COMPARATIVE STUDIES OF EDM PROCESS CONDUCTIVE LAYER ON SILICON NITRIDE WITH BRASS AND COPPER ELECTRODES

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Abstract

Insulating materials are now subjected to precision electrical discharge machining (EDM) using an assisting electrode method (AEM). The electrode materials usually comprise copper, graphite and copper alloys that have high melting temperature and excellent electrical and thermal conductivity. A brass electrode is known as a humble electrode. Performances of brass and copper pipe electrodes were compared on silicon nitride machining. Results showed that a brass electrode had more advantages than a copper electrode. Material removal rate (MRR), electrode wear ratio (EWR) and surface roughness were compared, while the conductive layers were examined by a scanning electron microscope (SEM) energy dispersive spectrometer (EDS).

KEYWORDS

Electrical Discharge Machining, Electrode, Silicon Nitride, Brass, Copper

1 INTRODUCTION

Non-contact shaping as laser processing and electrical discharge machining (EDM) is gaining attention as an efficient technique to fashion fragile and difficult-to-process ceramic materials. Arc discharge stability when processing poorly conductive materials can be achieved by reducing the material dielectric constant [Grigoriev 2020]. EDM is recognized as a precision process for hard materials such as electrically conductive ceramics and hardened metals [Koenig 1998, Dauw 1989]. Recently, insulating ceramics have been successfully machined by EDM using the assisting electrode method (AEM) proposed by [Mohri 1996, Fukuzawa 1997]. Ceramics have low wear resistance and low coefficient of thermal expansion and are widely used in engineering applications; However, their hardness and brittleness make conventional machining challenging. In this review, EDM is presented as a method for cutting non-conductive ceramics. Electrical qualities determine whether or not ceramics may be conducive to EDM. Some approaches subjected insulating materials to EDM using impulses directed to helpful layers or particles [Grigoriev 2021]. Silicon nitride ceramics are an excellent choice for use in microturbines or micro-electromechanical systems (MEMS) because of their outstanding mechanical, thermal and tribological properties. Minimizing complex mechanical components is a serious challenge [Hanaoka 2013]. Silicon nitride is the most widely used ceramic for industrial purposes but the EDM process on silicon nitride is very slow [Fukuzawa 1997]. Ceramic materials can be conductive, semi-conductive or non-conductive. Examples of commonly used ceramics are alumina, aluminum nitride, boron carbide, silicon nitride, zirconium, searon, titanium carbide, titanium nitride, zirconium nitride and silicon carbide [Bilal 2018]. Silicon nitride is now increasingly used as a cutting edge with high efficiency. The cutting process requires high mechanical force with low temperature resistance. Silicon nitride (Si_3N_4) is a non-oxide ceramic with good thermal and mechanical properties that can be used as a highly efficient cutting edge in the turning process. Traditional machining is limited, and non-tension EDM is required for hard and fragile ceramics. Dissolution of silicon nitride during EDM in water dielectric has a negative impact on workpiece behavior under mechanical load and reduces process usage efficiency. Therefore, improving the surface quality is important [Bonny 2008, Klocke 2018]. A pipe electrode is widely used in EDM, giving higher material removal rate (MRR) than a solid electrode. Poco EDM-C3 is a suitable electrode material for machining insulating alumina with EDM that gives a large conductive layer, high MRR and an improved surface finish [Muttamara 2009]. Several researchers have investigated the effect of parameters on EDM such as pulse current, pulse on time, pulse off time and gap voltage [Selvarajan 2016, Lin 2009]. The relationship between machine performance and parameters was evaluated as material removal rate and electrode wear ratio using similar work tool electrodes of graphite, copper and brass. The performance of a copper electrode was assessed on alloy steel, composite material and ceramics [Bilal 2018]. Brass, an alloy of copper and zinc [Fonda 2013], is used to create EDM wire or small electrode hose. Brass is less resistant to wear than copper or tungsten but can be easily machined and formed by casting or extrusion for a particular task. EDM wire does not need to provide wear resistance or curve because new wire is fed continuously during the cutting process. Copper and copper alloys with EDM corrosion resistance are better than brass or graphite but more expensive and also difficult to use in many machines. Copper is a common base material with high electrical conductivity that is used in EDM lathing of tungsten carbide or in applications which require intricate decoration [Engineering 360 2018]. This study compared the performance of brass and copper as electrode materials. Rodic et al. [2021] investigated EDM of nonconductive ceramic to improve the current using methods such as supported electrode and powder mixed dielectric. Their goal was to enhance zirconium oxide machining performance parameters of surface roughness, material removal rate and relative tool wear. The flowchart was used to create RSM models of output attributes in this study.

