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EFFECT OF TOOL MATERIAL ON SURFACE ROUGHNESS IN ELECTRICAL DISCHARGE MACHINING

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Abstract: *H11 die steel is widely used in forging dies, aircraft landing gears and shafts. Electric discharge machining (EDM) is one of the most suitable processes to shape this material. This work demonstrates the effect of pulse-on-time (T_{on}) on surface roughness during EDM of H11 tool steel by taking three different tool electrode materials. Experiments have been conducted by varying T_{on} in four steps (10 µs, 20 µs, 30 µs, 40µs) while keeping the values of other variables fixed. On the basis of experimental results, it is concluded that tool properties of electrode play a vital role in machining characteristics of die-sinking EDM process. The results demonstrate that Copper-tungsten electrode offers the best surface finish followed by graphite and copper electrode in EDM of H11 too steel.*
Key words: *electrical discharge machining, surface roughness, pulse-on-time, H11*

Uticaj materijala alata na hrapavost obrađene površine kod elektro-erozivne obrade. *Alatni čelik H11 je široko primenjen kod alat za hladnu deformaciju, donjeg trapa aviona i vratila. Elektro erozivna obrada je jedan od najadekvatnijih postupaka obrade ovakvog tipa materijala. U ovom radu je demonstriran efekat vremena ciklusa pražnjenja na površinsku hrapavost obratka kod elektro erozivne obrade alatnog čelika H11 korišćenjem tri različita materijala elektrode. Eksperimenti su sprovedeni variranjem dužine vremena ciklusa pražnjenja na četiri nivoa (10 µs, 20 µs, 30 µs, 40µs) dok su ostali parametri konstantni. Na osnovu eksperimentalnih istraživanja zaključeno je da osobine materijala elektrode igraju ključnu ulogu u karakteristikama procesa elektro erozivne obrade punom elektrodom. Rezultati pokazuju da elektrode od legure bakar-volframa nude najbolju površinsku hrapavost a iza njih su grafitne i čisto bakarne elektrode kod elektro erozivne obrade alatnog čelika H11.*
Ključne reči: *elektro erozivna obrada, hrapavost površine, vreme ciklusa pražnjenja, H11*

1. INTRODUCTION

H-11, a hot die steel material, with distinctive properties like high hardenability, high strength, high toughness, resistance to thermal softening and high heat generation makes this steel suitable for the production of hot work dies, extrusion, forging, die casting etc.Its distinctive properties encompass the automotive and aerospace industries and find usage in gears, bearing, tool, aircraft landing gears, helicopter rotor blades and shafts [1].

The difficulties faced in the machining of H11 on conventional machines can be attributed to its mechanical and metallurgical properties. The addition of 1.5% Molybdenum imparts high hardenability to this steel and make difficult to machine by conventional process [2]. Non-traditional machining is found to be one of the alternatives for machining H11.EDM is a process in which material is eroded from the work piece by the use of electric sparks occurring between the tool and the work piece separated by a dielectric medium. The temperature which is created by the electrical spark is around 8000-12000^{0}C which is enough to melt and erode the work piece surface as well as tool electrode also. EDM is known for its thermal behaviour which can machine any electrically conductive material regardless of its strength and hardness [3]. Therefore, EDM is specialized in generating a complex structure with high precision in the range of several micrometres with remarkable surface finish [4].

EDM is a very complex process whose performance depends on the parameter chosen.Thus, certain input parameter which when varied in EDM process have a significant effect on performance measures such as material removal rate (MRR), tool wear rate(TWR),and surface roughness (SR) of the machined work piece. The efforts are constantly being made in the area of EDM to obtain high MRR and TWR along with low SR.A lot of work has been reported in the literature in respect of obtaining a high level of surface finish in the field of EDM.Payal et al. [5] investigated the machining characteristics of H11and H13 material by taking three electrode material i.e. aluminium, copper and graphite. They reported that copper electrode achieved the best surface finish among other electrodes. Singh et al. [6] conducted an experimental investigation on EDM for H11 tool steel. It was found from the experimental results that by selecting the negative polarity of the electrode and mixing of dielectric with suspension powder there will be an improvement in the SR. Singh et al. [7] explained the influence of electrode type and material on the EDM process by taking EN-31 tool steel as a work piece and copper, copper-tungsten, aluminium, and brass as an electrode material. They have taken discharge current as the input parameter which varies in steps. They reported that copper electrode showed better results related to MRR, diameter overcut, TWR and SR followed by the aluminium electrode. Jahan et al. [8] investigated the performance of micro-edm on Tungsten carbide (WC) using copper tungsten (CuW), Tungsten (W) and silver-tungsten (AgW) as an electrode material. The performance measures selected were surface characteristics, average surface roughness and peak-to-valley. It was observed that AgW was the best electrode material in all performance measures. Muthuramalingam and Mohan [9] explained the importance of tool electrode materials (copper, brass, tungsten carbide) on the machining performance of AISI 2020 stainless steel in EDM process. They reported that copper electrode produces higher MRR and tungsten carbide electrode showed better surface finish. Dewangan et al.[10] studied the effects of EDM parameters as well as tool electrode materials (copper, brass and graphite) onAISIP20 tool steel .They have reported that graphite tool showed better results in regards towhite layer thickness,surface crack density and SR followed by brass, copper. Lee and Li[11] conducted an experimental investigation on EDM for Tungsten carbide material using copper, copper tungsten and graphite as tool electrode material. They have taken MRR, SR, TWR as the performance measures.It was observed from the results that graphite electrode offers higher MRR whereas copper electrode showed higher TWR but better surface finish.They also reported that with negative tool polarity maximum MRR, minimum TWR and SR could be achieved.

