OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Investigation of Surface Morphology in EDM process using Response Surface Methodology

Ravinder Kumar[1], Surabhi Lata[1], Ramakant Rana[1], Pankaj Kumar[2], Abhinav Kumar[2], Lakshay Kumar[2], Jitender Kumar Verma [2]Roop Lal[3]

[1]*Assistant Professor, Mechanical and Automation Engineering Department, Maharaja Agrasen Institute of Technology, Delhi, India*
[2] *Student, Mechanical and Automation Engineering Department, Maharaja Agrasen Institute of Technology, Delhi, India*
[3]*Assistant Professor, Mechanical Engineering Department, Delhi Technological University, Delhi, India*

ABSTRACT:- *Electric Discharge Machining is used to produce complex and intricate shapes that are difficult-to-machine by the conventional methods. The present research work carries out the investigation of surface roughness trend depending on the process parameters of EDM process. The work material and electrode material selected are Stainless Steel 202 and EN 31 (AISI 52100) respectively. The optimization process of surface roughness (SR) of electrical discharge machining (EDM) is concluded by the Response Surface Methodology. The process control parameters of EDM chosen were current, pulse on time and machining time. RSM method was used to design the experimental model whose adequacy checking was carried out using Minitab software. Experimental results formed the basis of the formulation of the regression equations. The results successfully supported the prediction of surface roughness through the proposed regression equation. It was concluded that the analysis carried out yielded the optimum results of surface roughness within the experimental constraints while varying the EDM process parameters.*

Keywords:- *EDM, RSM, Design of Experiments, Surface Roughness*

I. INTRODUCTION AND LITERATURE REVIEW

Today's technologically advanced world demands materials which are high strength temperature resistant alloys and possess all desired mechanical properties such as high strength, corrosion resistance, toughness, etc. The emerging needs of the automation world led to the development of such difficult-to-machine materials which meets the stringent design requirements and enhance the surface quality. With the advent of these high strength materials, innovation became mandatory in order to search new technologies for machining and processing of the new materials. These materials enhance in terms of thermal, chemical and mechanical properties which are of huge economic benefit to manufacturing industries but defy the traditional machining processes. Therefore, solution is discovered in the advanced machining processes which makes use of different class of energy for material removal using the material properties, like electrical and thermal conductivity, melting temperature, electrochemical equivalent etc. EDM is a non-traditional machining technique which extensively and effectively machines such materials with ease. It machines electrically conductive materials where material is removed due to the thermal energy of the spark. In this process precisely controlled sparks are generated in the presence of a dielectric fluid between the electrode and the workpiece. The sparks or electrical discharge are of short duration and high current density between the tool and the workpiece. It is assertion that after milling, turning and grinding i.e. conventional machining processes, EDM is the fourth most extensively used machining method. Though efficiency of machining is less but the product quality and productivity in terms of surface finish, geometrical dimensions, process accuracy etc. is high [1]. E. Weingärtner et al. [2] reviewed the paper on Modeling and simulation of electrical discharge machining founding a better correlation with experimental results when the latent heats of fusion and evaporation are taken into consideration, as well as temperature-dependent thermo-physical properties of the workpiece. Input parameters used are short discharge durations and high peak currents. Better simulation results were achieved when considering the material properties as temperature-dependent. Z. Qinjian et al. [3] reviewed the paper on electrical discharge and ultrasonic assisted mechanical combined machining of polycrystalline diamond. The metal bonded diamond grinding wheel was as a tool electrode and the workpiece was supplemented with ultrasonic vibration, electrical discharge and ultrasonic assisted mechanical combined machining achieves efficient precision machining of PCD materials by selecting appropriate combinations of process parameters. The conclusion drawn was that Ultrasonic vibration has chip removal function and it has limited impact on the material removal rate. Karthikeyan et al. [4] used Tungsten carbide/Cobalt (WC–Co) composite and made an attempt to investigate the fracture strength and the reliability of EDMed WC–Co composite using the Weibull distribution analysis. The comparison of results between the machined composites and un-machined composites is carried out and presented in this study. Rajesh et al. [5] optimized the operating parameters for unconventional electric discharge machining through the empirical models developed by conducting a designed experiment based on the Grey Relational Analysis. Genetic Algorithm (GA) based multi-objective optimization for maximization of MRR and minimization of Ra has been done to identify the optimized machining conditions. Jin-Bin et al. [6] analysed the efficiency of traditional cutting processes and found that they are limited by the mechanical properties of the processed material and the complexity of the workpiece geometry, while electrical discharge machining (EDM) being a thermal erosion process, is subject to no such constraints. This paper highlights the development of a comprehensive mathematical model for correlating the interactive and higher order influences of various EDM parameters through RSM, utilizing relevant experimental data as obtained through experimentation. Optimal combination of these parameters was obtained for achieving controlled EDM of the workpieces. Kanlayasiri et al. [7] investigated the following machining variables i.e. pulse-peak current, pulse-on time, pulse-off time, and wire tension. Analysis of variance (ANOVA) technique was used to find out the variables affecting the surface roughness. Results showed that pulse-on time and pulse-peak current are significant variables to the surface roughness of wire-EDMed DC53 die steel. Further, the developed model was validated with a new set of experimental data, and the maximum prediction error of the model was less than 7%. Anand et al. [8] described the selection of machining parameter Discharge current, Pulse on time, Pulse off time in EDM for the machining of AISI 202 Stainless steel material and further using the grey relational analysis for optimizing the machining parameters i.e. material removal rate and surface roughness. Ghoreishi et al. [9] have made a model to optimize process parameters in EDM of tungsten carbide-cobalt composite. Four independent input parameters, viz., discharge current, pulse-on time, duty cycle, and gap voltage were selected to assess the EDM process performance in terms of material removal rate, tool wear rate, and average surface roughness. RSM have been used to plan and analyse the experiments. It has been mainly revealed that all the responses are affected by the rate and extent of discharge energy. The obtained predicted optimal results were also verified experimentally and the values of confirmation errors were computed, all found to be satisfactory, being less than 10%.

