

A Neural Network Model for the Compressive Strength of a Hybrid LM6 Aluminium Alloy Composite

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ABSTRACT--- Adding more than one reinforcement increases the flexibility in composites. The objective of the work is to develop a model to predict the compressive strength in an LM6 aluminium alloy reinforced with SiC and flyash particles. Central composite rotatable design had been employed to carry out the experiments with size and composition of the reinforcements as the parameters. ANN model developed has good prediction accuracy with error being less than 5%.

Keywords—LM6 aluminium alloy, SiC, flyash, Compressive strength, ANN

I. INTRODUCTION

Metal matrix composites (MMC) due to their tailorability, have enabled the development of high strength to weight ratio materials possessing improved mechanical and thermal properties over conventional materials [1][2]. Aluminium, abundantly available and having very high strength to weight ratio is the widely used matrix material. SiC possessing good strength, excellent resistance to wear and corrosion has been the primary material used as reinforcement [3] in composites. Flyash, the waste material has been used primarily as a filler material in paints and polymers. Researchers have incorporated flyash particles in metal alloys to reduce density. They have observed reduced wear, improved modulus in the resulting composites [4].

Composites can be made more amenable to application requirement by adding more than one reinforcement. Various researches have been conducted to study the behavior of hybrid composites [5][6][7][8]. Particle reinforcements exhibit isotropy; possess good stiffness and commendable manufacturability besides being inexpensive [9]. The size of particles [10] impacts the behavior of composites. The properties of composites are influenced by the content of reinforcements [11].

Various techniques have been adopted to model the influence of parameters in physical phenomena. Factorial design of experiments [12] has been applied to predict the behavior of composites. Basavarajappa et al. applied Taguchi techniques [13] to study the dry sliding wear behavior of metal matrix composites. Artificial Neural Network models have been developed to predict the

behavior of composite materials under various loads [14][15].

SiC and flyash particles have been dispersed in LM6, aluminium silicon alloy, a highly corrosion resistant casting alloy. The corrosion resistance of the alloy is very good even in marine environments. An attempt has been made to develop a neural network model for the compressive strength of composite in terms of the size and weight of the reinforcement particles.

Nomenclature

σ_c – Compressive strength in MPa
 F_s – Flyash size in microns
 S_s – SiCsize in microns
 F – Weight of flyash as % of LM6
 S – Weight of SiC as % of LM6

II. EXPERIMENTAL

Flyash from Raichur power plant, India provided by ACC Cements Coimbatore, India, has been used in the study. The composition of flyash is presented in Table I. The reinforcement particles were sieved in different size ranges. Each of the reinforcement was considered for different size ranges to ensure distinctiveness in their role. The parameter levels were determined from trial runs. The maximum weight was constrained to 10% to ensure proper synthesizing of composites. The parameters and their limits determined from (1) are presented in Table II.

TABLE I. CHEMICAL COMPOSITION OF FLYASH

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	K ₂ O	CaO	MgO	Na ₂ O	SO ₃	LI*
62.8	28.2	4.17	1.9	0.89	0.84	0.38	0.26	0.01	0.53

* Loss on ignition

Central composite rotatable design for experimentation with four factors and five levels has been considered in arriving at the combination of parameters. All the star and factorial points of the 31 experiment design have been considered for the network. Only one centre point has been considered to ensure proper training of the network.

$$Z_i = \frac{2[2Z - (Z_{max} - Z_{min})]}{(Z_{max} - Z_{min})} \quad (1)$$

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TABLE II.LEVELS AND LIMITS OF PARAMETERS

Parameter	Parameter Levels				
	-2	-1	0	+1	+2
F_s	0-40	40-106	106-150	150-180	180-250
S_s	0-25	25-40	40-63	63-90	90-106
F	2	4	6	8	10
S	2	4	6	8	10



Fig. 1.Compressive fractured specimens

Hybrid composites were fabricated using the cost effective stir casting method [16]. SiC and flyash were heated and dispersed into molten aluminium alloy. Reinforcements are added and stirred when the temperature of the aluminium alloy reached 720°C. Magnesium has been added to improve wetting of the reinforcements [17]. Molten composite has been solidified in preheated metallic dies. Specimens with the combination of parameters as given by the design process have been cast.

