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# Optimization of Kerf Width & Kerf Taper Angle on Glass Fiber Reinforced Polymer by Abrasive Water Jet Machining using Taguchi Approach

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***Abstract:** Abrasive water jet machining is a process where the material is removed by the principle of erosion for metals and composite materials for the required cutting geometry. In the present study, machining of Glass fiber reinforced polymer was carried out where the input parameters are water jet pressure, abrasive flow rate, traverse speed and stand-off distance are taken into consideration for cutting operation. The experimental outputs are Kerf width, and kerf taper angle was measured using the design of experiments Taguchi L9 orthogonal array.*
***Keywords:** Glass fiber reinforced polymer, Kerf Width, Kerf Taper Angle, Stand-Off Distance, Water Jet Pressure, Traverse Rate and Taguchi L9 orthogonal array.*

## I. INTRODUCTION

Abrasive water jet machining (AWJM) process is developed in non-traditional machining processes which is categorized under mechanical machining process used for machining of hard materials and as well as composite materials. In this process, the removal of material takes place from the workpiece by impingement of abrasive particles mixed with high speed of water jet. In this process, the water from the reservoir is pumped to the intensifier where it increases the pressure from 4 bars to 40000 bars according to the requirement for the machining. This high pressure of water is converted into kinetic energy of abrasive water jet in the nozzle which is used for the machining.

Glass fiber reinforced polymer (GFRP) is a reliable and ultimately lightweight composite material which is used for various engineering applications like aerospace, automobile, propellers and propulsion shafts in marine industries. These composites are the assembly of reinforcement and a matrix which are physically separable. The individual properties of the reinforcement and the matrix are summed up in the laminate. The primary area focused in this study is the influence of kerf width and kerf taper angle of glass fiber reinforced material by AWJM.

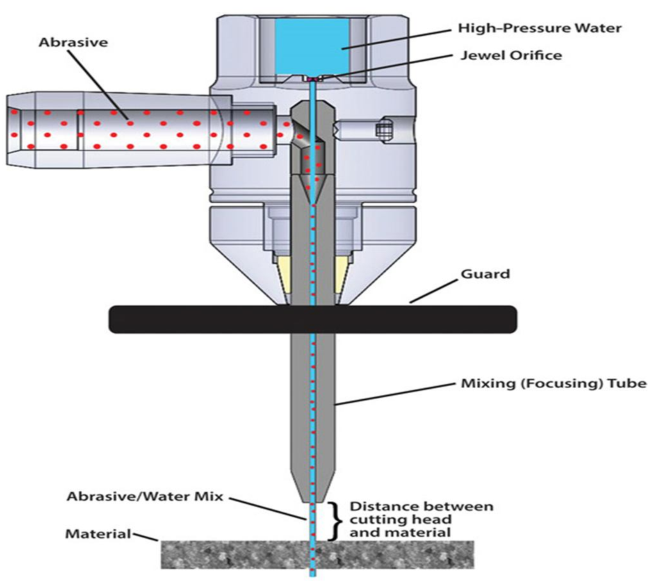


Fig. 1 Scheme diagram of Abrasive water Jet machining

## II. EXPERIMENTAL METHODOLOGY

### A. Experimental Machine setup

Aqua jet abrasive water jet machine G3020 German Engineering is used for the experiment. The machining parameters like water jet pressure, abrasive flow rate, traverse rate and stand-off distance is considered from the AWJM Machine shown in Table-I.

Table I Machining Range of Parameters of Abrasive Water Jet Machine

| Parameters | Range |
|---|---|
| Water jet pressure (psi) | 58015 |
| Abrasive flow rate (gm/sec) | 8-12 |
| Traverse speed (mm/sec) | 10-20 |
| Nozzle diameter (mm) | 1 |
| Orifice (mm) | 0.35 |
| Water flow rate (ml/sec) | 67 |
| Abrasive particles (mesh garnet) | 50-80 |

### B. Experimental Material required

Glass fiber is made up of a large number of fine fibers of glass. The fibers are light in weight, robust but; the strength is low when compared with carbon fibers. In this experiment glass fiber reinforced polymer with the horizontal orientation of material dimensions, 100*100*5 mm has been chosen to study the kerf width and kerf taper angle by AWJM process. The properties and composition of glass fiber reinforced polymer are as follows in table II and table III.

