Theoretical and Experimental Investigations of Mechanical Properties of Aluminum based Metal Matrix Composite

Dr . Selvi.S[a] Dr. Rajasekar.E[b] Sathishkumar.M[c,] Ramkumar. B[c]

[a] Faculty of Mechanical Engineering, Institute of Road and Transport Technology, Erode, TamilNadu, India.
[b] Faculty of Automobile Engineering, Institute of Road and Transport Technology, Erode, TamilNadu, India.
[c] Final year Mechanical Engineering, Institute of Road and Transport Technology, Erode, TamilNadu, India.

***Abstract*—In this research work, properties such as wear rate, hardness of the Aluminum-fly ash composite synthesized by stir casting were investigated by varying the weight % 5 and 10 of fly ash with constant zinc and magnesium metal powders. An attempt was made to develop a mathematical model leads to weight loss of Al MMC composites and the adequacy of the model was verified using analysis of ANOVA. Scanning electron microscopy was used for microstructure analysis. There was a uniform distribution of fly ash and also existing bonding between matrix and fly ash. Energy - dispersive X-ray spectroscopy [EDAX], is used for the elemental analysis or chemical characterization of a sample. The results show that addition of fly ash to Aluminum metal matrix improved the both mechanical and tribological properties of the composite. The fly ash particles improve the wear resistance of the Al MMC. The hardness of the Al MMC composites increases as the fly ash content increases.**

***Keywords - Metal Matrix Composites (MMC)s; Fly ash; Stir Casting; Dry sliding wear; Mathematical modeling; SEM* and EDAX**

I. INTRODUCTION

In the past three decades, the usage of aluminum – fly ash has greatly increased because of the easy availability of fly ash. It is therefore expected that the addition of fly ash in pure aluminum will greatly promote another use of thin low cost waste by-product and reduction in the cost of aluminum. Al MMC composites have shown improved mechanical properties such as high strength, stiffness and hardness, better wear resistance and good elevated temperature properties when compared to the unreinforced matrix alloy [1].

II. MATERIALS AND METHODS

The metal matrix used in this investigation is commercial aluminum with a purity of 99.5% and the reinforcement material is fly ash particulates. 500 gm of fly ash was taken and preheated in the muffle furnace at about 750˚ C for 3 hours and the loss of ignition was found to be 2.23% and then it was cooled to atmospheric temperature. The chemical composition of the fly ash was determined using spectrocast spectrometer and it is given in Table 1.

TABLE1 : CHEMICAL COMPOSITION OF FLY ASH (WT %)

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	Loss on Ignition
59.04	30.02	8.75	2.46	1.0	1.01	0.99	1.89	2.23

III. SYNTHESIS OF AL METAL MATRIX COMPOSITE

Synthesis of Al MMC composites (Al with fly ash of 5 & 10) wt %, 0.5% Mg and 0.1% Zn) was carried out by stir casting technique. Initially, the furnace temperature was maintained at 725°C while melting the aluminum. With progressive melting, the temperature was raised to 800˚C the 0.5% Magnesium chips and 0.1% of zinc powders were added to the molten metal and it was held at this temperature for 15 minutes. A vortex motion was created using a graphite stirrer. When the stirring was continued, the fly ash particulates, zinc and magnesium were introduced at a uniform rate. The molten aluminum was stirred at 250 rpm by using argon as shielding gas and stirring was continued for 20 minutes after the addition of fly ash in order to get a thorough mixing and uniform distribution of it in the molten metal [1].

IV. DEVELOPMENT OF MATHEMATICAL MODELING

The Erosion rate of the fabricated composite is a function of composition, time, and solution of wet slurry content [2], which can be expressed as:

$$E.R = f\,(c, t, s) \qquad (1)$$

TABLE2 EROSION PARAMETERS AND THEIR LEVELS

Parameters	Notations	Unit	Levels		
			-1	0	1
Composition	c	%	0	5	10
Time	t	Sec	8	16	24
Solution	s	---	Neutral	Base	Acidic

The second order polynomial regression equation used to represent the response surface ‘Y’ for k factors is given by

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$$Y = b_0 + \sum_{i=1}^{k} biXi + \sum_{i=1}^{k} biiXi^2 + \sum_{i=1}^{k} bij\ Xi\ Xj \quad (2)$$

b_0= Constant,
b_i=linear term coefficient,
b_{ii}= qudratic term coefficiecnt,
b_{ij}= interaction term coefficient

where b_0 is the average of responses, and b_i, b_{ii} and b_{ij} are the coefficients which depend on the respective main and interaction effects of the parameters.

