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Hardness and wear analysis of Cu/Al_2O_3 composite for application in EDM electrode

M Z Hussain [1,4], U Khan[2], R Jangid[3], S Khan[1]
[1]Depertment of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India
[2]Department of Mechanical & Automation Engineering, IGDTUW, New Delhi, India
[3]Department of MAE, G.B Pant Engineering College, New Delhi, India

E-mail: mechazakirhussain@gmail.com

Abstract. Ceramic materials, like Aluminium Oxide (Al_2O_3), have high mechanical strength, high wear resistance, high temperature resistance and good chemical durability. Powder metallurgy processing is an adaptable method commonly used to fabricate composites because it is a simple method of composite preparation and has high efficiency in dispersing fine ceramic particles. In this research copper and novel material aluminium oxide/copper (Al_2O_3/Cu) composite has been fabricated for the application of electrode in Electro-Discharge Machine (EDM) using powder metallurgy technique. Al_2O_3 particles with different weight percentages (0, 1%, 3% and 5%) were reinforced into copper matrix using powder metallurgy technique. The powders were blended and compacted at a load of 100MPa to produce green compacts and sintered at a temperature of 574 ^{0}C. The effect of aluminium oxide content on mass density, Rockwell hardness and wear behaviour were investigated. Wear behaviour of the composites was investigated on Die-Sink EDM (Electro-Discharge Machine). It was found that wear rate is highly depending on hardness, mass density and green protective carbonate layer formation at the surface of the composite.

1. Introduction

The composite materials are used in extensive areas like aerospace industry, automobile industry, cutting tools, and engine parts, etc. Composite material is a combination of two or more materials with improved properties [1]. The incorporation of reinforcement material into metal matrix improves both mechanical as well as tribological properties by acting as load-bearing component. In this research, aluminium oxide-copper (Al_2O_3/Cu) composites were fabricated through powder metallurgy route, and the wear behaviour was examined on Die-Sink EDM in order to use this material as EDM electrode.
In Electric Discharge Machining (EDM) process, the material is removed through erosion of material from the work piece [2, 3].The erosion occurs due to melting of material, which is caused by the spark between work-piece and electrode separated by dielectric fluid medium [4]. During the generation of high temperature spark, electrode material also melts and vaporizes [5]. The EDM has been widely used in industry for production of complex shape cavities in moulds and dies, which are difficult to manufacture by other conventional machining process [6]. For machining operation, both the electrode and the work piece of EDM should have good electrical conductivity. The ideal electrode material

[4] To whom any correspondence should be addressed.

should also have a good strength, but copper lacks in high strength and therefore reinforced copper composite with Al_2O_3 may serve as ideal electrode material.