Table II
Mechanical Properties of Glass fiber reinforced polymer

| Property | Value |
|---|---|
| Young's Modulus | 72.35*103 Mpa |
| Tensile Strength | 3.45*103 Mpa |
| Density | 2.58 g/cm3 |
| Longitudinal Thermal Expansion | 5.04*10-6/0C– 5.4*10-6/0C |
| Poisson Ratio | 0.22 |
| Maximum Operation Temperature | 5500C |

Table III
Composition of Glass fiber reinforced polymer

| S.no | Type | Weight | Description |
|---|---|---|---|
| 1 | Silica | 54% | Increases strength and acid resistance. |
| 2 | Na2O + 2O | 2% | Reduce durability and poor electrical properties. |
| 3 | CaO + MgO | 22% | Reduce durability, poor electrical properties and Slow down the rate at which the glass crystallises. |
| 4 | B2O3 | 10% | It expands less on heating. |
| 5 | Al2O3 | 14% | Increase durability, improve moisture resistance. |

### C. Machining Parameters

To achieve forthright in the kerf width and kerf taper angle, it requires the combinations of the process variables that give the water jet high enough energy to penetrate through the workpiece, which is considered for machining parameters. The machining parameters considered in this study depending on the literature survey are stand-off distance, water jet pressure, traverse rate and abrasive mass flow rate, shown in table IV.

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Table IV Machining Parameters for Abrasive Water Jet Machining Process

| Parameter | | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Stand-off Distance | (mm) | 1 | 1.5 | 2 |
| Water Jet Pressure | (psi) | 44000 | 46000 | 48000 |
| Abrasive Mass Flow Rate | (gm/sec) | 4 | 6 | 8 |
| Traverse Rate | (mm/sec) | 2 | 3 | 4 |

### *D. Design of Experiments*

The experiment is performed by using Taguchi's L9 Orthogonal Array. There is a total of 9 workpiece samples have been machined by AWJM, to examine the individual and interactive effects of machining parameters which could affect the results in any design models. Kerf width and kerf taper angle of machined samples were measured by using a video profile measurement system, respectively. Table V shows the design of the experiment technique by Taguchi's L9 Orthogonal Array for AWJM OF GFRP.

Table V Design of experiment technique by Taguchi's L9 Orthogonal Array

| Expt. No | Stand-off Distance (mm) | Water Jet Pressure (psi) | Abrasive Mass Flow Rate (gm/sec) | Traverse Rate (mm/sec) |
|---|---|---|---|---|
| 1 | 1 | 44000 | 4 | 2 |
| 2 | 1 | 46000 | 6 | 3 |
| 3 | 1 | 48000 | 8 | 4 |
| 4 | 1.5 | 44000 | 6 | 4 |
| 5 | 1.5 | 46000 | 8 | 2 |
| 6 | 1.5 | 48000 | 4 | 3 |
| 7 | 2 | 44000 | 8 | 3 |
| 8 | 2 | 46000 | 4 | 4 |
| 9 | 2 | 48000 | 6 | 2 |

### *E. Experimental Findings*

An experimental study of AWJM on GFRP material to improve kerf properties is presented.

Kerf Width = (Top Width + Bottom Width)/ 2

Kerf Taper Angle = Tan-1(Top Width - Bottom Width)/ 2T

Where T is the thickness of the workpiece. Top width is the width of the cut on the surface of the material which is facing the abrasive water jet. The bottom width is the width of the cut at the bottom surface.

