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Analyzing the Electrode Feed in Electrochemical Discharge Machining (ECDM) Process

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Abstract: Electrochemical discharge machining is recognized as one of the novels and hybrid processes for machining non-conductive materials irrespective of their chemical and physical properties. It utilizes the application of thermal heat and chemical dissolution to remove the material. Since the ECDM process comprises the involvement of several input variables, the tool electrode feed rate is identified as the crucial variable that signifies the formation of gas film underneath the tool electrode based on gap availability. This present study focusses on the performance evaluation of the ECDM process based on tool electrode feed rate i.e., the effect of tool electrode feed rate on material removal rate (MRR) is evaluated. Applied voltage, electrolyte concentration are the other two variables picked alongside tool feed rate while MRR is selected as a response parameter. The experiments are performed according to Taguchi's L9 orthogonal array. Results revealed that the tool feed rate significantly affects the material removal as too high feed deteriorates the MRR. The combination of input variables for maximizing the MRR is acquired through S/N ratios and determined as 4mm/min, 50V and 20 wt.%, tool feed being the dominant one with 76.86 % contribution.
Keywords: ECDM, tool feed, Material removal, gas film, S/N ratio

I. INTRODUCTION

With the increased demand for miniaturized products in the fields of micro-electro-mechanical system (MEMS) like glass in micro-fluidic devices, the development of the advanced non-conventional machining process also increases [1]. ECDM is used as a hybrid non-conventional technique for machining non-conductive materials with micro-features. It combines the machining attributes of the electrochemical machining (ECM) and electric discharge machining (EDM) process. ECDM consists of two electrodes, one being a tool electrode (cathode) and another being an auxiliary electrode (anode). These electrodes are separated by a small distance known as the inter-electrode gap (IEG) and dipped inside the aqueous solution of an electrolyte along with the work material as shown in Figure 1.

When the applied voltage is provided between the two electrodes, the formation of the gas bubbles (hydrogen and oxygen) starts at the cathode and anode respectively. With the further increase in voltage, the formation rate increases further which escalates the hydrogen bubble density at the cathode. These tiny bubbles physically coalescence with each other and transformed into a large bubble or often called gas film that insulates the tool electrode. This phenomenon is called as tool blanketing. It constricts the flow of the current within the circuit and its value drop to zero. Thereafter, an electric spark is generated owing to the electric breakdown of the gas film. Once the electric spark is produced, the work material is placed and maintained underneath the tool electrode at a very small distance (known as the machining gap). The material is removed due to the thermal heating of the sparks followed by the chemical dissolution [2,3].

ECDM was first demonstrated by Kurafuji and Suda [4] in 1968 in which they mentioned the possibility of glass drilling with the help of electric discharges. Basak and Ghosh [5] successfully demonstrated the mechanism of material removal in ECDM and emphasized the critical voltage-current values for generating the spark.

Wuthrich et al. [7-8] made several contributions to analyzing the fundamental principles of the ECDM process alongside the gas film phenomena. Numerous studies have been performed for studying the material removal analysis concerning different input variables [9-10]. Several authors have performed critical analysis on the ECDM process and highlighted the future areas for improving the machining performance [11-13]. Rajput et al. [6,14-17] performed experiments to analyze the effect of applied voltage and electrolyte concentration on MRR. It was found that both applied voltage and electrolyte concentration increases the MRR with their level increase. The tool feed rate also substantially controls the machining performance of the process. Tool feed rate should be selected wisely since tool low feed rate often results in high machining time while tool high feed rate may cause tool physical contact with the work material [18,19].

