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A Study on The Influence of Nd-Magnets On The Electrical Discharge Machining Surface Quality of Mild Steel

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Abstract

Electrical discharge machining (EDM) is one of the processing methods based on non-traditional manufacturing procedures. It is gaining increased popularity, since it does not require cutting tools and allows machining of hard, brittle and intricate geometries. In recent years, EDM researchers have explored a number of ways to improve the surface state of work pieces machined using EDM. In the present paper, roughness value of work pieces machined under the influence of varied magnetic intensities, peak current and pulse durations is investigated. A new laboratory setup, incorporating Nd-magnets, is created to carry out the experiments together with a TOOLCRAFT A25 EDM. Empirical modeling has been carried out to establish a mathematical relationship between the roughness and the machining parameters. Optimum settings have been identified that produce lowest roughness values. Results indicated that the presence of a magnetic field in the spark gap region increases the surface roughness of the machined work piece. Surface roughness of work piece was also noted to be highly influenced by current and pulse on-time. Higher values of these parameters increased surface roughness. Low magnetic intensity, lower current, lower pulse-on time and relatively higher pulse pause time produced a better surface finish.

Keywords: Electric discharge machining (EDM); surface roughness.

1. Introduction

Electric discharge machining (EDM) is one of the most popular non-traditional material removal processes and has became a basic machining method for the manufacturing industries of aerospace, automotive, nuclear, medical and die-mold production. The process uses thermal energy to generate heat that melts and vaporizes the work piece by ionization within the dielectric medium. The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. Thus, the amount of removed material can be effectively controlled to produce complex and precise machine components. However, the melted material is flushed away incompletely and the remaining material resolidifies to form discharge craters. As a result, machined surface has micro-cracks and pores caused by high temperature gradient which reduces surface finish quality. There have been many published studies considering surface finish of machined materials by EDM. It was noticed that various machining parameters influenced surface roughness and setting possible combination of these parameters was difficult to produce optimum surface quality. The influences of some machining parameters such as pulsed current [1–5], pulse time [6-7], pulse pause time [7], voltage, dielectric liquid pressure [8] and electrode material [9] have been examined.

The electrical discharge machined surface is made up of three distinctive layers consisting of white layer/recast layer, heat affected zone (HAZ) and unaffected parent metal [10-11]. Lim *et al.* [12] provided a review on the metallurgy of EDMed surface, which is dependent on the solidification behavior of molten metal after the discharge cessation and subsequent phase transformation. The thickness of the recast layer formed on the work piece surface and the level of thermal damage suffered by the electrode can be determined by analyzing the growth of the plasma channel during sparking [13]. Since the white layer is the topmost layer exposed to the environment, it exerts a great influence on the surface properties of the work piece. Several authors discovered the presence of micro-cracks and high tensile residual stresses on the EDMed surface caused by the high temperature gradient [14]. The adverse effect of discharge energy also provided some insights on the fatigue strength of the work piece, which propagates from the multiple surface imperfections within the recast layer [15]. In addition, the EDMed surface has a relatively high micro-hardness, which can be explained by the emigration of carbon from the oil dielectrics to the work piece surface forming iron carbides in the white layer [16]. The concentration of carbides, both as surface layer on the work piece and as fine powder debris, is dependent on the frequency and polarity of the applied current together with other processing parameters such as pulse shape, gap spacing and dielectrics temperature [17].

However, Thomson [10] argued that the pulse duration and type of electrode material under a paraffin dielectric has little effect on the amount of carbon contamination. Thomson also suggested that the number and size of micro-cracks increase with pulse duration when machining with copper electrode.

