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# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 6 **Issue:** IV **Month of publication:** April 2018

**DOI:** http://doi.org/10.22214/ijraset.2018.4150

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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Volume 6 Issue IV, April 2018- Available at www.ijraset.com

# Optimization of Surface Roughness and Hole Diameter Accuracy for Drilling of EN- 31 Based on GRA

Sunil Kumar[1]
[1]Department of Mechanical Engineering, Sant Longowal Institute of Engineering and Technology, Sangrur, Punjab-148106, India

***Abstract: In the present work drilling parameters has been optimized for EN-31 alloy steel using GRA (Grey Relational Analysis). The parameters optimized are spindle speed (SS), feed rate (FR) and point angle (PA) on bases of surface roughness and hole diameter accuracy responses. Drilling is performed with the help of cemented carbide twist drills. On the bases of GRA along with identification, significant contribution of parameters has been carried out by using ANOVA. The optimal values obtained are PA ($118^0$), SS (800 rpm), and FR (0.18 mm/rev). Out of three variables considered point angle has significant effect on responses as compare to other drilling parameters.***
***Keywords: Drilling. EN-31 alloy steel; Orthogonal array; Grey relational analysis; ANOVA; Optimization***

## I. INTRODUCTION

With the concern of quality of drilled products, numbers of the problems arise, such as hole surface roughness (SR), hole diametrical accuracy (HDA), burr height (BH) and tool wears (TW). SR and HDA have most effect on performance of a drilled products. These important characteristics depends on the drilling parameters for a specific combination of material and drill tool. Some of the parameters have been optimized by different researchers for different materials and drilling tool combinations. An experiment and numerical study for cutting forces (CF), TW and SR has been done by Davim et al. [1] for drilling of composite A356/20/SiCp-T6. Kurt et al. [2] and Kilickap [3] made use of Taguchi for optimizing SR and HDA in the dry drilling of Al 2024 and Al 7075 respectively. Genetic algorithm (GA) has also been used for optimization of multi-objective drilling by Gaitonde et al. [4], also Karnik et al. [5] developed an artificial neural network (ANN) model for high speed drilling by considering SS, FR and PA as parameters. Tosun [6] and Rajmohan et al. [7] optimized drill parameters (FR, CS, PA) by using Taguchi based GRA for SR and burr height for composites. Mathematical model has been developed by Pirtini and Lazoglu [8] and Furness et al. [9] for drilling process to estimate of CF and hole quality. Effect of coating on drilled cast Al 356 alloy has been investigated by Kalidas et al. [10] for both dry and wet conditions. Further, Nouari et al. [11] investigated the effect of drill parameters on SR and holes dimensions. The study of many researchers in this direction has led to the present work. In this presented work Taguchi based GRA has been applied for the optimization of drilling parameters (PA, SS and F). The responses consider for optimizing are SR and HAD. The most effective parameter has been identified along with the range and confirmative test has been conducted.

## II. EXPERIMENTAL PROCEDURE

Experimentation has been conducted on the bases of Taguchi design for GRA. The correlation has been done between variables and responses.

### *A. Description of Experimental set up And Measurements*

The material selected for study is EN-31 alloy and chemical composition is given in table 1. The drilling tests are carried out on KMC-11VC CNC VERTICAL MACHINE CENTRE, with FANUC OiMD-PB Controller, made by KENT Industry. The material has been prepared by cutting the plates of size 200×75×16 mm and facing has been performed on CNC machine with face milling cutter to obtain flat surface and reduce the thickness up to 14 mm. This plate is then mounted rigidly on the table and holes have been drilled in the plate. The surface roughness (SR) and hole diameter accuracy (HAD) are responses considered for study. Measurement of SR has been taken in surface roughness tester (Mitutoyo Surf test 4) and have been repeated three times. The diameters of holes created are measured on co-ordinate measuring machine (CMM) having accuracy of 0.1 µm

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Table 1: Chemical composition of EN 31 alloy steel

| SYMBOL | CHEMICAL COMPOSITION (Wt %) | | | | | |
|---|---|---|---|---|---|---|
| | C | Cr | Si | Mn | P | S |
| EN 31 | 0.95-1.05 | 1.30-1.65 | 0.15-0.35 | 0.25-0.45 | <0.027 | <0.025 |

*B. Cutting Tool*

In this study, drilling operations were performed using three cemented Carbide twist drill of 10.08 mm diameter with two flutes and three different point angles ($118^0$, $127^0$, $135^0$) shown in Figure 1.


