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Optimization of MIG Welding Process Parameters on AISI 304 Stainless Steel Using Taguchi Method and Fuzzy Logic

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***Abstract:** The present paper tells about how to predict and optimize the Metal Inert Gas (MIG) welding of AISI 304 Stainless Steel (AISI 304 SS) work pieces, which are most widely in used in many industrial applications. The powerful tool known as Design of Experiments (DOE) was used to optimize the welding process parameters for effective welding joint of the work pieces. The following welding voltage, welding current and welding speed were considered as input parameters and similarly tensile strength, percentage of elongation, and hardness were considered as performance characteristics for DOE application. The values after experimental measurements, compared with corresponding predicted results of tensile strength, percentage of elongation, and hardness. Moreover, the Taguchi Method was also used for DOE and considered L_{27} orthogonal array matrix and Signal-to-Noise Ratio, the tensile strength, percentage of elongation, and hardness of the predicted values have been creditably acquired via Fuzzy representation.*

***Keywords**: AISI 304 SS, MIG welding, DOE, Tensile Strength, Percentage of elongation, Hardness, Fuzzy logic*

I. INTRODUCTION

Gas metal arc welding (GMAW), sometimes referred to by one of its subtypes metal inert gas (MIG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metals, which heats the work piece metals, causing them to melt and join. Originally developed for welding of aluminum and other non-ferrous materials in the 1940s, it was soon applied to steels because it provides faster welding time compared to other welding process.

Aghakhani et al. [1] have carried out research on optimization of gas metal arc welding process parameters to enhance quality and productivity of weld ment. They have chosen ST-37 steel plate as work piece, 80% argon combination with 20% CO_2 as shield gas depends on type of base metal being welded. The experiment was designed by Taguchi with L_{27} orthogonal array and it was carried out by Analysis of Variance (ANOVA) by considering weld dilution as output characteristic and wire feed rate, welding voltage, nozzle to plate distance, welding speed, and gas flow rate were as the input parameters. They reported that, the wire feed rate has no much significant effect on the weld dilution while gas flow has no effect at all on it. In another research made by Ajithooda *et al*. [2], AISI 1040 medium carbon steel was used for welding, output characteristic tensile strength was predicted with response surface model. The welding voltage, current, wires speed and gas flow rate were kept as input parameters. Tensile strengths in transverse and in longitudinal were almost same with input parameters explored by face centered design matrix.

Optimization of process parameters in MIG welding of dissimilar metals such as AISI SS with grade 304 and 316 have been studied, Artificial Neural Network (ANN) and Genitic Algorithm (GA) were used to predict tensile strength and the ANN was successfully integrated as other regression model by Amit kumar *et al.* [3]. Arya *et al.* [4] reported that, the optimization of tensile strength and higher penetration of filler metal was prosperously analyzed by Taguchi method followed by grey relational analysis, after completion of MIG welding with its process parameters. The weld ability of MIG welded EN-3A mild steel specimens have been studied to see the influence of process parameters on depth of penetration of welding joint. They were analyzed this issue with help of surface plots, reported by Das *et al.* [5]. Parametric optimization of MIG welded 316L Austenitic stainless steel was studied by Taguchi method. The optimal parameters were identified for maximum tensile strength and percent of elongation in case when Butt welded joints have been made by several levels of current, gas flow rate, and nozzle to plate distance by Ghosh et al. [6].

Kapil et al. [7] carried out research to identify the factors that have most significant effect on welding of AISI 316 Austenitic stain less steel and its welding quality and productivity. Moreover, other mechanical properties such as tensile strength and hardness were assessed with DOE and optimized process parameters using Taguchi technique. Similarly, two different materials like AISI 304 steel and low carbon steel were used for MIG welding with CO_2 as shielding gas. They kept tensile strength and hardness as performance characteristics and current, voltage, and flow rate of welding as input parameters. The experiment was designed with

L_9 orthogonal array which is for very small values by Pawnkumar *et al.* [8]. Pradeep *et al.* [9] investigated on effect of process parameters on tensile strength of SS 3Cr12 specimen after MIG welding. Reported that, the tensile strength was increasing by increasing of welding speed and flow rate, but it was remains increasing with decreasing of voltage and wire feed rate. It was revealed through central composite matrix using Minitab software.