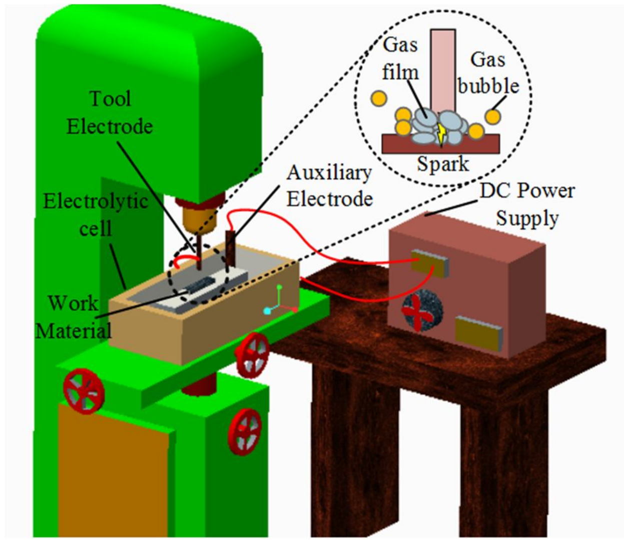

Fig. 1 Schematic diagram of the ECDM principle Operation [6]

It causes damage to the tool or work material. Behroozfar et al. [19] performed studies on tool-related parameters and highlighted the major areas for improving the process related to tool feed. They put forward a crucial phenomenon of tool i.e., stick and jump. The selection of tool feed rate is important since it controls the machining between the tool and work material. The machining gap enables the flow of electrolyte that further forms the effective gas film underneath the tool. Thus, the machining gap serves a crucial purpose that helps in maintaining a stable gas film which further relies on the tool feed rate. Apart from experimental studies, various numerical studies have been performed to date that discusses the development of a thermal model for analyzing the MRR in the ECDM process [20-22].

Based on the literature, it is evident that the ECDM process still possesses the scope for improvement and its exploration related to tool feed needs further analysis. This study investigates the effect of tool feed rate on MRR followed by the optimization of MRR for its maximization.

II. METHODOLOGY AND MEASUREMENTS

The experiments were carried out on a developed ECDM set up (fabricated in the house) and integrated into the vertical milling machine. The electrolytic cell was made up of polycarbonate material which is non-reactive in nature. It consists of a non-reactive fixture for holding work material which is dipped inside the electrolyte as shown in Figure 2. Stainless steel of diameter 1 mm was used for producing micro-holes in the glasswork material. A soda-lime glass of 1 mm thickness was used as a work material. A full-wave continuous DC voltage of range 0-80 V and 10 A was used as a power source.

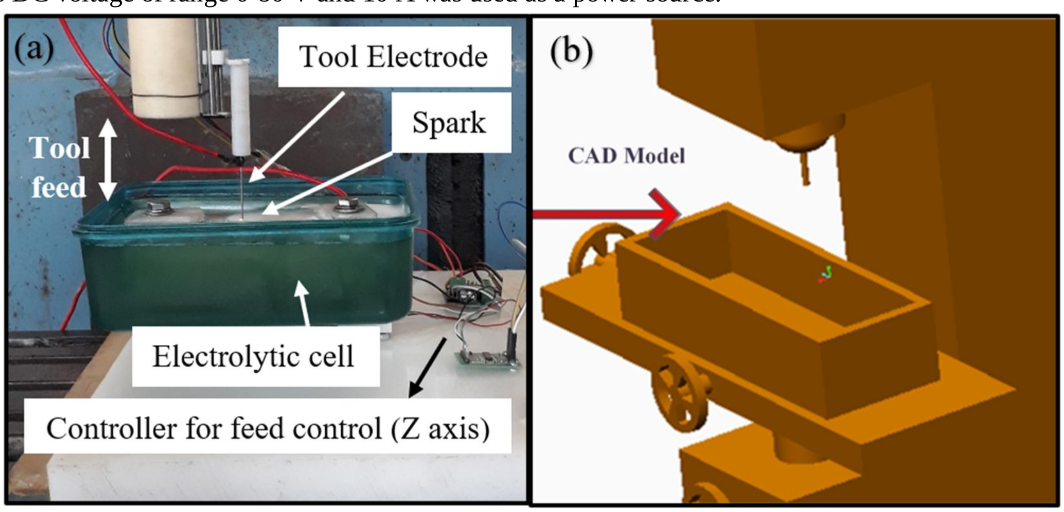

Fig. 2 ECDM experimental setup

The MRR is computed as the weight difference before and after the micro-hole fabrication process divided by the total machining time, expressed as