Magnetic field extensively is used in non-traditional manufacturing process. Yamaguchi and Shinmura [18] used the magnetic field for finishing of the inner surfaces of tube. They reported that this process achieves average surface roughness as fine as 0.02 m and imparts minimal additional residual stress to the surface. That study also revealed the mechanism to polish the inner surface of alumina ceramic tube and to improve the form accuracy. Wang and Hu [19] proposed an internal magnetic abrasive finishing process for producing highly finished inner surfaces of tubes. Experimental results indicated that finishing parameters such as polishing speed, magnetic abrasive supply, abrasive material, magnetic abrasive manufacturing process and grain size have critical effects on the MRR. Although some researches associated the magnetic field with the manufacturing process, only a few work investigated the effects of magnetic force on EDM performance. Lin and Lee [20] used the magnetic field in EDM process and reported that the magnetic force run the debris away from machining gap and improve the characteristics of this operation especially in high discharge energy regime. Chattopadhyay et al. [21] used the multi level intensity of magnetic field and rotary tool electrode with various speed in EDM process and indicated the effects of them on MRR and tool wear rate. Results established that the rotary electrical discharge machining with a polarity reversal magnetic field delivers better machining output than machining in a non-magnetic field. The present study examines the effects of magnetic field strength intensity, current, pulse time and pulse pause time on surface roughness in mild steel.

2. Experimental Procedure

The experimental study was carried out on TOOLCRAFT A25 EDM machine. The dielectric liquid was standard kerosene. The selected work piece material was mild steel that is widely used in the manufacturing industry. The properties of work piece material were presented in Table I. The work piece specimen was prepared 50mm×50 mm×5 mm of dimension and the surfaces of work piece were milled and finish ground before EDM method application.

Table 1: Chemical composition of mild steel material

Element	C	Si	Mn	P	S
Wt-percent	0.45	0.2	0.7	0.03	0.035

A cylindrical pure copper with a diameter of 25mm was used as an electrode which was finish ground before experimental study. It was mounted axially in line with work piece. The surface roughness of the machined surface was measured by using Mitutoyo surftest-402 perthometer. The surface roughness, which is measured by central line average (Ra) was employed to assess the quality of the machine surface quantitatively. Each surface roughness value was obtained by averaging five measurements at various positions of work piece and electrode surfaces for each machining condition. The cutoff length was set as 2.5 mm. The evaluation length was selected as the maximum value which was 2.5 mm. Stylus type was diamond with 5μm radius.

3. Experimental results and discussion

The resulting values of Ra are tabulated in Table II.

Table II: Experimental results

Expt No.	M(G)	Tn (μs)	C(A)	Tf(μs)	Ra(μm)
1	4667	60	21.875	80	9.43
2	1601	80	21.875	80	11.17
3	1601	80	9.375	60	8.50
4	4667	60	9.375	60	8.30
5	2952	60	9.375	60	7.00
6	2952	80	21.875	60	9.50
7	2952	60	21.875	80	8.50
8	3309	70	15.625	60	11.61
9	3309	70	15.625	50	3.20
10	5903	70	15.625	70	11.97
11	3309	70	15.625	70	11.61
12	2952	60	9.375	80	10.21
13	4667	60	21.875	60	7.70
14	2952	60	21.875	60	11.30
15	3309	50	15.625	70	10.00
16	4667	80	21.875	60	10.01
17	3309	70	15.625	70	11.61
18	1601	70	15.625	70	11.97
19	4667	80	9.375	60	9.70
20	3309	70	15.625	70	11.61

21	3309	70	15.625	90	10.50
22	3309	70	15.625	70	12.21
23	4667	80	9.375	80	11.20
24	4667	80	21.875	80	13.72
25	3309	70	15.625	70	12.21
26	3309	90	15.625	70	12.70
27	3309	70	15.625	70	11.61
28	4667	60	9.375	80	10.21
29	3309	70	3.125	70	8.50
30	3309	70	23.4375	70	11.72
31	2952	80	9.375	80	13.12

3.1 Model for surface roughness Ra

The ANOVA results for the quadratic model for Ra are shown in Table III. The P-value of the lack-of-fit term indicates that model selected is highly significant. The linear and square factors were observed to be highly significant as compared to the interaction factors.

Table III: ANOVA table for Ra.

Source.	DF	seq SS	adj MS	F	P
Regression	14	113.802	8.127	6.18	0.000
Linear	4	57.819	14.4547	10.98	0.000
Square	4	48.331	12.0829	9.18	0.000
Interaction	6	7.652	1.2753	0.97	0.477
Residual error	16	21.062	1.3164		
Lack-of-fit	10	20.548	2.0548	23.97	0.000
Pure error	6	0.514	0.0857		
Total	30	134.864			

The results of the quadratic model for Ra are given in Table IV. The value of R2 is 84.38% indicating that the regression model is providing an excellent explanation of the relationship between the independent variables (factors) and the response (Ra).

