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Tribological Behaviour of Aluminium/WC Metal Matrix Composite Using ANN

Deepak S[1], Balasubramanya H S[2], Nandeesha H L[3], Veeresh Kumar G B[4],

Divakara Shetty A S[5]

[1, 2, 3]Department of Mechanical Engineering, Ramaiah Institute of Technology, Bangalore, Karnataka 560054,
[4]Department of Mechanical Engineering, NIT Tadepalligunden, Andhra, India
[5]Engineering Department, University of Technology and applied sciences IBRI, Sultanate of Oman 516

Abstract

This paper analyses wear behavior of Al6061 alloy reinforced with Tungsten carbide WC and compare it with the base Al6061 alloy. The selected reinforcement material has an average particle of size 5 microns. The reinforcement content was varied in the range 1-4% by weight in the steps of 1%. Dry sliding wear studies on composites were carried out using pin-on-disc testing machine for varying loads. The experiments were conducted using four different loading levels of 10, 20, 30 and 40 N at constant sliding distance of 3000 m and constant disc speed of 500 rpm under multi-pass condition. Height loss method has been considered for the analysis. The height loss of the composites was found to increase with the increase in normal load. Reduction in height loss and were noticed after WC reinforcements additions to the composite. The result indicates that WC has an influence on the wear properties of the composite. Height loss prediction was done using artificial neural network (ANN). The obtained results are used to develop and train an artificial neural network, which can predict the wear behavior of aluminum metal matrix composite. It was found that predicted wear rate using ANN technique was in good agreement with the experimental values.

Keywords: *TRAINLM function, epochs, height loss, NN training module*

1. Introduction

Future technologies will necessitate the development of new materials to deal with them, as existing materials are limited in number and have certain limits in comparison to emerging technology. Artificial intelligence (AI) is a branch of computer science that focuses on creating intelligent computer systems, or systems that display the traits we associate with intelligence in human behavior [1]. However, because the term intelligence isn't precisely defined, it's been misunderstood. As a result, intelligence-related tasks like learning, intuition, creativity, and inference appear to be only partially understood.

The purpose of AI research is to better understand intelligence by creating intelligent computer programs. It is concerned with the concepts and methods of symbolic inference, or reasoning, by a computer, as well as the representation of the knowledge required to make those inferences within the machine [2].

1.1 Need for Composite Materials

Designers are looking for materials that have a high strength-to-weight ratio, are easy to work with, cast well, have good thermal conductivity, and are corrosion resistant., which can be easily obtained in metal matrix composite (MMCs). MMCs find its application in several fields like aerospace, automotive, marine and in critical industrial sector etc. There is large scope for the improvement in the mechanical and tribological properties of composite material [2]. A composite material's main benefit over a traditional material like monolithic metal is the combination of numerous qualities that traditional materials rarely have. High strength to weight ratio, higher stiffness to weight ratio, improved fatigue resistance, improved corrosion resistance, higher resistance to thermal expansion, excellent optical and magnetic properties, combination wear resistance and fracture toughness, and so on are some of the unusual combination properties [3].

There are a variety of scenarios in service that necessitate a unique set of skills. Furthermore, the current tendency is to use light weight constructions for ease of handling and reduced space, as well as for aesthetic look and excellent resistance to weathering damage. These factors have pushed current designers to create newer composite materials that meet stringent standards for large-scale manufacture.

1.2 Need for Artificial Intelligence Technique

From the past decade, several researchers have attempted to study the mechanical and tribological behaviour of composite materials through applied soft computing techniques. Computers are ideally suited to doing mechanical computations based on pre-programmed principles. This enables artificial machines to execute simple boring jobs that humans are ill-suited to effectively and dependably [4]. Things become more difficult when situations become more complex. Computers, unlike humans, have difficulty comprehending specific situations and adapting to new ones. Artificial Intelligence (AI) strives to improve computer behaviour when dealing with such difficult jobs.

AI aids in the comprehension of human intelligence. Humans have a unique problem-solving strategy based on abstract thinking, high level deliberative reasoning, and pattern recognition [5]. Artificial Intelligence aids in the understanding of this process by reproducing it, enabling us to potentially improve it beyond our existing capabilities.

1.3 Neural Networks

'Artificial neural network' is a state-of-the-art technique, which tries to mimic the function, or the operations performed by the human brain. It can be initially trained to a particular application with a rich set of practical data and after sufficient training, the same network can be used to predict the same in its own domain knowledge with appreciable accuracy, precision and repeatability.

