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Friction Stir Weld Strength Evaluation and Mechanical Characteristics Investigation on AA 6082 with Various Tool Shoulders

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Abstract: The design of the friction stir welding tool controls the transverse rate at which FSW may be performed and is crucial to material flow. Three main purposes are performed by the tool: (a) heating the work piece; (b) moving material to create the joint; and (c) holding the hot metal under the tool shoulder. Friction between the rotating tool pin and shoulder as well as significant plastic deformation of the work cause heating within the work piece. The purpose of the tool shoulder is to contain the softened, plasticized metal underneath it and to apply heat to the surface of the material being welded by rotating the tool and applying a significant compressive force. One of the key elements of the friction stir welding process is comprehending the temperature generation surrounding the tool shoulder contact. The current study examined how different tool shoulder end features affected the 6082 aluminum alloy's mechanical characteristics and temperature. Convex tool shoulders provide the highest level of weld quality across all types when compared to other tool shoulders, according to the same criterion we used during the FSW joining procedure of AA6082.In the end, it was determined that the FSW of AA6082 would benefit greatly by tapper cylindrical, concave tool shoulders.
Keywords: Shoulder end feature, Temperature, Axial force, Mechanical properties.

I. INTRODUCTION

A component's general needs in the automotive, aerospace, and mechanical industries have created many difficult situations. It is possible to modify new materials and then build them into a usable component [1-3]. The conventional solid phase joining procedure is one such fabrication approach. Solid phase joining is a generic term used to describe a variety of procedures. Depending on the amount of time, pressure, temperature, and heat used, each procedure may differ. There is a point at which many different metals or alloys can be merged together using cold pressure welding without the need for heating. Other extreme processes that use plastic deformation at greater temperatures include friction welding, explosive welding, magnetically impelled arc butt welding, etc [4-7]. The easiest way to solve the issue is through solid state joining, which eliminates the faults because melting is not done. This solid state joining also makes it feasible to integrate immiscible or partially miscible alloy systems, which is difficult with conventional fusion welding. Large-scale industrial operations have made extensive use of a variety of solid state joining techniques [8-10].

A. Principles Of FSW Process

There are two primary groups into which welding methods fall:

1) Liquid-phase welding, which encompasses all welding techniques such laser, electron beam, and conventional arc welding [11-12].
2) Solid-state welding, such as solid-state diffusion bonding, friction stir welding, forge welding, and explosive welding.

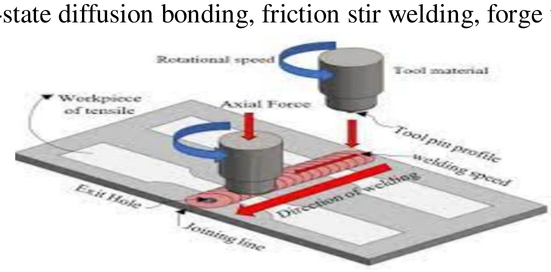

Figure: 1 Principles of FSW Process

Without bulk melting, FSW produces a weld junction. One of FSW's intrinsic advantages over popular fusion welding methods (such as arc and laser welding) is that it is impervious to the flaws and property degradations brought on by solidification. FSW eliminates porosity, solidification cracking, and melting and coarsening of strengthening phases. Furthermore, the microstructure of the weld site is refined by the significant thermomechanical deformation of FSW [13-15]. Therefore, FSW can provide a weld with mechanical qualities comparable to or superior to those of the base metal, while fusion welding typically results in a decrease of the weld properties.

Since the weld zone created by fusion welding procedures is frequently the weakest part of a welded structure for a range of high-performance engineering materials, the enhanced mechanical qualities are a crucial component of FSW [16-18]. The friction stir procedure has also been used to create ultra-fine or even nanostructures, increase casting properties, and refine or change microstructures for super plasticity forming. These days, low-melting-temperature materials mostly different aluminum alloys that are challenging to fusion-weld are joined via the FSW technique.

B. Major Applications Of FSW

Both structural and non-structural applications make extensive use of aluminum alloys. Among the structural applications are

1) Aerospace equipment and automotive components.
2) Industrial, commercial, and material handling uses.
3) Brake and clutch pedal support bracket.
4) Lock housing for steering columns.
5) Manufacturing of honeycomb, rocket engines, helicopter rotor hubs, and turbine parts for the rocket and aerospace missile industries.
6) Production of reactor parts for the atomic energy sector.
7) Diffusion bonding has been introduced into the space shuttle and the lightweight B-1 bomber by controversial aerospace vehicles.
8) Composite material fabrication.