$$MRR=((wt_1 - wt_2)/t) \quad (1)$$

where wt_1= work material weight before micro-hole fabrication (g), wt_2 = glass material weight after micro-hole fabrication (g), and t=time in minutes. A weighing machine (model: CAY220, make: CAS corporation) having a resolution of 0.0001g was used for measurement. An average of three measurements was considered. The experiments were performed according to orthogonal L9 array with three input variables having three levels. Applied voltage, electrolyte concentration, and tool feed rate were chosen as an input variable while MRR was selected as a response characteristic. The machining conditions used in this study are illustrated in Table 1.

TABLE 1 Machining conditions used for micro-hole drilling

Constant Variable		Input variables				
		Levels		I	II	III
Cathode and Anode Material	Stainless steel	Tool feed rate (mm/min)	A	4	5	6
Electrolyte	KOH	Applied Voltage (V)	B	40	45	50
Electrolyte temperature	50^{o}C	Electrolyte Concentration (wt/v %)	C	15	20	25
Electrolyte Level	1 mm (approx.)	Machining time (min)			4	

III. RESULTS AND DISCUSSIONS

A. S/N Ratio analysis

The S/N ratio for MRR is computed based on "higher the better" approach as given in equation

$$S/N = -10 \log_{10}[\frac{1}{n}\sum_{i=1}^{n} y_i^2] \quad (2)$$

where y_i= response measurements in each experiment; n=number of measurements.

The measured MRR and corresponding S/N ratio are given in Table 2. Generally, higher magnitudes of the S/N ratio indicate that the combination of input variables corresponding to that experiment number is the desired result. However, in this study the delta value i.e., the difference between the highest and lowest mean S/N ratio was used to identify the optimum set of input variables. The delta values for three levels of input variables are shown in Table 3. Figure 3 shows the main effects plot of the MRR S/N ratio.

TABLE 2 Taguchi's L9 Design and Response measurements of MRR

Exp	Tool feed rate (mm/min)	Applied Voltage (V)	Electrolyte Concentration (wt/v. %)	MRR (mm^3/min)	S/N Ratio (dB)
1	4	40	10	0.7985	-1.9545
2	4	45	15	0.8214	-1.7089
3	4	50	20	0.8654	-1.2557
4	5	40	15	0.7732	-2.2342
5	5	45	20	0.7964	-1.9774
6	5	50	10	0.8215	-1.7078
7	6	40	20	0.7554	-2.4365
8	6	45	10	0.7122	-2.948
9	6	50	15	0.7257	-2.7849

TABLE 3 Mean S/N ratio and Delta values for MRR

MRR's mean S/N Ratio			
Level	Tool feed rate (A)	Applied Voltage (B)	Electrolyte Concentration (C)
1	-1.640	-2.208	-2.203
2	-1.973	-2.211	-2.243
3	-2.723	-1.916	-1.890
Delta	1.083	0.295	0.353
Rank	1	3	2

Delta values revealed that MRR improves with the increase in both applied voltage and electrolyte concentration. It was seen because the formation rate of the gas film underneath the tool electrode enhances with the level increase in both voltage and concentration. It results in quick gas film formation. As a result, the high intensity of sparks underneath the tool electrode observes that further increases the thermal energy in the machining area. Hence, more MRR is obtained at a higher level of voltage and concentration.

