Investigation on the Effect Of Process Parameters For Machining Of EN31 (Air Hardened Steel) By EDM

N.Arunkumar [1*], H.Shareef Abdur Rawoof [2] and R.Vivek [2]

[1]Professor, Department of Mechanical Engineering, St.Joseph's College of Engineering, Old Mahabalipuram Road, Chennai -600 119, TamilNadu, India

[2]Graduate, Department of Mechanical Engineering, St.Joseph's College of Engineering, Old Mahabalipuram Road, Chennai -600 119, TamilNadu, India

Abstract

This paper presents the results of experimental work carried out in electrical discharge machining (EDM) of EN31 (air hardened steel) using three different tool materials namely copper, aluminium and EN24, and also the problems involved in using graphite and brass as tool material. The machining process was carried out at three different supply current levels (8Amps, 12Amps, 14Amps), flushing pressure levels (10lb/sq. in, 15lb/sq. in, 20lb/sq. in) and pulse-on time (38µsec, 48µsec, 58µsec), and their influence on surface roughness, material removal rate, tool wear rate and taper.

Keywords: EDM; Supply current; Flushing pressure; Pulse-on time; Surface roughness; Material removal rate; Tool wear rate; Taper

1. Introduction

Electrical Discharge Machining is now one of the main methods used in die production and has good accuracy and precision with no direct physical contact between the electrodes so that no mechanical stress is exerted on the work piece stated by Jose Marafona and Catherine Wykes,(2000).Wong .Y.S et al.,(1995) described material removal is achieved by preferential erosion of the workpiece electrode as controlled discrete discharges are passed between the tool and the workpiece in a dielectric medium . Pandey .P.C and Shan .H.S,(2009) stated that this process is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation often leads to poor surface conductivity (electrical) of the workpiece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment .Wong .Y.S et al.,(1995) described characteristics required of a dielectric used in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability .Rajurkar .K.P,(1986);Soni .J.S,(1994) investigated the responses by controlling the electrical parameters, removal of material may be confined to some extent to the workpiece. Wear of the tool (electrode), however, cannot be ignored because when this occurs the geometrical characteristics of the electrode will not be reproduced on the workpiece. The surface generated by EDM consists of debris, which has been melted or vaporized during machining, lying on or incorporated into the cratered spark-eroded surface. This resulting product of the erosion process, commonly known as debris, has an important relation to the various aspects of EDM.

In this study EN-31 high carbon tool steel is used as the work material and investigations were carried out on the material removal rate, tool wear rate, taper and surface finish using different electrode materials and experimental parameters.

2. Literature Review

Review of the research work reveals that much work has been done on various aspects of electro-discharge machining on low carbon steels, carbides and few die-steels with only one or two electrode materials.Jose Mara and Catherine Wykes,(2000) have found that it is possible to improve the material removal rate for a given tool wear ratio using two-stage processing method. This work has led to the development of a two-stage EDM machining process where different EDM settings are used for the two stages of the process giving a significantly improved material removal rate for a given tool wear ratio.Narender Singh .P et al.,(2004) have performed the optimization by grey relational analysis of EDM parameters and observed that this technique converts the multiple response variable to a single response grey relational grade and, therefore, simplifies the optimization procedure.

Han-Ming Chow et al., (2000) performed a study of added powder in kerosene for the micro-slit machining of titanium alloy using electro-discharge machining.Manoj Mathew and Rajendrakumar .P.K, (2011) studied the optimization of process parameters of boro-carburized low carbon steel for tensile strength by Taquchi method with grey relational analysis and observed that the optimal process parameters and their levels for pre-carburized AISI 1015 steel are carbon content 0.45% at 950 C temperature and 4 h process duration. The results revealed that process time, case carbon content and process temperature influenced the yield strength and % elongation. The ultimate strength is influenced by the process temperature, process time and carbon content. The process temperature was the most influential control factor that affects the tensile strength properties.George .P.M et al., (2004) performed EDM machining of carbon–carbon composite—a Taguchi approach and observed that the process variables affecting electrode wear rate and MRR, according to their relative significance, are *V*g, *I*p and Ton, respectively and, Ton is insignificant.