In general, "a neural network is a densely connected network of processing elements called neurons with an architecture inspired by the human brain" [6]. A neural network can process data in a massively parallel manner, which is referred to as "parallel distributed processing." Example-based learning is how neural networks learn. They can be taught to learn about a problem by using well-known examples. The trained neural network can be used to similar issues with success.

This paper analyses wear of Aluminium 6061 alloy and with 1 - 4 wt. % WC particles as re-inforcement. The main aim of the paper was to verify wear of tested composites by using of Experimental and artificial neural network (ANN). Furthermore, the comparison of the experimental data with both of these methods to check its reliability. The work highlights the potential benefits of WC with respect to applied load on the alloy and composite is examined for a sliding distance of 3000 m and at a constant disc speed of 500 rpm[7]. It also demonstrates and analyze the potential of artificial neural network (ANN).

2. Materials and methods

In this investigation, the aluminium 6061 alloy was used as the matrix. A computerized electronic weighing equipment was used to weigh the aluminium 6061 alloy. The weight percent of WC in particle form to be added to the aluminium was calculated [8]. The matrix (Al) was melted to molten in a crucible furnace at 720°C. The WC particle was warmed for 30 minutes at 180°C before being introduced to the molten aluminium. To ensure homogeneity of reinforcement dispersion in the Aluminium matrix, the molten mixture is continually agitated. Each mix was placed into a sand mould that had been warmed. This procedure was repeated for all the weight fractions from 1-4 wt.% in steps of 1% by weight[9]. The cast composites of Al6061 -WC obtained were cylinders of 20 mm x 200 mm.

Pin on disc tribometer is employed to characterize the Alloy and composite specimens. The pin specimen dimensions are 6 mm in diameter and 30 mm in length. The surfaces of pin is cleaned thoroughly using emery paper in order to ensure the effective surface contact with steel disc. The samples and wear track of the machine were cleaned with acetone before and after each test[10]. The height loss of the pin materials is measured before and after the test. Figure 1 shows the pin on disc experimental setup.

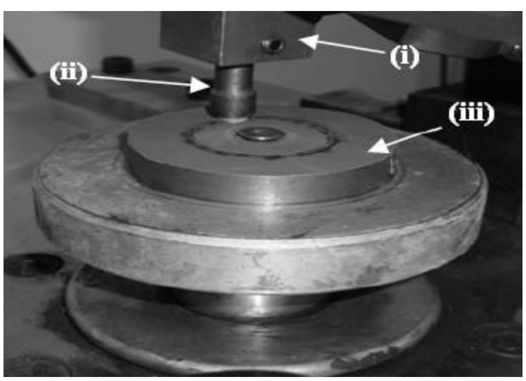

Figure 1: Details of pin-on-disc machine setup
(i) Pin holder with screw (ii) Specimen with holder (iii) EN31 steel disc

Table 1 shows different process parameters used to conduct the experiment.

3. Results and Discussion

The Neural Network Toolbox in MATLAB® was used to model an ANN (MATLAB 7.7). The experimental wear data was separated into two groups: training and testing. Five tests were conducted to gather data. A total of 380 data points was collected, with 300 being used as training data and the rest as testing data for verification. To prevent confining the output value to a small range, a nonlinear tan sigmoid transfer function was employed between the layers (excluding the output layer), between the last hidden layer and the output layer, a linear transfer function was applied. The ear-height loss was predicted using this model. The LMBP method was used to train the feed forward back propagation network, with Mean Square Error (MSE) as the performance metric. The TRAINLM function, which is part of the neural network toolkit, was used to obtain the optimization process. TRAINLM is a network training function that uses Levenberg–Marquardt optimization to update weights and bias values in a back-propagation method. The Levenberg–Marquardt algorithm is a fast way to solve nonlinear optimization problems. A sliding wear test was conducted over a distance of 3 km at an applied load of 10, 20, 30 and 40 N. The variation of height loss with sliding distance is shown in the Figures 2, 3, 4 and 5 respectively. It is observed that height loss increased linearly with the increase in sliding distance. The height loss reduced with increased content of WC in MMCs when compared with base alloy.

