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Experimental Investigation of Material Flow and Welding defects in Friction Welding process of Cu-SS Dissimilar Materials

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Abstract: A particular form of welding that makes use of the heat produced by friction is called friction welding. A pressure force contacts the surfaces of two materials that need to be connected; one is rotating while the other is at rest. In order for the heat produced by the continuous friction to continue rising, friction is applied continually to the second contact surface. In this study, dissimilar friction welding between grade 308 L stainless steel (SS) and copper (Cu) is investigated for a pipe joint design with a wall thickness of 1.50 mm and an outer diameter of 13 mm. The machine RPM, dwell duration, friction time, and friction force are the constant parameters that are used. The maximum ultimate tensile strength of 764 MPa, or almost 128% of the SS base material, was found in the SS to SS weld sample and 104 MPa, or nearly 80% of the Cu basis material, in the CU to CU weld sample. The most significant maximum tensile strength of 349 MPa was achieved by SS to Cu. In along with the study of the mechanical behavior and microstructure, the weld quality was evaluated using corrosion behavior analysis and leak proof testing.
Keywords: Friction welding, SS308L, Copper, Tensile strength, VHN.

I. INTRODUCTION OF DISSIMILAR WELDING

Dissimilar materials welding is an amazing process that has many benefits, such as the capacity to fuse different properties into one part, build lightweight structures, lower total costs, and boost productivity through innovative engineering methods. Copper (Cu) and stainless steel (ASS) is one of these material pairings having distinct physical, chemical, and thermal properties. However, there is a lot of interest in Cu-SS welding because of its unique uses, cost-effectiveness, and independent thermal performance at both ends. It also improves the mechanical and thermal efficiency of heat exchangers. Despite the appealing engineering solutions and future uses, the Cu-SS combination is challenging to weld due to variations in metallurgical properties. Because welding this unique combination Cu-ASS joint presents substantial problems, traditional fusion welding procedures are not sufficient to produce robust, error-free welds. It is not practical to use traditional fusion welding to join many of these incompatible metal combinations due to metallurgical incompatibility, large melting point variations, temperature incompatibilities, and other factors.

II. PRINCIPLE OF FRICTION WELDING

In conventional friction welding, one component is moved in relation to the other along a shared interface while a compressive force is applied across the joint. Both components are softened by the friction heating created at the interface, and as they plasticize, the interface material is forced out of the joint's edges, leaving only the clean material from each component along the original interface. After stopping the relative motion, the joint may be allowed to cool down before applying a higher ultimate compressive force. The secret of friction welding is that the weld forms in a solid state without the production of molten material.

A. Friction Welding

One method of solid-state welding is friction welding. The heat produced by friction between rubbing surfaces is what causes the coalescence because it elevates the temperature at the interface to a point where high pressure forces the two surfaces to meld together. When it comes to joining techniques that are easily automated and result in joints with uniform mechanical qualities, friction welding is the favored method during the fabrication process. Friction welding's sub-melting temperatures and quick weld periods enable the joining of a wide variety of work metal combinations.

This procedure does not call for the use of shielding gas, flux, or filler metal. In the instance of a metal matrix composite (MMC) with oxide particles or short fibers as the strengthening phase, friction welding was successfully used.

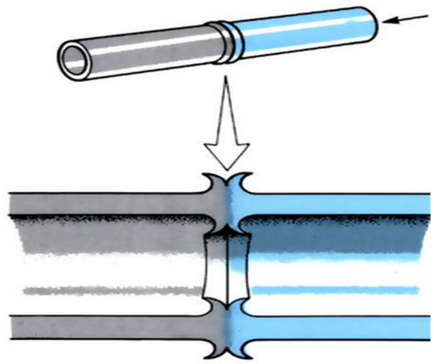

Fig 1 Friction welding

B. Application of Friction Welding

Because inertia welding is fast and requires little cleanup, it is a good option for a lot of commercial items. Tool extensions, tool blanks, baseball bats, golf putters, air cylinders, munitions, fasteners, oil and water pipe fittings, and commercial parts like bicycle parts, medical equipment, and marine equipment are examples of items where the 100% strength weld produces a stronger part than traditional welds.