Krishna Mohana Rao .G et al., (2009) developed a hybrid model and optimized the surface roughness in electric discharge machining using artificial neural networks and genetic. The experiments are carried out on Ti6Al4V, HE15, 15CDV6 and M 250. Multiperceptron neural network models were developed using Neuro Solutions package. Genetic algorithm concept is used to optimize the weighting factors of the network. Chena .S.L et al., (2007) performed Electrical discharge machining of TiNiCr and TiNiZr ternary shape memory alloys and observed that the roughness of EDMed surface increases with the discharge current and pulse duration and the thickness of the recast layer for the EDMed TiNiX alloys varies with the pulse duration and exhibits a minimum value at the maximal MRR. They observed that the hardening effect near the outer surface for EDMed TiNiX alloys originates from the recast layer. The EDMed TiNiX alloys still exhibit a nearly perfect shape recovery at a normal bending strain, but slight degradation of shape recovery occurs at a higher bending strain due to the constrained effect on the TiNiX matrix by the recast layer.

Yan-Cherng Lina et al.,(2009) performed the optimization of machining parameters in magnetic force assisted EDM based on Taguchi method and observed that the machined surface of standard EDM depicted more obvious micro-cracks than that of magnetic force assisted EDM.Petropoulos .G et al.,(2004) have done modeling of surface finish in electro-discharge machining based upon statistical multi-parameter analysis and identified that the mutually independent parameters such as *R*a and *W*a, *R*sk, *R*ku, *β*, *D* are considered to make-up a minimum set for surface texture description regarding both industrial quality control and research.Lin .J.L and Lin .C.L,(2002) performed a study on the use of the orthogonal array with grey relational analysis to optimize the electrical discharge machining process with multiple performance characteristic and found that a grey relational analysis of the experimental results of electrode wear ratio, material removal rate and surface roughness can convert optimization of the multiple performance characteristics into optimization of a single performance characteristic called the grey relational grade.Lina .J.L et al.,(2000) performed the optimization of the electrical discharge machining process based on the Taguchi method with fuzzy logics and fount that the performance characteristics such as EWR and MRR can be improved through this approach.

Kansal .H.K et al.,(2005) studied the Parametric optimization of powder mixed electrical discharge machining by response surface methodology and observed that there is discernible improvement in surface roughness of the work surfaces and MRR after suspending the silicon powder into the dielectric fluid of EDM.Joshi .S.N and Pande .S.S,(2011) conducted an intelligent process modelling and optimization of die-sinking electric discharge machining and inferred that the proposed integrated (FEM–ANN–GA) approach was found efficient and robust as the optimum process parameters suggested were found to give the expected optimum performance of the EDM process. It also provides flexibility to the user to choose optimum parameters suiting specific shop needs.Katsushi Furutani et al.,(2001) investigated the accretion of titanium carbide by electrical discharge machining with powder suspended in working fluid and observed that after considering flow of working fluid during EDM,we find two appropriate shapes for accretion EDM with powder suspended in the working fluid: a thin electrode and a rotating disk electrode, TiC layer can be accreted by using a thin electrode to keep the powder concentration high, and a wider area with uniform thickness can be deposited with a gear shaped rotating electrode.Puertas .I et al.,(2004) analysed the influence of EDM parameters on surface quality, MRR and EW of WC–Co and observed that for *R*a,MRR and TWR the most influential factor is intensity and the second is pulse time for Ra and TWR and that the second influential factor for MRR is duty cycle factor.Kansal .H.K et al.,(2007) studied the effect of Silicon Powder Mixed EDM on Machining Rate of AISI D2 Die Steel and observed that Peak current, concentration of the silicon powder, pulse-on time, pulse-off time, and gain significantly affect the MR in PMEDM, Peak current and concentration of silicon powder are the most influential parameters for causing material removal and the nozzle flushing when applied at the interface of tool electrode and work piece does not significantly affect the MRR.

Puertas .I, and Luis .C.J,(2003) conducted a study on the machining parameters optimisation of electrical discharge machining and observed the factor having the most important influence on the surface roughness is the factor of intensity, also it has been observed that there is a strong interaction between the I and the ti factors being advisable to work with high I values and low ti values.Ming-Guo Her, and Feng-Tsai Weng,(2002) performed a study of the electrical discharge machining of semi-conductor BaTiO3 and understood that for the EDM of semi-conductor BaTiO3 positive polarity machining should be selected to ensure better surface roughness, minimum surface roughness can be achieved using GA, and to avoid the work piece being broken the discharge current cannot exceed 0.25 A and the on-pulse cannot exceed 10µs.Velusamy Senthilkumar, and Bidwai Uday Omprakash,(2011) studied the effect of Titanium Carbide particle addition in the aluminium composite on EDM process parameters and found that the flushing pressure plays an important role in continuing the process and improving the material removal rate at higher discharge current and pulse duration levels.

