Enhancing Material Removal Rate in EDM with Green Dielectrics: A Regression Modeling Approach

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Abstract**—** *Electrical Discharge Machining (EDM) is one of the electrical based advanced machining method where electrical energy is used as a source to cut or remove material. Green dielectrics are utilized in machining to make the process extremely competent and secure. Hybrid aluminum 2021 tools with different copper percentages are utilized for super alloy superni 909 machining research in an effort to further lower manufacturing costs. The impact of different input parameters Investigations are conducted on the work material for material removal rate as a reaction to changes in pulse on time, pulse off time, current, voltage, and tool material. A mathematical model is created and the influence of process parameters on response is determined using the Taguchi design of experiments. Each factor's percentage contribution is calculated. The goal of this research is to provide a substitute dielectric that can be machined in an environmentally friendly and sustainable manner while producing a satisfactory output at the lowest possible tooling cost.*

Keywords**— EDM, material removal rate, process parameters, regression equation.**

I. INTRODUCTION

EDM supports a persuasive manufacturing method that authorizes production of components made of hard matters accompanying difficult geometry that are troublesome to manufacture by a normal machining method. EDM does not form direct contact across the tool and the workpiece, eliminating mechanical stresses, chatter, and vibrations while machining. The talent to control process limits to obtain the necessary precision and surface texture has established this build movement in an outstanding position in industrialized requests. The outstanding interest in EDM has upshot excellent bettering in its field and concedes it as main non-traditional machining method, widely used in automobile, aerospace, die and tool industry. Applications vary from simple die and tool making to producing complicated components. Surface characteristic damage on account of machining operations is straightforwardly had connection with the strength used to eliminate the metal. The major determinants effecting machining in EDM are electrical parameters (discharge current, and voltage), material characteristics of tool and workpiece, and the dielectric fluid used.

The main research concern in advancing the status of EDM process is to have a better understanding of the relation between the input parameters and the responses.

1.1 Material Removal Mechanism:

In EDM the electric sparks strike the electrically conductive materials immersed in a dielectric medium and divided by a tiny gap, which erodes and removes material. The electrodes receive electric energy in the form of brief impulses with a predetermined shape. Spark generators made specifically for this purpose are a good way to provide the necessary energy, which is often needed as rectangular pulses. An electric spark discharge takes place inside the interelectrode gap, when the electrodes are subjected to such a voltage pulse. It is commonly recognized that the heat action of an electrical discharge is primarily responsible for erosion on the electrode surfaces. A spark generator's induced charge on electrodes produces a powerful electric field. Where the electrodes are nearest to one another, this field is strongest. The dielectric fluid's molecules and ions are polarized and directed between these two peaks. Anode and cathode electron avalanche strikes generate a low resistance discharge channel when the dielectric strength of the liquid in the gap surpasses a natural limit. Heat and pressure are produced during this collision event, which changes the kinetic energy of the atomic particles. Even for brief pulse durations, heat produced within the discharge channel is expected to reach 1017 W/m2, which might elevate electrode temperatures locally to as high as 20000K. There isn't a machining technique that produces comparable high temperatures in such small dimensions. Current density in the interelectrode gap reduces as a result of the pressure rise in the plasma channel, which also drives the discharge channel borders to expand. The pressure rise is usually so great that heated metal on electro de surface cannot evaporate. A sudden drop in channel pressure upon the cessation of the pulse voltage starts a severe erosion. The superheated cavities burst into the dielectric liquid. Ultimately, the surfaces instantly cool, with all of the evaporated material being carried away by the dielectric liquid along with a portion of the molten material in the form of hollow or rugged particles. The end effect is a small crater where some of the residual molten material has spilled across both electrode surf aces. Applying rapid high-frequency spark discharges one after the other and pushing one electrode in the direction of the other progressively erodes the workpiece.

II. DEVELOPMENT OF MODEL

A Mathematical model is formed to improve the input limits for every tool used for machining by Design of Experiments(DOE). In DOE, numbers of trails expected attended are contingent upon Taguchi DOE and design matrix is built for five input parameters with four distinct levels. Experiments are completed activity according to the design model. Once the design matrix is developed, regression coefficients are computed. Adequacy of model is proven by fisher test at 5% significan ce level. For every regression coefficient Student's t-test is carried to find out its importance. The mathematical model is generated after ignoring unimportant coefficients. Finally Analysis of Variance (ANOVA) is carried to find the contribution of each determinant to the MRR.