TABLE3 DESIGN MATRIX

Trail run	Erosion rate parameters			Erosion rate $*10^2$ gm/m^3
	c	*t*	*s*	
1	-1	-1	0	202
2	1	-1	0	119.2
3	-1	1	0	309
4	1	1	0	340
5	-1	0	-1	138.6
6	1	0	-1	116.1
7	-1	0	1	380
8	1	0	1	351.8
9	0	-1	-1	110
10	0	1	-1	210
11	0	-1	1	274.06
12	0	1	1	470
13	0	0	0	240
14	0	0	0	240
15	0	0	0	240

$$W=b_0+b_1c+b_2t+b_3s+b_{11}c^2+b_{22}t^2+b_{33}s^2+ b_{12}ct+b_{13}cs+b_{23}ts \quad (3)$$

The coefficients were calculated using the software SYSTAT 13. The mathematical model was developed after determining the coefficients. All the coefficients were tested for their significance at 95% confidence level. The in significant coefficients were eliminated without affecting the accuracy of the mathematical model using t-test. The developed final mathematical model is given as:

$$E.R = 240-13.87c+70.37t+118s+25.75ct \quad (4)$$

The adequacy of the developed mathematical model was tested using the analysis of variance (ANOVA) technique which is presented in Table 4. The calculated values of F-ratio are greater than the tabulated values at 95% confidence level, which means the developed mathematical model is considered to be adequate. The model has a higher r^2 value of 0.984.The scatter diagram of the developed mathematical model was shown below. The experimental values and predicted values from the mathematical model are scattered both sides and close to 45^o line, which further proves the adequacy of the model.

V. TABLE 4 ANALYSIS OF VARIANCE

Source	Df	Type I SS	Mean Squares	F-Ratio	p-Value
Regression	7	4,995,040.483	713,577.212	6.525	0.012
Residual Error	3	3,640,976.250	1,213,658.750	11.337	0.004

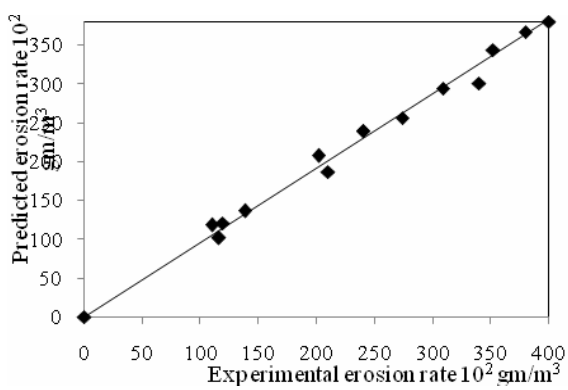


Fig. 1. Scatter Diagram for Erosion rate

III. CHARACTERIZATION OF AL MMC

A. *Hardness test*

The hardness of pure aluminum and composites were determined using Rockwell hardness testing machine.

Fig. 2. Hardness test sample

The test was conducted on each specimen with 100 kg load and a 1.587 mm steel ball intender. The detention time for the hardness measurement was 20 seconds.

B. Dry Sliding Wear test

To analyze the tribological properties of AL MMC composites, DUCOM pin-on-disc sliding wear testing machine was used. The dry sliding wear tests were conducted as per ASTM G99-04 standards. The pin was properly cleaned with acetone and the initial mass was measured and then it was pressed against the rotating chromium disc during the test [3].

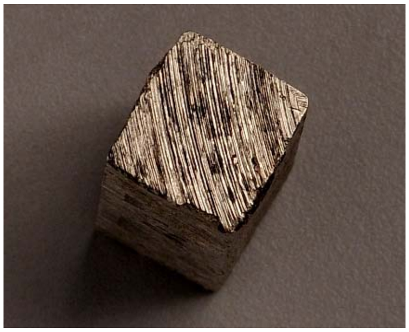


Fig. 3.Wear test Samples

Fig. 4. Wear test Samples

The test was carried out by varying the applied normal load for a constant sliding speed of 300 rpm and sliding distance of 3000 m. At the end of each test, after cleaning the pin, the final mass and the loss mass of the pin were determined. Then the volume loss due to dry sliding wear was calculated for each test .The wear rate of the composite was then calculated as the ratio between the volume loss to the sliding distance.