Figure 1: Drill bits having different point angles

*C. Plan of Investigation*

Experiments have been performed as per L27 OA by considering the levels of parameters given in Table 2. Table 3 shows the results obtained for the responses.

Table 2: Factors and levels of independent variables

| Factors | Unit | Levels | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Point angle (PA) | Degree | 118 | 127 | 135 |
| Spindle speed (SS) | Rpm | 800 | 1200 | 1600 |
| Feed (F) | mm/rev. | 0.10 | 0.14 | 0.18 |

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Table 3: Experimental results for Surface roughness and diametrical error

| Experiment no. | Point angle | Spindle Speed | Feed | Surface roughness value/ µm | Diametrical error/ µm |
|---|---|---|---|---|---|
| 1 | 135 | 1600 | 0.1 | 1.12 | 20.3 |
| 2 | 135 | 1600 | 0.14 | 2.67 | 9.5 |
| 3 | 135 | 1600 | 0.18 | 2.74 | 8.5 |
| 4 | 135 | 1200 | 0.1 | 2.06 | 10.6 |
| 5 | 135 | 1200 | 0.14 | 2.39 | 13.4 |
| 6 | 135 | 1200 | 0.18 | 2.42 | 8.9 |
| 7 | 135 | 800 | 0.1 | 3.37 | 21.2 |
| 8 | 135 | 800 | 0.14 | 3.7 | 7.5 |
| 9 | 135 | 800 | 0.18 | 2.2 | 4 |
| 10 | 118 | 1600 | 0.1 | 3.09 | 15.3 |
| 11 | 118 | 1600 | 0.14 | 2.67 | 8.2 |
| 12 | 118 | 1600 | 0.18 | 3.33 | 10 |
| 13 | 118 | 1200 | 0.1 | 3.11 | 14.2 |
| 14 | 118 | 1200 | 0.14 | 2.91 | 11.3 |
| 15 | 118 | 1200 | 0.18 | 3.03 | 24.1 |
| 16 | 118 | 800 | 0.1 | 3.94 | 19.1 |
| 17 | 118 | 800 | 0.14 | 4.55 | 25.5 |
| 18 | 118 | 800 | 0.18 | 5.54 | 20.5 |
| 19 | 127 | 1600 | 0.1 | 1.17 | -3.8 |
| 20 | 127 | 1600 | 0.14 | 1.91 | 5.5 |
| 21 | 127 | 1600 | 0.18 | 2.69 | 8 |
| 22 | 127 | 1200 | 0.1 | 2.36 | -6.2 |
| 23 | 127 | 1200 | 0.14 | 2.43 | 4.5 |
| 24 | 127 | 1200 | 0.18 | 2.87 | 10.6 |
| 25 | 127 | 800 | 0.1 | 4.23 | 7.5 |
| 26 | 127 | 800 | 0.14 | 2.67 | 9.2 |
| 27 | 127 | 800 | 0.18 | 4.45 | 15.5 |

## III. OPTIMIZATION STEPS USING GREY RELATIONAL ANALYSIS

The smaller-the-better methodology for GRA has been implemented for the considered responses of drilling process. Accordingly, S/N ratios and respective normalized values has been calculated and further deviation sequences have been determined to calculate the grey relational co-efficient. Table 4 represents the Grey relational grade with rank and Grey relational co-efficient for each experiment.

