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Investigation of wear behaviour of magnesium reinforced with boron nitride nanocomposite using ANN

The present study aims to study the wear behaviour of Mg reinforced with boron nitride nanocomposite. The dry sliding wear behaviour of Mg reinforced with boron nitride (0.5 wt.%) is reviewed by following ASTM standards G99, i.e., dry sliding on pin-on-disk wear test apparatus. Three wear parameters, namely load, sliding speed, and sliding distance, were considered in this study. The experiments for wear rate have been conducted as per ASTM standards G99. The wear rate obtained for Mg reinforced with boron nitride (0.5 wt.%) is predicted by the ANN toolbox of Matlab R2021a using the Levenberg-Marquardt (trainlm) algorithm, which trains the feed-forward neural network having 3-5-1 (three input neurons, five hidden neurons in the single hidden layer and one output neuron). Experimental data sets obtained from the pin-on-disk wear test have been utilized to develop ANN. The results concluded that the error for wear loss of Mg reinforced with boron nitride (0.5 wt.%) lies within 20%, with an average percentage error of 2.6% between experimental values and ANN predicted values.

Keywords: Mg nanocomposite, wear rate, and (ANN) artificial neural network.

1.0 Introduction

Mg is the lightest metal, making it very useful for the automobile, aerospace, and transportation sectors. Its potential is to dramatically reduce the weight of components that would otherwise be made from aluminum, which is 65% denser than magnesium [1, 2]. The addition of reinforcement to magnesium and its alloys improves its strength and stiffness. In any case, at room temperature these materials have very low flexibility compared to other materials and limit their broad applications [3–5].

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Magnesium will watch out of the overwhelming majority of the problems checked out by enterprises during which the strength to weight proportion is significant, as an example, the car, space, and telecommunication industries. The literature shows that Mg usage is continually increasing and may be expected to still grow within the future [6,7]. Metal matrix composites produced by adding ceramic materials for reinforcement exhibit improved mechanical properties, including structural, wear, and creep properties, among others, and thereby find many applications. An MMC's properties mainly depend upon matrix material, particle size, and materials used to reinforce and manufacture the composite [8]. The main drawbacks of magnesium and its alloys are wear and consumption protections. From all the problems, wear is the most predominant problem in mechanical segments, prompting a lessened lifetime for magnesium-based parts and making magnesium unsuitable for use in bearings, gears, pistons, and cylinders [9–11].

The reinforcement stage in MMC's can be a particle, continuous and tiny fiber. Among these, particle-reinforced MMC's are isotropic and easier to fabricate. Its high damping capability associate degreed stiffness Mg are fortified with an assortment of ceramic particulates, as an example, Al2O3, zinc oxide, TiC, SiC, B4C, TiB2. Among these ceramic particulates, Al2O3 and twitching have emerged as exceptional creative fortifications because of their distinguished mechanical, optical, and electrical properties and intensive type of uses. [12-14].

Magnesium could be a better metal than Al and Ti in terms of its physical properties, as well as process, machining, and exercise properties, which might staggeringly cut back continual prices [17]. Even though friction and wear rate depend upon several factors, like applied load, sliding speed, material type, specimen geometry and surface roughness, it is ascertained with sliding speed and load had a considerable influence on the wear and tear rate [19-22]. Venkatesha, B K et al. [27, 29, 30] studied the mechanical properties of hybrid composites. In light-weight of this distinctive state of affairs, this analysis work aims to check the wear behaviour of Mg reinforced with boron nitride nanocomposite.

2.0 Materials and methods

2.1 Nanocomposite Preparation

The Mg/BN (0.5 wt.%) nanocomposite is synthesized by using the metallurgy technique. The process includes microwave aided two-directional sintering and a hot working process called hot extrusion. After extrusion, the required composite of diameter 8 mm is obtained.

2.2 Method of Testing

Nanocomposite specimens were tested by sliding the samples against an OHNS steel disk with higher surface contact. The sample's weight is measured by an electronic balancing instrument with the least count of 0.0001g. Tests were performed under sliding speeds of 0.6, 0.9, and 1.2m/s at normal weights of 5, 7, and 10N for a sliding separation of 500, 1000, and 1600 m [15, 16, 18].

$$\text{Friction coefficient}\mu = \frac{F}{P} \quad \text{... (1)}$$

Where 'F' is the force due to friction and 'P' is the load acting on pin.

