

Wear Studies on Al 7075/Al₂O₃ Particulate MMC by Artificial Neural Network

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ABSTRACT: Particulate composite material systems are used in automobiles due to light weight and enhanced Mechanical and Tribological properties. The present work involves the development of Particulate Composite with Al 7075 alloy reinforced with Alumina (Al₂O₃) by stir casting process with bottom pouring arrangement. The reinforcement used in volume fraction of 5%, 10%, 15% and 20%. The Mechanical and Tribological behaviour of the developed particulate composite was carried out. Artificial neural Network model was developed and was used for the prediction of wear rate and wear coefficient of composite. Thirteen input parameters are considered for the ANN. The Levenberg Marquardt algorithm with 10, 30 and 50 neurons are used for ANN. The ANN model with 50 Neuron predicted better results than the other two. The wear rate reduces with the increase in volume fraction of reinforcement. The model has a capability to predict the wear rate with minimum relative error.

KEYWORDS: Wear Rate, Al7075, Al₂O₃, ANN, Levenberg Marquardt, Stir casting.

I. INTRODUCTION

The composite material systems are developed over the alloys when it becomes saturated in terms of improvement in property by further alloying and heat treatment. The particulate metal matrix composite are developed for automobile applications as it reduces the weight and fuel consumption. Also the particulate composites can be produced at lower cost and mass production [1]. The stir casting process is a liquid state process with addition of reinforcement to matrix in the liquid melt. The process uses a stirrer for the uniform distribution of reinforcement and bottom pouring for satisfactory dispersion of the reinforcement [2]. The weight fraction of the reinforcement varies from 0% to 80% for Particulate MMC. The Particulate MMC possesses good wettability and Interface bonding and it has isotropic properties. Mechanical and Tribological properties are improved in Particulate MMC as compared to alloys [3] [4].

Wear behaviour of the particulate MMC was studied by many researchers to develop automobile parts with improved wear resistance [5]. Wear is a complex phenomenon which has to be studied for interacting surfaces in motion. Adhesive wear and Abrasive wear are common phenomenon which depends on system, environment, and material properties [6]. Large number of test has to be conducted at various speed and load to evaluate the wear which is time consuming and not economical.

The Artificial Neural Network (ANN) is one of the developments of artificial intelligence which are used to predict the wear behaviour of any system [7]. The martial behaviour are predicted by ANN model was successfully developed for different composite material system by many researchers [8] [9]. The Aim of present research work is to develop an Aluminum based Particulate composite and to investigate the mechanical and Wear behaviour with varying speed and load conditions. Wear phenomenon is complex nonlinear process which depends on more than 100 parameters. Maximum of 13 parameters are considered as input for the ANN and 8 parameters related to wear behaviour are predicted as output of ANN. The developed model can be effectively utilized for prediction of wear behaviour at higher load, speed and volume fraction with various combination of parameters related to material, process and wear.

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II. EXPERIMENTAL WORK

The matrix material used in the development of composite was Al-Zn-Mg Alloy. The Aluminum containing Zinc, Copper, Magnesium, Silicon and traces of Iron, Chromium, and Zirconium are the composition of Al7075. The reinforcement used in the present work was Alumina (Aluminum oxide- Al_2O_3). Ceramic materials are used for various applications in the past for grinding wheel, high temperature parts, corrosion resistance, refractory materials etc. Recent advances in particulate MMC made it possible to use the ceramics for development of composite. Alumina has superior thermal, chemical and mechanical properties as compared to alloy. Matrix Material like Al 7075 (AA 7075) are strongest metal among aluminum alloy series. The general characteristics of Aluminum 7075 are very high strength, good stress corrosion cracking resistance, good fracture toughness. Applications of Al 7075 are aircraft fittings, gear, shafts, missile parts, regulating valve parts.

For most of the composite material in the literature the maximum volume fraction is 80:20. But for the structural parts and packaging applications it is 50:50. The reinforcement in the present case is selected as 5%, 10%, 15, and 20% based on volume fraction. The volume fractions are converted in to weight fractions of matrix and reinforcement for the fabrication process. Initial pre heating the reinforcement are performed at 450°C to remove moisture and to promote wettability.