III. MATERIAL AND METHODS

The tube materials chosen for purchased upon confirmation of the tube chemical composition,

1. Stainless steel (SS 308L)
2. Copper

A. Stainless Steel (SS308L)

The low carbon version of grade 308 stainless steel is called grade 308L. Specifically, submerged arc welding of grade 304 stainless steel is carried out with it. In non-corrosive circumstances, it can also be utilized to weld stabilized grades 321 and 347.

B. Copper

With thousands of years of use, copper is one of the most beneficial metals known to man. Because of their special qualities and the fact that they may be produced into foils, strips, rods, plates, tubes, sheets, pipes, forgings, extrusions, wires, and castings from foundries, copper alloys are highly sought-after in a wide range of industries.

C. Machine Details

One of the work components in Fig. 1's direct drive friction welding variation is fixed to a motor-driven unit, while the other is kept from rotating. The workpiece operated by the motor rotates at a set, continuous speed. After moving the work pieces that need to be welded together, a friction welding force is applied. As the faying surfaces (weld interface) rub against one another, heat is produced. This goes on for a given period of time, or until the current level of disturbance occurs. The braking force is applied to stop the spinning workpiece when the rotary driving force is cut off. After rotation stops, the friction welding force is either maintained or increased (forge force). An apparatus for vertical milling designed for the friction stir welding process.

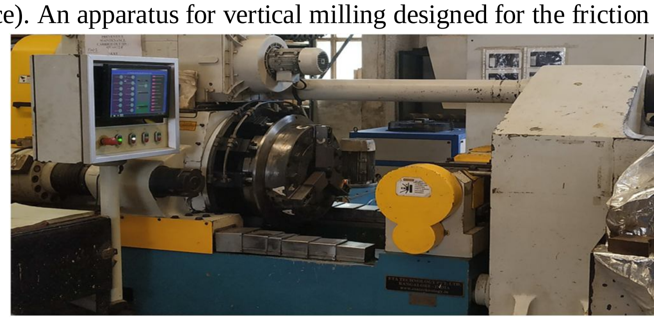

Fig 1 Continuous Drive Friction Welding Machine

D. Welding Parameter
The parameters used in other research friction welding process is as follows and figure (3.3) parameter and phases of continuous driven friction welding.
1) Friction pressure (Pf) 40 MPa
2) Dwell time (t), 15 seconds
3) Rotation (N), 1000 Rpm
4) Upset time (t), 10 seconds

E. Welds Strength Evaluation
Following the friction-dissimilar welding process, a variety of mechanical and optical behavior responses were examined.

F. Visual Inspection
During analyzing welded samples visually, flaws that are obvious to the unaided eye are looked for, including flash generation. The weld surfaces of pipes from both the inner and exterior surfaces are shown in Fig. (2). It is apparent that the flash generation is seen as an inside flash for the inner surface and an outs flash for the outer surface, respectively.

Fig 2 Friction welded dissimilar welded specimens

No surface flaw is seen, and for every weld condition, there is no discernible change in the amount of flash generation. Furthermore, because to variations in the behavior of plastic deformation under applied heat and pressure, there is a greater flash generation from Cu material and a lesser amount from SS material.

Table:1 Visual inspection result analysis

Sample No	Sample name	Spindle speed (rpm)	Dwell time (sec)	Friction pressure (MPa)	Upset time(sec)	Weld quality
1	SS-SS	1000	15	40	10	Good
2	SS-SS	1000	15	40	10	Good
3	SS-SS	1000	15	40	10	Good
4	SS-CU	1000	15	40	10	More CU flash
5	SS-CU	1000	15	40	10	More CU flash
6	SS-CU	1000	15	40	10	More CU flash
7	CU-CU	1000	15	40	10	Good
8	CU-CU	1000	15	40	10	Good
9	CU-CU	1000	15	40	10	Good

IV. TENSILE RESULT OF SIMILAR AND DISSIMILAR FRICTION WELDED SPECIMENS

A. Test 1: Copper to Copper weld sample tensile result

The stress-strain curve in Figure 3 and constant spindle speed of 1000 Rpm and 40 MPa friction pressures were made possible by the copper-to-copper tube weld connections. This demonstrated that, in comparison to the parent material, their weld joints exhibited better tensile characteristics. The CU to CU weld sample showed a maximum ultimate tensile strength of 104 MPa, or about 80% of the Cu base material.

