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WEAR CHARACTERISTICS OF COPPER AND ALUMINUM ELECTRODES DURING EDM OF STAINLESS STEEL AND CARBIDE

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ABSTRACT
The present work gives a comparative analysis of the performance of copper and aluminum electrodes for machining stainless steel and carbide. It was found that MRR (material removal rate) increases with increase in current and voltage, but MRR is higher during machining of stainless steel than that of carbide. During machining carbide, electrode wear and corner wear were higher than those during machining stainless steel. Wear of copper electrodes was less than that of aluminum electrodes. Volumetric wear ratio i.e., the ratio of the material removed from the work to the same removed from the electrode decreases with increase of current or voltage. That means, comparatively more material is removed from the electrode than that removed from the work. Investigations on work surface finish show that aluminum electrodes produce smoother surface than copper electrodes during machining of both stainless steel and carbide. The surface was found to be smoother on carbide than on stainless steel.

Keywords: EDM, Electrode wear, Corner wear, Volumetric wear ratio, Material removal rate.

1. INTRODUCTION
Electrical discharge machining (EDM) is one of the main methods of die production with high accuracy and precision with no physical contact between the tool and the workpiece. Therefore, no mechanical stress is developed on the work surface. The important output parameters of the process are material removal rate (MMR), tool wear, tool wear ratio and surface roughness [1, 2]. EDM process is widely used for machining high strength steel, tungsten carbide and hardened steel [3]. These materials are extremely hard and cannot be machined by conventional techniques. Electrodes for EDM are usually made of graphite, brass, copper and copper-tungsten alloys [4]. Among the other electrode materials tungsten, tungsten carbide, aluminum alloys and zinc alloys are worth mentioning. MRR is the primary factor that should be considered for EDM. Many works have been done on MRR as a function of current, voltage, pulse duration, etc. [5,6]. In all those works it was found that MRR tends to increase with the increase in current, voltage and duration of the pulse. But no comparative analysis of different electrodes was done. In fact EDM process is based on thermal energy that is generated by an electric arc between the electrode and the work that melts and vaporizes the work material. Due to this high temperature developed during the electric spark, a portion of material is also eroded from the electrode which is termed as electrode wear. Due to this wear, electrode looses its length and the depth of cavity formed becomes smaller than the desired one. However, attempts have been made to compensate the shortening of the electrodes by continuous monitoring. [7-10]. Volumetric wear ratio, which is the ratio of the material removed from the work to the same removed from the electrode, is also an important factor. It is desirable that MRR should be high keeping the electrode wear as small as possible. Again, if the cross-section of the electrode is a complicated one, sharp corners are eroded intensively and the electrode looses its normal shape. As a result, the shape of the cavity formed looses its precision.

Finally, high quality dies and cavities require good surface finish. In the present work, carbide and stainless steel have been taken as the work materials for investigations due to their extensive use in die making. They have been machined using copper and aluminum electrodes at different values of current and voltage. The output parameters that have been investigated in the present study are MRR, electrode wear, corner wear, volumetric wear ratio and work surface finish.

2. EXPERIMENTAL DETAILS

2.1 Electrode and Work Materials
Copper and aluminum electrodes were used in the present study. The physical properties of the aluminum electrode material are: electrical resistivity- 4.3 x10^{-6} ohm-cm, electrical conductivity compared to silver- 63%, thermal conductivity- 157 W/m-K, melting point- 650^{o} C, heat capacity- 0.893 J/g-^{o}C and coefficient of thermal expansion- 23.2 μm/m-^{o}C. The main properties of the

copper electrode material are: electrical resistivity- 1.71x10^{-6} ohm-cm, electrical conductivity compared to silver 92%, thermal conductivity- 391 W/m-K, melting point- 1083^{o}, heat capacity- 0.385 J/g-^{o}C and coefficient of thermal expansion- 17 µm/m-^{o}C. Work materials used in the present work were stainless steel and carbide. The principal mechanical and chemical properties of the carbide plates of grade GC-US16 used in the study are: 84% WC, 15% Co, grain size of the constituents 0.8 microns, hardness of 90.8 HRA and density of 13.8 g/cc. The main properties of the stainless steel of grade SUS 304 used are: 18% to 20% Cr, 8% to 10.5% Ni, tensile strength of 75 ksi, yield strength of 30 ksi and hardness of 187 HB.

