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Optimization of Process Parameters by using TIG Welding on Aluminium Alloy 8011

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Abstract: Aluminium alloys are applied in various industries because of their high strength to weight ratio. Aluminium Alloy 8011 is also lightweight, corrosion resistant and has high wettability. It is being currently used in various applications such as Storage tankers, Military equipment, high pressure containers, Air conditioning foil etc. The aim of this research is to study the effect of TIG welding using butt weld joint on microstructural and mechanical properties of Aluminium Alloy 8011. Here, we have designed an experiment using Bevel angle and welding current as variables in process parameters to study the tensile strength and hardness of weld joint of Aluminium alloy 8011. Gas flow rate, Electrode work piece distance, welding speed and welding voltage were kept constant. Then properties of samples were tested using Dye Test, Hardness test, Grain size analysis and Tensile Test. The results thus produced were then analyzed using Grey Relational analysis using Taguchi array.
Keywords: TIG welding, Aluminium Alloy 8011, Tensile strength, Grey Relational analysis, Taguchi array

I. INTRODUCTION

Welding is a process of joining two metals or thermoplastics together by the use of heat or pressure or both. They are fused together and then cooled so that they can become one. Welding is usually done on metals and thermoplastics but can also be done on wood. In this the completed welded joint is known as weldment.

A. TIG Welding

TIG Welding is an arc welding process in which non-consumable electrode made of tungsten is used. A filler may or may not be used. An inert gas like argon, helium or a mixture of inert gases can be used to provide a shield to the weld area. The inert gas protects the weld area from reacting with atmospheric gases such as oxygen and nitrogen and from the atmospheric contamination. The power is supplied through a power source, through a hand piece or welding torch and is delivered to tungsten electrode which is fitted into the hand piece. By using a constant current and constant voltage power source an arc is produced between the metals to be welded and the tungsten electrode. The energy from the power supply conduct through the arc through a column of ionized gas and metal vapors. This electric arc produces very high temperature which is generally above the melting points of the metals to be welded. Now the heat produce due to this large amount of temperature is used to weld different materials. One has a choice to add a filler material to the molten weld pool in order to create the weld joint. Weld area is protected by the inert gas.

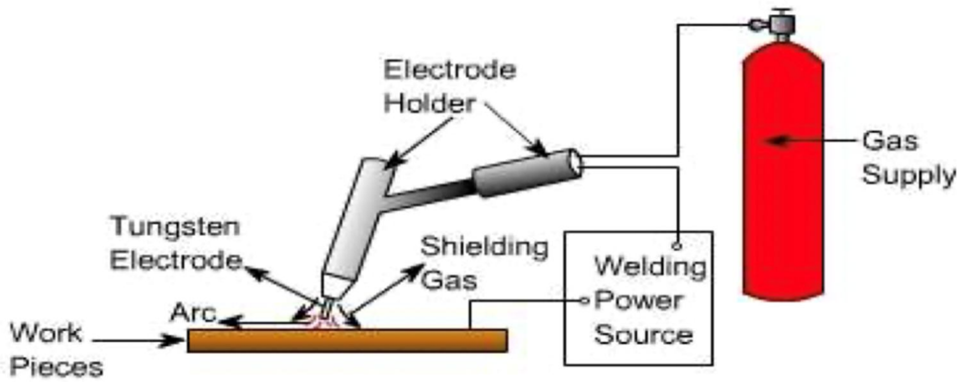

Fig 1 TIG welding machine

B. Welding Joint

Welds are made in different geometrical configurations. As per American welding society there are five types of weld joints: - Butt Joint, Lap Joint, Corner Joint, Edge joint and T Joint. Butt joints are preferred over other joints.

1) *Butt Joint:* In this type of welding joint, joint is formed between the ends or edges of two parts making an angle of 135-180 degrees to one another within the region of joint. Butt welds are utilized for their simplistic design to feed through automated welding machines efficiently.