Stir casting is a liquid state process which is flexible, simple and suitable for large volume production. The distribution of reinforcement and high volume reinforcement can be easily be controlled by stir casting process. It does not involve application of any pressure which can cause the particle damage. Stir casting process was carried out at 700°C by melting Al7075 in bottom pouring type stir casting furnace as shown in figure1, supplied by Swam equip, Chennai. The metal moulds are used for rapid solidification purposed to generate fine grain size. Mechanical tests are carried out evaluate density, hardness, tensile strength as per ASTM standards. Microstructure characterization and XRD analysis are carried out to estimate the reinforcement distribution and Interface reactions.

Wear test was performed on the Composite specimen of 10x10x30mm dimension using Magnum pin on disc wear testing machine as per ASTM G99 standards. The weight loss was calculated up to an accuracy of 1mg. The weight loss is converted to volume loss by using density of the composite. Wear test at various speeds and Loads were carried out on all the composite developed. The wear rate and wear coefficient are calculated by Archard's wear equation.

III. ARTIFICIAL NEURAL NETWORK MODELING AND WEAR RATE PREDICTION

Artificial neural network are derived from inspiration of biological neurons. The ANN consists of input layer, hidden layer and output layer. The ANN is used for forecasting, predicting and classification in different fields of study. ANN are used for optimizations also, which requires large set of experimental data as input. ANN is a form of regression or classification modeling which can help in resolving complex problem in behavior of material science in low cost and minimum time for long term solutions. Various training algorithms are used in ANN for predicting the behavior of the system. The ANN prediction results shows that it is in good agreement with the experimental results for LevenBerg Marquardt training algorithm which is also fastest converging one and working with high accuracy in prediction .

The present work consists of developing an ANN model which can predict the wear behaviour of the Particulate composite at various volume fractions of reinforcement. The test has been carried out by Pin on Disc wear testing machine. These data are converted to wear rate and wear coefficient. The input data has been utilised for both training and testing the ANN. The ANN utilises 80% of the data for training and 20% of the data for testing the ANN model. The ANN can predict the best results for given set of neurons and number of hidden layers. The complex nonlinear behaviour of the wear rate for particulate MMC can be predicted by ANN with minimum mean Square error.

The present work involves developing ANN by considering single hidden layers with three different set of hidden layer neuron. The most commonly employed training algorithm trainlm was used for the ANN model. The testing range with the parameters of input and out put are Input- Speed, Load, Hardness, Density, Sliding Distance, Tensile strength, Compressive Strength, CTE, Thermal conductivity, Pressure, young's modulus, and Elongation. The output parameters are weight loss, volume loss, wear rate, and wear coefficient.

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The ANN developed by selecting Levenberg Marquardt algorithm which uses least square method. The numbers of neurons are selected by trial and error method. The least mean square error (MSE) value corresponding to the given number of neurons was considered and the training will be stopped for least value of MSE. The neurons selected for training was 10,30 and 50. The correlation coefficient and MSE for each set of neuron are computed and the network is optimized. The component of ANN model are shown in table 1.

Table 1 Entities and Components of ANN structure

Particular	ANN Parameters	Remarks
Training Algorithm	Levenberg-Marquardt Method	Nonlinear, medium Data set
Number of Hidden layer	1	Best prediction capability
Number of Neuron in	10, 30, 50	For optimization of MSE
Transfer function	Trainlm	Commonly used for Prediction
Performance function	MSE	Best Error function

The developed ANN model consists of input layer with 13 parameters and output layers with 4 parameters. The ANN model contains single hidden layer with three set of neurons. The number of neuron used for the preset work is 10, 30 and 50. The algorithm used in the network is Levenberg Marquardt (trainlm). Selections of transfer function and trining algorithm are crucial for the ANN model. Feed forward back prapogation algorithm containing one hidden layer with different neuron in the hidden layer was configured. The ANN model is shown in figure 1.