The investigation in the non-conventional machining processes is generally related to the effect of Pulse ON time, Pulse OFF time, Spark gap set Voltage, Peak current, Flushing Pressure, Work piece height, wire tension and wire feed on the material removal rate, surface roughness, kerf and gap current. The quality of the surface produced during these processes is of great importance and hence, it is exclusively researched. Surface quality is dependent on the appropriate selection of the machining parameters for any particular material and also on the operator's experience. These papers present the effect of various process parameters extensively on the surface roughness as the response factor in EDM process [10, 11, 12].

II. EXPERIMENTAL SETUP

The effect of various machining parameters was studied by conducting number of experiments on the EDM process. The experiments were conducted to investigate the effects of current, pulse ON time and processing time on surface roughness [13]. The selected workpiece was Stainless Steel 202 while the electrode material were EN 31 (AISI 52100). Table 1 shows the chemical composition of the work material i.e. Stainless Steel 202.

Table I: Composition of SS 202 Steel

Iron (Fe)	Chromium (Cr)	Manganese (Mn)	Nickel (Ni)	Silicon (Si)	Nitrogen (N)	Carbon (C)
68	17- 19	7.50-10	4-6	≤ 1	≤ 0.25	≤ 0.15

This chromium-nickel-manganese alloy was selected as at low temperatures it exhibits excellent toughness. It possess high hardness, strength and good corrosion resistant properties. It was chosen due to its emergent range of applications which includes restaurant equipment, sinks, cooking utensils, automotive trim, architectural structures, railway cars, hose clamps as can be made into plates, sheets and coils.

Figure 1: Photographic view of SS 202

Design of Experiments was carried out in order to study and analyse the effect of various process parameters of EDM on response factor i.e. surface roughness. DOE was used to estimate an unknown function for which only a few values were computed while least square error fitting was used to model the generated relations of the response surface [14]. The weight of work piece is measured using digital weighing machine to maintain the weight uniformity of the workpiece.

