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Study of Weld Quality characteristics of Tungsten Inert Gas Welding of Dissimilar Metals SS 316L and IS 2062 Plates

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Abstract: The successful weld between dissimilar metal is one that is as strong as the weaker of the two metals being joined. Bimetallic combinations of SS 316L and IS 2062 are used widely in the heat exchangers, super heaters employed in the oil gasification plants, chemical processing equipments, and nuclear sector. However effective welding of dissimilar metals has represented a major challenge in thermal and mechanical properties of the material to be joined under a common welding condition. Over the years the lifespan of many machines have been reduced or have not matched its estimated lifespan due to poor joints. The poor joints may be due to the improper welding joints. And variety of problems come up in dissimilar welding like cracking, large weld residual stresses, migration of atoms during welding causing stress concentration, stress corrosion cracking etc. To overcome these problems, it is required to study the effect of welding process parameters. The main purpose of this project is to study the mechanical properties of SS 316L and IS 2062 alloys welded by TIG welding and to achieve the optimized process parameters using Taguchi and ANOVA techniques. And lastly micro structural properties of the jointed materials were investigated. This process provides a purer and cleaner high volume weldment. The effect of different welding Current (110, 120,130Amp), different Voltage (40, 50,60V) and different Gas flow rate (8, 9,10Lit/min) on ultimate tensile strength and Hardness of dissimilar welding, are used to find out the significance of input parameter by DOE.
Keywords: SS 316L, IS 2062, dissimilar materials, TIG Welding, Hardness test, ANOVA, Optimization, Taguchi technique, Microstructural Analysis.

I. INTRODUCTION

In industry, most of the materials are fabricated into the ideal shape mainly via one of the following methods viz. casting, forming, machining and welding. The selection of a particular method depends upon various factors which may incorporate shape and size of the component, precision required, cost, material and its accessibility. Sometimes one specific method may be used to achieve the desired object. Among the available options economy plays the decisive role in making the final choice.

Welding of dissimilar metals is generally a difficult task because of the major problems encountered throughout welding. Several critical purposes in defence, especially nuclear power plants require materials with high strength while possessing number of different other important characteristics and more over good joining capabilities. The acceptance of the welded samples is most important, in order to meet its requirements and standards.

Welding is broadly used by manufacturing engineers and production personnel to quickly and successfully set up manufacturing processes for new products. Until the end of 19th century, forge welding was the only welding process the blacksmith had used earlier to join dissimilar metals by hammering and heating. Arc welding, oxy fuel welding and electric resistance welding process followed soon after. Due to advanced technologies, several modern techniques were developed by welding engineers such as semi automatic and automatic process, gas metal arc welding, submerged arc welding. Among them one of the best welding techniques is gas tungsten arc welding popularly known as TIG welding.

The weld quality is dependent on right choice of key welding parameters like welding current, Voltage and gas flow rate. It is seen that limited work has been done on dissimilar welding of SS 316L and IS 2062 Plates. Taguchi method is a powerful tool that uses a special design to study the parameters. This technique provides an efficient approach to optimize design for quality and performance. This technique provides an efficient, simple and systematic approach to optimize design for quality at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic. Large number of experiments has to be done, when the levels and factors increases. To solve this problem, an orthogonal array is developed in Taguchi. In this research Larger-the-better quality characteristics is considered in Hardness and Tensile strength prediction. Analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. This work also investigated the microstructural characteristics of optimized specimen welded by tungsten inert welding.

This research studies the influence of various input parameters on Hardness and Tensile strength of dissimilar materials SS 316L and IS 2062 welded joints. The influence of welding Current, Voltage and Gas flow rate is identified by ANOVA method. And the microstructural inspection of the dissimilar weld was performed.

II. RESEARCH METHODOLOGY

For any project, there should be a proper methodology. Methodology is precise order in which we carry out the project. It starts from the selection of the material to the conclusion of the project. The methodology that is adopted is explained in the form of a flow chart as shown below

