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Full Length Research Paper

Modeling the machining parameters of AISI D2 tool steel material with multi wall carbon nano tube in electrical discharge machining process using response surface methodology

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This work investigates the machining characteristics of American Iron and Steel Institute (AISI) D2 tool steel with copper as a tool electrode during electrical discharge machining (EDM) process. The multi wall carbon nano tube (MWCNT) is mixed with dielectric fluids in EDM process to analyze the surface characteristics of surface roughness. Regression model were developed to predict the surface roughness (SR) in EDM process. In the development of predictive models, machining parameters of pulse current, pulse duration and pulse voltage were considered as model variables. The collection of experimental data adopted Box-Behnken central composite design (CCD). Analysis of variance (ANOVA) and *F*-test were used to check the validity of regression model and to determine the significant parameter affecting the surface roughness. Later, the AISI D2 tool steel was analyzed and the parameters are optimized using MINITAB software, and regression equation are compared with and without MWCNT used in EDM process. The average 34% of surface finish was improved by using carbon nano tube (CNT) mixed as dielectric fluid. The maximum test errors for regression model using copper electrode are 8.18% for without CNTs and 5.44% for with CNTs. The R^2 value of developed empirical model for SR with MWCNTs is 69.45% compared without CNT is 55.4%. The high R^2 value indicates that the better the model fits the data.

Key words: Multiwall carbon nanotube, electrical discharge machining (EDM), roughness, Box-Behnken central composite design, analysis of variance (ANOVA).

INTRODUCTION

Electrical discharge machining (EDM) is one of the most successful and widely accepted processes for production of complicated shapes and tiny apertures with high accuracy. This method is commonly used for profile truing of metal bond diamond wheel, micro nozzle fabrication, drilling of composites and manufacturing of moulds, and dies in hardened steels. These hard and brittle materials fabricated by conventional machining operation cause excessive tool wear and expense. The mechanical properties of tool steels have been studied extensively for many years. During EDM, the tool and the work piece are separated by a small gap, and submerged in dielectric fluid. The discharge energy produces very high temperatures on the surface of the work piece at the point of the spark. The specimen is subject to a temperature rise of up to 40,000 K causing a minute part of the work piece to be melted and vaporized. The top surface of work piece subsequently resolidifies and cools at very high rate.

EDM technology is increasingly being used in tool, die and mould making industries, for machining of heat treated tool steels and advanced materials (super alloys, ceramics and metal matrix composites) requiring high precision, complex shapes and high surface finish. Traditional machining technique is often based on the material removal

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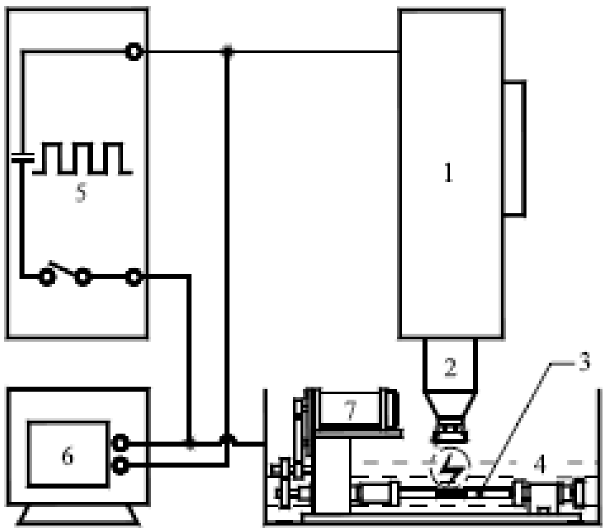

Figure 1. Schematic drawing of EDM. 1, Servo-control; 2, electrode; 3, work piece; 4, dielectric fluid; 5, pulse generator; 6, oscilloscope; 7, DC motor.

using tool material harder than the work material and is unable to machine them economically. Heat treated tool steels have proved to be extremely difficult-to-machine using traditional processes due to rapid tool wear, low machining rates, inability to generate complex shapes and imparting better surface finish.