## III.RESULTS AND DISCUSSIONS

Influence of machining parameters on kerf width and kerf taper angle is investigated through Taguchi's L9 Orthogonal Array to obtained the minimal values. Table VI shows the experiment results of kerf width and kerf taper angle by Taguchi L9 for GFRP material.

Table VI Experimental Results of Kerf Taper by Taguchi's L9 for GFRP material

| Expt. No | Output Parameters | |
|---|---|---|
| | Kerf Width | Kerf Taper Angle |
| 1 | 1.1530 | 0.057 |
| 2 | 1.2005 | 0.040 |
| 3 | 1.1880 | 0.023 |
| 4 | 1.1455 | 0.086 |
| 5 | 1.1830 | 0.034 |
| 6 | 1.1715 | 0.074 |
| 7 | 1.1240 | 0.149 |
| 8 | 1.1925 | 0.017 |
| 9 | 1.1875 | 0.097 |

From table VI, shows the results of kerf width and kerf taper angle where none of the experiments matches with Taguchi L9 orthogonal array. So, the confirmation test is required.

### *A. Analysis of S/N Ratio on Kerf Width*

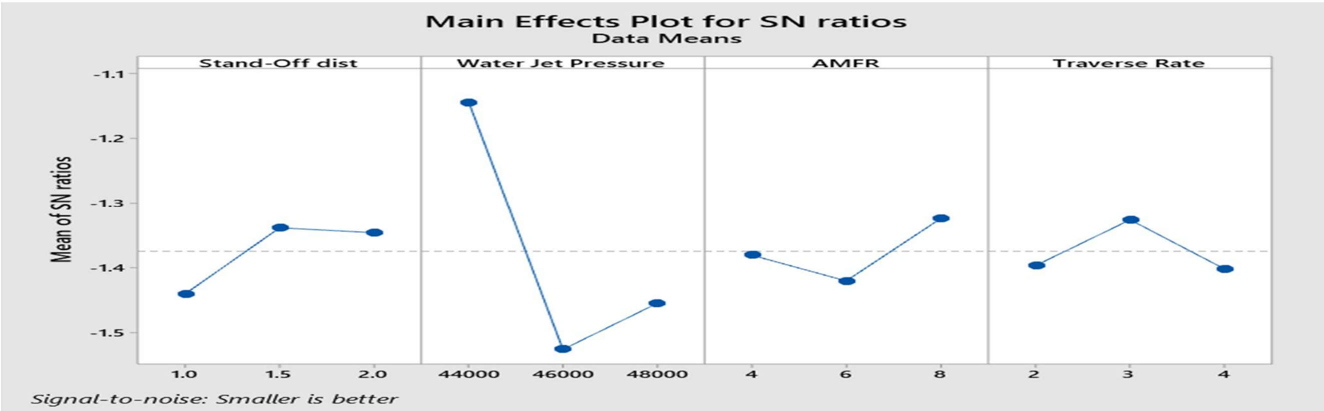


Fig. 2 Graph Signal to Noise Ratio response of Kerf width Abrasive water Jet machining

From the fig 2 shows, the graphical representation of the S/N ratio of kerf width, i.e., A2-1.5_B1-44000_C3-8_D2-3. It does not match with the L9 orthogonal array. (Combination – A2-B1-C3-D2).

Table VII Signal to Noise Ratio response of Kerf width

| Level | Stand-Off Distance | Water Jet Pressure | AMFR | Traverse Rate |
|---|---|---|---|---|
| 1 | -1.440 | -1.144 | -1.380 | -1.396 |
| 2 | -1.338 | -1.525 | -1.420 | -1.326 |
| 3 | -1.346 | -1.455 | -1.324 | -1.402 |
| Delta | 0.102 | 0.381 | 0.096 | 0.076 |
| Rank | 2 | 1 | 3 | 4 |

Table VIII Mean response of Kerf width

| Level | Stand-Off distance | Water Jet Pressure | AMFR | Traverse Rate |
|---|---|---|---|---|
| 1 | 1.181 | 1.141 | 1.172 | 1.174 |
| 2 | 1.167 | 1.192 | 1.178 | 1.165 |
| 3 | 1.168 | 1.182 | 1.165 | 1.175 |
| Delta | 0.014 | 0.051 | 0.013 | 0.010 |
| Rank | 2 | 1 | 3 | 4 |