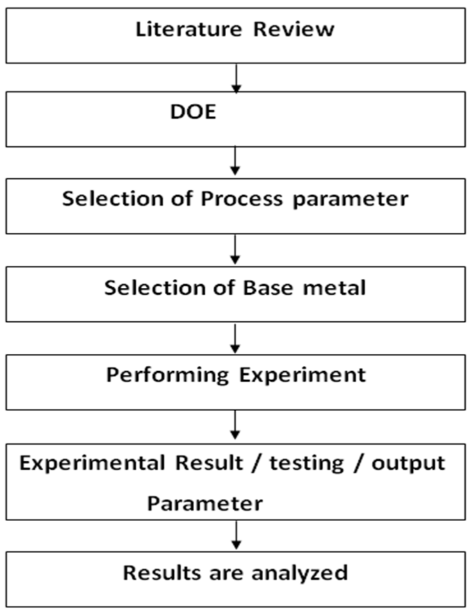

Figure: 1 Methodology steps

This study starts with the concept of Design of Experiment (DOE). The preliminary result determines the welding parameter levels. After the preliminary results are known, levels of parameter are then entered into MINITAB- 18 to generate the design matrix table. Then experiments were conducted based on input parameter. Total 9 experiments were conducted based on L9 orthogonal arrays. The primary effect of various welding parameters such as welding current, voltage and gas flow rate of dissimilar metals SS 316L and IS 2062 was analysed.

III. EXPERIMENTAL PROCEDURE

Stainless steel316L and Mild steel IS 2062 are selected over other materials because of its distinct properties, its availability in the market and cheaper cost. It has high corrosion resistance and can be operated at elevated temperature. Specimen of 300x20x3mm dimension was prepared and welded according to the ASTM E8 standards. The chemical composition of SS 316L and IS 2062 are shown in the table1 and 2. The selected welding parameters and levels for each factor are given in Table 3.

Figure: 2 dissimilar materials welded using TIG welding

Table 1: Chemical Composition of stainless steel 316L

Elements	C	Si	Mn	P	S	Cr	Mo	Ni
Wt %	0.03	0.29	1.58	0.027	0.003	16.25	2.27	11.90

Table 2: Chemical Composition of Mild steel IS 2062

Elements	C	Mn	S	P	Si	Ni	Cr
Wt %	0.22	1.5	0.049	0.050	0.37	0.016	0.02

Table 3: Process parameters and their values at different level

MATERIAL	PARAMETER	LEVEL1	LEVEL2	LEVEL3
(SS 316L, IS 2062)	Current (Amp)	110	120	130
	Voltage (volts)	40	50	60
	Gas Flow Rate (Lit/min)	8	9	10

Orthogonal arrays are the standard arrays which are selected based on the number of selected parameters and levels. L9 orthogonal array is chosen from Minitab 18 software and the welding was carried out in sequential order with the parameters as shown in the table 4

Table 4: L9 Orthogonal array

Experiment	Current(Amp)	Voltage(Volt)	Gasflow Rate(Lit/min)
1	110	40	8
2	110	50	9
3	110	60	10
4	120	40	10
5	120	50	8
6	120	60	9
7	130	40	9
8	130	50	10
9	130	60	8

In order to determine the mechanical properties of welded plate, all specimens were subjected to Hardness test and Tensile strength test. And also weld quality was assessed through microstructure study using optical microscope. For microscopic observation, the specimen was carefully cut, polished and then etched.

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A. TIG Welding Machine

It is engineered range of inverter based, TIG machine, which is in compliance with industrial benchmarks. It is used to weld stainless steel, mild steel, copper and titanium. It is known for accurate dimension and capability to deliver optimum performance.

Figure 3: Experimental set up of TIG Welding

Figure 4: prepared specimen after machining

B. Testing Machine

In this experimental work, the tests have been investigated on Hardness and Tensile strength by varying various process parameters like Current, Voltage and Gas flow rate.

Fig 5: Vickers Hardness Tester Machine

Figure 6: UTM Tensile Testing M/C

C. Microstructural Study

Microstructure is known as the shape of a prepared surface or very narrow foil of material as revealed with the aid of a microscope above 25x magnification. The microstructure of a pattern can completely motivate physical properties such as stability, toughness, hardness, corrosion resistance, temperature behaviour, wear, resistance, and so on which in turn guess the availability of these materials in industrial repeating skill. Microstructure and microstructural methods are employed in areas such as routine quality control, failure analysis and research studies. In quality control, microstructural analysis is used to determine if the structural parameters are within sure specification. It is used as a criterion for approve or rejection. The equipment used is optical microscope with a magnification 500X.

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Figure 7: Optical Microscope

IV. RESULT AND DISCUSSIONS

The values of welding process parameters are given below in the table 5. Hardness test and tensile tests are performed on 9 specimens. After welding operation and mechanical tests were performed, the microstructural study was made in order to understand the effect of welding heat across the specimen.