2.1 Taguchi DOE:

Taguchi envisioned a brand-new approach to experiment design that is predicated on clearly laid out rules. A unique class of arrays known as orthogonal arrays is used in this technique. These standard arrays specify how to carry out the fewest tests necessary to fully understand every element influencing the performance parameters. Standard orthogonal arrays come in a variety of forms, and each one is intended for a particular quantity of independent design variables and values. L16 orthogon al array, for instance, would be the best option if one wishes to carry out an experiment to determine the influence of five distinct independent variables, each of which has four level values. This array makes the assumption that no two factors interact. While there are numerous situations in which the interaction model premise is not met, there are other instances in which interaction is amply demonstrated. Such example of such interaction would be the relationship between temperature and material properties.

2.2 Postulation of Mathematical Model:

The relationship between the responder and predictor variables is described by the regression expression, which is an algebra ic description of the regression line. The general form of regression equation looks like this:

Response = constant + coefficient * predictor + …… + coefficient * predictor

or $Y = C_0 + C_1X_1 + C_2X_2 + \dots + C_kX_k$

Where:

(Y) is the response numeral.

(C_0) is the response variable when the predictor variable(s) is zero. The constant is known as intercept because it determines where the regression line cuts the Y-axis.

(X) is the predictor variable(s) value. It can be a polynomial term.

Coefficients (C_1, C_2, , C_k) represent the change in mean response for each unit variation in the predictor value. In other words, it is the variation in Y that happens when X rises by one unit.

In order to create a mathematical model that predicts the MRR, the EDM process variables are determined. These include current (I), pulse on time (T_{on}), pulse off time (T_{off}), voltage (V), tool electrode (Tool). It is assumed that the first order model has two, three, and four interactions.

Regression models and examines the connection between a predictor (X) and response (Y). Although categorical and continuous predictors are both acceptable, the response must be continuous. Both polynomial and linear relationships can be modeled.

Regression analysis is particularly useful for figuring out how the response variable changes in response to changes in a given predictor variable. For every response variable, Minitab keeps track of the most recent regression model you fitted. Predictions, overlaid contour plots, and optimum responses can all be produced rapidly with saved models. You must fit a model for every response in analyses that make use of numerous responses.

III. EXPERIMENTATION

The Electrical Discharge Machine, Die-Sinking Type SYCNC PC-60 as shown in figure 1, is used for the experimentation. Its electrode polarization is situated as negative, while the work piece polarization is located as positive. The workpiece in figure 3 is 66.8 mm in diameter and 6 mm thick, and it is shaped like a cylinder made of superalloy Superni 909. Four distinct tool electrodes in figure 2 are employed, with the proportion of copper varied and aluminum2021 serving as the foundation material. The regenerated dielectric liquid had a specific gravity of 0.763 and was EDM oil. Using a stopwatch, the machining time for each experiment is maintained at 10 minutes. To determine the MRR, the workpiece is thoroughly cleaned and its weight is recorded both before and after each trial. Table 1 displays the process parameters and their corresponding levels. The machine's capability is taken into account when choosing the range of parameters for the trials. In order to ensure more accurate optimization, a wide range is used. For this investigation, an L16 orthogonal array with 8 columns and 16 rows was chosen.

FIGURE 1: Die-sinking EDM machine

FIGURE 2: Al2021 Electrodes with varying % of Cu

FIGURE 3: Workpiece machined

TABLE 1
INPUT PARAMETERS AND THEIR VALUES

Parameter	Units	Level 1	Level 2	Level 3	Level 4
Current(A)	A	10	20	30	40
Pulse on Time(µs)	µs	250	500	750	1000
Pulse off Time (µs)	µs	100	200	300	400
Voltage (V)	V	30	40	50	60
Electrode		T1	T2	T3	T4

Three dielectric fluids were tested in the experiments: used vegetable oil, used gear oil, and EDM oil. MRR was computed for each trial. Before beginning the studies, the dielectric tank was thoroughly cleaned and emptied. To carry out the studies, fresh EDM oil was added to the tank. Similar to this, used vegetable and used gear oil were added to the tank after it had been emptied and cleaned. 48 trials in all were conducted, 16 runs of each using used gear oil, used vegetable oil, and EDM oil. While machining with each of the three dielectric fluids, results have been noted. Figure 4(a-b) displays dielectric fluid samples.