C. Objectives Of The Research

The impact of using different shoulder profile tools, such as square, concave, convex, and tapper cylindrical tools, on Al 6082 alloy plates that are welded using friction stir processing is recorded in this study. It is necessary to use a macro test to evaluate friction stir welded Al 6082 alloy plates. The tests were carried out in accordance with the comparison process, and the tested weld samples from different shoulders were correlated to determine the results.

II. SCOPE OF RESEARCH

Three main purposes are performed by the tool: (a) heating the work piece; (b) moving material to create the joint; and (c) holding the hot metal under the tool shoulder. Friction between the rotating tools pin and shoulder as well as significant plastic deformation of the work cause heating within the work piece. The purpose of the tool shoulder is to contain the softened, plasticized metal underneath it and to apply heat to the surface of the material being welded by rotating the tool and applying a significant compressive force [19].

Additionally, the compressive stress reduces the amount of voids or pores that occur in the consolidated metal. A 100 × 100 × 4 mm Al 6082 specimen with the following parameters variable RPM, feed, and tool shoulder profile with constant axial load will be used for the experimental work.

III. MATERIALS AND METHODS

For this research analysis AA6082 is a base material and LML-KODI 40-VMC is the machine setup used for this research analysis were used many type of tools shoulder profiles. The Figure: 2 shows the LML KODI-40 Setup.

A. Aluminium-6082

Silicon and Magnesium is the main alloying element of 6082 aluminum, a heat-treatable aluminum alloy. It can be heat-treated to high strength levels after forming and is pliable when in the fully soft, annealed temper. It is frequently utilized in aircraft applications because of its strong strength to weight ratio [20].

Figure: 2 Vertical Milling Machine

IV. TOOL PROFILE USED

In this investigation, friction stir welding was performed using aluminum alloy as the base metal. Although different tool shoulders are utilized in the welding process, the prepared samples were welded cylindrical tool pin profiles.

A. Diagram Of Tool Shoulders With Dimension

Figure: 3 shows various types of tool shoulder diagrams of various shoulder tools with dimensions made-up of H-13 Cold work steel. The below mentioned various tool shoulders were utilized joining process of AA6082 with constant parameters and Figure: 4 illustrates the photography of the various tool shoulders FSW Tool images.

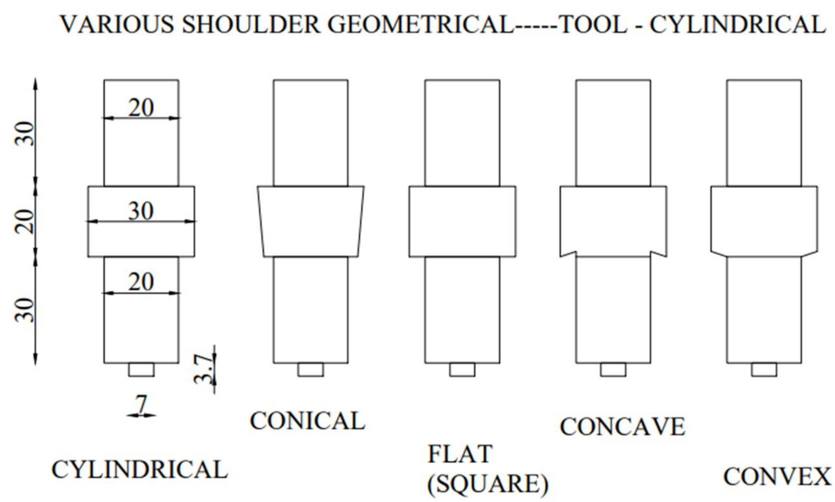

Figure: 3 FSW tool shoulder Diagram

Figure. 4 Friction stir weld tool with various shoulder images

V. EXPERIMENTAL WORK

In this investigation, friction stir welding have been performed using aluminum alloy 6082 as the base metal. Although different tool shoulders were utilized during the welding process, the produced samples were welded with cylindrical tool pin profiles. And weld plate images shows on the Figure no: 5. The Table: 1 illustrates the machining parameters of the FSW process of the corresponding tool shoulder images.

