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EROSION WEAR CHARACTERISTICS OF NOVEL AMMC PRODUCED USING POWDER METALLURGY

Currently, the world of material requires intensive research to discover a new-class of materials those posses the properties like lower in weight, greater in strength and better in mechanical properties. This led to the study of light and strong alloys or composites. This study focuses to produce current novel aluminium composite with an appreciable density, good machinable characteristics, less corrosive, high strength, light weight and low manufacturing cost product. In this research, an aluminium metal matrix composites (AMMC) (Al-0.5Si-0.5Mg-2.5Cu-15SiC) was developed using the metallurgical powdered method and subjected to the investigation of erosion wear characteristics. Here the solid particle erosion test was conducted on AMMC samples. The article presents, the design of Taguchi experiments and statistical techniques of erosion wear characteristics and the behaviors of the composite. The rate of erosion wear found to decrease with increasing impact angle, regardless of the rate of impact. With higher impact velocity erosion rate increases but decreases with stand of distance.

Keywords: AMMC; Powder metallurgy; Microstructure; Wear behavior; Particle erosion; Taguchi technique

1. Introduction

The mechanical properties of AMMC can be modified to meet the requirements in various industrial applications using the appropriate combination of metal matrix, reinforcement, and processing methods. The production process of aluminum composites was obtained using the powder metallurgy technique [1-5] and tested in terms of erosive wear in this work. A "sand-blasting" type erosion device is used, in which sand particles hit a fixed disc under the required pressure. Erosive-wear can be carried out over a wide-range of particles-size, particle flows, impact velocities and angles of impact to obtain the quantitative material data and investigate failure mechanisms. The test was performed in accordance with ASTM G76 standards. Statistical methods are used to analyze, predict and / or optimize a number of engineering processes [6-9]. This research paper was adopted using a systematic and statistical-approach known as the Taguchi-method, which should optimize and analysis of the process parameters. The research aim is to inquire about the wear characteristics behavior by erosion of a new aluminium composite (Al-0.5Si-0.5Mg-2.5Cu-15SiC), which was prepared in the route of powder metallurgy method. Particulate erosion on the matrix composites was achieved using sand particles. The implementation of statistical methods using the Taguchi technique was analyzed in terms of composite erosion. The rate of particulate erosive wear can be determined by removing metal from the surface of the composite by calculating the cumulative weight loss of materials, and erosive wear depends on the removal of material from its surface. The parameters of the erosive wear process are impact speed, impact angle, stand-off distance, nature of erosion and material properties. Here, we use the Taguchi method, which helps us to design a high quality system based upon an orthogonal-array (OA) for designing the experiments with the optimal adjustment in the process control parameters.

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2. Method and materials

2.1. Composite production

A metallurgical powder method for processing of AMMC was adopted in this experiment and the metal powders like Si, Mg, Cu and SiC were reinforced to the matrix aluminium. The composite was manufactured with different steps followed by metal powders selection, weighing the powders, proper blending or mixing, digital compacting and the sample sintering. The AMMC was reinforced with 15 weight percentage of SiC in the aluminium metal-powder. Silicon, Magnesium, Copper and Silicon carbide powders with more than 99.00% of purity were mixed properly with aluminium powders. Al-Mg-Si-Cu mixtures [10-13] were properly blended/ mixed by weight percentage with the help of a ball mill in a fixed ratio of 91.5-0.5-0.5-2.5 respectively. The blended powders were forced to compact inside a C-45 steel die using a digital-compression test machine and the load was applied to 250 kN. The green-samples after compacting were removed from the die cavity and processed further for sintering inside a muffle-furnace. The sintering temperature was maintained at 620°C and was annealed about 24 hours because the melting temperature of aluminium is 660.32°C and the temperature of magnesium is 650°C. Sintering is processes where the temperature was chosen below the melting point of all reinforcement particles otherwise one particle may fuse with others to form another compound.