Ahmet Hascalık, Ulas Caydas,(2007) performed electrical discharge machining of titanium alloy (Ti–6Al–4V) and observed that the electrode material has an obvious effect on the white layer thickness, surface crack density is related to average white layer thickness and the thicker the white layer the lower the surface crack density was obtained, surface cracking can be eliminated after 6 and 3 A pulse currents for aluminium and graphite electrodes, respectively, while the copper always creates surface cracks under applied conditions.Che Haron .C.H et al., (2001) investigated the influence of machining parameters when machining tool steel using EDM and observed that low current was suitable for small diameter electrode and high current for big diameter electrode.Lee .S.H, and Li .X.P,(2001) studied the effect of machining parameters on the machining characteristics in electrical discharge machining of tungsten carbide and observed that the material removal rate decreases gradually with the flushing pressure, and becomes constant at higher values of flushing pressure, and that there is a maximum material removal rate with pulse duration at all current setting.

Shankar Singh et al.,(2004) performed investigations into the electric discharge machining of hardened tool steel using different electrode materials and observed that for the EN-31 work material, copper and aluminium electrodes offer higher MRR, Copper and copper–tungsten electrodes offer comparatively low electrode wear for the tested work material, and aluminium electrode also shows good results while brass wears the most, of all the tested electrodes. Lonardo .P.M, Bruzzone .A.A,(1999) studied the effect of Flushing and Electrode Material on Die Sinking EDM and observed that the electrode material has significant influence in finishing operations on wear and height roughness parameters. When copper electrodes are used wear is larger and surface height is smaller and that flushing in roughing operations increases both MRR and electrode wear. In finishing operations flushing influences the form parameters.Lauwers .B et al.,(2004) investigated the material removal mechanisms in EDM of composite ceramic materials and points out that besides the typical EDM material removal mechanisms, such as melting /evaporation and spalling, other mechanisms can occur such as the oxidation and decomposition of the base material.

From the various literatures that has been reviewed it is understood that much work has not been done with the machining of EN-31, which happens to be a widely used material in the manufacturing of ball and roller bearings, spinning tools, beading rolls, punches and dies. EN-31 is a high carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance. By its character, this type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading.

3. Experimental Details

1.1. Workpiece material

In this study, EN–31 tool steel (IS designation: T105 Cr 1 Mn 60) was selected as the workpiece material. The material was purchased as raw stock in the dimensions of 135 x 80 x 45 mm and then cut into slabs of dimension 75 x 35 x 8.5 mm. The chemical composition of EN–31 material used is shown in table 1.

Table1 Composition of EN – 31

Elements	**% Composition**
Carbon	1.08
Silicon	0.183
Copper	0.003
Manganese	0.452
Phosphorous	0.023
Sulphur	0.0195
Molybdenum	0.07
Chromium	1.19
Lead	0.005
Titanium	0.002
Vanadium	0.003
Aluminium	0.057
Iron	96.9125

The slabs are hardened by heating in a muffler furnace to a temperature of 840 ºC with a soaking period of 30 minutes after which it is removed from the furnace and is air hardened by keeping it in the open atmosphere. The hardness of the work material before and after hardening are 231.7 H. V and 695 H. V.

1.2. Tool Material

The various tool materials that were used in the study are copper, aluminium, and EN–24 each 35 mm long of which 20 mm length is of 16 mm diameter for tool holding and the remaining 15 mm is of 10 mm diameter which is used for machining.