FIGURE 4(a): Used gear oil sample

FIGURE 4(b): Used gear oil sample

IV. RESULTS AND DISCUSSIONS

The Fisher Test was then used to see if the model was adequate. According to this method, the produced model's F-ratio do not surpass the tabulated value of F- ratio at a 95% confidence level. Therefore the model was suitable. Students T-test was performed to determine the significance of the coefficients, and only significant coefficients were employed to create the mathematical model. The final model for the MRR for used vegetable oil, used gear oil, and EDM oil is provided below in coded form.

Regression equation for material removal rate developed for EDM oil as dielectric fluid.

$$MRR = -1.89 + 0.00408\ T_{on} + 0.00150\ T_{off} + 0.1050\ I + 0.0099\ V + 0.0487\ Tool \quad (1)$$

Regression equation for material removal rate developed for used gear oil as dielectric fluid.

$$MRR = 1.93 + 0.00326\ T_{on} - 0.00438\ T_{off} + 0.0648\ I - 0.0567\ V + 0.0942\ Tool \quad (2)$$

Regression equation for material removal rate developed for used vegetable oil as dielectric fluid

$$MRR = 3.46 + 0.00202\ T_{on} - 0.00747\ T_{off} + 0.1056\ I + 0.0267\ V - 0.0639\ Tool \quad (3)$$

The calculated material removal rates and regression coefficients for MRR are shown in the tables 2 and 3.

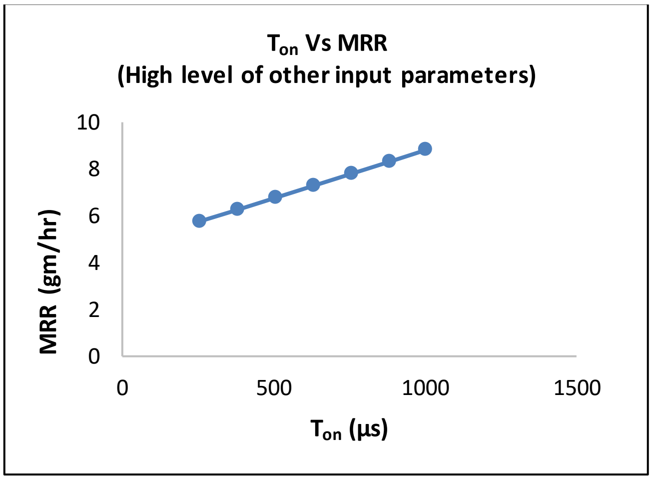
TABLE 2
CALCULATION OF REGRESSION COEFFICIENTS FOR MRR

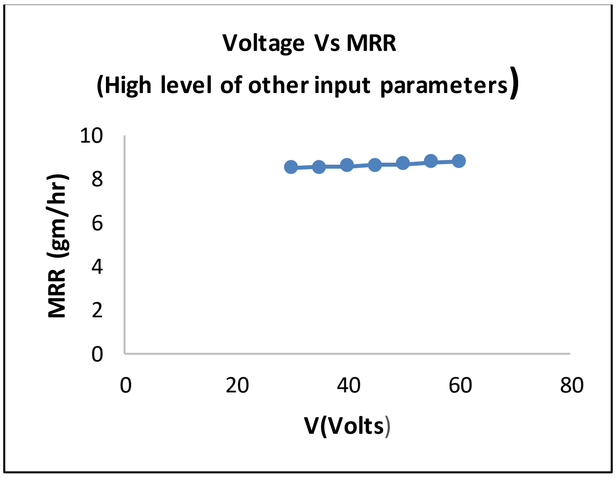
Regression coefficients	EDM oil	Used gear oil	Used vegetable oil
constant	-1.89	1.93	3.46
Ton	0.00408	0.00326	0.00202
Toff	0.0015	-0.00438	-0.00747
I	0.105	0.0648	0.1056
V	0.0099	-0.0567	0.0267
Tool	0.0487	0.0942	-0.0639