Table IV: Regression Coefficients for Ra

Term	Coefficient	T	P
Constant	11.7814	27.168	0
M	0.0404	0.172	0.865
Tn	0.8196	3.5	0.003
C	0.397	1.695	0.109
Tf	1.2562	5.364	0
M×M	0.031	0.144	0.887
Tn×Tn	-0.124	-0.578	0.571
C×C	-0.43	-2.023	0.06
Tf×Tf	-1.249	-5.821	0
M×Tn	0.2319	0.809	0.431
M×C	-0.0119	-0.042	0.967
M×Tf	0.1343	0.468	0.646
Tn×C	0.0419	0.146	0.886
Tn×Tf	0.4657	1.624	0.124
C×Tf	-0.4332	-1.51	0.15

S = 1.14734 PRESS = 119.056

R-Sq = 84.38% R-Sq (adj) = 70.72%

For a 95% significance level, the linear factors Tn and Tf are applicable. This is also true for the square factor Tf. The response equation for Ra is given in equation 1

Ra = 11.7814 + 0.0404M + 0.8196Tn + 0.3970C + 1.2562Tf + 0.0310M2 − 0.1240Tn2 − 0.430C2 − 1.2490Tf2 + 0.2319MTn − 0.0119MC + 0.1343MTf + 0.0419CTn + 0.4657TnTf − 0.4332CTf

M is the magnetic field intensity, Tn is pulse-on time, C is current and Tf is pulse-off time.

To ascertain proper fitting of the quadratic model for Ra, the normal probability graph of the residuals for Ra was plotted as shown in Figure 1. The residuals are falling on a straight line which means that the errors are normally distributed and the regression model agrees fairly well with the observed values.