Irfan et al. [10] found that the penetration depth was increasing with welding speed, current and voltage in case of MIG welding of galvanized steel. Experimental investigation for welding aspect of AISI 304 and 316 grades was done for die penetrate testing by using Taguchi technique for the process of TIG and MIG welding by Suresh et al. [11]. Vinita et al. [12] preferred aluminum alloys of 6061 and 5082 grades for MIG welding, with aluminum 4043 wire as filler material of diameter 1.2 mm and an orthogonal array of L_9 was used to conduct to optimize the process parameters via Taguchi through statistical software minitab-17. Moreover, similar methods applied to study of welding parameters on tensile strength of AM-40 aluminum alloy as workpiece in MIG welding. They were identified for maximum tensile strength and reported that the welding current and voltage were shown major influence on tensile strength of weld joint by Viveksaxena *et al.* [13].

In the present work, AISI 304 SS work pieces after MIG welding carried out were studied for tensile strength, percent of elongation, and hardness (performance characteristics) with influence of process parameters. Taguchi Method was used for DOE and considered L_{27} orthogonal array matrix and Signal-to-Noise Ratio to optimize process parameters.

II. EXPERIMENTATION

AISI 304 Stainless Steel of 3.5 mm thickness sheet is used in this investigation. Chemical composition of AISI 304 Stainless Steel is listed in Table 1. MIG welding is done, the arc and weld pool is shielded from the atmospheric contamination by an externally supplied shield gas (CO_2) and welding specifications listed in Table 2, MIG welding process parameters are listed in Table 3.

Table 1. Chemical composition of AISI 304 SS

C	Mn	P	S	Si	Cr	Ni	Fe	*Component*
0.08	2	0.045	0.03	1.0	18-20	8-10.5	66.345-74	*Weight. %*

Table 2. Specifications of MIG Welding Machine

Item	*Description*
Model	SB-10
Rated welding current	350 A/500 A
Feeding voltage of motor	DC 24 V
Rated drawing force	100 N
Wire feeding speed	1.5-15 m/min
Cable length	3 m
Wire type	Soft steel solid core, flux cored

Table 3. MIG welding process parameters

Parameters	Units	Code	Level-1	Level-2	Level-3
Welding Voltage	volts	A	26	25	24
Welding Current	amps	B	140	130	120
Welding Speed	mm/min	C	110	100	90

The MIG welding setup and welded component is shown in Figure 1. Tensile specimens were prepared with help of Electric Discharge Machine as per ASTM standards shown in Figure 2. Hardness of weld zone recorded using Vickers hardness (HV), 200gr load, and dwelling time of 10 sec. were measured by using, MVD-402TS-Level-2 micro hardness measuring system HNDS Kelly Instruments, china Expert.

Fig. 1. (a). MIG welding setup, (b). Welded component.

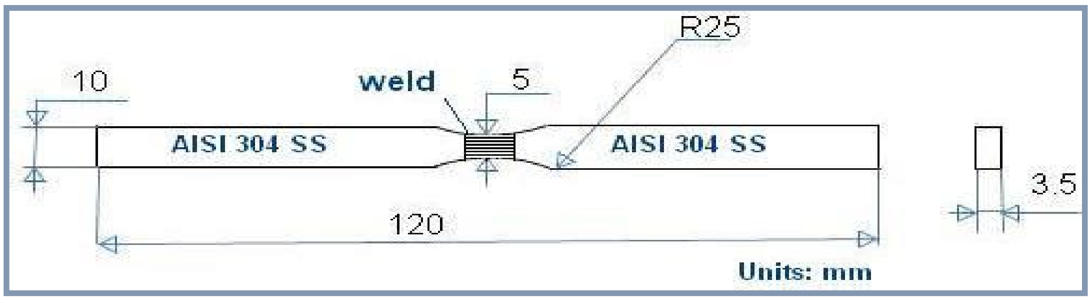

Fig. 2. Tensile test specimen dimensions

Tensile test was carried out by using SM 1000-S3 UTM TQ228687-001, Tec Quipment Ltd., UK.

III. RESULTS AND DISCUSSIONS

Experiments were conducted to join the AISI 304 stainless steel by MIG welding technique, total experiments were conducted based on the Taguchi method. Moreover, the experimental results obtained by considering L_{27} orthogonal array matrix. The response averages of Tensile strength, Percentage of Elongation and Hardness were exhibited via S/N ratios.

The results are blocked in terms graphs and have been shown in Figure 3, 4, and 5. The X-axis represents Welding voltage for (a), Welding current for (b) and Welding speed for (c), it is common for all figures such as 3, 4, and 5. Only Y-axis is varying for figure 3, 4 and 5 as referred as Tensile strength for Fig. 3, Percent of elongation for Fig. 4, and Hardness for Fig. 5 respectively.