Guu et al. (2003) proposed and investigated the EDM of American Iron and Steel Institute (AISI) D2 tool steel. The surface characteristics and machining damage caused by EDM were studied in terms of machining parameters. Based on the experimental data, an empirical model of the tool steel was also proposed. Surface roughness (SR) was determined with a surface profilometer. Guu (2001) proposed the surface morphology, SR and micro-crack of AISI D2 tool steel machined by EDM process were analyzed by means of the atomic force microscopy (AFM) technique. Pecas and Henriques (2008) presented on EDM technology with powder mixed dielectric and to compare its performance to the conventional EDM when dealing with the generation of high-quality surfaces. Kansal et al. (2005) study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). Response surface methodology has been used to plan and analyze the experiments. Izquierdo et al. (2009) pro-posed and presented a new contribution to the simulation and modeling of the EDM process. Prabhu and Vinayagam (2008a) analyzed the surface characteristics of tool steel material using multiwall carbon nanotube (MWCNT) to improve the surface finish of material to nanolevel. Prabhu and Vinayagam (2008b) proposed nanosurface generation in grinding process using MWCNT with lubricant mixture to improve the surface finish of grinding process to nanolevel due to good thermal conductivity of carbon nanotubes (CNTs). Ozlem and Cengiz (2008) proposed roughness values obtained from the experiments that have been modeled by using the genetic expression programming (GEP) method and a mathematical relationship has been suggested between the GEP model and SR and parameters affecting it. Moreover, EDM has been used by applying copper, copper–tungsten (W–Cu) and graphite electrodes to the same material with experimental parameters designed in accordance with the Taguchi method. Yan-Cherng et al. (2009) developed the force assisted standard EDM machine. The effects of magnetic force on EDM machining characteristics were explored. Moreover, this work adopted an L18 orthogonal array based on Taguchi method to conduct a series of experiments and statistically evaluated the experimental data by analysis of variance (ANOVA). Ko-Ta et al. (2007) proposed a methodology for modeling and analysis of the rapidly resolidified layer of spheroidal graphite (SG) cast iron in the EDM process using the response surface methodology. The results of ANOVA indicate that the proposed mathematical model obtained can adequately describes the performance within the limits of the factors being studied.

Mustafa and Ali (2011) proposed dependent and independent variables which were also modeled by regression analysis. The results showed that cutting force, surface roughness, cylindricity and vibration were minimised in machining process and production quality was improved. Yang et al. (2009) proposed an optimization methodology for the selection of best process parameters in EDM. Regular cutting experiments are carried out on die-sinking machine under different conditions of process parameters. The system model is created using counter-propagation neural network using experimental data. Jegaraj and Babu (2007) attempted to make use of Taguchi's approach and ANOVA using minimum number of experiments for studying the influence of parameters on cutting performance in abrasive water jet (AWJ) machining considering the orifice and focusing tube bore variations to develop empirical models. Chattopadhyay et al. (2009) investigated the machining characteristics of EN8 steel with copper as a tool electrode during rotary EDM process. Three independent input parameters of the model viz: peak current, pulse on time and rotational speed of tool electrode are chosen as variables for evaluating the output parameters such as metal removal rate (MRR), electrode wear ratio (EWR) and SR.

EDM shown in Figure 1 is an important non-traditional manufacturing method to produce plastics moldings, die castings and forging dies etc. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics, having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. The die sinking EDM SD35-5030 model is used to do the machining. AISI D2 tool steel is one of the

Table 1. Chemical composition of the AISI D2 tool steel (wt. %).

Element	**C**	**Si**	**Mn**	**Mo**	**Cr**	**Ni**	**V**	**Co**	**Fe**
Wt.%	1.5	0.3	0.3	1.0	12.0	0.3	0.8	1.0	Balance

Table 2. Mechanical properties of the AISI D2 tool steel at room temperature.

0.2% offset yield strength	1532 MPa
Tensile strength	1736 MPa
Hardness (HRC)	57

Table 3. Specification of MWCNTs.

Outer diameter	10 to 20 nm
Length	10 to 30 µm
Purity	> 95 wt%
Ash	< 1.5 wt%
Specific surface area	> 233 m^2/g
Electrical conductivity	> 10^{-2} S/cm

carbon steels alloyed with Mo, Cr, and V and is widely used for various dies and cutters for its high strength, and wear resistance due to formation of chrome carbider in heat treatment. Table 1 shows the chemical composition (wt.%) of the material, while Table 2 shows the mechanical properties of the AISI D2 tool steel.

CNTs are related to graphite. The molecular structure of graphite resembles stacked, one-atom-thick sheets of chicken wire, a planar network of interconnected hexagonal rings of carbon atoms. In conventional graphite, the sheets of carbon are stacked on top of one another, allowing them to easily slide over each other. That is why graphite is not hard, but it feels greasy and can be used as a lubricant. When graphene sheets are rolled into a cylinder and their edges joined, they form MWCNT (Table 3). Only the tangents of the graphitic planes come into contact with each other, and hence their properties are more like those of a molecule as mentioned in the above passage clearly. Furthermore, the high-frequency carbon-carbon bond vibrations provide an intrinsic thermal conductivity higher than even diamond. The TEM images of multi wall carbon nano tubes are shown in Figure 2 was received from Cheap tubes Inc., USA.

