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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 machining in EDM process was investigated. Copper, brass, stainless steel, mild steel and grey cast iron were used in various combinations as work and tool materials. From the experimental results it was observed that the curves of MRR versus machining time show convex behaviour, specially after long duration of machining. It was also observed that the MRR and WR are inversely proportional to the melting points of the work and tool materials respectively. Though electrical conductivity of the tool material was found to have influence on tool wear ratio but brass tool was found to have minimum wear ratio although its electrical conductivity was next to copper. From the bar chart of the recast layer thickness it was observed that for all combinations of work and tool material the thickest recast layer was formed in the case of copper electrode. Photo micrographs of the machined surface reveal that micro cavities formed in the cases of lower melting point electrode materials like copper and brass having higher electrical conductivity are comparatively smaller in size (2-3 μm) as compared to the sizes of the micro cavities (8-20 μm) formed in the cases of high melting point electrodes also having lower electrical conductivity. Consequently the machined surface roughness in the latter cases is higher. It was also observed that the tendency of debris concentration is at the middle of the tool-job interface resulting in high bottom surface inaccuracy, specially when high melting point work material are machined by low melting point electrodes like brass. On the basis of material removal rate, wear ratio and job surface finish brass electrodes were found to be most suitable.

1. Introduction

With the advancement of technology new materials and alloys with high mechanical properties are being introduced to the production arena. These materials can not be machined by conventional methods but require special techniques. Electro-discharge machining is among the earliest of the non traditional manufacturing processes, having had its inception roughly 50 years ago in a simple die sinking application. In Bangladesh EDM has very limited application in a few industries. The process is mainly applied for final machining of die surfaces. The materials of dies for various applications are stainless steel or various grades of alloy steels. In the absence of technical know how effective application of the process is hindered leading to improper selection of tool material and process parameters. This adversely affects the material removal rate, accuracy, surface roughness and surface quality of the work piece. As a consequence the process is becoming unnecessarily expensive and also less popular. To overcome the existing situation the present work was undertaken. The main objective of the work was to determine the appropriate tool materials for machining various work materials on the basis of material removal rate, tool wear, machining accuracy, job surface roughness, thickness of the recast layer and other criteria.

2. Experimental Procedure

Experiments were conducted on an electrical discharge machine, Model No-18401, employing

pulse generator and electro-mechanical type servo motor for gap control. Brass, copper, mild steel, stainless steel, cast iron were used as electrode as well as work piece materials. Machining was performed at right angle to the job surface. Kerosene was used as the dielectric fluid. Depth of the cavity machined was measured by using a dial gauge and tool wear was measured using an instrument microscope after a fixed interval of machining. From these data the material removal rate (MRR) and the wear ratio (W.R) were calculated. The thickness of 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 ration of the electrode is 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 sulftest AB.5.

2.1 Condition and Assumption of the experiment

From the earlier theoretical investigations it was observed that 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 on the tool wear was neglected through out the investigation. Although dielectric 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) (Servo control)	:	0-1 mm/min
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 restivity 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-1: Physical Properties of the Materials.

Properties	Material				
	Copper	Brass	Stainless steel	Mild Steel	Cast iron
Electrical Resistivity micro ohm/cm	1.96	5.74	70.50	19.58	73.00
Electrical Conductivity Compared with Silver, %	92.00	67.00	19.33	17.70	15.33
Thermal Conductivity cal/cm²/cm/°C/sec	92%	67%	19.33%	17.7%	15.33%
Melting point °C	1083	850	1535	1430	1250
Specific heat, cal/g°C	0.092	0.0928	0.107	0.1027	0.101
Specific gravity at 20 °C, g/cm³	8.9	8.24	7.9	7.85	7.8
Coefficient of thermal expansion per °Cx10⁻⁶	6.6	20.53	11	8.2	6.6

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 ddoes not show exactly linear behaviour in all cases. Convex behaviour 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 canbe 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 the both the machining as well as the tool surfaces. 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 interferes 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 rate 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 behaviour. 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