Table: 1 FSW input process parameters

SHOULDER PROFILE	SPEED RPM	TOOL-TR Mm/min	AXFC KN
Cylindrical	1000	14	10
Taper Cylindrical	1000	14	10
Square	1000	14	10
Concave	1000	14	10
Convex	1000	14	10

A. Various Tool Shoulders And Weld Plate Images

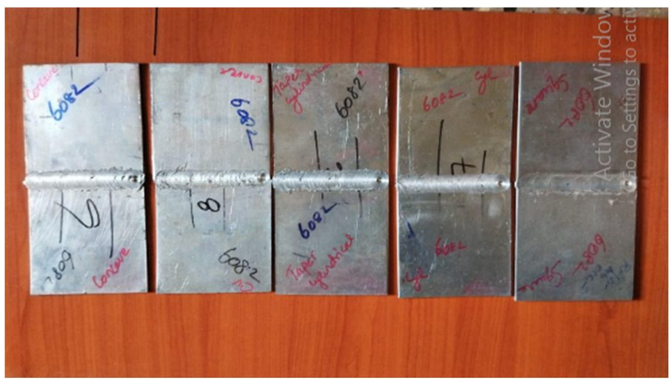

Figure: 5 FSW Plates

B. Macro Weld Behaviour Analysis

After the FSW process as per ASTM standard size were followed to create the weld specimens of the FSW plates. During the process mechanical behaviour such as hardness, tensile strength & Root bend strength were found. The Figure no: 6 [a] shows Rockwell hardness, 6 [b] illustrates tensile test & 6[c] illustrates root bend test during the evaluation.

[a] [b] [c]

Figure: 6 Mechanical behaviour analysis FSW test Plates

The Table no: 2 signifies the various mechanical behaviour results such as hardness, tensile strength & root bend strength.

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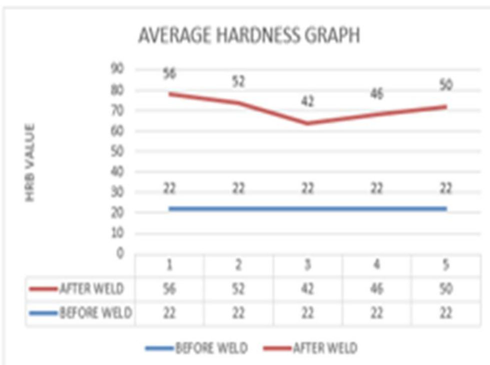
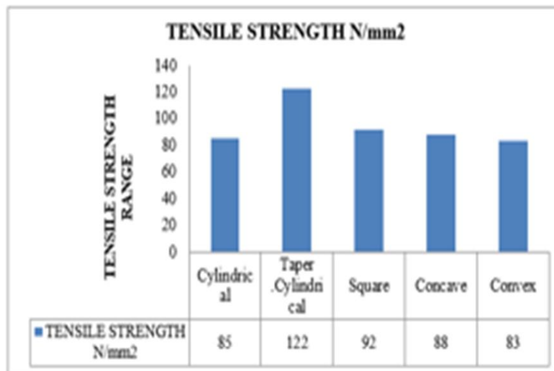
Table: 2 Mechanical behaviour results of various FSW tool shoulders

SHOULDER PROFILE	BEFORE HARDNESS HRB	SPEED RPM	TOOL-TR Mm/min	AXFC KN	Avg HARDNESS (HRB) AA 6082	TENSILE STRENGTH N/mm2	ROOT BEND STRENGTH N/mm2
Cylindrical	22	1000	14	10	56	85	153.98
Taper Cylindrical	22	1000	14	10	52	122	99.64
Square	22	1000	14	10	42	92	172.10
Concave	22	1000	14	10	46	88	190.22
Convex	22	1000	14	10	50	83	135.87

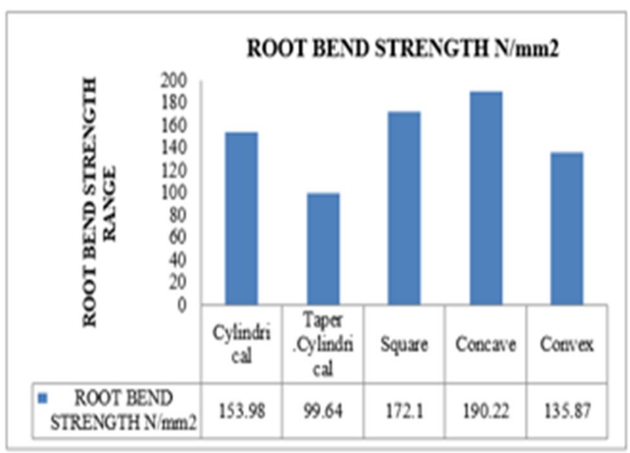
The Figure no: 7 was illustrates the graphical representations of tool shoulders Vs Hardness, Tensile strength & Root bend strength.



