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Investigation of Critical Success Parameters for Sustainable Manufacturing of Smart Alloy using EDM: Optimization and Appraisement

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Abstract:
Electrical discharge machining (EDM) is the spark machining process where the metal is removed from erosion process with series of recurring electrical discharges between an electrode and a conductive work piece which is submerged in a dielectric fluid. EDM is widely employed in machining of serious hard and tough materials that are continuously demanded for critical engineering applications. Inconel 825 is such a super smart material that is having numerous applications in defense sectors, power sectors, refinery filed, nuclear field, etc. In current study, Inconel 825 is selected in order to identify the impact of controllable process parameters i.e. Pulse on Time (Ton), Pulse off Time (Toff), Gap Voltage (Vg) and Spark Gap (Sg) on the Metal removal rate (MRR) in EDM machining using copper electrode. It is found that optimal process parameters setting is $Ton_3Toff_1Vg_2Sg_1$ *for maximizing MRR. The results clearly depict that the combination of independent process parameters i.e. Ton, Toff, Vg and Sg is found as 300, 20, 60 and 0.05 for maximizing MRR.*
Keywords: *Electrical Discharge Machining (EDM); Taguchi Technique; Orthogonal Array (OA); Metal Removal Rate (MRR).*

I. Introduction

Electrical Discharge Machining (EDM) is a modern manufacturing process, where material is removed from electrically conductive material via controlled erosion. Material is removed through a series of electricsparks that are generated for short duration by applying high current density between the electrode and the work piece that are submerged in a dielectric fluid. During machining process, multiple sparks per second are generated, and each spark produces a tiny crater from the materialalong the cutting path by melting and vaporization (Figure 1). EDM found its widest in manufacturing of press tools and dies, plastic molds, forging dies, die castings, aerospace, automotive, surgical components, and many other manufacturing industries etc. As there is no physical contact between the work material and the electrode and dielectric continuously flushed the eroded material that was generated in between the tool and the work piece. Flushing of filtered dielectric plays a critical role as if the concentration of the particles in between the electrodes gap became high at certain points, it crates bridges, which will lead to strange discharges of the current and spoil the tool as well as the work piece. Today's manufacturing organization wants to manufacture their product in such a manner that it will lead to higher production, quality products with low machining cost. At the same time, it is also demanding that energy consumption, environmental impact, waste etc during manufacturing of products should be minimum in order to attain sustainable production.

II. Sustainable mechanism requirement in manufacturing

Today, energy consumption and environmental impact, while doing manufacturing is now been considering by the researchers as an important field of interest and thus researchers are now seeking performance drivers and optimized setting for the sustainable manufacturing. Sustainable manufacturing deals with doing more and better with less exploitation of natural resources. Nowadays it is required to process smart alloys having high strength to satisfy the societal needs and thus electrical discharge machining (EDM) machining process is found as an alternative means, but there needs to determine the effect of Machining Parameters in EDM for evaluating output parameters. Sustainable manufacturing is the production of manufactured goods by the course of economically sound process with the aim to minimize the negative environmental impacts. Sustainability attempts to retrieve conservation of energy and natural resources. Sustainability endeavours economical advantages and thus it is significant to investigate sustainable manufacturing initiatives. The same is necessary for retaining green manufacturing and yielding elevated outputs. The study presents sustainable manufacturing practices, which chiefly concentrated to improve the output characteristics with the intention to reduce energy consumption and environmental loads. It is demonstrated in present study, that EDM possesses significant advantages and potential for the manufacturing applications of smart alloys in the field of sustainable manufacturing. The study disclosed that the experiments conducted needs to be properly designed based on machine levels to acquire the effects of the main process parameters on the Material Removal Rate (MRR).