This paper reviewed and described the most recent research trends in EDM and compares the conduction layer of the EDM process on silicon nitride using brass and copper electrodes. Different input process factors such as voltage (Vo), discharge current (Ip), pulse on time and pulse off time were investigated to explore different measurement output correlations with the performance characteristic of surface integrity, material removal rate (MRR) and electrode wear ratio (EWR) on silicon nitride. This paper optimized MMR using the AEM technique. Machining trials were applied on many insulating ceramics, while machining mechanisms of the electrode assisted method were assessed to predict the EDM process response characteristics of different materials.

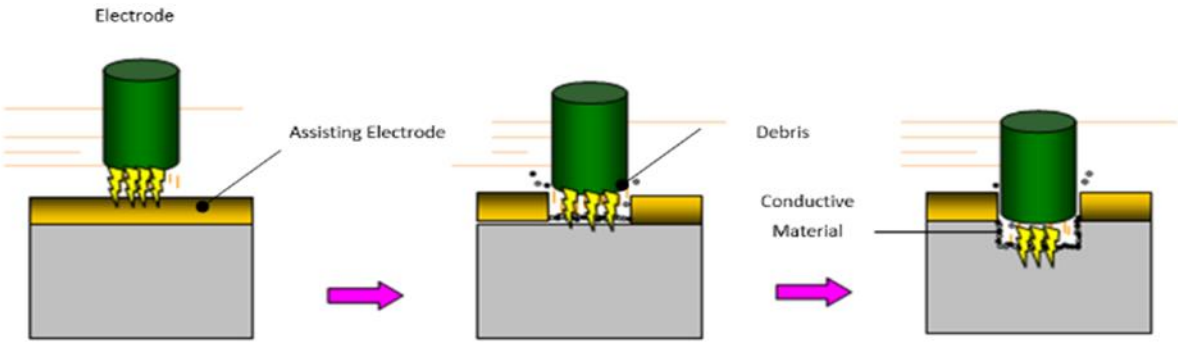


Figure 1. EDM for an insulating material using the assisting electrode method

2 BACKGROUND OF THE ASSISTING ELECTRODE METHOD (AEM)

The fundamental machining process is shown in Figure 1. The discharge starts from the top of the carbon-baked layer as an assisting electrode and creates electrically conductive products on the workpiece [Bilal 2018]. The electrode tool enters into the workpiece and passes through the assisting electrode. Products made from carbon mainly emanate from the components of the working oil during discharge and from the electrode electrical conductivity during the discharge. Machining trials have been applied for many insulating ceramics. The machining mechanism of the electrode assisted method has been described in the literature to explain the adhesion phenomenon of charcoal products. The surface of the insulating specimen is covered with or bonded to the electrical discharge material and installed in the machine under the working oil [Hanaoka 2013]. A schematic diagram of the assisting electrode method is presented in Figure 2.

The surface of the workpiece is insulated with or bonded to the power supply material and installed in the machine under the working oil as follows [Hanaoka 2011].

(1) At the beginning of the EDM, a discharge occurs between the instrument electrode and the covering layer, similar to the conductor EDM.

(2) Discharge occurs between the electrode and the covering material at a deeper level. In this region, conductive products consisting of carbon machined material adhere to the insulating surface.

(3) Carbide products are in contact with the insulating materials.

(4) Carbide products formed by dissociation of working oil under discharge maintain conductivity on the discharge area after removing the auxiliary electrode material.

3 EXPERIMENTS

The machining material was silicon nitride. A carbon-baked layer was used as an assisting electrode [Mohri 1996]. Electrodes used in this study comprised 1 mm diameter brass and copper pipe. Specimen fractures were observed by a scanning electron microscope (SEM) (JEOL 700). The EDM surfaces were measured using an optical laser microscope (Olympus OLS 3000). The DC electrical conductivity was measured the voltage and ?. Table 1 presents the major properties of electrode materials in this experiment. Brass is a copper and zinc alloy. Wire EDM and tiny tubular electrodes are made of brass material. Brass is less resistant to wear than copper or tungsten but easier to manufacture and can be molded or extruded for particular uses. EDM wire does not need to be resistant to arc wear or corrosion because during the EDM wire cutting operation additional wire is continually supplied. Copper alloys are more resistant to EDM wear than brass or graphite but machining copper alloys is more difficult at higher cost. Copper is a popular foundation material because of its excellent conductivity and strength [Lohar 2018]. The experimental EDM parameters are shown in Table 2.