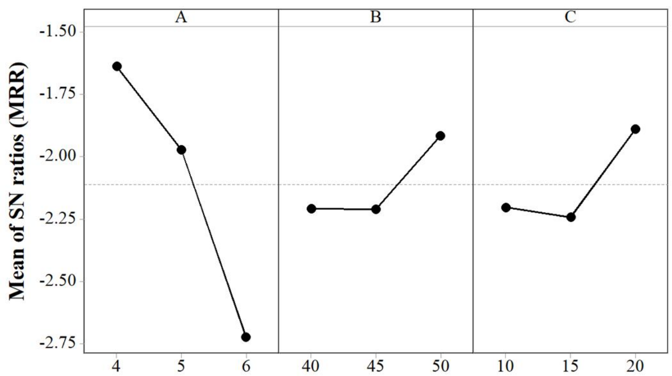

Fig. 3 Main effect plot of mean S/N ratio for MRR

An increase of 0.0669 mm^3/min in MRR was observed with the voltage increase from 40 V to 50 V and concentration increase from 10 wt.% to 20 wt.%. Figure 4 shows the individual plot of MRR concerning voltage and concentration that determines the increase in MRR. It was concluded that the MRR is strongly influenced by the tool feed rate (Rank 1, 1.083) trailed by the electrolyte concentration (Rank 2, 0.353) and applied voltage (Rank 3, 0.295). The contour plot of MRR concerning applied voltage and electrolyte concentration is shown in Figure 5.

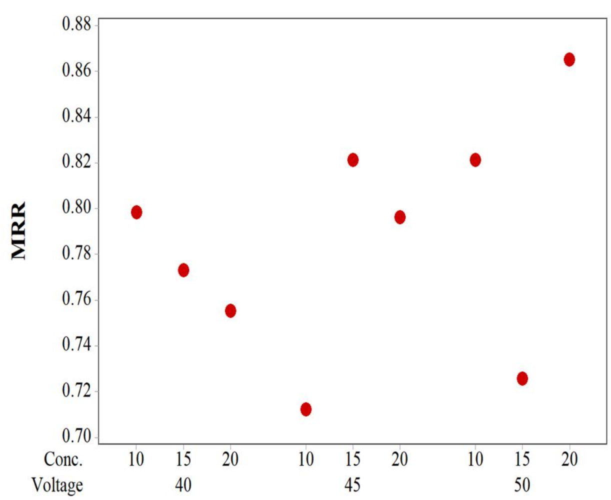

Fig. 4 MRR variation concerning applied voltage and electrolyte concentration

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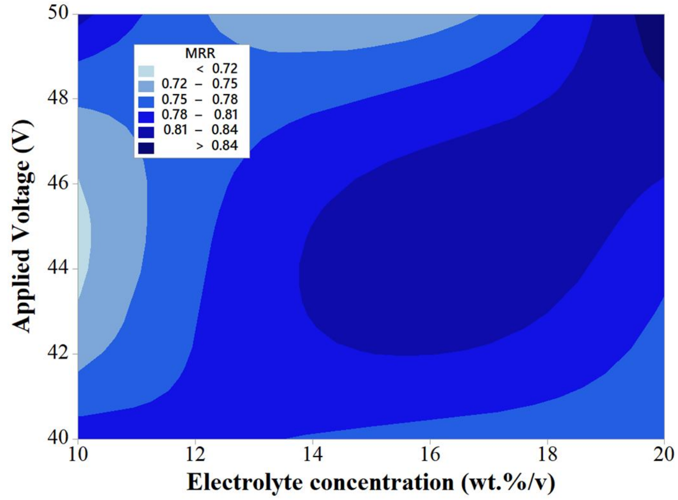

Fig. 5 Contour plot of MRR concerning applied voltage and electrolyte concentration

B. Tool electrode feed effect on MRR

Electrode feed was observed as an influential input variable for controlling the MRR. Figure 6 shows the effect of the tool electrode feed rate effect on MRR. It was found that MRR improves with the decrease in tool electrode feed rate since at low tool feed rate more interaction time occurs between electrode and work material for thermal energy transference. It causes more material to remove from the glass. On the contrary, a high tool feed rate causes more electrode contact with the work material and deteriorates the gas film formation. An improvement of 0.1397 mm^3/min was observed with the decrease in tool electrode feed from 6 mm/min to 4 mm/min. As a result, a reduction in the MRR is observed. The combined effect of all three input variables on MRR is shown in Figure 7.