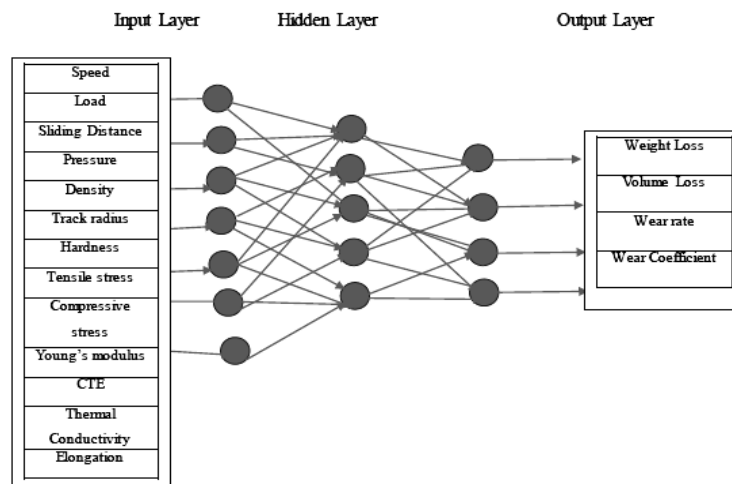


Fig 1 Single hidden layer neural Network with input and output parameters

The input parameters for the ANN Training are determined from the wear test at various load and speed. The mechanical properties like hardness, density, tensile strength and compressive strength are found by experiments. Other properties are found by empirical relations using rule of mixture and extrapolation. The MATLAB 2016 was used for the training the ANN with 10, 30 and 50 neurons. The MSE was calculated for different trial run until it shows minimum value for the given Epoch. The regression plot and error histogram are compared for each of the neuron set used in ANN training and the ANN model was generalized for minimum MSE and higher regression value. The regression curve for all the trials are shown in figure 2 which indicates best prediction by ANN with 10 neuron.

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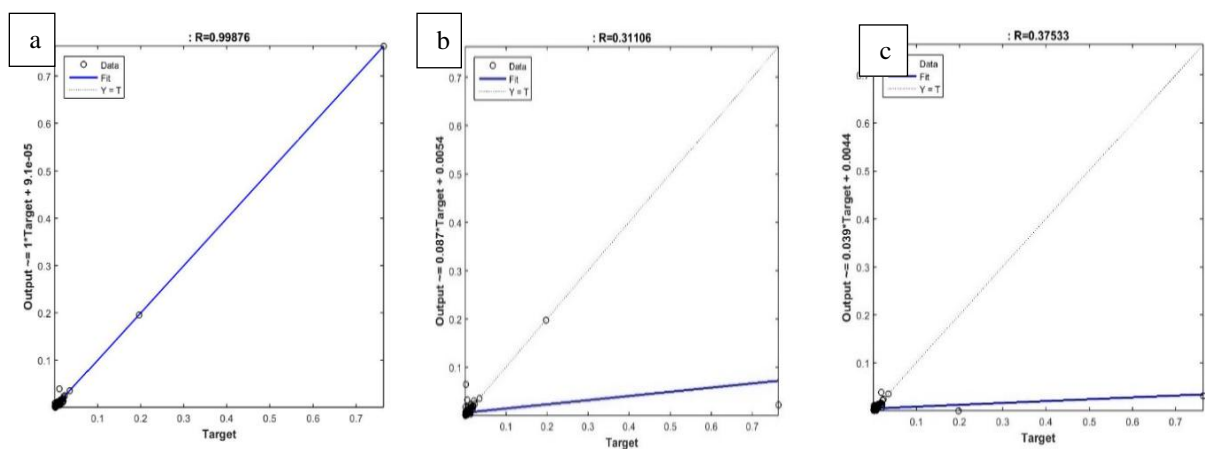


Fig 2 Mean square error for a) model 13-[10]-1 with 10 hidden neuron and LM algorithm, b) model 13-[30]-1 with 30 hidden neuron and LM algorithm, c) model 13-[50]-1 with 50 hidden neuron and LM algorithm,

The regression curve for all the trials are shown in figure 3 which indicates best prediction by ANN with 10 neuron. Figure 4 indicates Training results of ANN with 10 hidden neuron which indicates the best model wear rate prediction. The ANN model is tested with remaining 20% data and the predicted results are compared with experimental results.