III. Motivation and Research objective

The smart materials have strengthening properties like high thermal conductivity, superior wear resistance properties, high corrosion resistance etc., which makes their elevated applicability in the industrial realm of aerospace, automotive, radiators, tool manufacture, robots design, hazardous works, radioactive means, biomedical industry etc., Today, hybrid materials are the demand of the society and that needs to be processed by the manufacturing resources under sustainable aspects. Today, it is required to develop decision making framework and tools for prescise manufacturing and industrial applications (Sahu et al., 2017a; Sahu et al., 2017b). Additionally, it is fruitful to evaluate multiple outputs for assuming effectiveness and efficacy from implicated resources (He et al., 2021; Sahu et al., 2018b). The smart materials can be machined with electrical discharge machining (EDM), but that needs the proper selection and attention of process parameters to attain outputs parameters. The same is nowadays are in the high interest of the researchers and industries and is holding an application of producing near net shape metal components and precise manufacturing for assembly purpose. It is profitable to appraise multiple outputs for assuming effectiveness and efficacy from implicated resources (Wang et al., 2019; Sahu et al., 2019). It is significant to determine the crucial machining characteristics and optimum setting for extracting elevated outputs from group of inputs (Chaturvedi et al., 2018; Sahu et al., 2018a). Thus, the present study highlights the influence of detecting important process parameters to be considered by manufacturing materials by EDM.

The EDM machine possess a bunch of process parameters like pulse-on time, pulse-off time, peak current and voltage, which needs to be synchronized for attaining appropriate setting. The same can be attained by utilizing Design of experiment (DOE). The analysis is required after DOE to determine effect of the surface characteristics based on hardness of work material. The machining in EDM needs to be properly evaluated from the insights of control variable and uncontrolled variables by generating a decision making model, which can accurately correlate the input parameters of EDM with the responses because the parameters setting are restricted with the operator's experience. Significant driving characteristics should be identified for extracting elevated outputs from group of inputs (Kang et al., 2022; Sahu et al., 2020). The same is required to help in the attainment of less consumption of resources and to analyze the information receiving from the customers and operators (Sahu et al., 2014; Sahu et al., 2015). A decision making process is required, which possess series of steps to determine the best option or course of action to meet the needs of the society (Guo et al., 2022; Sahu et al., 2022). The present study demonstrated that the elevated levels of output can be attained by the final result of optimization of process parameters.

IV. Sate of art

Since several years, many researchers are continuously analyzing and evaluating the Electrical discharge machines (EDM) in order to improve the material removal rate, Electrode wear ratio, Surface roughness, etc, which are the most critical aspects of the machining process. Karthikeyan et al. (1999) investigated the effect of the current, pulse duration and the percent volume fraction of SiC on aluminum-silicon carbide particulate composites for optimizing MRR, TWR, SR in EDM. Yan et al. (2000) investigated the feasibility and optimization of a rotary EDM with ball burnishing for inspecting the machinability of Al2O3/6061Alcomposite by employing Taguchi method for maximizing machining rate and surface roughness. Lee et al. (2001) reported the effect of the machining parameter on tungsten carbide materials and found that with the electrode as the cathode and the work piece as anode enhances the material removal rate, & surface finish and minimizes the tool wear rate. Mohan et al. (2002) investigated the impact of current, polarity, pulse duration and rotation of electrode on Al-Sic with 20-25 vol. %SiC material in order to analyze MRR, TWR and SR. It is found that MRR increased with increased in discharge current and decreases with increase in pulse duration. Lin et al. (2006) identified the effects of the machining parameters on high-speed steel for optimizing machining performances characteristics in EDM by employing Taguchi method. Dhar et al. (2007) evaluated the effect of current, pulse-on time and gap voltage on Al–4Cu–6Sialloy–10wt.%SiCP composites material and found that there is significant increase in MRR, TWR and OC with increase in current. Tomadi et al. (2009) studied the influence of peak current, power supply voltage, pulse on time and pulse off time for optimizing Material removal rate and electrode in order to identify significant process parameters. Puertas et al. (2004) selected current intensity, pulse on time and duty factor for analyzing surface roughness, electrode wear and material removal rate by employing design of experiments methodology. In present study evaluation of material removal rate (MRR) has been taken into account in order to enhance the machining performance over EDM for Inconel825 smart material.