Table 5: welding process parameters

Specimen no.	Current (Amp)	Voltage (volt)	Gas flow rate (Lit/min)	VHN at Weld Metal	Tensile Strength(N/mm^2)
1	110	40	8	171	431
2	110	50	9	178	438
3	110	60	10	181	442
4	120	40	10	173	439
5	120	50	8	172	445
6	120	60	9	184	448
7	130	40	9	176	444
8	130	50	10	175	460
9	130	60	8	183	452


Figure 7: Specimen after Tensile Test

It is very clear that failure has occurred in the mild steel of grade IS 2062 and not in the welded region, welded region formed by TIG welding has strong joint and reduces cracks and pores on the surface which shows Tungsten inert gas welding is most significant than other welding process.

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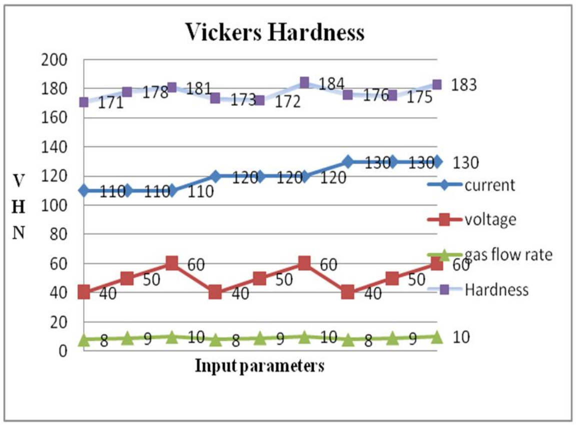

Figure 8: input parameters versus hardness

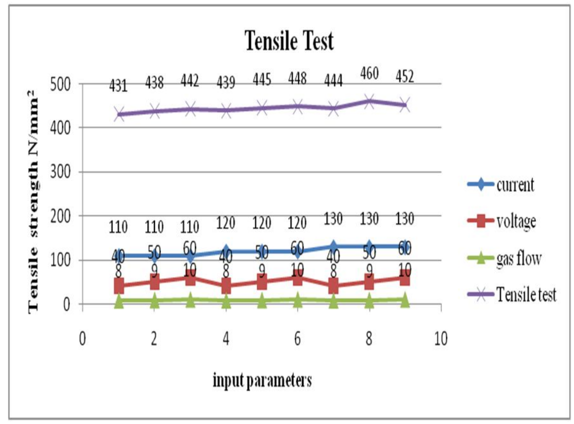

Figure 9: input parameters versus Tensile strength

Figure 8 shows the comparison of input parameters and Hardness. It is observed that hardness increases with increase in voltage. Maximum hardness is obtained at 120(Amp) current, 60V voltage and 9Lit/min gas flow rate. Sample 6 has highest Hardness.

Figure 9 shows the comparison of the input parameters and tensile strength. It is noticed that as current increases, tensile strength of the specimen increases. Current has reasonably large effect on tensile strength. Maximum Tensile strength is obtained at 130A current, 50V Voltage and 10 Lit/min gas flow rate

A. Hardness Results

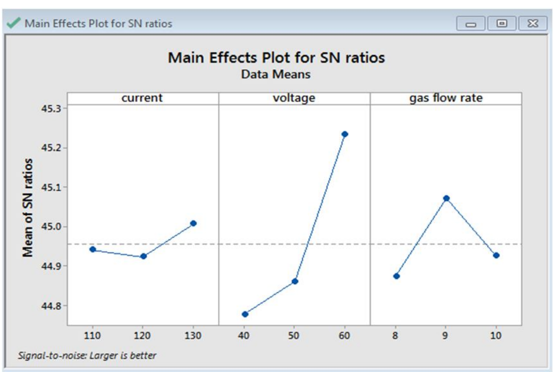

Figure 10: Main Effect plot for SN ratio

Table 6: Response Table for SN ratio

Level	Current (Amp)	Voltage (volt)	Gas flow Rate (Lit/min)
1	44.94	44.78	44.87
2	44.92	44.86	45.07
3	45.01	45.23	44.93
Delta	0.08	0.46	0.20
Rank	3	1	2