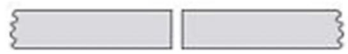

Fig 2 Butt joint

C. Grey Relational Analysis (GRA) Using Taguchi Array In Minitab 20 Software

TAGUCHI Based GRA Model is very popular in Engineering. It has been used to solve a wide variety of problems.

Taguchi array helps in limiting the number of experiments and Grey Relational analysis is especially helpful in situations with uncertain and incomplete information. This is particularly useful in our present experiment in which there are a wide no. of factors that can be varied and relationship between various factors is also not known.

GRA was developed in 1982 by Deng Ju-Long. Grey system works like a black box concept where the known and unknown factors are put together to get optimized responses. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes, which contain Dispersed knowledge (partial information), are described as being grey, hazy or fuzzy. GRA uses normalization of data. Tensile Strength, Hardness and Percentage elongation of TIG weld joint are extremely important quality factors. All these characteristics are of 'larger-the-better' type and their maximum values are desirable.

II. OBJECTIVE

In this thesis Aluminium Alloy 8011, will be welded using Automated TIG welding process. Butt weld joint will be used to make different samples of AA 8011 using **Bevel angles**-40^0, 45^0 and 60^0 and **current** of 125A, 160A and 190A. Effect of welding parameters on tensile strength, hardness and % Elongation will be analyzed.

III.EXPERIMENT PROCEDURE

A. Material

Aluminium alloy 8011 is used to prepare different plates of samples. Chemical composition of the material is given below in the table.

TABLE 1 Chemical composition of the Material

Component	Content (%)
Aluminum (Al)	97.5～99.1
Iron (Fe)	0.60～1.0
Silicon (Si)	0.50～0.90
Copper (Cu)	0～0.1
Manganese (Mn)	0～0.1
Magnesium (Mg)	0～0.1
Zinc (Zn)	0～0.1
Chromium (Cr)	0～0.1
Titanium(Ti)	0～0.05
Residuals	0～0.05

B. Preparation of Weld Joint

TIG welding with AC current is used for this experiment as in the welding area it can concentrate the heat generated during the process. Now, selection of tungsten electrode is done. The type and size of electrode is selected. For aluminum, pure tungsten electrode is suitable and is mostly and typically used with ball-end preparation on alternating current. The electrode diameter will be around 4-6 mm and ball end diameter is 1.5 times of electrode diameter.

Different samples of V groove butt welded joints are prepared using different welding parameters. Total 9 samples of configuration 100mm*37mm*3mm with different bevel angles (40,45 and 60 degrees) have been prepared. For shielding gas pure argon is used. Filler metal used in this experiment Aluminium alloy Grade 31000 H2 as per ISI standard. Filler material is added so that strong joint can be produced with high ductility.

TABLE 2: Different welding parameters and their ranges

PARAMETERS	RANGE
Voltage	50 Volt
Speed	3 mm/sec
Current	(125-190) Amperes
Gas flow rate	(8-10)l/min
Distance of tip from the weld center	3 mm
Current type	AC
Dimension	100*75*3
Bevel angles	40,45,60 degrees

1) Experiment Images

Fig 3 Aluminium Alloy 8011 plate

Fig 4 Automated TIG Welding Machine

Fig 5 Milling

Fig 6 Prepared sample after milling

Fig 7 Automated TIG welding Machine

Fig 8 Prepared samples after welding

C. Experimentation

Dye Test, Tensile Test, Hardness Test and Grain size analysis is then done on the prepared samples. Dye test is used to analyse the weld quality of different samples. Values of Ultimate Tensile strength, Hardness and % Elongation measured from above test is optimized using Taguchi based GRA model. Welding parameters used in the experiment are shown in the table 3.3.1 and Taguchi array designed for the experiment is shown in table 3.3.2

Table 2 Welding Parameters

Process Parameters	Level 1	Level 2	Level 3
Bevel Angle (^{0}or Degree)	40	45	60
Current (Ampere or A)	125	160	190

Table 3 L9 Taguchi Orthogonal Array

Bevel Angle ($^{0 \text{ or Degree}}$)	Current (Ampere or A)
60	125
60	160
60	190
45	125
45	160
45	190
40	125
40	160
40	190