Figure 2: EDM Machine and Control Panel

III. SURFACE ROUGHNESS MEASUREMENTS

Surface roughness (Ra) is the measure of the fine surface irregularities on the surface texture of the machined workpiece. It is the arithmetic average deviation of the surface valleys and peaks over the entire cut-off length expressed in micro-meters. Cut-off length is the length that the stylus was dragged across the surface. A longer cut-off length will give a more average value, and a shorter cut-off length gives a less accurate result over a shorter stretch of surface.

Surface roughness measurement was carried out using the Mahr Federal Pocket Surf III (Figure 2). The Pocket Surf is a shop–floor type surface-roughness measuring instrument, which traces the surface of various machine parts and calculates the surface roughness based on roughness standards, and displays the results in μm. The work piece was attached to the detector tracing the minute irregularities of the work piece surface and the vertical stylus displacement during the trace being processed and digitally displayed on the display of the instrument [15, 16]. The surface tester has following measuring range:

R_a = 0.03 μm to 6.35 μm / ***1 μ inch to 250 μ inch***

The roughness values are taken by calculating average of at least three values of measurements per specimen at different locations of specimens.

Surface roughness is an important parameter in the EDM process. The parameters that affect roughness are current, pulse ON time and processing time. Centre-line average 'Ra' SR measurements of machined surfaces were taken to evaluate quantitatively the effect of EDM parameters on surface finish.

Figure 3: Surface Tester

IV. RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology, or RSM, is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. The objective is to find the correlation between the variables investigated and the response [17, 18].

Design of Experiments (DOE) was used to estimate an unknown function for which only a few values were computed while least square error fitting was used to model the generated relations of the response surface. A Central Composite Design (CCD) gives a comparatively accurate prediction of all response variable averages related to quantities measured during experimentation, hence it was also used [19]. CCD offers the advantage that certain level adjustments are acceptable and can be applied in the two-step chronological RSM. In these methods, there is a possibility that the experiments will stop with few runs and decide that the prediction model is satisfactory [20]. The current, Pulse ON time and processing time are the machining variables selected for this investigation. The different levels taken for this study are depicted in Table II.

TABLE II: Different Variables Used In The Experiment And Their Level

VARIABLES	UNITS	CODE	LEVELS	
			1	**2**
CURRENT	Ampere (A)	X_1	3	6
PULSE ON TIME	Micro-seconds (µsec)	X_2	8	11
MACHINING TIME	Minutes (min)	X_3	55	65

Machining was carried out by varying the input process parameters each at a time, two replications of surface roughness measurement were taken, and the planning design matrix of the experiments has been shown in Table III.

Table III: PLANNING MATRIX OF THE EXPERIMENTS WITH THE OPTIMAL MODEL DATA

Trial Runs	Current (Amp)	Pulse on Time (µsec)	Machining Time (min)
R1	3	8	55
R2	3	8	65
R3	3	11	55
R4	3	11	65
R5	6	8	55
R6	6	8	65
R7	6	11	55
R8	6	11	65

In this investigation, a second-order model has been utilized. The experimental values are analyzed and the mathematical model is then developed that illustrate the relationship between the process parameters and response factor. The second-order model given below explains the behavior of the system [19, 20, 21].

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

Where Y is the corresponding response, X_i is the input variables, $X_i X_j$ are the interaction terms, respectively, of these input variables. The unknown regression coefficients are β_o, β_i, and β_{ij}.
The equation for calculating the approximate SR is

$SR = 86.59 - 13.99\ X_1 - 7.286\ X_2 - 1.314\ X_3 + 1.184\ X_1X_2 + 0.1182\ X_2X_3 + 0.2259\ X_3X_1 - 0.01927\ X_1X_2X_3$

Where X_1 is current in amperes, X_2 is Pulse On time in microseconds and X_3 is Machining Time in minutes

IV. RESULT AND DISCUSSION

Regression analysis developed the correlation between the input process parameters and the response factor i.e. surface roughness (SR) based on the responses obtained from the experiments. In this experimental investigation, a regression equation have been developed by considering three process parameters i.e. current, pulse on time and machining time and surface roughness as the response factor by the MINITAB 16 software. The coefficients of regression model are estimated from the experimental outputs. Main effects of the process parameters were further studied on the response.

