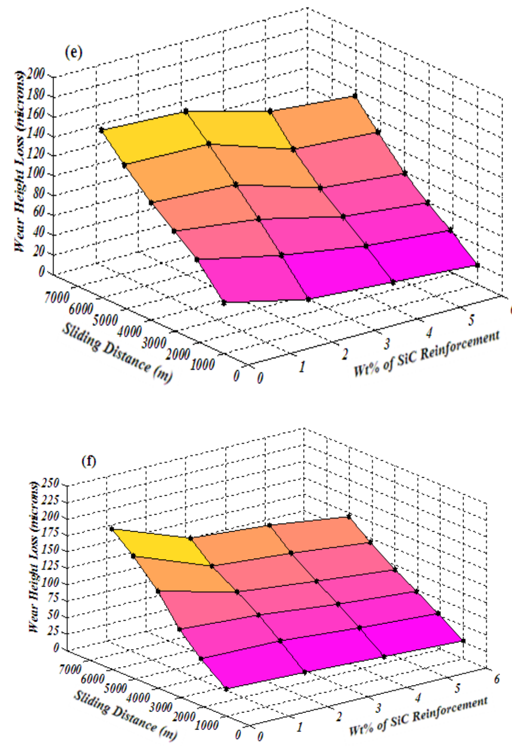


Figure 4 (a) to (f). Prediction for the relationship of wear height loss as a function of sliding distance and wt% of SiC reinforcement at a constant applied load (10 to 60N).

The prediction of wear height loss of the pin (Al7075-base and its SiC filled composites) as a function of applied load, sliding distance and wt% of SiC reinforcement material are shown in the Figures 4 and 5. A non-linear relationship ANN model for the prediction of wear height loss has been built. The test results show that the well trained neural network can precisely predict the wear height loss. The developed ANN model showed excellent performance at an appreciable level within an error range of ±5%. From the results, it can be observed that the prediction accuracy is realistic. Moreover, if the experimental data base for training the network could be expanded, the network has the potential to yield better results. The results revealed that the well trained ANN model can be used to predict any new data from the same knowledge domain thus avoiding repetition of long-term experiments, wastage of manpower and money [22,23].

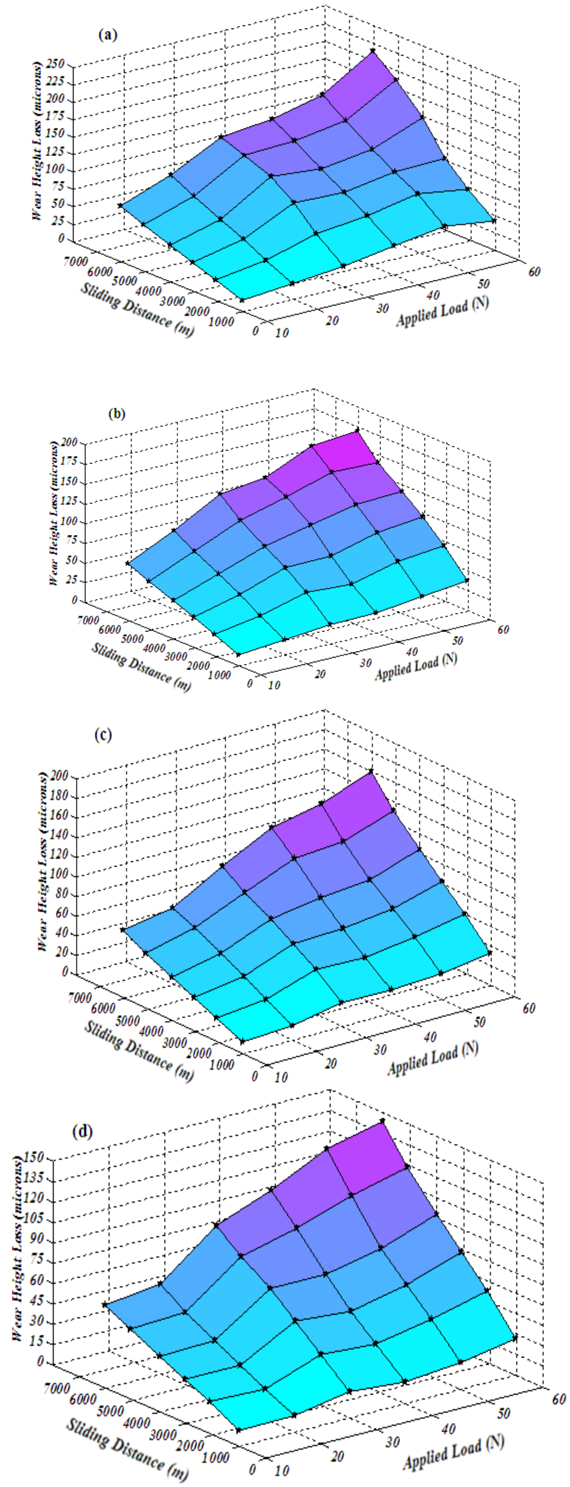


Figure 5 (a) to (d). Prediction for the relationship of wear height loss as a function of sliding distance and applied load for Al7075 alloy and its SiC filled Composites.

IV. Conclusions

The following conclusions can be drawn from the studies on the tribological behaviour of Al7075-base material and its SiC filled composites using artificial neural networks.

a) The wear height loss of the Al7075 alloy and its SiC filled composites increased as the applied load and sliding distance increased, but the same was found to decrease as the SiC content increased in the matrix material.
b) The Al7075-6 wt% SiC composite showed excellent wear resistance than the other composites studied.
c) A non-linear relationship between sliding distance, wt% of reinforcement, density, applied load and wear height loss was built by using an artificial neural network.
d) The results obtained from the trained ANN model were found to be in close agreement with that of the experimental results.
e) A well trained neural network can precisely predict the wear height loss of Al7075 alloy and its SiC filled composites.

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