2.2 Experimental Technique

Copper and aluminum electrodes used were of the cross-section of 15mm x 15mm and a length of 75 mm. The experiments were carried out on a CNC die sinking machine of model ATC-VSH. The experimental set-up is shown in Fig. 1. Ionized water was used as the dielectric

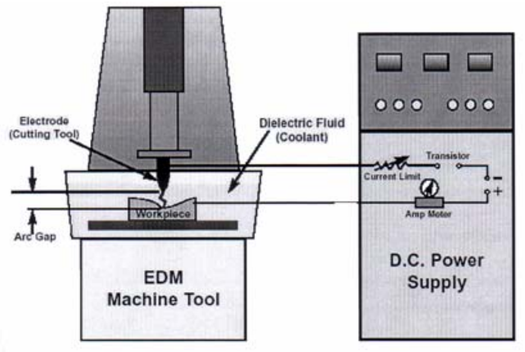

Fig 1. Set-up for the experiments

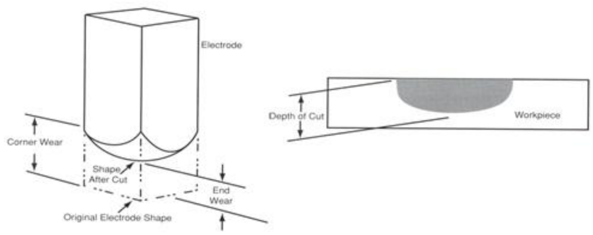

Fig 2. Wear of an electrode

material during machining. Machining tests were carried out at current ranging from 1.5 A to 7.5 A and voltage of 10V to 25 V. Rectangular holes of cross-section 15 mm x 15 mm with a depth of 5 mm were made on stainless steel and carbide plates using copper and aluminum electrodes. The lengths and weights of the electrodes were measured before and after machining. The difference between the weights of the electrodes before and after machining gives the electrode wear and the difference of weights of the work specimens before and after machining gives the weight of the material removed from the work. Volumetric wear ratio was calculated as the ratio of the volume of material removed from the work to the same removed from the electrode material. Corner wears of the electrodes, as shown in fig. 2, were measured using an optical microscope Mitutoyo Hisomet II. Roughness of the horizontal machined surface was measured by the surface roughness measuring equipment Mitutoto SURFTEST SV-500.

3. RESULTS AND DISCUSSION

3.1 Material Removal Rate

The material removal rate (MMR) shows an increasing trend with increase in current as illustrated in Fig. 3. A higher current produces stronger sparks with higher thermal energy causing increase in MRR. Similar results were fond during machining of composite materials, silicon carbide and 94WC-6Co carbides and tool steels [11-14]. Influence of current on MMR is more prominent during machining of stainless steel compared to carbides. This is because of lower specific thermal energy of stainless. Carbides need more thermal energy than stainless steel to be melted and vaporized. Copper electrodes show better performance in terms of MRR which is due to its better thermal stability than aluminum electrodes.