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Table 4: Grey relational co-efficient and grade values

| Experiment no. | Grey relational coefficient: Surface Roughness | Grey relational coefficient: Diametrical error | Grey Relational Grade | Rank |
|---|---|---|---|---|
| 1 | 0.333333333 | 0.806713883 | 0.570023608 | 10 |
| 2 | 0.522362017 | 0.490834495 | 0.506598256 | 16 |
| 3 | 0.53133796 | 0.464209436 | 0.497773698 | 18 |
| 4 | 0.446727379 | 0.520226194 | 0.483476786 | 21 |
| 5 | 0.487134312 | 0.596665897 | 0.541900104 | 14 |
| 6 | 0.49086168 | 0.474859017 | 0.482860349 | 22 |
| 7 | 0.615982158 | 0.837505784 | 0.726743971 | 5 |
| 8 | 0.663709713 | 0.437503453 | 0.550606583 | 12 |
| 9 | 0.463749494 | 0.339430483 | 0.401589989 | 26 |
| 10 | 0.577427575 | 0.650756761 | 0.614092168 | 7 |
| 11 | 0.522362017 | 0.456214749 | 0.489288383 | 19 |
| 12 | 0.61037212 | 0.504169995 | 0.557271057 | 11 |
| 13 | 0.580128261 | 0.619172615 | 0.599650438 | 8 |
| 14 | 0.553458735 | 0.53906718 | 0.546262958 | 13 |
| 15 | 0.569371571 | 0.943998498 | 0.756685034 | 3 |
| 16 | 0.700208551 | 0.767099124 | 0.733653838 | 4 |
| 17 | 0.801111585 | 1 | 0.900555793 | 2 |
| 18 | 0.997751445 | 0.813473199 | 0.905612322 | 1 |
| 19 | 0.339509904 | 0.333333333 | 0.336421619 | 27 |
| 20 | 0.428636809 | 0.382915175 | 0.405775992 | 25 |
| 21 | 0.524919094 | 0.450878543 | 0.487898819 | 20 |
| 22 | 0.483417104 | 0.402304153 | 0.442860629 | 23 |
| 23 | 0.492106452 | 0.354312317 | 0.423209385 | 24 |
| 24 | 0.548210846 | 0.520226194 | 0.53421852 | 15 |
| 25 | 0.746605531 | 0.437503453 | 0.592054492 | 9 |
| 26 | 0.522362017 | 0.482844872 | 0.502603445 | 17 |
| 27 | 0.783676744 | 0.656586683 | 0.720131714 | 6 |