CNT nanofluids, is of special interests to researchers because of the novel properties of CNTs -extraordinary strength, unique electrical properties and efficient conductors of heat. CNTs are fullerene-related structures that consist of either a grapheme cylinder or a number of concentric cylinders (Wen and Ding, 2004). Choi et al. (2001) measured the effective thermal conductivity of MWCNTs dispersed in synthetic (poly-α-olefin) oil and reported the enhancement up to a 150% in conductivity at approximately 1 vol% CNT, which is by far the highest thermal conductivity enhancement ever achieved in a liquid (Lockwood and Zhang, 2005). Solid lubricants are useful for conditions when conventional liquid lubricants are inadequate such as high temperature and extreme contact pressures. Their lubricating properties are attributed to a layered structure on the molecular level with weak bonding between layers. Such layers are able to slide relative to each other with minimal applied force, thus giving them their low friction properties. CNT is having high strength to weight ratio used in aero space industry. Young’s modulus of CNT is over 1 TPa versus 70 GPa for aluminium, steel 200 Gpa and 700 GPa for C-fibre. The strength to weight ratio is 500 times greater than aluminium. Maximum strain will be 10% much higher than any material. Thermal conductivity of 3,000 W/mK in the axial direction is with small values in the radial direction. Conductivity of CNTs is 109 A/cm^2 and copper is 106 A/cm^2. CNT’s having very high current carrying capacity, excellent field emitter and high aspect ratio. Model Hommel Tester TR500 SR tester is a multi-application measuring instrument for component surface quality evaluation. It is capable of checking the work piece SR on plane, cylinder, groove and bearing raceway.

In this paper, CNT mixed dielectric fluids are used in the EDM process to analyze the surface characteristics of AISI D2 tool steel material. Till now, no work has been carried out by using CNT mixed dielectric machining. CNT based nano fluid is used to improve the surface finish from micro level to nano level which improves the accuracy of the work piece. The collection of experimental data adopted Box-Behnken Central composite Design (CCD) using Table 5 coded level of three machining parameters. ANOVA and *F*-test were used to check the validity of regression model and to determine the significant parameter affecting the surface roughness. Later the AISI D2 tool steel was analyzed and the parameters are optimized using MINITAB software and regression equation are compared with and without multiwall carbon nanotubes used in EDM process.

Table 4. Electrical discharge machining conditions.

Work material	AISI D2 tool steel
Dielectric	Kerosene
Electrode material	Copper
Pulsed current	4.5, 5, 5.5A
Pulse-on duration	6 to 25 µs
Pulse voltage	40- 80 v

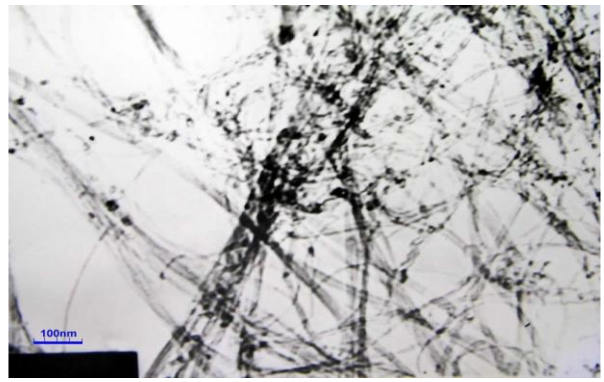

Figure 2. A TEM image of our MWCNTs 95wt% <8nm OD.

Figure 3. EDM set up using MWCNT.

EXPERIMENTAL WORK

The specimen was made of the AISI D2 tool steel, which is widely used in the mold industry. The electrode material used is copper. The raw materials were machined as using conventional methods such as turning, parting and grinding. The specimens were made to a size of diameter 20mm and length 20.5 mm and the electrode were made to a size of 24 mm diameter and length 50 mm. The machined material was heated to 1030°C at a heating rate of 20°C/min in muffle furnace. It was kept at 1030°C for 1 h and then quenched. After quenching, the specimens were tempered at 520°C for 2 h and then air cool. The hardness obtained for the specimen is 58HRC Table 2 shows the chemical composition (wt. %) of the material. The EDM specimens were sparked on a die-sinking EDM machine model type SD35 – 5030. The experiment was carried out in kerosene dielectric covering the work piece by 40 mm. A cylindrical copper rod machined was used as the electrode for sparking the work piece. The copper electrode was the negative polarity and the specimen was the positive polarity during the EDM process. During EDM, the primary parameters are pulsed current, pulse-on duration, and pulse-off duration. Table 4 shows the EDM conditions.