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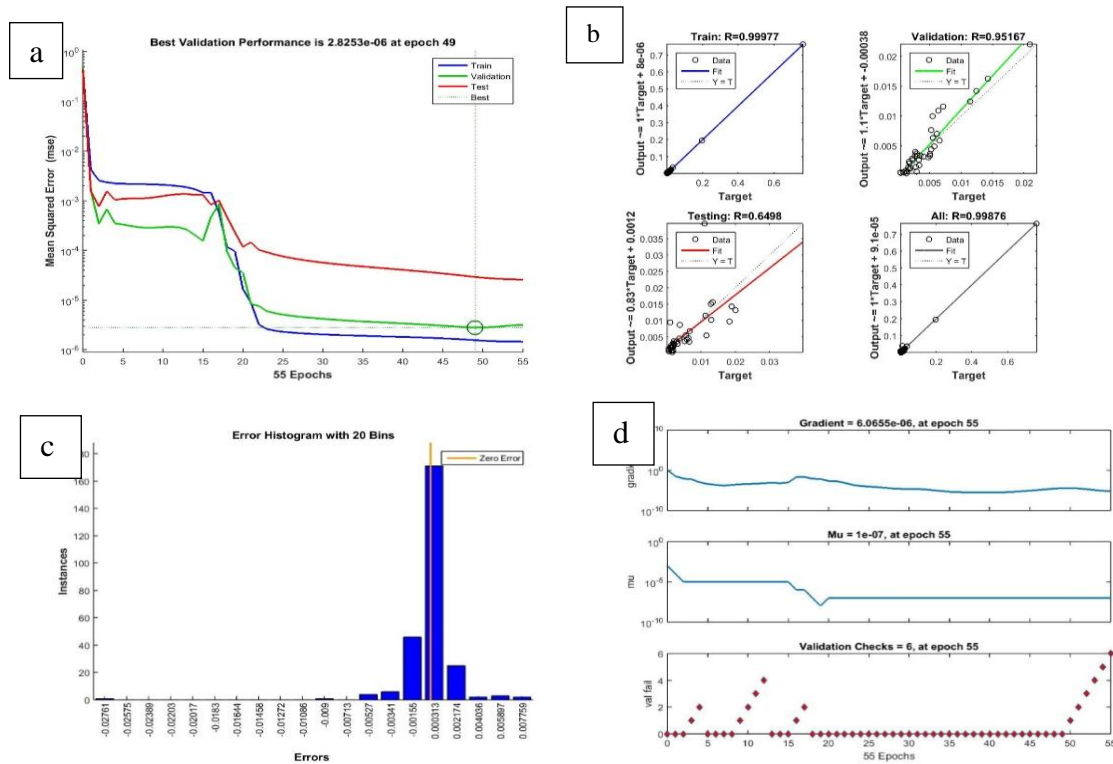


Fig 3 Training results of ANN with 10 hidden Neuron a) Mean Square error plot, b) Histogram of Error, c) Comparison of regression plot of Training, Testing, validation and overall. d) Plot of gradient, mu and val fail.

IV. RESULTS AND DISCUSSION

The developed composites are analysed for reinforcement distribution, interface reactions and bond strength. The figure 4 indicates the uniform dispersion of alumina reinforcement in all the composite developed. The black particles indicate Al_2O_3 particles and the light back ground is Al7075 matrix. Comparing microstructure of the composite and alloy in figure 5a and 5b it is observed that the grain size in alloy is larger compared to grain size of the composite. This is due to grain refinement in composite as it contains the reinforcement particles. The rapid solidification also promotes the strengthening by grain refinement. The stirring process carried out imparts uniform dispersion of the reinforcement in the composite.

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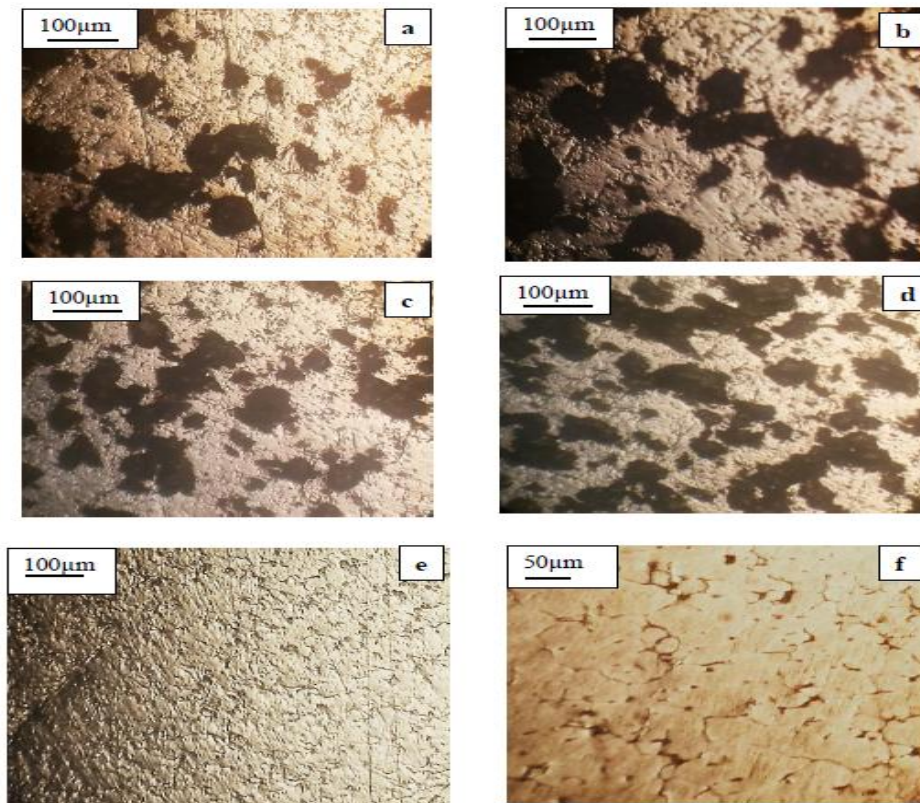