Compression testing had been carried out on 10 mm square specimens. The responses of the testing along with the combinations of parameters are presented in Table III. The specimens fractured by compression testing are shown in Fig.1.

TABLE III.DESIGN AND RESPONSES

Exp	F_s	S_s	F	S	σ_c
1	-1	-1	-1	-1	386
2	+1	-1	-1	-1	324
3	-1	+1	-1	-1	345
4	+1	+1	-1	-1	335
5	-1	-1	+1	-1	331
6	+1	-1	+1	-1	314
7	-1	+1	+1	-1	319
8	+1	+1	+1	-1	355
9	-1	-1	-1	+1	317
10	+1	-1	-1	+1	306
11	-1	+1	-1	+1	326
12	+1	+1	-1	+1	324
13	-1	-1	+1	+1	329
14	+1	-1	+1	+1	321
15	-1	+1	+1	+1	384
16	+1	+1	+1	+1	367
17	-2	0	0	0	312
18	+2	0	0	0	354
19	0	-2	0	0	327
20	0	+2	0	0	318
21	0	0	-2	0	354
22	0	0	+2	0	339
23	0	0	0	-2	382
24	0	0	0	+2	364
25	0	0	0	0	366

Neural network toolbar of MATLAB has been used in developing the model. Normalization of input and output data from 0.1 to 0.9 to support training and testing has been done using (2). Feedforward back propagation network has been developed, with training being carried out with Levenberg-Marquardt algorithm, providing fastest convergence [18].

$$X_{norm} = 0.1 + 0.8 \left(\frac{X - X_{min}}{X_{max} - X_{min}} \right) \tag{2}$$

where X_{norm} - Normalized value
 X - Value to be normalized
 X_{min} - Minimum value
 X_{max} - Maximum value

III. RESULTS AND DISCUSSION

A neural network with 5 neurons in the single hidden layer has been developed to predict the compressive strength of the composite. The very low mean square error value of 0.000218761 indicates very good accuracy of the model.

Simulink toolbar of MATLAB has been enabled to build a model to test the developed neural network. Comparison of actual values with predicted ones for testing and training are presented in the form of scatter plots in Fig. 2 and Fig. 3 respectively. The correlation coefficient (R^2) during training and testing stages are 0.9991 and 0.9864 respectively. The closeness of values to 1 indicates the integrity of learning and testing [19]. The application of systematic concept of design of experiments has been a key factor in the accuracy of the model.

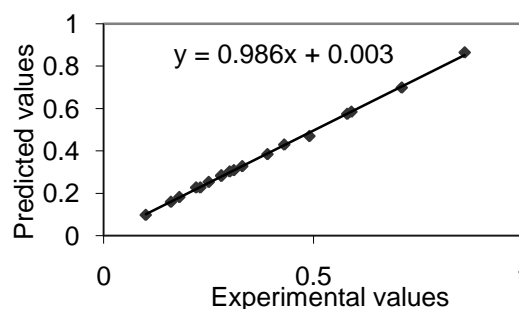


Fig. 2.Scatter plot for the training stage of compressive strength



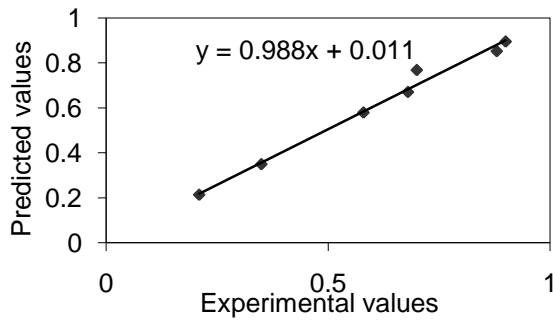


Fig. 3. Scatter plot for the training stage of compressive strength

IV. CONCLUSION

LM6 aluminium alloy composites reinforced with SiC and flyash have been synthesised using the stir casting. ANN model to predict the compressive strength of the hybrid composite in terms of the content and size of the reinforcements has been developed. The ANN model prediction was accurate with the maximum error in prediction being about 2% within the selected domain.

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