During the EDM process, the varying pulse-off duration setting from 1 to 10 µs could effectively control the flushing of the debris from the gap, giving machining stability. Hence, the effect of the pulse-off duration on the machined characteristics was not considered in the present work. After each experiment, the machined surface of the EDM specimen was studied by means of a scanning electron microscope. The dielectric fluid was mixed in a proportion of 2 g of MWCNT for 0.5 litre of kerosene. The sparking was carried out in this setting (Figure 3). After experiment, the machined surface of the EDM specimen was studied by means of a scanning electron microscope. Different samples were examined.

A separate tank was made to hold the dielectric fluid containing MWCNT in which the specimen was placed. After experiment, the machined surface of the EDM specimen was studied by means of scanning electron microscope. Statistical technique was used for investigating and modeling the relationship between variables. Models of functional relationships are usually approximations. Uses of regression: data description, parameter estimation, prediction and estimation, control. Iterative procedure from data to selection of model, model fitted to data, model adequacy checking and modification of the model or fit. The SR was measured using SR tester Hommel Tester TR500 for given working condition of EDM for with and without CNT (Table 6). The collection of experimental data adopted Box-Behnken CCD. It is an independent quadratic design in that it does not contain an embedded factorial or fractional factorial design. In this design the treatment combinations are at the midpoints of edges of the process space and at the center. These designs are rotatable (or near rotatable) and require 3 levels of each factor. These designs require fewer treatment combinations than a CCD in cases involving 3 or 4 factors. This property prevents a potential loss of data in those cases. Each factor with low (-1) and high (+1) value of variables also center full factorial value (0). To determine the number of measurement points needed to take a measurements are based on no of factorial runs $\alpha = 2^k$, where k is no of parameters are used. Here, 3 parameters are used so 8 corner points, 6 star points are used and 1 central point is used. So totally, 15 readings were taken for Box-Behnken CCD. The input parameters are chosen within the processing guides of material and correlated the machine.

The coded values are obtained by using the following transformation

Pulse current $X1 = I - I_0 / \Delta I$ (1)

Table 5. The coded level of three machining parameters and their range.

S/N	Parameter	Unit	Coded value		
			-1(low)	0	+1(High)
1	Pulse current (I)	Amp	4.5	5	5.5
2	Pulse duration (τ)	Second	6	12	25
3	Pulse voltage (V)	Voltage	40	60	80

Table 6. Experimental results along with design matrix.

S/N	Coded value			Actual value			With CNTs surface roughness (Ra)	Without CNTs surface roughness (Ra)
	X1	X2	X3	X1	X2	X3		
1	-1	-1	0	4.5	6	60	1.30	4.02
2	+1	-1	0	5.5	6	60	2.03	4.60
3	-1	+1	0	4.5	25	60	1.90	4.87
4	+1	+1	0	5.5	25	60	3.04	4.83
5	-1	0	-1	4.5	12	40	2.98	3.08
6	+1	0	-1	5.5	12	40	2.34	3.38
7	-1	0	+1	4.5	12	80	2.98	3.71
8	+1	0	+1	5.5	12	80	2.60	3.28
9	0	-1	-1	5	6	40	3.00	4.30
10	0	+1	-1	5	25	40	3.95	5.89
11	0	-1	+1	5	6	80	2.34	4.75
12	0	+1	+1	5	25	80	2.74	3.10
13	0	0	0	5	12	60	3.04	4.58
14	0	0	0	5	12	60	3.48	4.72
15	0	0	0	5	12	60	4.25	5.74
				Mean (µ)			**2.79**	**4.32**

Pulse duration $X2 = \tau - \tau_0 / \Delta\tau$ (2)

Pulse voltage $X3 = V - V_0 / \Delta V$ (3)

Where $X1, X2, X3$ are coded value of I, τ and V respectively. The I_0, τ_0, $V0$ are cutting speed, feed and depth of cut at zero level. ΔI, $\Delta\tau$, ΔV are the units of variation in I, Γ and V. The experimental matrixes with coded and actual values are shown in Table 6.