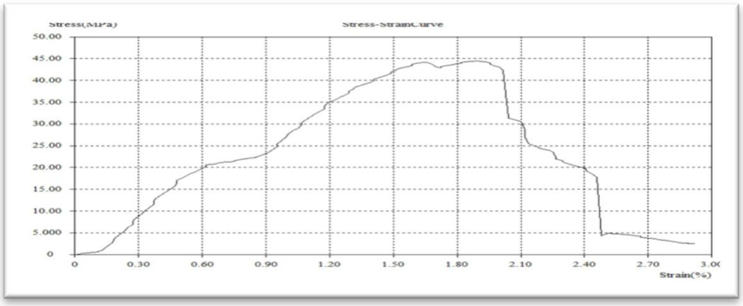

Fig 4 stress strain curve-Cu to Cu

B. Test:2 Copper to Copper Stainless steel to Stainless steel tensile result

The stress-strain curve in Figure 4 and consistent spindle speed of 1000 Rpm and 40 MPa friction pressures were made possible by the stainless steel to stainless steel tube weld connections. This demonstrated that, in comparison to the parent material, their weld joints exhibited better tensile characteristics. The SS to SS weld sample showed a maximum ultimate tensile strength of 764 MPa, or nearly 128% of the SS base material.

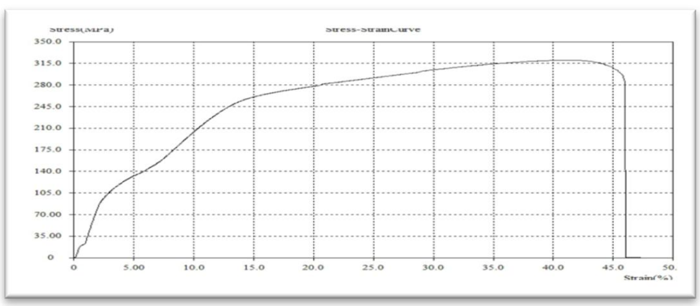

Fig 4.1 stress strain curve-SS to SS

C. Test:3 Stainless Steel to Copper tube Tensile Result

The stainless steel to stainless steel tube weld connections allowed for the steady spindle speed of 1000 Rpm and 40 MPa friction pressures, as well as the stress-strain curve shown in Figure 4. This proved that their weld joints had superior tensile properties compared to the parent material. The maximum ultimate tensile strength of the SS to SS weld sample was 764 MPa, or over 128% of the SS base material.

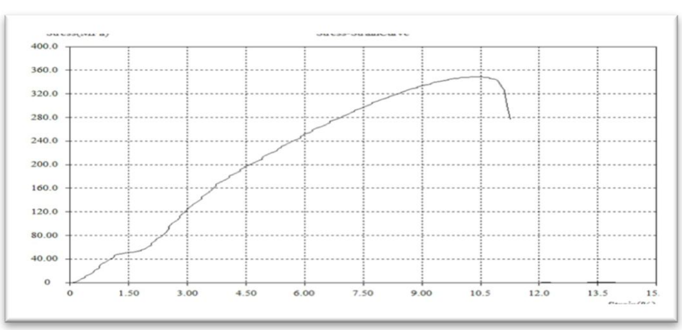

Fig 4.2 stress strain curve-SS to Cu

D. Macro Examination

By using constant rotating speeds in conjunction with constant friction pressure, friction time, forging pressure, and forging time, rotary friction welding of Copper and SS materials was able to create a defect-free joint of CU-CU, SS-SS, and dissimilar material SS-CU.

