INVESTIGATION OF THE INFLUENCE OF THE PROPERTIES OF THE WORK AND TOOL MATERIALS ON PERFORMANCE LEVEL OF ELECTRICAL DISCHARGE MACHINING (EDM) PROCESS.

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Abstract: Influence of the properties of work and tool materials on material removal rate (MRR), wear ratio (WR), thickness of the recast layer, surface roughness and accuracy of the tool was studied in EDM process. Copper, brass, stainless steel, mild steel and grey cast iron were used as working materials in EDM work. From the experimental results it was observed that the WR of MRR vs machining time shows a curve behavior, inversely proportional to the melting point of the work and tool materials respectively. Though brass tool was found to have lower wear ratio but it has lower MRR. Further work was done to observe the thickness of the recast layer, surface roughness and accuracy of the tool. The Recast layer (RL) was measured on a metallographic microscope. Calculation of Material Removal Rate was based on the measurement of volume loss of work material per minute of machining time. The wear ratio of the electrode was defined as the percentage of volume of electrode wear per unit volume of material removal in the same machining interval. The average surface roughness of the machined surface was measured on a surface roughness measuring instrument model Systest AB5.

2.1 Condition and Assumption of the experiment
From the earlier theoretical investigations it was observed that the tool wear ratio, material removal rate and job surface roughness depend on electrical conductivity and melting points of the work and tool materials, current polarity, gap between the electrode and the work piece, etc. Influence of the magnetic properties of the tool material was neglected throughout the investigation. Although electrical flow influences material removal rate yet only immersion type fluid flow was used. Following assumptions were made during the study:
(a) Temperature and Pressure of dielectric fluid were assumed to be constant.
(b) Formation of the recast layer on the machining surface occurs at steady state condition.
(c) Current consumption was constant throughout the whole study.
(d) Particles were eroded uniformly from the electrode.

2.2 Conditions of EDM
Feed rate (f) : 0.1 mm/min
(Servo control)
Gap voltage (V) : 2 - 3 V.
Peak current (I) : 0.4 - 0.5 A
Total Machining time (t) : 225 mins.

2.3 Properties of the tool and work material
The electrical conductivity of the different material used as work and tool materials were measured using standard procedure. The values of resistivity, melting points, specific gravity and conductivity are shown in Table-1.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Copper</th>
<th>Brass</th>
<th>Stainless steel</th>
<th>Mild Steel</th>
<th>Cast iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Resistivity micro ohm/cm</td>
<td>1.96</td>
<td>5.74</td>
<td>70.50</td>
<td>19.58</td>
<td>73.00</td>
</tr>
<tr>
<td>Electrical Conductivity Compared with Silver, %</td>
<td>92.00</td>
<td>67.00</td>
<td>19.33</td>
<td>17.70</td>
<td>15.33</td>
</tr>
<tr>
<td>Thermal Conductivity cal/cm²cm°C/sec</td>
<td>92.5%</td>
<td>67.5%</td>
<td>19.33%</td>
<td>17.7%</td>
<td>15.33%</td>
</tr>
<tr>
<td>Melting point °C</td>
<td>1083</td>
<td>850</td>
<td>1525</td>
<td>1430</td>
<td>1250</td>
</tr>
<tr>
<td>Specific heat, cal/g°C</td>
<td>0.092</td>
<td>0.0928</td>
<td>0.107</td>
<td>0.1027</td>
<td>0.101</td>
</tr>
<tr>
<td>Specific gravity at 20 °C, g/cm³</td>
<td>8.9</td>
<td>8.24</td>
<td>7.9</td>
<td>7.85</td>
<td>7.8</td>
</tr>
<tr>
<td>Coefficient of thermal expansion per °C X10⁴</td>
<td>6.6</td>
<td>20.53</td>
<td>11</td>
<td>8.2</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Table-1: Physical Properties of the Materials.
3.0 Experimental Results

3.1 Material Removal Rate (MRR): Curves of MRR, version machining time are plotted using lot 1-2-3 (Fig.1). It is observed from these relationships that MRR does not show any linear behavior in all cases. Convex behavior of MRR with time, specially after a long duration of machining is observed. This may be due to a number of reasons. First of all, there have possible losses of thermal energy to surrounding atmosphere. Secondly, an increase in discharge duration beyond certain limit, for a given electrode and job material may lead to arcing due to carbon deposition on both the machining as well as the tool surface. Apart from that the particle which come out after erosion does not get effective expulsion due to lack of turbulence of the dielectric fluid. These particles remaining on the machining surface interfere with the discharge process and resists the pace of erosion. It is also observed from the curves that during machining of mild steel, brass and copper maximum material removal ratio is offered by brass tools. But during machining of stainless steel and cast iron copper and cast iron electrodes show better performance.

Curves of MRR and electrode wear rate versus melting points of job and electrode materials are plotted using micro soft windows version-6.0 on log-log scale (Fig.2). The relationships show almost linear behavior. MRR of the job having lower melting points are higher than that of higher melting point materials. This may be associated with lower energy requirement of the lower melting point materials to be eroded during EDM bombardment. The figure also shows that the MRR is higher than the wear rate of the electrodes. This is associated with the direct polarity used in the process in which the tool acted as the cathode, causing bombardment of the anode (work piece) by electrons. Since the bombardment caused by the electrons had higher energy than the bombardment caused later by ions and particle from the vaporized anode (job materials), wear of the cathode (tool) is lower than that of the anode (work piece).

