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Optimizing the Process Parameters of FSW of AA7050 to Enhance the Weldability

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Abstract: A solid state metal joining process known as Friction Stir Welding (FSW), is largely used to weld alloys of aluminium. The influence of the various parameters associated with the process such as speed of rotation of the tool, speed of welding and angle the tool makes with the horizontal surface of the workpiece or tilt angle on the weldability of AA7050 is studied in this paper. The study was performed on VMC (i.e. Vertical Milling Machine and Universal Testing Machine was interrogated to find the output parameters. A convincing result was achieved wherein the above factors mentioned are strongly influencing the weld strength. Implementation of Taguchi method to optimize the results was conducted. ANOVA analysis revealed the amount of contribution each factor have with the improvement in the weld strength. .Signal to Noise, ratio (S/N ratio)) gave the optimal parameters which largely influenced the weldability.

Taguchi method validated the test results and showed that the performance of the welded joint is improved.

Keywords: FSW, speed of rotation of the tool, Speed of Welding, Tilt angle of the tool, ANOVA analysis, S/N ratio, Orthogonal Array.

I. INTRODUCTION

A metal joining method called as Friction. Stir. Welding which was flourished in the years 1991 at The Welding Institute (T W I) in UK [1]. The joining of the metals does not takes place by melting of the parent metal but due to plastic flow of the material caused by tool plunging inside the workpiece and stirs the material due to frictional heat generated at high temperatures. Friction between the shoulder of the tool along with the pin and the workpiece causes the heat generation. Friction Stir Welding , sometimes called as process. Aluminium alloys having high strength/weight are preferably welded by Friction stir welding process. Friction Stir Welding (FSW) process do not need any kind of a fillers material unlike other welding techniques. Functions [2] of the tool such as

A. Material distortion and softening of the workpiece is achieved.
B. Transportation of the material during plastic deformation.
C. Forge of deformed material opposite to tool shoulder.
D. Not only relevant with aluminium alloys FSW process can be used for material like Ti, Cu, Mg etc.
E. Cost reduction can be achieved by Friction stir welding since it causes less distortion than conventional welding process.

Fabrication of butt or lap joint is possible by this welding technique. Because of the frictional heat generated which is volumetric in nature with the advancement of the tool we get continuous joint. Welds produced by FSW process are not vulnerable to the defects like the one produced by fusion welding methods. The application of Friction Stir welding is more prominently found in aircraft structures. Aluminium and its alloy will find large number of application in near future were there will be requirement of high strength to weight ratio. With no usage of any filler material or a kind of any flux, renders this process as environment friendly. This welding technique is also applicable for welding of composites.

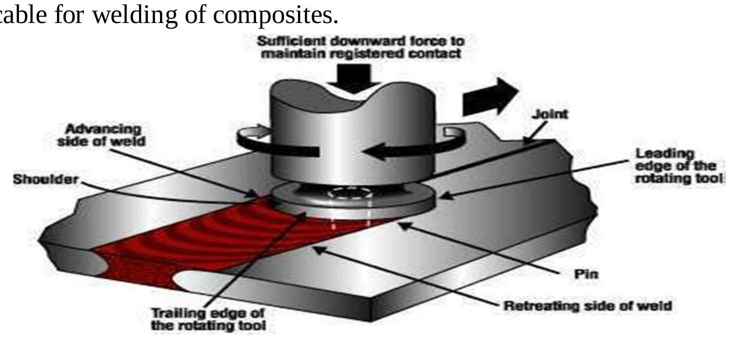

Figure 1: Mechanism of Friction stir welding [2]

II. RELATED WORK

The friction stir welding of similar as well as dissimilar aluminium alloys comprises two important parameters namely: Tool rotational speed and the welding speed, also called as tool travel speed respectively [5]. The dominance of the above two process parameters clearly influences the mechanical properties of the welded joint. The heat input is having a major influence on the mechanical properties compare to deformation of the base material by the tool. It is also observed that with the decrease in tool rotational velocity and increases in weld velocity of the tool the ultimate tensile strength (UTS) and yield strength both increases. The major contribution of the heat input to the Friction stir welding process is because of friction caused between the tool and the workpiece. Hence tool geometry plays a vital role in heat generation. The escaping of the plasticized material from the workpiece is prevented by the shoulder of the tool. Following parameters [4-5] are the most influencing parameters when it comes to enhancing of the weldability of friction stir welds:

A. The Tool Geometry
B. Velocity of rotation of the tool
C. Tool travel speed or welding speed
D. Downforce or Axial force
E. Tool tilt angle

III.METHODOLOGY

A. Material Selection

The aluminium alloy AA7050 in as weld condition is employed in this experimental work. The Composition (Chemical) of the said alloy is summarized in the table below.