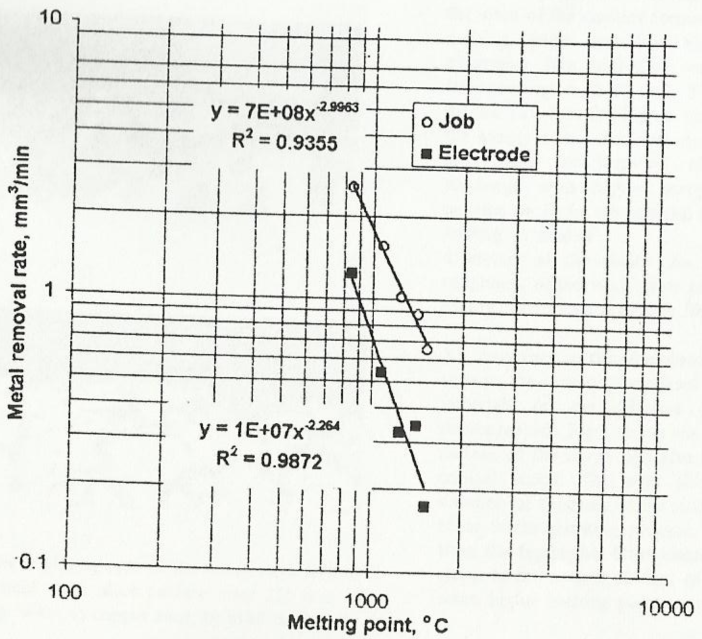


Figure 2 : Average metal removal rate versus melting point

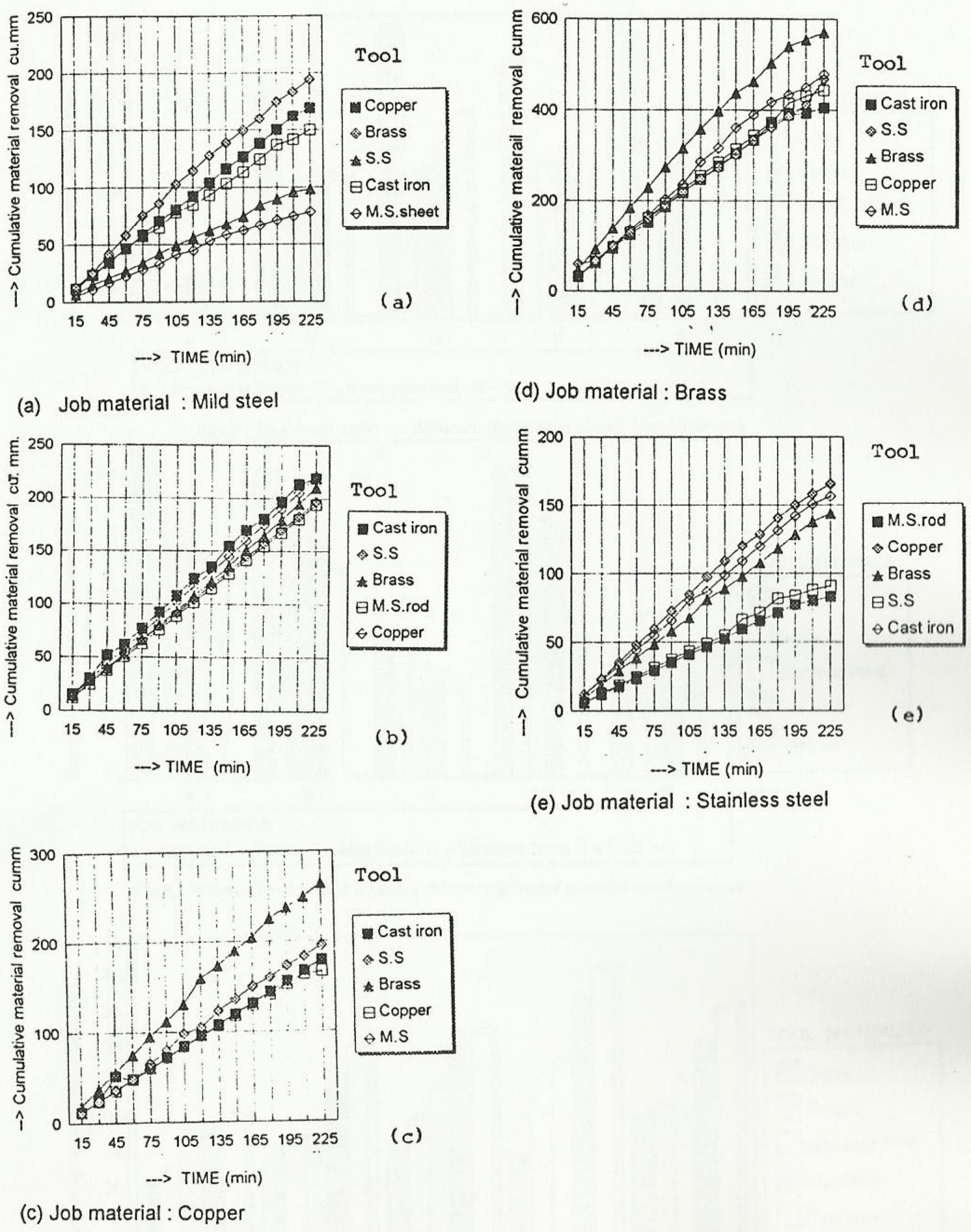
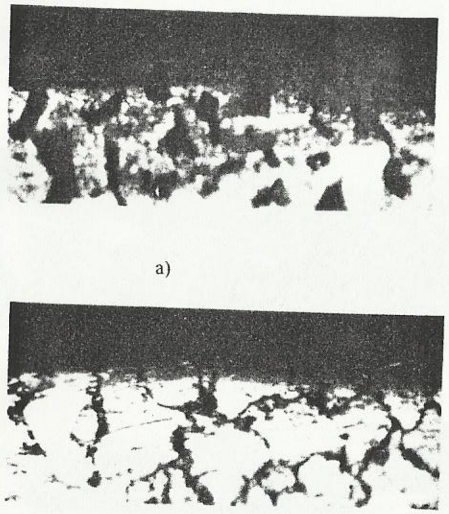