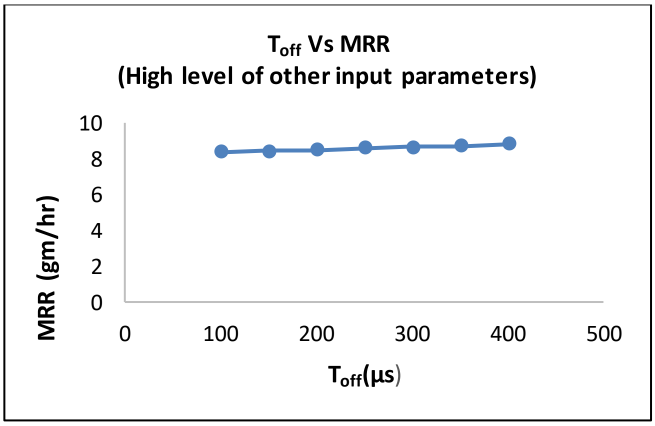
TABLE 3
CALCULATED MRR FOR EDM OIL, USED GEAR OIL AND USED VEGETABLE OIL

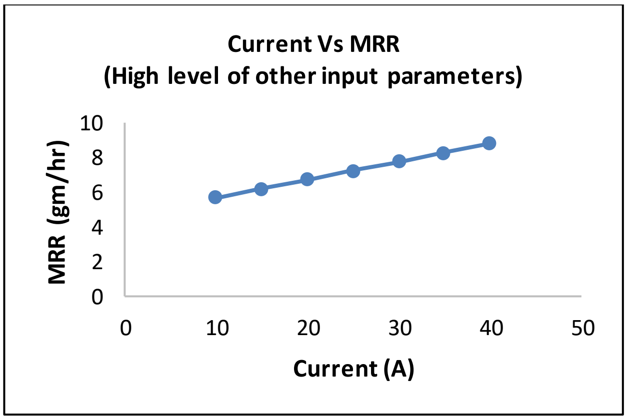
S No	Ton	Toff	I	V	Tool	MRR gm/hr		
						EDM oil	Used gear oil	Used vegetable oil
1	250	100	10	30	T1	2.82	1.56	4.32
2	250	200	20	40	T2	1.02	3.84	5.4
3	250	300	30	50	T3	3.6	2.1	4.32
4	250	400	40	60	T4	7.32	2.82	5.16
5	500	100	20	50	T4	4.92	3.36	5.28
6	500	200	10	60	T3	2.46	2.64	3.96
7	500	300	40	30	T2	6.12	3.24	7.32
8	500	400	30	40	T1	3.84	3.3	4.68
9	750	100	30	60	T2	5.34	2.4	10.26
10	750	200	40	50	T1	5.52	2.82	7.44
11	750	300	10	40	T4	2.46	2.82	2.82
12	750	400	20	30	T3	5.04	3.48	4.86
13	1000	100	40	40	T3	8.4	9	9.36
14	1000	200	30	30	T4	7.2	7.14	4.68
15	1000	300	20	60	T1	5.7	2.64	5.4
16	1000	400	10	50	T2	6.72	2.76	5.1