A. S/N Ratio Average Values for Tensile Strength

In Fig. 3, S/N ratio of tensile strength clears that, the welding voltage is the more influential parameter followed by welding current and welding speed on MIG welding of AISI 304 SS.

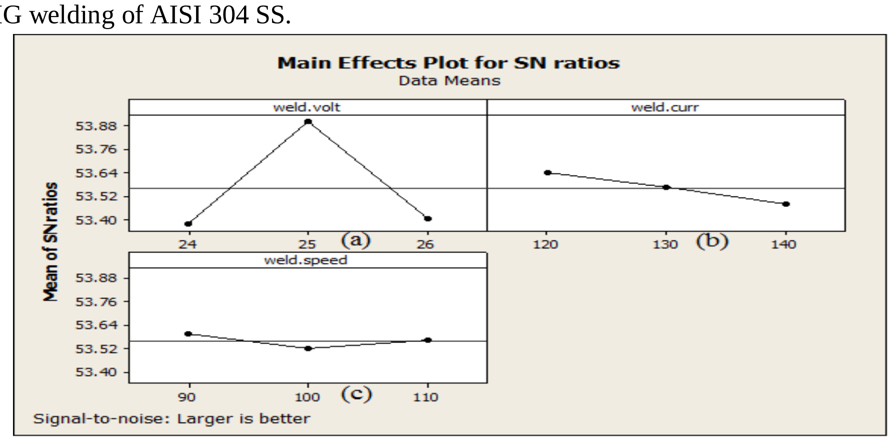

Fig. 3. Variation of mean of S/N ratios Vs tensile strength

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Table 4. Numerical representation of Responses for S/N ratio average

Parameter / S/N Ratios	Welding Voltage	Welding Current	Welding Speed
S/N Ratio Level 1	53.37	53.64	53.59
S/N Ratio Level 2	53.90	53.56	53.52
S/N Ratio Level 3	53.40	53.48	53.56
Delta = S/N (Max)-S/N (Min)	0.53	0.16	0.07
Rank	1	2	3

B. S/N Ratio Average Values for Percentage of Elongation

In Fig. 4, S/N ratio of tensile strength clears that, the Welding speed is more influencing parameter followed by Welding voltage and Welding current on MIG welding of AISI 304 SS.

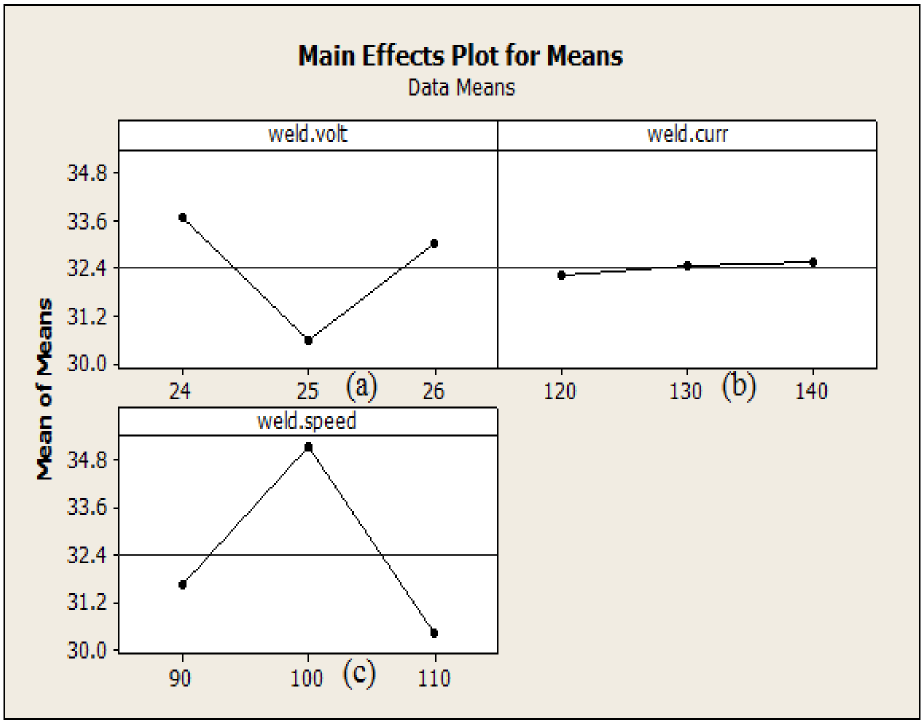

Fig. 4. Variation of mean of S/N ratio Vs Percentage elongation

Table 5. Numerical representation of Response for mean of percentage of Elongation