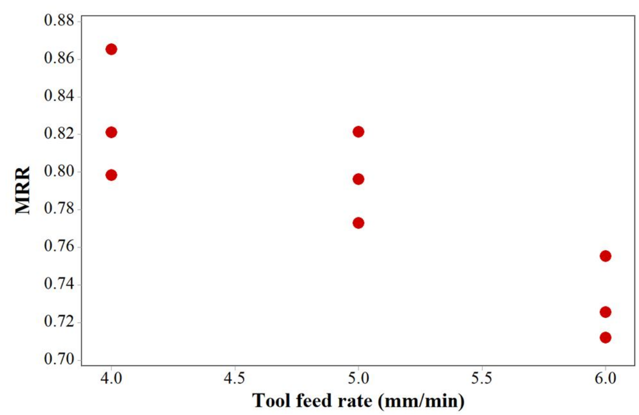

Fig.6 MRR variation concerning tool feed rate

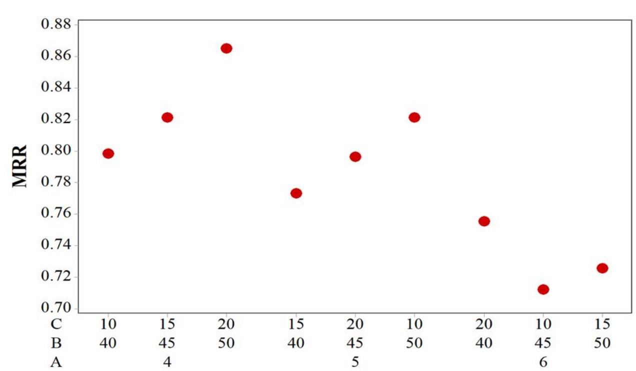

Fig.7 MRR variation concerning input variables

C. ANOVA results

ANOVA is performed to identify the contribution of the input variables as shown in Table 4. It was found that the tool feed rate contributes a maximum percentage (76.86) in controlling the MRR trailed by the electrolyte concentration (9.67) and applied voltage (8.17).

Table 4 ANOVA results for MRR

Source	DOF	Sum Squares	Variance	F-Value	Percentage Contribution (%)
Tool feed rate	2	0.01480	0.00740	14.48	76.86
Applied Voltage	2	0.00157	0.00078	1.54	8.17
Electrolyte Concentration	2	0.00186	0.00093	1.82	9.67
Error	2	0.00102	0.00051		5.29
Total	8	0.01926			

IV. CONCLUSIONS

In this present investigation, the effect of the tool electrode feed on MRR was evaluated alongside applied voltage and electrolyte concentration. The experiments were performed according to Taguchi's L9 array and analyzed using the S/N ratio. The major conclusions withdrawn from the study are given underneath:

A. Tool electrode feed is found as the most dominant and influential input variable for controlling the MRR with a maximum percentage of 76.86.
B. MRR was found to be increased with the increase in both the applied voltage and electrolyte concentration while it decreases with the increase in tool feed rate.
C. The optimum combination of input variables for maximum MRR is A1B3C3. i.e., (4 mm/min, 50V, 20 wt.%), low level of tool electrode feed, high level of both voltage and concentration.
D. An increase of 0.0669 mm^3/min in MRR was observed with the voltage increase from 40 V to 50 V and concentration increase from 10 wt.% to 20 wt.%.
E. An improvement of 0.1397 mm^3/min was observed with the decrease in tool electrode feed from 6 mm/min to 4 mm/min.

