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Experimental Analysis of Erosive Behavior on Al-SiC$_P$ BasedMMC Using Micro Particle (Al_2O_3) as Erodent

A K Matta[1], N Tamiloli[2],PSPrema Kumar[3], SMohanty[4] and SS Pattnaik[5]

[123]Dept. Of Mech &FED, KLEF, Vaddeswaram, Guntur Dst, A.P-522502, India.

[4]Veer surendrasai University of Technology, burla, India.

[5]MEMS, Orissa, India.

anilkumarmatta7@gmail.com, anilkumarmatta@kluniversity.in

Abstract. The Effectiveness of the erosion process mainly depends on different properties of the erodent as well as the process parameters. The process parameters such as the impingement angle, Eroded velocity and erodent size have the significant effect on the productivity of the erosion mechanism. To investigate properly on aluminium-based metal matrix composite the erodent chosen was micro Al_2O_3. A Taguchi based design of experiment was conducted and the effect of the response parameters such as the erosion rate and Signal to Noise ratio (S/N ratio) were studied. It was observed that erosive behaviour of the surface and the mechanisms of material removal mainly depend on the shape and size of the crater formed by the erodent particles which are subjected to variation in shape, velocity & impact angle. Therefore, SEM Analysis was done to find out the surface characteristics and also developed mathematical model for output responses was examined by Analysis of variance (ANOVA) to investigate the suitability of the model. Finally, the cause and effect analyses of various eroded surface characteristics were studied in detail to find out the optimal parameter settings.

1. Introduction

Aluminium based MMC as a high strength, lightweight composite plays a leading role in technical components manufacturing with high degree of surface finish, negligible heat affected zones, no residual stress, less cutting force and the high flexibility in terms of machining as the primary requirements which in turn leads to the development of micro abrasive air jet machining process However, it is much more important in designing hydraulic and aerodynamic structure that subjected to severe erosion in their operation[1][2][3][4][5].Therefore, there is a strong necessity for erosion test of these materials under different operating conditions. The material removal mechanism of this process is mainly two types based on the nature and properties of the material surface i.e. ductile or brittle. For ductile materials, the material removed from the surface is mainly due to micro cutting action which followed by plastic deformation and microchip formation. But in contrast to the brittle material the mechanism of material removal follows the simultaneous crack formation and intersection of a number of cracks on some concentrated regions which contributes the material removal [6][7][8][9].So, the efficiency of the process depends on optimal process parameter which in turn leads to the examination of the erosive behaviour of composite surface. For experimental purpose Al-6061 based MMC was manufactured by stir casting process and homogeneity of this casting product mainly depend on the process characteristics of the stir casting method [10] [11].

Theengineering properties of this casting MMC were measured through various measurement processes. It was found properties are lying within specified range as previously explained by various authors [12] [13]. The mechanical property of the composite mainly depends on the combining properties of matrix phase and the reinforcement particle. The function of the matrix phase is to transfer the stress throughout the composite; on the other hand, the reinforcement phase increases the strength and stiffness characteristics of the composite [14]. A rigorous study of scientific papers on erosive analysis was incorporated which contributes some important outlines about preparation of MMC by stir casting method and erosive behaviour of this material at different operating conditions. The material properties of erodent and MMC, size of erodent, velocity of erodent and impingement angle variation were studied by various researchers. The erosion criterion for Polyphylene Sulphide composite was experimented by Sari [15]. Later he came out with a conclusion that if the erodent is aluminium oxide and silica sand then the mechanism of erosive wear initiated firstly by matrix phase then the fracture is taking place towards reinforced fibre. He also gave the idea that for impingement angle of 45^0 for silica and 30^0 for aluminium and glass bead as erodent particle the peak erosion effect occurred. Similarly Impact and erosion for the ductile and brittle material are explained by previous researchers that material removal mainly follows the formation of crack and its propagation in the material. It was clearly explained that at the time of indentation of erodent the radial crack leads to the deformation of the material and movement of the crack but as the particle is getting out from the indentation zone the lateral crack being generated which actually contributes towards material removal [16]. The effective functional life of engineering structures and components are declined due to the degradation of surface morphology on the effect of erosion [17].so the development of high erosion resistance material is a trend towards new material innovation. The potential of these materials gave better performance if this is fully erosive proof. Still now whatever the research work carried out there is a lack of erosive behaviour of this particular type composite. [24] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] suggested the design and development of components by R.P process and material identification. The main objective of this research is to find the particular erosive behaviour of this Metal matrix composite which is subjected to particular aluminium oxide as erodent. The wear behaviour of composite under variable testing condition i.e. (variation in the size of the micro-erodent, impact velocity, and impingement angle) is clearly understood by analyzing the SEM image of the surface.