1) *Observations:* After Welding is done, Dye Test is performed to observe the weld quality of the samples. Dyes test brings out micro-fractures in weld area if any.
2) *Dye Testing:* For this we used Magna flex Dye Penetrant testing kit, which contains three sprays i.e., Cleaner, penetrant and developer. Dye testing is based up on the principle of capillary action in which a fluid of low surface tension is allowed to penetrate in the surface breaking discontinuity. First, it is cleaned using cleanser spray. Then Penetrant spray is applied. After this work pieces are allowed to rest and dye is applied from time to time so that dye does not dry. After 15 min, the excess amount of penetrant is removed from the surface. Now developer is applied over the area as it will draw the penetrant out of the micro-fracture in the surface which was earlier invisible for inspection and now due to developer it will become visible to the inspector.

Fig 9 Samples after applying Dye penetrant

Fig 10 Sample after applying Developer

After the test, we inspected the pieces for dye absorption. Appearance of red dye was found to be minimal. Very little dye was observed between weld zone and HAZ. This shows that welds contain negligible micro-fractures. From this we determined that welds are of excellent quality.

3) *Grain Size Analysis Using Inverted Optical Metallurgical Microscope:* Grain size is an important for many mechanical properties. For e.g., fatigue strength, tensile strength, hardness, etc. Fine grain materials are less hard and have lower tendency to crack than similar coarse grain materials. Coarse grain materials have better creep and stress rupture properties because diffusion at high temperatures is impeded by sub-grain low angle boundaries present in coarse grain materials. These properties are especially useful in manufacturing of high-pressure containers which is primary application of aluminum alloy 8011. Grain size is measured using an optical microscope on a transverse metallographic mount. Then number of grains are counted within a given area. Grain size can range from 00 to 14.00 as per ASTM E112-96 (2004). When grain size number is small i.e., in coarse structures number of grains can be counted manually. After welding, testing and GRA, we observed the best sample under inverted optical microscope to observe its micro structural properties. When observed under inverted optical microscope, no fractures or strain was observed. Grain size was found to be 3. We found that grain size refinement occurred under welding, which led to increase in its mechanical properties.

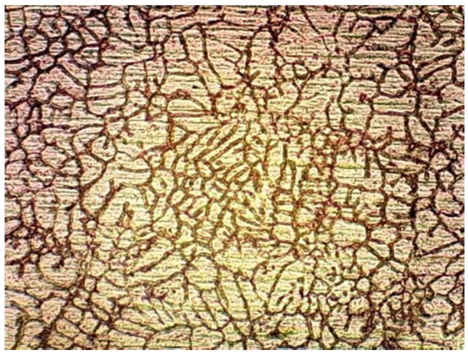

Fig 11. Grain structure in weld zone

4) *Mechanical Testing:* Observations of UTS, Hardness and % Elongation are done by performing the tests on Universal Testing Machine (UTM), Vickers Hardness Machine and Elongation is measured after Tensile Testing, using Vernier callipers. Observed values of different process parameters is given below in the Table 3.3.3

Table 4 Observations

Bevel Angle (^{0} or Degree)	Current (Ampere or A)	Ultimate Tensile Strength (N/MM2)	Load at tensile strength (N)	%ELONGATION	Hardness
60	125	41	3945.38	8.0	34.67
60	160	52	4877.08	10.7	29.33
60	190	53	5146.83	11.4	33
45	125	50	4534.40	11.8	32.67
45	160	49	4705.96	9.9	34.33
45	190	50	4726.50	10.9	34.67
40	125	61	5869.96	11.6	30.33
40	160	56	5295.02	12.9	39.67
40	190	61	5869.72	12.9	32.67

D. *Optimization of Process Parameters using Taguchi Based GRA*

1) *Designing an Orthogonal Array:* Firstly, Taguchi orthogonal array in Minitab 20 software to calculate S/N Ratios

For This we selected L9 Orthogonal array as we had 2 factors and 3 levels each for each of the factors

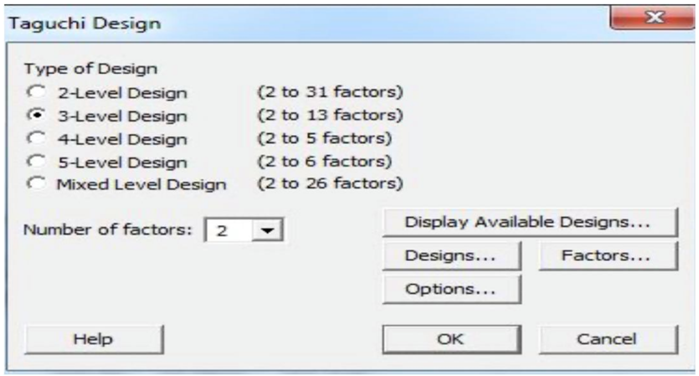

Fig 12: Taguchi Design (2-Level Design)

2) *Calculation of S/N Ratio:* Taguchi method uses signal-to-noise (S/N) ratios so that we can better responses which helps us to lower the quality characteristic variation caused by uncontrollable factors. In this experiment quality characteristic is Tensile strength, Hardness value and % Elongation. S/N ratios for all three responses have been calculated. As mentioned earlier, higher values of UTS, HV and per- centage elongation give better welding performance; therefore, Formula for the calculation of S/N ratio for " the larger the better" concept is: -

$$\text{Signal-to-noise ratio } (k) = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{1}{y_{ijk}^2} \quad (1)$$

Table 5 shows output values of S/N ratios for “the larger the better” scenario:

Table 5 S/n Ratio output values

Bevel Angle $^{(0)}$	Current (A)	UTS	Hardness	% Elongation	SNRA
60	125	41	34.67	8.0	-17.8558
60	160	52	29.33	10.7	-16.1375
60	190	53	33	11.4	-13.0729
45	125	50	32.67	11.8	-15.5457
45	160	49	34.33	9.9	-16.2496
45	190	50	34.67	10.9	-15.5978
40	125	61	30.33	11.6	-12.1813
40	160	56	39.67	12.9	-11.1504
40	190	61	32.67	12.9	-11.1818

Response Table for Signal to Noise Ratios

Larger is better

Level	Bevel angle	Current
1	-11.50	-15.19
2	-15.80	-14.51
3	-15.69	-13.28
Delta	4.29	1.91
Rank	1	2

Fig 13 Response table for S/N ratios

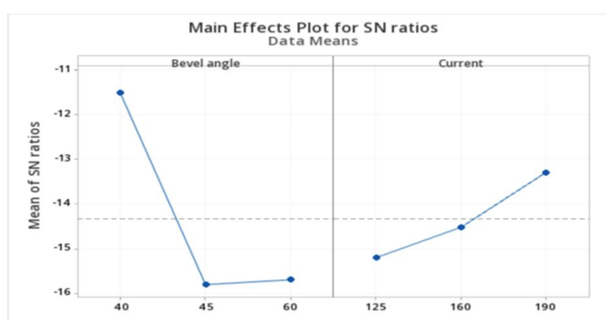

Fig 14 main effects for S/N ratios

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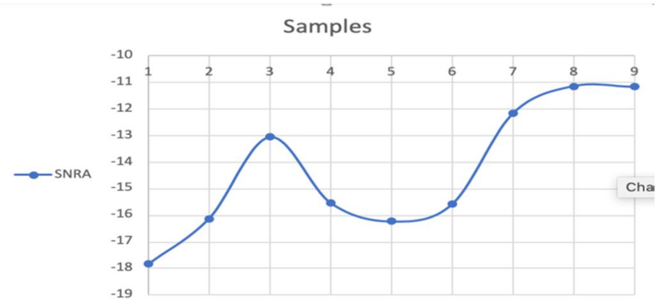

Fig 15 SNRA plot of samples

From Fig 15 we can see that Bevel Angle 40^0 the highest S/N ratios at Induced current 160A.Values of samples 8 and 9 are comparable.

