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Experimental Study on Effect of Process Parameters of Wire EDM on Maraging Steels Using Plain Brass Wire.

B. Swathi
Department of Mechanical Engineering
University College of Engineering
Hyderabad (T.S.) [INDIA]
Osmania University
Email: beeramswathireddy@gmail.com

M. Sangeetha
Department of Mechanical Engineering
University College of Engineering
Hyderabad (T.S.) [INDIA]
Osmania University
Email: msangeetha114@gmail.com

K. Saraswathamma
Department of Mechanical Engineering
University College of Engineering
Hyderabad (T.S.) [INDIA]
Osmania University
Email: saraswathi.ouce@gmail.com

ABSTRACT

With the increasing demands of high surface finish and machining of complex shape geometries, conventional machining process are now being replaced by unconventional machining processes. Wire Electric Discharge Machining (WEDM) is well known unconventional machining process and is capable of machining geometrically complex shapes or hard material components, that are precise and difficult-to-machine such as heat-treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. Maraging steels are considered as the best tooling materials and possesses excellent mechanical properties like high level of strength, hardness, and extreme resistance to crack propagation. The objective of the present work is to investigate the effect of various WEDM process parameters on Maraging steels using plain brass wire as electrode. In the present work, the detailed study through full factorial design was carried out to know the effect of process parameters such as peak current (Ip), Pulse on time (Ton) and Pulse off time (Toff) on response variables such as cutting rate (CR) and surface finish (SR). ANOVA is developed to know the most significant variable. Regression equation is developed for correlating influence of these variables on cutting rate and surface roughness of the workpiece. The experimental results indicate that with increase in pulse-on-time and peak current, the cutting rate and surface *roughness increases. The effect of pulse-off-time is less compared to the effect of peak current and pulse- on-time.*

Keywords:— *WEDM, Maraging Steel, Process Parameters, ANOVA, Cutting Rate, Surface Finish.*

I. Introduction

Electric Discharge Machining (EDM) also called as electro-erosion machining process is a controlled material removal technique where by high frequency electric sparks are used to erode the work piece which takes a shape corresponding to that of the tool electrode. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. When the gap voltage is sufficiently large (i.e. reaches the breakdown voltage of dielectric fluid), high power spark is produced, which increases the temperature. Work piece material in the localized regions of high temperature melts, vaporizes and flow in the form of debris particles. It is a recognized process to produce tiny apertures with high accuracy and complicated profiles.

This process is widely used for producing dies, moulds, and finishing parts for aerospace, automotive, and surgical components [1]. The process can get required dimensional accuracy and surface finish by controlling the process parameters [2]. EDM performance is generally evaluated based on material removal rate (MRR), tool wear rate (TWR), and surface roughness (SR) [1]. The machining parameters affecting to the performance measures of the process are discharge current, pulse on time, pulse off time, arc gap, and duty cycle [3].

Rao et al. [4] studied the influence of process parameters on EDM of MDN 250 steel. They have considered discharge current, pulse on time, and duty factor as performance measures whereas process parameters are MRR and SR. However, in their study, parametric optimization was not done. TWR and RWR ratios were not considered. Furthermore, they extended their studies and developed a hybrid model for SR is to predict the behaviour of the MDN 250 steel [5].

Maraging steels have the unique combination of ultra-high yield and tensile strength, ductility, and fracture toughness. It can retain its strength up to 350 degrees centigrade. Having a very low carbon Martensite, the structure is soft and readily machinable. The properties are achieved through the age hardening of Low Carbon Martensite that forms when the steels are cooled from Austenitic temperatures.

Deepu P. Nair et al. [6] aimed at characterizing the electric discharge machining of Maraging Steel for effective machining. Taguchi's L9 orthogonal array was chosen to conduct the experiments by varying EDM parameters like voltage, current and pulse-on-time. The surface roughness is taken as the output response. Quick and T.M. JOM [7] studied with the machining of Maraging steel 250 by Electrical Discharge Machining (EDM) introduces Hydrogen into it. This results into brittle fracture surfaces from embrittlement accelerated by slow-strain-rate Tensile tests. Experimental control was provided by test specimens machined by abrasive waterjet, a machining technique that does not evolve hydrogen as a part of the machining process. Rangilal et al. [8] studied the machinability of Maraging steel and AISI 304 steel whose hardness values are 58 HRC and 29 HRC respectively. The experiments were conducted on a CNC Retrofitted VDF lathe machine. The experiments were conducted using Design of experiments (DOE), L27 orthogonal array, while machining Maraging steel and AISI 304 steel. Minitab16 Software also used for analysing the results.

From the Literature review, it was found that most of the research has been carried on machining of various materials like, Titanium Alloys, Die and Tool steels etc. using Electric Discharge machines. But the research survey relating to super alloys and special steels is very less. Most of the research studies available are on optimizing the input parameters like current and Pulse-on-time with respect to tool electrode wear rate (EWR), relative wear (RW), texture properties etc. only. Very few investigations have been found relating to the machining of Maraging Steels using Wire Electric Discharge Machine using plain brass wire as electrodes and adding Distilled water as di-electric medium.

Table 1: Chemical Composition of Maraging Steels

Element	Ni	Co	Mo	Ti	Al	C	Mn	Si	P	S	Zr	B	Ca	Fe
Min	17	7	4.6	0.3	0.05	-	-	-	-	-	-	-	-	Bal
Max	19	8.5	5.2	0.5	0.15	0.03	0.1	0.1	0.01	0.01	0.02	0.003	0.05	Bal

Table 2: Experimental results obtained after machining using Plain Brass wire

Process Parameters				Responses	
S. No	Ton (µs)	Toff (µs)	Ip (A)	Cutting rate(mm/min)	Surface roughness(µm)
1	2	2	2	0.9	2.02
2	2	2	4	1.3	4.60
3	2	2	6	1.6	5.86
4	2	4	2	0.8	3.51
5	2	4	4	1.2	3.63
6	2	4	6	1.5	5.30
7	5	2	2	1.2	4.41
8	5	2	4	1.5	5.80
9	5	2	6	1.8	7.02
10	5	4	2	1.0	4.67
11	5	4	4	1.4	5.08
12	5	4	6	1.7	6.83
13	7	2	2	1.2	5.20
14	7	2	4	1.7	6.46
15	7	2	6	2.2	8.00
16	7	4	2	1.1	5.60
17	7	4	4	1.6	6.46
18	7	4	6	2.0	7.93

II. Materials and Methods

Experiment was performed with Maraging steel as a workpiece material and plain brass wire of 0.25mm diameter as electrode. The experimental work was conducted on CNC Maxcut-734 (flushing type) machine. De-ionized water was used as the dielectric fluid. Surface Roughness of the workpiece was measured using Perthometer and Cutting rate was displayed digitally on the machine. The photograph of the CNC EDM electronica make machine is given figure 1.

Figure: 1 Wire Electric Discharge Machine

The Elektra wire cut EDM comprises of a machine tool, a power supply unit and a Dielectric unit. The machine tool comprises of a main work table (called X-Y table) on which the work piece is clamped, an auxiliary table (called U-V table) and wire drive mechanism. The workpieces of size 50 X 20 X20 mm was used. Plain brass wire of diameter 0.25±0.002 of tensile strength 500 N/mm2 and elongation 5% was used. The chemical composition of Maraging steels is given in table 1.

Spool of plain Brass wire was kept in the machine, which is used as an electrode for set of 18 experiments. The machining parameters are set as per the experimental plan for each set of experiment. After machining each work piece, Cutting rate was recorded. The Surface roughness was measured using Perthometer. The experimental plan and the results are tabulated in table 2. Experimental plan was set up using General full factorial design with Ip, Ton, Toff as machining parameters with different levels as illustrated in table 3.

Table 3: Machining Parameters and Their Levels

Machining parameters	units	Levels		
		-1	0	+1
Current(Ip)	A	2	4	6
Pulse-off-time (Toff)	µs	2	4	-
Pulse-on-time(Ton)	µs	2	5	7

III. Results and Discussions

Regression analysis is done to evaluate the effect of individual parameter and their interactions on response parameters viz. CR and SR using Minitab software.

3.1 Effect of Pulse-On-Time (TON), Pulse-Off-Time (TOFF), Peak Current (IP) On Cutting Rate

Cutting rate is the speed difference in cutting tool and the workpiece, when it is operating. It is expressed in units of distance along the workpiece surface per unit of time, typically surface feet per minute(sfm) or meters per minute (m/min). The analysis is done using Maraging steel as workpiece and Plain Brass wire as electrode. The effect of all the parameters is studied as follows.

3.1.1. General Factorial Regression for Cutting Rate

Table 4: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	13	2.41056	0.185427	133.51	0.000
Linear	5	2.35611	0.471222	339.28	0.000
Ton	2	0.52111	0.260556	187.60	0.000
Toff	1	0.06722	0.067222	48.40	0.002
Ip	2	1.76778	0.883889	636.40	0.000
2-Way Interac-tions	8	0.05444	0.006806	4.90	0.071
Ton*Toff	2	0.00111	0.000556	0.40	0.694
Ton*Ip	4	0.05222	0.013056	9.40	0.026
Toff*Ip	2	0.00111	0.000556	0.40	0.694
Error	4	0.00556	0.001389		
Total	17	2.41611			

Table 5:Model Summary

S	0.0372678
R-sq.	99.77%
R-sq(adj)	99.02%

3.1.2. Regression Analysis: Cutting Rate Versus Ton, Toff, Ip

Table 6 Coefficients

Term	Co-eff	SE Co-eff	T Value	P-Value	VIF
Constant	0.4684	0.0642	7.30	0.00	
Ton	0.07939	0.00679	11.69	0.00	1.00
Toff	-0.0556	0.0140	-3.98	0.001	1.00
Ip	0.18750	0.00855	21.94	0.00	1.00

3.1.3. Summary (Effect of Ton, Toff, Ip on Cutting Rate)

- From the table 4, the model F-value of 133.51 implies that the model is significant.
- Value of "Prob>F" less than 0.05 indicates model terms are significant. In this case Ton, Toff, Ip and Ton*IP are significant model terms.
- The "Pred R-squared" is in better agreement with the "Adj R-squared".
- The value of standard error of regression 'S' is low, which indicates that the observations are closed to the fitted line.

3.1.4. Regression Equation

From the Table 6, the regression equation is formulated as below

Cutting rate= 0.4684 + 0.07939 Ton - 0.0556 Toff + 0.18750 Ip ---------------- Eqn (1)

3.2 Effect Of Pulse-On-Time (Ton), Pulse-Off -Time (Toff), Peak Current (Ip) On Surface Roughness (Sr)

3.2.1. General Factorial Regression For Surface Roughness

Table 7: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	13	82.5970	6.3536	176.49	0.000
Linear	5	80.5835	16.1167	447.69	0.000
Ton	2	10.1540	5.0770	141.03	0.000
Toff	1	1.0082	1.0082	28.01	0.006
Ip	2	69.4213	34.7106	964.18	0.000
2-Way Interac-tions	8	2.0135	0.2517	6.99	0.039
Ton*Toff	2	0.1933	0.0967	2.68	0.182
Ton*Ip	4	1.7299	0.4325	12.01	0.017
Toff*Ip	2	0.0903	0.0451	1.25	0.378
Error	4	0.1440	0.0360		
Total	17	82.7410			

Table 8: Model Summary

S	0.189737
R-sq	99.83%
R-sq(adj)	99.26%
R-sq(pred)	96.48%

3.2.2. Regression Analysis: Surface Roughness Versus TON, TOFF, IP

Table 9. Coefficients

Term	Coef	SE Coef	T Value	P-Value	VIF
Constant	-0.936	0.662	-1.41	0.180	
Ton	0.3645	0.0701	5.20	0.000	1.00
Toff	-0.237	0.144	-1.64	0.123	1.00
Ip	1.1762	0.0882	13.34	0.000	1.00

3.2.3. Summary (Effect of TON, TOFF, IP on Surface Roughness)

- From the Table 7, the model F-value of 176.49 implies that the model is significant.
- Value of Prob>F" less than 0.05 indicates model terms are significant. In this case Ton, Toff, Ip and Ton*Ip are significant model terms.
- The "Pred R-squared" is in better agreement with the "Adj R-squared".
- The value of standard error of regression 'S' is low, which indicates that the observations are closed to the fitted line.

3.2.4. Regression Equation

From the Table 9, the regression equation is formulated as below

Surface roughness = -0.936 + 0.3645 Ton - 0.237 Toff + 1.1762 Ip----------------Eqn (2)

3.3. Effect of Parameters on Cutting Rate

3.3.1. Effect of Current (IP)

From the ANOVA Table 4, it was found that the current is the most significant factor on CR. The increase in CR with the increase in discharge current as shown in Figure 2 since the spark discharge energy is increased to facilitate the action of melting and vaporization, and advancing the large impulsive force in the spark gap, thereby increasing the CR.

The CR increases when current increases and the CR increases with increase in Ton time, but the increase rate is lower with the individual parameters. The interaction of both current and T_{on}, on CR is greater as shown in figure 3. In real condition, discharge current and duration increases cutting rate, as well as gas bubbles in the discharge zone. Due to the impaired evacuation of machining products, a portion of the discharge energy is spent on re-melting and evaporation of solidified metal particles.

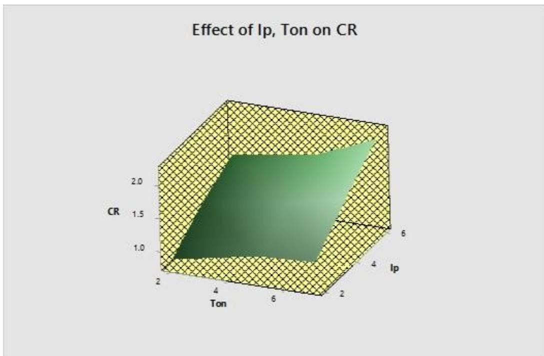

Figure:= 2 Effect of Ip on CR

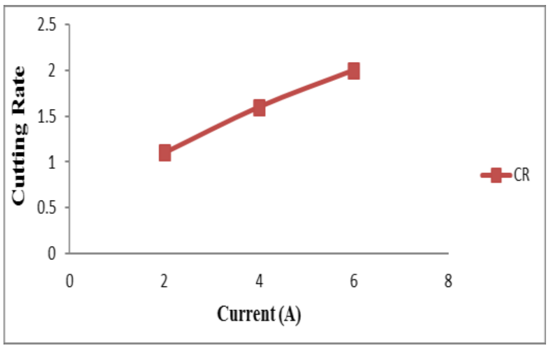

Figure: 3 Current and Ton interaction effect on CR

3.3.2. Effect of Pulse-On-Time (TON)

CR increases with the increase in Ton time at slower rate. By the increase in pulse on-time, the discharge energy of the plasma channel and the period of transferring of this energy into the electrodes increase. This phenomenon leads to a formation of a bigger molten material crater on the workpiece which results in a higher CR. In increasing on time, the spark gets more time to contact with the work which results in increase the CR.

3.3.3. Effect of Pulse-Off-Time (TOFF)

Pulse-off-time (T_{off}) has less significant effect on CR. On increasing Pulse-off-time the CR will decrease as shown in figure 5. With the increase in off time the spark contact time with work piece decreases so that the CR will decrease.

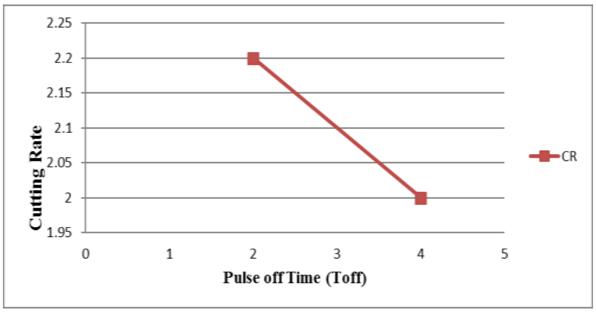

Figure 4: Effect of Ton on CR

The individual effect of T_{off} decreases the CR on increase in its value. Due to the more time gap in between the successive spark will leads to less cutting rate. But the CR increases with increase in Current value and it was shown in figure 6.

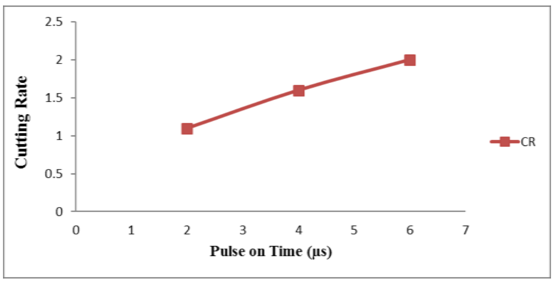

Figure 5: Effect of Toff on CR

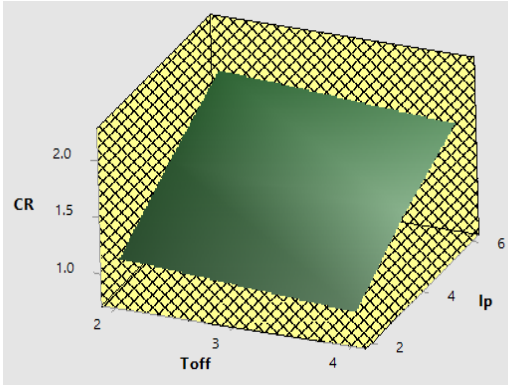

Figure 6: Current and T_{off} interaction effect on CR

3.4. Effect of Parameters on Surface Finish

3.4.1. Effect of Current(IP)

It is observed from the plots that increase in peak current produce rough surface. This is since when the pulse current increase, more intense spark discharges to strike the surfaces and a great quantity of molten and floating metal suspended in the electrical discharge gap during EDM. The higher pulse energy increases the metal removal rate and that set off the rough surface. Therefore, increase peak ampere increases the discharge energy and energy intensity that deteriorates in the surface finish of the workpiece. The current alone shows high influence on SR at greater rate whereas the Ton also has considerable effect on SR. The interaction of Current and Ton on SR is higher.

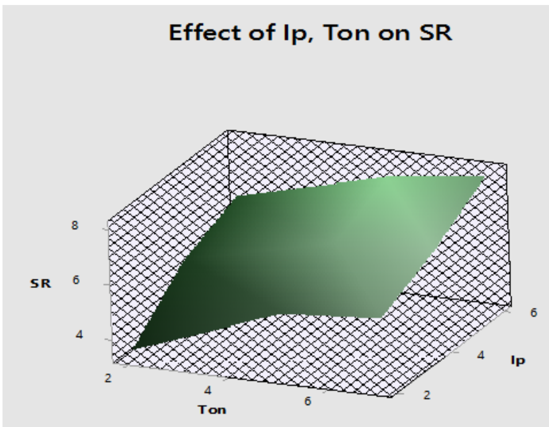

Figure 7: Effect of Ip on SR

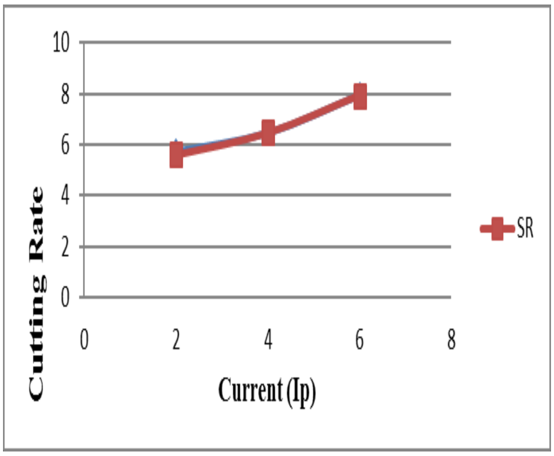

Figure 8: Interaction effect of Current and T_{on} on SR

3.4.2. Effect of Pulse-On-Time (TON)

Surface roughness increases as the Pulse-on-time increase. Long Pulse-on-time causes the more heat transfer into the sample and the dielectric fluid is unable to clear away the molten material, as the flushing pressure is constant. In other words, while the Pulse-on-time is increased the melting isothermals penetrate further into the interior of the material, and the molten zone extends further into material and this produce a greater white layer thickness. Accordingly, as the Pulse-on-time increase the surface roughness increase.SR increases with increase Ton alone but decreases with increase in Toff. The combined interaction can be observed below.