The present work investigates the EDM of AISI H11 tool steel material using three different electrode materials copper (Cu), copper-tungsten (CuW) and graphite (Gr). The pulse –on –time has been varied in four steps to study the SR.

2. EXPERIMENTATION

The experiments were conducted on Electronica PS50ZNC die sinking machine shown in figure 1with commercial grade EDM oil (density=0.784Kg/m^3, flash point=103^0 C, dielectric strength=45) was used a dielectric fluid. The work piece material was AISI H11 tool steel with the rectangular shape of 40mmx36mmx18mm dimension. Three different tool electrodes of cylindrically shaped namely Copper (Cu), Copper tungsten, Cu20%W80%) and Graphite (Gr) as shown in figure 2 were used in the present study. Typical mechanical properties and chemical composition of H11 are depicted in table 1and table 2. Table 3 represents the experimental conditions in which all the parameters were kept constant except pulse-on-time. The different properties of all the tool materials are depicted in table 4. The input parameter pulse-on-time has been varied in four steps. The other input parameters were kept fixed during experimentation. The SR is taken as the response variable.SR in measurement is defined in different ways like arithmetic average (R_a), average peak to valley height (R_z) and peak roughness (R_p), etc. In the present study arithmetic mean SR value (R_a) is found out. Arithmetic average roughness is defined as the deviation of the roughness profile from the central line along the measurement.The mathematical formula to calculate R_a isaverage deviation of profile *y(x)* from the mean line as shown in equation 1 and 2 [12].

$$R_a = \frac{Total\ shaded\ area}{L} \quad (1)$$

$$R_a = \frac{1}{L}\int_0^L |y(x)|dx \quad (2)$$

Where, y(x): Value of roughness profile L: Evaluation length. Figure 3 shows the photograph of Mitutoyo Surface Roughness Tester SJ2100 has been used in the evaluation of surface roughness value.

Property	Unit	Value
Density	g/cm^3	7.81
Melting Point	$^{\circ}$C	1427
Elastic modulus	GPa	207
Thermal expansion	(10-6/$^{\circ}$C)	11.9
Thermal conductivity	(W/m-K)	42.2
Hardness	HRC	57

Table 1. Mechanical properties of H11

Elements	C	Si	Mn	P	S
Wt. %age	0.648	0.603	0.262	0.0078	0.0145
Elements	Cr	Mo	V		
Wt. %age	5.17	1.23	0.756		

Table 2. Chemical composition (wt %) of H11 material

Pulse on Time	10μs,20μs,30μs,40μs
Sparking Voltage	60V
Current	8A
Dielectric used	Spark Erosion oil (SEO-250)
Polarity	Straight
Servo system	Electro Hydraulic
Electrode polarity	Negative
SEN/ ASEN	6/4

Table 3. Experimental Conditions

Material	Gr	Cu	CuW
Composition	-	99.9 % Cu	20%Cu +80%W
Density(g/cm^3)	1.811	8.904	15.2
Melting point(^{o}C)	3350	1083	3500
Electrical-resistivity(Ωmm^2/m)	10	9	5.5

Table 4. Electrode material properties

Fig.1. Physical set up of Electrical Discharge Machine

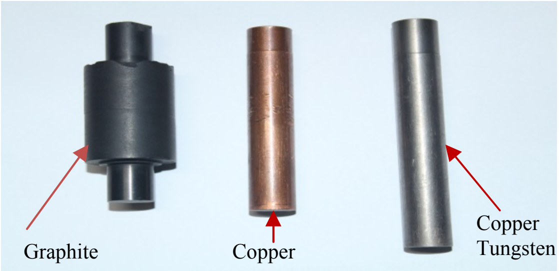

Fig. 2. Electrodes Gr, Cu and CuW

Fig.3. Mitutoyo Surface Roughness Tester SJ2100

The initial and final weights of the electrode and work piece are measured by the electronic weighing balance of make Shimadzu ATX224 having a resolution of 10mg. Figure 4 shows the H11 work piece machined by different electrode material i.e. copper tungsten, copper and graphite.