C. Wet erosion test

Erosion is the process by which materials are removed from the surface and transported to another location. It works by hydraulic or Aeolian actions and transport of solids (sediment, soil, rock and other particles) in the natural environment, and leads to the deposition of these materials. It usually occurs due to transport by wind, water, or ice; by down-slope creep of soil and other material under the force of gravity; or by living organisms, such as burrowing animals, in the case of bio erosion.

Fig. 5. Wet erosion test setup

Fig. 6. Samples used for testing

Excessive erosion, however, causes serious problems, such as receiving water sedimentation, ecosystem damage and outright loss of soil. Erosion is distinguished from weathering, which is the process of chemical or physical breakdown of the minerals in the rocks.

1) Wet slurry preparation and test

SiO_2 (Silicon dioxide) has been used as the erosive media and the particle size of SiO_2 is 40-150 mesh size. The wet slurry was prepared by mixing 82.5 gm of SiO2 in 200 ml distilled water and it is thoroughly mixed. Then it is filled in slurry jar as shown in Fig. 5 then three samples were fitted in the stand in fig. 6.Then the speed of the motor was set 500 rpm and 800 rpm and it was run for 24 hours. After every 6 hours the weight loss was measured by using digital weighing balance. It is observed that as the time increases the weight loss due to erosion increased for both Aluminum as well as ALMMC composites. However the weight loss was minimum for the ALMMC composites. The presence of more silica in the composite as given higher erosive resistance. [9]

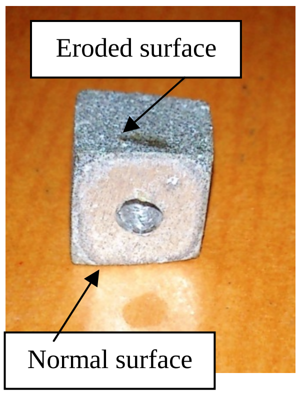


Fig. 7. Samples used for testing

VI. Results And Discussion

A. Hardness test

Fig.8 shows the increasing trend in hardness of the pure Al and Al MMC in as cast condition. This hardness observed was 27 HRc for pure Al and 33.5 and 40 HRc for 5 to 10% Al MMC. As the amount of fly ash increased, the hardness of the composite increased [6]. This could be due to the presence of silica and alumina which are hard in nature in the fly ash [7].

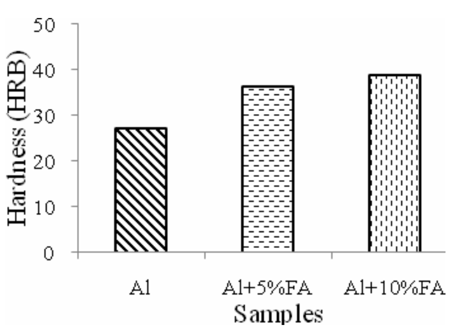


Fig.8 Effect of fly ash on hardness

B. Dry Sliding Wear test

The dry sliding wear tests conducted on the five samples revealed that the load was one of the dominant parameters influencing the wear rate of the composites.

It is observed that, as the applied normal load increased, the wear rate increased. The predominant factor for this behavior was found to be adhesive wear. The wear rate for three applied normal loads of 5 kg at speed of 400 rpm are shown in Fig 9, Similarly the wear rate was plotted for a time period of 1800 seconds for two loads of 5 kg at a constant speed of 400 rpm is given in Fig 10.

However, it is also observed that the wear rate decreased as fly ash content increased, because of the high percentage of silica and alumina. Silica and alumina are basically hard and the increase in weight % of fly ash increases the quantity of these two hard elements which results in the reduction in the wear loss during the dry sliding wear process [5].

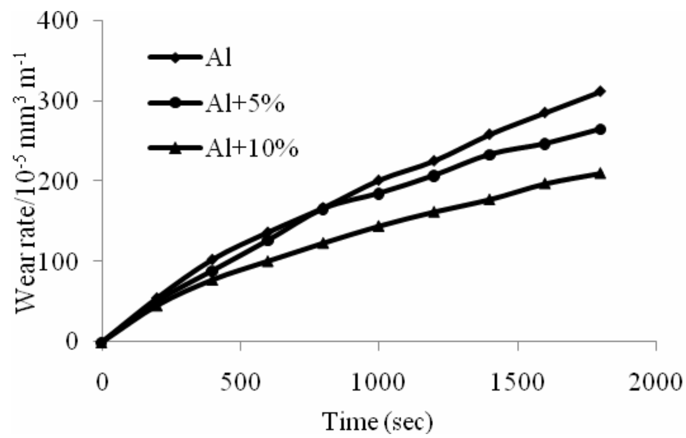


Fig 9. Time Vs Wear rate (rpm = 400 & Load = 5 Kg)