Fig 4 Optical microstructure of as alloy and cast composite material reinforced with a) 5% Al_2O_3 , b) 10% Al_2O_3 , c) 15% Al_2O_3 , d) 20% Al_2O_3 , e) Al 7075 alloy, f) Al 7075 alloy.

The mechanical test is carried out on all the developed composite to evaluate the hardness and strength. The influence of the particles in the matrix has improved the properties of the composite. The hardness has increases for increase in the volume fraction of reinforcement and sue to strengthening mechanism the tensile and compressive stress are increased. The grain refinement and use of metal mold has contributed for enhancement of the tensile strength and the variations of the mechanical properties are shown in figure 5. The 10% alumina reinforced has better tensile strength and as the reinforcement volume friction increases beyond this value due to brittleness of composite and interface reaction reduces the strength.

Wear test carried out at various speed and load on all the specimen developed and the plot of wear rate with volume fraction of reinforcement is shown in figure 6 and 7. The wear rate of the composite increases with increase in load and speed. The wear rate of composite is lower as compared to unreinforced alloy.

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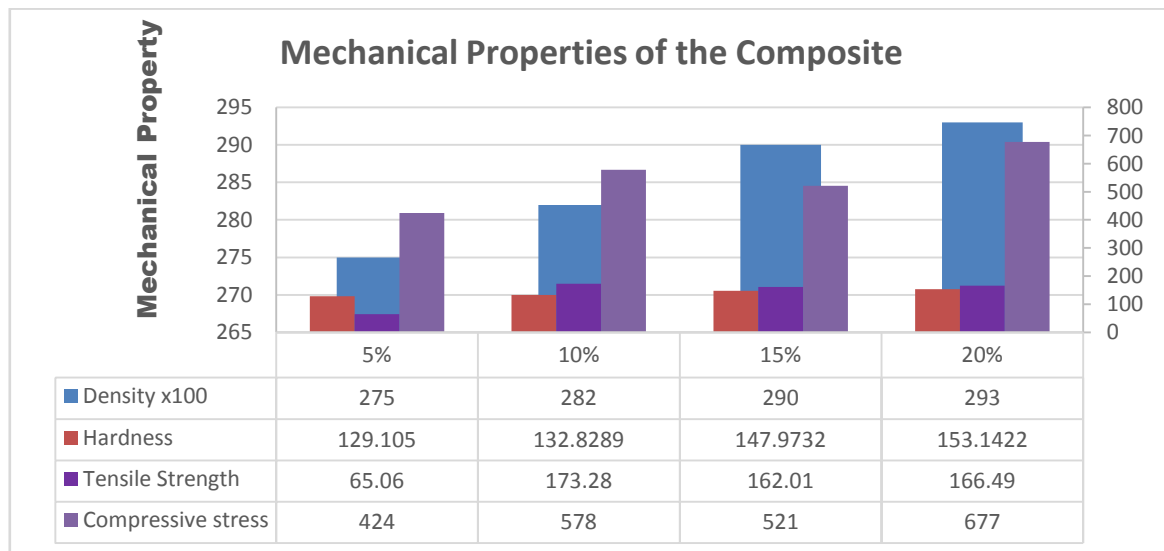


Fig 5 Plots showing variation of mechanical properties of composite

The composite exhibits lower wear rate at low load and low speed as the prevailing mechanism is ultra mild wear. As the speed increases the ultra mild wear will be transformed to mild wear and the wear rate increases. At high load and high speed the severe wear mechanism develops highest wear rate. The wear rate of composite with higher volume fractions is lower than the Al7075 alloy as seen from the figure 6.