Figure 2. Experimental set up

Table 1. Electrode properties

Properties	Copper	Brass
Thermal conductivity ($g.cm^{-3}$)	8. 96	7.1
Melting point (°C)	1084.62	419
Electrical resistivity (Ω·cm)	1.68	4.7
Specific heat capacity (J/g-°C)	0.385	0.38

Table 2. Machining parameters

EDM parameters	Value
Polarity	Negative
Current (A)	2-18
Open load voltage (V)	250
Pulse on time, off time (µs)	3.5, 6
Rotating spindle (RPM)	150

4 RESULTS AND DISCUSSION

The relationship between MRR and current during silicon nitride machining using brass and copper electrodes is illustrated in Figure 3. At low current, the MRR was very low but with increase in current the MRR increased. At low current, a small quantity of heat was generated and utilized in melting and vaporizing the work material. However, EDM performance on an insulating ceramic also depends on other factors. The EWR of an electrode is highly dependent on the electrical and thermal properties of the electrode material as evaporation point, melting point, thermal conductivity and heat dissipation. Figure 4 shows that the relationship between electrode wear ratio and current was higher for the brass electrode than the copper electrode. At low current, the electrode wear ratio was very low but increased with an increase in current. Basic requirements of an electrode material are high melting point and evaporation point, and high thermal conductivity. Results showed that EWR was almost inversely proportional to the melting point of the electrode material [Muttamara 2010].

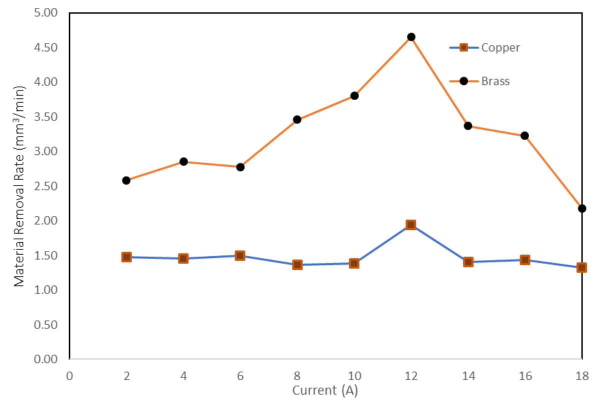


Figure 3. Relationship between material removal rate (MRR) and current

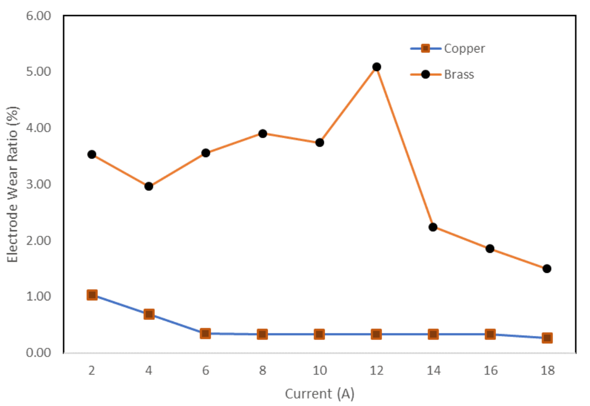


Figure 4. Relationship between electrode wear ratio (EWR) and current

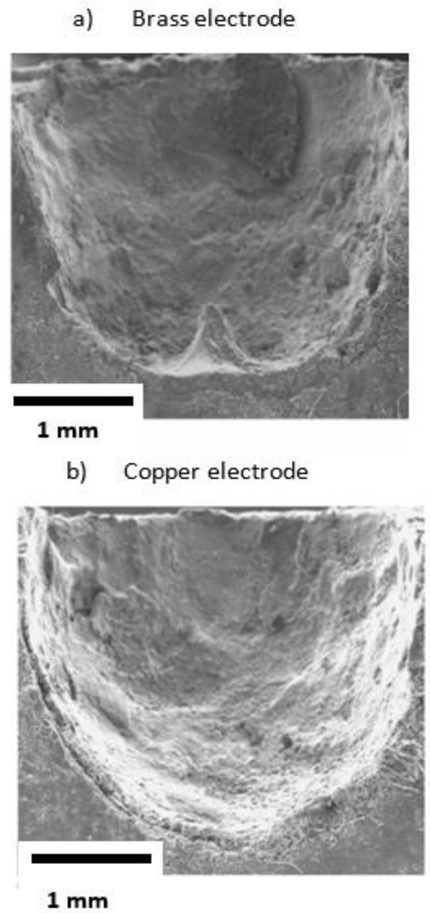


Figure 5. SEM of cross-sectional EDM holes with (a) Brass electrode and (b) Copper electrode