2.2. SEM overview

The composite material has been produced with the powder metallurgical process, and the SEM photo of the composite is shown in Fig. 1. The selected metal powders in the weight ratio of 91.5Al-0.5Mg-0.5Si-2.5Cu was reinforced with 15% of SiC followed by compaction and sintering as stated above. 15% SiC is considered for composite preparation because when using solid route that is in powder metallurgy (P/M) processes, the metal matrix powders are mixed with the reinforcing powders in any form followed by cold compaction and sintering. The maximum volume or weight fraction of the ceramic powders such as silicon carbide and graphite reinforced in aluminum matrix composite obtained by P/M process is about 25 percent whiskers and less than 40 percent in the case of powder particles. The figure shows that the mechanical properties are improved due to the uniform dispersion of the reinforcing particles in the produced composite. The matrix alloy microstructure contains a mixture of both primary α-aluminum and copper in eutectic phase materials. This is due to the hardened particles present inside the metal matrix which acts as an efficient grain refiner. The particle-size in the matrix decreases with increases in the number of reinforcing particles. Reinforced composites grains have been purified with silicon carbide particles. The average size of the matrix element particles decreases in appearance with the silicon-carbide particles.

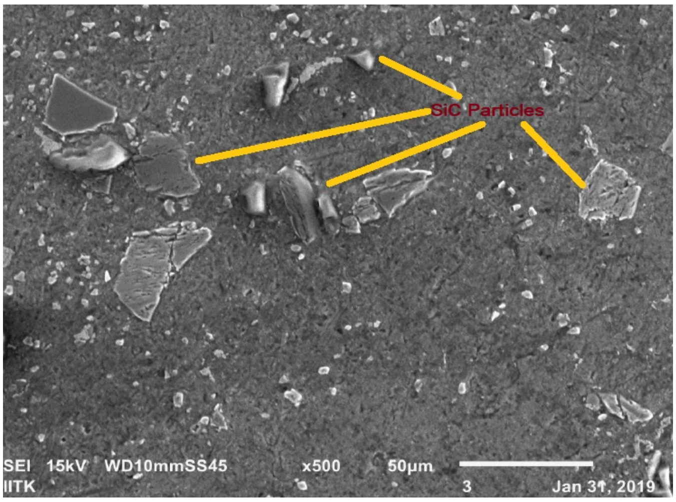

Fig. 1. Scanning electron microscopic view of aluminium matrix composite

2.3. Hardness and density

The AMMC specimens were hardness tested and performed better when SiC was reinforced with 15 wt%, a maximum of 53 on the Rockwell HRB scale, and was found to be much higher than metallic aluminum. Also, the density of the AMMC specimens was recorded as 2. 6977 gm/cm^3. Thus, it was confirmed that the hardness of the new novel composite affects better to its resistance to erosive wear.

3. Methodology

This study is used to design an AMMC erosion experiment to obtain optimal results with a minimum number of experiments. The design of the experiment was proposed by Taguchi, which involves the use of OA (orthogonal arrays) to organize the factors influencing the processes as well as the levels at which these factors must be systematically adjusted to complete this experiment with a minimum number of tests to save time, money and resources, instead of making all possible combinations.

3.1. Preparation of samples

For the erosive wear test, the samples of the Al-0.5Si-0.5Mg-2.5Cu-15SiC composite were cut into required dimension. The test was carried-out in-accordance with ASTM G76 standard [14-18]. Specimens with dimensions (25×25×3) mm were pierced and polished with sandpaper of various-grades 1/0, 2/0, 3/0 and 4/0. The control-parameters for the erosive-wear test are (i) impact / impact angle, (ii) impact / impact velocity and (iii) SOD (Stand-off distance). Silica-sands were used as an erosive-agent, that is, an erosive agent. The samples were eroded at different impact angles, i.e. 30°, 45°, 60° and 90°. The erosion was hit at the speeds of 15 m/s, 45 m/s, 60 m/s and 75 m/s and with different SODs, i.e. 10 mm, 20 mm, 30 mm and 40 mm the samples were tested.

3.2. Erosion test

A sandblasting erosion device shown in Fig. 2 is used when the sand particles pressed under the required pressure into the target. In order to optimize the flow parameters and save time, a methodical approach known as the Taguchi method [19-23] was introduced.