SR obtained from the experiment is compared with the predicted value calculated from the regression model and further percentage error is calculated. As all the points on plot come close enough to form a straight line, it implies that the data are normal [22, 23]. Hence, the regression model is reasonably well fitted with the observed values.

Table IV: Plan of Experiments and Output Responses

Trial Runs	Current (X_1)	Pulse on Time (X_2)	Machining Time (X_3)	X_1X_2	X_2X_3	X_1X_3	$X_1X_2X_3$	SR Experimental	SR Theoretical	% Error
R1	3	8	55	24	440	165	1320	4.795	4.7913	0.077
R2	3	8	65	24	520	195	1560	5.562	5.5572	0.086
R3	3	11	55	33	605	165	1815	5.091	5.08545	0.109
R4	3	11	65	33	715	195	2145	5.285	5.28138	0.068
R5	6	8	55	48	440	330	2640	4.075	4.04784	0.666
R6	6	8	65	48	520	390	3120	5.065	5.04048	0.484
R7	6	11	55	66	605	330	3630	4.445	4.41612	0.649
R8	6	11	65	66	715	390	4290	5.210	5.1837	0.504

5.1 Effect of Current on SR:

The Figure 4 shown below indicates that SR is 5.285 µm when the current is 3 amp. It decreases steeply to 4.795 µm when the current is 6 amp. As the current is increased the SR depicts a decrease in the surface roughness though the number of sparks increases. This is due to the low value of current and also due to the low pulse ON time.

5.2 Effect of Pulse ON Time on SR:

The SR increases from 4.86 µm to 5.012 µm when the pulse on time increases from 8 µsec to 11µsec. As the pulse on time increases the intensity of spark is affected as the duration of the spark increases which is directly influencing the amount of material being removed. Increase in number and frequency of sparks leads to increase in SR.

5.3 Effect of Machining Time on SR:

Figure 6 shows an increase in SR value on the increase in the value of machining time. As the machining time is increased from 55 min to 65 min a steep slope is experienced in SR due to the increased duration while all other parameters remaining fixed. SR increases due to the low range of current on which machining process was carried out.