3.2 Tool Wear Ratio: The wear ratio of the electrode is defined as the percentage of volume of electrode wear per unit volume of material removal. The wear ratios for different tool-job material combinations are shown in the form of bar charts.

Figure 2: Average metal removal rate versus melting point

Fig.1: Dependence of material removal on machining time for different tool-job material combinations in finish cut.
in Fig. 3. Minimum wear ratio is observed in the case of the brass electrode for all the combinations of tool and work materials. It is observed from Fig. 2 that the lower melting point electrodes are eroded at higher rate than the higher melting point electrodes in absolute values though the wear ratios are lower for these materials.

3.3 Recast Layer (RCL): Metallographic specimens of the middle section of the machined specimens were prepared to study the thickness and properties of the recast layer. Specimen photographs of these samples are illustrated in Fig. 4. The recast layer is also termed as the white layer due to its appearance since it is uncontaminated and can be easily identified. This layer is chromatographically different from the original surface when observed with polarized light and viewed under a microscope.

Since the electrode was fed vertically from the top into the work piece it prevented the dielectric fluid from effective flushing of the particles from the bottom of the EDM hole. As a result these particles are deposited on to the surface ensuring the reinforcement in the form of recast layer.

Fig. 4: Micro photograph of the recast layer formed on mild steel work piece surface after 223 min. of machining with: a) copper tool, b) mild steel tool.

thicknesses of the recast layers formed on the machined surface for different combinations of the tool and work piece materials are represented by bar charts (Fig. 5). It may be observed that copper electrodes form recast layers of higher thicknesses than other electrodes. It is due to the fact that copper electrode emits charges of higher energy which are able to penetrate deeper into job materials. Any molten metal which is not expelled during the process is resolidified to form a hard skin on the surface. Thermal stress, plastic deformation and shrinkage result in residual tensile stresses. Directly beneath the hard skin is a heat affected zone. This layer is softer than parent metal. This layer has lubricant retaining properties as are desirable for dies. So far machining dies copper electrodes are more suitable than other types of electrodes.

3.4 Micro Size Cavities and Surface Finish:

Sample photographs of the micro size cavities formed on the machining surface are shown in Fig. 6. It is observed from the figure that the cavities formed by the brass and copper electrodes, having lower melting points and higher electrical conductivity, are small in size (2-3 μm), where as, the sizes of the cavities formed in the cases of high melting point and low electrical conductivity electrodes, like mild steel, cast iron and stainless steel are higher (8-20 μm). This may be explained by the fact that for higher conductivity electrodes the energy of the electrical discharge is higher than for lower conductivity electrodes. Electrical discharge with higher energy causes a deeper penetration in the job material along a narrow cavity leading to smaller diameters of the cavity. As a result the surface roughness of the work piece is lower in the case of highly conductive materials like copper and brass.

3.5 Accuracy of the Machined Surfaces: Sections across the cavity machined by different tool materials on the different job materials were photographed. Fig. 8 shows the shape of the bottom surface of the cavity and also the over size due its conical shape. The over size is due to higher duration of exposure of the side surface of the work piece to the sparking process. It may be observed from the figure that brass electrodes impart convex shape to the bottom surface of the cavity specially when higher melting point materials are machined.
This may be related to the fact that the tendency of debris to concentrate at the middle of the tool-work interface results in high bottom surface inaccuracy when the duration of machining is high. Apart from that, the bottom surface of the tool-work interface does not get effective circulation of the dielectric fluid and get heated up. At an elevated temperature the low melting point electrode (brass) starts eroding out at a faster rate than the high melting point tool material leading to the concave shape of the tool at its bottom surface and a corresponding convex shape to the mating job surface. But when high thermal conductivity material like copper is used as electrode material there is absence of concavity on the job surface due to fact that the particles at middle portion also gain freezing point simultaneously with the side particles. So in the case of copper electrode the bottom surface is almost flat and side taper was also low. This leads to the accurate shape of cavity machined by copper electrodes as compared to the same machined by other electrodes.

4.0 Conclusions: From the experimental results and analysis the following conclusions may be drawn.

1. Material removal rate offered by brass electrode is the highest followed by copper, cast iron, mild steel and stainless steel in most of the cases.

2. Tool wear rate of brass electrode is the highest in all the combinations of tool and work materials. In machining cast iron, mild steel and stainless steel the second highest tool wear rate is for copper electrode, closely followed by cast iron, mild steel and stainless steel electrodes.

3. Tool wear per unit volume of job material removal (tool wear ratio) is the highest in the case of brass electrode and lowest in the case of copper electrode for all the investigated work piece materials. With regard to tool wear ratio cast iron stainless steel and mild steel electrode occupy intermediate positions.

4. Tool materials may be ranked, with respect to the thickness of the recast layer formed on the machined surface, in the descending order as follows: copper, brass, stainless steel, mild steel and cast iron.

From the point of view of surface roughness imparted to the machined surface tool materials may be ranked in the ascending order as follows: copper, brass, stainless steel, mild steel and cast iron.

6. With respect accuracy of machining copper is the best tool specially for high melting point job materials where as brass is the worst tool.

7. Brass electrode offering the highest rate of metal removal may be recommended for rough EDM machining and copper electrode having minimum wear ratio and offering highest accuracy of machining may be recommended for finishing operations.

References:


