

Research Article

Effect of Machining Parameters of AISI D2 Tool Steel on Electro Discharge Machining

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Accepted 05 January 2014, Available online 01 February 2014, Vol.4, No.1 (February 2014)

Abstract

AISI D2 tool steel is a high-carbon and high-chromium cold-work tool steel alloyed with molybdenum and vanadium. It has many properties such as high wear resistance, high compressive strength, and high stability in hardening and good resistance to tempering back. The chemical composition of AISI D2 tool steel is (1.55 % C, 0.3 %Si, 0.4 %Mn, 11.8 % Cr, 0.8 % Mo, and 0.8 % V). The application of AISI D2 is Deep drawing and forming dies, cold drawing punches, hobbing, blanking, lamination and stamping dies, shear blades, burnishing rolls, master tools and gauges, slitting cutters, thread rolling & wire dies, extrusion dies etc. The unique features of this alloy have made it useful in all type of industries. Due to these characteristics this alloy difficult to perform machining by traditional method. Electro discharge machining is the one of the most machining, in which that material can be used. Purpose of this study is the effect of machining parameters such as pulse on time (T_{on}), pulse off time (T_{off}) and discharge current (I_p) on the material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) of AISI D2 tool steel. For the experimentation were used grey relational analysis and entropy measurement method based on response surface method. The experiments signify that the parameters of pulse on time, pulse off time and discharge current, have a direct impact on material removal rate (MRR), and with their increase, MRR increases as well. With the increase of pulse off time tool wear rate (TWR) decreases. The analysis of results for surface roughness shows that pulse on time and off time have the highest impact on the surface roughness of AISI D2 tool steel.

Keywords: AISI D2 tool steel, Electro discharge machining, Response surface method, entropy measurement analysis, material removal rate, tool wear rate, surface roughness.

1. Introduction

AISI D2 is one of the most popular high-chromium and high-carbon steels of D series and it is characterized by its high compressive strength and wear resistance, good through-hardening properties, high stability in hardening and good resistance to tempering-back. Cold work tool steels of Series D, also known as die steels, are high alloy steels Fe-Cr-C-base. This alloy has the ability to preserve its desirable mechanical properties intact upon cycling over a range of temperatures, which can be an advantage for applications including, piercing and blanking dies, punches, shear blades, spinning tools, slitting cutters, as well as variety of higher-end wood working tools (V. Sistaet *al.* 2011, Wu-Ling Pan *et al.* 1998, K.H. Prabhudev 1992) Despite good mechanical properties of D2 steel, the lifetime of pieces and accessories fabricated with this alloy is negatively affected by the increase in the severity of operating conditions due to continuing evolution of industrial processes and corrosive operation environments (G. Ramírez *et al.* 2012)..

Electro Discharge Machining (EDM) is a brilliant solution to this problem; it is generally used to machine difficult-to-machine materials, high strength, temperature resistant alloys and manufacturing of tools and dies for machining cavities and counter shaping and cutting, As long as the Work material is conductive. It is a widely applied and very useful technique based on erosion of metal caused by the discharge occurring between the electrode and the process part. The electrical spark is generated and material removal mainly occurs due to the thermal energy of the spark. In EDM, material removal depends on mainly thermal properties of the work material rather than its strength, hardness etc.

Among several attempts RSM was employed (Pradhan *et al.* 2011) to investigate the influence of processing variables on the responses MRR & SR. (Ranganathan&senthivelan 2011) used TM to optimization of SR, TWR & MRR and study the effect of cutting speed, feed rate, depth of cut, and work piece temperature. (Pradhan&Biswas 2010) have established Empirical models variables with MRR & SR. (Lin B *et al.* 2002). Optimized the machining parameters like work piece polarity, pulse on time, duty factor, open discharge voltage, discharge current and dielectric fluid with

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responses MRR, SR, and electrode wear ratio use of orthogonal array with GRA. (Rao et al. 2009) used GRA in entropy measurement for determination of need-YAG laser cutting process parameters. (Singh et al. 2004) optimizing MRR, TWR, SR, taper, radial on EDM by GRA. (Reddy Sreenivasulu et al. 2013 review paper) obtain the optimal levels of process parameters that yield the burr size and hole quality in drilling of Aluminum 6061 alloy & enhance the effectiveness of the drilling process using design of experiments based grey relational analysis. (Li Shichang et al. 2011) optimize the fermentation medium of high-yielding L-lactic acid strains using Response surface method. (Saurav Datta et al. 2010) study the effect of parametric influence of wire EDM on MRR, SR and width of cut to establish mathematical models & simulation. (Sharma & Yadava 2012) present a hybrid approach of RSM & TM for modeling and TM, GRA coupled with entropy measurement method for optimization of cut quality during pulsed Nd: YAG laser cutting of thin Al-alloy sheet for straight profile.

2. Experimentation

For the experiment a die sinking EDM machine model electronic electraplus S50 smart CNC is used. Evaluating the machining performance such as MRR, TWR, and SR is considered. All three performance characteristics correlated with machining parameters such as pulse on time, pulse off time and pulse current. AISI D2 tool steel was selected as a workpiece due to its emergent range of applications in the manufacturing tool and moulds industries and a pure copper was used as a tool electrode, commercial grade EDM oil (specific gravity=0.763, freezing point 94°C was used as a dielectric field.) The experiments were conducted with three variables, having a total 20 runs in three blocks. The different level of parameters considered for this study is listed in table 1. The machining time for all experiments was kept constant of 15 min.

Table 1 Input parameters and their levels

Parameters	Units	Level 1	Level 2	Level 3
Discharge current (I_p)	A	5	7	9
Pulse on Time (T_{on})	μs	20	40	60
Pulse off Time (T_{off})	μs	15	30	45

2.1 Measurement Of Response

2.1.1 Material Removal Rate

MRR is calculated by using the volume loss from the work piece divided by the time of machining. The calculated weight loss is converted to volumetric loss in mm^3/min as per equation -1

$$MRR = \frac{\Delta V_w}{t} = \frac{\Delta W_w}{\rho_w t} \quad (1)$$

Where ΔV_w = volume loss from the work piece, ΔW_w = the weight loss from the work piece

t = the duration of the machining process, $\rho_w = 7700 kg/m^3$ the density of the work piece

2.1.2 Tool Wear Rate

TWR is expressed as the volumetric loss of tool per unit time, expressed as

$$TWR = \frac{\Delta V_t}{T} = \frac{\Delta W_t}{\rho_t g T} \quad (2)$$

Where ΔV_t = the volume loss from the electrode, ΔW_t = the weight loss from the electrode, T = the duration of the machining process, $\rho_t = 8960 kg/m^3$ the density of the electrode.

2.1.3 Surface Roughness

Surface roughness is a measure of the technological quality of a product, which mostly influence the manufacturing cost of the product. Roughness measurement was carried out using a portable stylus type profilometer, Talysurf. It is defined as the arithmetic value of the profile from the centerline along the length, expressed as

$$SR = \frac{1}{L} \int_0^L |y(x)| dx \quad (3)$$

Where L = sampling length, Y = profile curve, X = profile direction.

3. Methodology

In this research, there are three methods employed for estimating the effect of process parameters of EDM on AISI D2 tool steel.

- 1- Response Surface Method (RSM)
- 2- Grey Relational Analysis (GRA)
- 3- Entropy Measurement Analysis

3.1 Response Surface Method

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. (Box and Draper 1987) were introducing RSM in 1951. This methodology is based on experimental design with the final goal of evaluating optimal functioning of industrial facilities, using minimum experimental effort. Here, the inputs are called factors or variables and the outputs represent the response that generates the system under the causal action of the factors. Afterwards, the use of the RSM was shown in the design of new processes and products. In RSM second-degree polynomial model is used. This model is known as quadratic model, which is as follows:-

$$Y = \beta_0 + \sum_{i=1}^k \beta_i X_i + \sum_{i=1}^k \beta_{ii} X_i^2 + \sum_{i,j=1, i \neq j}^k \beta_{ij} X_i X_j + \epsilon \quad (4)$$

Where X_i is the linear input variables, X_i^2 and $X_i X_j$ are the squares and interaction terms, respectively; of these input variables, ϵ is the noise or error observed in the response Y . The unknown second order regression coefficients are β_0 , β_i , β_{ij} and β_{ii} , which should be determined in the second-order model, are obtained by the least square

method. The Minitab Software was used to analyze the data (2003)[15].

