Evaluation of Erosive Wear Rate of Al\textsubscript{2}O\textsubscript{3}-Cu Composite

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Abstract. This paper presents the analysis of erosive wear rate of Al\textsubscript{2}O\textsubscript{3}-Cu composite with 0, 1, 3, 5 and 7 wt\% loading of Al\textsubscript{2}O\textsubscript{3} particles. Composite samples were fabricated through cost effective powder processing technique. The surface morphology of the composites was analysed by Scanning Electron Microscope (SEM) and composition was examined by Energy Dispersive X-Ray (EDX). The density analysis show that the mass density increases with increase in wt\% of Al\textsubscript{2}O\textsubscript{3} particles up to 5 wt\% and then decreases from 5 wt\% to 7 wt\% o. The decrease in mass density of composite at 7 wt\% of Al\textsubscript{2}O\textsubscript{3} particles may be due to agglomeration of Al\textsubscript{2}O\textsubscript{3} particles. Hardness results show that the addition of Al\textsubscript{2}O\textsubscript{3} particles, the hardness value increases up to an optimum level of wt\% of Al\textsubscript{2}O\textsubscript{3}. The analysis of erosive wear shows that the erosive wear rate decreases with increasing wt\% of Al\textsubscript{2}O\textsubscript{3} from 0 wt\% to 5 wt\% of Al\textsubscript{2}O\textsubscript{3} particles and then increases to 7 wt\%. The erosive wear rate of the Al\textsubscript{2}O\textsubscript{3}-Cu composite depend on optimum level addition of Al\textsubscript{2}O\textsubscript{3}, sintered mass density, hardness value and distribution of Al\textsubscript{2}O\textsubscript{3} particle in the composite.

1. Introduction

Material wear due to slurry erosion is a major issue in turbines, pumps, pipe lines, etc. Metal matrix composites are widely used as structural parts fabrication where erosion of solid particle is a mode of failure of parts. The Alumina/Copper (Al\textsubscript{2}O\textsubscript{3}-Cu) composite can be used in many engineering component fabrication due to its high thermal conductivity and good wear characteristics. Al\textsubscript{2}O\textsubscript{3} has high hardness and wear resistance which improves performance of low strength matrix material. Copper has high electrical, thermal and corrosion resistance material, but poor hardness and wear resistance. The improvement of wear resistance has been noticed with addition of small amount of Al\textsubscript{2}O\textsubscript{3} particles in to Cu matrix [1]. Since Al\textsubscript{2}O\textsubscript{3} has high wear resistance and combination of these two material can make high wear resistance engineering material.

Erosive wear is defined as loss of material caused by impingement of solid particles or fluid droplets which strike at high impact velocity on the material surface [2-3]. Erosion resistance of materials is depend on erosion conditions, particle size, shape, composition, striking velocity and temperature [4]. Bagci et al. investigated erosion behaviour of epoxy resin reinforced with E-glass fiber and silicon dioxide particles under different conditions [5]. They concluded that the impact angle was most effective wear parameter that affect erosion rate of composite. Jach et al used a replicate method for fabrication of Al\textsubscript{2}O\textsubscript{3}/Cu composite [6]. Dash et al. used spark plasma sintering technique to fabricate different vol. % of Al\textsubscript{2}O\textsubscript{3} and Cu micro and nano composite and observed that the wear