Figure 1 Copper tool electrode

Figure 2 Aluminium tool electrode

Table 2 shows the chemical composition of the tool electrodes. Figure 1 and 2 shows the copper and Aluminium electrodes respectively that were used in the study

Table 2 Chemical Composition of Tool Electrodes

Elements	Copper Electrode	Aluminium Electrode	EN–24 Electrode	Brass Electrode
	% Composition			
Lead	0.05			2.943
Tin	0.15	0.005		0.246
Zinc	0.28	0.0081		36.476
Oxygen	0.22			
Copper	99.3	0.21	0.063	59.756
Silicon		0.585	0.273	0.034
Iron		0.289	96.1878	0.110
Manganese		0.202	0.482	0.02
Magnesium		0.902		
Nickel		0.0005	0.997	0.058
Chromium		0.165	1.278	
Aluminium		97.6334	0.018	
Phosphorous			0.0192	0.087
Arsenic				0.092
Antimony				0.156
Bismuth				0.002
Sulphur			0.032	0.017
Carbon			0.432	
Molybdenum			0.217	
Titanium			0.001	

4. Experimental procedure

The machining process is carried out in ELECTRONICA EMS5030 ELEKTRA PRIDE – Z, the workpiece is mounted on the V- block which is placed on the magnetic table of the machine. The tool is placed on the tool holder and its alignment is checked with the help of dial gauge. The number of runs was decided to be eighteen with different parameter combinations based on Taguchi's Orthogonal Array. The input parameters that were varied for this study are supply current, flushing pressure, pulse-on time and tool material. Table 3 presents the experimental conditions used in the study. Figure 3 shows the machining process.

Figure 3 Machining Process underway

.

Table 3 Design scheme of experimental parameters for EDM

Experimental Conditions	
Supply current	8, 12 and 14 A
Flushing pressure	10, 15 and 20 lb/sq. inch
Pulse-on time	38, 48 and 58 µsec
Pulse-off time	9µsec
Electrode material	Cu, Al and EN-24
Electrode polarity	Positive
Dielectric used	Kerosene
Dielectric flushing	Injection flushing

There were few unforeseen problems faced during the machining process,

a. Even though the machining diameter (Φ 10mm) was small the side flushing technique was not effective in cleaning the machined surface there by resulting in carbon deposits due to which material removal ceased. Hence a 3mm hole was drilled through the centre of the tool electrode (as shown in Figure 4) and injection flushing was adapted.

Figure 4 Electrode with centre hole

b. The third electrode which was initially chosen to be brass, underwent excessive wear and extended machining time. Therefore it was replaced with graphite as it is a good tool material for EDM. The chemical composition of this brass material is presented in Table 2.

c. But when graphite (shown in Figure 5) was used, the machining surface of the tool happened to disintegrate into powder and deposited on the blind hole in the work material. As a result arcing occurred and more over the brittle nature of graphite made it difficult to align in the tool holder due to that the electrode brokens (as shown in Figure 6). Hence the third tool material was chosen to be EN-24, since it had similar properties to EN-31 and to carry out with metal – metal machining. The reason for choosing this material is because not much work has been carried out with metal to metal combination, hence to figure it out its effect and influence we used it as an electrode material. The purity of the graphite used was found to be 86.348% and the density was 1.87 gm/cc. Figure 7 shows the graphite electrode after machining.

Figure 5 Graphite electrodes

Figure 6 Broken graphite

Figure 7 Used graphite electrodes

With the above said modification the machining process was carried out and after machining each hole both the tool and the work piece are thoroughly cleaned using alcohol and their weight was measured using precision balance (max. 200g). A surface roughness tester (make: Mitutoyo SJ-201, LC 0.001µm) was used, giving the Ra values in µm. The same experiment was repeated with different electrode materials and experimental conditions.

5. Results and discussions

5.1. ***Material removal rate***

Material removal rate (MRR) is the amount of material removed in unit time of machining. From the Figures 8, 9 and 10 we understand that the MRR increases with increase in supply current with copper electrode showing good response even though it has low MRR with 8A it increases with consecutive increase in current. Increase in flushing pressure has a negative influence with Al and EN-24 electrodes but with copper it gives a positive result with increasing MRR. The variation of pulse-on time increases the MRR at first but goes down with the next consecutive increase, but with Al as electrode is shows similar effect as the variation with current. Overall, it can be inferred that copper electrode has the highest MRR than the other electrodes under most of the varied values of input parameters.