Parameter / S/N Ratios	Welding Voltage	Welding Current	Welding Speed
Mean Level 1	33.67	32.23	31.67
Mean Level 2	30.56	32.44	35.11
Mean Level 3	33.00	32.56	30.44
Delta = S/N (Max)-S/N (Min)	3.11	0.33	4.67
Rank	2	3	1

C. N Ratio Average Values for Hardness

In Fig. 5, S/N ratio of tensile strength clears that, the Welding speed is more influencing parameter followed by Welding voltage is the more influencing parameter followed by Welding speed and Welding current on MIG welding of AISI 304 SS.

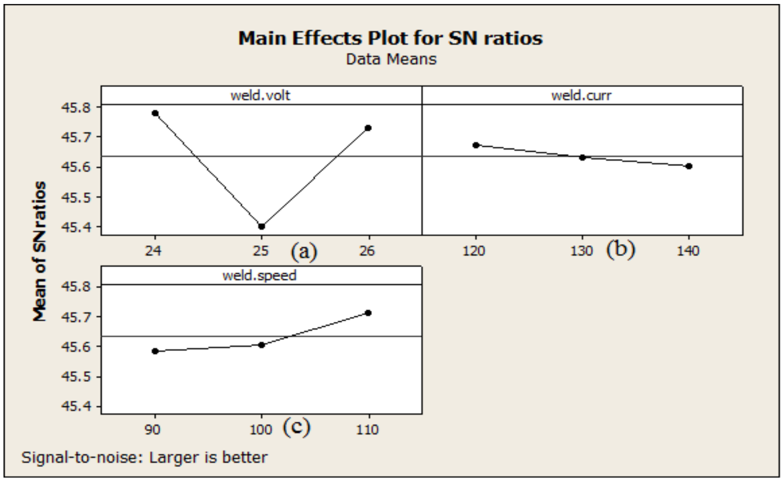

Fig. 5. Response for mean of Hardness

Table 6. Numerical representation of Response for S/N ratio average

Parameter / S/N Ratios	Welding Voltage	Welding Current	Welding Speed
S/N Ratio Level 1	45.78	45.67	45.58
S/N Ratio Level 2	45.40	45.63	45.60
S/N Ratio Level 3	45.73	45.60	45.71
Delta = S/N (Max)-S/N (Min)	0.38	0.07	0.13
Rank	1	3	2

D. Experimental (Exp.) and Predicted Values from Fuzzy Model

Though the experiments conducted for 27 runs, but considered only 9 with 3 runs intervals for simplicity. From the figure 6, it can be seen that the graph for experimental and predicted values have been increased up to the end of Exp. 5 then the same trend is observed from experiment No.6. From the Exp. 9, again it was raised and continued for 18 run and then again there is a sudden falling at Exp. 21 until Exp. 27 but not like Exp.6 can be observed.

Further, it can be seen that the graph for two results follow the same path. Thus trend shows that the experimental and modeling results are in correlation and therefore it can be said the experiments conducted are found to be correct.

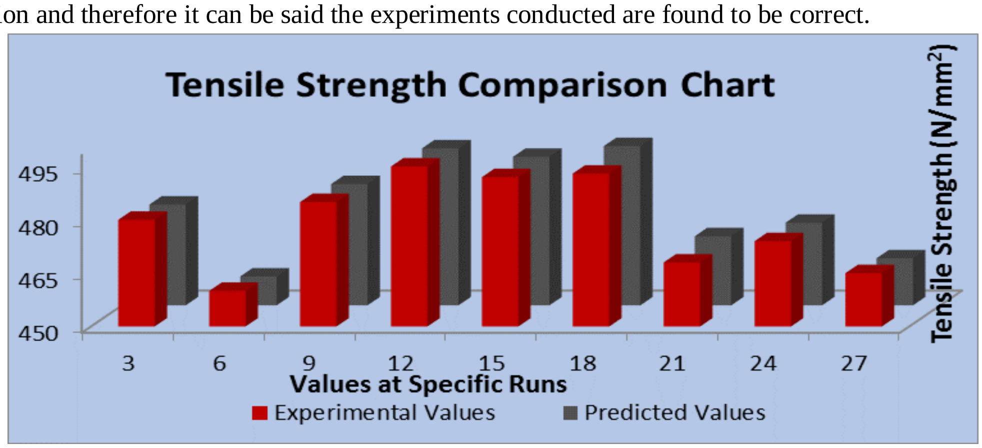

Fig. 6. Comparison of Tensile Strength

From the figure 7, it can be seen that the graph for experimental and predicted values show that the increasing trend at the beginning and then drastically decreased at Exp. 15.then the same trend is observed from experiment No.15 and till Exp. 27.Further, it can be seen that the graph for two results follow the space path. Thus trend shows that the experimental and modelling results are in correlation and therefore it can be said the experiments conducted are found to be correct.