RESPONSE SURFACE MODELING

Regression model is determining the relationship between independent variable with dependent variables. Here, pulse current, pulse duration and pulse voltage were used as independent variable and SR was used as dependent variable. Empirical expressions have been developed to evaluate the relationship between input and output parameters. The average output values of SR have been used to construct the empirical expressions. The empirical model was developed based on relationship between SR with pulse current, pulse on duration and pulse voltage in EDM process.

The empirical model was

$$Y = A\,(X_1)^a\,(X_2)^b\,(X_3)^c \quad (4)$$

Y, Surface roughness (µm); A, coefficient; X_1, pulse current (A); X_2, Pulse on Duration (µs); X_3, pulse voltage (V).

The non- linear Equation 4 is converted to linear form by:

$$\log Y = \log(A) + a\log(x1) + b\log(x2) + c\log(x3) \quad (5)$$

Now, Equation (2) can be written as:

$$\bar{Y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \quad (6)$$

where $\bar{Y}$ is a true value of dependent machining output on a logarithmic scale, x_1, x_2, x_3 are the logarithmic transformation of the different input parameters β_0, β_1, β_2, β_3 are corresponding parameters to be estimated. MINITAB 15 software was used to estimate the parameters of the above first order model using the data shown in Tables 6a, b and c are coefficients determined by regression analysis.

RESULTS AND DISCUSSION

Surface roughness

To determine the effect of the EDM process on the SR of the tool steel, the surface profiles of the EDM specimens

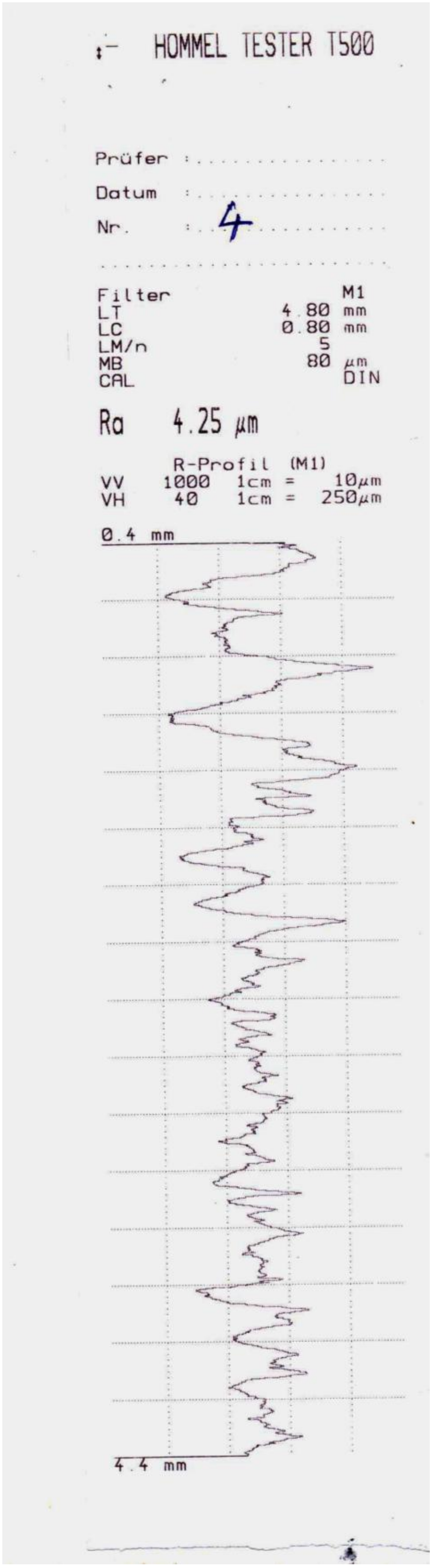

Figure 4. Surface roughness (Ra) value for 5 amps with MWCNT.

were measured by SR tester (Hommel Tester TR500). Figure 4 shows the surface roughness (Ra) value and its graph results for the specimen which was sparked using MWCNT. The parameters used are pulse current 5 amps, pulse duration 12 µs and pulse off duration 60 µs. The roughness value obtained for the specimen using this parameter is 4.25 µm.