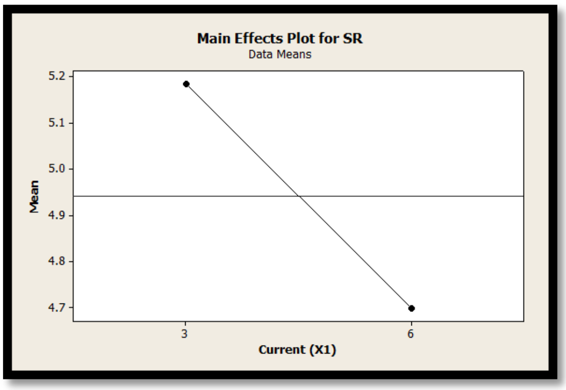


Figure 4: Effect of Current on SR

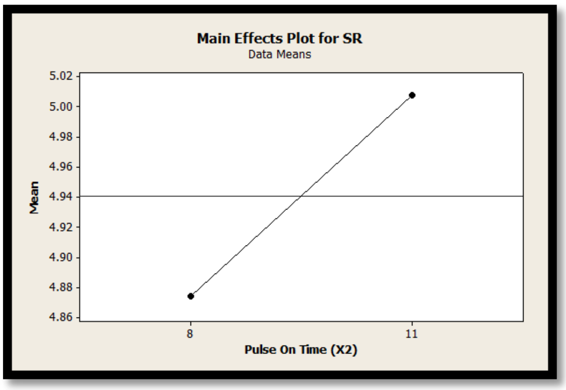


Figure 5: Effect of Pulse ON Time on SR

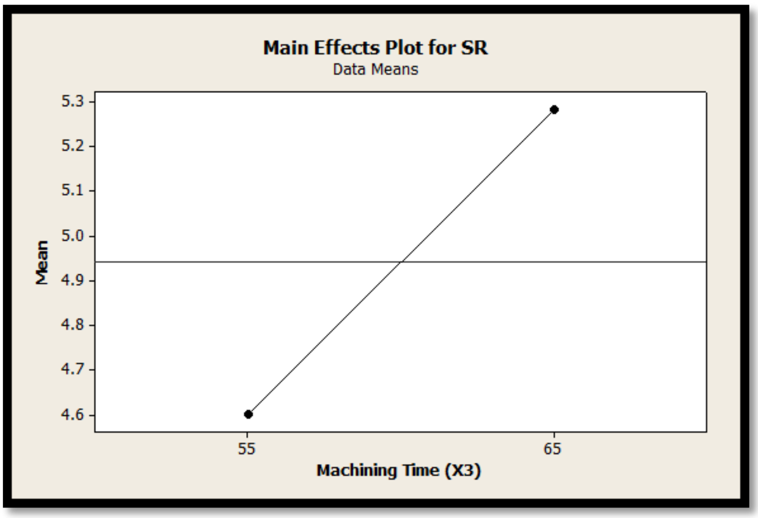
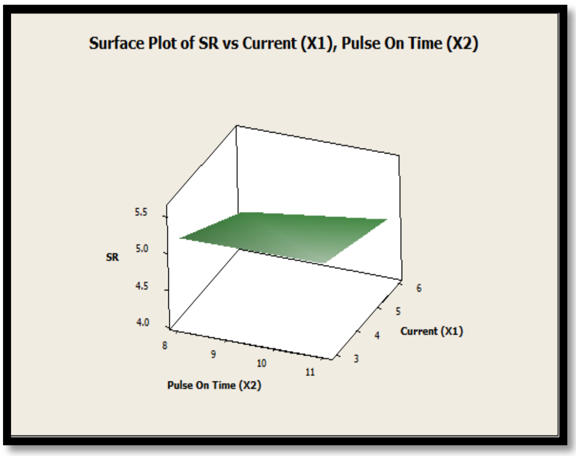


Figure 6: Effect of Machining Time on SR

5.4 Effect of Current and Pulse ON Time on SR:



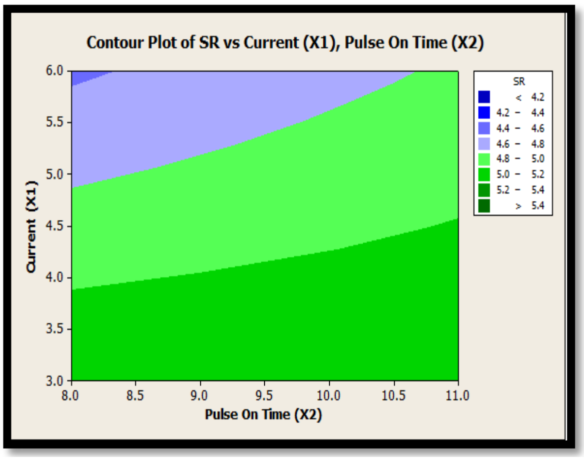
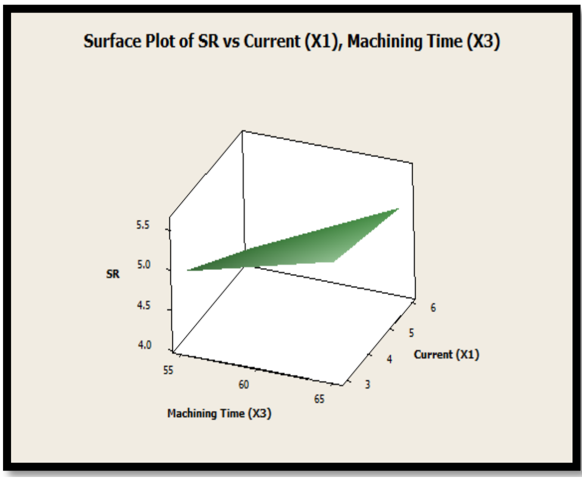