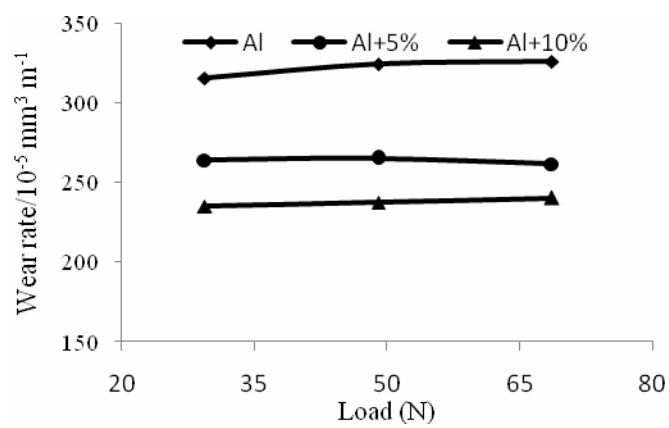


Fig.10 Load Vs Wear rate (rpm = 400 & Time = 1500 sec)

C. Microstructure & EDAX of Al Metal Matrix Composite

The cut samples were mechanically grounded by initial rough grinding using SiC impregnated emery paper of grit size 200-300 and fine grinding with a paper of grit size 600-700. Then the grinded samples were polished by 1µm aluminum powder. SEM was used to evaluate the morphological changes occurred in the composites.

In order to confirm the results related to the interactions between the Al matrix and fly ash particles, EDAX was used. EDAX spectra indicate the clusters consisting of a mixture of both alloy and the fly ash. Scanning electron microscope (Make: Jeol,Model: JSM 6390, Japan) [8]

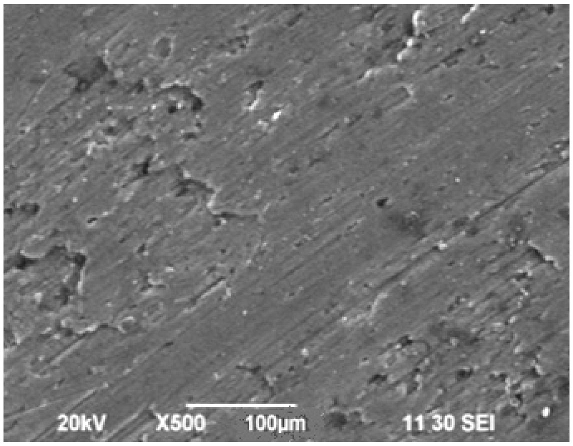


Fig 11 (a)

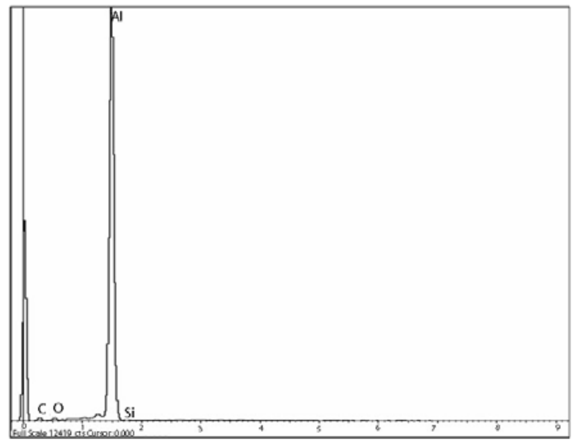


Fig 11 (b)

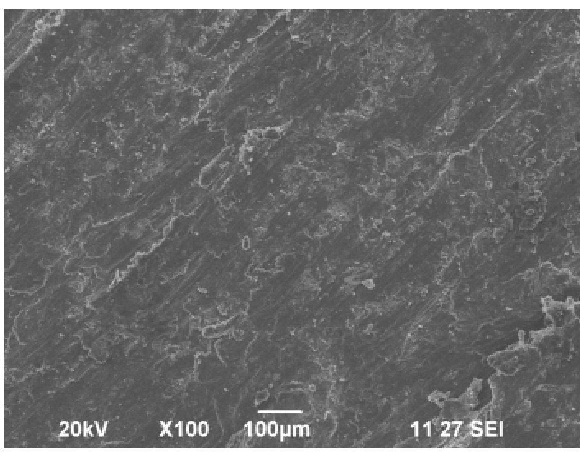


Fig 12 (a)