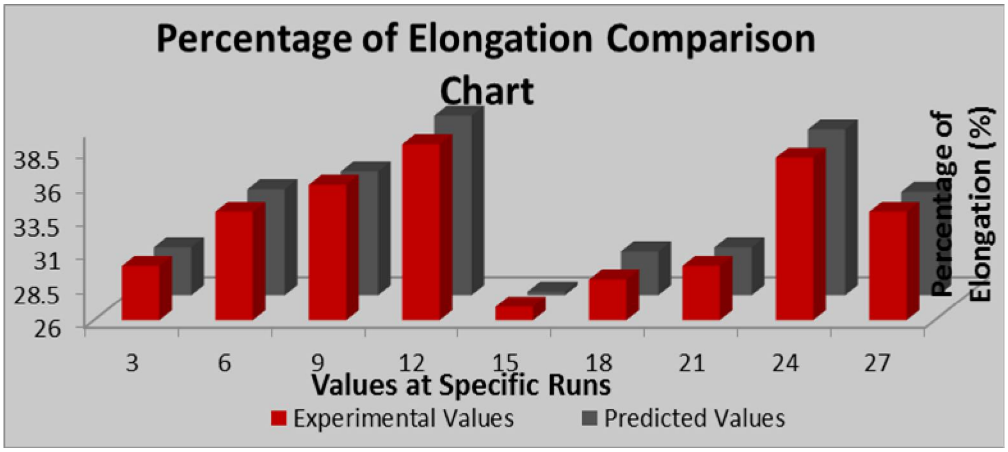

Fig. 7. Comparison of Percentage of Elongation

From the figure 8, it can be seen that the graph for experimental and predicted values show that the increasing trend at the beginning and then decreasing Exp. 9. Then continued until beginning of Exp. 18. Further, it can be seen that the two results follow the space path. The trend is also exhibited abnormal pattern, observed from Exp. 3 till experiment No.27. But the difference is not much considerable. Thus trend shows that the experimental and modelling results are in correlation and therefore it can be said the experiments conducted are found to be correct.

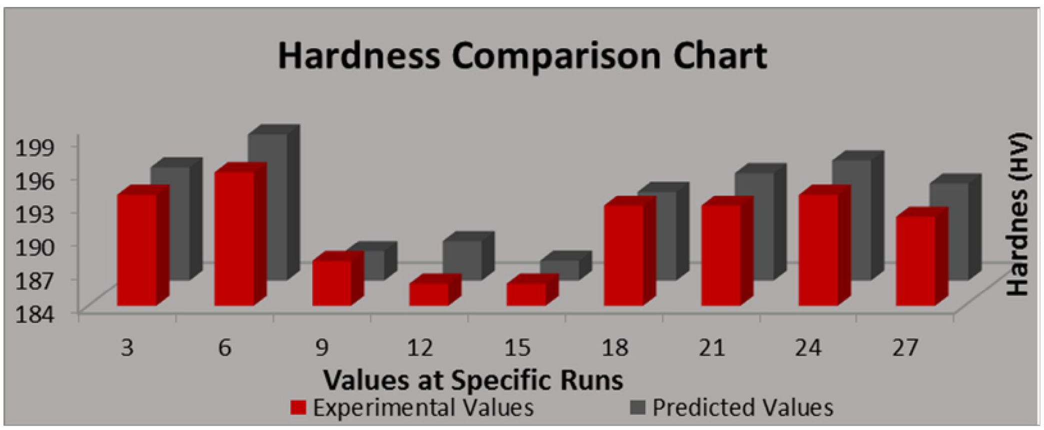

Fig. 8. Comparison of Hardness

IV. CONCLUSIONS

Optimization of MIG welding process parameters on 304 AISI Stainless Steel using Taguchi method and Fuzzy logic has been carried out for tensile strength, percent of elongation, and hardness with influence of process parameters.