### *B. Analysis of S/N Ratio on Kerf Taper Angle*

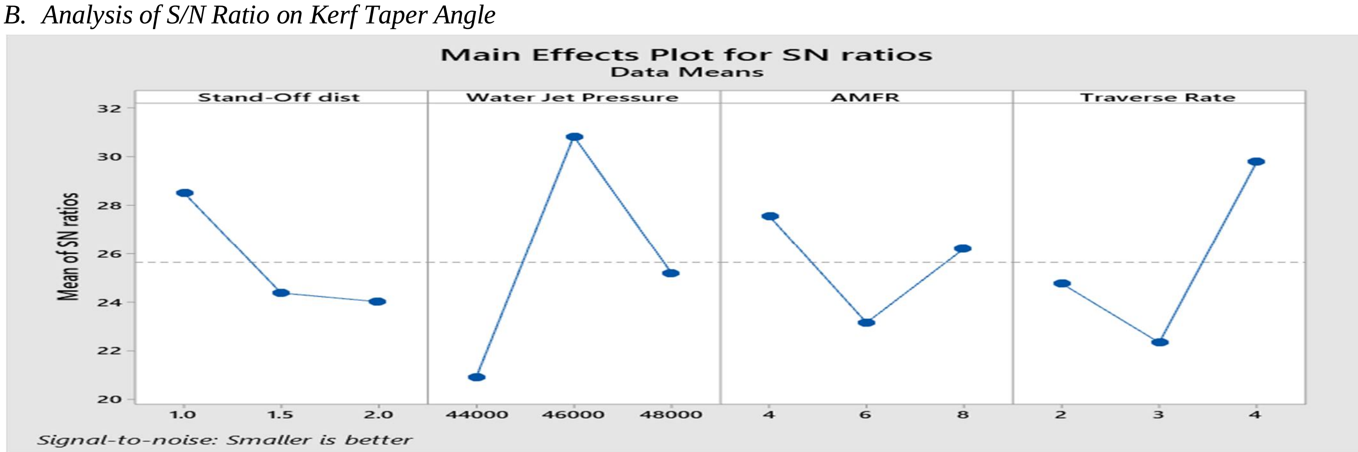


Fig. 3 Graph of Signal to Noise Ratio response of Kerf Taper Angle with Abrasive Water Jet machining

From the fig 3 shows, the graphical representation of the S/N ratio of kerf taper angle, i.e., A1-1_B2-46000_C1-4_D3-4. It does not match with the L9 orthogonal array. (COMBINATION A1-B2-C1-D3).

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Table IX
Signal to Noise Ratio response of Kerf Taper Angle

| Level | Stand-Off distance | Water Jet Pressure | AMFR | Traverse Rate |
|---|---|---|---|---|
| 1 | 28.52 | 20.90 | 27.56 | 24.78 |
| 2 | 24.38 | 30.84 | 23.16 | 22.34 |
| 3 | 24.02 | 25.19 | 26.20 | 29.80 |
| Delta | 4.50 | 9.94 | 4.40 | 7.46 |
| Rank | 3 | 1 | 4 | 2 |

Table X
Mean response of Kerf Taper Angle

| Level | Stand-Off distance | Water Jet Pressure | AMFR | Traverse Rate |
|---|---|---|---|---|
| 1 | 0.040 | 0.097 | 0.049 | 0.063 |
| 2 | 0.064 | 0.030 | 0.074 | 0.087 |
| 3 | 0.087 | 0.064 | 0.068 | 0.042 |
| Delta | 0.047 | 0.066 | 0.024 | 0.045 |
| Rank | 2 | 1 | 4 | 3 |