Many researchers have shown through their research that copper has high corrosion resistance, good electrical and thermal conductivities, but has low strength. Improvement of mechanical properties is possible by introduction of ceramic particles in Cu composites. Due to its high electrical and thermal conductivities, copper and copper alloys based composite materials are developed for resistant welding electrodes, heat exchangers, electrical connectors and contacts [7]. Al_2O_3 particles are used as the reinforcement material due to its high mechanical and tribological properties. The combination of copper and aluminum oxide opens up wide possibilities for applications where good wear resistance, good electrical, and thermal conductivities are required [7,8] . Zuhailawati et al. fabricated copper-aluminium oxide composites through powder metallurgy technique [9]. The results showed that the mechanical alloying had produced Cu-Al_2O_3 composite with better hardness and low electrical conductivity in comparison to the samples prepared by ball milling method [9] Kaczmar et al. manufactured Copper based composite by the squeeze casting method [7]. The metallographic examination indicated that aluminium oxide particles were uniformly distributed in copper matrix. The composite materials containing 30 volume% of aluminium particle achieved hardness value of 208 HBW. The thermal and electrical conductivity were decrease with increasing volume content of reinforcing aluminium oxide particles, but the materials were still good electrical and thermal conductors and they were also used as a promising materials in industries where high thermal and electrical conductivity are required [7]. Kumar et al. studied the micro-crystallite copper with aluminium oxide reinforcement for particle reduction by mechanical alloying [10]. The Mechanical alloying creates a repeated fracture and cold welding and by which the particle size gets reduced. The distribution of aluminium oxide was improved with increase in milling time and it also helps in improving the wear property of the material. The material can also be used as a resistance welding electrodes [10]. Parvin et al. successfully used response Surface Methodology to optimize and also examine the effects of four most effective parameters namely density, compaction pressure, lubricant content and compaction temperature during the fabrication of Copper-Aluminium oxide powder [11]. It was shown that compaction temperature was the most effective parameter as compared to other parameters. Dhadsanadhep et al. fabricated Cu/Al_2O_3 composite by in-situ reaction between aluminum and silica powders [12]. Angelito et al. fabricated copper and aluminium oxide of different compositions and investigated hardness of the composite [13]. Higher hardness of the composite was achieved at increased temperatures and wt% of aluminium oxide. Taweel investigated the relationship of process parameters in electro-discharge of CK45 steel with novel tool electrode material such as Al–Cu–Si–TiC composite and fabricated the composite material using powder metallurgy technique [14]. RAJKOVIĆ et al. studied the effect of different size of the copper and Al_2O_3 powder particles on grain size, morphology and microstructure of the Cu–Al_2O_3 composite and composites were prepared using powder metallurgy technique [15]. They found that the size of starting copper particles and Al_2O_3 particles affected the morphology, size and microstructure of the composite powders.

2. Methodology

In this paper Cu and 1, 3 and 5 wt% of Al_2O_3 in Al_2O_3/Cu composite has been fabricated through powder metallurgy technique [16, 17] and the hardness and wear behaviour of these composites were investigated.

The samples were compacted in a hydraulic press machine (Make: Model: NHP-01, Nitin hydraulic and Engineering). The muffle furnace (Make: Wild Barfield, Maximum Temperature, 1200^{o}C) was used for sintering of Al_2O_3/Cu composites. Video measuring machine (Make: Nikon) has been used for optical micrograph at 12X and 123X. The hardness test was performed on Rockwell hardness tester (Make: HUATEC,model: HR150P), ball indenter size 1/16″. The wear behaviour was investigated using EDM Die Sink machine (Make: Electronica Hitech).

2.1 Materials and methods

2.1.1 Materials
The reinforcing material used was Al_2O_3 powdered particles (Sigma Aldrich, average particle size ≤10 µm, purity 99.5% trace metals basis) and matrix material used was copper powder (Sigma Aldrich, density 8.94 g/mL at 25 °C, average particle size <25 µm, purity 99%)
2.1.2 Fabrication of Cu and Al_2O_3/ Cu composite

The powder metallurgy technique has been used to make the pellet shaped of Cu and different wt% of Al_2O_3 in Al_2O_3/Cu composite. Four samples were prepared with different wt% as given in Table 1.

Table 1. The composition of copper and aluminium oxide

Sl. No.	Wt% ratio	
	Cu	Al_2O_3
1	100	0
2	99	1
3	97	3
4	95	5

The powder metallurgy steps are as follows:

2.1.2.1 Blending
The different wt% of Al_2O_3 and copper powder were blended by using self designed ball milling technique having ball diameter 5mm. Ball to powder weight ratio was take as 4:1. The uniform distribution of mixture was attained using automatic Lathe Machine (make: HMT) at r.p.m of 150. The experimental setup is shown in Figure 1.

Figure 1. Experimental set up for blending process

2.1.2.2 Compaction of powder
The samples were compacted in a hydraulic press machine at a pressure of 100 MPa, to produce disc shaped solids called green sample at room temperature. The die and punch assembly used during bulk composite preparation had die of 15 mm diameter.

2.1.2.3 Sintering
The sintering process was done in Muffle furnace. The samples were heated from room temperature to 574°C at a heating rate of 15^0C/min for 40 minutes and the temperature was held constant for 1 hour. All samples were then allowed to attain room temperature inside the furnace. The sintered samples are shown in Figure: 2(a) to Figure: 2(c). It can be observed from these figures that a green layer of

carbonate is formed on the surface of Cu and Al_2O_3/Cu composite. This layer may come due to the heating of all samples in furnace atmosphere which was not inert.