3.2 Grey Relational Analysis

Grey system theory introduced by Deng in (1982). Grey relational analysis uses a specific concept of information. It defines situations with no information as black and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey. Grey analysis does not attempt to find the best solution, but does provide techniques for determining a good solution, an appropriate solution for real world problem.

When the range of the sequence is too large or the standard value is too enormous, it will cause the influence of some factors to be neglected. Also, in the sequence, if the factors' goals and directions are different the relational analysis might also produce incorrect results. Therefore, preprocessing of all the data is necessary. This process is called as Grey relational generating. The range of data processing is zero to one (0-1). There are three different types of data pre-processing lower is better, higher is better, and nominal the best. But in this research only two conditions are required, lower is better & higher is better. Higher is better

$$X_i^*(k) = \frac{X_i(k) - \min X_i(k)}{\max X_i(k) - \min X_i(k)} \quad (5)$$

Lower is better

$$X_i^*(k) = \frac{\max X_i(k) - X_i(k)}{\max X_i(k) - \min X_i(k)} \quad (6)$$

Nominal the best

$$X_i^*(k) = \frac{1 - |X_i(k) - X_0b(k)|}{\max X_i(k) - X_0b(k)} \quad (7)$$

Where $I = 1, 2n$, $k = 1, 2, y, p$; $X_i^*(k)$ is the normalized value of the k^{th} element in the i^{th} sequence, $\max X_i^*(k)$ is the largest value of $X_i(k)$, and $\min X_i^*(k)$ is the smallest value of $X_i(k)$, $X_0b(k)$ is desired value of the k^{th} quality characteristic, n is the number of experiments and p is the number of quality characteristics.

After the data pre-processing, calculated grey relational co-efficient, which shows the interaction between optimal & actual normalized experimental results. GRC can be presented-

$$\gamma_i(k) = \gamma(x_0(k)) = \frac{\Delta \min + \zeta \Delta \max}{\Delta_{0,i}(k) + \zeta \Delta \max} \quad (8)$$

$I=1; \dots; n; k=1; \dots; p$

Where $\Delta_{0,i}(k) = |x_0(k) - x_i(k)|$ is the difference of the absolute value called deviation sequence of the reference sequence $x_0(k)$ and comparability $x_i(k)$. The ζ is the distinguishing coefficient or identification coefficient $0 \leq \zeta \leq 1$. In general, it is set to 0.5. The GRG is a weighting-sum of the grey relational coefficients and it is defined as-

$$\gamma(x_0, x_i) = \sum_n \beta_k(x_0, x_i) \quad (9)$$

Where β_k represents the weighting value of the k^{th} performance characteristic, and $\sum_{k=1}^n \beta_k = 1$.

3.3 Entropy Measurement Method

In GRA, for the determination of weights of each quality characteristics, entropy measurement method was used. This is an objective weighting method. Suggested by wen *et al.* discrete type of entropy is used in grey entropy measurement for properly conduct weighting analysis. Entropy method is used for calculating grey relational grade. For the calculations of weights of each characteristic seven steps are given below-

1- Compute the summation of each attribute's value for all sequences, D_k -

$$D_k = \sum_{i=1}^m x_i(k) \quad (10)$$

2- Compute the normalization coefficient K-

$$K = \frac{1}{(e^{0.5} - 1)n} \quad (11)$$

Where n represents the number of attributes.

3- Find the entropy for the specific attribute, e_k -

$$e_k = \frac{1}{K} \sum_{i=1}^n f \left(\frac{x_i(k)}{D_k} \right) \quad (12)$$

4- Compute the total entropy value E-

$$E = \sum_{k=1}^n e_k \quad (13)$$

5- Determine the relative weighting factor λ_k -

$$\lambda_k = \frac{(1 - e_k)}{n - E} \quad (14)$$

6-The normalized weight of each attribute can be calculated as-

$$\beta_k = \frac{\lambda_k}{\sum_{k=1}^n \lambda_k} \quad (15)$$

For calculation of GRG, grey relational co-efficient multiplying with corresponding weight of quality characteristics.