2. Materials and methods

2.1. Material Preparation

For experimental necessity desired dimension of in form of ($24\times20\times4mm^3$)rectangular plates were cut from a solid bulk Al-SiC_p material. The stir casting technique was adopted for manufacturing the Al-SiC_p in bulk form with keeping suitable process parameters [18] [19]. The melting process of Al was done at a temperature around $750^{\circ C}$ and kept for 2 hrs. in vacuum to prevent any oxidation to initiate. Then silicon carbide particulates as reinforcement of size 40 micron were added at desired proportion with the aluminium matrix. Bonding of the composite can be properly accomplished by following and controlling striation process. The cast experimental materials in the form of solid bar Al-SiC_p is shown in fig.1.

2.2. Experimental setup and procedure

The detailed machine set up and specification with nomenclature was mentioned in the below fig.2 For successful experimental work an air erosion testing machine which was developed and assembled by Ms. DUCOM instruments limited Bangalore (TR-470) and the test ring was designed. For successful test purpose, the pressure of air was kept equal or above to 4 bars. The variant shape of the erodent was approximated in an angular shape. The size variation of aluminium oxide erodent was taken to be (80, 100,120) microns. Appropriate erosion test specification was given below Table no.1.

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Figure 1. Al-SiC solid specimen.

Figure 2. Experimental Setup

Table 1. Erosion test specification.

	Experimental parameters		
1.	Erodent	Alumina powder	
2.	Erodent size (μm)		80, 100, 120
3.	Erodent shape		Angular
4.	Diameter of jet nozzle		1.5
5.	(mm)		50,60,80
6.	Jet velocity (m/s)	45°, 60°, 90°	
7.	Impact angle	15	
	Distance between nozzle		
8.	and sample (mm)		Room temperature
	Test temperature		

3. Experimental Results

Taguchi plan of test is a straightforward, monetary, productive, efficient way to deal with upgrade execution and most intense logical instrument for modelling[20] [21] [22]. In this exploration work Taguchi L_9 orthogonal array is implemented for experimental design purpose. The results of erosion wear rates mention in Table no.2 where six column prompts to the estimation of S/N ratios of erosion wear rate. The overall mean for Signal to Noise ratios (S/N ratio) of erosion wear is found 42.0823db with assistance of MINITAB 17 [23]. The four main effects were clearly demonstrated in plot no fig.3 and it represents the most effective factors among the impingement angle, erodent velocity and erodent size considering the concept of smaller is better. From experimental analysis it was found that combination of $A_1B_1C_1$ has minimum erosion wear rate. The line of the graphs of impingement angle and erodent size are almost parallel to the mean line of the plot however the graph of the impact velocity has a distance from the mean line. If the line of control element is mostly close to horizontal line then the factor is considered to have no significant effect. From the effect plot it can be concluded that the impact velocity of the erodent particle is most significant towards the wear rate. Smaller is the better signal ratio generally chosen when the ideal value for undesirable characteristics like 'defects' is zero. At the point when a perfect esteem is limited and its maximum or minimum value is defined then the difference between the measured data and the ideal value is expected to be as small as possible. This analysis confirms that erosion rate not only depends the on-impact velocity but on filler content and impingement angle.

Table 2. Results of erosion wear rate.