Figure 2(a). 1wt% Al_2O_3/Cu composite

Figure 2 (b). 3wt% Al_2O_3/Cu composite

Figure 2(c). 5wt% Al_2O_3/Cu composite

3. Results and discussion

3.1 Optical microscope image

Video measuring machine as shown in Figure 3 has been used for showing optical microscope image of Cu and Al_2O_3/Cu composites. Figure 4(a) to 4(d) show the optical microscope micrograph of 1wt%, 3wt% and 5wt% Al_2O_3/Cu composites respectively.

Figure 3. Video Measuring Machine

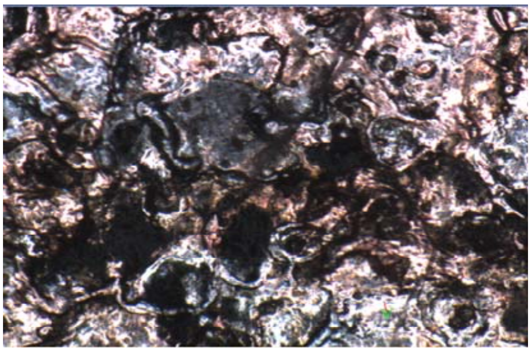

Figure 4(a). 1wt% Al_2O_3/Cu composite

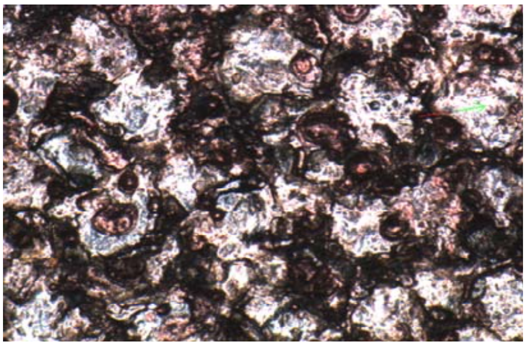

Figure 4(b). 3wt% Al_2O_3/Cu composite

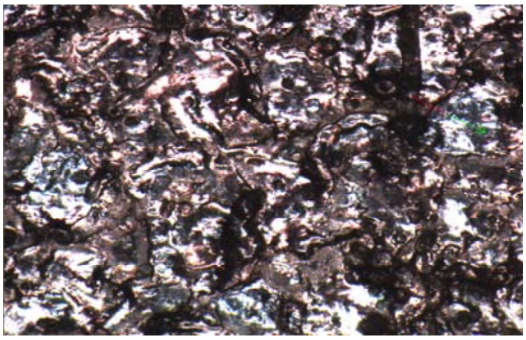

Figure 4(c). 5wt% Al_2O_3/Cu composite

3.2 Mass Density of Al_2O_3/Cu composite

The mass density is determined using mass and volume of the composite. Table 2 shows sintered mass density of Cu and different w% of Al_2O_3 in Al_2O_3/Cu composite. Mass density analysis shows that the sintered mass density of the composite increase with addition of Al_2O_3. The variation of mass density with wt% of Al_2O_3 is shown in Figure 5 and the variation shows that the 5 wt% exhibits higher mass density. The increase in mass density is attributed to decrease in porosity [13] due to the presence of Al_2O_3 reinforcement after sintering process.