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resistance of composite increases with increasing Al₂O₃ loading [7]. Guevara et al. prepared Al₂O₃/Cu composites by powder metallurgy route and found that Al₂O₃ layer restricted reinforcement mechanism which could improve its mechanical properties [8]. Guanghong Zhou & Hongyan Ding fabricated Cu– Al₂O₃ composite by powder metallurgy route. They found that wear loss of composite was minimum at 2 wt% of Al₂O₃ content [9]. Lidiya et al. studied erosion of solid particles pressed Al₂O₃ and found that hard SiC particles caused more damage as compare to softer SiO₂ particles. They also found that maximum erosion occurred at impact angle of 90° for both type of particles [10]. Hussain et al. prepared Al₂O₃/Cu composite by using powder processing method and observed that electrode wear of composite depended on hardness, mass density and formation of protective layer at composite surface [11]. Amar Patnaik et al. investigated the effect of Al₂O₃ on erosive wear of polyester glass fiber composites and found that erosive wear of composite was improved due to restriction of fiber and matrix de-bonding [12]. Yildizli et al. studied the solid particle erosion and found that the erosion rate depended on impact angle and maximum erosion rate was occurred at an impact angle of 90°[4]. Irina Hussainova found that the microstructural parameters showed an important role for evaluating wear resistance of titanium carbide-based composite [13]. Sreenivas Rao et al. investigated slurry erosion of plasma sprayed Titanium oxide coating on AISI 410 steel [14]. The titanium oxide coated steel showed excellent erosion resistance due to its higher hardness and less porosity as compare to uncoated sample. Ajit Behera et al. found that impact velocity and impact angle were most influential factors affect on wear rate of coatings [15]. Khalid et al. fabricated Al₂O₃-Al-Si alloy matrix composites by stir casting process. They found that wear resistance of the composite was improved with addition of Al₂O₃ particles and also heat treatment process [16]. Mahapatra et al. found that fiber loading was significant parameter affecting erosion rate of E-glass polyester composites [17]. Panda et al. fabricated aluminum nitride reinforced glass fiber epoxy composite and investigated different operational factors on specific wear. The result indicated that with increasing filler particles, hardness and erosion resistance of composite were improved [18]. Mohsin & Dixit investigated effect of speed, sand content and slurry on erosive wear of SiC-aluminium composite. They found that the wear rate was higher with increasing sand concentration due to the higher impinging action of sand particles [19]. Hussain & Khan investigated effect of Electro Discharge Machine Die-Sinking parameters on Electrode wear rate and Material removal rate of electrode material Al₂O₃/Cu composite and found that the peak current was most influential factor compare to other considered factors [20].

In this paper, we investigated Erosive wear rate of 0, 1, 3, 5 and 7wt% of Al₂O₃ particles in Al₂O₃-Cu composite.

The fabrication of composite samples have been done with Automatic Lathe machine (HMT), Nitin hydraulic press machine and Wild Barfield muffle furnace. JEOL JSM-IT300 has been used for surface morphology and elemental analysis at high resolution and Nikon Video Machine used for low resolution i.e. x12. Future tech Rockwell hardness tester has been used for hardness measurement. A self design pot tester was used for erosive wear rate measurement.

2. Fabrication of pure Cu and Al₂O₃-Cu composite
Powder metallurgy method is used to fabricate Al₂O₃-Cu composites [21-22]. Accordingly, 0, 1, 3, 5 and 7 wt% of Al₂O₃ powder (average particle size ~3-5 μm, density ~3970 kg/m³) were mixed with Cu powder (average particle size ~45 μm, density 8940 kg/m³) and the mixture was then mechanically mixed in ball milling container [22]. The ball milling container was attached to Automatic Lathe Machine and rotated at 250 rpm for two hours. The mixed powders were then compacted in a hydraulic type press machine at 200MPa compaction pressure. All the composite samples are heated at 700°C in Muffle furnace, held at this temperature for 30 minutes duration and then cooled slowly inside the furnace. The sintered 5 wt% composite specimen having 15mm diameter and 6.1242 gm weight is shown in figure 1.
3. Result and discussion

3.1 SEM surface image and Energy dispersive X-ray spectroscopy spectrum

Scanning Electron Microscope image of 5wt% of Al₂O₃-Cu composite is as shown in figure 2. From the image, it is observed that bright white Al₂O₃ particles are uniformly distributed in Cu matrix and confirmed the presence of Al₂O₃ particles in composite. Figure 3 shows EDX spectroscopy spectrum of 5 wt% Al₂O₃-Cu composite The EDX analysis also shows that the composition contain chemical elements of Cu, Al and O.