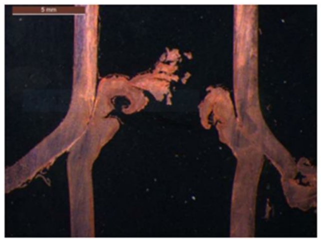

Figure 5.1

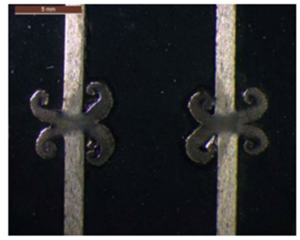

Figure 5.2

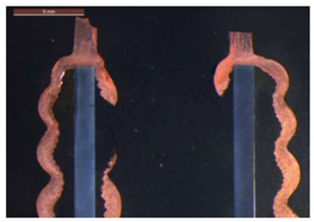

Figure 5.3

The macrophotograph of CU-CU in Figure 5.1 demonstrates that no significant changes were found in The macro-photograph of SS-SS in Figure (5.2) demonstrates that no significant differences in the weld joints' deformation and friction weld between CU-SS (dissimilar materials) were noticed. It is evident from the macrograph in Figure 5.3 that there were no significant differences in the weld joints' deformation.

V. MICRO EXAMINATION

To prepare samples for optical metallography, the welded joint was sectioned at an angle of 90 degrees to the bond-line. The normal metallographic approach was followed in the preparation of the microstructural tests.

A. Micro Examination analysis of SS to SS

The parent metal of austenitic stainless steel showed a "step" between the grains, indicating the presence of carbide particles in the austenitic matrix and annealed twin boundaries. Figure (4.12)

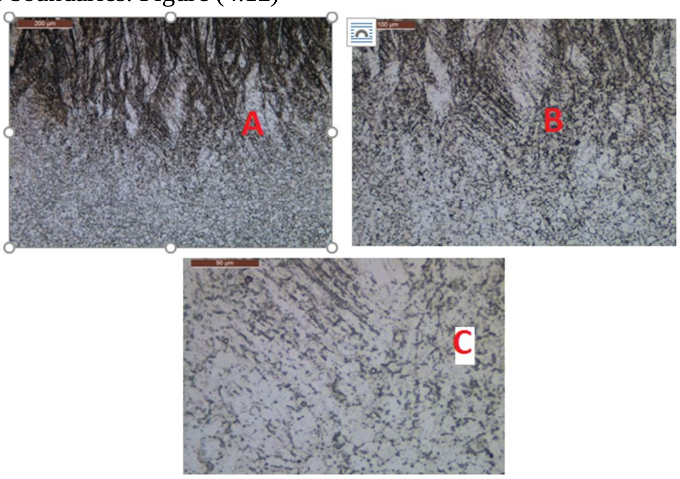

Fig 6 Microstructure of austenitic Stainless Steel Weld sample

B. Micro Examination Analysis of Cu to Cu

In contrast with HAZ, where the microstructure clearly displays recrystallized alpha grains during friction welding and seems coarser, the weld metal in copper (Fig. 4.13) displays coarse alpha grains.

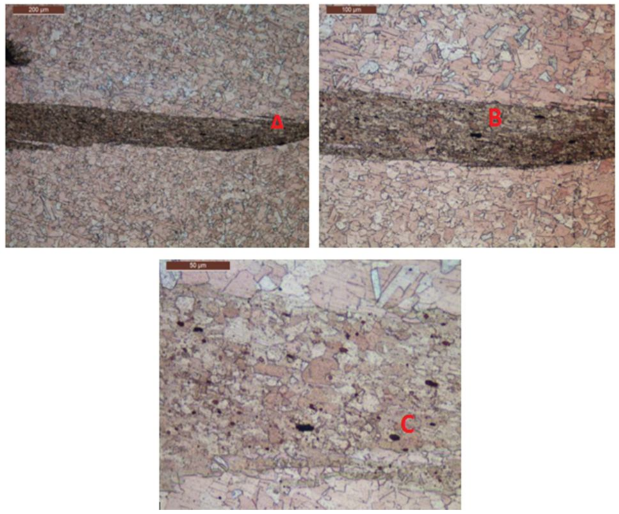

Fig 7 Microstructure of austenitic copper Weld sample

C. Micro Examination Analysis of SS to Cu

Austenitic stainless steel exhibits post-weld grain sizes comparable to the parent material, while copper exhibits finer grains than the parent material (Fig. 8). Fine grains enhance hardening and reveal copper oxide particles in the structure. At the weld contact, certain intermetallic compounds produced as a result of the interdiffusion of constituent elements from the two materials.

