iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** X **Month of publication:** October 2025

DOI: https://doi.org/10.22214/ijraset.2025.74663

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue X Oct 2025- Available at www.ijraset.com

Influence of FSW Tool Pin Profile and Mechanical Properties of Friction Stir Welded of Dissimilar Aluminium Alloy

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Abstract: Friction stir welding (FSW), a solid-state joining technique, is being extensively used in similar as well as similar joining of Al, Cu, Ti, and their alloys. In the present study, friction stir welding of two aluminium alloys— AA 6082 and AA5052 were carried out at various combinations of tool rotation speeds and various shapes of tool profile pin and axial force. In this experimental proper selection of input friction welding parameters necessary in order to control weld distortion and subsequently increase the productivity of the process. In order to obtain a good quality weld and control weld distortion, it is therefore, necessary to control the input welding parameters. During the FSW process, the materials were transported from the advancing side to retreating side behind the pin where the weld were formed. Based on the above results FSW process with cylindrical pin profile execute highest tensile and medium hardness strength value fifth sample 57.7 N/mm2, 59 HRB and depth of penetration value obtained fourth sample good compared than others. Medium speed and higher axial force were very important parameter for the FSW process of bimetallic aluminum alloy with cylindrical tool profile pin.
Keywords: FSW, AA6082, Tensile Strength, DOE, Taguchi analysis, AA5052

I. INTRODUCTION

One of the most energy-efficient solid-state joining techniques that humans have yet encountered is friction stir welding. Because of its adaptability, FSW is especially used for high strength aerospace aluminium alloys and other metallic alloys that are challenging to fuse using traditional fusing techniques. Using a non-consumable spinning probe of tougher material that is jumped between the bordering sides, friction stir welding is a continuous procedure. A plasticized zone forms around the engrossed piece of the tool, joining the adjacent faces, thanks to the frictional heat created by the relative motion between the revolving tool and the host material. To prevent softened material from being expelled, the pin is passed through the joint line while the shoulder is in close proximity to the work piece's upper surface. Consequently, in order to produce high-quality welds, several other factors also need to be considered in order to get excellent results. The impact of tool pin profiles, tool dimensions, and process parameters on the mechanical characteristics, microstructure development, and material flow behaviour of friction stir welded joints has been extensively studied. RajKumar.V [1] et.al was deals with the characterization of friction stir welded dissimilar Aluminum alloys AA 5052 and AA5052. The coupons of above metals were friction - stir welded using cylindrical pin tool using at constant speed of 710 rpm and at two different feed rates of 28 and 20 mm/min. Tensile, test and hardness measurements were done as a part of mechanical characterization. Correlating mechanical and metallurgical properties it is deduced that the sample welded at lower feed rate performed better in terms of ductility. Sadeesh Pa [2] et.al were carried out by friction stir welding (FSW) technique. Optimum process parameters were obtained for joints using statistical approach. Five different tool designs have been employed to analyze the influence of rotation speed and traverse speed over the micro structural and tensile properties. R. K. Kesharwania, [3] et.al were executed optimization of parameters affecting weld quality in tailored friction stir butt welding of 2.0 mm thin dissimilar sheets of AA5052-H32 and AA5754-H22 using Taguchi grey based approach. After welding, the weld strength and percentage elongations have been evaluated using uniaxial tensile test. Based on the experimental data, empirical relations among the parameters correspond to each output feature has been developed using simple regression method. M. Ilangovan [4] et.al were analyzed Joints between two different grades of aluminum alloys are need of the hour in many lightweight military structures. In this investigation, an attempt has been made to join the heat treatable (AA 5052) and non-heat treatable (AA 5086) aluminum alloys by friction stir welding (FSW) process using three different tool pin profiles like straight cylindrical, taper cylindrical and threaded cylindrical.