As can be observed from the graphs, the composites containing WC have less wear loss and so have better wear resistance. The presence of WC in the Aluminium alloy, which improves wear resistance, is responsible for the reduction in wear loss. The composite with the maximum wear resistance is the one having 3 wt% WC. The Al6061-4 percent WC composite has a larger wear height loss than the base material, much more so than the base material. This is primarily due to the Al6061-4 percent WC composite's decreased hardness.

Table 1: Test parameters

Control factor	Unit	Level 1	Level 2	Level 3	Level 4
WC	Wt. %	1	2	3	4
Applied Load	N	10	20	30	40
Sliding speed	rpm	500 rpm			
Sliding distance	m	3000			

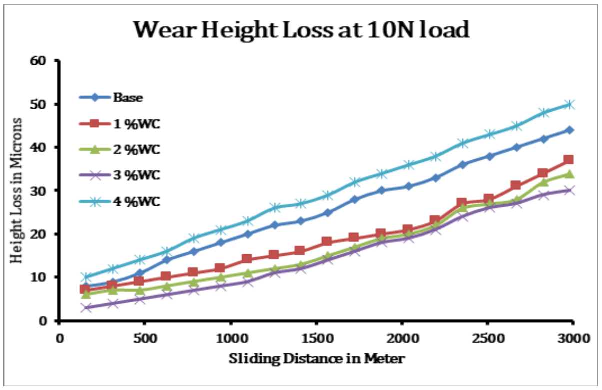

Figure 2: Wear at 10 N

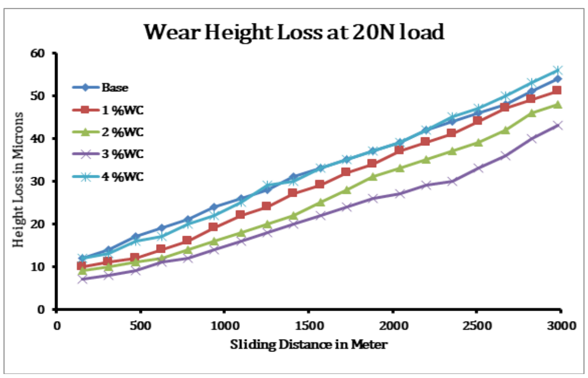

Figure 3: Wear at 20 N

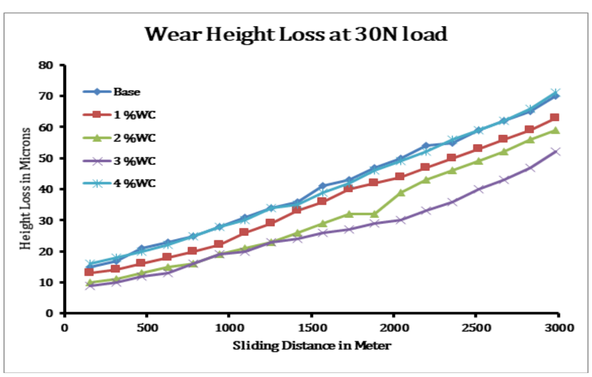

Figure 4: Wear at 30 N

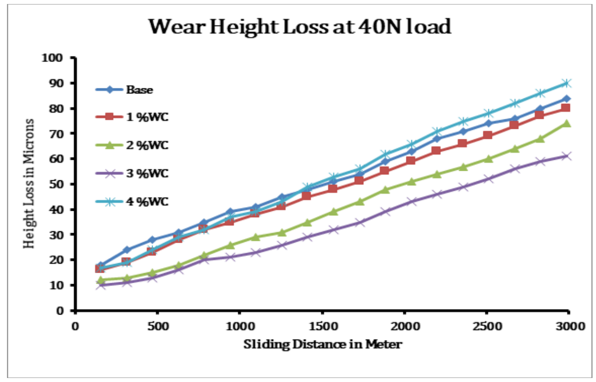

Figure 5: Wear at 40 N

MSE over epochs, i.e. the number of repetitions carried out by the network in order to accomplish generalization, is used to measure the performance of the network displayed in Figure.6. Validation error is minimum occurred at iteration 10 and the network at this iteration is returned. After this iteration similar characteristics were observed for the test set error and the validation set error without over-fitting occurred and the validation stopped at 16 iterations.

