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Experimental Study During Electrical Discharge Machining of Reinforced Carbon Fiber Plastic Material

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Abstract:** The proper selection of machining conditions and machining parameter is an important aspect, before going to machine a carbon-fiber composite material by Die sinking electrical discharge machining (EDM). Because these conditions will determine such important characteristics as; Material removal rate (MRR), Electrode wears rate (EWR), and Surface roughness (R). The purpose of this work is to determine the optimal values of machining parameters of electrical discharge machine, while machining carbon-fiber-composite with copper electrode. The work has been based on the affect of four design factors: pulse current(I_p) supplied by power supply system of electrical discharge machine (EDM), pulse-on-time(T_{ON}), gap voltage(V_g) and duty cycle (η) on such characteristic like material removal rate (MRR), electrode wear rate(EWR), and surface roughness(R_a) on work-piece surface. This work has been done by means of the technique of design of experiment (DOE), which provides us to perform the above-mentioned analysis with small number of experiments. In this work, a L_9 orthogonal array is used to design the experiment. The adequate selection of machining parameters is very important in manufacturing system, because these parameters determine the surface quality and dimensional accuracy of the manufactured part. The optimal setting of the parameters are determined through experiments planned, conducted and analyzed using the Taguchi method. It is found that material removal rate (MRR) reduces substantially, within the region of experimentation, if the parameters are set at their lowest values, while the parameters set at their highest values increases electrode wear rate (EWR).
***Keywords:** EDM, Material removal rate, Surface roughness, Tool wear rate,*

I. INTRODUCTION

EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive. Fuelled by a growing need for high strength materials in technologically advanced industries and supported by the advances in the field of material science, there has been an increase in the availability and use of difficult-to-machine materials. Nontraditional machining processes are necessary for machining of such materials. Electrical Discharge Machining (EDM) is one such process which is widely used to machine electrically conductive materials. EDM is a thermo-electric process in which material removal takes place through the process of controlled spark generation. It is one of the most popular non-traditional machining processes being used today in the industry. EDM is commonly used in mould and die making industry and in manufacturing automotive, aerospace and surgical components. Since there is no mechanical contact between the tool and the work piece, thin and fragile components can be machined without the risk of damage. EDM has achieved a status of being nearly indispensable in the industry because of its ability to machine any electrically conductive material irrespective of its mechanical strength. Composite materials are extensively used for the manufacturing of body parts of aircrafts and robots due to its special characteristics like low weight and high strength. Composite materials are gaining popularity due to its broad application area, therefore to choose the appropriate machining process which gives good surface finish and high material removal rate, is a big task. Machining of nonmetallic composite materials which are electrically conductive in nature using hybrid machining of EDM and conventional diamond grinding is the aim of our work, therefore composite material of carbon fiber is used as work material. Carbon fiber composite is an anisotropic material so its strength and thermal conductivity are directional dependent.[1] Due to directional dependency of thermal conductivity mostly heat is transferred in longitudinal direction so at higher current larger crater are formed in longitudinal direction as compare to transverse direction. Machining of carbon fiber composite material from conventional machining gives poor surface finish and low material removal rate so we use non-conventional machining process i.e. EDM process which is known for its inefficiency

Fig1. Set up of Electrical Discharge Drilling on Sparkonix EZNC EMS-5535

II. LITERATURE SURVEY

I.Puertas et al mentioned that during EDM machining of conductive ceramic, the main factor which effect the MRR, EW and surface finish is intensity or pulse on time. When either pulse or intensity increased, the roughness value also increased. For high values of MRR, the values of intensity, pulse time and duty cycle should be high. For low value of EW the values of intensity and pulse time should be low.

I.Puertas et al mentioned that during die sinking EDM machining the parameters which affect the MRR, EW and roughness of work surface are current and pulse time. Low values of current takes long time for process. So it is advisable to take higher values of current with low intensity, which gives better surface finish.

I.Puertas et al mentioned that the descending order of parameters which affect the MRR, current (I), voltage (V), pulse on time, duty cycle and flushing pressure. For EW the order is current (I), pulse on time and flushing pressure.

I.Puertas et al mentioned that EW tends to decrease with increase in pulse on time in case of boron carbide. But in case of silicon carbide and tungsten carbide, EW tends to increase with increase in pulse on time. EW tends to increase when duty cycle is increased in case of boron carbide and silicon carbide, but in case of tungsten carbide EW increases up to a maximum value after which it decreases. In case of MRR, its value increases with increase in duty cycle for all cases. Furthermore in case of increasing pulse time, the value of MRR is decreased.