It also resulted in higher hardness values of 83 HV in the stir zone and higher tensile strength of 169 MPa compared to other two profiles. The increase in hardness is attributed to the formation of fine grains and intermetallic in the stir zone, and in addition, the reduced size of weaker regions, such as TMAZ and HAZ regions, results in higher tensile properties. K. Kimapong [5] et.al were investigated the effects of pin rotation speed, position of the pin axis, and pin diameter on the tensile strength and microstructure of the joint. The maximum tensile strength of the joint was about 86% of that of the aluminum alloy base metal. A small amount of intermetallic compound was also often formed at the interface between the steel fragments and the aluminum matrix. N. T. Kumbhar [6] et.al were carried out at various combinations of tool rotation speeds and tool traverse speeds. The inter diffusion of alloying elements and development of similar orientations in the nugget could have contributed to the better tensile properties of the friction-stir-welded AA5052-AA5052 specimens. W H Jiang [7] et.al were demonstrates that friction stir welding (FSW) is a feasible route for joining 5052 aluminum (Al) alloy to AISI 1018 steel. The weld has a good weld quality and is free of cracks and porosity. During FSW, localized melting of the Al alloy in the nugget occurred, and the molten Al alloy reacted strongly with steel pieces spread through the nugget, which resulted in the formation of the Al–Fe intermetallic compounds, Al13Fe4 and Al5Fe2. Vukčević Milan [8] et.al were analyzed mechanical parameters in friction stir welding process is current and insufficiently explored, it is particularly present considering the class of aluminum alloy series 6000 (Al Mg Si). The research paper includes forces measurement: the down force - Fz, which is known as the welding force, traversing force Fx – and side force - Fy, as well as mechanical testing - tensile testing of welded joints and tensile testing of welding zone using standard machines and standard test pieces. A Boșneag [9] et.al was experimentally studied which includes welding three dissimilar aluminum alloys, with different properties, used in aeronautics industry, these materials are: AA 2024, AA5052 and AA7075. After welding with different parameters, the welding join and welding process will be analyzed considering process temperature, process vertical force, and roughness of welding seams, visual aspect and micro hardness. K.V.P.P Chengdu, [10] et.al were analyzed in many industrial applications, steels are readily replaced by non-ferrous alloys, in most cases by aluminum alloys. The main aim of goal is to satisfy the mechanical properties of Al alloy5052 like yield strength, ultimate tensile strength and percentage of elongation etc by using FSW technique.

II. FABRICATION OF TOOL PROFILES

Three distinct fashioned tool profiles—such as square, cylindrical, taper cylindrical, are established locally in this investigation (Figure .1A to 1C).

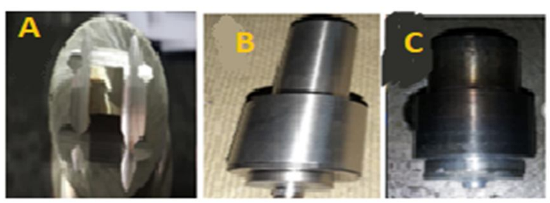

Fig. 1 (A) Square profile (B) Taper cylindrical profile (C) cylindrical profile

H-13 hot and cold work tool steel, which is renowned for its resistance to thermal fatigue cracks, is used to create tool profiles. Because its primary alloying elements are chrome, molybdenum, and vanadium, H-13 steel can tolerate temperatures of up to 530°C. The interference surface configuration between the shoulders and the work piece, as well as the shoulder to pin diameter (D/d) ratio, are same in all three profiles. CNC turning and milling centres are used in the production of FSW tools. In order to achieve a hardness of 45 to 53 HRC, oil hardening has been started on the manufactured tools.

Fig. 2 Vertical Milling Machine, LML – KODI 40

1) Welding condition and process parameters.
2) Parameters AA 6082& AA5052 (Bimetallic joint)
3) Tool rotational speed Rpm-800,900 &1000
4) Tool traverse speed-20 mm/min
5) Axial force-8, 9 & 10kN
6) Tool profile- Square, Taper cylindrical, Hexagonal
7) Tool shoulder diameter- 22 mm
8) Tool pin length- 5.6 mm
9) Tool inclination-1°
10) Tool material H-13.