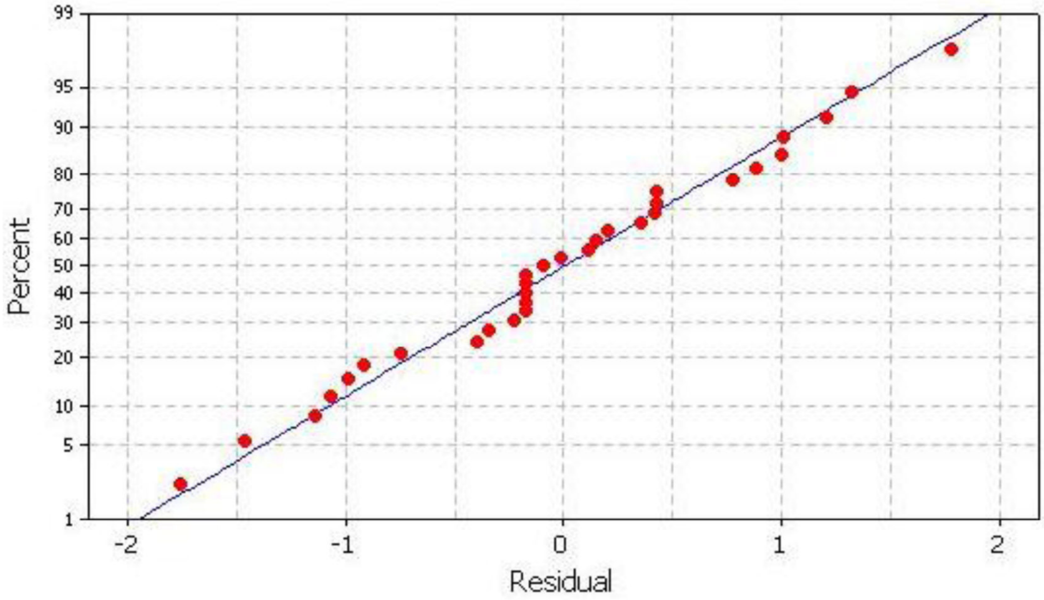
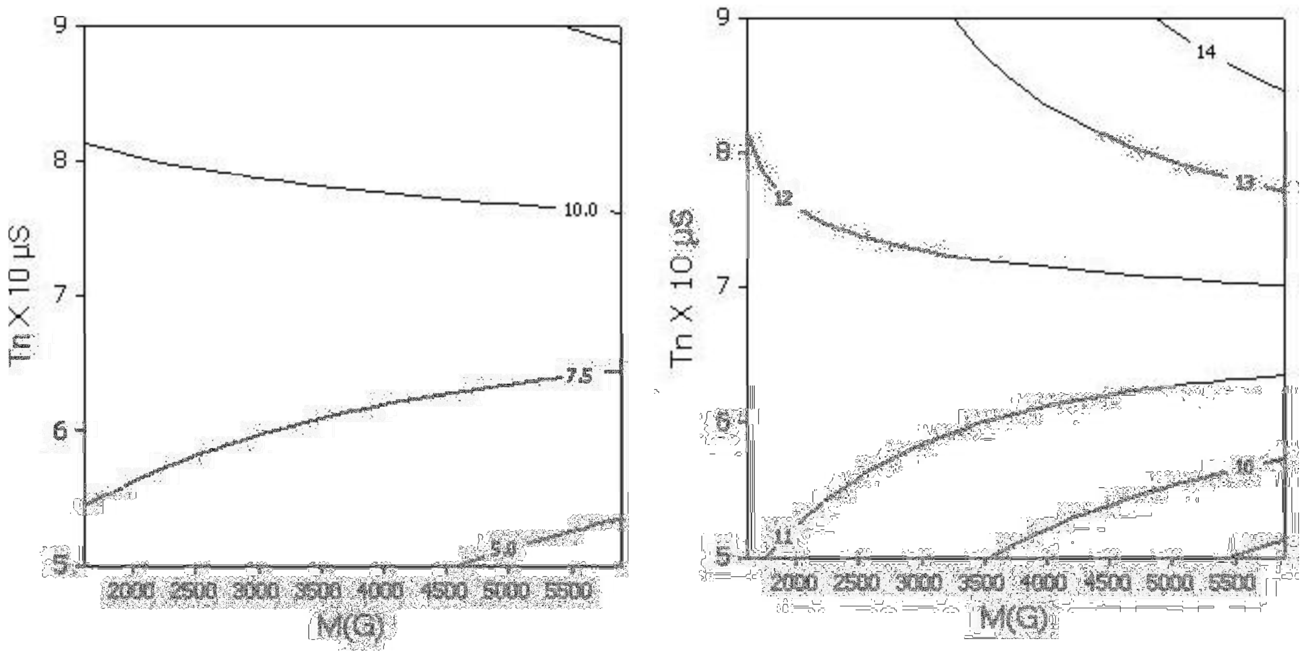


Figure. 1. Normal probability plot residuals for Ra

3.2 Response surface analysis

The effect of parameters on MRR and Ra has been analysed through contour graphs. The contour plot can help the response surface to be visualized. In machining, interaction between the parameters also plays a leading role. An interaction occurs when the change in response from the one level of a factor to another level differs from the change in response at the same two levels of a second factor. That is, the effect of one factor is dependent upon a second factor. In the present study, interest lies on the effect of magnetic field influence on RA, as such among the factor interactions considered, TnM, TfM, and CM are investigated.