[a]



[b]



[c]

Figure: 7 Graphical representation of mechanical behaviour

According to mechanical behavior studies, the cylindrical tool pin profile had the maximum hardness and square tool shoulders the lowest. In accordance with the tensile strength, the FSW tool's concave tool shoulder produced a greater root bend strength than the tapper cylindrical tool shoulder.

C. Angle Distortion

The bead distortion analysis of FSW Plates is displayed in Figure No. 8. The bead straightness was assessed using AUTOCAD software and recorded in Table No. 3.

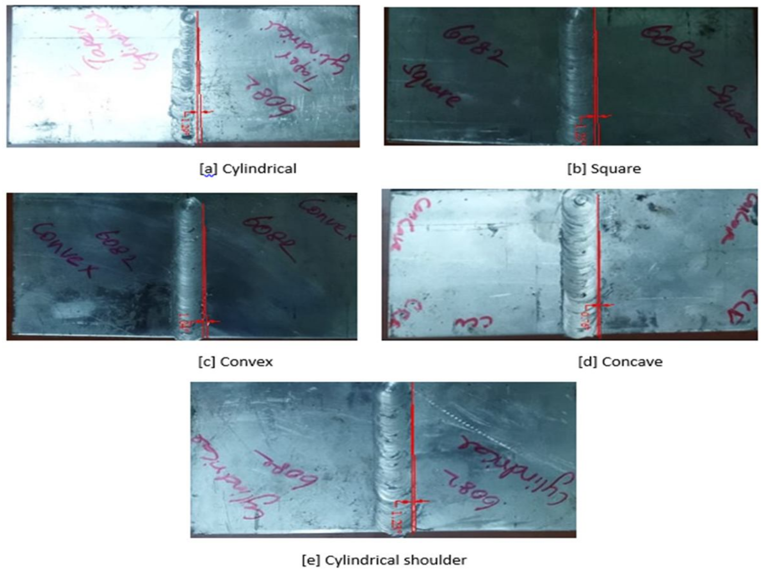


Figure: 8 Angle Distortion evaluation of various test plates

Table: 3 Angle distortion of various shoulders

SHOULDER PROFILE	ANGLE DISTORTION°
Cylindrical	1.23
Taper Cylindrical	1.25
Square	1.25
Concave	1.04
Convex	1.04

The concave and convex tool shoulders showed the least amount of variation (1.04°). The Figure no: 9 represents the tool shoulders Vs Angle distortion of the weld plates.

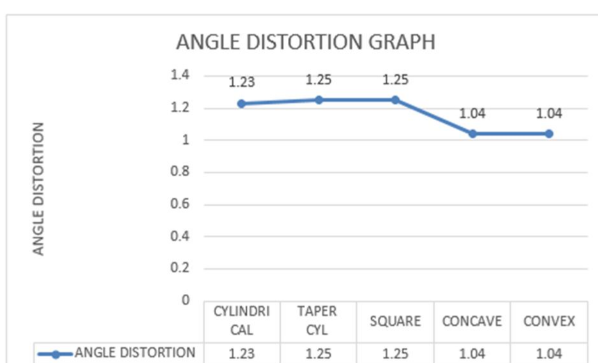


Figure: 9 Angle distortion analysis

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D. Weld Appearance

Weld bead appearance were observed and the following conclusions were reported in the Table no: 4. In our experiment, we discovered that a smooth bead appearance was achieved at both cylindrical and concave shoulder tools at a speed of -1000 RPM, a traverse speed of 14 mm/min, and an axial force of 10 KN. The cylindrical shoulder tool profile exhibits a mild transverse crack and a coarse bead images.

Table: 4 Weld appearances

SHOULDER PROFILE	WELD APPERANCE
Cylindrical	Fine weld texture at weld region
Taper Cylindrical	Very fine texture but crack occurs on the center of the weld.
Square	Rough texture at weld region some pin holes found middle of the weld,
Concave	Rough texture at weld region it has no crack of the weld region
Convex	Very fine texture but mild porous effects formed at the initial weld.