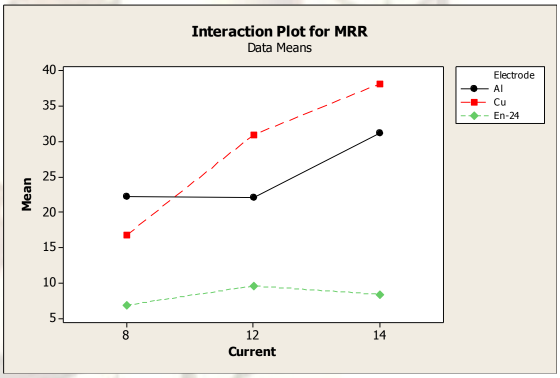

Figure 8 MRR vs. Current, Electrode

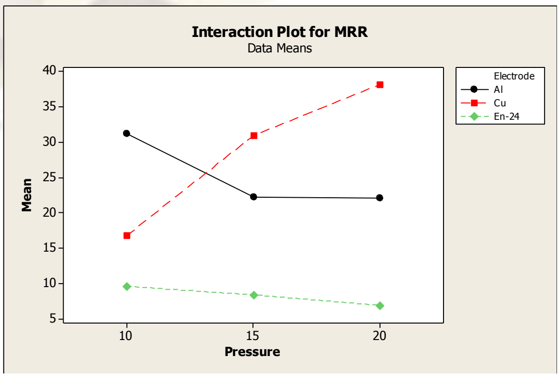

Figure 9 MRR vs. Pressure, Electrode

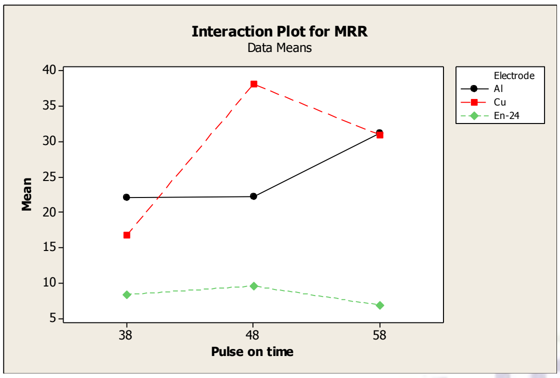

Figure 10 MRR vs. Pulse on time, Electrode

5.2. Tool wear rate

The loss of tool material in the process of machining in unit time of machining is known as tool wear rate (TWR).From the Figure 11,12 and 13 it can be observed that the variation in machining parameters does not have much impact when copper or EN-24 is used as tool electrode but when Al electrode is used it is observed that the TWR is high overall. So amongst electrodes with lesser TWR and machining parameter influence, copper and EN-24, the TWR is the least for copper on the whole..

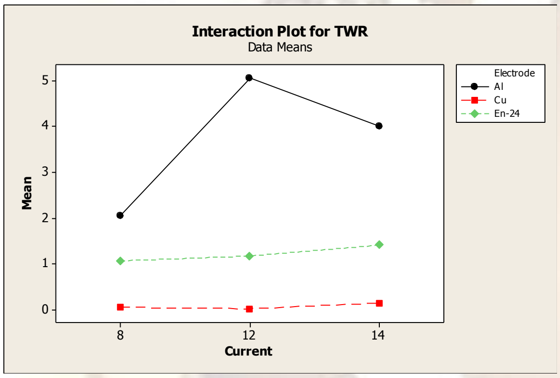

Figure 11 TWR vs. Current, Electrode

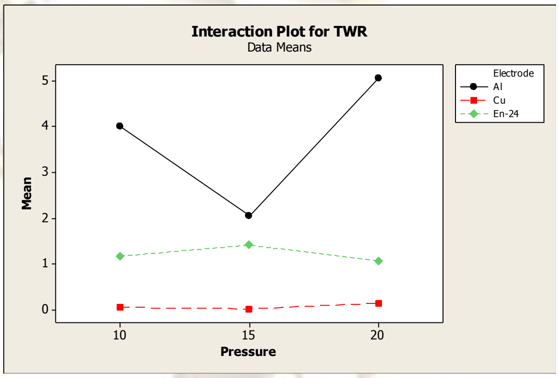

Figure 12 TWR vs. Pressure, Electrode

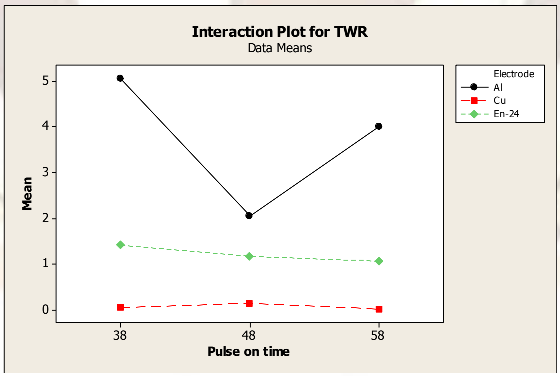

Figure 13 TWR vs. Pulse on, Electrode

5.3. Surface roughness

The figures 14, 15 and 16 indicate the variation in the surface roughness of the machined hole due to the influence of the machining parameters. It is found that the variation in the surface roughness of the machined hole varies erratically for all electrodes but when copper is used as tool electrode the variation is less.