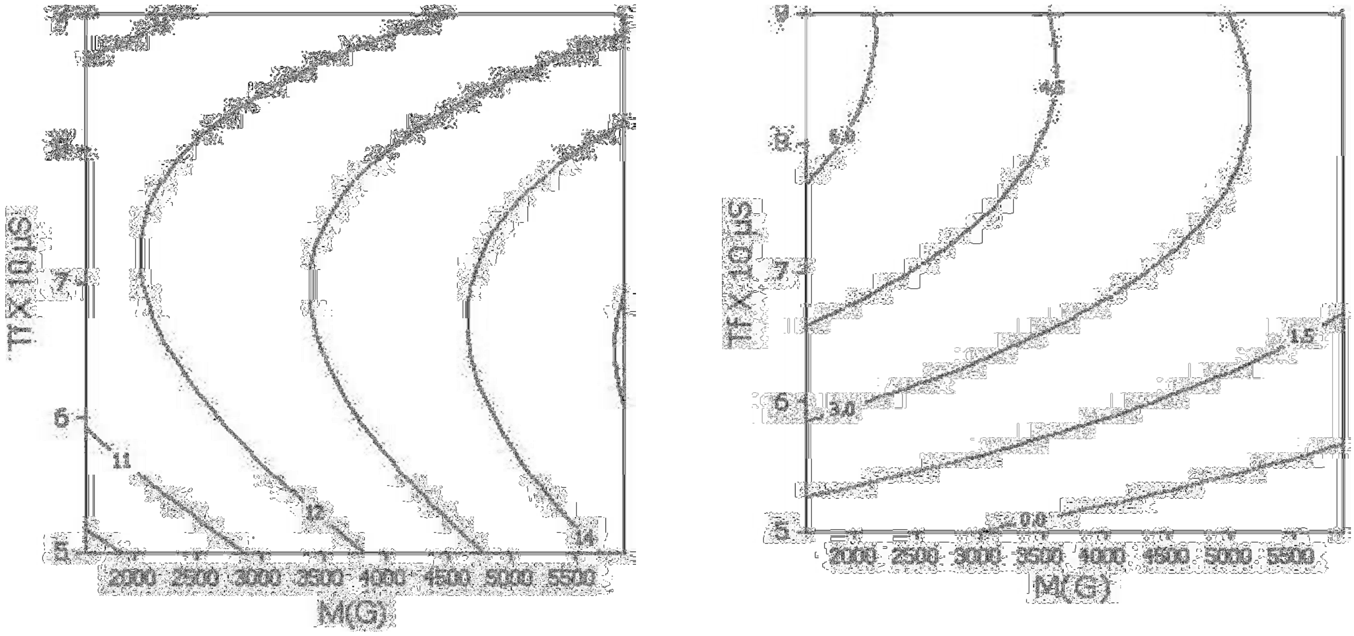
Figure 2 shows the response surface for Ra in relation to the design parameters of magnetic intensity (M) and pulse-on time(Tn) at two sets of hold values. When the current and pulse-off time are set at high values i.e 23A and 90µs, it can be seen that the Ra is more affected by the pulseon time as opposed to magnetic intensity. However at the maximum magnetic intensity and minimum pulse-on time, the surface roughness is noted to be at its highest level. Lowest Ra values(≤5 µm) are attained at low Tn(≤55µs)and high magnetic intensities(≥4600G). At lower settings of the hold values, low Ra (≤9µm)are observed at low Tn(≤5.5A)and high M values(≥3600G). The reason for the larger roughness values with higher pulse duration can be explained by the generation of the large craters owing to large amounts of energy [20, 21]. The surface contains larger craters and cracks, which would result in poor surface finish. High magnetic intensity at low pulse-on time(no machining) allows debris flushing uniaxially, this allows for uniform abrasion and reduced abnormal discharges thus smoother surfaces.



(a) (C=23A, Tf=90µs) (b) (C=16A, Tf=70µs)

Figure. 2. Response Plots of Ra (µm) vs Tn, M

The interaction effect of Pulse-off time (Tf) and Magnetic intensity (M) on Ra at two sets of hold values is shown in Figure 3. At high pulse-on time and current, it is observed that the value of Ra increases with increase in magnetic intensity. Minimum Ra values (10-11µm) are seen at low Tf values (≤60µs) and at low magnetic intensities (≤2800G). At lower hold values, minimum roughness values (_1.5µm) are attained at low Tf (_5.5µs) and high magnetic intensity (_3500G).