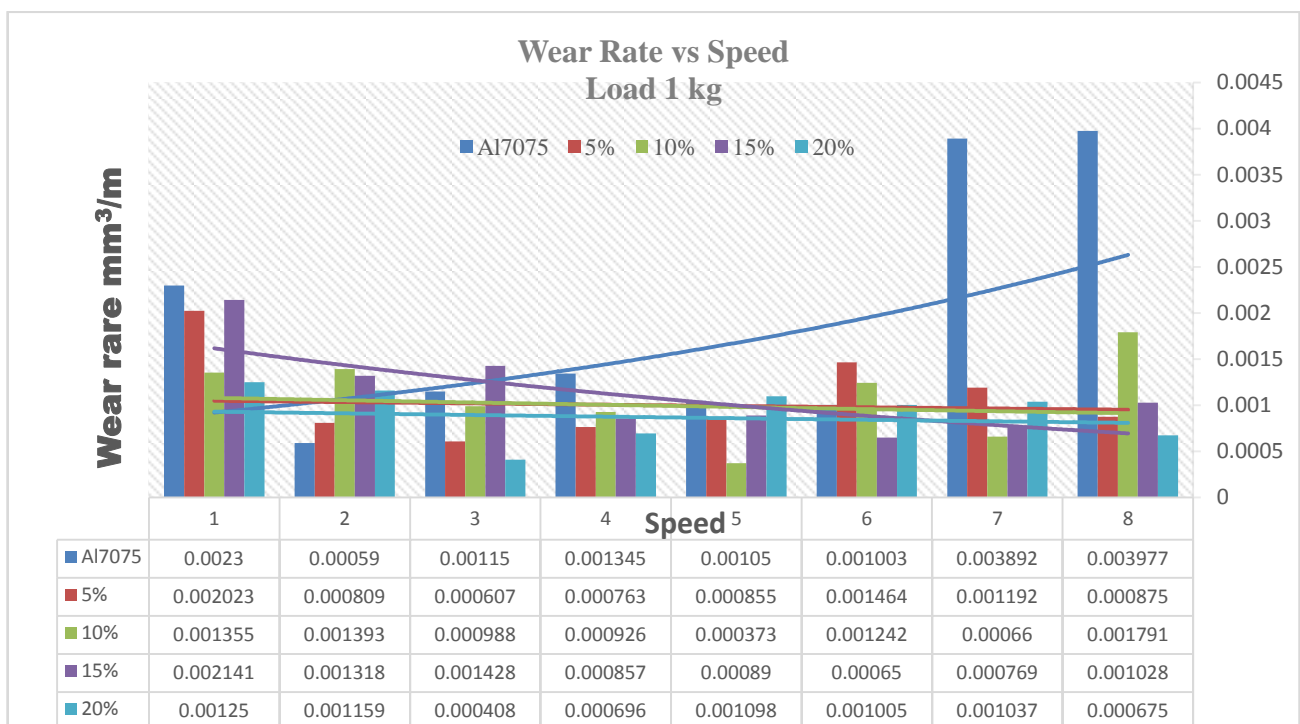


Fig 6 Plots showing variation wear rate with speed at 1 kg load for Al7075 alloy and Al7075/Al₂O₃ composite