### *C. Confirmation Test*

This test is done because the L9 Taguchi experiment orthogonal array does not match with any combination. So, it is required to do confirmation test with the unknown combination for kerf width and kerf taper angle, i.e., A2-B1-C3-D2 and A1-B2-C1-D3.

$$Y_{opt} = m + (m_A - m) + (m_B - m) + (m_C - m) + (m_D - m)$$

$$Y_{kerf\ width} = 1.172 + (1.167 - 1.172) + (1.141 - 1.172) + (1.165 - 1.172) + (1.165 - 1.172)$$

$$Y_{kerf\ width} = 1.122\ mm$$

$$Y_{kerf\ taper\ angle} = 0.064 + (0.040 - 0.064) + (0.030 - 0.064) + (0.049 - 0.064) + (0.042 - 0.064)$$

$$Y_{kerf\ taper\ angle} = 0.031$$

### *D. Anova Of Kerf Width & Taper Angle By AWJM*

TABLE XI
ANOVA OF KERF WIDTH BY AWJM

| Source | DF | Adj SS | Adj MS | %CONTRIBUTION |
|---|---|---|---|---|
| Stand-Off distance | 2 | 0.000349 | 0.000175 | 6.689 |
| Water Jet Pressure | 2 | 0.004434 | 0.002217 | 84.991 |
| AMFR | 2 | 0.000249 | 0.000124 | 4.772 |
| Traverse Rate | 2 | 0.000185 | 0.000092 | 3.546 |
| Error | 0 | 0 | 0 | 0 |
| Total | 8 | 0.005217 | | 100 |

From table XI shows, the ANOVA of kerf width with % contribution where water jet pressure is shown high value, i.e., 84.99 % and the remaining shows the fewer values, i.e., stand-off distance, abrasive mass flow rate and traverse rate. The most influential factor is Water Jet Pressure. The experiment has been performed with the above combination, i.e., A2 – B1 - C3 – D2 and took the three trails with the same combination.

$$\%\ error = (Predicted - Experiment) / (Predicted) * 100$$

$$\%\ error = (1.122 - 1.120) / (1.122) * 100 = 0.178$$

Table XII
ANOVA of Kerf Taper Angle by AWJM

| Source | DF | Adj SS | Adj MS | % Contribution |
|---|---|---|---|---|
| Stand-Off distance | 2 | 0.00342 | 0.00171 | 23.926 |
| Water Jet Pressure | 2 | 0.0067 | 0.00335 | 46.887 |
| AMFR | 2 | 0.00101 | 0.00051 | 7.0919 |
| Traverse Rate | 2 | 0.00316 | 0.00158 | 22.094 |
| Error | 0 | 0 | 0 | 0.000 |
| Total | 8 | 0.0143 | | 100.00 |

From table XII shows, the ANOVA of kerf taper angle with % contribution where water jet pressure is shown high value, i.e., 46.88 % and the remaining shows the fewer values, i.e., stand-off distance, abrasive mass flow rate and traverse rate. The most influential factor is Water Jet Pressure. The experiment has been performed with the above combination, i.e., A1 – B2 – C1 – D3 and took the three trails with the same combination.

$$\% \text{ error} = (\text{Predicted} - \text{Experiment}) / (\text{Predicted}) * 100$$

$$\% \text{ error} = (0.031 - 0.030) / (0.031) * 100 = 3.225$$

## IV. CONCLUSIONS

The present work deals with the abrasive water jet machining of GFRP material. The following results were drawn as follows

*A.* For kerf width the combination is A2 – B1 – C3 – D2, i.e., SOD – 1.5, WJP – 44000, AMFR – 8, TR – 3.
*B.* For kerf taper angle the combination is A1 – B2 – C1 – D3, i.e., SOD – 1, WJP – 46000, AMFR – 4, TR – 4.
*C.* It shows clearly that none of the output responses matches with the L9 orthogonal array. So, confirmation test is done.
*D.* Confirmation test values for kerf width is 1.122 and kerf taper value is 0.031.
*E.* From ANOVA, it is clearly showing that the Water Jet Pressure is playing a significant role in machining operation.