Figure 7: Surface Plot for SR vs X_1 vs X_2 **Figure 8: Contour Plot for SR vs X_1 vs X_2**

Figure 7 and 8 shows the estimated response for SR in relation to the process parameters of current (X_1) and Pulse ON time (X_2) while other parameters remaining constant at their lowest value. It is clear from the above plots that SR significantly decreases with the increase in the value of current for any value of pulse ON time. Though the effect of pulse on value is not prominent in above graphs but at higher values of current SR tends to increase with increase in pulse ON time. This happens due to their individual dominant control over the input energy. As the current increases, the intensity and frequency of the sparks generated increases which develops high temperature and creates crater thereby generating rough surface in the workpiece.

5.5 Effect of Current and Machining Time on SR:

Figure 9 and 10 shows the predicted response for SR in relation to the process parameters of current (X_1) and Machining Time (X_3) while other parameters remaining constant at their lowest value. It is depicted in the above plots that SR decreases parabolically with the increase in the value of current for all values of machining time. The machining time is directly proportional to SR i.e. on low values of machining time smooth surfaces are generated and at high values rough surfaces. Therefore, an optimum surface is generated when current and machining time both are high. This is due to the fact that high and uniform intensity sparks are generated for long duration of time hence, generating smooth surface.



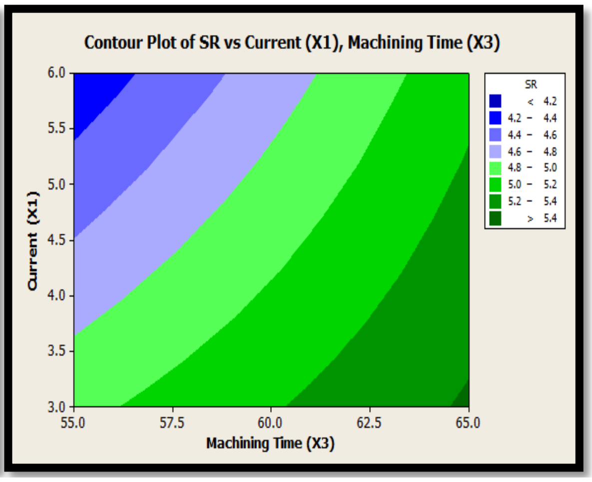
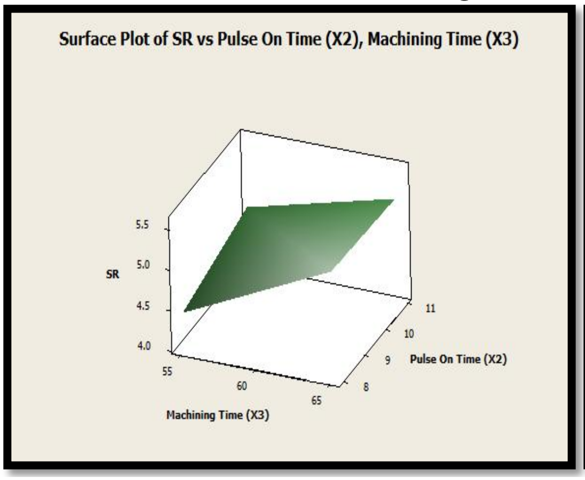


Figure 9: Surface Plot for SR vs X_1 vs X_3 Figure 10: Contour Plot for SR vs X_1 vs X_3