A. *Friction Stir Welding of Aa6082&Aa5052*

Both aluminium alloy 6082 & 5052 is a medium strength alloy with excellent corrosion resistance, chiefly used in highly stressed applications; it is highly ductile and tough due to the presence of manganese. Its chemical properties can be observed from Table 1. Rolled both alloy sheets of 100 X 100 X 4 mm were prepared using shearing process. Initially a mathematical table was constructed based on Taguchi's orthogonal array formation technique as shown in Table 2, to associate FSW process parameters like tool rotational speed, types of pin profile and axial force with the weld quality. Vertical milling machine LML – KODI 40 milling setup and welded plate shown in Figure 3 .

TABLE 1
CHEMICAL COMPOSITION OF AA6082&AA5052 IN (%)

Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	Al
1.00	0.5	1.20	1.30	0.1	0.2	0.1	0.25	Bal
AA5052								
0.1	0.4	2.8	0.25	0.1	0.1	0	0.35	Bal

All the produced samples are extensively analysed by employing Taguchi based Analysis method. Progressions are further made to refine between the better outcomes from each tool profiles. Welding is further repeated by producing 9 trials with the obtained results from Taguchi based for each tool profile, thereby optimizing the process parameters for Friction stir welding. All the produced samples had been thoroughly scanned for bead width, depth of penetration and heat affected zone.

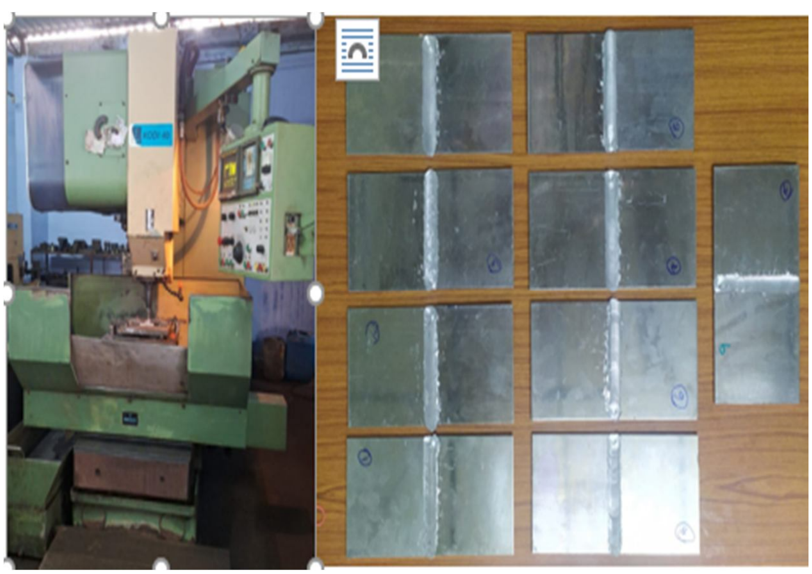

Fig. 3 VMC Setup & FSW trials from different tool profiles

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue X Oct 2025- Available at www.ijraset.com

The figure 4 illustrates the testing photo of hardness and tensile characteristics.

Fig. 4 Testing photo of mechanical behaviours

III. TAGHUCHI PHILOSOPHY

In the manufacturing sector, Taguchi promoted a great philosophy of quality control. Indeed, his philosophy is producing a completely new breed of quality-thinking, quality-living engineers. Indeed, he has created a new culture of quality in this nation. For instance, Ford Motor Company mandated in the early 1990s that all engineers working for Ford Motor and its suppliers receive training in the Taguchi approach and that quality problems be addressed using these concepts. Despite its broad implications, Taguchi's worldview is based on three extremely basic ideas.

A. Design of Experiment

Using a single objective function, three levels and three factors were chosen for the FSW process in accordance with the Taguchi design. Both super alloys were machined using different process parameters in accordance with the L9 array. Process parameters and their levels are shown in Table 2.