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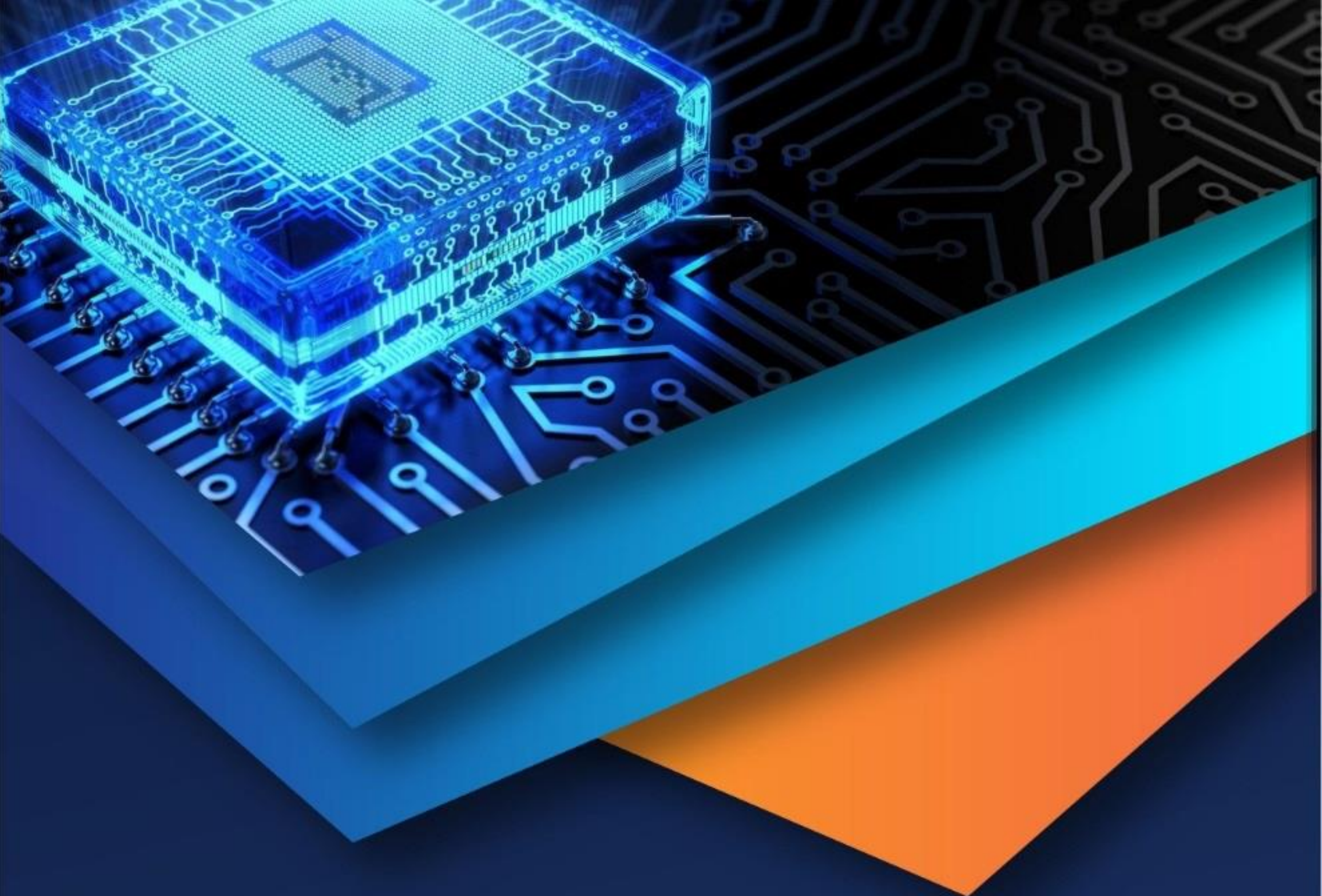


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