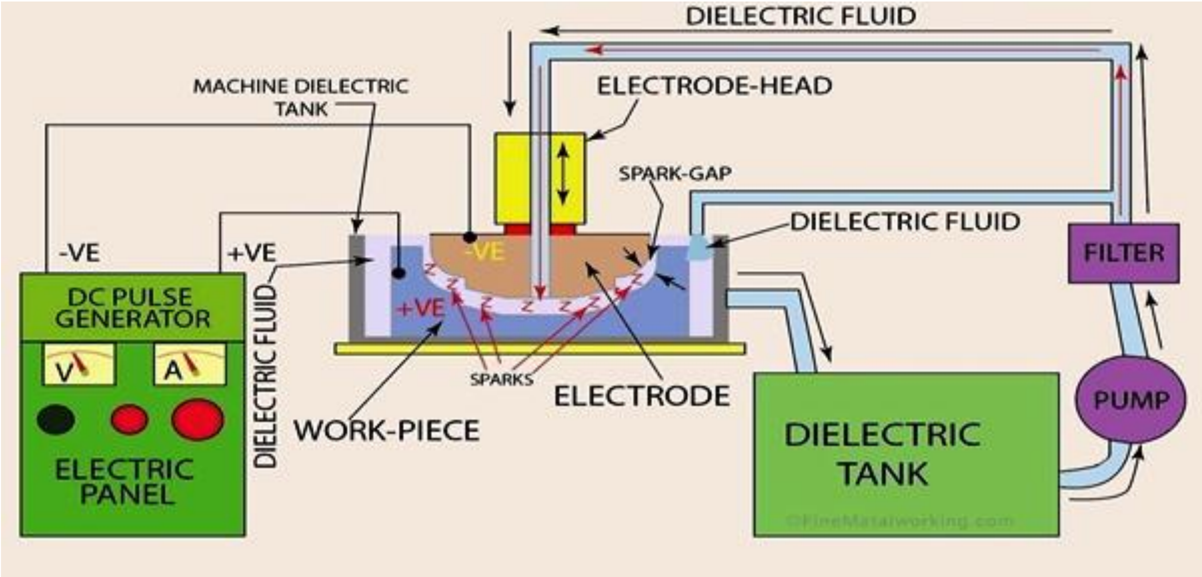


Figure 1: EDM schematic representation

Machining parameters

For the optimization of machining process or to perform efficient machining one should identify the process and performance measuring parameters. The input parameters of EDM process which affects the performance of machining process are discharge current, spark-on time, voltage, duty factor, flushing pressure, work piece material, tool material, quill-up time, inter-electrode gap, working time, positive and negative polarity. So, process parameters are selected accordingly for optimal machining condition. Moreover, response or performance parameters are used for evaluation of machining process in both qualitative and quantitative terms. Some of the response parametersare Material Removal Rate, Surface Roughness, Over Cut, Tool Wear Rate, White Layer Thickness and Surface Crack Density. In present investigation, the following defined process parameters are selected.

❖ Spark On-time (pulse time or Ton): The duration of time over which the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of theon-time.

❖ Spark Off-time (pause time or Toff): The duration of time over which there is no sparks. This time allows the molten material to solidify and to be wash out of thearc gap.

❖ Arc gap (Sg): The Arc gap is distance between the electrode and work piece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system.

❖ Voltage gap (Vg): It is a potential that can be measure by volt it is also affect to the materialremoval rate and allowed to per cycle.

Experimentation Procedure and data collection

In current investigation, the authors are trying to investigate the effect of various process parameters on Material Removal Rate (MRR) on Inconel 825 material. The machining process is carried out by employing kerosene as a dielectric fluid which creates path for discharge. The work piece is connected to the positive terminal and the tool electrode is connected across the negative terminal. The reason behind using these polarities is that approximately two third of the total heat generated is generated across the positive terminal i.e. work piece. First, both the work piece as well as tool is submerged into dielectric fluid. The dielectric fluid help to control the arc discharge and removes suspended particles of work piece material and tool from the work cavity. Proper arc gap is maintained by the EDM servomechanism in between the work piece and the tool. Copper tool electrode is used for the experimentation purpose whose diameter is 20mm and length is 50 mm.
Moreover, initial weight of the workpiece is measured with electric balance (range 0.1-10) mg. Also, the depth of cut is taken a 1 mm for all experiments and kept constant throughout the experimentation. After, each experimentation, the weight of the work piece is measured against the machining time in order to identify the MRR. The following equations is employed in order to identify the MRR.

$$MRR\,(mg/\min) = \frac{W_i - W_f}{M_t}$$

Where, W_i is the initial weight of work piece before each experiment; W_f is the final weight of work piece after completion of each experiment; M_t is the machining time of each experiment.
Based on literature survey and the preliminary investigations, four process parameters are scrutinized i.e. pulse ontime, pulse offtime, servo voltage, spark gap as input parameters where MRR is selected as an output response. Taguchi L_9 orthogonal array is utilized for performing experiments and each process variable is varied at three levels. The range of each factor varied at three different levels are shown in table 1.Table 2 represents L_9 Orthogonal Array and collected experimental data against the process parameters.