3) *Calculation of Grey Relational Grade:* After calculating S/N ratios, we will perform Gray relational analysis on the output values for UTS, Hardness and % Elongation. All of the units in Grey relational analysis or GRA are first normalised into dimensionless values, so that they can be analysed and transformed into one comparable value of Grey relational Grade.

First step in GRA is Grey Data processing. In which each output value is turned dimensionless and within range of 0 and 1. Usually, each series is normalized by dividing the data in the original series by their average.

If the target value of the original sequence is ''the- larger-the-better'', then the original sequence is normalized as follows,

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min .x_i^{(0)}(k)}{\max .x_i^{(0)}(k) - \min .x_i^{(0)}(k)} \quad (2)$$

If the purpose is ''the-smaller-the-better'', then the original sequence is normalized as follows,

$$x_i^*(k) = \frac{\max .x_i^{(0)}(k) - x_i^{(0)}(k)}{\max .x_i^{(0)}(k) - \min .x_i^{(0)}(k)} \quad (3)$$

where x_i (k) is the reference series or sequence; max X_i (k) and min X_i (k) are the maximum and minimum values in the sequence, respectively; x_i (k) is the sequence generated after data processing. i = 1, 2, 3, m; k = 1, 2, 3, n; m is the number of experiments, and n is the number of experimental data.

Now GRCs have been calculated with the respective deviation calculations as given in equations (4) and (5)

$$\Delta_{oi}(k) = \left| x_o^*(k) - x_i^o(k) \right| \quad (4)$$

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta \cdot \Delta_{\max}}{\Delta_{oi}(k) + \zeta \cdot \Delta_{\max}} \quad (5)$$

where $\Delta_{oi}(k)$ is the deviation series of reference series $x_o(k)$ and compatibility series x_{oi} (k). z is the identification coefficient, which is weight of output parameters. The weight of output parameters was calculated using Analytic Hierarchy Process (AHP) and weights were found to be 0.5,0.3 and 0.2 for the responses of tensile strength, Hardness and elongation respectively.

GRC for each experiment of L9 orthogonal arrays have been calculated through equation (4). The final step of calculation of GRG is performed for calculating the relationship strength between the reference series and the compatibility series. Its value varies between 0 and 1. Higher value of GRG shows better relationship and it is considered as an ideal case. GRG is the average summation of GRCs. It is calculated by the following equation (6)

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \zeta_i(k) \quad (6)$$

where y_i is a GRG of i^{th} experiment and n is the number of performance characteristics.

Larger value of GRG indicates that the corresponding experimental results are closer to the ideal value or normalized value.

Table 6 Output Normalized Values

SAMPLE	Bevel Angle (0 or Degree)	Current (Ampere)	U.T.S.	HARDNESS	%ELONGATION
1	60	125	0	0.516	0
2	60	160	0.55	0	0.551
3	60	190	0.60	0.935	0.694
4	45	125	0.45	0.323	0.775
5	45	160	0.40	0.483	0.388
6	45	190	0.45	0.516	0.592
7	40	125	1.00	0.097	0.735
8	40	160	0.75	1.000	1.000
9	40	190	1.00	0.323	1.000

Table 7 Grey-Relational Grade

SAMPLE	TENSILE	HARDNESS	ELONGATION	GREY-RELATIONAL GRADE
1	0.333	0.508	0.333	0.128
2	0.526	0.333	0.527	0.156
3	0.555	0.884	0.620	0.222
4	0.476	0.425	0.690	0.167
5	0.454	0.492	0.450	0.154
6	0.476	0.508	0.551	0.166
7	1.000	0.356	0.653	0.246
8	0.666	1.000	1.000	0.277
9	1.000	0.424	1.000	0.276

