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Experimental Research on MRR in EDM Process Using Regression Modelling

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ABSTRACT:- *Electric Discharge Machining is used to produce intricate shapes that are difficult-to-machine in conventional machine tools and also to provide good surface finish. In the present research work, the work material used is Stainless Steel 202 which is machined by using EN 31 (AISI 52100) as electrode. This work demonstrates the optimization process of material removal rate (MRR) of electrical discharge machining (EDM) by Response Surface Methodology. The current, pulse on time and machining time were the process control parameters of EDM. RSM method was used to design the experimental model whose adequacy checking was carried out using Minitab software. Regression equations were formulated based on the experimental results. The results evidence that the proposed regression equation can successfully predicted the material removal rate. It was concluded that the analysis carried out yielded the optimum results of material removal rate when the process parameters were current, pulse on time and machining time.*

Keywords:- *EDM, RSM, Design of Experiments, MRR*

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.

In today’s fast growing technological environment, the advanced industries like aeronautics, automobiles, nuclear reactors, missiles, turbines etc., need materials which are high strength temperature resistant alloys. These alloys possess properties such as high strength, corrosion resistance, toughness, and other diverse properties. To meet the growing demands of the automation world there has been a rapid development in the field of materials. These new developed materials further demand new processes so that they can be utilized to fulfill their desired purpose. The solution is discovered in the new machining processes which are capable of machining these materials conveniently for sustained productivity, high accuracy and versatility at automation. Electrical Discharge Machining is a non-traditional machining technique, which can machine such new materials with ease. It can fulfil the demands of the parts which have intricate and compact shapes as such designs defy machining by conventional methods. It is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. The main requirement for the EDM machining process is the electrically conductive nature of the workpiece. It finishes parts through the action of an electrical discharge of short duration and high current density between the tool and work piece. The tool and the work piece do not have any physical contact with each other. Heat resistant steels, super alloys, carbides, heat treated tool steels, composites and ceramics can be easily machined to attain geometrically complex shape through EDM process. Generally 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 can be investigated.

EDM is a non-traditional machining technique which extensively and effectively machine 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. METHODOLOGY

Response Surface Methodology is used to model the equations for the process parameters of the Electric Discharge Machining process. Experimental investigation is carried out through the design of experiments and the graphs showing the main and interaction effects of the process parameters on the response factor i.e. material removal rate.

Work Piece and Electrode Material

The work material selected for the experimental work is Stainless Steel 202 which is a difficult-to-machine material. The electrode material are EN 31 (AISI 52100).

Characteristics

Grade 202 stainless steel is a type of Cr-Ni-Mn stainless with similar properties to A240/SUS 302 stainless steel. The toughness of grade 202 at low temperatures is excellent.It is one of the most widely used precipitation hardening grades, and possesses good corrosion resistance, toughness, high harness, and strength.

This chromium- nickel-manganese alloy possesses properties similar to A240/SUS 302 stainless steel. At low temperatures SS 202 exhibits excellent toughness. It is the most widely used precipitation hardening grades possessing high hardness, strength and good corrosion resistant properties. It has good wear resistance and is used in low temperature environments. Typical applications include restaurant equipment, sinks, cooking utensils, automotive trim, architectural structures, railway cars, hose clamps as can be made into plates, sheets and coils.The following datasheet depicts the composition of SS 202 Steel.

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 measure material removal rate and maintain the weight uniformity of the workpiece.

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

Figure 1: Photographic view of SS 202

Figure 2: EDM Machine and Control Panel

III. MATERIAL REMOVAL MEASUREMENTS

A digital weighing machine is used to measure the weight of work piece before and after the machining process to determine the material removal rate.

Figure 3: Weighing machine

Measurement of MRR

$$MRR = \frac{(w_i - w_f)}{t}$$

Where

W_i = weight of work piece in milligrams before machining
W_f = weight of work piece in milligrams after machining
t = period of machining in minutes

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.

Mathematical models are developed on the basis of data obtained through the experiment. The experimental planning is done based on Design of Experiments. The Box Behnken design was used to find the quadratic response surfaces to construct the second order polynomial models. Design of Experiments (DOE) is a method used to obtain useful information about a process by conducting only minimum number of experiments. 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. In these methods, there is a possibility that the experiments will stop with few runs and decide that the prediction model is satisfactory. Each controllable variable (T_{on}, I_p, T_{off}) can be set on EDM machine at two consecutive levels and hence the design consisting of 9 experiments was generated. Table III shows the levels used for the design of experiments.