Table -1: Percentage of Chemical composition in AA7050

Al	Fe	Pb	Zn	Mg	Mn	Cr	Cu
87.55	0.09	8.2914	5.7	2.001	0.0071	0.05	1.92

Table -2: Mechanical Properties of the base Metal

MATERIAL	YIELD STRENGTH	UTS	ELONGATION	HARDNESS
BASE MATERIAL	469 MPA	524MPA	11%	140BHN

B. Fabrication of the Weld

To produce the welded specimen we have produced twenty four plates of 200x125x6(mm) made of AA7050 and then performed FSW [3]. To cut the samples we have used power hacksaw milling machine. Figure 2 shows the configuration to produce FSW samples.

Material	AA7050
Dimensions	200x120x6(mm)

C. Tool Geometry

The tool geometry is very important in order to define the weld strength of the joint. In this work we have used square pin profile and its dimensions are as follows:

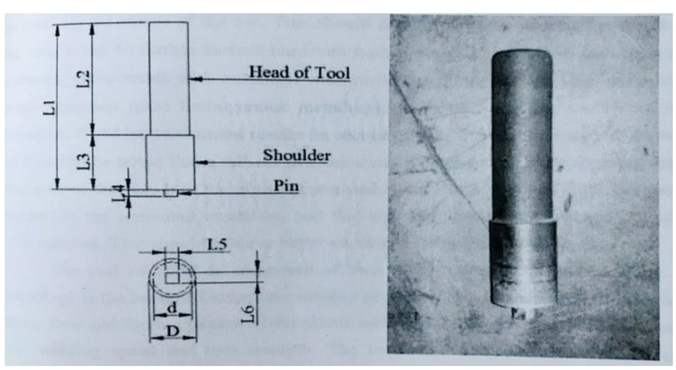

Figure 3: Tool Geometry [3]

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The properties of the welded joint are significantly affected by the tool geometry. The tool performs the following functions [4]:

1) Generates heat by friction between the tool shoulder and the workpiece.
2) Stir the material plastically and avoid further wearing.

In addition to above functions the tool geometry produces appropriate downforce required for efficient welding by FSWP.

Table 3 defines the various tool specification used in the study.

Simulation and numerical study performed [6] shows that in comparison to hexagonal tool pin profile a square tool pin profile generates more heat. Study also revealed that with increase in velocity of rotation of the tool and at constant welding speed maximum heat was produced.

Table -3: Tool Specifications [3]

Specifications	Index	Value
Length of the FSW tool	L_1	75 mm
Tool Head	L_2	50 mm
Length of the Tool shoulder	L_3	25 mm
Height of the pin	L_4	5.5 mm
Length of the pin	L_5	5 mm
Width of the pin	L_6	5 mm
tool head diameter	D	15 mm
Diameter of the shoulder	D	18 mm
Material of the tool	High speed steel	
Melting point of HSS	4680°C	
Hardness of shank, Shoulder and Pin Profile	60-62 HRC	

D. Fixture Design

A kind of a workpiece holding device which is used to hold the two plates while welding is been performed. Usually a fixture is made of Mild Steel. The fixture can be modified according to the job in hand. A total of six nuts and bolts were employed in this study for holding of the job. The fixture which we have produced should have sufficient strength to withstand the forces encountered during the welding operation.

Table 4 states the dimensions of the fixture which has been used in this study.

Table – 4: Fixture Dimension in mm [3]

Sr No	Fixture Part Name	Dimensions
1	Plates of the bottom of the fixture	300x200x10 (mm)
2	Clamping plate	270x40x6(mm)
3	M 18 (Nut Bolt)	2 (in number)
4	M 15 (Nut Bolt)	4 (in number).

Following figure shows the fixture which was used in this welding operation.

Figure 2: FSW Fixture and its parts

E. Tensile Test of Sample

Standard weld samples were produced as per ASTM: B557-M 10 guidelines. In this process a power hacksaw was used to slice the samples. The test was carried on 100 Ton electro mechanically operated UTM at atmospheric temperature. The ASTM guidelines suggest that the sample should be loaded at 1.5 kN/min in order to get the appropriate deformation. Finally the sample fails at certain loads followed by necking phenomenon. Accordingly we have valuated the percentage elongation, joint efficiency and weld strength in tension.