	Impingement angle (deg) A	Erodent velocity (m/s) B	Erodent size (µm) C	Erosion rate (mg/kg)	Signal to noise ratio (S/N)(db)
1	45	50	80	85.34	-38.6231
2	45	60	100	101.43	-40.1233
3	45	80	120	158.16	-43.9819
4	60	50	100	102.32	-40.1992
5	60	60	120	112.67	-40.9973
6	60	80	80	210.67	-46.4721
7	90	50	120	106.67	-40.5608
8	90	60	80	117.65	-41.4118
9	90	80	100	208.25	-46.3717

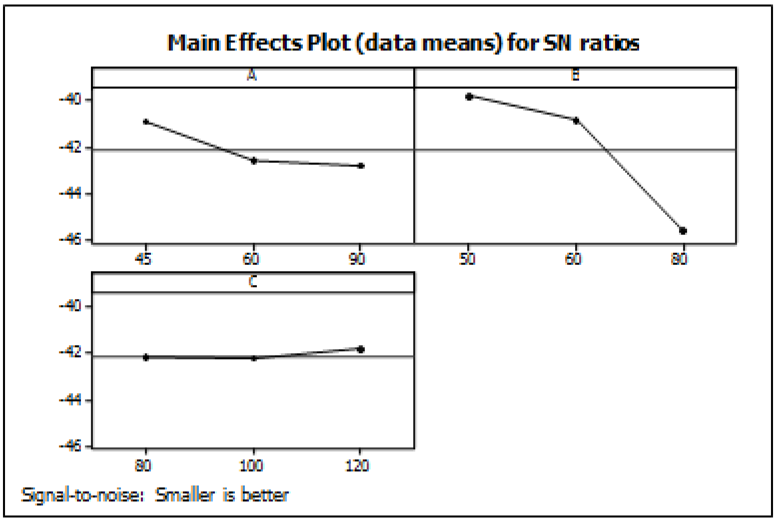

Figure 3. S/N ratio of Machining Parameters.

4. Linear regression and ANOVA

In this present work, an attempt is made to derive optimal settings of the control factors for minimization of erosion wear rate. The single objective optimization requires quantitative determination of the relation between erosion wear rate with control factors. The following equation (1) is suggested to express wear rate in terms of the mathematical model.

$$E_r = K_0 + K_1 \times A + K_2 \times B + K_3 \times C \quad (1)$$

Where, E_r is the erosion wear rate in mg/kg and K_i(i= 0,1,2,3) are the model constants. A- is the impingement angle (degree), B is the impact velocity (m/s) and C is the erodent size (µm).The constantsare calculated for each test run in separately using nonlinear regression analysis with help of MINITAB 17 and the following relation is obtained,

$$E_r = -80.4 + 0.568A + 3.28B - 0.306C(2)$$

The Equation (2) can be used for predictive purpose to obtain wear rate of aluminium alloy based composites filled with Sic particulates. In order to find out the statistical significance of various factors like impingement angle (A), erodent velocity (B) and erodent size (C) on erosion rate, analysis of variance (ANOVA) is performed on the experiment. At the 5 % level of significant (i.e. the level of confidence 95%) ANOVA analysis is carried out. The outcome from ANOVA analysis manifests that smaller the p value better is its significance. Final conclusion from the analysis reveals that, erodent velocity has most significant factor (p = 0.018) rather than impingement angle and erodent size. In contrast to erodent size (p = 0.501) which has lowest influence towards the erosion rate. The table 3 shows the maximum influence parameter is Eroded velocity is involved (54.85%) followed by impingement angle.

Table 3.ANOVA table.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Impingement angle (A)	2	1574.7	1574.7	787.3	5.48	0.154
Erodent velocity (B)	2	15749.4	15749.4	7874.7	54.85	0.018
Erodent size (C)	2	285.8	285.8	142.9	1.00	0.501
Error	2	287.1	287.1	143.6		
Total	8	17897.0				

5. Results and Discussion

The worn-out surface of the samples is observed under the optimal level to get better knowledge about the erosion rate. The silicon carbide particulates which are formed in black patches. The uniformly distribution of the SiCp are clearly seen in the micrographs. A small portion of the damage surface is taken under the observation. The worn surfaces of Al/SiCp samples are found to be smooth and shallow grooves at lower impingement angle (45°) with low impact velocity such as 50m/s. hard silicon carbide particulates are tightly bonded with AA6061 aluminum alloy matrix. So, it is difficult to apart from the matrix material at lower impingement angle with low impact velocity. Figure 4 shows the smooth and shallow grooves at 45° impingement angle. The flow direction of extensive plastic deformation shows in figure. Due to the repeated impact of Al_2O_3 solid erodent particles on the surface of Al/SiCp composite. During the normal impact or 90° impingement angle the erosion rate may be directly involved in kinetic energy of erodent particle which are formed the deep craters. The dispersion of hard silicon carbide particles has the better elevated temperature property and it is improved the wear resistance. This hard phase is protected to AA6061 alloy matrix and performed as a load observing component. However, an increase in erodent velocity, the composite shows the craters along with patches of damaged region.