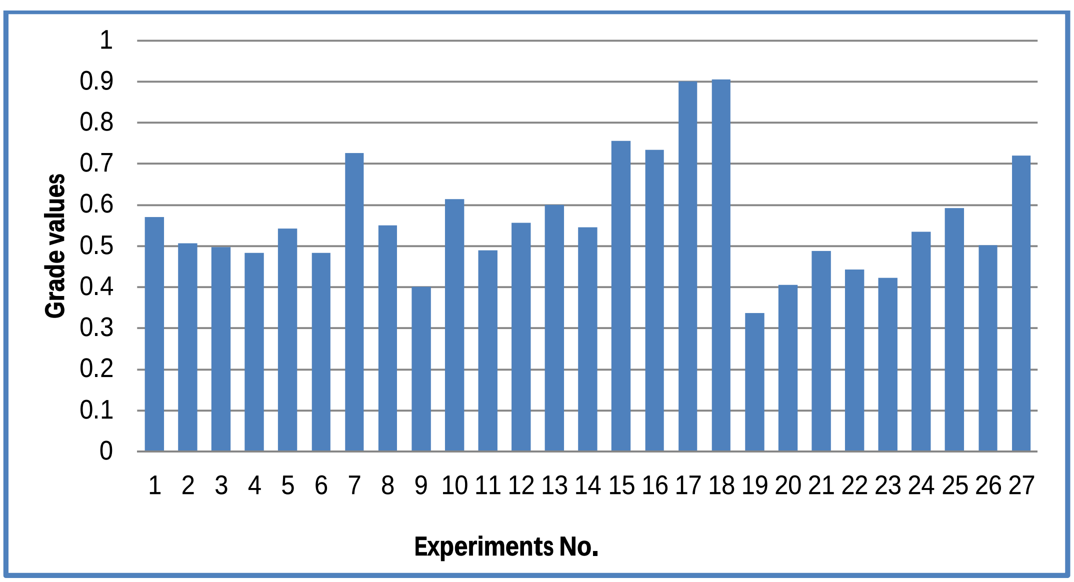


Figure 2: Grey relation grades for the SR and HDA

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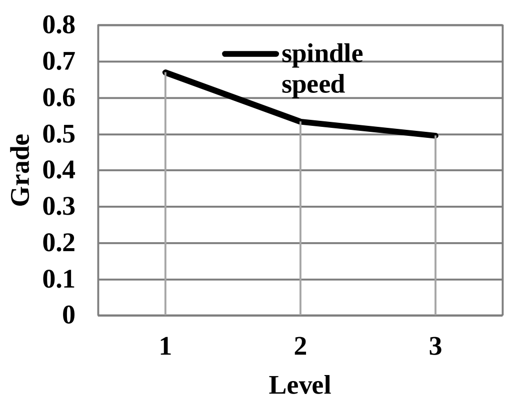
From Table 4 and Figure 2, it is observed that experiment 18 has best results for multi performance characteristics. Further, mean of grey relational grade for all levels has been summarized as shown in Table 5. It also shows the response table for average grey relational grade by factor level. Bold numerals represent optimized value of factors with respect to their corresponding levels. So, the optimized level of parameters for good SR and HDA is (PA1=$118^0$, SS1=800 rpm, and F3=0.18 mm/rev) as shown in Table 5.

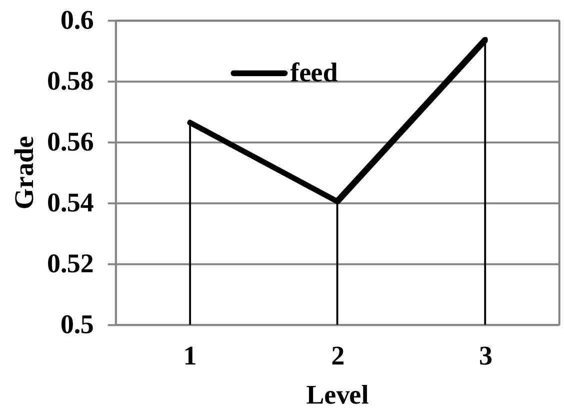
Table 5: Response table for grey relational grade; Main effects on Grey grade

| | Level | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | max.-min (Δ) | Rank |
| Point angle | 0.678119 | 0.493908 | 0.529064 | 0.18421082 | 1 |
| Spindle speed | 0.670395 | 0.534569 | 0.496127 | 0.174267616 | 2 |
| Feed | 0.566553 | 0.540756 | 0.593782 | 0.053026734 | 3 |

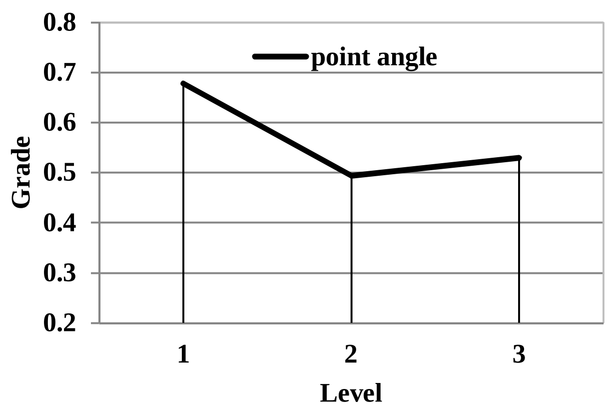
Further, Table 5, shows difference of maximum and minimum grey relational grade i.e. 0.18 (point angle), 0.17 (spindle speed), and 0.05 (feed). It is observed that point angle is most effective and spindle speed and feed follows it.