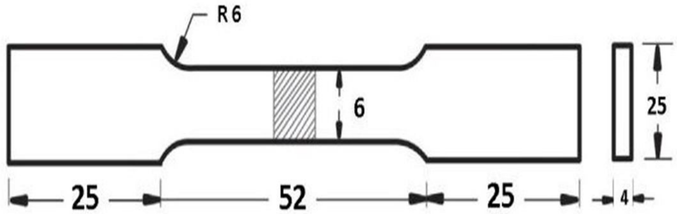

Figure 3: Dimensions of tensile specimen prepared as per ASTM: B557M-10 guideline

IV. EXPERIMENTAL RESULTS

After obtaining the plates of AA7050 of the above said dimensions. Vertical milling machine was use to shear of the edges of the plates and checked for perpendicularity.

Table -5: L_9 Orthogonal Array or input variables

Sample	Tool Rotational speed(rpm)	Tool Travel Speed (mm/min)	Tool tilt angle (°)
A	1000	30	0
B	1000	35	1
C	1000	40	2
D	1500	30	1
E	1500	35	2
F	1500	40	0
G	2000	30	2
H	2000	35	0
I	2000	40	1

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The number of experiment in our case is twenty seven because there are three factors and three values. The parameters which we have considered are tool rotational speed, tool travel speed and tool tilt angle respectively.

Table -6: Process parameters and there levels

Parameter	Level 1	Level 2	Level 3
Tool. Rotational speed(rpm)	1000	1500	2000
Tool. travel speed(mm/min)	30	35	40
Tool tilt angle (°)	0	1	2

The rotation of the tool leads to a stirring action of the material at the tool pin and carries the welding from front to back [4]. Because of friction between the tool shoulder and the workpiece at high velocity of the tool causes high amount of heat generation. Thus the generation of heat due to different coefficient of friction and at different speed will be different.

Table -6: Response table for signal to noise ratio

Sr no.	Tool rotational Speed (rpm)	Tool traverse Speed	Tilt. Angle (°)	UTS N/mm^2	S/N ratio	Mean
A	1000	30	0	345.23	50.7622	64.56
B	1000	35	1	353.63	50.9710	79.46
C	1000	40	2	350	50.8814	81.22
D	1500	30	1	351.2	50.9111	82.37
E	1500	35	2	353.46	50.9668	83.75
F	1500	40	0	353.2	50.9604	83.44
G	2000	30	2	354.6	50.9948	88.89
H	2000	35	0	353.5	50.9678	91.61
I	2000	40	1	358.76	51.0961	110.79

Analyzing the hardness and tensile strength of the welded joint was carried out in order to optimize the process parameters in relation to the friction stir welding process. MINITAB software enabled us to study the parameters influencing the response by merely calculating the Signal to noise ratio and means. Selection of the Signal to noise ratio was based on the criteria 'larger the better'. Signal to noise ratio are the logarithmic functions of the expected output are vital in order to optimize the parameters [4].
The experiment performed consisted of nine different process factors in FSW process. With the help of MINITAB statistical software the effects of these different welding parameters were studied. Optimizations of the responses help to evaluate the set of combinations of input parameters that are optimize for single set of response.

A. Analysis. of Variance. (ANOVA)

To study the influence of discrete factors on process response the application of statistical method called as ANOVA is been implemented. The influence of individual factor on the tensile strength and hardness is revealed by the results obtained by ANOVA analysis.

Table - 7: Analysis of variance for tensile strength (S/N ratio)

Ex	Source	DOF	Seq. SS	Adjusted SS	Adjusted MS	F	P	Percentage of Contribution
1	Tool Rotational speed	2	8.9	8.9	4.45	9.7	0.21	48.21
2	Tool Traverse speed	2	8.74	8.74	4.37	8.91	0.18	41.89
3	Tilt Angle	2	1.42	1.42	0.71	1.34	0.58	7.39
4	Error	2	1.24	1.24	0.62	-	-	2.51
5	Total	8	20.3	-	-	-	-	100.00

Table -8: Analysis of variance for tensile strength (Means)

Ex	Source	dof	Seq. SS	Adjusted SS	Adjusted MS	F	P	Percentage of Contribution
1	Tool rotational speed	2	921.96	921.96	460.98	19.95	0.08	51.92
2	Tool traverse speed	2	736.32	736.32	368.16	15.-76	0.07	40.39
3	Tilt angle	2	89.65	89.65	44.825	1.89	0.46	4.94
4	Error	2	54.33	54.33	27.16	-	-	2.75
5	Total	8	1802.26	-	-	-	-	100.00

The influence of discrete parameters on the overall process is difficult to achieve by Taguchi experimental method. Hence to remunerate this effect percentage of contribution using ANOVA was implemented[4]. The comparative power a factor can have on the process is signified by the percentage contribution. Hence from the table we can study that speed of rotation of the tool has a major contribution in enhancing the mechanical properties of the welded specimen as compared to tool travers speed and tool tilt angle respectively .