3. RESULTS AND DISCUSSION

On the basis of the experimental results, the effect of pulse-on-time on SR with different tool electrode materials has been shown in Figure 6. The surface profile of different electrode material for different value of pulse-on-time is given in figures 7-9. Figure 6 indicates that SR increases with increase in pulse-on-time for all the three electrode material. This may be attributed to the formation of deep craters with the increase in pulse-on-time resulting in rougher surface. SR is dependent on the value of the pulse-on-time, lower the value of pulse on time smoother will be the surface formed [13]. Hence, the surface finish of the work piece depreciates with an increase of pulse-on-time and gets better with low pulse-on-value. In the present study, the results depict that CuW exhibits best surface finish as compared to the other two electrodes because of the thermophysical property of the electrode. CuW has high density, high strength, high melting point as well as good thermal and electrical conductivity which contribute in obtaining high surface finish.

The melting point of electrode material can also be linked up with the surface quality of work piece. Higher pulse- on- time leads to more discharge energy resulting in more heat and temperature at the electrode part. At higher temperature, electrode melts and the debris of electrode material fall at the surface of work piece making the surface rougher. The melting points of Cu, CuW and Gr are 1083^{0}C, 3500^{0}C and 3350^{0}C respectively [14]. Therefore, CuW showed better surface finish than the other two electrodes.

Pulse on time (μs)	Ra by Cu (μm)	Ra by CuW (μm)	Ra by Gr (μm)
10	5.072	3.5385	3.563
20	5.4215	5.0855	4.322
30	5.5712	5.362	5.1155
40	5.6012	5.5585	6.202

Table 5. SR with Cu, CuW and Gr electrodes at different pulse-on-time.

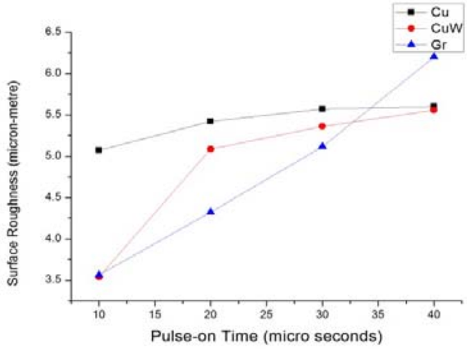

Fig.6. Pulse –on- Time vs SR

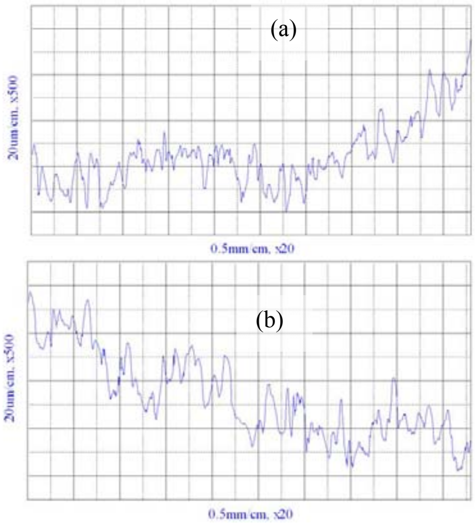

Fig. 7. SR profile of Cu at (a) 10 μs and (b) 40μs.

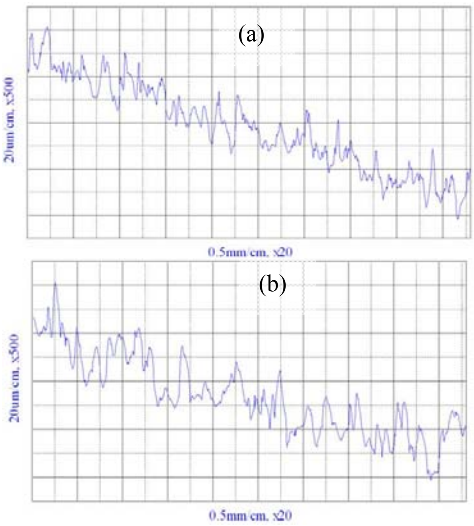

Fig .8. SR profile of CuW at (a) 10 μs and (b) 40μs.

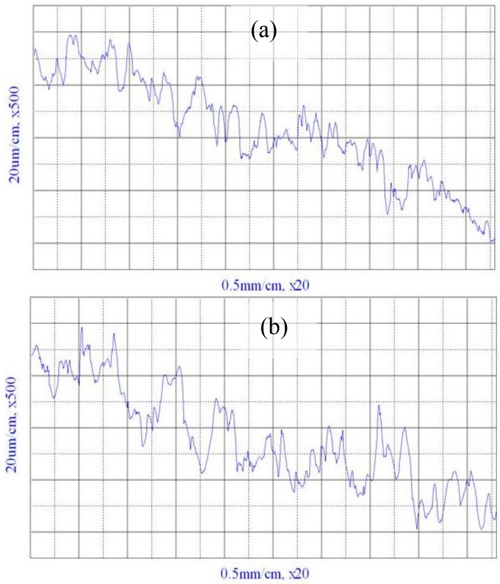

Fig. 9.SRprofile of Gr at(a) 10 µs and (b) 40µs.

4. CONCLUSION

The experimental study has been conducted to investigate the effect of pulse-on-time on SR during EDM of AISI H11 tool steel material by taking three different tool electrode materials. The value of SR with initially increases at a faster rate with increase in pulse-on-time and after a particular value that rate decreases. In the instant case, it is concluded that CuW offers the lowest SR followed by Gr and Cu.

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