The V_{loss} is determined with the help of a W_{loss} as per the formula given below [16]

$$V_{loss}(mm^3) = \frac{W_{loss}\,(gr)}{\rho\,(\frac{gr}{mm^3})} \quad \text{... (2)}$$

Where V_{loss} is the volume loss, W_{loss} is the weight loss and ρ is the density

The following formula is used to determine the wear loss

$$\text{Wear loss } (mm^3/m)\ \frac{V_{loss}(mm^3)}{\text{Sliding distance (m)}} \quad \text{... (3)}$$

3.0 Experimental procedure

The operational condition under which the wear study of Mg/BN (0.5 wt.%) was carried out is given in Table 1 at room temperature. Three parameters, namely normal load, sliding distance, and sliding speed, were considered in this study.

Table 1: Input variables and their levels

Input variables	Level		
	I	II	III
Load (N)	5	7	10
Sliding speed (m/s)	0.6	0.9	1.2
Sliding distance (m)	500	1000	1600

3.1 Artificial Neural Network (ANN)

ANN is a modelling approach successfully applied in modelling many biological systems [23]. They can deal with multiple independent (input) and dependent (output) variables simultaneously without prior information about their functional relationship. The wear loss of Mg/BN (0.5 wt.%) is predicted by the NN toolbox of Matlab R2021a using a Levenberg-Marquardt (trainlm) algorithm [24-26], which trains the neural network having 3-5-1 (three input neurons, six hidden neurons in the single hidden layer, and one output neuron) shown in Fig.1. Experimental data consisting of 27 datasets has been utilized to develop ANN to understand the correlation between the input and output.

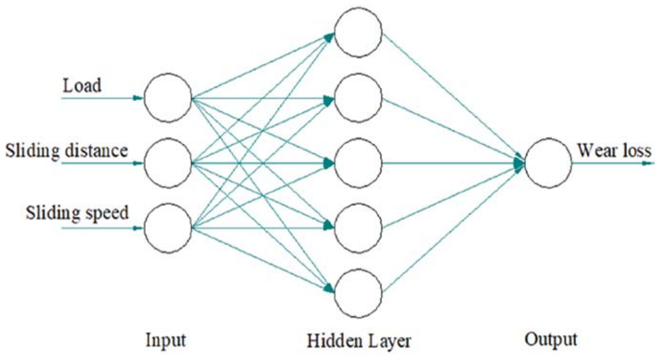

Fig.1: Neural network architecture

4.0 Results and discussions

The experimental wear test results for Mg/BN (0.5 wt.%) nanocomposite were obtained using pin on disc apparatus under various test conditions [28]. The validation of wear loss

Table 2: Test conditions with output results for Mg/BN (0.5 wt.%) nanocomposite using pin on disc apparatus

	Load (N)	Sliding distance (m)	Sliding velocity (m/s)	Wear loss (mm^3/m)
1	5	500	0.6	4.358798
2	5	500	0.9	4.588208
3	5	500	1.2	4.702914
4	5	1000	0.6	5.735260
5	5	1000	0.9	5.792613
6	5	1000	1.2	6.366139
7	5	1600	0.6	6.523859
8	5	1600	0.9	6.631395
9	5	1600	1.2	6.703086
10	7	500	0.6	7.455838
11	7	500	0.9	5.964671
12	7	500	1.2	6.194081
13	7	1000	0.6	8.717596
14	7	1000	0.9	8.086717
15	7	1000	1.2	8.660243
16	7	1600	0.6	9.140571
17	7	1600	0.9	9.248107
18	7	1600	1.2	9.391489
19	10	500	0.6	9.176417
20	10	500	0.9	9.176417
21	10	500	1.2	9.061711
22	10	1000	0.6	10.839642
23	10	1000	0.9	10.896995
24	10	1000	1.2	11.757284
25	10	1600	0.6	11.649748
26	10	1600	0.9	11.900665
27	10	1600	1.2	12.044047

TABLE 3: EXPERIMENTAL TEST DATA AND PREDICTED ANN VALUES FOR WEAR LOSS OF MG/BN(0.5 WT.%).