5.6 Effect of Pulse ON Time and Machining Time on SR:



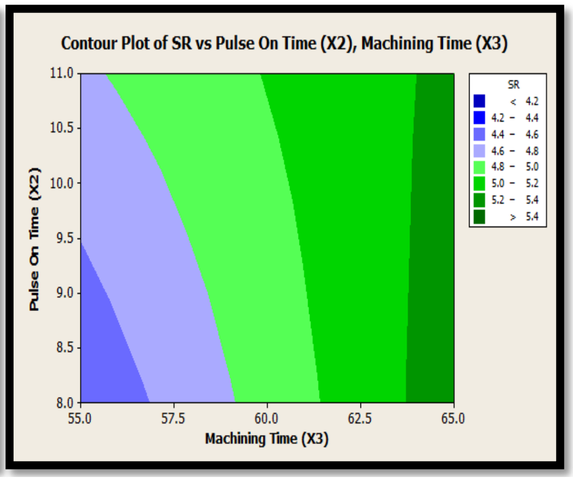


Figure 11: Surface Plot for SR vs X_2 vs X_3 Figure 12: Contour Plot for SR vs X_2 vs X_3

Figure 11 and 12 shows the predicted response for SR in relation to the process parameters of pulse ON time (X_2) and Machining Time (X_3) while other parameters remaining constant at their lowest value. It can be seen from the plots that SR increases significantly if pulse ON time and machining time both are kept at high values. As stated earlier, at high machining time high roughness is obtained, this phenomenon is enhanced by high values of the pulse ON time. This is due to high intensity sparks generated per cycle of pulse and for long duration of time.

Therefore, an optimum surface is generated when pulse ON time and machining time are low. This is due to the fact that sparks are generated with uniform frequency and of uniform intensity.

V. CONCLUSION

In this research work, regression analysis of process parameters of EDM machining process was carried out which determined the factors having maximum influence on the surface roughness [24]. A response model of these parameters was developed and found that current, pulse ON time and interaction term of pulse current with other parameters significantly affected the surface roughness. SR is directly proportional to linear effect of current and pulse ON time [25]. The machining of SS 202 workpiece was done with EN 31 electrode and the following conclusion was drawn from the conducted analysis:

1. It has been confirm that the regression technique can be successfully applied to model the input and output variable of electro discharge machining of SS 202 with EN 31.
2. Within the experimental scope, the SR value increases with the increase in the value of pulse-on time.
3. Surface roughness decreases with the increase in current at low values due to predominant increase in intensity of spark generated between tool and workpiece.
4. The proper selection of input parameters can help in achieving a specific output parameter (SR) and a higher efficiency can be determined by theoretical and experimental characteristic diagrams, especially the two dimensional surface and contour plots.

Finally, a research has been conducted to estimate the optimum machining conditions to achieve the best possible outcome of the response factor within the experimental constraints [26, 27]. This study can help automobile and manufacturing industries for developing a robust, reliable knowledge base and early prediction of surface roughness without actual experimenting with EDM process.