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

The experimental values were analysed and then a mathematical model developed an equation illustrating the relationship between the process response and the variables. The model in equation 1 explains the behavior of the system.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \epsilon \qquad \ldots 1$$

Where y = Surface Roughness, x_1 = Current (A), x_2 = Pulse On Time (μsec), x_3 = Machining Time (min) and β_1, β_2, β_3= Partial Regressors.

The equation for calculating the approximate MRR is

$$MRR = -173.6 + 32.24\,X_1 + 18.24\,X_2 + 2.811\,X_3 - 3.217\,X_1X_2 - 0.2877\,X_2X_3 - 0.5070\,X_3X_1 + 0.05051\,X_1X_2X_3$$

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

V. RESULT AND DISCUSSION

Regression analysis developed the correlation between the process parameters and the response factor i.e. material removal rate (MRR) based on the data acquired from the experiments. In this experimental study, a regression equation have been developed by taking into consideration three process parameters i.e. current, pulse on time and machining time.

The coefficients of regression model were estimated from the experimental outputs. The effects of the process parameters was further studied through the main effects.

Table IV: Plan of Experiments and Output Responses

Trial Runs	Current (X_1)	Pulse on Time (X_2)	Machining Time (X_3)	$X_1 X_2$	$X_2 X_3$	$X_1 X_3$	$X_1 X_2 X_3$	MRR Experimental	MRR Theoretical	% Error
R1	3	8	55	24	440	165	1320	4.80	4.8736	1.11
R2	3	8	65	24	520	195	1560	3.82	3.8704	1.31
R3	3	11	55	33	605	165	1815	6.11	6.16615	0.91
R4	3	11	65	33	715	195	2145	4.65	4.71106	1.31
R5	6	8	55	48	440	330	2640	6.32	6.37048	0.78
R6	6	8	65	48	520	390	3120	4.58	4.64056	1.32
R7	6	11	55	66	605	330	3630	4.89	4.80784	1.43
R8	6	11	65	66	715	390	4290	4.05	4.1254	1.86

Effect of Current on MRR:

The figure 4 shown below indicates that MRR is 4.82 mg/min when the current is 3 amp. It increases steeply to 6.32 mg/min when the current is 6 amps. As the current is increased the MRR increases due to the increase in the number of sparks taking place between the electrode and the work material.

Effect of Pulse ON Time on MRR:

The MRR increases from 4.80 to 4.89 mg/min when the pulse on time increases from 8 µsec to 11µsec. As the pulse on time increases the intensity of spark is affected which is directly influencing the amount of material being removed. Increase in number of sparks leads to increase in MRR.

Effect of Machining Time on MRR:

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

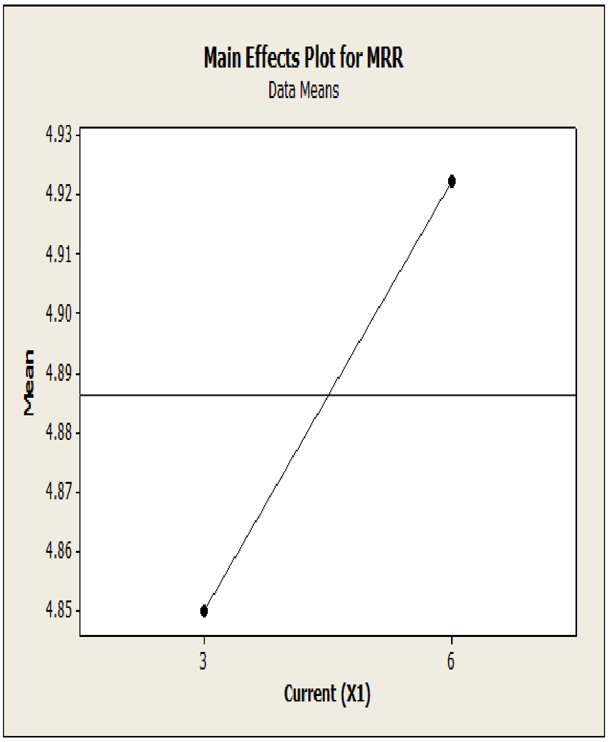

Figure 4: Effect of Current on MRR

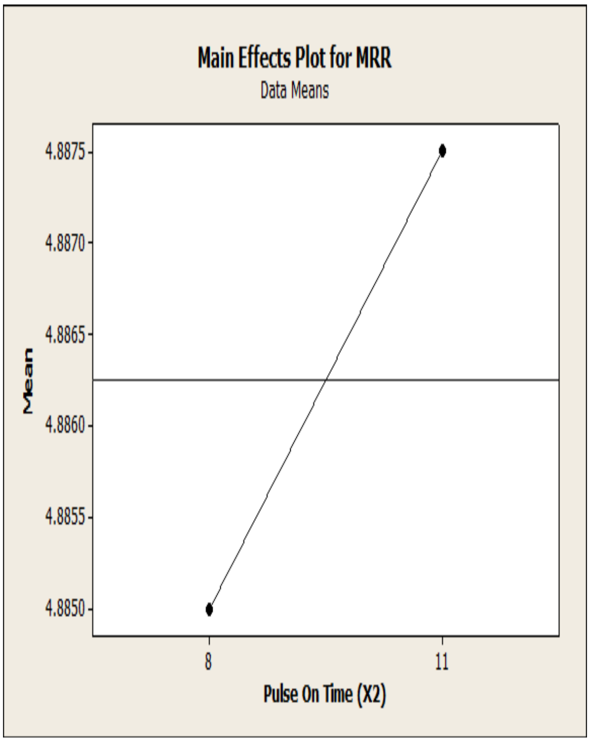

Figure 5: Effect of Pulse ON Time on MRR

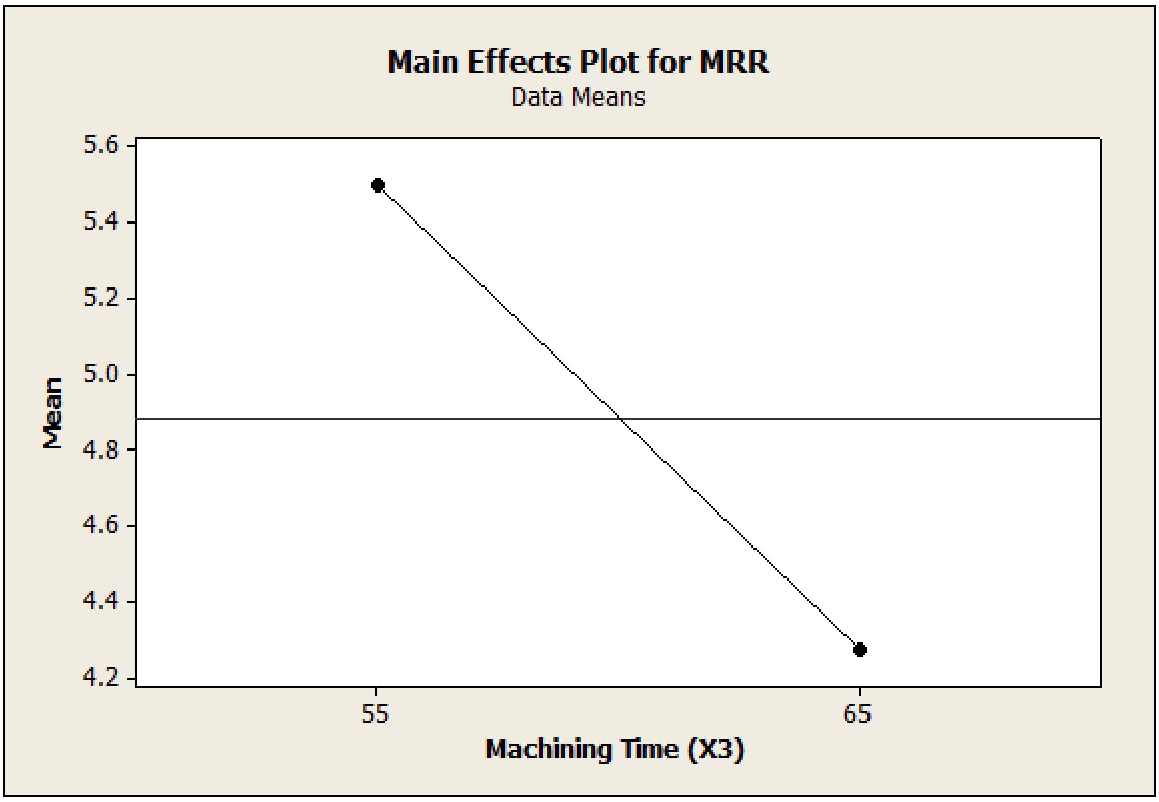

Figure 6: Effect of Machining Time on MRR

Effect of Current and Pulse ON Time on MRR:

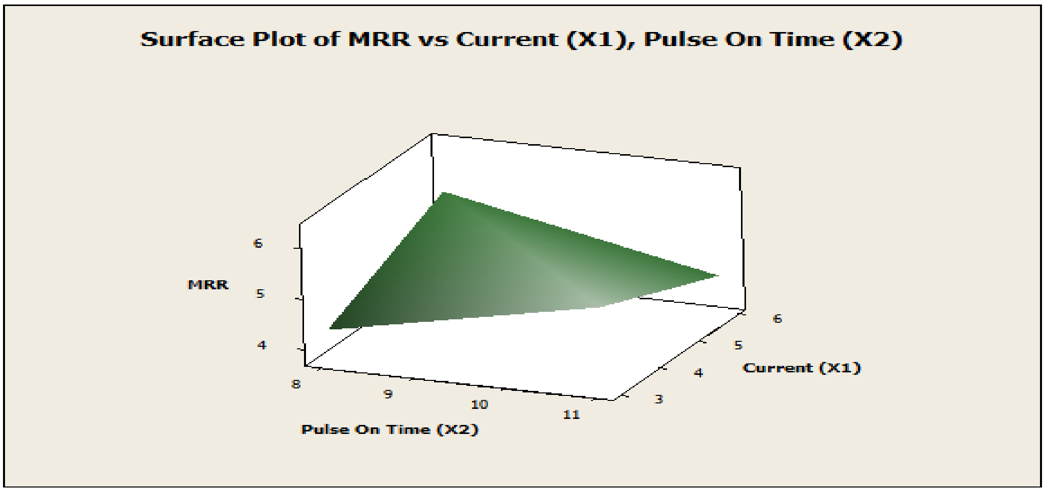

Figure 7: Surface Plot for MRR vs X_1 vs X_2

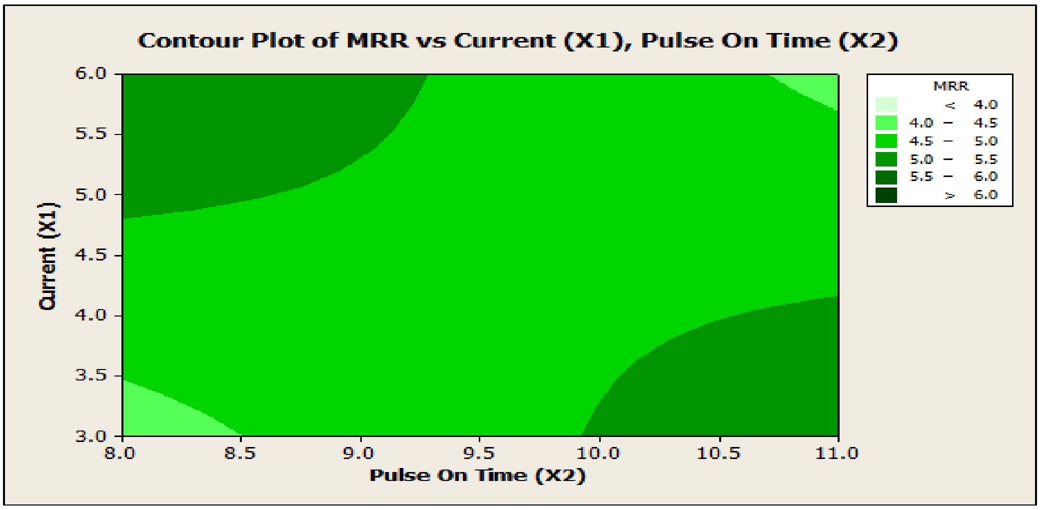

Figure 8: Contour Plot for MRR vs X_1 vs X_2

Figure 7 and 8 shows the estimated response for MRR 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 MRR significantly increases with the increase in the value of current for smaller range of pulse ON time. On the same point the effect of pulse on value on MRR increasesit at a higher range of ON time.

VI. CONCLUSION

In this research, regression analysis of process parameters of EDM machining process was carried out. 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 MRR value increases with the increase in the value of pulse-on time.
3. Machining rate increases with the increase in current due to predominant increase in spark energy.
4. The proper selection of input parameters can help in achieving a specific output parameter (MRR) and a higher efficiency can be determined by theoretical and experimental characteristic diagrams, especially the two dimensional contour diagrams.

Finally, an attempt has been made to estimate the optimum machining conditions to achieve the best possible outcome of the response factor within the experimental constraints. This study can help in developing a robust, reliable knowledge base and early prediction of MRR without performing the actual experiment with EDM process for EN 31 steel.

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