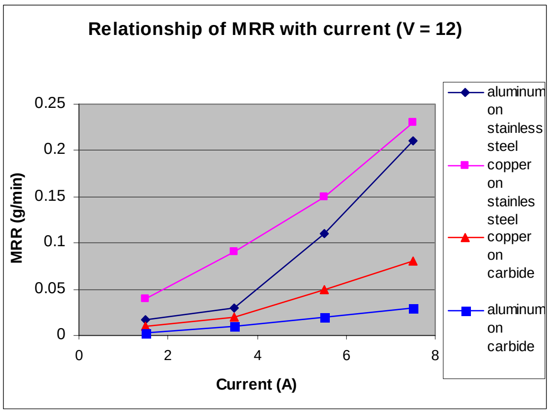

Fig 3. Relationship of MRR with current

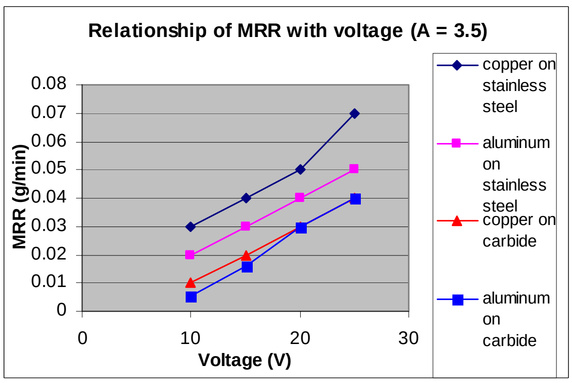

Fig 4. Relationship of MRR with voltage

Influence of voltage on MRR is shown in Fig. 4. The reason of increasing of MRR with the increase of voltage is similar to the reason for current. In this case also copper electrodes showed better performance than aluminum electrodes and MRR was found to be higher during machining of stainless steel than machining of carbide. It can be concluded that melting point of the work material is a key factor for MRR.

3.2 Electrode Wear

A higher current or voltage produces stronger spark with more thermal energy causing more electrode wear as shown in Fig. 5 and Fig. 6. Thermal conductivity of copper is about 1.5 times higher than that of aluminum. As a result, heat is more easily dissipated into the body of the electrode causing less electrode wear compared to the aluminum electrodes. It can be concluded that thermal conductivity is an important factor that reduces electrode wear.

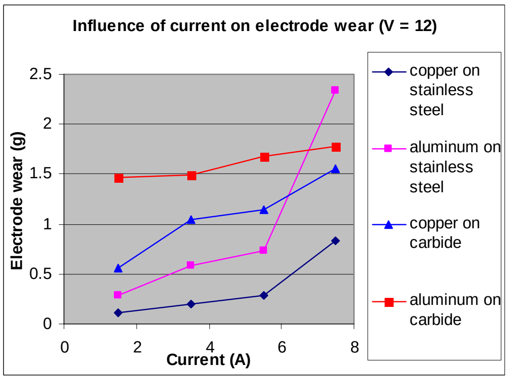

Fig 5. Influence of current on electrode wear

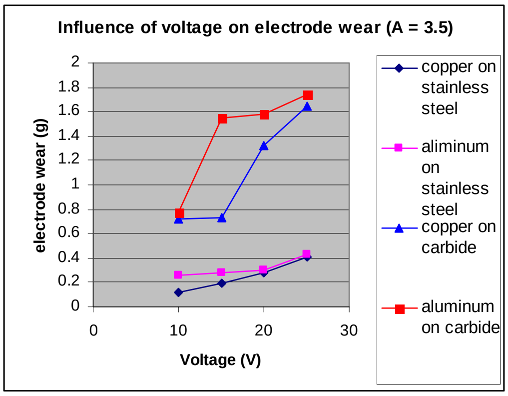

Fig 6. Influence of voltage on electrode wear

Figures 5 and 6 also show that during machining of carbide, electrode wear is higher than during machining of stainless steel. The heat energy required to remove unit volume of carbide is much higher than that required for stainless steel. As a result, it needs a longer time for machining of carbides causing more electrode wear.

3.3 Corner Wear

Relationship of corner wear with current and voltage during machining of stainless steel and carbide with copper and aluminum electrodes is illustrated in Fig. 7 and Fig. 8. Corner wear increases almost linearly with increase of current or voltage which is due to the availability of more thermal energy at a higher current or voltage. Again, better thermal conductivity of copper results less corner wear than on aluminum. Higher requirement of thermal energy during machining of carbides causes more corner wear of electrodes than during machining of stainless steel.