(a) Spindle speed Vs Grey grade




(b). Feed rate Vs Grey grade




(c). Point angle Vs Grey grade

Figure 3 (a, b, c): Effect of drilling parameters on the multi-performance characteristics

ANOVA has been formulated as per the grey grade values obtained in previous steps for finding the substantial factors. From Table 6 it is clear that PA (32.69%) effects more on drilling of EN 31 alloy steel then by SS (28.65%) and FR (2.40%). The interaction between PA x SS and PA×FR had lesser effect on multiple performance characteristics (minimum surface roughness and minimum hole diametrical error) i.e. 4.2% and 5.4%. Further, interaction of spindle speed and feed rate (S×F) has no effect on multiple performance characteristics.

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Table 6: ANOVA for multiple performance characteristics; Result of ANOVA on Grey Relational Grade

| Factors | DOF | Sum of square | Mean Square | F Ratio | Percentage contribution |
|---|---|---|---|---|---|
| Point angle(PA) | 2 | 0.172161129 | 0.086080565 | 5.004487596 | 0.326927493 |
| Spindle speed(S) | 2 | 0.150886593 | 0.075443297 | 4.386066058 | 0.286527952 |
| Feed(F) | 2 | 0.012656331 | 0.006328165 | 0.367902155 | 0.024033895 |
| PA×S | 4 | 0.022019352 | 0.005504838 | 0.320036162 | 0.041813919 |
| S×F | 4 | 0.002661959 | 0.00066549 | 0.038689746 | 0.00505496 |
| PA×F | 4 | 0.028612635 | 0.007153159 | 0.415864996 | 0.054334314 |
| Error | 8 | 0.1376054 | 0.017200675 | | 0.261307466 |
| Total | 26 | 0.526603399 | | | 1 |

The predicted value of GRG at the optimal level as per standard calculation [12] is obtained as **0.8082.** The 95% confidence interval for obtained for present study is between 0.654 and 0.962. In last confirmation test has been conducted by setting drilling parameters and two trials have been conducted. The values corresponding to predicted and confirmation test of surface roughness, hole diametrical error and grey relational grade have been given in Table 7.

Table 7: Optimal values of machining and response parameters

| | Optimal drilling parameters | | Final gain | % improvement | Confidence Interval |
|---|---|---|---|---|---|
| | Prediction | Confirmation Test | | | Range |
| Setting level | PA1, SS1, F3 | PA1, SS1, F3 | | | |
| Grey relational grade | 0.8082 | 0.8321 | 0.0239 | 2.9 % | $0.654 \leq \mu \leq 0.962$ |

The value of grey relational grade has increased from 0.8080 to 0.8321, i.e. 3% of improved grade has been archived. Thus, confirmation tests expose that GRA for optimization is efficient for drilling parameters of EN31.

## IV. CONCLUSIONS

Drilling experiments have been performed on a CNC vertical machining centre using carbide twist drill on EN 31 alloy steel as work material. $L_{27}$orthogonal array was used for different combinations of drilling experiments. The surface roughness and hole diametrical error have been selected as responses for different combinations of drilling parameters. Taguchi based Grey relational analysis optimization technique has been used for multi response optimization. The recommended level of parameters for better SR and HDA simultaneously are PA1 ($118^0$), SS1 (800 rpm), and F3 (0.18 mm/rev). Out of three parameters considered, PA has most effect on responses as compare to other considered drilling parameters. Order of importance of factor is A (point angle), B (spindle speed), C (feed rate). Main contribution percentages for multiple performance characteristics in drilling EN31 steel alloy are 32.7% (PA), 28.6% (SS) and 2.4% (F). Predicted weighted GRG has increased from 0.8080 to 0.8321, which confirms the enhancement in the performance of drilling EN31 with optimal values of process parameters.