Table 1: Levels of Input Parameters

Parameters	*Notations*	*Units*	*Level of variations*		
			1	*2*	*3*
Pulse on Time	(Ton)	μs	100	200	300
Pulse Off Time	(Toff)	μs	20	22	24
Gap Voltage	(Vg)	v	50	60	70
Spark Gap	(Sg)	mm	0.05	0.1	0.15

Table 2: Design of experiment (L_9) Orthogonal Array and collected experimental data

Exp No	*Taguchi L_9 Orthogonal Array*				Collected experimental data
	Ton	*Toff*	*Vg*	*Sg*	*MRR (mg/min)*
1	100	20	50	0.05	23.143
2	100	22	60	0.1	22.254
3	100	24	70	0.15	4.265
4	200	20	60	0.15	21.846
5	200	22	70	0.05	32.476
6	200	24	50	0.1	28.157
7	300	20	70	0.1	31.569
8	300	22	50	0.15	20.367
9	300	24	60	0.05	31.192

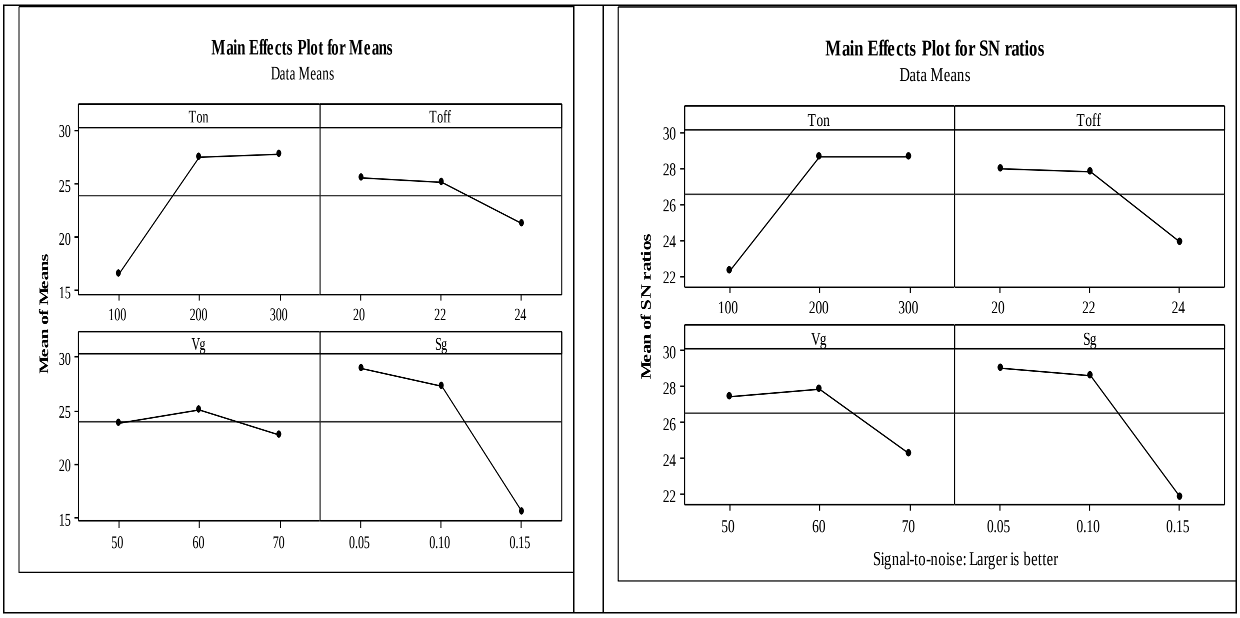


Figure 2: Main effect plot and S/N Ratio Plot for MRR

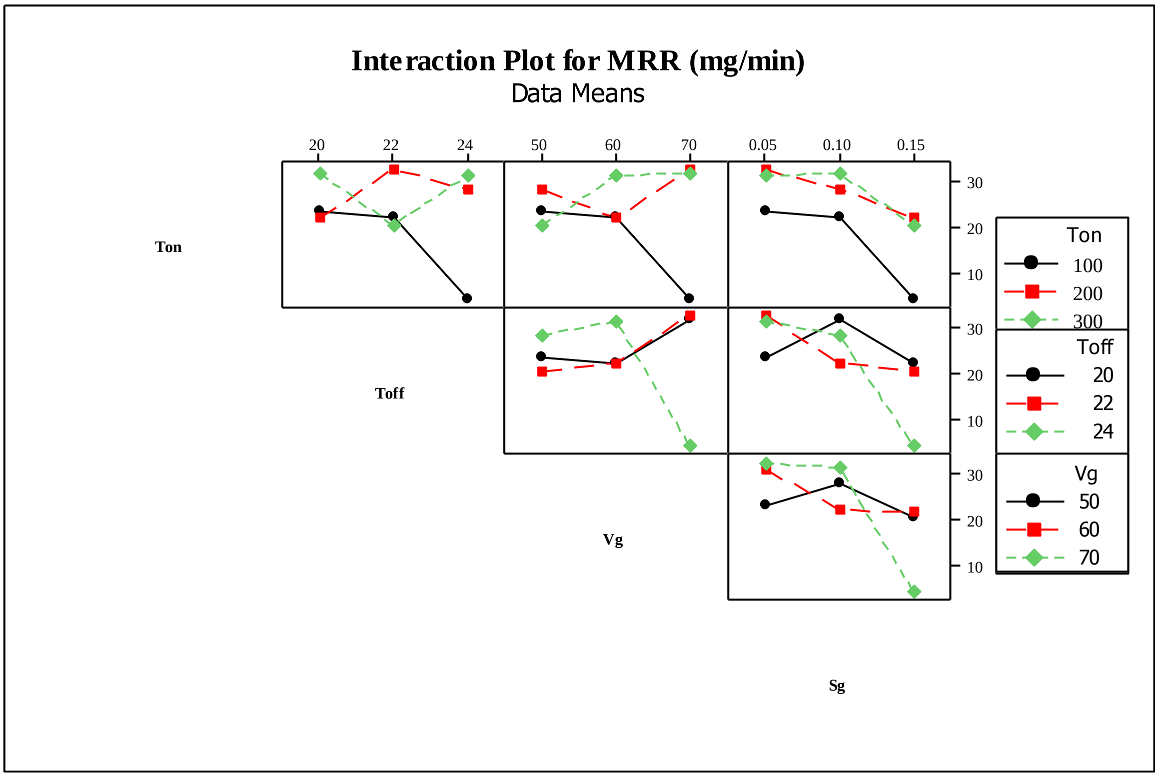
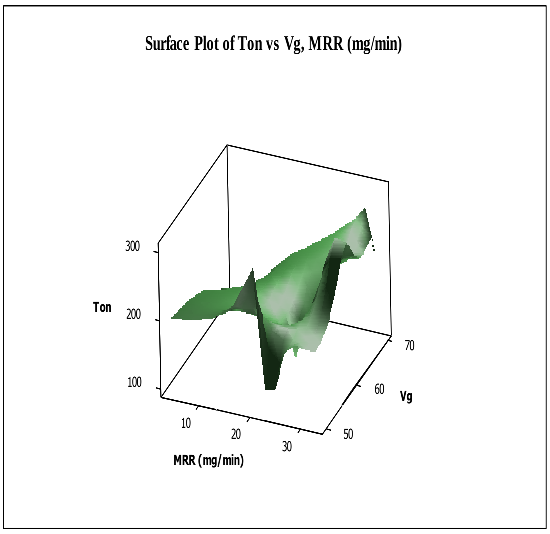