TABLE II

LEVELS OF PROCESS PARAMETERS

S.NO	Rotational speed (RPM)	Tool pin profile (Shape)	Axial force (KN)
1	800	TAPCYL	8
2	900	CYL	9
3	1000	SQUARE	10

The table 3 shows Taguchi L9 array with output responses of bimetallic joints during the various output mechanical behaviours

TABLE III

BIMETALLIC AA- FSW INPUT AND OUTPUT RESPONSES

T.NO	Rotational speed (RPM)	Tool pin profile (Shape)	Axial force (KN)	Hardness (HRB)	TS N/mm2
1	800	TAPCYL	8	52	6.63
2	800	CYL	9	55	22.26
3	800	SQUARE	10	55	6.12
4	900	TAPCYL	9	48	1.68
5	900	CYL	10	59	57.71
6	900	SQUARE	8	56	25.1
7	1000	TAPCYL	10	56	45.2
8	1000	CYL	8	68	44.56
9	1000	TAPCYL	9	52	21.81

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B. Graphical Representation Of Mechanical Behaviours Of FSW Process Of Bimetallic Joints

Parameters versus various mechanical behaviours such as hardness and tensile of the FSW process are depicted in Figure 5 &6.

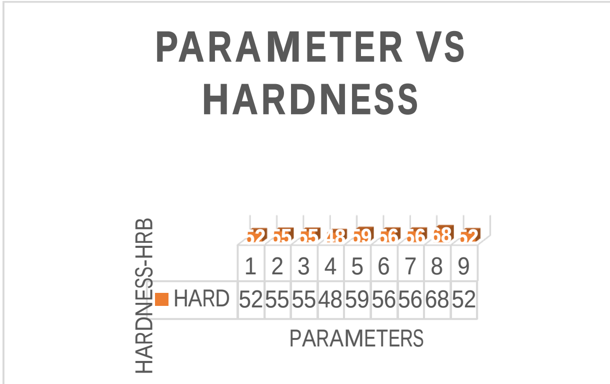

Fig 5 Parameter Vs Hardness

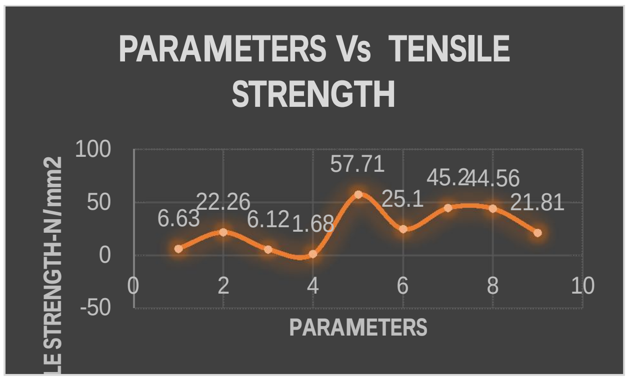

Fig. 6 Parameter Vs Tensile strength

IV. OPTIMAL CONTROL FACTOR OF MECHANICAL AND GEOMETRICAL CHARACTERISTICS

Using MINI TAB17, the optimal control factor results from Tables: 6 to 11 were assessed for each output response analysis using the Taguchi design's single objective function.

A. Optimal Control Factor &ANOVA Table - Hardness

The Table: 4 Shows hardness response for each level of the process parameter and obtained optimum level rank was A_3 B_1 C_2 by using Taguchi approach.

TABLE IV

RESPONSE TABLE OF HARDNESS – (CONDITION IS SMALLER IS BETTER)

Level	RPM	TPP	AXF
1	-34.64	-35.62	-35.31
2	-34.67	-34.89	-34.25
3	-35.31	-34.31	-35.06
Delta	0.67	1.32	1.06
Rank	3	1	2

TABLE V
ANOVA TABLE FOR HARDNESS

Source	DF	Seq SS	Adj MS	F	P	% Of Contribution
Speed	2	55.392	27.696	14.94	0.063	23
Tool profile pin	2	127.625	63.812	34.42	0.028	52
Axial force	2	40.225	20.112	10.85	0.084	23
Error	2	3.708	1.854			2
Total	8	250.000				100

B. Optimal Control Factor & ANOVA Table - Tensile Load

The Table: 6 shows tensile load response for each level of the process parameter and obtained optimum level rank was A_2 B_1 C_3 by using Taguchi approach.