4.1 Experimentation with EDM oil:









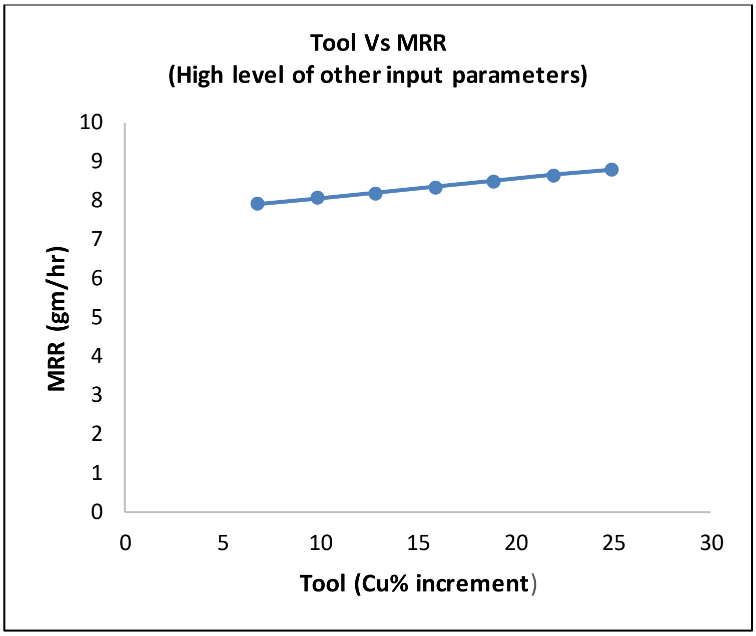
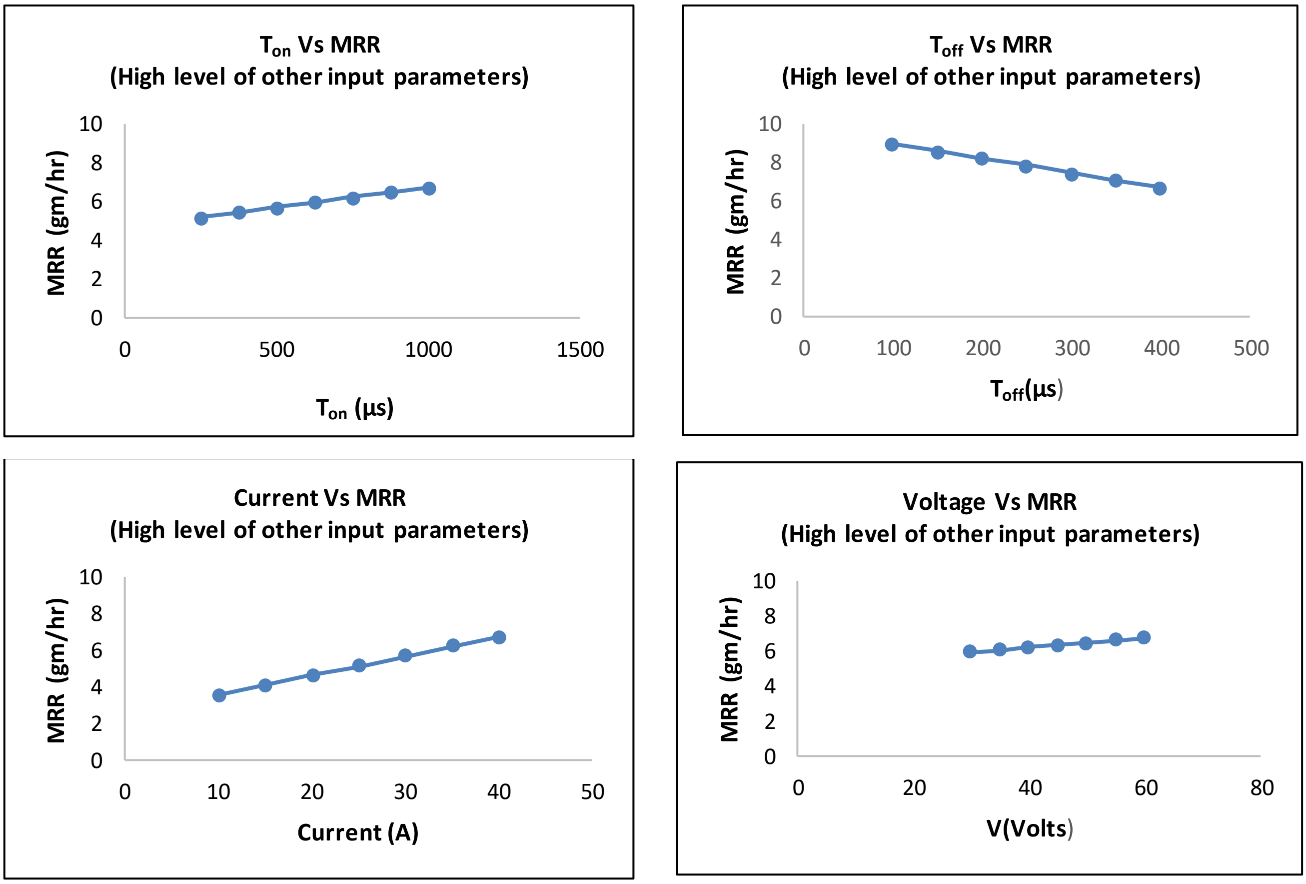


FIGURE 5: Response behavior of MRR (EDM oil as dielectric)

Under the impact of the chosen control settings, the response behavior of MRR was recorded and is depicted in the figure 5. A higher MRR is necessary in order to produce more economically. It's a crucial variable in this process economy. We can infer from the figure that the MRR falls with pulse-off time but rises with pulse-on time and current. voltage doesn't have much impact on MRR. It is noticed that MRR is rising with increasing percentage of Cu in the Al2021 tool.