VI. DEPTH OF PENETRATION OF VARIOUS SHOULDERS PROFILE OF FSW PLATES

Since penetration impacts a welded joint's ability to withstand stress, inadequate weld bead dimensions, such as a shallow depth of penetration, may lead to the collapse of a welded structure. In order to prevent such incidents, the welding process variables that affect the weld bead penetration must be carefully chosen and adjusted in order to achieve a satisfactory weld bead penetration and, consequently, a high-quality union. Researchers have used a variety of methods to forecast how welding process variables would affect the geometry of the weld beads and, consequently, their quality. Through Image J software the depth of penetrations were calculated and illustrates it Figure no 10.

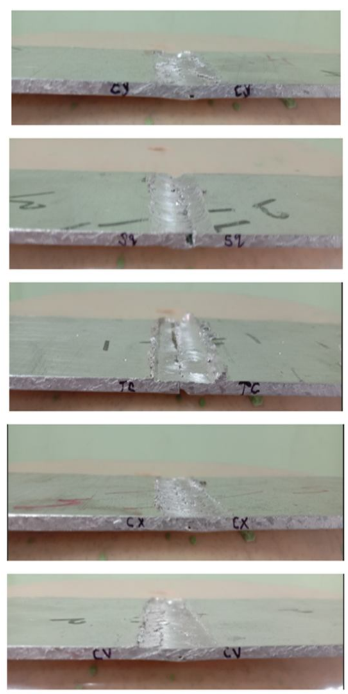

Figure: 10 Bead geometry analysis

The Table no: 5 illustrates the depth of penetration value were found through IMAGE-J software.

Table: 5 Depth of Penetration values of various tool shoulders

Samples	Tool Profile	Depth of Penetration mm
S_1	Concave	2.56
S_2	Convex	2.4
S_3	Square	3.333
S_4	Tap Cylindrical	3.2
S_5	Cylindrical	2.364

A. Tool Shoulder Versus Depth Of Penetration

Image J software is used to measure the depth of penetration. After all the plating was completed using different AA6082 tool shoulders, square and taper cylindrical tool shoulders were discovered to have the greatest penetration depth.

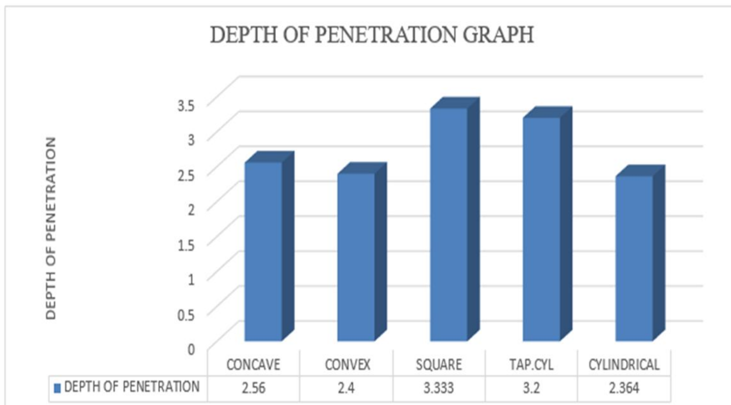

Figure: 11 Depth of penetration

VII. RESULT & CONCLUSION

Several FSW tool shoulder profiles were compared and the FSW constant process parameter was assessed. In general, the weld quality has also been impacted by the tool shoulder profile. We have utilized square, convex, concave, wedge, and cylindrical tool shoulders for the FSW procedure.

1) According to this study, the concave tool shoulder profile tool executes without cracking and displays a nice weld bead following the FSW process.
2) During the process of welding with a square shoulder tool pin (42HRB), a low hardness value was attained.
3) In contrast to other tool shoulders, the cylindrical tool profile tool shoulder was accomplished with a very fine texture based on the weld appearance.
4) Compared to other tool shoulders, the taper cylindrical tool shoulder produced the highest tensile strength (122 N/mm^2).
5) Compared to other shoulders, the concave tool shoulder produced the highest bending strength (190.22 N/mm^2).
6) AUTOCAD analysis of the Angle Distortion Plate or Bead Straightness revealed that the maximum deviation was 2.5° in the tool shoulders at the square, taper cylindrical, and cylindrical shapes. The concave and convex tool shoulders showed the least amount of variation (1.04°).
7) Image J software is used to measure penetration depth. After all the plating was completed using different AA6082 tool shoulders, the Square tool shoulder was discovered to have the greatest penetration depth.