Table 7: ANOVA Result for Hardness

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**% Contribution**
current	2	4.667	2.333	1.00	3
Voltage	2	148.667	74.333	31.86	50
Gas flow rate	2	26.000	13.000	5.57	15
Error	2	4.667	2.333		

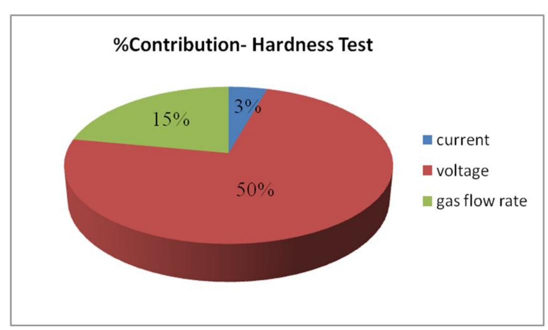

Figure 11: Pie Chart for Percentage Contribution of different parameters for Hardness test

The optimal process parameters have been established by analyzing response curves of S/N ratio and means. From the results of Response table and ANOVA table of Hardness, Voltage is found to be the major factor affecting Hardness since its F value is 31.86 and Gas flow rate is found to be second ranking factor since its F value is 5.57. Welding current ranks last since its F value is 1.00. From ANOVA table it is also noted that Percentage contribution of current is 3%, voltage is 50% and Gas flow rate is 15%. So it is clear that Voltage has significant effect on Hardness at 95% confidence level.

B. Tensile Results

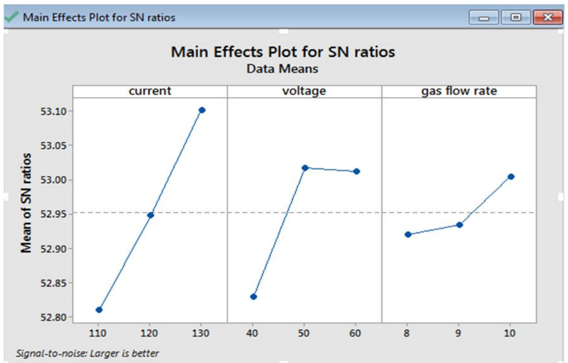

Figure 12: Main effects plot for S/N ratio- Tensile test

Table 7: Response Table for Signal to Noise Ratios – Tensile test

Level	Current (Amp)	Voltage (volt)	Gasflow Rate(Lit/min)
1	52.81	52.83	52.92
2	52.95	53.02	52.93
3	53.10	53.01	53.00
Delta	0.29	0.19	0.08
Rank	1	2	3

Table 8: ANOVA Result for tensile test

Source	DF	Adj SS	Adj MS	F-Value	% Contribution
current	2	338.00	169.000	18.11	50
Voltage	2	180.67	90.333	9.68	36
Gas flow rate	2	32.67	16.333	1.75	10
Error	2	18.67	9.333		

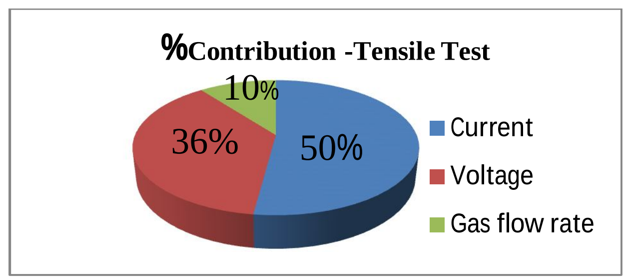

Figure 13: Pie Chart for Percentage Contribution of different parameters for tensile test

From the results of Response table and ANOVA table, welding current is found to be the major factor affecting ultimate tensile strength since its F value is 18.11 and Voltage is found to be second ranking since its F value is 9.68 and Gas flow rate ranks last since its F value is 1.75. From ANOVA table it is also noted that Percentage contribution of current is 50%, Voltage is 36% and Gas flow rate is 10%. So it is clear that welding current only has significant effect at 95% confidence level. Figure 13 shows pie chart for Percentage Contribution of different parameters for tensile test.

C. Confirmatory Test

Once the optimal level of design parameters has been selected, the final step is to verify the improvement of quality characteristics using optimal level of design parameters.

Table 9: Result of Confirmation Experiment

Test	Before Optimization	After Optimization
Hardness	184	187
Tensile Strength	460	480

Confirmation experiment is done at optimal process level and the value of Hardness and Tensile Strength after optimization is 187 and 480 N/mm^2 respectively. Thus effectiveness of Taguchi Optimization method was verified.