P.M.George, B.K.Ragunath et al states that during EDM machining of carbon-carbon composite with a copper electrode, the major influencing parameters are current (I), voltage (V), pulse on time. Among all the process parameters pulse on time is insignificant. For high values of current and voltage, the value of MRR is high, but surface roundness is increased and tool wear is also increased. For low values of current and voltage, the value of MRR is decreased, but values the surface roughness and tool wear are decreased. Machining at 1amp. Current value, 20volts voltage value and 150µs pulse on time value, gives low values of EW, MRR and surface roughness. Machining at 9amp. Current value, 100volts voltage value and 750µs pulse on time value, gives high values of EW, MRR and surface roughness.

Mustafa Kurt, Eyup Bagci et al states that confirmation tests with the optimal levels of machining parameters are carried out in order to illustrate the effectiveness of the Taguchi optimization method. The validity of Taguchi's approach to process optimization is well established. Traditional experiment design procedures are too complicated and not easy to use. Taguchi method reduces the number of experiments and cost of experiments also. This method analyses the process by using the signal-to-noise ratio approach, Regression analysis and analysis of variance (ANOVA). The confirmation experiment for surface finish has shown that Taguchi design parameters can successfully verify the optimum cutting parameters.

A.A. Khan et al mentioned that during EDM machining of aluminum and mild steel with copper and brass electrodes, electrodes get more wear along their cross-section compared to its length. EW increases with increase in current and voltage. Copper electrode wear less than brass electrode because of high thermal conductivity of copper electrodes compared to brass electrode. During machining of mild steel electrode gets more wear in comparison to machining of aluminum, it is due to high thermal conductivity of aluminum compared to mild steel, so the maximum heat is dissipate into the electrode during machining of mild steel. The wear ratio increases with increase in current and gap voltage. Maximum MRR was found during machining of aluminum with brass electrode.

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Y.H.Guu et al states that during EDM machining of carbon fiber reinforced carbon composite, the material gets erode in both liquid and gaseous states. The scanning micro graph shows that the resolidified particles which again adhere to the work surface are in the form of solid spheres and range from 3-30µm in diameter. Delamination of fibers can be avoided by using smaller pulse energy. While using large pulse energy high temperature is produced which causes melting of fibers and delamination of fibers. Higher pulse energy also increases surface roughness and creates a much larger recast layer. The optimal level to get high rate of material removal is at a pulse current of 5A and a pulse on time of 100 µs.
W.S.Lau et al mentioned that during machining of carbon fiber composite with copper and graphite electrodes, copper gives good surface finish and less tool wear ratio in comparison to graphite. Positive polarity should be used during machining of carbon fiber, because it gives better MRR and low tool wear ratio. The resistivity of carbon fiber is higher than copper and graphite, due to which maximum heat is produced at the work piece that causes less tool wear ratio and higher material removal rate. Low current should be used, because high current causes debonding of fibers and delamination of layers.

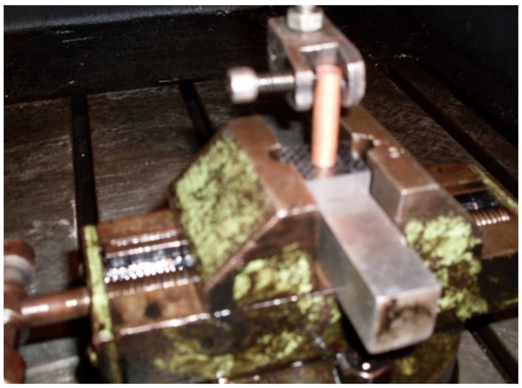
Fig. 2.EDM experimental setup


Fig.3. EDM machining of Composite work material

A. Work Material
The material used for this work is carbon fiber composite developed from carbon fiber cloth of 0.2mm thickness. Resin is used as a bonding material. Phenolic resin (Code LY 556) is used for laminate the carbon fiber cloth's layers. These layers are kept over another, and then these overlapped fiber cloth layers are pressed under cure of a particular pressure and temperature. The resistivity of the material is $57\times10^{-3}\ \Omega$ cm. Density of the material is 1850 kg/m^3. Composition of work material is given in following table.

Table.1. Shows Chemical composition of Al 6061/ SiC MMC

Work Material	**Electrical Resistivity (Ωcm)**	**Type of resin**	**Density (kg/m³)**	**Volume fraction of carbon (%)**	**Fiber Diameter (µm)**
Carbon Fiber composite	87×10^{-3}	LY-556	1850	70	7.45

B. Process Parameter Design
The selection and design of parameter is also an important task for the completion of experimental work and study the effect of input parameters on the output responses. The controllable parameters selected in the present study are pulse current (1-5amp.), gap voltage (20-60 volts), pulse on time (50-100µs) and duty cycle (0.4-0.6). The range of parameters for EDM process is shown in Table 2.