TABLE VI
RESPONSE TABLE OF TENSILE LOAD (CONDITION IS LARGER IS BETTER)

Level	SPEED RPM	TOOL PIN PROFIL	AXIAL FORCE KN
1	19.71	31.72	25.80
2	22.57	23.50	19.41
3	30.95	18.01	28.02
Delta	11.25	13.71	8.61
Rank	2	1	3

TABLE VII
ANOVA TABLE OF TENSILE STRENGTH

Source	DF	Seq SS	Adj MS	F	P	% of contribution
Speed	2	1004.8	502.4	3.23	0.236	32
Tool profile pin	2	1128.5	564.2	3.63	0.216	36
Axial force	2	667.7	333.8	2.15	0.318	22
Error	2	311.0	155.5			0
Total	8	3111.9				100

V. ANGLE DISTORTION

Angle distortion analysed through AUTOCADD software. During the inspection, plate 2, 3, 6, 8 & 9 found no any deviation from the axis the bead distortion and the bead straightness was assessed using AUTOCAD software and recorded in Table No.8.

TABLE VIII
ANGLE DISTORTION

NO OF PLATES	1st	2nd	3th	4th	5th	6th	7th	8th	9th
ANGLE DISTORTION	1 °	0 °	0 °	1 °	1 °	0 °	1 °	0 °	0 °

VI. VARIOUS SIZES OF BEAD WIDTH, DEPTH OF PENETRATION OF FSW JOINTS

The various bead geometry analysis were executed with the help of Image–J software. The table 9 shows depth and width of weld bead. Fifth weld bead appears maximum depth of penetration and moderate bead width.

TABLE IX
Depth of Penetration and bead width

SL.NO	AREA	MEAN	MIN	MAX	ANGLE	DEPTH	WIDTH
1	0.081	62.662	37.667	92	90	4	14.745
	0.061	60.338	46.667	105.333	90	3.03	
2	0.113	63.889	40.333	87.333	90	4	18.264
	0.083	76.906	53.333	101.333	90	2.87	
3	0.105	71.065	58	100.333	90	4	20.961
	0.092	85.993	58.667	200.667	90	3.529	
4	0.113	60.379	41	131	90	4	15.923
	0.115	71.544	53.333	96.333	90	3.721	
5	0.113	85.358	55.444	252.667	90	4	17.277
	0.121	80.045	56	123	90	3.629	
6	0.105	74.646	55	148.667	90	4	17.642
	0.109	66.123	50	104	90	3.417	
7	0.072	37.827	25.667	62.333	90	4	19.245
	0.136	81.259	54.667	141.667	90	3.286	
8	0.085	43.016	33	70.667	90	4	17.962
	0.07	37.835	27.667	59.667	90	2.929	
9	0.101	81.955	57.333	148.667	90	4	15.763
	0.092	72.325	59.333	98	90	3.234	

VII. WELD APPEARANCE

After friction stir welding process the weld beads were observed and following conclusion were informed below mentioned table.

TABLE X
WELD APPEARANCES

SL.NO	RESULT
T1	Rough texture at weld region, cracks found on top portion of advancing side
T2	Rough texture at weld region, mild cracks found on top portion of advancing side
T3	Very fine texture but Flash effects formed at the Retreating side.
T4	Mild coarse texture but it has no any surface defects.
T5	Very fine texture but excessive flash formed at the Advancing side
T6	Very fine texture but it has no any surface defects. But mild flash effect found
T7	Very fine texture but it has no any surface defects.
T8	Course texture but it has no any surface defects.
T9	Rough texture at weld region, no crack & small warm hole found.

VIII. CONCLUSION OF BEAD GEOMETRY & BEAD APPEARANCE ANALYSIS

1) Through IMAGEJ software depth of penetration and bead width calculator among them fourth sample has satisfied depth and width obtained during this investigation.
2) Seventh specimen is found smooth bead appearance it has no any crack, porosity followed by 4th sample.

IX. RESULT & CONCLUSION

Welds were obtained according to the experimental design with using without filler materials. All welds were found without major defect. The intermixing of metals was also found in the welded samples. During the FSW process, the materials were transported from the advancing side to retreating side behind the pin where the weld were formed. Based on the above results FSW process with cylindrical pin profile execute highest tensile and medium hardness strength value fifth sample 57.7 N/mm2, 59 HRB and depth of penetration value obtained fifth sample good compared than others. Medium speed and higher axial force were very important parameter for the FSW process of bimetallic aluminium alloy with cylindrical tool profile pin.