Table 2. Mass density of Al_2O_3/Cu composite

Sl. No	Wt% Al_2O_3	Sintered Density (kg/m$^{3)}$
1	0	4546.6
2	1	4762.5
3	3	4948.8
4	5	5332.0

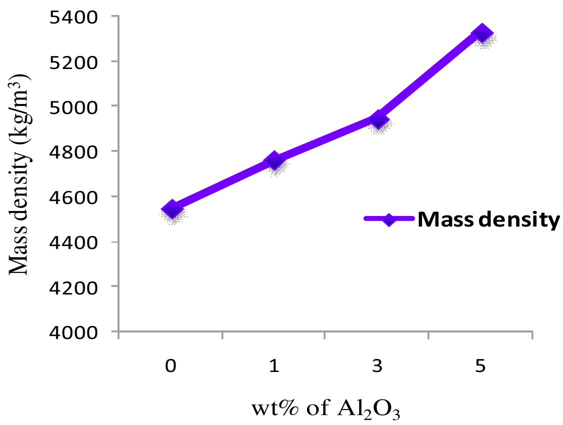

Figure 5. Variation of mass density with wt% of wt% Al_2O_3

3.3 Hardness Test

Hardness test was carried out according to ASTM [18]. Hardness of Cu and Al_2O_3/Cu composites was determined using automatic Rockwell hardness tester at major load of 100 kgf and with an indenter diameter of 1/16″ on a Rockwell B scale**.** All the specimens were disc shaped of 15 mm in diameter and 8 mm in thickness. Hardness was measured at different points on different wt% Al_2O_3 in Cu matrix in order to get average reading.

The hardness data of Cu and different wt% of Al_2O_3 in Al_2O_3/Cu composite specimens are shown in Table 3. The average hardness of 1 wt% Al_2O_3/Cu composite is HRB 8.275. Similarly the hardness value of 0, 3 and 5 wt% are HRB 7.74, HRB 9.2 and HRB 14.15 respectively. The indentation marked by indenter on the specimen as shown in Figure 6. Figure 7 shows the variation of hardness with wt% of Al_2O_3 It can be observed that with increase in wt% of Al_2O_3 the hardness value also increases [12]. The increase in hardness value is due to increase in mass density of the composite, wt% of Al_2O_3 and also a protective carbonate layer formed at the surface of the composite.

Table 3. Rockwell hardness of Al_2O_3/Cu composite

Sl. No.	Wt% Al_2O_3	Rockwell Hardness Value(HRB)
1	0	7.74
2	1	8.275
3	3	9.2
4	5	14.15

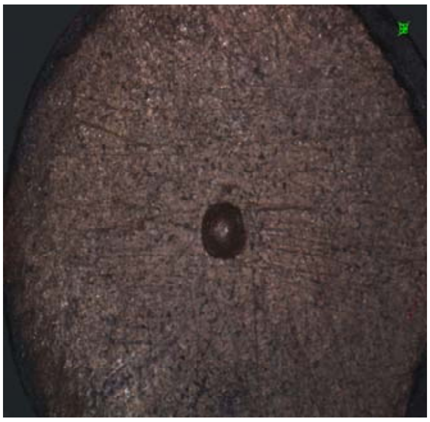

Figure 6. Indentation marked by indenter.

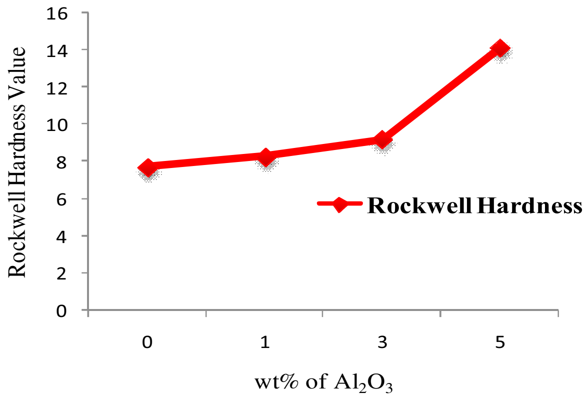

Figure 7. Variation of Rockwell hardness with wt% of wt% Al_2O_3

3.4 Wear analysis

Wear behaviour of the composites was investigated on Die-Sink Electro-Discharge Machine and experimental set-up for wear analysis is shown in Figure 8, at current of 5amp, and a voltage of 30 Volts. The machining time was set for 10 minutes for every sample. The Cu and Al_2O_3/Cu composite samples were fixed in a holder and attached with Die sink EDM Machine, and work-piece material was taken as high speed steel. The wear rate of 1wt% Al_2O_3/Cu composite after 10 minutes was 0.1183×10^{-3}kg/s. Similarly the wear rates of 0wt%, 3wt% and 5wt% of Al_2O_3/Cu composites were found to be 0.1208×10^{-3}kg/s, 0.0946×10^{-3} kg/s and 0.06875×10^{-3} kg/s respectively given in Table 4. The variation of wear rate with wt% of Al_2O_3 is shown in Figure 9. It shows that wear rate of the composite decreases with addition of Al_2O_3. The wear rate is dependent on hardness, weight fraction of Al_2O_3, mass density, and protective oxide layer formation at the surface of the composite.