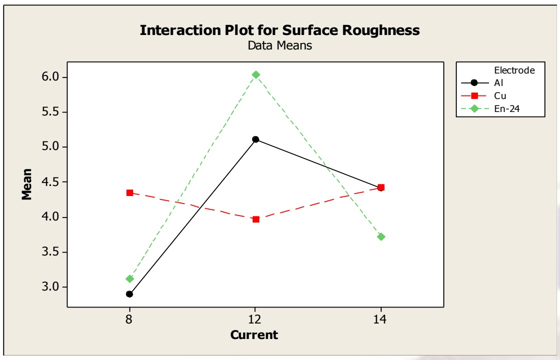

Figure 14 Surface Roughness vs. Current,Electrode

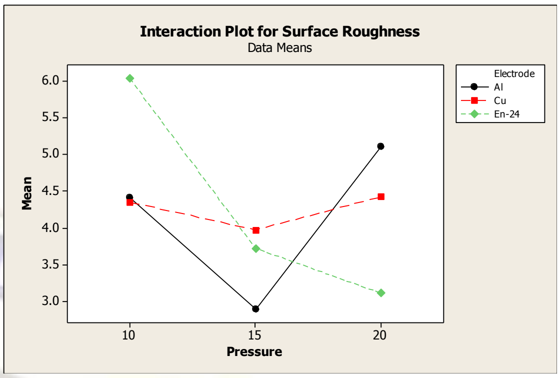

Figure 15 Surface Roughness vs. Pressure,Electrode

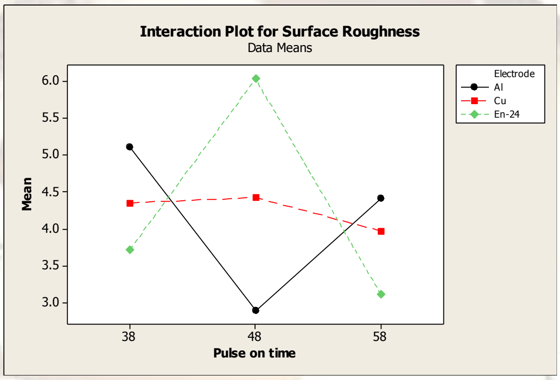

Figure 16 Surface Roughness vs. Pulse on, Electrode

4.3. Taper

Taper is the angular measure of the change in the diameter of hole made between the opening of the hole and its corresponding end, it is a result of tool wear. Form the figures 17,18 and 19, it can be understood that copper electrode has the least taper with respect to the other electrodes and also it has the least influence with the machining parameters.