V. RESULTS AND DISCUSSION

The experimental results obtained by MINITAB statistical software reveled that FSW of AA7050 aluminium alloy exhibited superior tensile properties by using parameters as tool rotational speed, tool travel speed and tool tilt angle. The various effects of process parameters on tensile strength of the welded joint is as follows:

A. Influence of the tool Rotational Speed

There is a considerable increase in the tensile strength as the tool rotation speed increases. A linear behaviour between tensile strength and speed of rotation of the tool is observed up to certain limit and beyond which causes decrease in tensile strength with further increase in speed. When speed of rotation of the tool is lesser, say 1000 rpm generation of heat is less and causes plastic flow to be below par of the material being friction stir welded and hence lower tensile strength. With the increase in speed of rotation of the tool results in microstructural changes and influences cause by work hardening of the weld zone takes place. Change in the tool pin profile also changes the amount of heat generation which eventually influences the material flow behaviour in the thermo-mechanically heat affected zone (TMAZ). Therefore, as the tool rotational speed increase causes tensile strength to decrease when there is welding of dissimilar material.

B. Effect of tool Traverse Speed

When the welding speed is less the amount of frictional heat generated between the tool shoulder and the workpiece is also less which eventually leads to less tensile strength. The lowest welding speed encourages the metallurgical transformation of the weld zone and this leads to lower tensile strength. Joints made by square pin profile have highest tensile strength irrespective of the welding speed used to fabricate the joint. Hence when the speed of rotation of the tool increase the tensile strength will increase.

High travel speed decrease the tensile strength and lead to poor mixing of the material. Whereas in the literature choosing the feed rate as high as possible does not cause any defect in the weld quality. It seems that higher travel speeds prevent the hot shoulder and the rotating pin to heat the weld area for a longer time. The tensile strength, encountered in the weld area were deformation takes place, with an increase in the traverse speed of the tool, the material flow caused by the stirring action of the tool is below par and hence decreases .

C. Influence of the tool Tilt Angle

Tool tilt angle is a vital parameter when the workpiece and the plunge depth of the tool is concerned.. When along the transverse direction a suitable tilt angle is chosen it ensures that the material movement from front to back takes place more efficiently.

Intermetallic compounds are formed when tool tilt angle increases and which eventually decreases the weld strength. The increase of tool tilt angle causes the concentration of aluminium to increase in the compound resulting in tensile strength. Tilt angle also influences the downward force which acts on the tool. . But with welding performed on vertical milling machine ensures that appropriate downward force is applied on the tool. . Without tilt angle normal stirring action takes place but tilt angle also influences the movement of material along with stirring.. Thus tilt angle helps to provide better material flow at the welded zone.. It was also observed that a 1° of tool tilt angle produces defect free weld joints.

D. Confirmation Test

In the final step a confirmation of the process parameters was conducted and its results were tabulated as follows:

Table-9: Confirmation test for tensile strength

Ex	Speed of rotation of tool (rpm)	Tool traverse speed mm/min	Tilt angle (°)	U.T.S N/mm^2	Actual UTS in N/mm^2	Predicted UTS in (N/mm^2)
1	2000	40	1°	357.6	358.43	361.42
2	2000	40	1°	358.4		
3	2000	40	1°	359.3		

VI. CONCLUSION

It is inferred from this experimental study that:

A. With the use of MINITAB software to maximize the UTS of the welded joint, for the given combination of the process parameters following optimal results were obtained:

1) Optimum speed of rotation of the tool=2000 rpm
2) Optimum tool traverse speed=40 mm/min
3) Optimum tilt angle=1°

B. Tool travel speed paly crucial role and contributed 45% to the overall contribution.

C. ANOVA analysis in case for signal to noise ratio for tensile strength inferred that the tool rotational speed is the most critical factor with a percentage of 48.21%, followed by tool travel speed of 41.89% and tool tilt angle of 7.39% respectively.

D. ANOVA for the tensile strength (Mean) concludes that the tool rotational speed is the significant parameter with a percentage of 51.92%, followed with tool travel speed of 40.39% and tool tilt angle of 4.94% respectively.

E. As speed of rotation of the tool increases the tensile elongation reduces. The tensile elongation also reduces with increase in downward force.

F. The optimum combinations of parameters obtained from the main effect plot for the S/N ratio and mean is 2000rpm, 1° tool tilt angle and 40mm/min traverse speed , the tensile strength has been predicted as 361.42 N/mm². The confirmation test performed with the optimum process parameter is found to have an average tensile strength of 358.77 N/mm² and hence the optimization is useful.