The developed empirical model for surface roughness without carbon nanotube

$$R_a = A I^a \tau^b V^c \qquad (7)$$

Where A, 4.21; a, 0.100; b, 0.0207; c, - 0.0113; R^2, 6.9%. Here R^2 is defined as a measure of the amount of reduction on the variability of machining output. The regression analysis of the experimental data yields the semi empirical model

$$R_a withoutCNT = 4.21 I^{0.100} \tau^{0.0207} V^{-0.0113} \qquad (8)$$

The developed empirical model for surface roughness with carbon nanotube:

$$R_a = A I^a \tau^b V^c \qquad (9)$$

Where A, 1.97; a, 0.213; b, 0.0271; c, - 0.0101; R^2, 11.8%.

The regression analysis of the experimental data yields the semi empirical model

$$R_a withCNT = 1.97 I^{0.213} \tau^{0.0271} V^{-0.0103} \qquad (10)$$

Results of regression analysis are compared with experiments in Table 6 for 15 check sets. The comparison results are shown in Table 7. The maximum test errors for regression model using copper electrode are 8.18% for without carbon nanotubes and 5.44% for with CNTs. This method is suitable for estimating SR in an acceptable error ranges. The model generation of regression model took just a couple of seconds. From the results, errors of measurements occurs in SR with CNT is less than without CNTs.

Figure 5 represents error showing actual SR of measurement results with predicted SR through empirical model with and without using multi wall carbon nanotube used in EDM machining process. ANOVA test produce total variability of experimental results into components of variance and then their significant. F-test is utilized for comparing variances for this purpose.

Non-significant effects of the unusual observations were removed from the model because it will affect the

Table 7. Comparison of regression model with experiment measurements for copper electrode.

Experiment number	With CNTs surface roughness (μm)		Without CNTs surface roughness (μm)	
	Experimental measurement	Regression model	Experimental measurements	Regression model
1	1.30	2.485	4.02	4.1062
2	2.03	2.698	4.60	4.2062
3	1.90	3.00	4.87	4.4995
4	3.04	3.213	4.83	4.5995
5	2.98	2.8497	3.08	4.4564
6	2.34	3.0627	3.37	4.5564
7	2.98	2.4457	3.71	4.0044
8	2.60	2.6587	3.28	4.1044
9	3.00	2.7936	4.30	4.3822
10	3.95	3.3085	5.89	4.7755
11	2.34	2.3896	4.75	3.9302
12	2.74	2.9045	3.10	4.3235
13	3.04	2.7542	4.58	4.2804
14	3.48	2.7542	4.72	4.2804
15	4.25	2.7542	5.74	4.2804

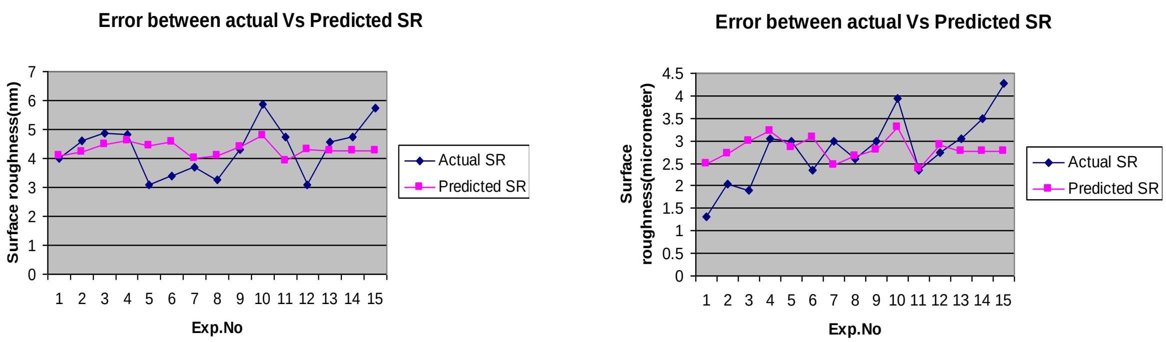

Figure 5. Error showing actual Vs predicted surface roughness without and with carbon nanotubes.

output parameters. The R^2 value of developed empirical model for SR with multi wall carbon nanotubes is 69.45% compared without CNT is 55.4%. The high R^2 value indicates that the better the model fits your data. The more variance 69.45% that is accounted for by the regression model the closer the data points will fall to the fitted regression line using MWCNTs.

In determining the appropriateness of rejecting the null hypothesis in a hypothesis test, the smaller the p-value, the smaller the probability that rejecting the null hypothesis is a mistake. A commonly used value is 0.05. Here p-value 0.04 of cutting speed is less than the alpha value which means fewer mistakes occurs than without CNT is 0.211 p-values. The results predicted by regression model are compared with experimental measurements results with multi wall carbon nanotubes and without CNT used in EDM process.