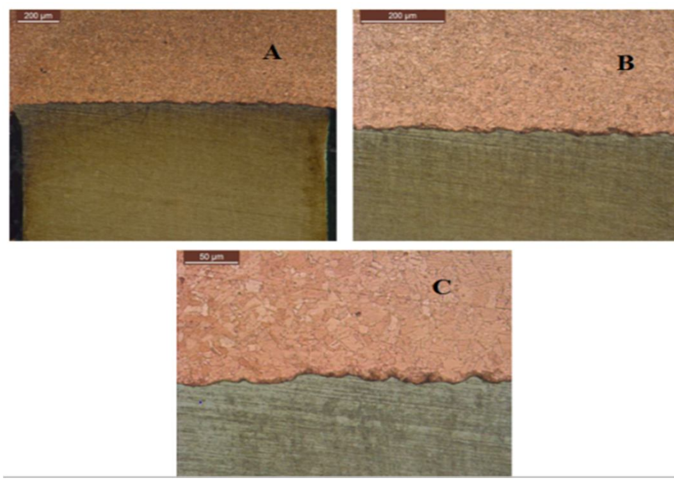

Fig 8 Microstructure of SS and Cu Weld sample

VI. MICRO VICKER HARDNESS EXAMINATION

Using a Vickers Hardness Testing equipment, the micro hardness changes were measured. A continuous load of 300 gms was applied for 15 seconds to determine the hardness value along the weld interface.

The cross-sectional hardness measurements of sample 3, the dissimilar CU-SS welded sample, are displayed in Figure (9). The joint line's hardness was almost the same as that of the copper substance. There are no notable differences in the copper material amongst the CU-SS joint weld samples. Due to mechanical load and the action of frictional heat, which is discussed in the section that follows, deformation and re Crystallization cannot be avoided at the CU side. The hardness of the CU material close to the joint line did not vary much despite the fact that the microstructures did. The side hardness peaks of SS308L were found to be three times higher than those of CU material. Both the SS-SS weld material Fig. (11) and the other combination of CU-CU material Fig. (10) showed a similar trend of hardness changes.