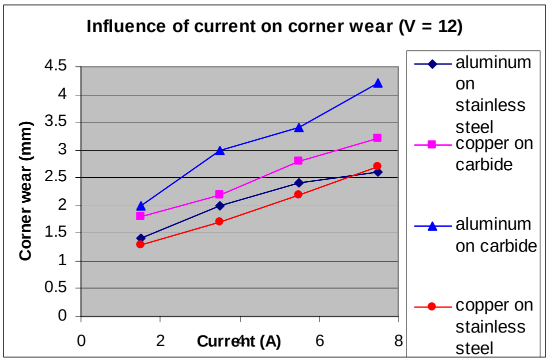

Fig 7. Influence of current on corner wear

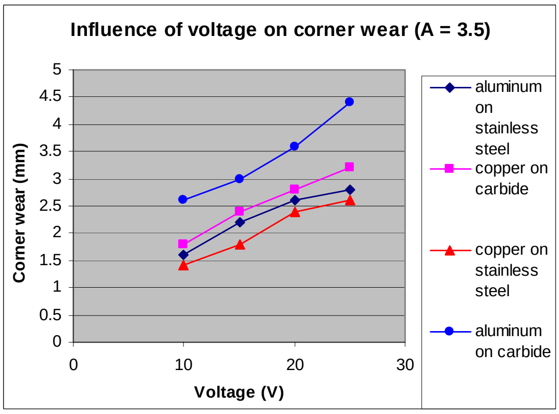

Fig 8. Influence of voltage on corner wear

3.4 Volumetric Wear Ratio

Volumetric wear ratio was calculated as the ratio of the volume of material removed from the work material to the same removed from the electrode material. Figure 9 and 10 illustrate the relationship of volumetric wear ratio with current and voltage. It was found that volumetric wear ratio decreases with increase in current and voltage. It can be supported by the fact that at a higher current and voltage comparatively more material is removed from the electrode than from the work.

During machining of stainless steel volumetric wear ratio was found to be higher than that during machining of carbide. This is due to the fact that the specific heat energy and melting point of carbide is higher than those of stainless steel which causes less MRR for carbide. Moreover, volumetric wear ratio was found to be higher while using copper electrodes. This is because of higher melting point and thermal conductivity of copper than aluminum.

During machining of stainless steel volumetric wear ratio was found to be higher than that during machining of carbide. This is due to the fact that the specific heat energy and melting point of carbide is higher than those of stainless steel which causes less MRR for carbide. Moreover, volumetric wear ratio was found to be higher while using copper electrodes. This is because of higher melting point and thermal conductivity of copper than aluminum.

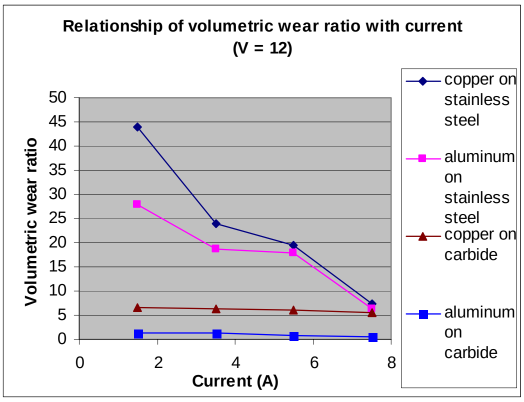

Fig 9. Relationship of volumetric wear ratio with current

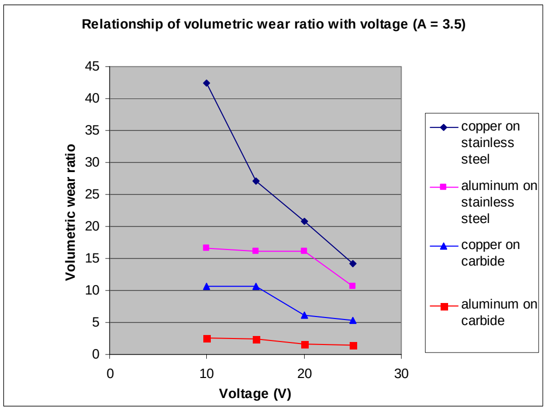

Fig 10. Relationship of volumetric wear ratio with voltage

3.5 Surface Finish

A higher current or voltage produces a strong spark with higher energy. As a result a crater of larger dimension is made on the work material resulting a poorer surface finish as illustrated in Fig. 11 and Fig. 12. Puetas [16] also found similar results on 94WC-6Co. However, it was stated that with the increase of current, surface roughness value reaches to a maximum value, then it decreases. With increase in voltage, surface finish increases steadily (Fig. 12). But an increase in current causes a sharp increase in surface roughness during machining of stainless steel (Fig. 11). This is due to the formation of craters of larger size on stainless steel at a higher current.