Table2. Process parameters with their range

S.No	Variable Parameters	Level 1	Level 2	Level 3
1.	Pulse current (Amp)	1	3	5
2.	Gap voltage (Volts)	20	40	60
3.	Pulse on time (µs)	50	75	100
4.	Duty cycle	0.4	0.5	0.6

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C. Experimental Method

Experiments are per formed on a die-sinking EDM machine of model EMS-5535 EZNC manufactured by ELECTRONICA, PUNE. The design of experiment is done by using 'MINITAB 14' statistical software. This statistical software is used to code the variables and to develop the experimental design table. Total nine experiments with three repitions were performed to study the effect of input on output parameters.

Table.3. Shows experimental table with full factorial design

Experiment No.	Pulse current (I_P) (in amp.)	Gap voltage (V_g) (in volts)	Pulse on time (T_{ON}) (in µs)	Duty cycle (η)	MRR in (g/min.)	TWR in (g/min.)	Surface roughness (SR)(R_a) (in µm)
1	1	20	50	0.4	0.0005817	0.000025	4.18
2	1	40	75	0.5	0.0006204	0.000039	4.67
3	1	60	100	0.6	0.0007011	0.000046	5.13
4	3	20	75	0.6	0.0007650	0.000119	6.36
5	3	40	100	0.4	0.0008676	0.000142	7.16
6	3	60	50	0.5	0.0010283	0.000168	7.94
7	5	20	100	0.5	0.0012916	0.000254	8.67
8	5	40	50	0.6	0.0015897	0.000390	9.41
9	5	60	75	0.4	0.0020933	0.000434	10.12

III. RESULTS AND DISCUSSION

A. Effect of Input Parameters on MRR, TWR and SR

Fig. 4 (a) shows effects of variables on material removal rate. Current at level 1 shows low material removal rate and at level 3 it gives high material removal rate. At level 1 & 2 MRR value is below the overall mean value, when current value changes from level 2 to 3, MRR value increases above the overall mean value. In case of voltage, at level 1 & 2, MRR value is below the overall mean value, when voltage value changes from level 2 to 3, MRR values increase above the overall mean value. At level 1 of pulse on time MRR value is above the overall mean value, when its value changes from level 1 to 2, MRR value increases, but when its value changes from level 2 to 3, MRR value decreases. In case of duty cycle, when its value changes from level 1 to 2, MRR value decreases and when its value changes from level 2 to 3 its value again decreases.

Fig 4(b) Figure shows effects of variables on tool wear rate. Current at level 1 shows low tool wear rate and at level 3 it gives high tool wear rate. At level 2 & 3 TWR value is below the overall mean value, when current value changes from level 2 to 3, TWR value increases. In case of voltage, at level 2 & 3, TWR value is below the overall mean value, when voltage value changes from level 2 to 3, TWR values increase. At level 1 of pulse on time TWR value is above the overall mean value, when its value changes from level 1 to 2, TWR value increases, but when its value changes from level 2 to 3, TWR value decreases. In case of duty cycle, when its value changes from level 1 to 2, TWR value increases and when its value changes from level 2 to 3, TWR value decreases.

Fig.4(c) Figure shows effects of variables on surface roughness. Current at level 1 shows good surface finish and at level 3, surface finish becomes rough. At level 2 & 3, SR value is below the over all mean value, when current value changes from level 2 to 3, SR value increases (it means surface becomes rough). In case of voltage, at level 3, SR value is below the overall mean value, when voltage value changes from level 2 to 3, SR values increase. At level 1 of pulse on time, SR value is equal to the over all mean value, when its value changes from level 1 to 2, SR value decreases, because increased value of pulse on time erode material equally from the surface of work-piece and gives a good surface finish, but when its value changes from level 2 to 3, SR value increases, because material removal becomes unequal due to increase in pulse on time. In case of duty cycle, when its value changes from level 1 to 2, SR value increases and when its value changes from level 2 to 3, SR value decreases.