The main output from an ANOVA study arranged in a table, shows the sources of variation, their degrees of freedom, the total sum of squares and the mean squares. The ANOVA table also includes the F-statistics and p-values. Use these to determine whether the predictors or factors are significantly related to the response. The CNT used in machining process pulse current and pulse durations are significant parameters which influence the surface finish when compared without CNT no parameters are significant. In this, error occurs during CNT 30.54% is less than the without using CNT 44.59%. Also the percentage contribution of each parameter which influences the surface finish is analyzed. Tables 8 and 9 show the results of ANOVA for the SR of CNT and without CNT. Larger FA_o value indicates that the variation of the process parameter makes a big change on the SR and *P* denotes its percent contribution on surface roughness.

Table 8. The results of ANOVA for the surface roughness with MWCNT copper electrode.

Machining parameter	Degree of freedom (f)	Sum of squares (SSa)	Variance (Va)	FA_o	P	Contribution (%) with CNT
I	2	2.8756	1.5600	4.93	0.040*	34.7
τ	2	2.5506	1.2649	4.00	0.063*	30.78
V	2	0.3283	0.1642	0.52	0.614	3.98
Error	8	2.5310	0.3164			30.54
Total	14	8.2855				100

*, Significant; S, 0.562471; R^2, 69.45%; R^2 (adj), 46.54%.

Table 9. The results of ANOVA for the surface roughness without MWCNT copper electrode.

Machining parameter	Degree of freedom (f)	Sum of squares (SSa)	Variance (Va)	FA_o	P	Contribution (%) without CNT
I	2	2.1521	1.1671	1.90	0.211	19.55
τ	2	0.7997	0.3021	0.49	0.629	7.28
V	2	3.1464	1.5732	2.56	0.138	28.58
Error	8	4.9090	0.6136			44.59
Total	14	11.0073				100

S, 0.783344; R^2, 55.40%; R^2 (adj), 21.95%.

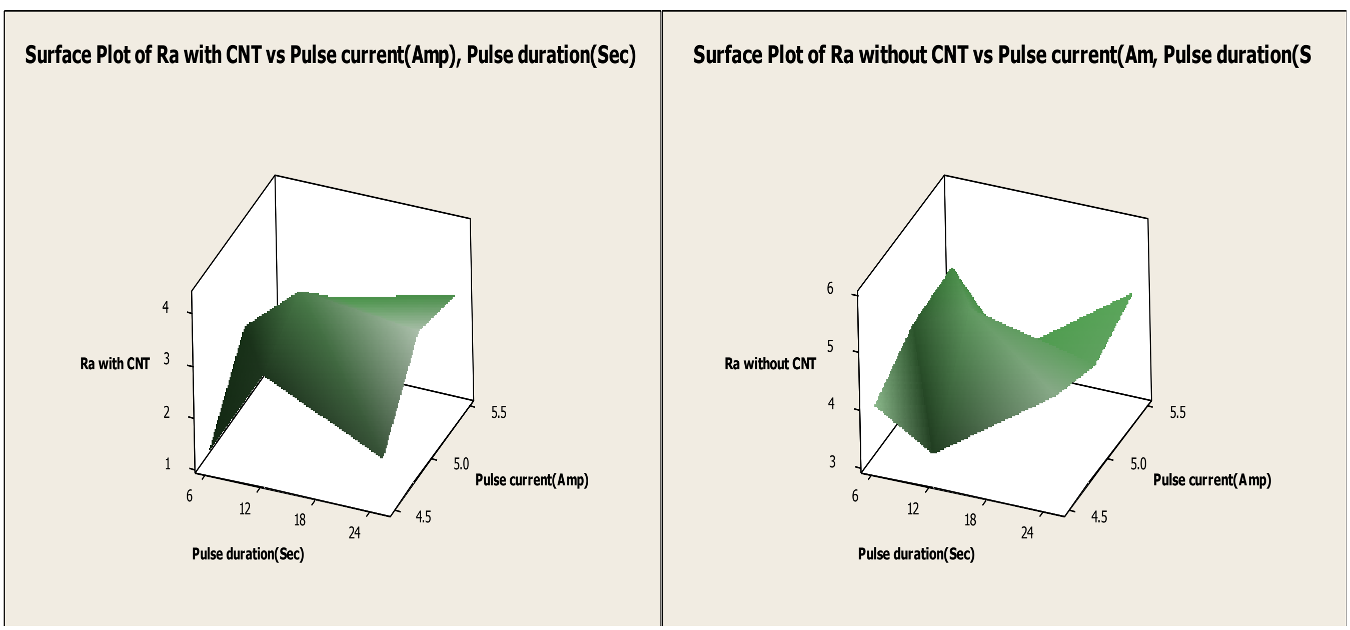

Figure 6. Response surface of Surface roughness (Ra with and without CNT) to pulse current (A) and pulse duration (T).