	Load (N)	Sliding distance (m)	Sliding Velocity (m/s)	Wear loss (mm^3/m)		Error (%)	Absolute error (%)
				Exp.	ANN		
1	5	500	0.6	4.359	4.541	-4.17	4.17
2	5	500	0.9	4.588	4.575	0.29	0.29
3	5	500	1.2	4.703	4.514	4.01	4.01
4	5	1000	0.6	5.735	5.443	5.09	5.09
5	5	1000	0.9	5.793	5.755	0.65	0.65
6	5	1000	1.2	6.366	6.046	5.03	5.03
7	5	1600	0.6	6.524	6.355	2.59	2.59
8	5	1600	0.9	6.631	6.656	-0.37	0.37
9	5	1600	1.2	6.703	6.931	-3.40	3.40
10	7	500	0.6	7.456	6.908	7.35	7.35
11	7	500	0.9	5.965	6.559	-9.97	9.97
12	7	500	1.2	6.194	6.105	1.43	1.43
13	7	1000	0.6	8.718	8.639	0.90	0.90
14	7	1000	0.9	8.087	8.639	-6.82	6.82
15	7	1000	1.2	8.660	8.632	0.32	0.32
16	7	1600	0.6	9.141	9.173	-0.35	0.35
17	7	1600	0.9	9.248	9.320	-0.77	0.77
18	7	1600	1.2	9.391	9.497	-1.13	1.13
19	10	500	0.6	9.176	9.139	0.41	0.41
20	10	500	0.9	9.176	9.141	0.39	0.39
21	10	500	1.2	9.062	9.023	0.42	0.42
22	10	1000	0.6	10.840	11.178	-3.12	3.12
23	10	1000	0.9	10.897	11.164	-2.45	2.45
24	10	1000	1.2	11.757	11.151	5.16	5.16
25	10	1600	0.6	11.650	11.990	-2.92	2.92
26	10	1600	0.9	11.901	11.989	-0.74	0.74
27	10	1600	1.2	12.044	11.985	0.49	0.49

was done by using the neural network tool in Matlab R2021a. According to experimentation, the wear test results of Mg/BN (0.5 wt.%) nanocomposite are given in Table 2.

Experimental data consists of 27 datasets that are utilized to develop ANN to understand the correlation between input and output. The test and predicted values of wear loss for Mg/BN (0.5 wt.%) are depicted in Table 3. It must be noted that 60% of the experimental data was used for training the neural network model, and around 20% is used for validation and testing purposes [17]. The predicted ANN values and the experimental values of wear loss are compared, and the percentage error between them is calculated using Eq.4.

$$\% \text{ Error} = = \left[\frac{W_{Loss}(Exp) - W_{Loss}(ANN)}{W_{Loss}(Exp)}\right] x\ 100 \qquad \text{... (4)}$$

Where W_{Loss} (Exp) = Experimental value of Wear loss, W_{Loss} (ANN) = ANN predicted value of Wear loss.

The error for wear loss of Mg/BN (0.5 wt.%) lies within 10% with an average error of 2.62% between experimental data and neural network prediction. Hence, we can conclude that neural network prediction has proceeded correctly. A regression plot is plotted between the network output, and the target is shown in Fig.2. The tracking of output values with the targets values holds good for the correlation coefficient (R^2-value) 0.99335. Also, it shows a better match with the experimental data. A performance plot showing the training, validation, and test errors are shown in Fig.3. At iteration nine, best validation performance occurs with a mean squared error value of 0.047771. After the 9th iteration, the test set error and the validation set error will have similar characteristics, and there will be no over-fitting occurrence. Therefore, validation stops at the 15th iteration.

5.0 Conclusions

In the present work, analyzing wear properties of Mg/BN (0.5 wt%) have been analyzed using ANN. The wear test was conducted using pin-on-disc apparatus and determined experimental results for wear loss. Load, sliding distance, and sliding velocity were selected as input parameters. The comparison between experimental results and ANN results shows a good agreement having a correlation coefficient of R^2=0.99335. The prediction of wear loss using ANN was