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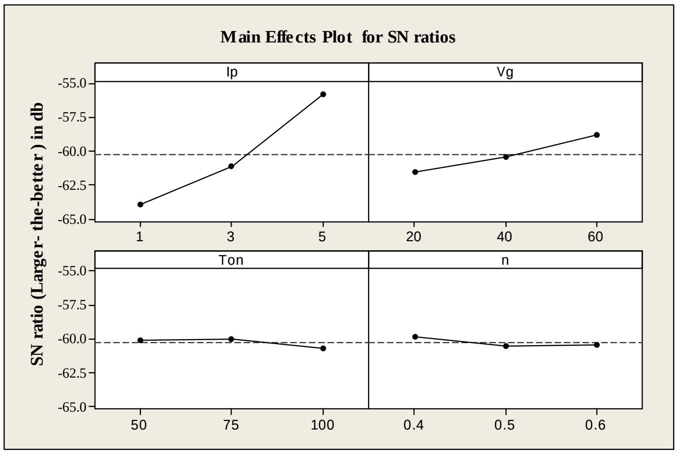

Fig. 4(a): shows effect of control factors and their levels on MRR

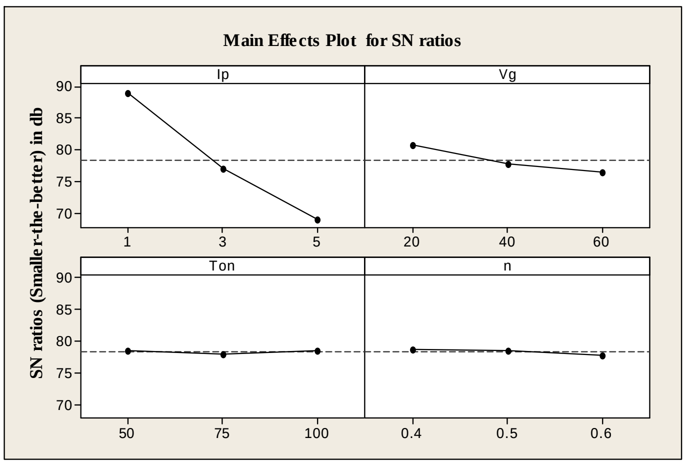

Fig. 4(b): shows effect of control factors and their levels on TWR

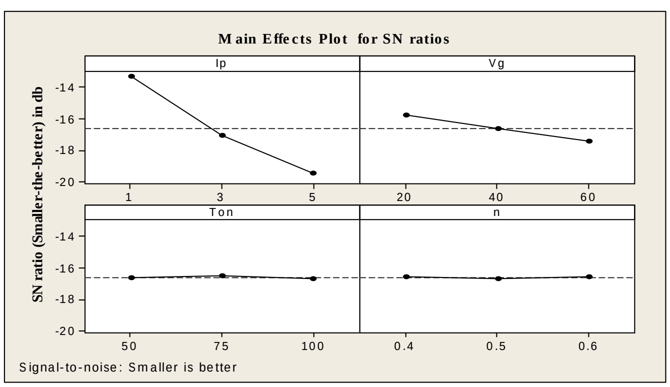

Fig. 4(b): shows effect of control factors and their levels on SR

1) *Regression Equation for MRR*

MRR=0.000473+0.000256 Ip+0.000010 Vg – 0.000002Ton –0.000811 η

2) *Regression Equation for TWR*

TWR = – 0.000037 + 0.000081 Ip + 0.000002 Vg – 0.000001 Ton – 0.000077 η

3) *Regression Equation for Surface Roughness (SR)*

SR = 2.94 + 1.19 Ip + 0.0332 Vg - 0.00380 Ton - 0.933 η

IV. CONCLUSIONS

The major objective of the research is to find the effect of input parameters on output responses like material removal rate (MRR), tool wear rate (TWR) and surface roughness (Ra) in Electrical Discharge Drilling machining of reinforced carbon fiber plastic composite mater. The conclusions based on the experimental results are summarized as follows:

The regression equation for MRR is:

MRR=0.000473+0.000256 Ip+0.000010 Vg – 0.000002Ton –0.000811 η

Optimum levels for MRR:

Process variables or Factors	Optimum Levels	
Pulse current	I_{P3}	5 Amp.
Gap voltage	V_{g3}	60 Volts
Pulse on time	T_{ON2}	75 µs
Duty cycle	η_1	0.4

The regression equation for TWR is:

TWR = – 0.000037 + 0.000081 Ip + 0.000002 Vg – 0.000001 Ton – 0.000077 η

Optimum levels for TWR:

Process variables or Factors	Optimum Levels	
Pulse current	I_{P1}	1 Amp.
Gap voltage	V_{g1}	20 Volts
Pulse on time	T_{ON1}	50 µs
Duty cycle	η_1	0.4

The regression equation for SR is:

SR = 2.94 + 1.19 Ip + 0.0332 Vg – 0.00380 Ton – 0.933 η

Optimum levels for SR:

Process variables or Factors	Optimum Levels	
Pulse current	I_{P1}	1 Amp.
Gap voltage	V_{g1}	20 Volts
Pulse on time	T_{ON2}	75 µs
Duty cycle	η_1	0.4

This work shows optimization of the machining parameters in the EDM machining of carbon fiber composite using Taguchi method. It is entirely feasible to machine carbon fiber composite materials by EDM process. The advantage of such a process with carbon fiber composite materials is the capability of producing irregular shaped holes with good surface finish and dimensional accuracy. Positive polarity should be used for machining carbon fiber composite. To avoid excessive melting of the composite surface, low current density should be used. At large current density, there is considerable damage to the composite material including melting of the surface, thermal expansion of the fibers, debonding between the fiber surface and the resin.