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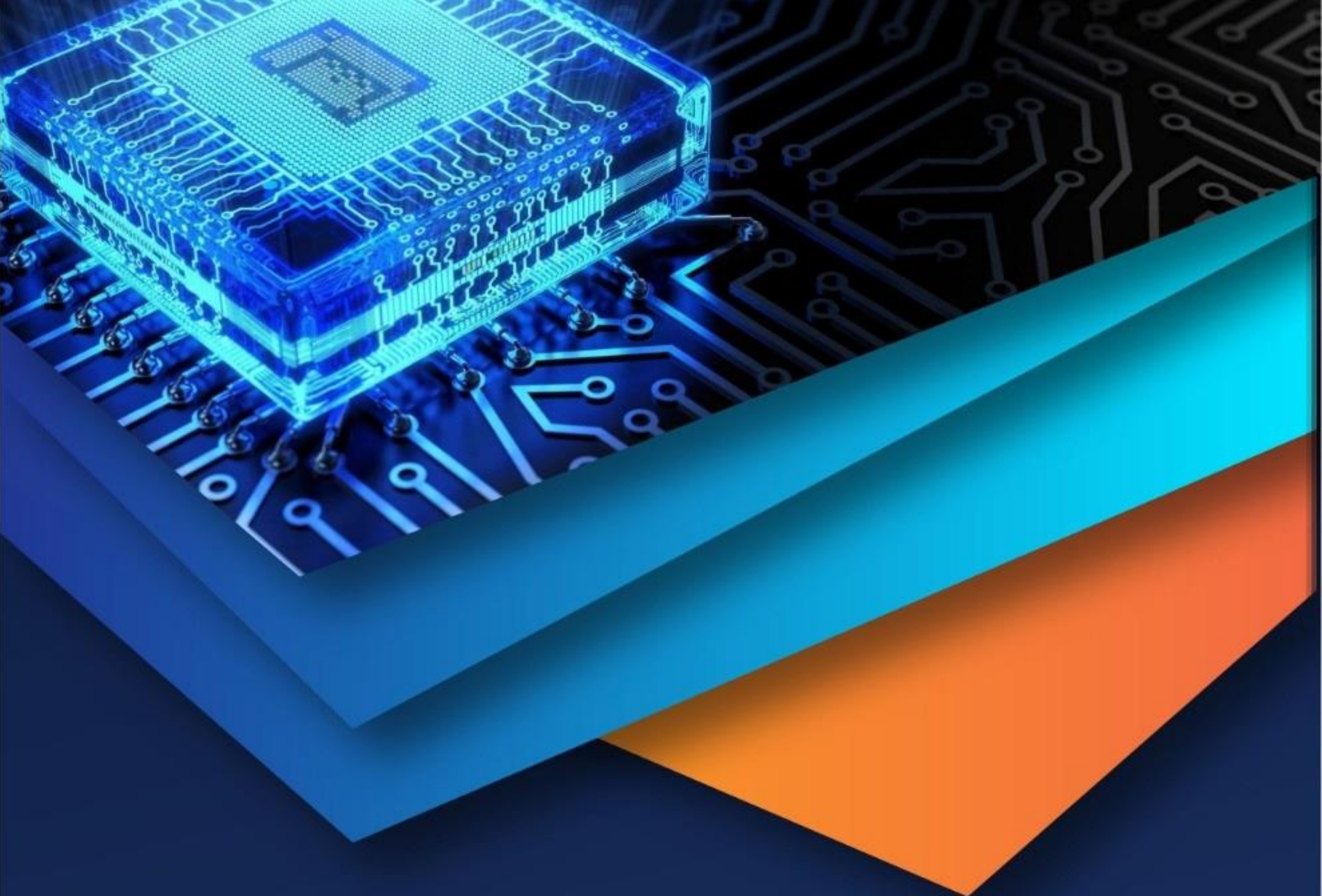

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