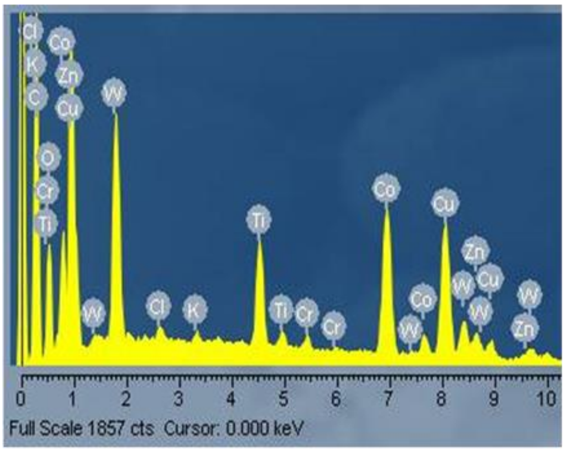
Figure 5 displays the SEM results of cross-sections of EDM holes using brass and copper electrodes. Hole diameters using the copper electrode were larger due to insufficient cooling. The brass electrode after machining showed lower misalignment because of higher thermal conductivity compared with the copper electrode, since heat from the EDM process was dissipated through the electrode. SEM results for the thickness of the conductive layer were similar for both electrodes. Cross-sections of the conductive layers produced by the brass and copper electrodes were investigated by energy dispersive spectroscopy (EDS). Results suggested that electrode material implanted on the conductive layer affected the machining process, as shown in Figure 5 shows SEM images of the top of the holes machined with brass and copper electrode. The hole obtained with the brass electrode was smoother than when using the copper electrode

Figure 6 shows the EDS analyses of the conductive layers produced by the brass and copper electrodes. Results indicated that the conductive layers were composed of carbon compound elements, mainly from the decomposed components of the working oil during discharge. Copper and zinc were found on the conductive layer when using brass as an electrode, while few copper compounds were found on the conductive layer when using copper as an electrode.

Figure 7 shows the SEM result surface of the electrodes after EDM. Craters were formed by the abnormal electrical crater discharge process. The copper electrodes were rougher than the brass electrodes. Surface roughness was measured after the

EDM process. Figure 8 shows the relationship between surface roughness and current using brass and copper electrodes. The workpiece surface using brass electrodes was smoother than when using copper electrodes. Surface roughness (Ra) values were evaluated using data obtained from the removed electrically conductive layer .The brass electrode gave lower values of surface roughness than the copper electrode. The comparatively lower thermal conductivity of the brass electrode did not allow absorption of much of the heat energy, and most of the heat was utilized in melting the workpiece . The copper electrode absorbed more heat, and sparking on the conductive layer was more violent than for the brass electrode, resulting in higher surface roughness [Lohar 2018] . Figure 9 shows waveforms of EDM for both electrodes . Numbers of discharges were more frequent using brass. When the frequency increased, the waveform and discharge also increased and improved the machine performance of MRR and surface roughness [Kumar 2021, Kuo 2021]. At a current of the discharge energy of a conventional EDM. The experiment results depend on the operation of the machine program controls the EDM process. The spark occurred between the electrode tool and the material. Abnormal wave amplitude occurred if the distance between the electrodes was too narrow [Lin 2014]. Figure 9 shows conventional EDM discharge voltage waveform at 5-7A. Discharge energy affected the surface roughness as well as the presence of abnormal discharge [Arikatla 2017].

a) Brass electrode



b) Copper electrode

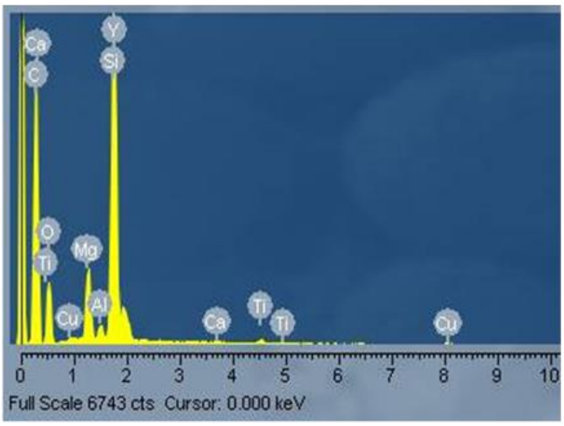
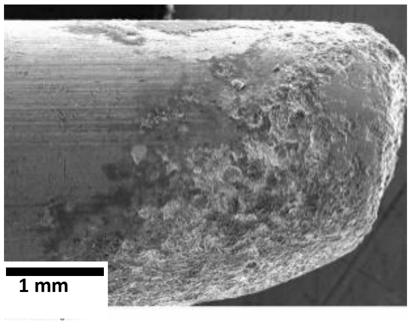