V. ACKNOWLEDGMENT

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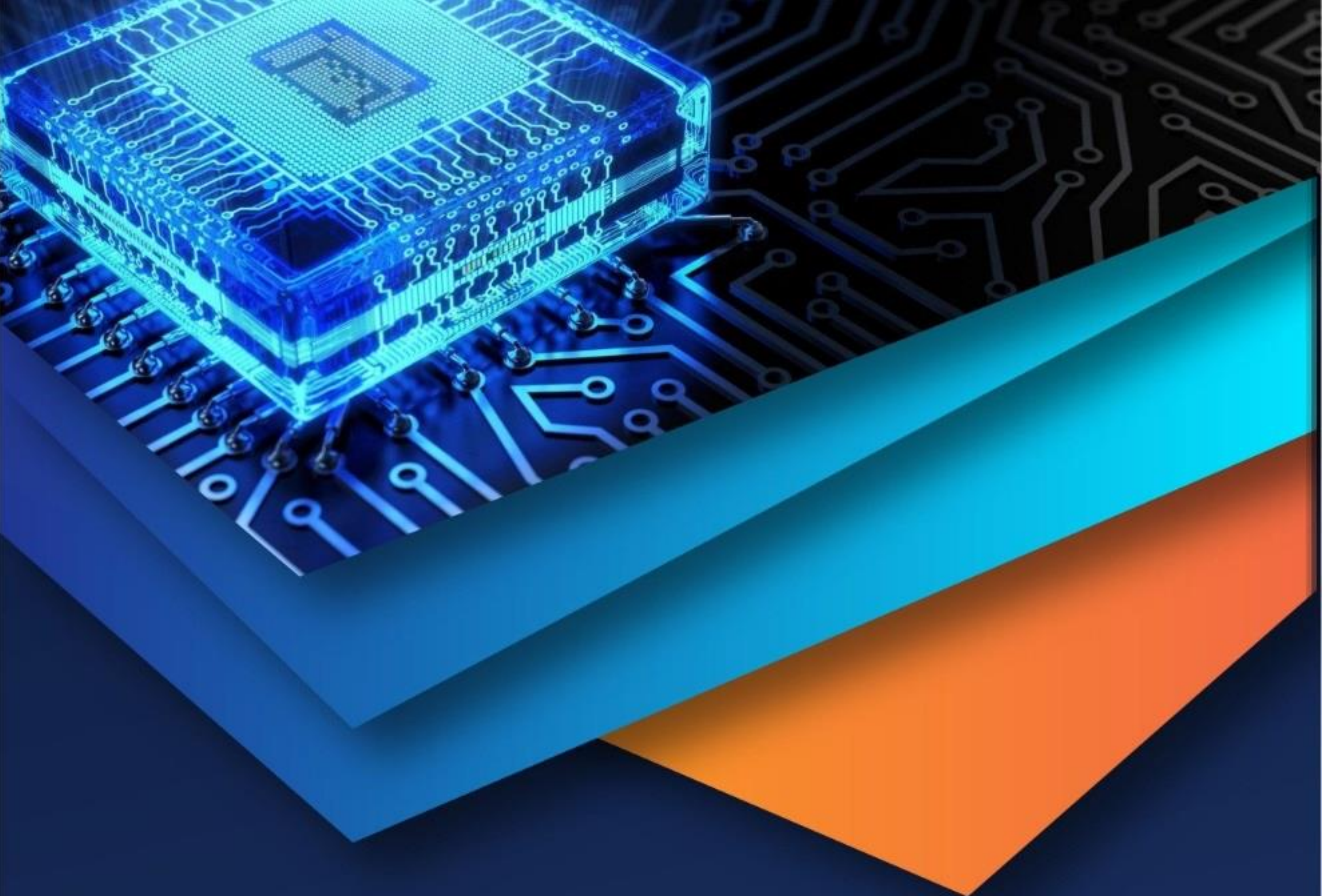

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