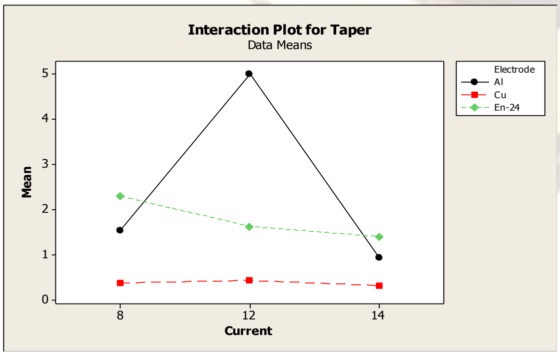

Figure 17 Taper vs. Current, Electrode

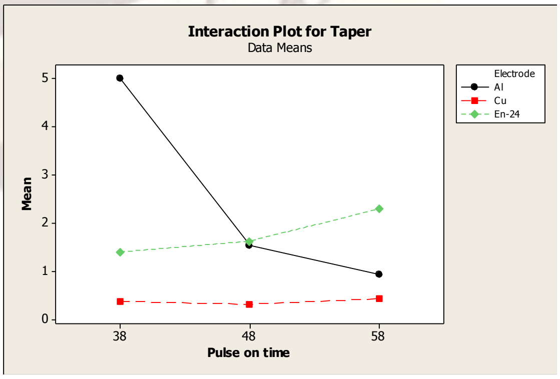

Figure 18 Taper vs. Pressure, Electrode

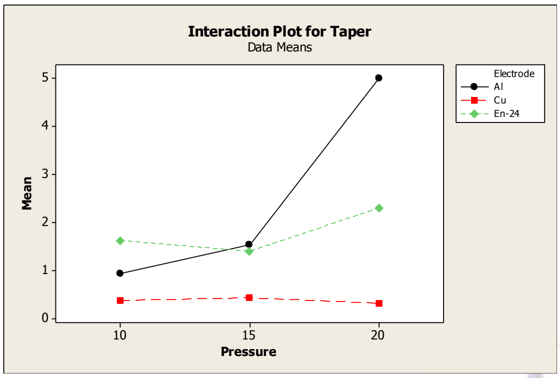

Figure 19 Taper vs. Pulse on, Electrode

5. Conclusion and future enhancements

5.1. Conclusion

The following conclusions are drawn from the investigation to describe the relation of the various machining parameters and the machinability factors when machining EN-31 tool steel using EDM.

- Copper undergoes less tool wear and based on the investigation tool wear is the least under the setting with a supply current of 12 amperes, a flushing pressure of 15 lb/sq. inch, and pulse-on time of 58µsec.
- Copper also has very high material removal rate under the setting of a supply current of 14 amperes, a flushing pressure of 20 lb/sq. inch, and pulse-on time of 48µsec.
- EN-24 when used with a supply current of 8 amperes, a flushing pressure of 20 lb/sq. inch, and pulse-on time of 58µsec, results in very less surface roughness of the machined area.
- Taper value is less when copper is used as tool electrode, and the value is least under the machining parameters of 14 amperes supply current, a flushing pressure of 20 lb/sq. inch, and pulse-on time of 48µsec.

5.2. Future work

The combinations of process parameters such as tool material, different tool geometry in each electrode material, and type of flushing technique can be investigated and the levels of current can be changed to a higher range since it is observed that material removal rate is increases with current and further investigation study can be carried out.

6. References

1. Ahmet Hascalık and Ulas Caydas, Electrical discharge machining of titanium alloy (Ti–6Al–4V), Applied Surface Science 253 (2007) 9007–9016.
2. Che Haron .C.H, Md.Deros .B and Ginting,M.Fauziah .A, Investigation on the influence of machining parameters when machining tool steel using EDM, Journal of Materials Processing Technology 116 (2001) 84-87.
3. Chen .S.L, Hsieh .S.F, Lin .H.C, Lin .M.H and Huang .J.S, Electrical discharge machining of TiNiCr and TiNiZr ternary shape memory alloys, Materials Science and Engineering A 445-446 (2007) 186-492.
4. George .P.M, Raghunath .B.K, Manocha .L.M and Ashish M. Warrier, EDM machining of carbon-carbon composite-a Taguchi approach, Juornal of Material Processing Technology 145 (2004) 66-71.
5. Han-Ming Chow, Biing-Hwa Yan, Faung-Yuan Huang, Jung-Cherng Hung, Study of added powder in kerosene for the micro-slit machining of titanium alloy using electro discharge machining, International Journal of Materials Processing Technology 101 (2000) 95-103.
6. Jose Marafona, Catherine Wykes, A new method of optimising material removal rate using EDM with copper-tungsten electrodes, International Journal of Machine Tools & Manufacture 40 (2000) 153 – 164.
7. Joshi .S.N and Pande .S.S, Intelligent process modeling and optimization of die-sinking electric discharge machining, Applied Soft Computing 11 (2011) 2743–2755.
8. Kansal .H.K, Sehijpal Singh and Kumar .P, Parametric optimization of powder mixed electrical discharge machining by response surface methodology, Journal of Materials Processing Technology 169 (2005) 427–436.
9. Kansal .H.K, Sehijpal Singh and Pradeep Kumar, Effect of Silicon Powder Mixed EDM on Machining Rate of AISI D2 Die Steel, Journal of Manufacturing Processes Vol. 9/No. 1, 2007.
10. Katsushi Furutani, Akinori Saneto, Hideki Takezawa, Naotake Mohri and Hidetaka Miyake, Accretion of titanium carbide by electrical discharge machining with powder suspended in working fluid, Journal of the International Societies for Precision Engineering and Nanotechnology 25 (2001) 138–144.
11. Krishna Mohana Rao .G, Rangajanardhaa .G, Hanumantha Rao .D and Sreenivasa Rao .M, Development of hybrid model and optimization of surface roughness in electrical

diacharge machining using artificial neural networks and genetic algorithm.