Figure 3: Interaction plot for control process parameters



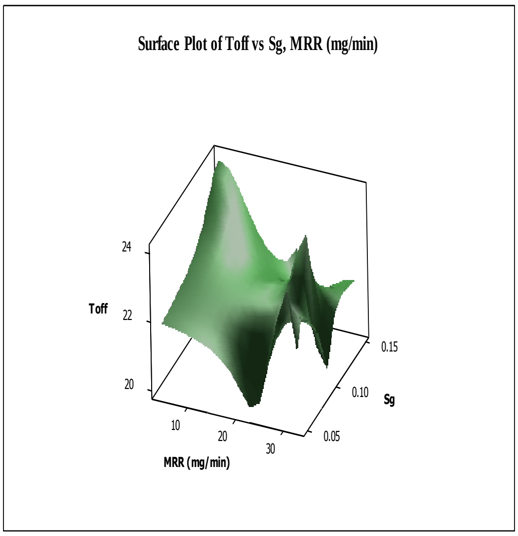


Figure 4: a) Effect of Ton and Vg over MRR, b) Effect of Toff and Sg over MRR

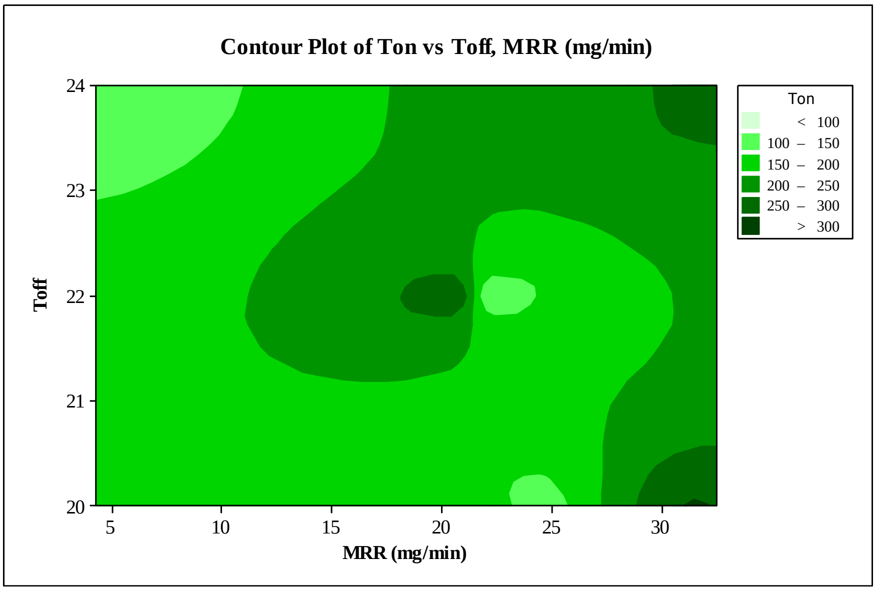


Figure 5: Effect of Ton and Toff over MRR

V. Result and Discussion

The study has been carried out based on experimental data to identify the effect of each control process parameters on MRR. It is found that the most preferable process condition for optimizing output response is $Ton_3Toff_1Vg_2Sg_1$ as shown in Fig. 2. Moreover, Interaction plot between Ton, Toff, Vg and Sg is also observed in order to identify the effect of individual independent process variable over another as shown in Fig. 3. Also, the effect of Ton and Vg as well as Toff and Sg over MRR is plotted in Figure 4(a) and Figure 4(b) respectively. It is found that increase in Vg results in high discharge and increases the erosion process, results in higher metal removal rate. Also, it is found that increase in Ton, increases the time duration of sparks, and enhances the MRR. Also, decrease in Sg results in the increase spark discharge energy which facilitates the action of melting and vaporization, and advancing the large impulsive force in the spark gap, thereby increasing the material removal rate (MRR). It is also found indeed necessary to identify the impact of Ton and Toff over MRR (Figure 5). It is found as the pulse on time increase, the pulse duration increases, results in more heat transformation to the work piece and increases the MRR.

VI. Conclusion

In present investigation, Inconel 825 super alloy is employed in EDM to evaluate the optimal setting between considered controllable process parameters i.e. Ton, Toff, Vg and Sg on MRR. For assessing the output responses, Taguchi L_9 orthogonal array design approach is efficiently applied. Furthermore, S/N ratio analysis has been carried out to identify the impact of controllable variables. It is found that optimal process parameters setting is $Ton_3Toff_1Vg_2Sg_1$ for maximizing MRR. The results clearly depict that the combination of independent process parameters i.e. Ton, Toff, Vg and Sg is found as 300, 20, 60 and 0.05 for maximizing MRR. It is found that increase in Vg results in high discharge and increases the erosion process, results in higher metal removal rate. It is also observed that increase in Ton firstly decrease the MRR and when it value increases beyond a certain level, there is significant increase in MRR.

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