4.2 Experimentation with used vegetable oil:



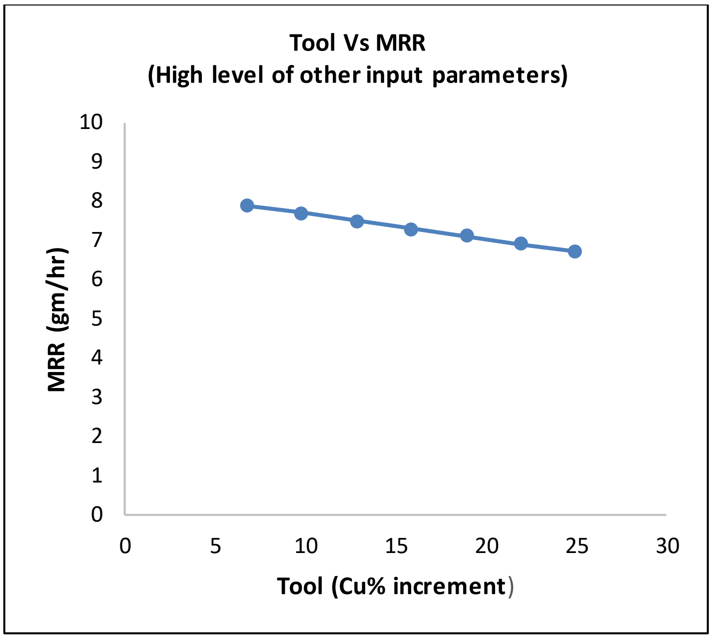
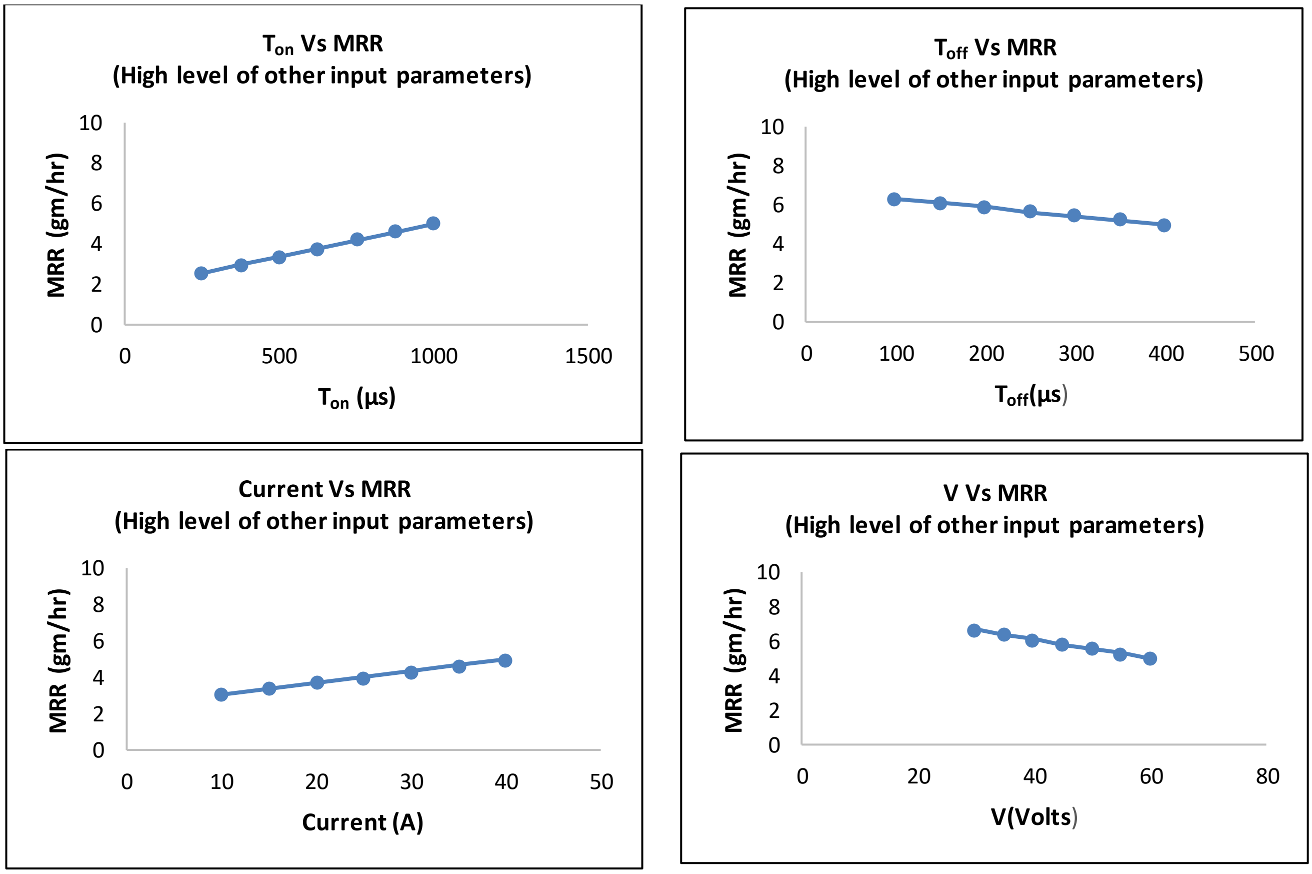