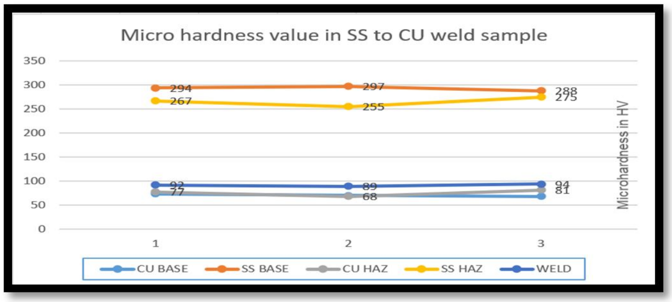

Fig 9 Micro hardness value in SS to CU weld sample

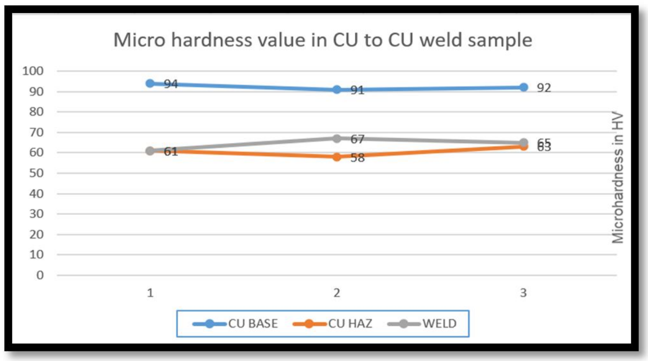

Fig 10 Micro hardness value in CU to CU weld sample

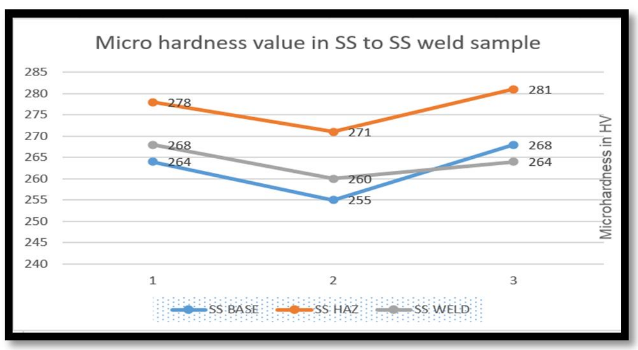

Fig 11 Micro hardness value in SS to SS weld sample

A. Salt Spray Examination

The salt spray test (ASTM B117) was used to determine the corrosion rates of the base and welded specimens.A hygrometer measured 98% humidity at room temperature (33 to 35 degrees Celsius) during the inspection. For atomization, a steady air pressure of two to three bar is maintained via the pressure regulator. The salt spray corrosion testing setup shown in Fig. (12).

Fig 12 Salt spray corrosion setup

Tests with salt spray were carried out for a total of 72 hours. Samples were evaluated at predetermined intervals. We looked at the different, similar, and dissimilar weld joints used in the salt spray analysis, and we could not see any noticeable alterations to the weld surface. The results are shown in the table below:1.

Table: 2 Salt spray test result of welded samples

Test Parameters	Observed Values
Copper to copper weld samples	Green spots formation noticed at 24Hrs and continued till 72Hrs.
SS to SS Weld samples	Red Rust formation noticed on weld joint area only at 24Hrs and continued till 72Hrs
SS to copper weld samples	Green spots formation noticed on copper tube surface only at 48Hrs and continued till 72Hrs

B. *Helium Leak Test Examination*

After testing at a pressure of 3.5*10-6 mbar l/sec, the helium leak test verified that all joints were sound. From friction-welded CU-CU, CU-SS, and SS-SS joints, joint efficiency was attained.An examination for helium leakage is performed on the welded specimens.

The results of vacuum tests conducted following helium spraying at 3.5*10-6mbar l/sec pressure are displayed in Table 2. It is verifiable that every specimen has reached acceptance without any leaks being discovered. The helium gas is drawn out in the event of a leak, which increases the rate of leakage.

Table:3 Helium leak test results

Sample Ids	A	B	C
	Copper to Copper tube	Copper to SS Tube	SS to SS Tube
Background reading (m bar)	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec
Initial leak rate (m bar l/s)	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec
Helium spray time leak rate (m bar l/s)	3.5*10-6mbar l/sec	3.5*10-6mbar l/sec	3.5*10-6mbar l/sec
Results	Acceptable without leak detection	Acceptable without leak detection	Acceptable without leak detection

VII. CONCLUSION

The current study effectively examines dissimilar friction welding on Cu-SS materials for tube joint arrangement, where the wall thickness to tube diameter ratio is 0.061 (with a wall thickness of 0.80 mm and a tube diameter of 13 mm). The current study allows for the deduction of the following conclusion.

Copper and austenitic stainless steel have been successfully joined using friction welding. Rotational speeds of 1000 revolutions per minute were used to vary the tensile strength values on joints. The bond strengths were similar to those of the copper parent material. The joints that were obtained had good strength and reasonable ductility in copper. The experiment found that copper tubes and austenite stainless steel are useful welding materials. Compared to copper tubes, austenite stainless steel is a more noble metal and a good corrosion-resistant material. The microstructural examination of the SS-SS, CU-CU, and CU-SS tube junctions revealed excellent material flow and weld quality. Furthermore, there were no flaws in the weld zone. While no discernible microstructure changes are seen at the SS side, there are noticeable microstructure changes at the Cu side close to the Cu-SS weld interface. Full dynamic recrystallization zone and partial dynamic recrystallization zone are the names given to the microstructures on the Cu side. Friction welding can be used to join various metals together, but for the process to work well, the parameters between friction time and frictional pressure must be determined. Friction welding has been successfully used to join the dissimilar materials of CU-CU, CU-SS, and SS-SS tube junctions, resulting in defect-free and leak-proof joints that can function in 3.5*10-6mbar l/sec refrigerators and air conditioners.