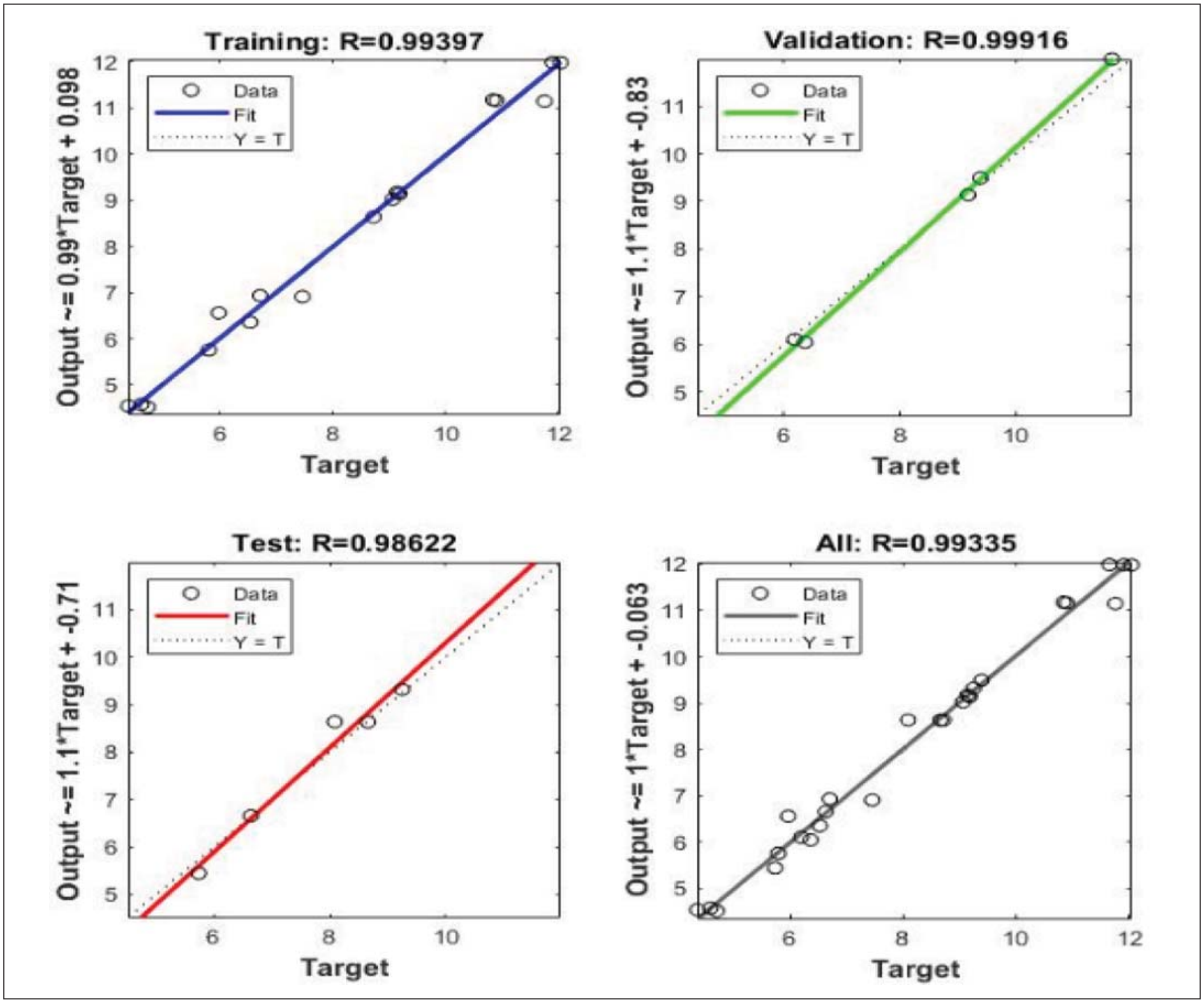

Fig.2: Regression plot using LM algorithm for wear test results of Mg/BN (0.5 wt.%)

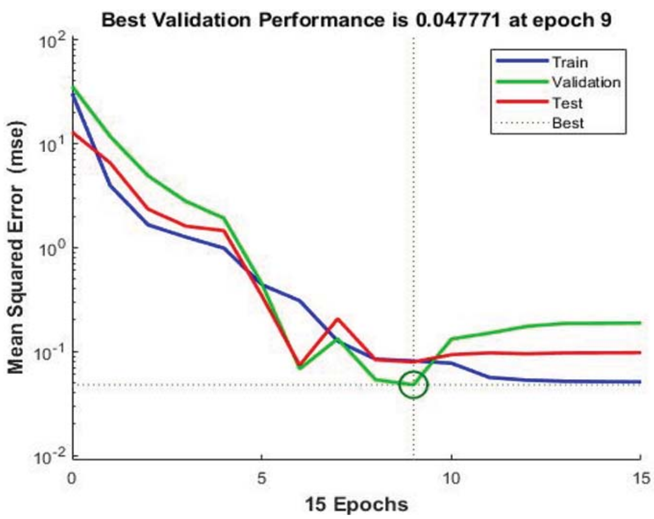

Fig.3: Performance plot using LM algorithm for Mg/BN (0.5 wt.%)

validated, and the accuracy of a result obtained was within 10% with an average error of 2.62%. Also, iteration 9 proved to be the best validation performance for wear loss, as it had a mean squared error value of 0.047771.

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