FIGURE 6: Response behavior of MRR (used vegetable oil as dielectric)

Figure 6 illustrates how response variable MRR is impacted by process factors. The MRR is found to increase linearly as current and voltage rise, and the energy applied used by pulse-on-time directly relates to the removal of metal. More metal from the workpiece will melt away with a longer pulse length. The elimination of metal is inversely correlated with the pulse-off-time and increase in cu percentage in Al2021 tool.

4.3 Experimentation with used gear oil:



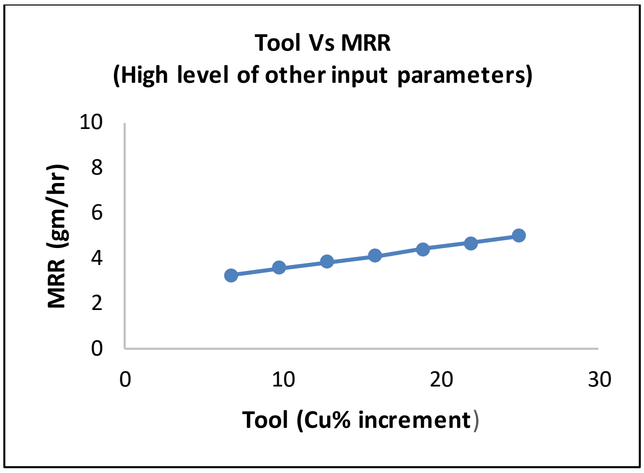


FIGURE 7: Response behavior of MRR (used gear oil as dielectric)

The impact of process factors on MRR is depicted in Figure 7. It has been found that when pulse-on time and current increase, the metal removal rate rises linearly. More metal melts when the pulse-on-time is raised because the same heating temperature is applied for more time. It is evident from the figure that voltage and pulse off time have negative bearing on MRR. Tool T4 exhibits the highest rate of metal removal with 25% weight copper.

V. CONCLUSIONS

The trials were conducted using the Taguchi methodology's design matrix. The work completed leads to the following findings.

- When testing with EDM oil as the dielectric, the highest metal removal rate of 8.4 gm/hr was achieved for input values Ton 1000, Toff 100, I 40, V 40, and T3 tool.
- Maximum metal removal rate of 10.26gm/hr was obtained for input values Ton 750, Toff 100, I 30, V 60 and T2 tool when experimentation was conducted with used vegetable oil as dielectric.
- When testing with used gear oil as the dielectric, highest metal removal rate of 9 gm/hr was achieved for input values Ton 1000, Toff 100, I 40, V 40, and T3 tool.
- According to the aforementioned observation, used vegetable oil utilized as a dielectric resulted in a maximum metal removal rate of 10.26 grams per hour.

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