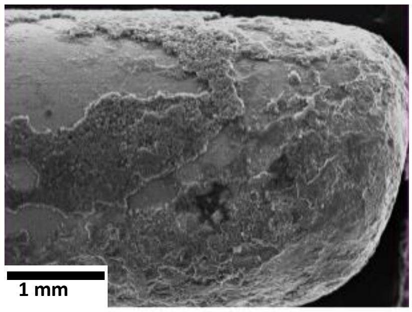
Figure 6. EDS of conductive layer EDMed with a) Brass electrode and b) Copper electrode

Figure 7. SEM of the electrode after EDM a) Brass electrode and b) Copper electrode

a) Brass electrode



b) Copper electrode



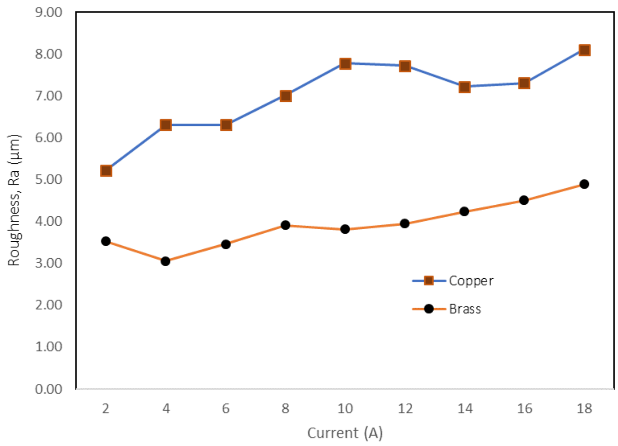


Figure 8. Relationship between surface roughness and current

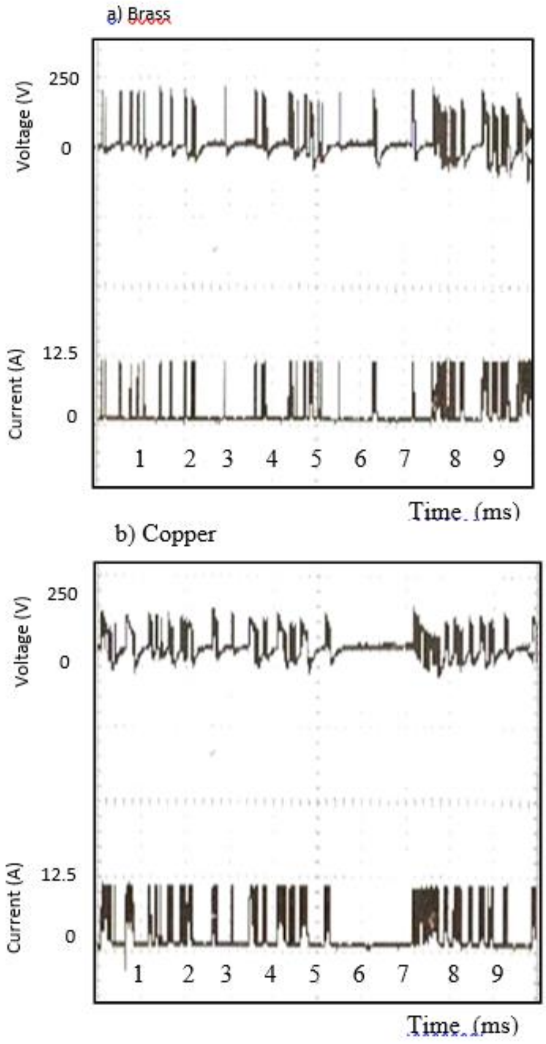


Figure 9. Waveforms of EDM with a) Brass and b) Copper electrode

5 CONCLUSIONS

EDM results of silicon nitride using brass and copper pipe electrodes are summarized as follows:

1. Brass was a better electrode material than copper because it gave lower electrical resistivity of the conductive layer, with higher MRR and reduced surface roughness.
2. Surface topography was greatly enhanced by copper electrodes due to their ability to produce uniform craters.
3. Electrode wear ratio of brass electrodes was higher than copper electrodes.
4. Discharge frequency obtained using a brass electrode was greater than for a copper electrode.
5. Analytical research suggested that one of the most promising methods for processing silicon nitride was to apply a contained assisting electrode. This was previously underutilized in experimental design and electrical discharge machining of insulating ceramics.

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