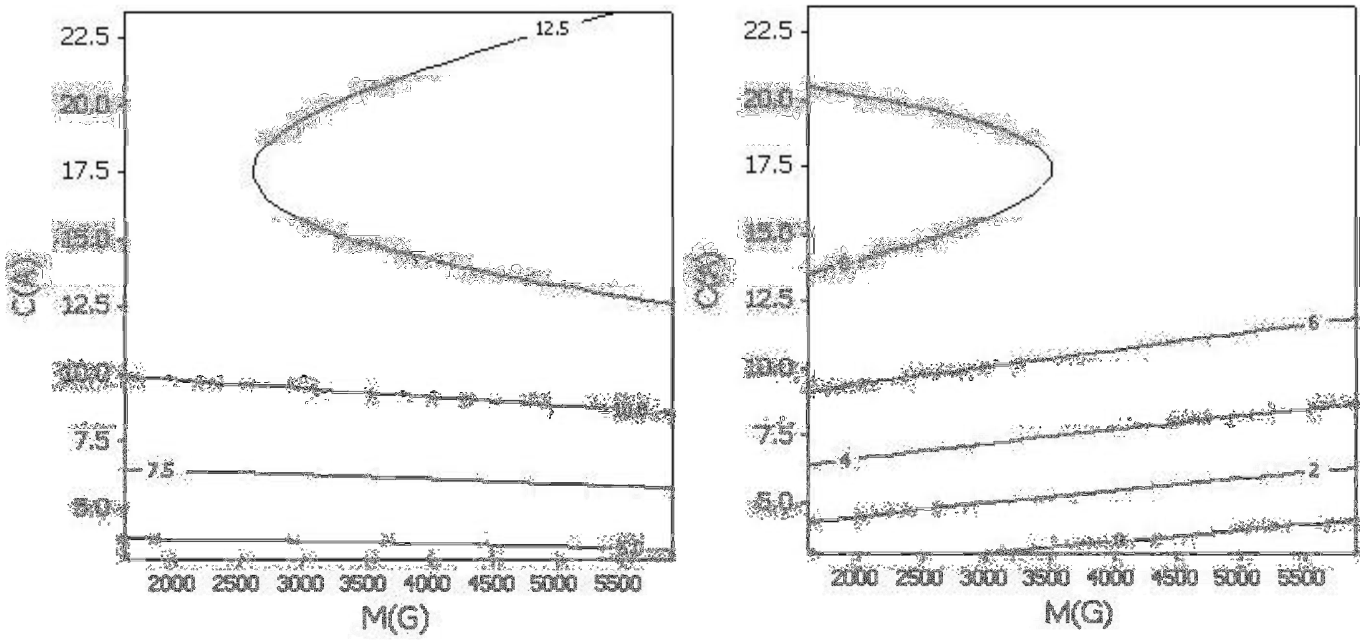
(a)(C=23A, Tn=90µs) (b) (C=16A, Tn=50µs)

Fig.3. Response Plots of Ra (µm) vs Tf, M

Figure 6 and 7 shows the interaction effect of current (C) and magnetic field intensity (M) on Ra at two sets of hold values. Surface quality is observed to be more dependent on current as opposed to magnetic intensity. When the pulse durations are high, the minimum Ra values (≤5.0µm) are observed when the current is set below 5A. High magnetic intensities at high currents are seen to produce rougher surfaces. This can be attributed to high discharging energy and accelerated flushing and consequent abrasion of the surface. At low hold values. The minimum roughnesses (≤2µm) are observed at C_5.5A.

The magnetic field has a notable effect on surface quality. For interaction scenarios whereby the magnetic influence is higher than other factors, the magnetic force can remove the debris out from machining gap, and leads to reducing in the SR. Also the magnetic field reduces the recast layer thickness and improves the surface integrity by prevention of remelting.

The electrical discharge machining process removes the material from work piece through melting. The removed melted material cool and solidify in dielectric medium. Because of this heat treatment on the debris particle, they are harder than the work piece material. When the magnetic field is applied around the gap space, the debris which was expelled from machining gap can remove the sharp edges and ridges off the work piece surface during the expulsion path and so reduces the SR.



(a) (Tn=90μs, Tf=90μs) (b) (Tn=50μs, Tf=50μs)

Figure. 7. Response Plots of Ra (μ m) vs C, M

4. Conclusion

In this paper the influence of magnetic field with various intensities on SR was studied. Surface response methods have been used to study the response and an empirical model Ra has been developed. The second-order response model has been validated with analysis of variance. Main conclusions of this research can be summarized as follows:

1. The surface roughness of the magnetic force-assisted EDM increased with peak current. Effect of magnetic presence was observed to come in play only at high magnetic intensity levels.

2. For the interaction of pulse-off time and magnetic field, the former is seen to be more influential. The magnetic field facilitates the removal of debris from the machining gap and they are not remelted and welded in work piece surface, so surface quality will be improved.

Future scopes in line with the current work can be defined as follows:

• Creation of new configurations of magnetic poles for better focusing on the spark gap region.

• Investigation on the effect higher magnetic intensity levels on Ra.

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