Fig. 2. Set up for Erosion Test

Erosion-wear tests of the composite sample materials were performed under various operating-conditions, taking into account of three parameters, namely: standoff distance, impingement velocity and impingement-angle with each at four parameter levels according to the Taguchi L_{16} orthogonal arrays. The effects on erosion wear of these three parameters were studied by using L_{16} arrays, and tests were carried out according to the experimental plan. Experimental observations are subsequently transformed into a minimal wear-rate, which can be performed as the characteristics "smaller is better" [24-26]. The objective of this study is to minimize MMC erosion by optimizing the parameters of tribological tests using the Taguchi method [27-28].

4. DOE for erosion test

In this test the solid-erodent particles (dry sand silica) impinged on upper surface of the composite materials and caused loss of the materials. Solid-particles impinged on the surface with a fixed velocity. Therefore, due to momentum and kinetic energy of sand particles, this has given the surface a shock effect and cause erosive wear. Sand particles collided at different impact angles, at different distances (SOD) and different impact rates to study the effect of process-parameters on the rate of erosion wear. When erosion particles hit the surface of a material, different wear mechanisms are triggered depending on the characteristics of the material and the process parameters. The erosion rate at different impact angles with different impact velocities is shown in the Table 1, showing the effect of impact angle on the erosion-rate of the metal-matrix composite when it is exposed to erosion by solid particles of silica-sand with a fixed SOD thickness of 10 mm. Mathematically, the erosive wear rate was formulated as follows:

$$\textit{The erosion rate}\,(ER) = \\ = \frac{\textit{Mass loss from sample due to erosion}}{\textit{Mass of erodent used}} \quad (\text{mg/Kg})$$

TABLE 1

Experimental erosion rate

Impingement/Impact angle (degree)	Impingement/Impact velocity (m/s)			
	for 15 (m/s)	for 45 (m/s)	for 60 (m/s)	for 75 (m/s)
30	76.428	145.632	195.526	223.126
45	70.329	100.238	142.628	183.319
60	68.416	98.491	135.793	172.114
90	66.218	95.438	132.215	168.222

5. Results and discussions

5.1. Design of predictive model

Design expert 11.0 was used to analyze the results obtained from the experimental erosion rate according to the response surface-methodology. It serves to originate the most suitable empirical-model which correlates the characteristics of the response to treatment (here rate of erosion) with different parameters (IA, IV and SOD). The equation for the regression of the ER response which can be represented by;

$$ER\ [\textit{Erosion Rate}] = 84.5 - 3.078\ \text{IA} + 4.70\ \text{SOD} + 1.749\ \text{IV} + 0.02837\ \text{IA2} - 0.0340\ \text{SOD2} + 0.01456\ \text{IV2} - 0.0284\ \text{IA} * \text{SOD} - 0.01127\ \text{IA} * \text{IV} - 0.0278\ \text{SOD} * \text{IV}$$

5.2. Analysis on erosion rate

The influence of the process-parameters like impact-angle, impact-velocity and stand-off-distances on the erosion-rate is graphically analyzed in three dimensional (3-D) surface-plots. Fig. 3 illustrates the effect of two process variables such as velocity and angle of impact on ER. The rate of erosion was found to decrease with increasing impact angle, regardless of the rate of impact. The rate of erosive wear is highest at the lowest angle of impact 30°, and lowest at the highest angle of impact 90°. Since the maximum erosive-wear occurs at lower impact angles, hence the erosion is caused by the ductile material mechanism.