G. FSW can produce satisfactory butt weld between two sheets of Aluminium AA7050 with a joint efficiency of around 74.77% (Base on AA7050 alloy)

VII. FUTURE SCOPE

There are large numbers of parameters in any experiment and it is not possible to check the effect of varying each and every parameter. So further work can be done on:

A. Varying the too material and tool geometry.(i.e. taper, cylindrical or taper-cylindrical tool profile)

B. Performing simulation analysis on ANSYS or some other simulation software to study the peak temperature and heat input during the FSW process.

C. Welding of materials like Copper, Titanium and Magnesium by using FSW process is another area of interest.

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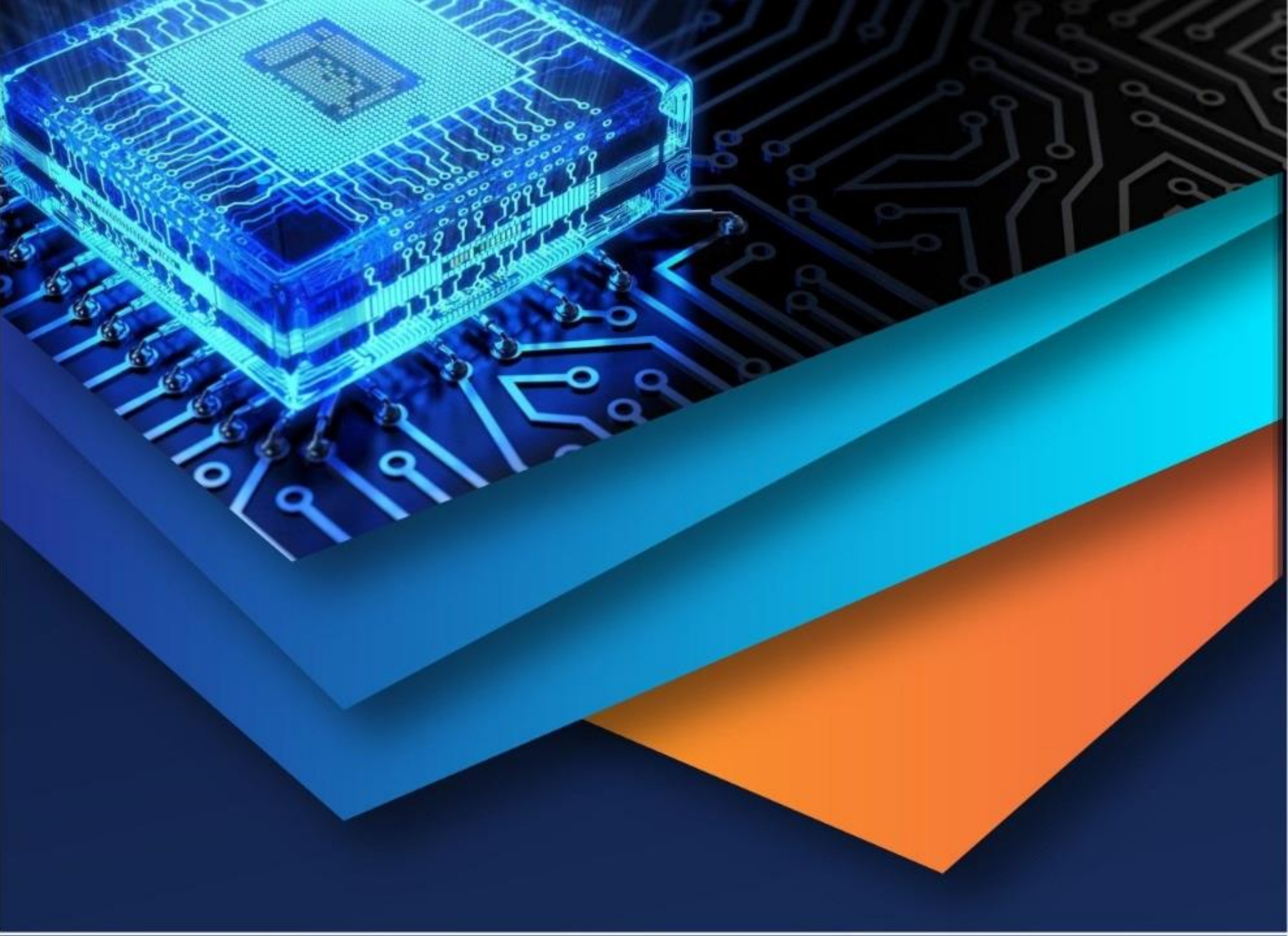

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