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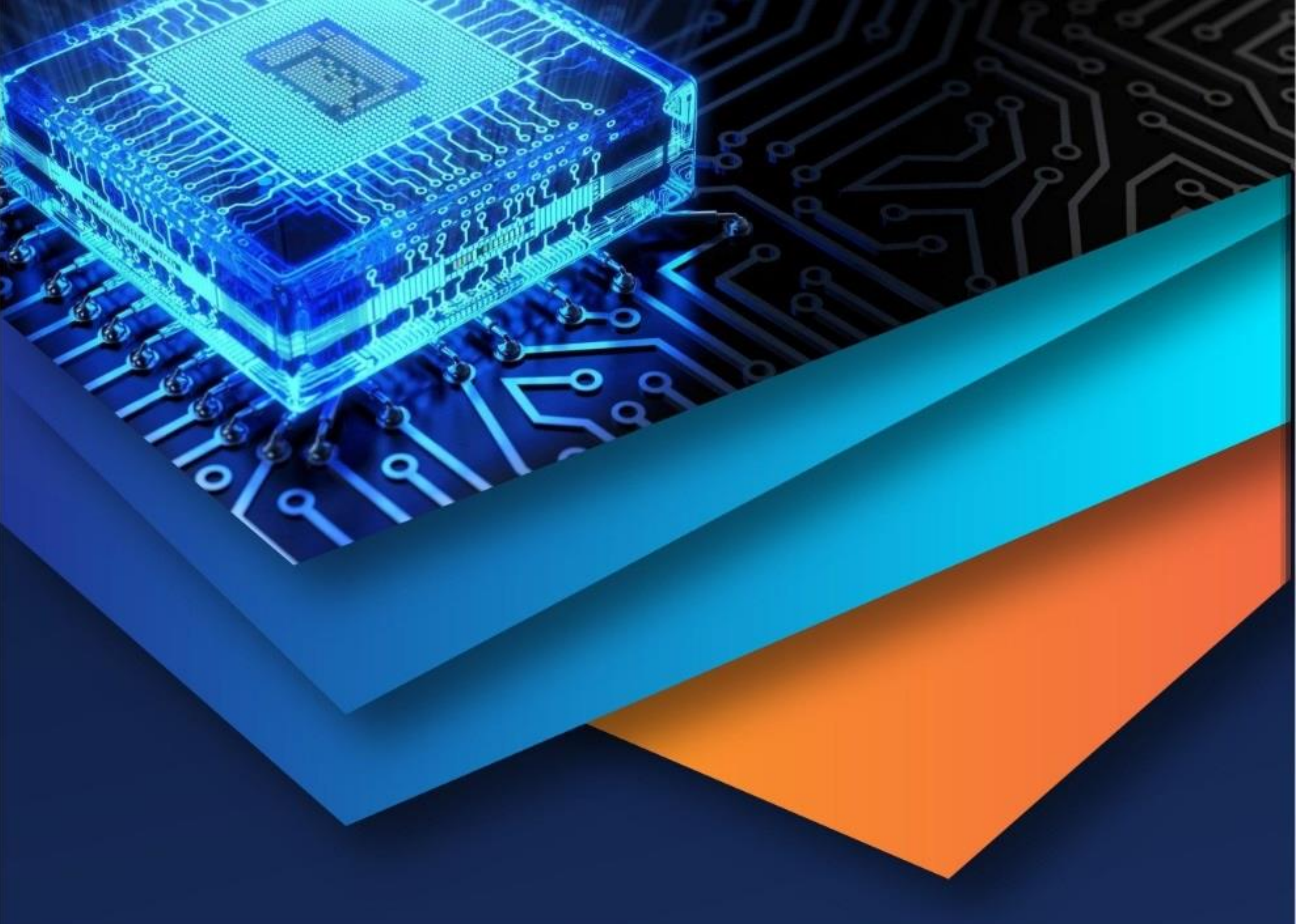

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