The ductile-material presents the maximum erosion during impact angle 15° to 30°, while erosion of brittle materials is maximum at 90°. Particles hitting the sample surface at a certain angle, the tangential particle velocity lead to plastic-deformation in the composite. The smaller the angle of impact is the greater tangential component velocity. Therefore, greater erosion rate

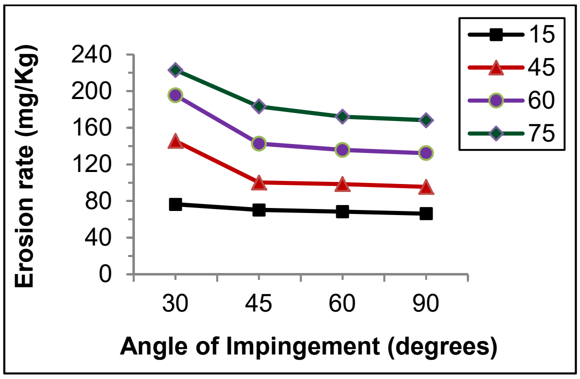

Fig. 3. Illustration plots for impact/impingement angle and erosion-rate on impact/impingement velocity i.e. Variation of erosion-rate on impact/impingement angles for different impact velocities of 15 m/s, 45 m/s, 60 m/s and 75 m/s with SOD 10 mm

will occur during plastic deformation of the composite. The rate of erosion illustrates in Fig. 3 is higher at lower impact angles. The higher the velocities, the higher the kinetic energy of the particles, therefore, the erosion rate increases. The rate of erosion at different angles of impact at different rates of impact velocities are shown in TABLE 1, which illustrates this tendency towards an increase in the rate of erosion. In Fig. 4 it shows Al-Mg-Si-

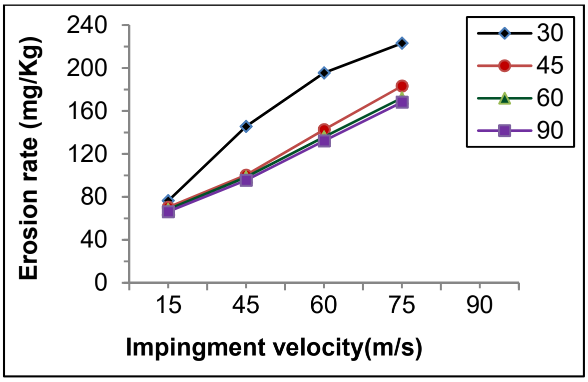

Fig. 4. Illustration plots for stand-off-distance and impact/impingement velocity on erosion rate i.e. Variation of erosion rate with impact/impingement velocity for different impact/impingement angles of 30°, 45°, 60° and 90°

Cu-SiC MMC surfaces eroded maximum when the solid particles at impact velocities 30°, SOD = 10 mm and IA = 60 degrees.

The erosion rate decreases as increasing in the SOD which shown in Fig. 5. This may because by increasing the fracture levels, the increase in the distance traveled by the erosive particles to strike on the surface. As a result, the particle losses the maximum kinetic energy before hitting the surfaces. When the impact intensity slowly drops, the erosion-rate also gets decrease. So, it can be seen that the change of erosion-rate during SOD is not very much noticeable or significant.

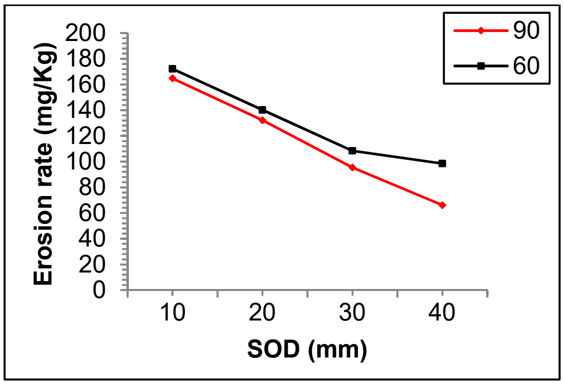

Fig. 5. Illustration plots for impact/impingement angle and stand-off-distance on erosion rate i.e. Variation of erosion rate with Standoff distance (SOD) for different impact/impingement angles of 60° and 90° with fixed SOD of 10 mm

The above SEM image shown in Fig. 6, the particles of the SiC in the composite actually change the location of the predominant effect, reducing the net area of the improved particles. It will also reduce erosive wear due to the agglomeration of SiC particles in the composite. Erosion rate also seen on an eroded surface, when SiC particle has not been removed from the aluminum matrix due to erosion or abrasion. The higher the energy of the erosion impact, the more in the composite attacks. Therefore, at higher impact velocities, the suspended particles from erosion scratch will be on the surface of the composite and have no noticeable effect due to the low plasticity of the SiC particles and this will increase the resistance to erosion.