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D. Microstructural study

Microstructural observation is performed on the optimized specimen, followed by welding operation .This study is to make a view of the material properties in the grain growth at the welded area.

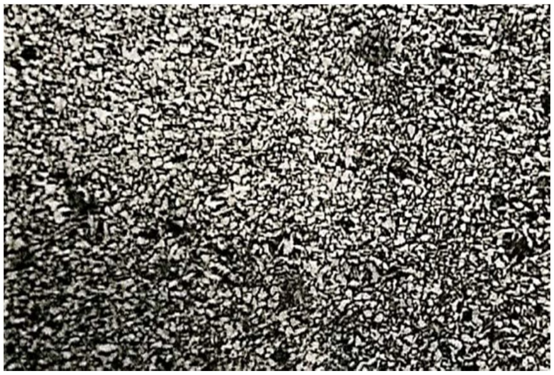

Figure 14: Microstructure of Parent Zone 100X

Figure 15: Microstructure of Weld Zone 100x 100X

Figure 14shows the parent zone with the presence of uniform distribution of ferrite grains of size. And grain size of 25µm is seen.Magnification of 100X is done for initial overview. The parent zone which is adjacent to the heat affected zone, there is rapid rate of cooling. Hence we can notice fine grains at the parent zone.

Here in TIG welding process, microstructural Analysis was carried out at the weld zone. Fig 15 Shows morphology of the weld zone, which evidence the presence of ferrite grains. It is shown that the boundary between MS and SS is apparent. If heat loses, adjacent grains also loses heat one by one, and forms coarse columnar grains which means grain structure will be long elongated columnar crystals. Size of the grain observed is of 25µm.

Figure 16 : Microstructure of Parent Zone 500X

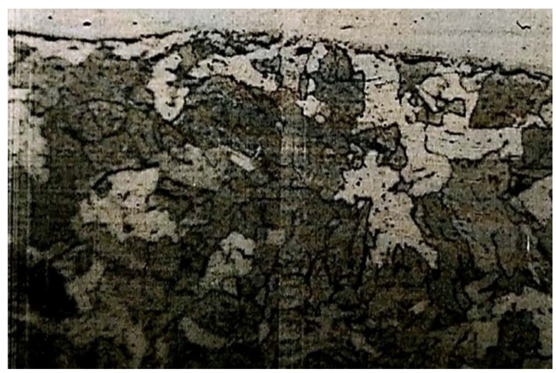

Figure 17: Microstructure of Weld Zone 500X

And then Magnification of 500X is done for clear Analysis. These Magnified images provide a clear idea about the problems or the characteristics of the specimen. At the centre of the weld, mix matrix of MS and SS was observed as shown in Figure 17. The ferrite grains are present with grain size 500X magnification. In the weld and heated portion, columnar grains of ferrite also seen.

V. CONCLUSION

The aim of present work was to Study and optimize the welding process parameters of TIG welding process on Tensile Strength & Hardness of dissimilar weld. Stainless Steel 316L and Mild steel IS 2062 plates are used as test material.TIG welding is one of the best welding technique by which we can join two similar and dissimilar materials. Taguchi optimization method was successfully applied to find the optimal level of TIG welding parameters for maximizing weld strength.

The following conclusions can be drawn from experimental results:

A. Hardness Test

The highest hardness value was recorded at 120(Amp) current, 60(V) voltage and 9(Lit/min) gas flow rate. It is noted that specimen 6 has highest Hardness.

B. Tensile Test

From analysis and experiments result it is concluded that maximum result achieved at 130(Amp) Current, 50 Voltage and 10(Lit/min). At this parameter obtain value for Tensile Strength is 460 N/MM^2.

C. Taguchi Technique

Taguchi design of experiment method was successfully applied to find the optimal level of TIG welding parameters. It has been observed that current, voltage and gas flow rate has some influence on the hardness and tensile strength of the material.

1) Optimum parameter for Hardness is obtained at 130(Amp), 60(Volt) and 9(Lit/min) Gas flow rate and for Tensile strength optimum parameter is obtained at 130(Amp), 50(Volt) Voltage and 10(Lit/min) Gas flow rate.
2) Taguchi orthogonal array, signal-to-noise ratio, analysis of variance and main effects plots for means and S/N ratio were used for the optimization of welding parameters.
3) From ANOVA it is found that Voltage is the factor that significantly contributed to a higher percentage followed by Gas flow rate and current in Hardness where as in tensile test, current is the factor that significantly contributed to a higher percentage followed by voltage and gas flow rate.
4) Thus welding Voltage has greater influence on hardness and Current has highest influence on tensile strength.