Fig.1: Dependence of material removal on machining time for different tool-job material combinations in finish cut.

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 are 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 unetchable and can be easily identified. This layer is chromatically 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 an EDM hole. As a result these particles are deposited on to the surface ensuring the reinforcement in the form of recast layer.



a)

b)

Fig.4: Micro photograph of the recast layerformed on mild steel work piece surface after 225 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 sizes (2-3 um), 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 um). 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.

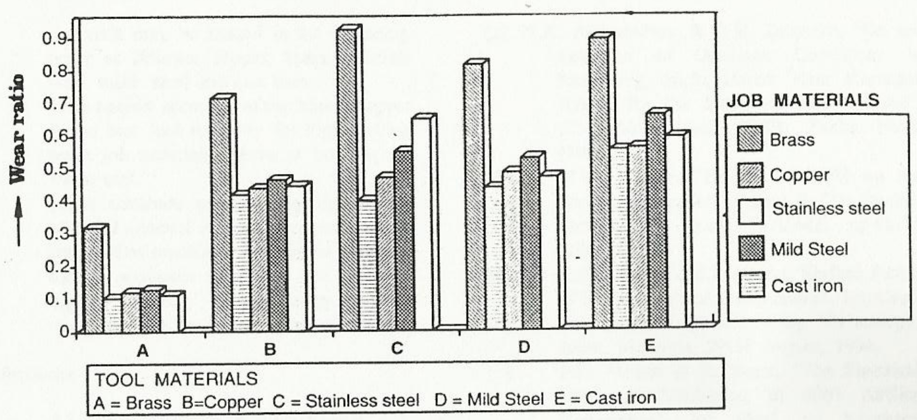


Fig.3 : Tool wear ratio for different tool-job material combinations