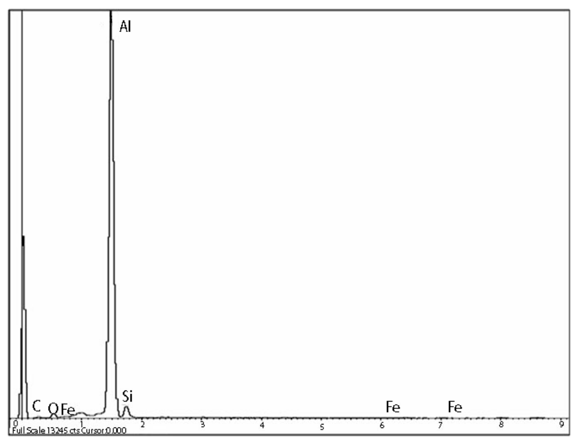


Fig 12 (b)

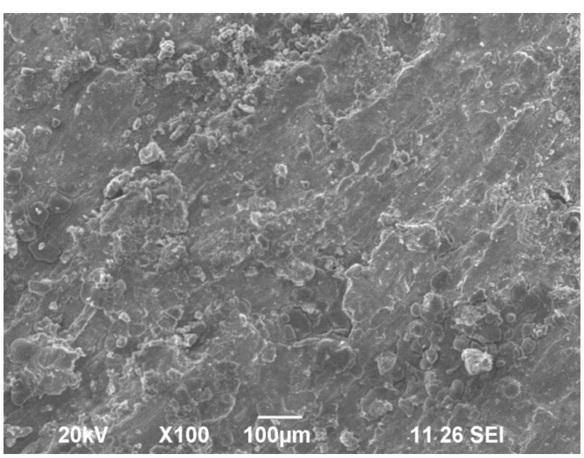
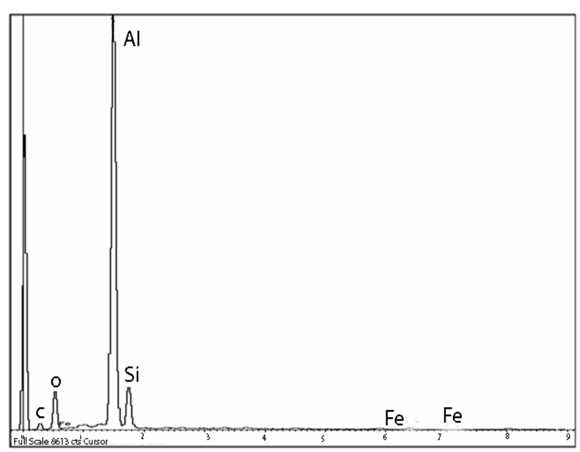


Fig 13 (a)



. Fig 13 (b)

Fig 11(a) 11(b), Fig 12(a) 12(b), Fig 13(a) 13(b) SEM Micrograph & EDAX analysis of Al Metal Matrix Composites

VII. Conclusion

- A mathematical model was developed to predict the weight loss of Al MMC .
- The hardness of the AL MMC composites increases as the fly ash content increases. For pure aluminum the hardness is 27 HR_c and the hardness of Al with 10% fly ash content is above 40% HR_c in the as cast condition as shown in Fig.8
- The presence of SiO_2 in fly ash increase wear resistance of Al MMC and that changes of wear rates are observed in the sliding wear test as shown in Fig.9 & 10
- It is observed that as the time increases the weight loss due to erosion increased for both Aluminum as well as ALMMC composites. However, the weight loss was minimum for the AL MMC composites.
- SEM - microstructure of composites reveals the uniform distribution of fly ash particulates in the metal matrix.
- In order to confirm the results related to the interactions between the Al matrix and fly ash particles, EDAX was used. The results of EDAX analysis are shown in Figures 11(b), 12(b), 13(b). EDAX spectra indicate the clusters consisting of a mixture of both alloy and the fly ash.

VIII. References

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AUTHORS PROFILE

Dr. S. SELVI, working as Associate Professor with the teaching experience of 27 years in the Department of Mechanical Engineering, IRTT, Erode. Published articles in both International and National Journals.

Dr.E. RAJASEKAR working as Associate Professor with the teaching experience of 27 years in the Department of Automobile Engineering, IRTT, Erode. Published articles in both International and National Journals.

Sathishkumar.M and Ramkumar B are pursuing their final year in Mechanical Engineering and doing their research work in Aluminum Metal Matrix Composites and awarded with THIRD Prize for their work in Al-MMC by Indian Institute of Technology, Kharaghpur.