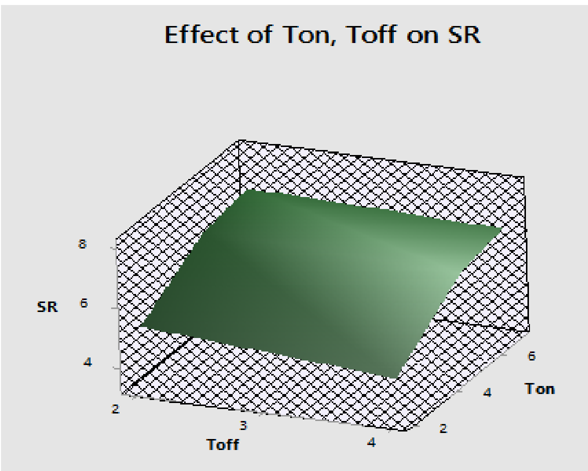

Figure 9: Effect of Ton on SR

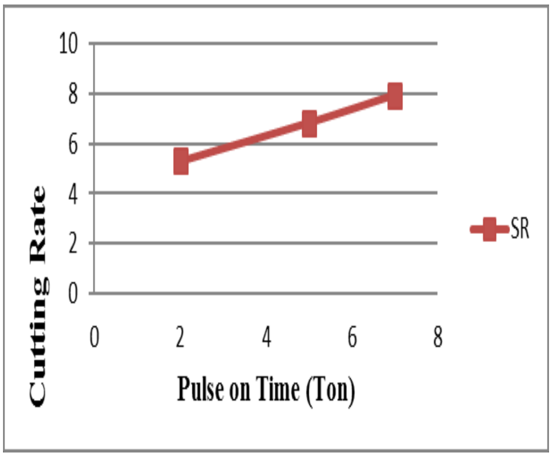

Figure 10: Interaction effect of T_{on} and T_o

3.4.3. Effect of Pulse-Off-Time(TOFF)

Short Pulse-off-time forms the higher frequency that yields low surface roughness. On the other hand, long Pulse-off-time yields low metal removal so that smaller and shallow craters are attained. The long pulse interval provides good cooling effect and enough time to flush away the molten material and debris from the gap between the electrode and workpiece. Thus, long Pulse-off-time presents low surface roughness.

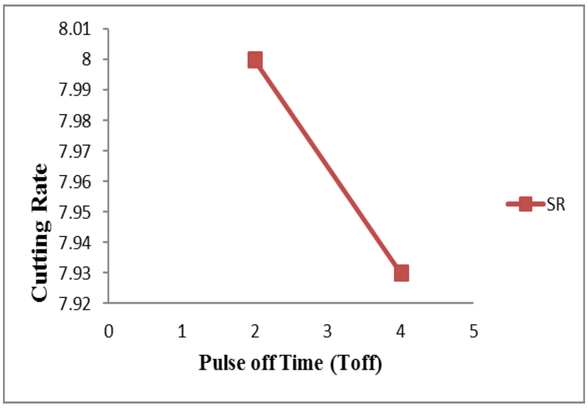

Figure 11: Effect of Toff on SR

IV. CONCLUSIONS

In this study, the influence of the process parameters and optimization of MDN 250 steel in the EDM was studied by using factorial design. From the results, it was found that discharge current, pulse on time, and pulse off time have been found to play significant role in EDM operations.

After analysing the results of the experiments of Maraging steel with Brass electrode, the following conclusions are arrived at:

- Increase in pulse current leads to a sharp increase in the cutting rate. And it was observed that, surface roughness increases with increasing the current.
- The increase in Pulse-on-time leads to an increase in cutting rate and there is slight increase was observed with Surface roughness.
- The increase in pulse pause times decreases both cutting rate and surface finish.
- It was found from the ANOVA, 6.0 A current (Ip), 2 µs Pulse-off-time (T_{off}) and 7 µs Pulse-on-time (T_{on}) are the optimum values to maximize the cutting rate.

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