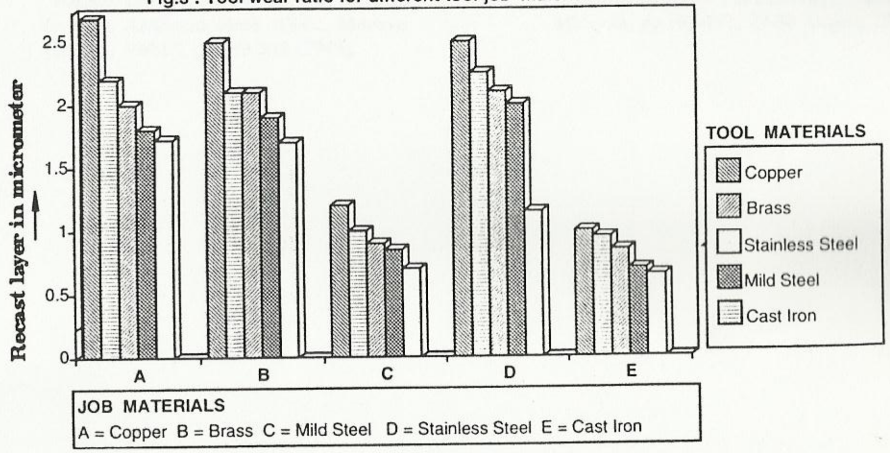


Fig.5 : Thickness of recast layer for different job-tool material combinations

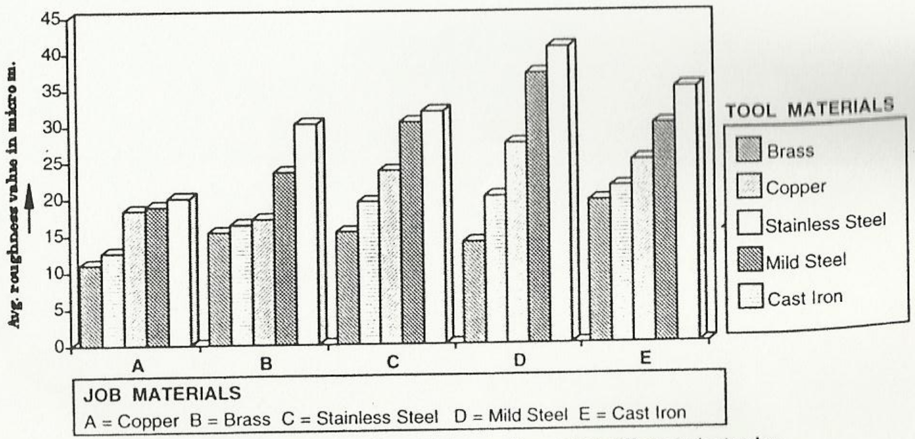
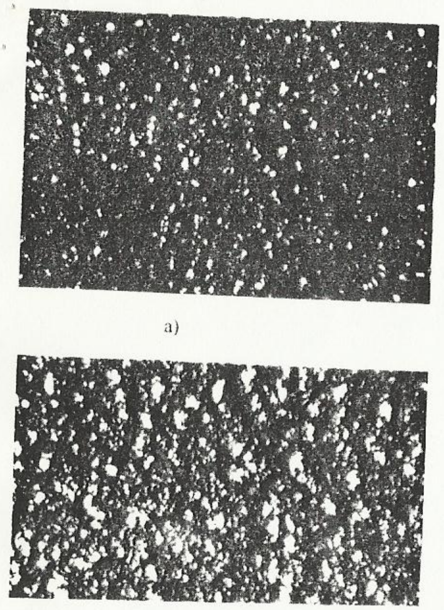


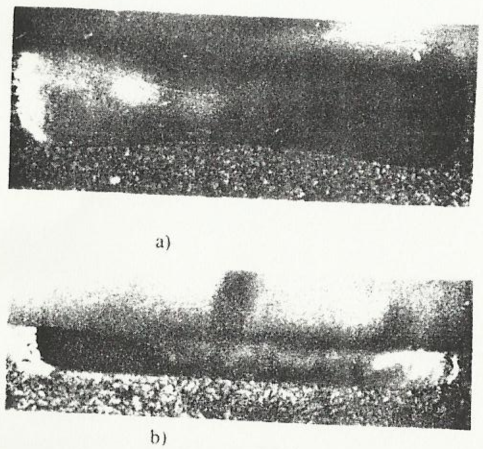
Fig.7 : Surface roughness value of machining surface using different electrodes



a)

b)

Fig.6: Photographs of machined surface after 225 min. of machining of stainless steel with: a) brass tool, b) stainless steel tool.



a)

b)

Fig. 8: Sample photographs of the section across the cavity machined on brass by: a) brass tool and b) copper tool

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 job 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.
5. 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.

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