12. Lauwers .B, Kruth .J.P, Liu .W, Eeraerts .W, Schacht .B and Bleys .P, Investigation of material removal mechanisms in EDM of composite ceramic materials, Journal of Materials Processing Technology 149 (2004) 347–352.
13. Lee .S.H and Li .X.P, Study of the effect of machining parameters on the machining in electrical discharge machining of tungsten carbide, Journal of Materials Processing Technology 115 (2001) 344-358.
14. Lin .J.L and Lin .C.L, The use of the orthogonal array with grey relational analysis to optimize the electrical discharge machining process with multiple performance characteristics, International Journal of Machine Tools & Manufacture 42 (2002) 237–244.
15. Lin .J.L, Wang .K.S, Yah .B.H and Tarng .Y.S, Optimization of the electrical discharge machining process based on the Taguchi method with fuzzy logics, Journal of Materials Processing Technology 102 (2000) 48-55.
16. Lonardo .P.M and Bruzzone .A.A, Effect of Flushing and Electrode Material on Die Sinking EDM, Dept. of Production Engineering, University of Genoa, Genova, Italy Received on January 6,1999.
17. Manoj Mathew and Ranjendrakumar .P.K, Optimization of process parameters of boro-carburized low carbon steel for tensile strength by Taguchi method with grey relational analysis, Materials and Design 32 (2011) 3637-3644.
18. Ming-Guo Her and Feng-Tsai Weng, A study of the electrical discharge machining of semi-conductor $BaTiO_3$, Journal of Materials Processing Technology 122 (2002) 1-5.
19. Murti .V.S, Philip .P.K, An analysis of the debris in ultrasonic assisted electrical discharge machining, Wear 17 (1987) 241-250.
20. Narender Singh .P, Raghukandan .K and Pai .B.C, Optimization by Grey relational analysis of EDM parameters on machining Al-10%SiC composites, International Journal of Machine tools & Manufacture 155-156 (2004) 1658-1661.
21. Pandey .P.C and Shan .H.S, "Modern Machining Processes", Tata McGraw-Hill, 2009.
22. Petropoulos .G, Vaxevanidis .N.M and Pandazaras .C, Modeling of surface finish in electro-discharge machining based upon statistical multi-parameter analysis, Journal of Materials Processing Technology 155-156 (2004) 1247-1251.
23. Puertas .I, and Luis .C.J, A study on the machining parameters optimisation of electrical discharge machining, Journal of Materials Processing Technology 143–144 (2003) 521–526.
24. Puertas .I,Luis .C.J, and Álvarez .L, Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC–Co, Journal of Materials Processing Technology 153–154 (2004) 1026–1032.
25. Rajurkar .K.P, Pandit .S.M, Formation and ejection of EDM debris, J. Eng. Ind. 108 (1986) 22-26.
26. Shankar Singh , Maheshwari .S and Pandey .P.C, Some investigations into the electric discharge machining of hardened tool steel using different electrode materials, Journal of Materials Processing Technology 149 (2004) 272–277.
27. Soni .J.S, Microanalysis of debris formed during rotary EDM of titanium alloy (Ti6Al4V) and die steel (T215 Cr12), Wear 117 (1994) 71-79.
28. Velusamy Senthilkumar and Bidwai Uday Omprakash, Effect of Titanium Carbide particle addition in the aluminium composite on EDM process parameters, Journal of Manufacturing Processes 13 (2011) 60–66.
29. Wong .Y.S, Lim .L.C, and Lee .L.C, Effects of Flushing on Electro-Discharge Machined Surfaces, Journal of Materials Processing Technology 48 (1995) 299-305.
30. Yan-Cherng Lin, Yuan Feng Chen, Der-An Wang and Ho-Shiun Lee, Optimization of machining parameters in magnaetic force assisted EDM based on Taguchi method, Journal of Material Processing Technology 209 (2009) 3374-3383.