3.2 Mass density measurement

The sintered density of the Al₂O₃-Cu composite was calculated using Archimede’s principle. Table: 1 shows sintered mass density of Al₂O₃-Cu composite. The density analysis shows that the mass density of the composites increases with addition of Al₂O₃ particle from 5177.9 kg/m³ to 5370.5 kg/m³ up to 5wt% and then decreases 5287.3 kg/m³ at 7wt% of Al₂O₃. The variation of sintered mass density of composite with wt% of Al₂O₃ content is shown in figure 4. The decrease in mass density may be due to agglomeration of Al₂O₃ particles at 7 wt% of Al₂O₃ which causes increase in volume of composite after addition of optimum wt% of Al₂O₃ particles.
3.3 Hardness measurement
Hardness value of pure copper and Al₂O₃-Cu composites were measured by Automatic Rockwell Hardness tester having ball diameter 1/16" and all tests have been conducted as per ASTM. Table 2 shows the hardness data of different wt% of Al₂O₃ in Cu matrix. The variation of hardness data of Al₂O₃/Cu composite with increasing wt% of Al₂O₃ particles is shown in figure 6. The Hardness result indicates that the hardness of composite increases with increasing wt% of Al₂O₃ up to 5 wt% and then decreases to HRB 14.63 at 7 wt% of Al₂O₃ reinforcement. The increase in hardness value is attributed to increase in sintered mass density and uniform dispersion of Al₂O₃ particle in Cu matrix. The decrease in hardness value at 7 wt% may be due to agglomeration of Al₂O₃ particles.

Table 1. Sintered Mass Density of Al₂O₃-Cu composites.

| Sl. no. | Sample                      | Mass density (kg/m³) |
|--------|-----------------------------|----------------------|
| 1      | 0 wt% Al₂O₃-Cu composite    | 5177.9               |
| 2      | 1 wt% Al₂O₃-Cu composite    | 5235.1               |
| 3      | 3 wt% Al₂O₃-Cu composite    | 5306.3               |
| 4      | 5 wt% Al₂O₃-Cu composite    | 5370.5               |
| 5      | 7wt% Al₂O₃-Cu composite     | 5287.3               |

Table 2. Hardness data of different wt% of Al₂O₃-Cu composite.

| Sl. No. | Sample                      | HRB |
|--------|-----------------------------|-----|
| 1      | Pure Cu                     | 11.74 |
| 2      | 1wt% Al₂O₃-Cu Composite     | 13.31 |
| 3      | 3wt% Al₂O₃-Cu Composite     | 15.79 |
| 4      | 5wt% Al₂O₃-Cu Composite     | 17.53 |
| 5      | 7wt% Al₂O₃-Cu Composite     | 14.63 |

Figure 4. variation of sintered mass density with different loading of Al₂O₃.
3.4 Erosive wear test of Al$_2$O$_3$-Cu composite

Accordingly, a pot tester has been fabricated and the schematic attachment of specimen holder as shown in figure 7 which was attached to vertical drilling machine rotated at 200 r.p.m [23]. The sample holding device is fabricated due to low sample thickness using a shaft having diameter 15mm, 250mm long. The slurry 6wt% sand mixture is filled in pot tester container of 4 liter capacity and the specimen holder is attached to vertical drilling machine. The erosion test has been conducted at 180 minutes duration and at 90° impact angle. The weight loss of all samples were measured by electronic weight balance. From weight loss measurement volume loss rate was measured, which is a measure of erosive wear of composites. The slurry exposed area was measured using SOLIDWORKS Software 18 shown in figure 8.