The following conclusions are drawn from results of performance characteristics:

The welding voltage has exerted the greatest effect on Tensile strength followed by welding current and welding speed.

The welding speed has exerted the greatest effect on Percentage of elongation followed by welding current and welding voltage.

The welding voltage has exerted the greatest effect on Hardness followed by welding current and welding speed. BThe predicted value agree fairly well with the experimental value for Tensile strength, Percentage of elongation and Hardness due to the Fuzzy representation of Tensile strength, Percentage of elongation and Hardness of the predicted values can be obtained well.

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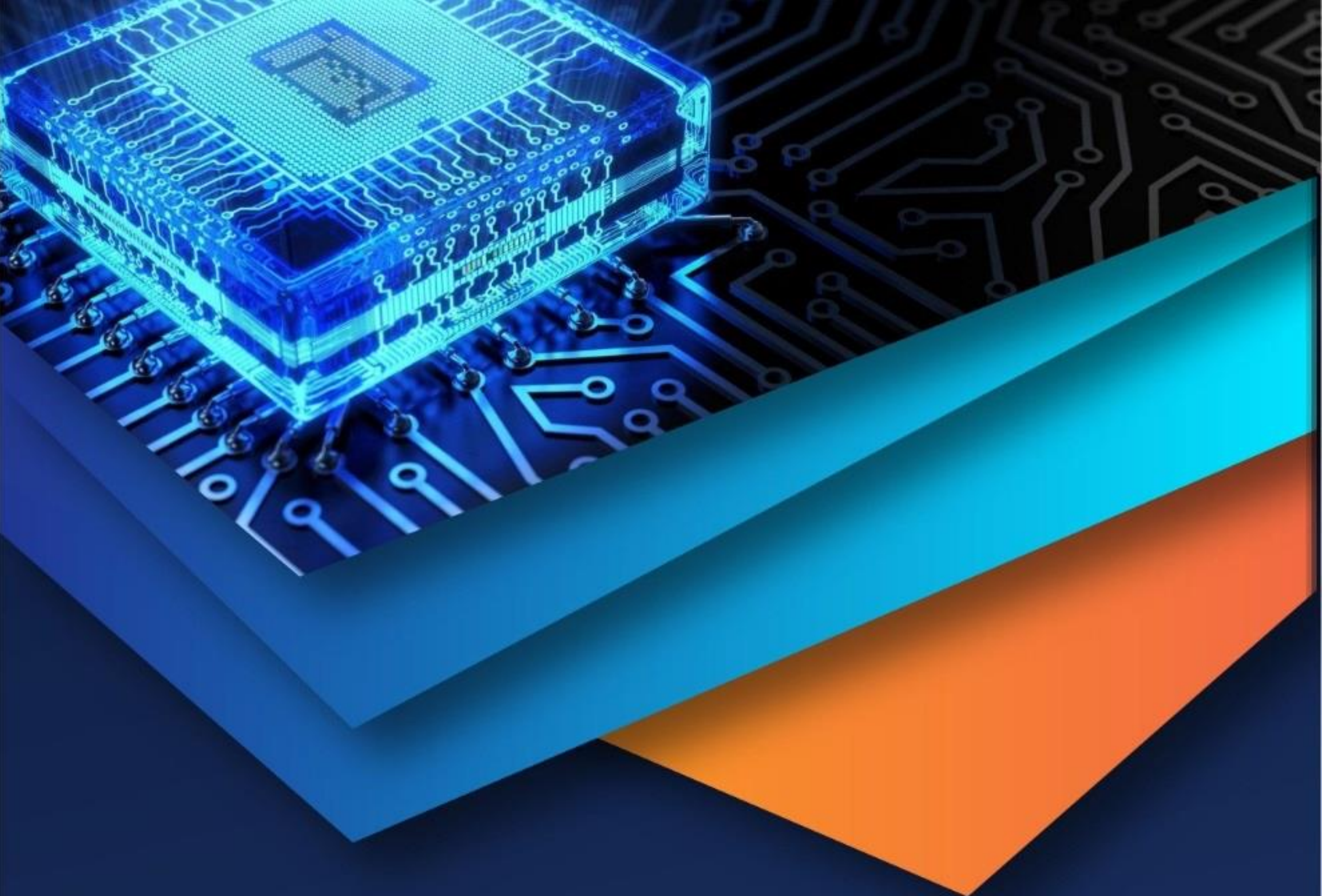

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