4. Result and Discussion

The experimental values are obtained from experiments conducted as per plan presented in Table 2. Normally, higher value of MRR and lower value of TWR & surface roughness are desired. Thus, the normalized equation (5) are used for higher the better (MRR) and lower the better for TWR & SR is used equation (6). In normalization, the original sequence must be normalized in the range of zero to one. Calculation of grey relational co-efficient, grey relational grade & rank are given in table 3. The grey relational co-efficient was calculated from equation (8). before calculating GRG, must be find weightage of each characteristic used by entropy measurement method. GRG calculated by equation (9). Statistical analysis of GRG was performed by using Minitab software. Effect of process parameters on MRR, TWR & SR are shown in figure 1, 2, and 3.

Table 2 Experimental results for three variables in coded units

Sl. No.	Ip	Ton	Toff	MRR	TWR	SR
1	5	20	15	4.31	4.38	4.25
2	9	20	45	17.59	4.67	7.99
3	5	60	45	6.42	4.47	1.01
4	7	40	30	13.434	4.36	6.446
5	9	60	15	43.1	7.14	6.66
6	7	40	30	12.826	4.831	6.864
7	7	40	30	12.943	4.846	6.372
8	5	60	15	5.98	4.64	1.07
9	9	60	45	43.45	6.89	6.65
10	9	20	15	17.39	4.75	7.95
11	7	40	30	13.48	4.633	6.52
12	5	20	45	4.75	3.19	4.27
13	9	40	30	30.62	5.74	7.92
14	7	60	30	18.08	5.59	2.02
15	7	40	30	13.54	4.926	7.783
16	7	20	30	9.02	4.32	7.85
17	7	40	45	13.55	4.96	6.58
18	5	40	30	5.59	3.83	2.64
19	7	40	30	13.55	4.96	6.58
20	7	40	15	13.168	4.673	7.744

Table 3 Grey relational co-efficient, grey relational grade and rank

GRC MRR	GRC TWR	GRC SR	GRG	RANK
0.333	0.624	0.519	0.487	8
0.431	0.572	0.333	0.441	13
0.346	0.607	1.000	0.644	1
0.395	0.628	0.391	0.467	9
0.982	0.333	0.382	0.560	6
0.390	0.546	0.374	0.432	16
0.391	0.544	0.394	0.439	14
0.343	0.577	0.983	0.628	2
1.000	0.348	0.382	0.571	5
0.429	0.559	0.335	0.436	15
0.395	0.578	0.388	0.449	11
0.336	1.000	0.517	0.611	3
0.604	0.436	0.336	0.454	10
0.435	0.451	0.776	0.549	7
0.396	0.532	0.340	0.418	20
0.362	0.636	0.338	0.441	12
0.396	0.527	0.385	0.432	18
0.341	0.755	0.682	0.587	4
0.396	0.527	0.385	0.432	17
0.393	0.571	0.341	0.431	19

Figure 1 show that the effect of process parameters on material removal rate. In this fig. with the increase of pulse current and pulse on time, material removal rate is sharply increased. And when pulse off time increase, material removal rate decrease up to 30 after that increase.

Figure 2 show that the effect of pulse current, pulse on time and pulse off time on the tool wear rate. With the increase of pulse current and pulse on time, tool wear rate increase. And with the increase of pulse off time tool wear rate slightly decrease up to 30 after that little increase.

Figure 3 show that main effect plot for surface roughness. With the increase of pulse current surface roughness slightly increase, and when pulse on time increase surface

roughness little increase up to 40 after that decrease. And with the increase of pulse off time surface roughness very little increase up to 30 then decrease.