Table 3 shows the erosive wear rate of different wt% of Al$_2$O$_3$-Cu composite. The erosive wear rate decreases from 0wt% to 5wt% and then increases at 7wt%. Figure 9 shows variation of erosive wear rate with wt% of Al$_2$O$_3$ particles loading. From the figure it is observed that Erosive wear rate decreases from 0wt% to 5 wt% of Al$_2$O$_3$ particles. The decreasing trend of Erosive wear rate up to 5wt% is due to increase in wt% of Al$_2$O$_3$ particles, uniform distribution of Al$_2$O$_3$ particles, increasing sintered mass density and hardness value of composites. Figure 9 also depicts that the erosive wear rate increases from 5wt% to 7wt% which is due to decrease mass density, hardness and may also agglomeration of Al$_2$O$_3$ particles at higher wt% of Al$_2$O$_3$ particles. Therefore, there is an optimum level addition of Al$_2$O$_3$ particles in composite which can increase erosive wear resistance of composite. The erosive wear rate is depend on sintered mass density, hardness, optimum level addition of Al$_2$O$_3$ in Cu matrix and also uniform dispersion of Al$_2$O$_3$ particles. The erosion samples for different wt% of Al$_2$O$_3$ loading are shown in figure 10 (a)-(c). From the figure 10 (a)-(c), it is observed that all samples are brittle fractured during erosion process and 5 wt% loading shows small particles removed from composite surface compare to other wt% loading. The material removed from composite sample surface is due to impinging action of sand particles during erosion test.
Figure 7. Specimen holder.  

Figure 8. Slurry exposed area.  

Table 3. Erosive wear rate of different wt% of Al₂O₃ in Cu matrix.

| Sl. No. | Sample            | Volume exposed to slurry (m³) | Erosive Wear Rate (m³/s) |
|---------|-------------------|------------------------------|--------------------------|
| 1       | Pure Cu           | 770.28×10⁻⁶                  | 1.555392×10⁻¹²           |
| 2       | 1wt% Al₂O₃-Cu     | 773.37×10⁻⁶                  | 1.385773×10⁻¹²           |
| 3       | 3wt% Al₂O₃-Cu     | 776.52×10⁻⁶                  | 1.208886×10⁻¹²           |
| 4       | 5wt% Al₂O₃-Cu     | 775.87×10⁻⁶                  | 1.120886×10⁻¹²           |
| 5       | 7wt% Al₂O₃-Cu     | 777.23×10⁻⁶                  | 1.270348×10⁻¹²           |

Figure 9. Variation of rate of Erosive wear with Al₂O₃ particles
4. Conclusion
From the detailed investigation of the results obtained, the following conclusions can be drawn:
(1) In the present study, Al$_2$O$_3$-Cu Composite was successfully prepared by powder metallurgy method.
(2) SEM Surface morphograph shows that the presence of Al$_2$O$_3$ particles in Cu matrix. SEM image of 5wt% loading of Al$_2$O$_3$ also shows that Al$_2$O$_3$ particles are uniformly distributed in Cu matrix. EDX spectrum also shows that the presence of elements Cu, Al and O in the composite.
(3) Sintered mass density of composites shows that the sintered density increases with increasing wt% of Al$_2$O$_3$ particles up to 5wt% and then decreases at 7wt% loading of Al$_2$O$_3$ particles.
(4) Hardness data indicate that optimum 5 wt% addition of Al$_2$O$_3$ particles increases composite hardness value.
(5) As the amount of Al$_2$O$_3$ increases in the composite, the erosive wear rate is also increases, but there is an optimum limit of Al$_2$O$_3$ particles addition which describes the optimum composition i.e. 5wt% of Al$_2$O$_3$.
(6) The surface morphograph at x12 of samples show that the brittle erosion phenomena of composite happened when impinging with sand particles during erosion test of composite during erosion test and
5 wt% loading shows small particles removal from surface compare to other considered wt% loading composites Therefore, Erosive wear rate is depend on sintered mass density, composites hardness value, optimum level of addition of Al₂O₃ particles and uniform distribution of Al₂O₃ particles.

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