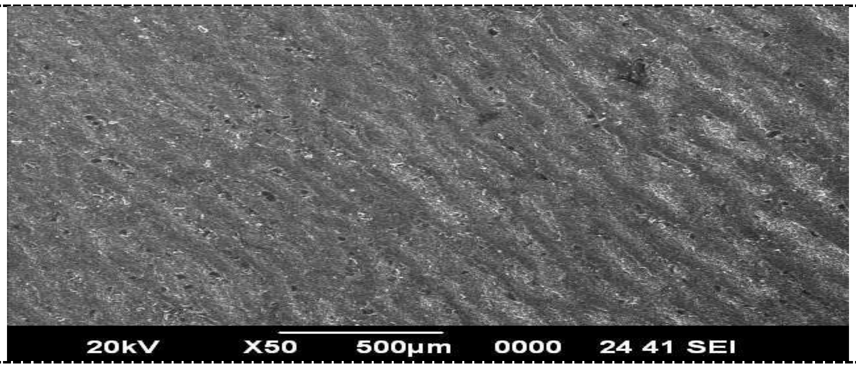

Figure 4. SEM Inage of silicon carbide.

5.1. Conformation test

The confirmation of design of experiment accomplished by conducting confirmation experiment with taking an arbitrary set of factor combination and compare with experimental results. The confirmation experiment was performed by conducting an arbitrary set of factor settings $A_1B_1C_1$ to predict the erosion wear rate. By using Taguchi's approach to estimate S/N ratio for erosion rate, the prediction can be formulated as given Equation (3).

$$\hat{\eta} = \bar{T} + (\overline{A_n} + \bar{T}) + (\overline{B_n} + \bar{T}) + (\overline{C_n} + \bar{T}) \quad (3)$$

Where $\hat{\boldsymbol{\eta}}$ is predicted average; $\bar{\boldsymbol{T}}$ is overall experimental average; and A1, B1 and C_1 are the mean responses for factors at designated levels. By combining the terms, the Equation (4) is reduces to,

$$\hat{\eta} = \overline{A_1} + \overline{B_1} + \overline{C_3} - 2\bar{T} \quad (4)$$

The new set of factor levels A_1, B_1 and C3 is predicted the wear rate to be 78.542 and the result of experimental erosion wear rate is found -37.902db. An error of 2.5%. The S/N ratio of erosion wear rate is observed. The calculated predicted average values are compared with the experimental results. It validates this mathematical model for predicting the measures of performance based on knowledge of the input parameters.

6. Conclusions

In the present work, the silicon carbide particulates are incorporated into the AA6061 matrix. Manual stir casting technique is used to develop the metal matrix composite in economic method and a detailed optimal level of erosion wear is studied with help of Taguchi method. The following conclusions have been made are obtaining from the investigation.

1. The maximum wear resistance is found at 45° impingement angle with 50 m/s erodent velocity and eroded size is 100μm. The analysis of experiment found the combination for minimum erosion wear rate found in the A1-B1-C3 Levels. The overall mean for S/N ratio of erosion wear is found -37.902db with the help of MINITAB 17.
2. Impact velocity (58.85%) is most significant factor acquired in Al/SiC_p composite. From main effect plot it is concluded that rather than impingement angle and erodent velocity the impact velocity of erodent particles is most significant control factors.
3. Taguchi method offers best design of experiment with optimization of single control parameters. This method also provides the best significant factor occurred in erosion wear

analysis. Signal to noise response also helped to identify the suitable rank of the parameters. A comparison mathematical model is formed between the experimental and predictive equation in erosion wear rate. At the final step the confirmation experiment is done to identify that all the experimental values are under validation.

4. Angular shaped alumina powders are repeatedly impacted over the surface of the composite. Because of this reason the extensive plastic deformation is occurred and the craters are formed. At 60° impingement angle maximum depth of crater is found.

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