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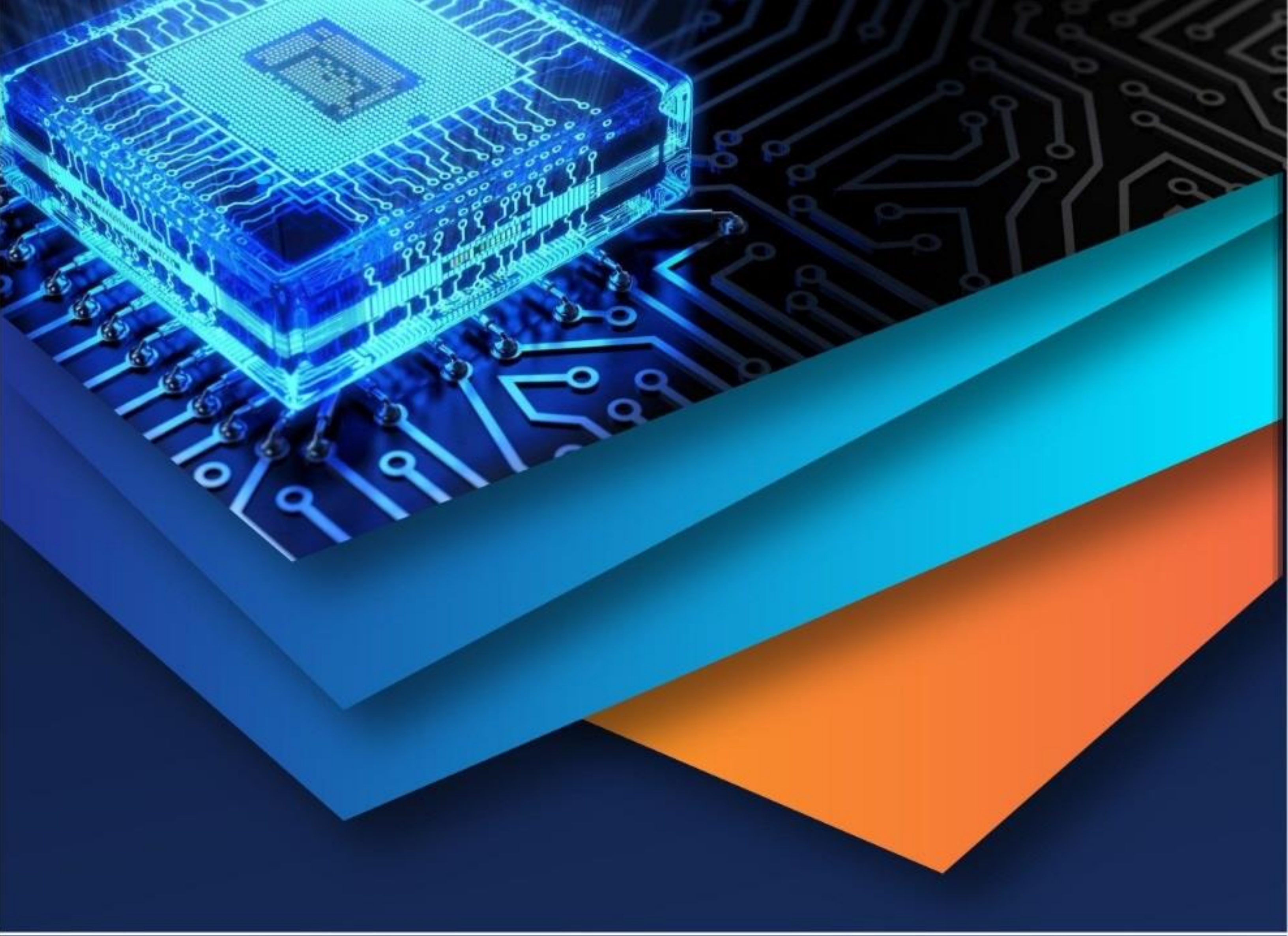


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