REFRENCES

[1]. M. K. Pradhan*, and C. K. Biswas, "Modeling and Analysis of process parameters on Surface Roughness in EDM of AISI D2 tool Steel by RSM Approach".
[2]. E. Weingärtner et al. / Procedia CIRP 2 (2012) 74 – 78
[3]. Z. Qinjian et al. / Procedia CIRP 6 (2013) 589 – 593.
[4]. D. Kanagarajan, K. Palanikumar, R. Karthikeyan, "Effect of Electrical Discharge Machining on strength and reliability of WC–30%Co composite", Materials and Design 39 (2012) 469–474.
[5]. R.Rajesha and M. DevAnandb, "The Optimization of the Electro-Discharge Machining Process Using Response Surface Methodology and Genetic Algorithms", Journal of Procedia Engineering 38 (2012) 3941 – 3950.
[6]. Shih Jing-Shiang, TzengYih-Fong, Yang Jin-Bin. "Study of the parameters in electrical discharge machining through response surface methodology approach".Applied Mathematical Modelling 33 (2009) 4397–4407.
[7]. Yan K. Kanlayasiri, S. Boonmungb. "Effects of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel: Design of experiments and regression model.".Journal of Materials Processing Technology 192–193 (2007) 459–464.
[8]. T.M chenthijegan, M.Devanand and D.ravindran, "Determination of electro discharge machining parameter in AISI 202 stainless steel using grey relation analysis", Mater Procedia engineering 38(2012), 4005-4012.
[9]. S. Assarzadeh, M. Ghoreishi, "Statistical modeling and optimization of process parameters in electro-discharge machining of cobalt-bonded tungsten carbide composite (WC/6%Co)", Procedia CIRP 6 (2013), 463 – 468.
[10]. S.H.Tomadi, M.A.Hassan, Z. Hamedon, R.Daud, and A.G.Khalid, "Analysis of the Influence of EDM Parameters on Surface Quality, Material Removal Rate and Electrode Wear of Tungsten Carbide", Proceedings of the International MultiConference of Engineers and Computer Scientists 2009, Vol II IMECS, March 2009.
[11]. S. H. Lee and X. P. Li, "Study of the effect of machining parameters on the machining characteristics in electrical discharge machining of tungsten carbide", The National University of Singapore, 2009.
[12]. R. Snoeys, F. Staelens, and W. Dekeyser, "Current trends in nonconventional material removal processes," Ann. CIRP, vol. 35(2), p. 467 480, 1986.
[13]. H.S. Payal, R Choudhary and S Singh, "Analysis of electro discharge machined surfaces of EN-31 tool steel", Journal of Scientific & Industrial Research, Vol. 67, p. 1072-1077, 2008.
[14]. A Bhatia, S Kumar, and P Kumar, " A study to achieve minimum roughness in wire EDM" ,International conference on advances in manufacturing and materials engineering, Procedia material science 5 p. 2560-2566, 2014.
[15]. I. Puertas, C. J. Luis, and L. Alvarez, "Analysis of the influence of edm parameters on surface quality, mrr and ew of wc-co," Journal of Materials Processing Technology, vol. 153-154, no. 1-3, pp. 1026–1032, 2004.
[16]. G. Petropoulos, N. Vaxevanidis, and C. Pandazaras, "Modeling of surface finish in electro-discharge machining based upon statistical multi-parameter analysis," vol. 155-156, no. 1-3, p
[17]. Korzynski M., "Experiment methodology", WNT Warszawa, 2006.

[18]. Md. A R Khan, and M. M. Rahman, “Development of Regression Equation for Surface Finish and Analysis of Surface Integrity in EDM”, International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering Vol 7, No. 3, 2013.
[19]. SingaramLakshmanan, and M Kumar, “Optimization of EDM parameters using Response Surface Methodology for EN31 Tool Steel Machining”, International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 2, Issue 5, September 2013.
[20]. S. S. Baraskar, S. S. Banwait, and S. C. Laroiya, “Mathematical Modeling of Electrical Discharge Machining Process through Response Surface Methodology”, International Journal of Scientific & Engineering Research, Volume 2, Issue 11, November-2011.
[21]. Mohd B. Ndaliman*, Ahsan A. Khan, and Zakaria M. Zain,” Performance of PM Compacted Cu-TaC Electrodes during EDM”,Kulliyyah of Engineering International Islamic University Malaysia, 2013.
[22]. Mohammed Yakub Ali, “Development in EDM process variables”, International Islamic University Malaysia, 2013.
[23]. Aligiri E., Yeo S.H., and Tan P.C., “A new tool wear compensation method based on real-time estimation of material removal volume in micro-EDM”, Journal of Materials Processing Technology 210, p. 2292–2303, 2010.
[24]. Uhlmann E, Roehner M., “Investigations on reduction of tool electrode wear in micro-EDM using novel electrode materials”, CIRP Journal of Manufacturing Science and Technology 1, p. 92–96, 2008.
[25]. Uhlmann E., Piltz S., Röhner M., “Influence of Diamond Coatings on Electrode Wear in Mirco-EDM”, Proceedings of the 7th Euspen International Conference – Bremen, 2007.
[26]. O. H. Erzurumlu, T., “Comparison of response surface model with neural network in determining the surface quality of moulded parts,” Materials and Design, vol. 28, no. 2, pp. 459–465, 2007.
[27]. M. K. Pradhan, R. Das, and C. K. Biswas, “Comparisons of neural network models on surface roughness in electrical discharge machining,” Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 223, p. (In Press), 2009.