Among the several types of tool shoulders, the taper cylindrical tool shoulder exhibited the highest tensile strength, whereas the square tool shoulder exhibited the greatest depth of penetration. The lowest angle distortion were achieved concave & convex during the FSW process. The maximum root bend strength obtained at concave tool shoulders compared to other shoulders. It was determined that the FSW of AA6082 would benefit greatly by concave tool shoulders compared to other tool shoulders.

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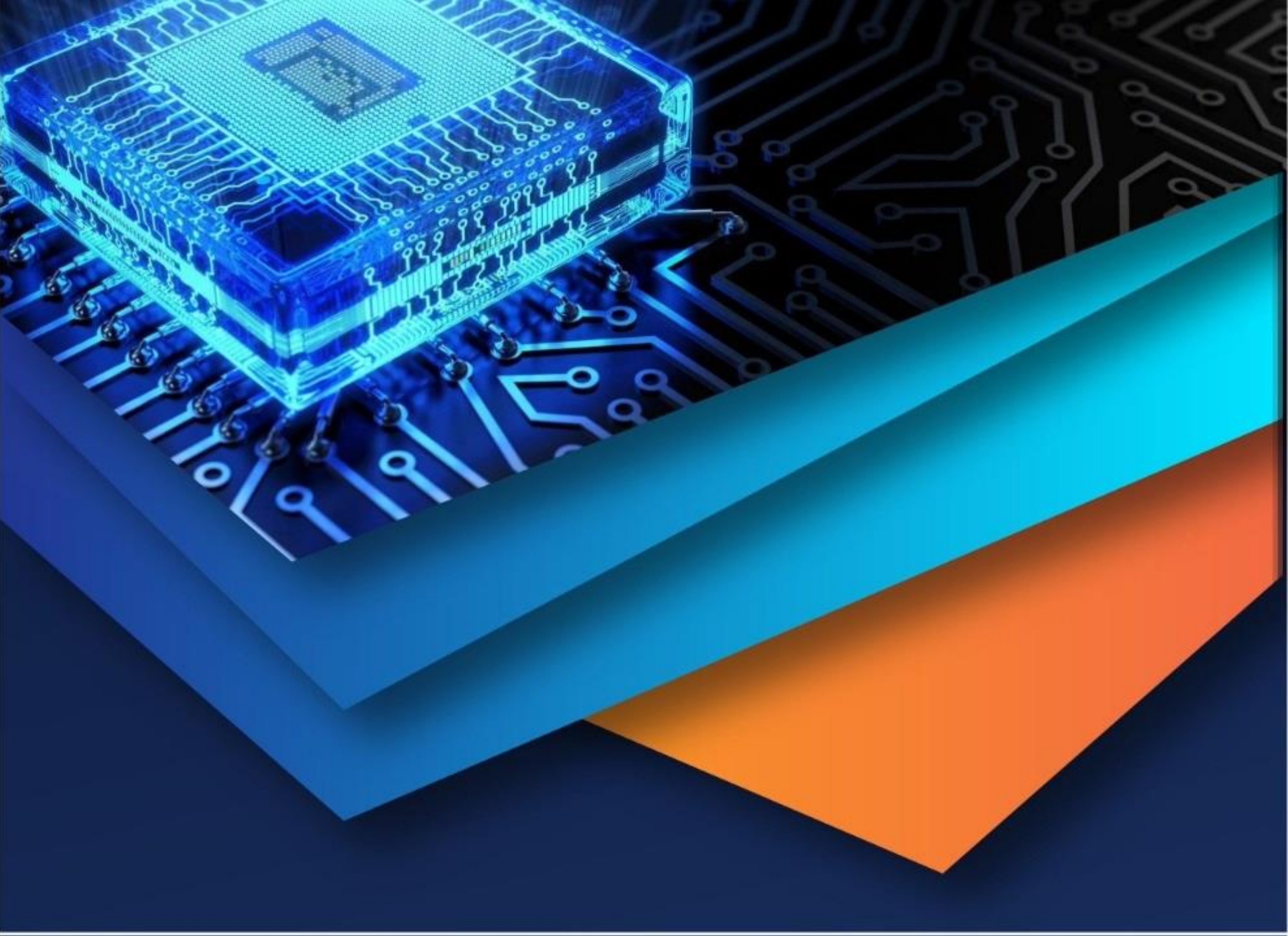

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