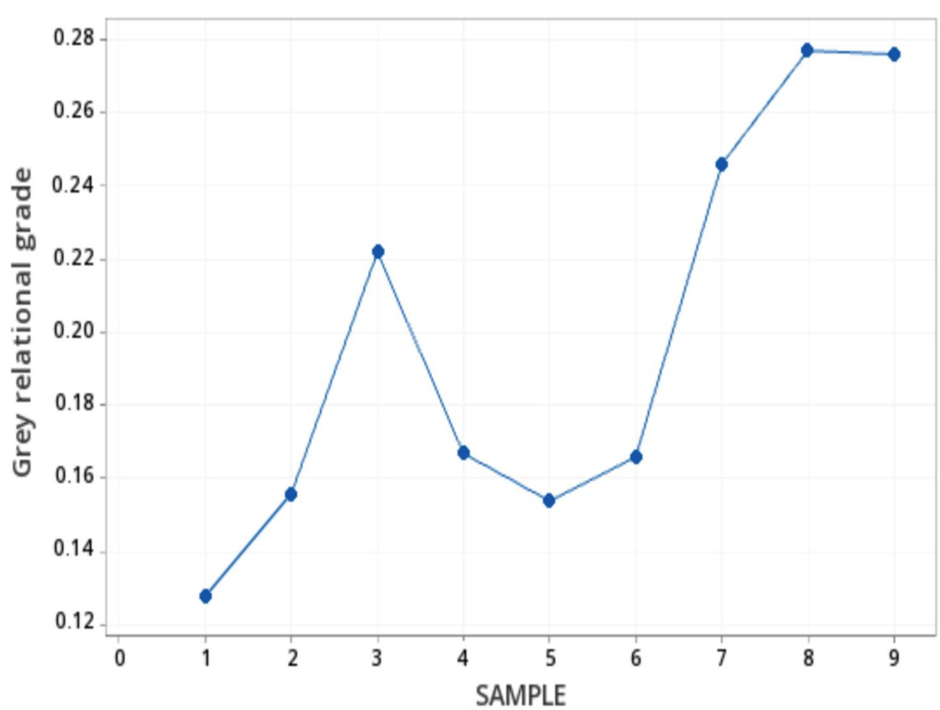

Fig 16 Grey relation grade of individual samples

IV. RESULTS

The output parameters measured from the experiments and data from Taguchi analysis using GRA is listed in Table 4.1

Final Output Values

	Bevel angle	Current	Grey relational grade	SNRA
1	60	125	0.128	-17.8558
2	60	160	0.156	-16.1375
3	60	190	0.222	-13.0729
4	45	125	0.167	-15.5457
5	45	160	0.154	-16.2496
6	45	190	0.166	-15.5978
7	40	125	0.246	-12.1813
8	40	160	0.277	-11.1504
9	40	190	0.276	-11.1818

FIG 17

From the Fig 4.1we can see that output values for GRA and SNRA is greatest for value of Bevel Angle 40^0 and Current 160A. Thus, we find out that used parameters are optimum for the experimentation.

V. CONCLUSIONS

From the experiment of TIG welding of aluminum plate following conclusions can be made: -

With the help of automated welding system uniform welding of aluminum plate can be possible.

1) Bevel angle affects the tensile properties of the material as different volume of filler metal is added in the welding.
2) In this experiment maximum tensile strength is observed at the smallest bevel angle (40 degrees) among the chosen set of bevel angles i.e., 40, 45 and 60 degrees respectively.
3) From this experiment, the bevel angle of 40 degrees shows the best tensile strength, %elongation and micro-hardness values.
4) Hardness value of the weld zone change with the distance from weld centre due to change of microstructure.
5) Welding strength depends upon the parameters like current and bevel angle.
6) With the increase in current welding strength increases.
7) By using Taguchi based GRA we have found that Sample 8 with Bevel Angle 40 degrees and Current 160 A shows the highest combined values of Tensile strength, hardness and % Elongation

A. Future Recommendations

The value of bevel angles must have a limitation and some range in which it affects the strength of the material which is acceptable for industrial purposes. So, future work can be done to find out such limitations and range of bevel angles.