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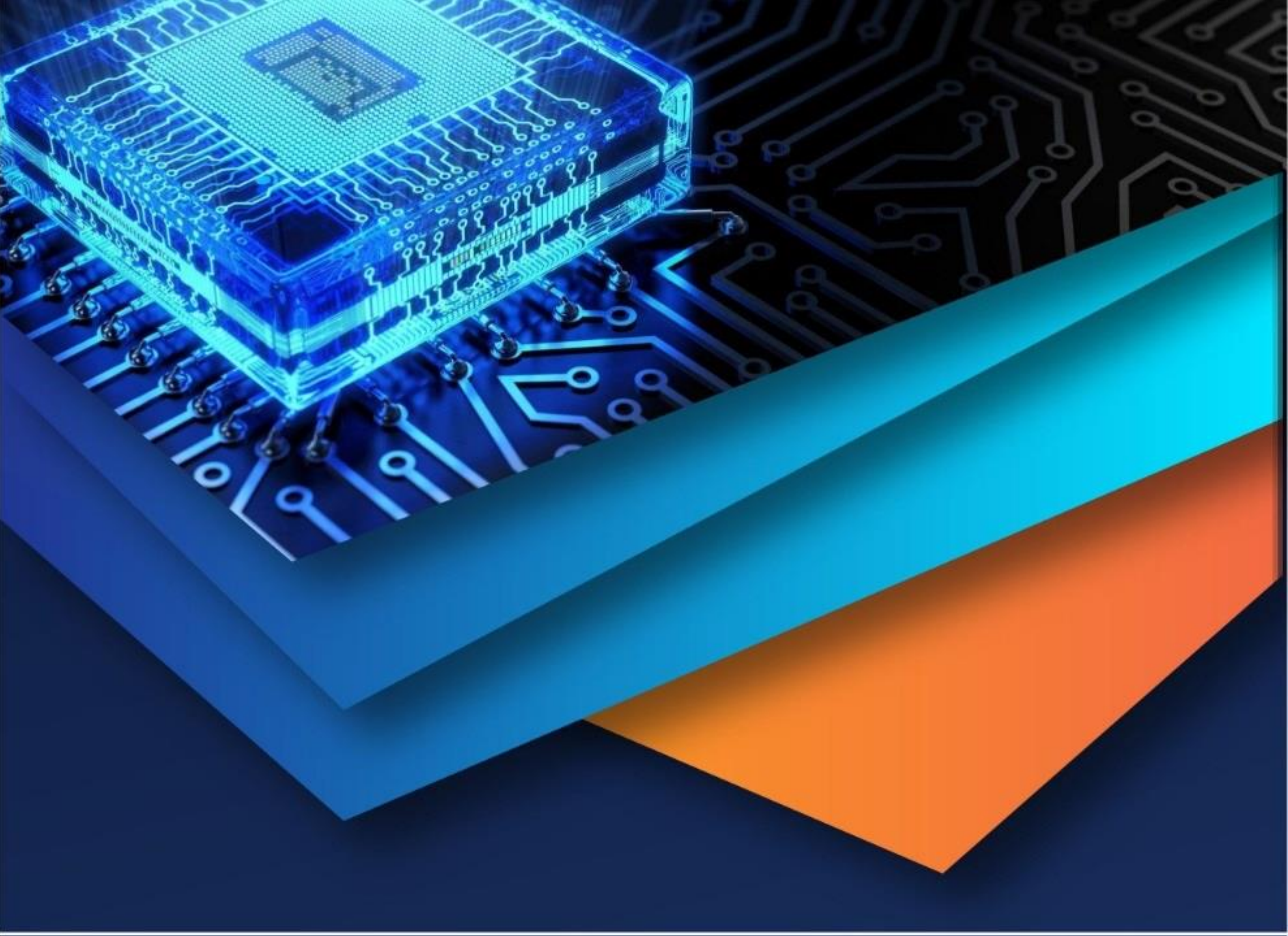

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