Effect of parameters on surface roughness using carbon nano tubes

The effect of pulse current and pulse on duration with and without CNT is shown in Figure 6. These Figure 6 indicate that SR increase with increase in pulse current.

CONCLUSION

In this investigation, experimental data adopted Box-Behnken CCD. The first order empirical models were developed for prediction of various output process parameters during EDM. The proposed models were successfully applied to estimate the values of SR under various machining conditions. Through this investigation of EDM of AISI D2 tool steel with copper electrode, the following conclusions are summarized that the main influencing factors for SR, in order of importance, include pulse current and pulse on duration, respectively. The developed empirical formulae can be used to evaluate SR produced by EDM with CNT, with low prediction error. The proposed empirical models were validated to conclude and as well fit for predictions of machining output such as SR with low prediction error.

REFERENCES

Choi SUS, Zhang ZG, Yu W, Lockwood FE, Grulke EA (2001). Anomalous thermal conductivity enhancement in nanotube suspensions. Appl. Phy. Let., 79: 2252-2254.

Guu YH (2001). AFM surface imaging of AISI D2 tool steel machined by the EDM process. Appl. Sur. Sci., 242: 245–250.

Guu YH, Hocheng H, Chou CY, Deng CS (2003). Effect of electrical discharge machining on surface characteristics and machining damage of AISI D2 tool steel. Mat. Sci. Eng., 358: 37-43.

Izquierdo B, Sancheza JA, Plazaa S**,** Pomboa I, Ortegaaet N (2009). A numerical model of the EDM process considering the effect of multiple discharges. Int. J. Mach. Tools Manuf., 49(3-4): 220-229.

Kansal HK, Singh S, Kumar P (2005). Parametric optimization of powder mixed electrical discharge machining by response surface methodology. J. Mat. Proc. Tech., 169: 427–436.

Lockwood FE, Zhang ZG (2005). The current development on nanofluid research. SAE 2005 World Congress and Exhibition, Detroit, MI, USA, Session: Military Vehicle Fuels, Lubes and Water, p. 7.

Ozlem S, Cengiz KM (2008). Evolutionary programming method for modeling the EDM parameters for roughnesses. J. Mat. Proc. Tech., 200: 347–355.

Prabhu S, Vinayagam BK (2008a). Analysis of Surface Characteristics of AISI D2 Tool Steel Material using Carbon Nano Tube. Int. J. Nano. Appl., 2(2-3): 107-122.

Prabhu S, Vinayagam BK (2008b). Nano surface generation in grinding process using carbon nano tube with lubricant mixture. Int. J. Nano. appl., 2(2-3): 149-160.

Pecas P, Henriques E (2008). Electrical discharge machining using simple and powder-mixed dielectric: The effect of the electrode area in the surface roughness and topography. J. Mat. Proc. Tech., 200: 250–258.

Wen D, Ding Y (2004). Effective thermal conductivity of aqueous suspensions of carbon nanotubes. J. Thermo. Heat Trans., 18(4): 481-485.

Yan-Cherng L, Yuan-Feng C**,** Der-An W**,** Ho-Shiun L (2009). Optimization of machining parameters in magnetic force assisted EDM based on Taguchi method. J. Mat. Proc. Tech., 209: 3374–3383.

Ko-Ta C, Fu-Ping C**,** De-Chang T (2007). Modeling and analysis of the rapidly resolidified layer of SG cast iron in the EDM process through the response surface methodology. J. Mat. Proc. Tech., 182: 525–533.

Mustafa AY, Ali T (2011). Determination and optimization of the effect of cutting Parameters and work piece length on the geometric tolerances and surface roughness in turning operation. Int. J. Phy. Sci., 6(5): 1074-1084.

Chattopadhyay KD, Verma S, Satsangi PS, Sharma PC (2009). Development of empirical model for different process parameters during rotary electrical discharge machining of copper–steel (EN-8) system. J. Mat. Proc. Tech., 209: 1454–1465.