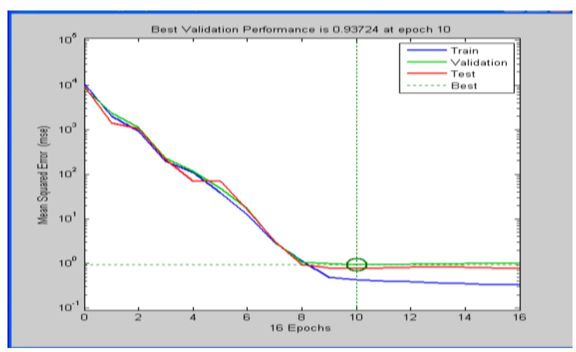

Figure 6: Validation error plot

The model with the specified parameters was generated using NN Toolbox of MATLAB. NN Tool is an acronym for neural network tool, it is a graphic user interface (GUI) module that helps a user to generate a neural network model (Figure 7) and train the same to minimize errors. It is capable of importing experimental data through a Microsoft Excel spreadsheet (Figures 8 & 9). In proportions of 70:15:15, the imported data was further separated into training sets, validation sets, and testing sets.

The Figures 8 and 9 is plot of graph for height loss measured experimentally and predicted using the NN Tool. The percentage of error for prediction is less than 5% for a single layer neural network.

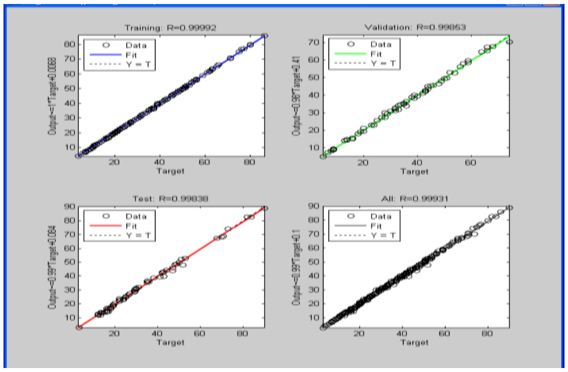

Figure 7: NN training Toolbox results

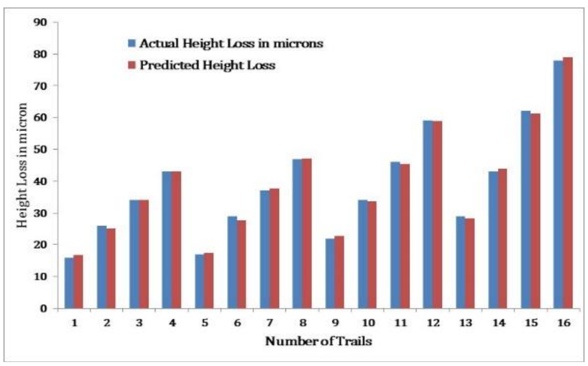

Figure 8: Comparison of Actual height loss to predicted height loss of 0 wt.% of WC

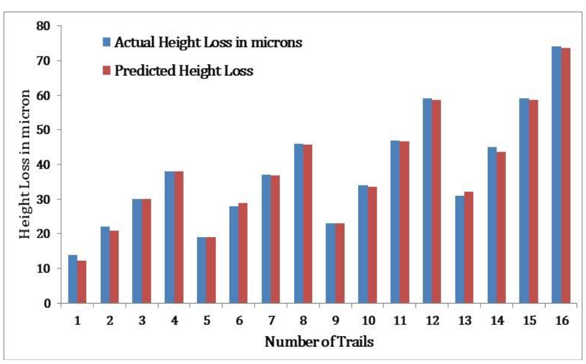

Figure 9: Comparison of Actual height loss to predicted height loss of 3 wt.% of WC

4. Conclusions

- The characterization shows that the Stir-Casting fabrication technique is efficient and economical to fabricate MMC's up to 4% wt. of WC.
- Microstructure of composites shows good and uniform distribution of reinforcement, minimal porosity, and increase in % wt. of reinforcement showed increase in distribution.
- The experimental density of the composites matches the theoretical density, indicating that the composites manufacturing process is working. The density of the composite increases with increase in concentration of WC in the composite.
- According to the findings of the literature review, the ANN can be used to forecast MMC wear.
- The wear results show that the increase in percentage reinforcements in the composite resulted in improved wear resistance.
- ANN model has been successfully implemented and trained to predict the "Wear Height Loss, Volume Loss and Wear Rate".
- The network predicted the "Wear Height Loss, Volume Loss and Wear Rate" with an error range of 5%.

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