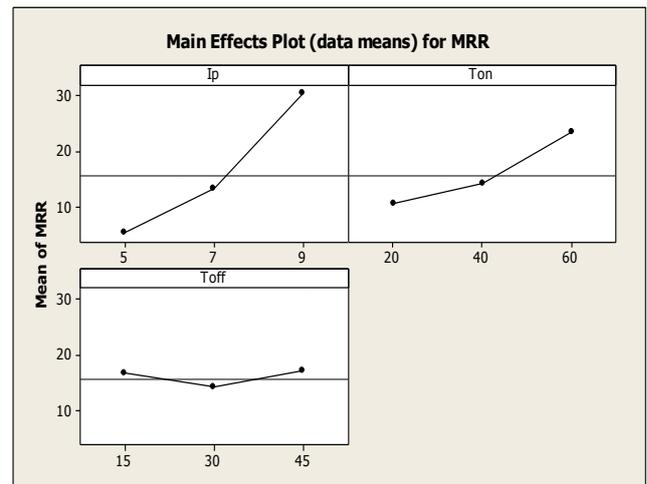


Fig. 1 main effect plot for material removal rate

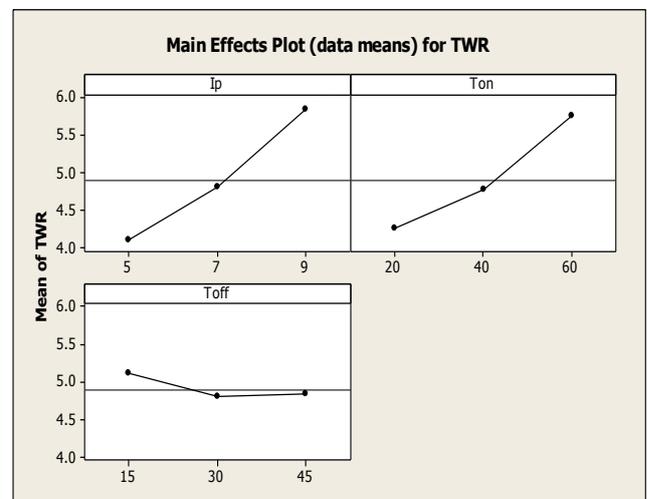


Fig. 2 main effect plot for tool wear rate

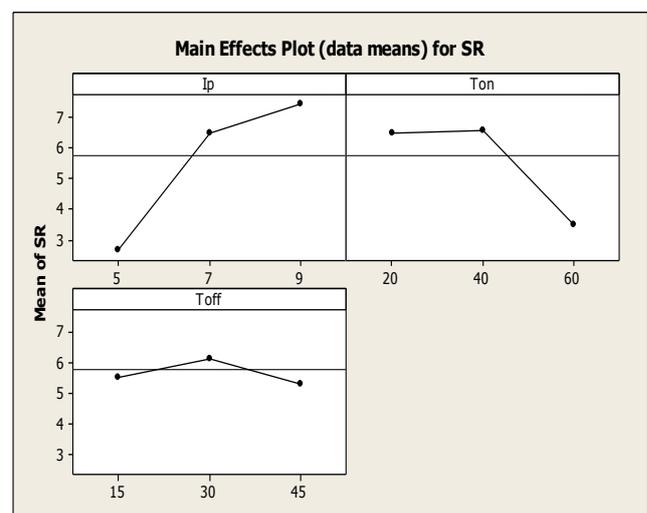


Fig. 3 main effect plot for surface roughness

5. Conclusion

In this study, the effect of input parameters of EDM machining process such as pulse current, pulse on time and pulse off time on the output parameters like MRR, TWR, and SR of machining of AISI D2 tool steel. In performing the experiment, the techniques was used in this study is GRA and entropy based on RSM in order to obtain the process responses. It was demonstrated in this research that the most significant & effective factors in the MRR of AISI D2 steel machined by copper tool are the pulse current and pulse on time, whose increase intensifies the specific energy & increase the MRR. With the increase of pulse current, surface roughness increases. And with the increase of pulse on time & pulse current, tool wear increase. The increase of pulse off time causes the reduction of tool wear and surface roughness.

To obtain the least amount of surface roughness, the least values of pulse current & pulse on time should be chosen and pulse off time between two pulses should be decreased. In the machining of AISI D2 steel using copper tools, the highest value of pulse current & pulse on time were selected to obtain the maximum MRR. To increase the sufficiency if the EDM process, MRR should be high. But with the increase of MRR, tool wear rate also increases, and according to obtained results, the quality of the machined surface will decrease as well. Therefore, it would necessary to carry out the process in several stages, first, by increasing the current and pulse on time, MRR is increased until the workpiece gets closer to its final shape and then in the final & finishing stage, the workpiece is machined with other tools & by applying a lower pulse current and pulse on time, so that the TWR is reduced and a higher quality surface finish is achieved by the EDM process.

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