On the contrary, during machining of carbides surface roughness increases slowly with increase in current due to the higher thermal stability of carbides and formation of smaller craters produced during each spark. Fig. 11 and Fig. 12 also show that aluminum electrodes produce better surface finish than copper electrodes during machining of both stainless steel and carbide. As it has already been discussed, during machining with copper electrodes, MRR is higher than that of aluminum. As a result, more number of particles removed from the work is accumulated within the gap between the electrode and the work. This accumulation of particles causes additional uncoordinated sparks that results a poor machined surface.

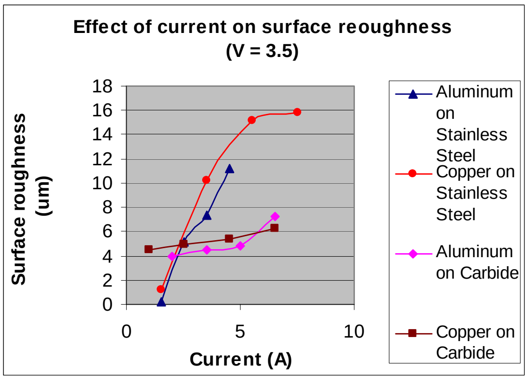

Fig 11. Effect of current on surface finish

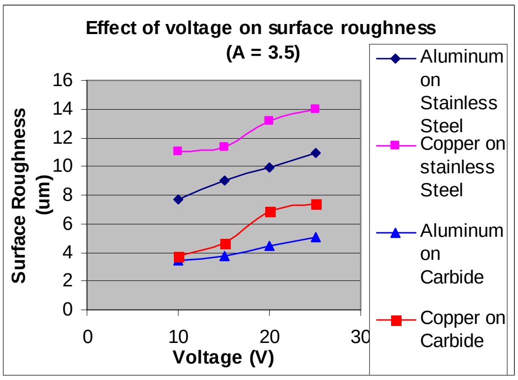

Fig 12. Effect of voltage on surface finish

4. CONCLUSIONS

From the above analysis and discussions the following conclusions can be made:

i. MRR increases with the increase of current and voltage. MRR of stainless steel is higher than that of carbide due to less specific energy of stainless steel than carbide.

ii. Copper electrodes give higher MRR than aluminum electrodes during machining of stainless steel and carbides.

iii. Aluminum electrodes undergo more wear than copper electrodes due to their lower melting point and specific thermal energy than copper electrodes. Corner wear of aluminum was also found to be higher than that of copper electrodes due to the same reason. Both copper and aluminum electrodes undergo more wear during machining of carbide than during machining of stainless steel due to more machining time required to remove the same volume of material from carbide.

iv. Volumetric wear ratio shows a decreasing trend with increase of current and voltage. It indicates that at a higher current or voltage comparatively more material is removed from the electrodes compared to the work materials. Volumetric wear ratio is higher during machining of stainless steel than machining of carbides. It was found that during machining of carbide with aluminum electrodes, volumetric wear ratio is very low which indicates an intensive wear of electrode material compared to the work material.

v. Surface finish becomes poorer with increase of current and voltage. A higher current or voltage gives a stronger spark, making a crater of higher depth on the work surface. As a result, the surface becomes rougher. Influence of current on surface finish is stronger on stainless steel than on carbide. Copper electrodes remove comparatively more work material than aluminum electrodes that accumulate within the gap between the work and the electrode. As a result, additional uncoordinated sparks occur making the work surface rougher.

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