D. Microstructure Study

In the microstructure, the fine flow shows good formation of the welding in the joint. No physical surface defects observed in weldment. It is witnessed that selection of process parameters are appropriate.

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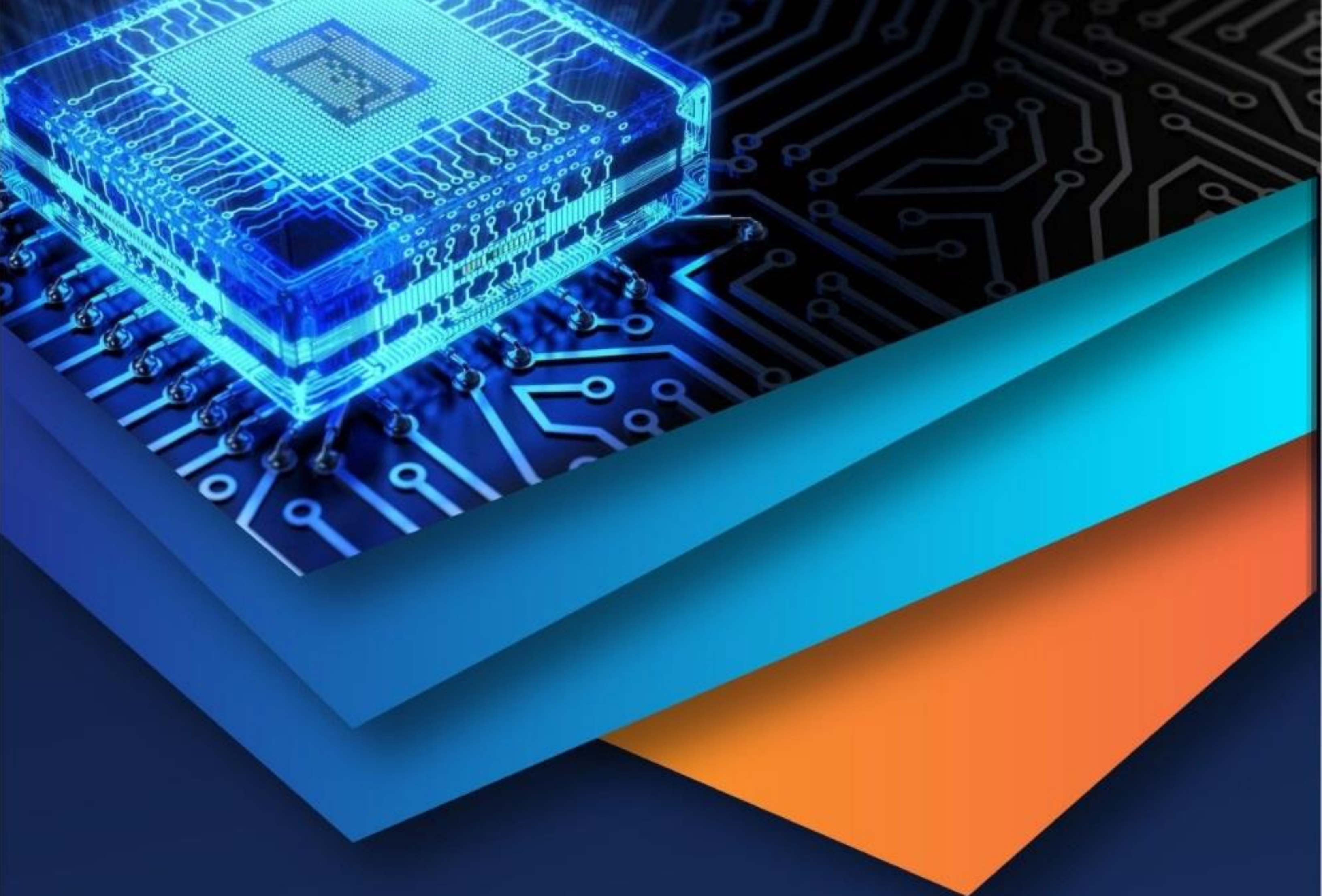

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