1) For future reference one can study and find out different parameters like fatigue limit, corrosion resistant, yield strength, ductility, etc.
2) One can also try to repeat the same experiment using different filler materials and can study their effect on the properties of the material.

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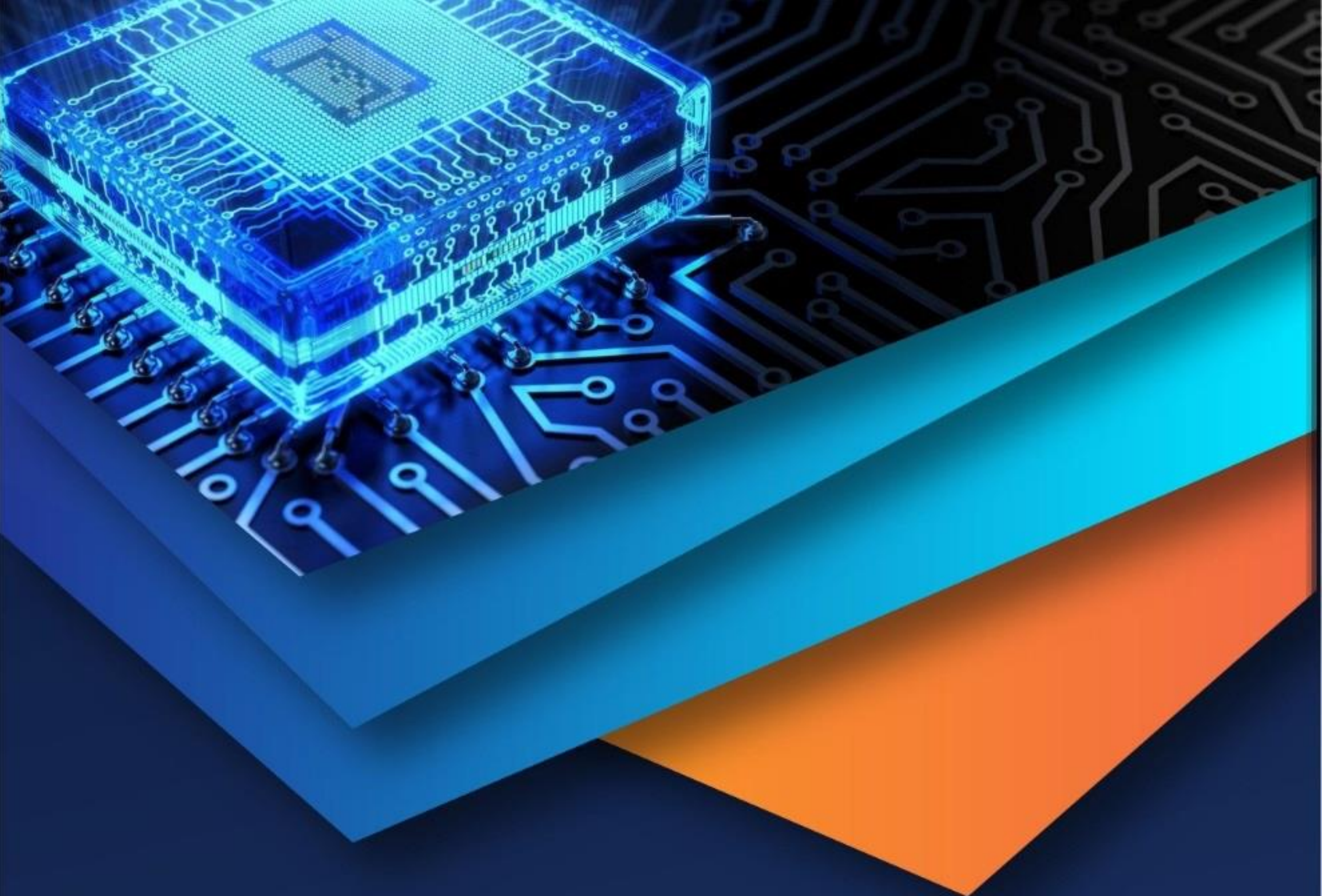

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