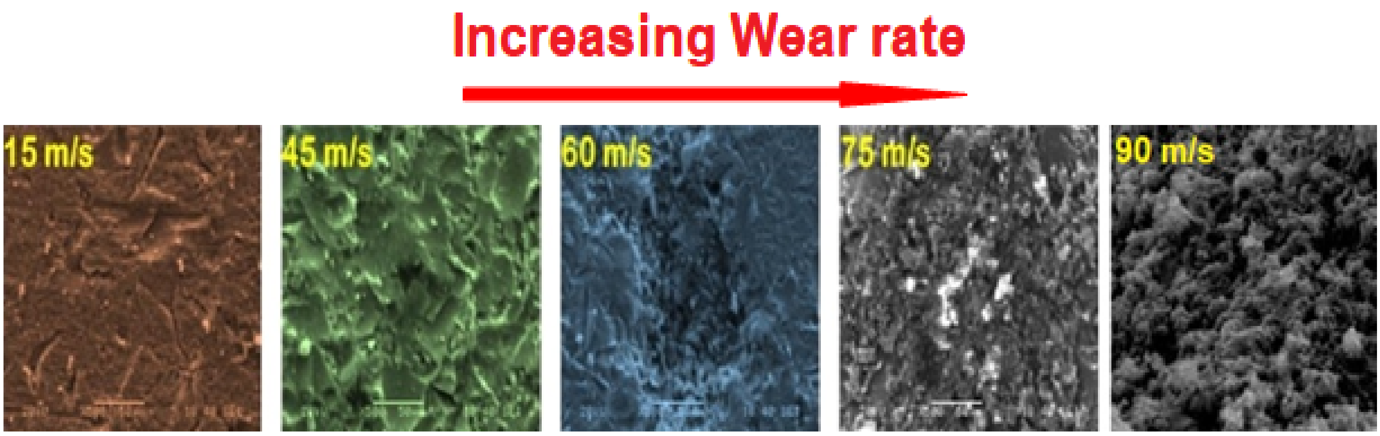

Fig. 6. Supremacy of impact velocity at eroded-surfaces of Aluminum metal matrix composite; SOD = 10 mm and IA = 60°

6. Conclusions

The erosion characteristics of the Al-0.5Si-0.5Mg-2.5Cu -15SiC composite have been successfully investigated in the Taguchi experimental project. The project provided a simple, systematic and efficient methodology to optimize the control factors. By solving the problem of optimizing the response using the analysis of the RSM utility, the optimal erosion-rate for AMMC at an impact-angle of 67 degrees, SOD of 26 mm and an impact-velocity of 18 m/s. The optimal calculated value of the erosion-rate is 65.150 mg/kg. Hence, the novel aluminium composite draws following conclusions:

- The inclusion of fine particles of SiC with help of metallurgical powdered route can improve the resistance to erosive wear by 200-300%.
- This improvement may be obtained by adding only 15 weight % of SiC particles; further increase provides only a slight improvement in wear-resistance.
- Porosity reduces the resistance to erosive-wear and it can be achieved with SiC reinforcement of 15% or more. The agglomeration of reinforced SiC particles will reduce the resistance to erosive-wear.
- The rate of erosion was found to decrease with increasing impact angle, regardless of the rate of impact.
- The higher the velocities, the higher the kinetic energy of the particles, therefore, the erosion rate increases.
- The erosion rate decreases as increasing in the SOD which shown in figure because the particle losses the maximum kinetic energy before hitting the surfaces.
- The above SEM image shown in Fig. 6, the particles of the SiC in the composite actually change the location of the predominant effect, reducing the net area of the improved particles. It will also reduce erosive wear due to the agglomeration of SiC particles in the composite.

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