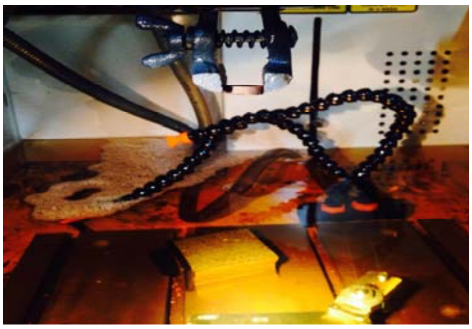

Figure 8. Wear experimental set-up on EDM

Table 4. Wear rate of Al_2O_3/Cu composite

S. No.	Wt% of Al_2O_3	Wear rate (kg/sec)
1	0 wt% Al_2O_3	0.1208×10^{-3}
2	1wt% Al_2O_3	0.1183×10^{-3}
3	3wt% Al_2O_3	0.0946×10^{-3}
4	5wt% Al_2O_3	0.06875×10^{-3}

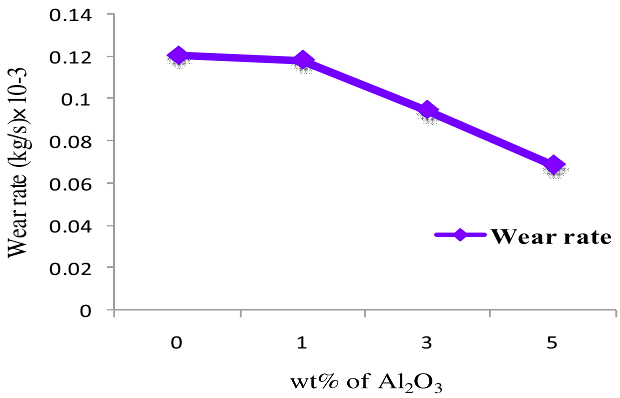

Figure 9. Variation of wear rate with wt% of Al_2O_3

The fractured samples are shown in Figure 10(a) to Figure 10(d) at magnification 12X. From these figures it has been observed that all the samples are brittle fractured during wear test and 5wt% exhibits higher wear resistance in comparison to other samples. The Figure 11(a) to Figure 11(c) shows the magnified surface morphograph (magnification 123X) of Al_2O_3/ Cu composite. It was confirmed that 5wt% of Al_2O_3/Cu composite exhibits small fragmented particles worn out from the surface.