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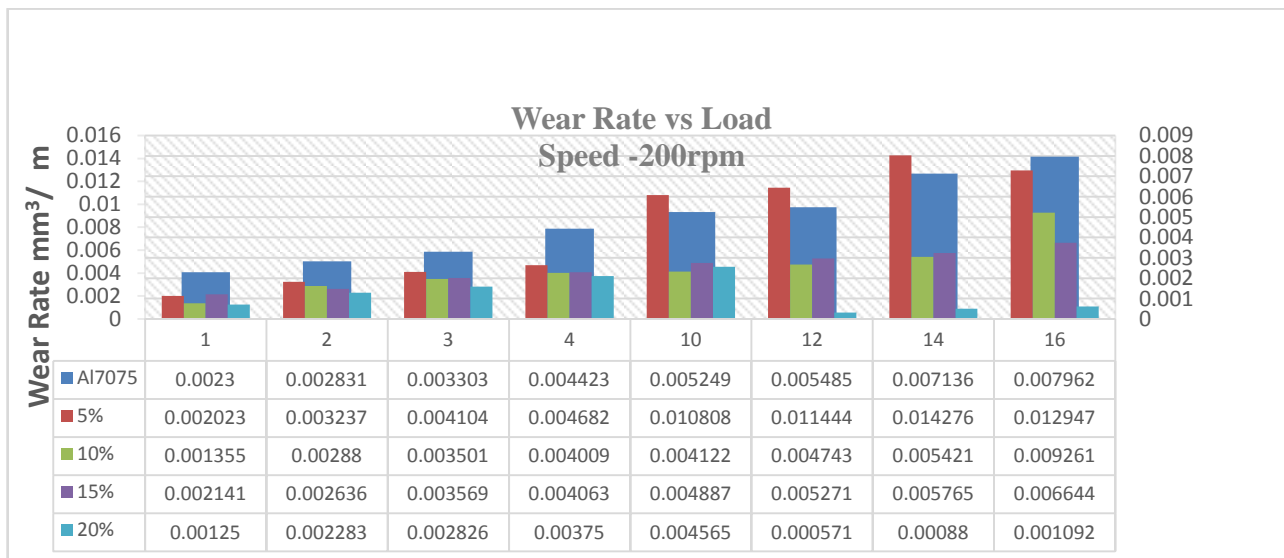


Fig 7 Plots showing variation of wear rate with load at 200 rpm speed for Al7075 alloy and Al7075/Al₂O₃ composite

Artificial Neural Network model developed for predicting wear rate was optimized for 10 neuron which gave satisfactory results for minimum MSE and higher Regression. The wear rate predicted during the training level is compared with the experimental results and it matches. The ANN can predict the wear rate at various speed and load for various volume fraction of reinforcement. Also, it can be used for predicting wear rate outside the training domain.

The predicted values of wear rate for load of 1kg to 25 kg and speed of 100 rpm to 1400 rpm are predicted by developed ANN is shown in figure 8. The higher wear rate starts corresponding to load of 5kg at 1400.

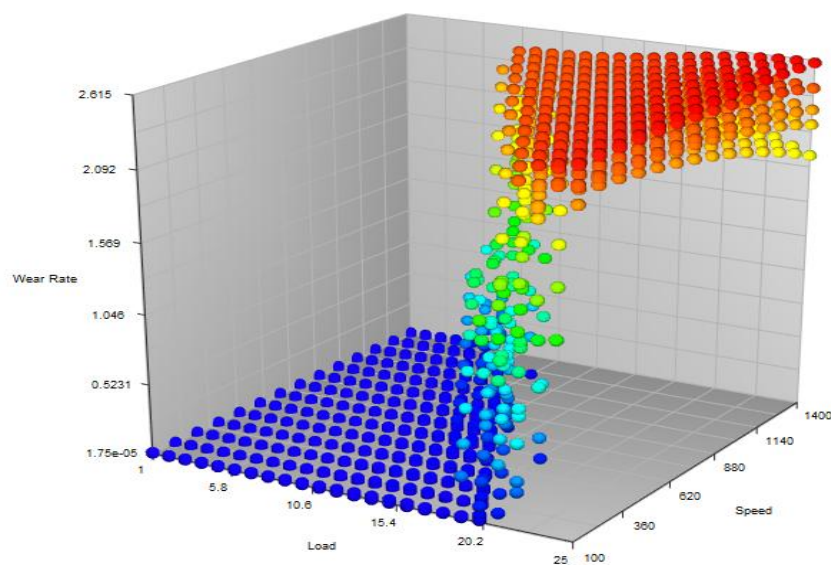


Fig 8 Wear rate vs Speed and Load for all the composite developed with Al7075 alloy

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V. CONCLUSIONS

The present work involved in development of Al7075/Al2O3 Particulate MMC with stir casting process successfully. The uniform distribution of the reinforcement was obtained due to stirring the melt. The grain refinement has induced the strengthening in the composite material.

The wear rate carried out with the pin on disc wear testing machine at various speed and load indicates the increase in wear rate with increase in speed and load. The developed ANN model shows lower MSE and higher Regression value. The optimized ANN model had predicted the wear rate which is in agreement with the experimental values. Feed forward Back propagation neural network with single neural network with 10 hidden neuron can be used to predict the wear behaviour of Particulate MMC at various speed and load.

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