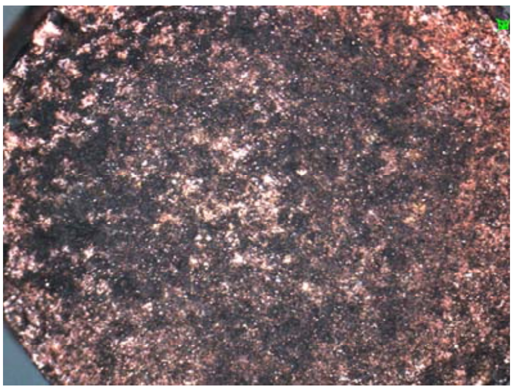

Figure 10(a). 0wt% Al_2O_3/Cu composite

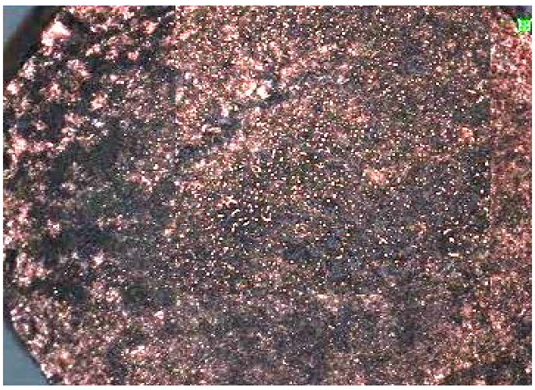

Figure 10(b). 1wt% Al_2O_3/Cu composite

Figure 10(c). 3wt% Al_2O_3/Cu composite

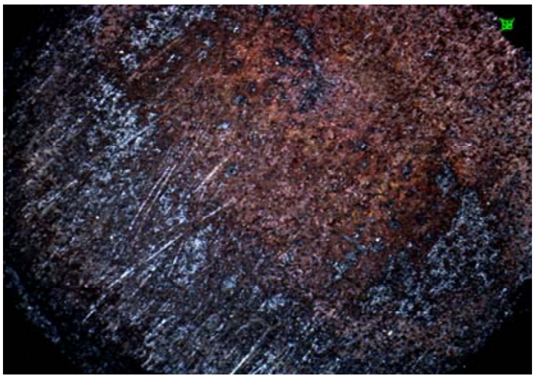

Figure 10(d). 5wt% Al_2O_3/Cu composite

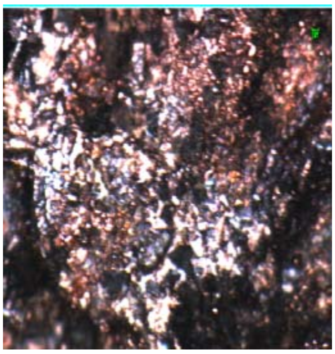

Figure11(a). 1wt% Al_2O_3/Cu composite

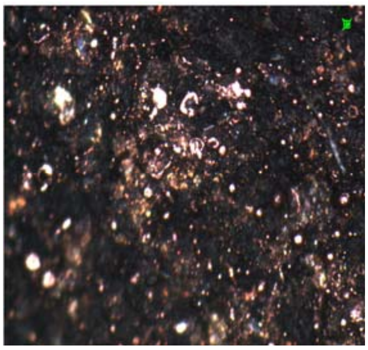

Figure 11(b). 3wt% Al_2O_3/Cu composite

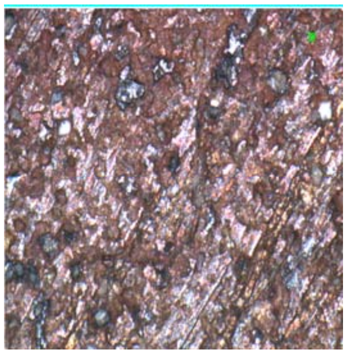

Figure 11(c). 5wt% Al_2O_3/Cu composite

4. Conclusion

In the present study, Cu and different wt% of Al_2O_3 in Al_2O_3/Cu composites was successfully fabricated by using simple and inexpensive powder metallurgy technique with self designed blending process. Mass density analysis shows that the density of the composite increases with addition of Al_2O_3. The analysis of hardness shows that hardness value increases with increase in wt% of Al_2O_3.
The wear analysis of Al_2O_3/Cu composite also shows that wear rate of the composite decreases with addition of Al_2O_3 and 5wt% exhibits more wear resistance in comparison to other samples. The optical surface images of Cu and different wt% of Al_2O_3/Cu composite confirmed that the composites are brittle fractured during wear test. During sintering process, all samples exhibits a green film of carbonate layer on the surface of Al_2O_3/Cu composite and 5wt% exhibits more carbonate layer on the surface which may increases its wear resistance. Therefore, the wear resistance of Al_2O_3/Cu composite depends highly on its hardness, mass density and green protective carbonate layer formation at the surface of the composite.
From the investigations performed in this paper, it is concluded that the fabricated Al_2O_3/Cu composite may be used as electrode material in electro-discharge machining process and further investigations can be made on other properties of the material for optimizing the machining process.

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