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A LITERATURE REVIEW ON CHARACTERIZATION OF DISSIMILAR JOINTS

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***Abstract**:* Friction Stir Welding (FSW) stands out as an advanced solid-state welding method in which a non-consumable tool with a rotating pin and shoulder creates frictional heat to soften materials without melting. This tool stirs and forges materials together along the joint line, distinguishing it from conventional welding. Unlike traditional methods, FSW minimizes the Heat-Affected Zone (HAZ), leading to joints with high strength and fewer defects. Extensively utilized in the aerospace and automotive sectors, FSW excels at joining materials such as aluminium and titanium, offering benefits like reduced distortion and improved structural integrity. Consequently, it is the preferred technique for applications demanding precision, strength, and reliability. Whereas TIG welding excels in dissimilar joint applications, joining different metals with precision. The process, using a non-consumable tungsten electrode and inert gas, ensures a clean, high-quality weld. Its versatility makes it ideal for dissimilar metal combinations, providing strength and durability in industries like aerospace and automotive manufacturing.

Keywords
Tungsten Inert Gas Welding
Friction Stir Welding
Dissimilar Joints
Heat-Affected Zone
Non-consumable Tungsten Electrode.

I. INTRODUCTION

Dissimilar metal weldments exhibit compositional and microstructural gradients, resulting in notable variations in chemical, physical, and mechanical properties throughout the weldment. Welding dissimilar metals is generally more intricate compared to welding similar metals due to these inherent complexities. The primary factors contributing to the failure, such as cracking, of dissimilar metal arc welds involve general alloying issues, such as the formation of brittle phases and limited mutual solubility between the two metals. Additionally, significant differences in melting points, coefficients of thermal expansion, thermal conductivity, and corrosion-related challenges, such as galvanic corrosion, oxidation, hydrogen-induced cracking, and sensitization, contribute to the complexity of dissimilar metal welding. [1]. Friction Stir Welding (FSW), as a solid-state joining method, enables the easy bonding of both similar and dissimilar metals, eliminating the usual defects associated with fusion welding. In the FSW process, a no consumable rotating tool, consisting of a pin and shoulder, is inserted into the adjacent edges of the sheets intended for joining and moved along the joint line. The heat generated from the friction between the tool and the sheets softens the material around the tool, allowing the tool to transfer the locally softened material. Through the localized forging of the weld zone, FSW creates a joint. [2].

II. LITERATURE REVIEW

Tanmay, Sudhan Shwekhar Panda [3] Studied The quality of the weld is highly influenced by the thermal diffusion of copper. A high-quality weld is achieved by increasing the welding speed to 250 mm per minute, coupled with an elevated current. This approach facilitates the proper fusion of copper and aluminium, leading to a significant enhancement in tensile strength.

G. Britto Joseph [4] Studied The tensile test results indicated that the fracture occurred in the heat-affected zone of the stainless-steel base metal. The primary focus of this study lies in the effective application of heat transfer and power electronic applications.

Dissimilar joining of AISI 304L/St37 steels by TIG welding process AR Khalifeh, A Dehghan, E Hajjari - Acta Metallurgical Sinica [5] Utilizing four distinct austenitic filler metals—ER3084, ER3094, ER3164, ER310—and employing optical, scanning electron microscopy, tensile, and impact tests, the study observed that an increase in the amount of delta ferrite in the microstructure of the metal resulted in a reduction in the impact strength of the weldments.

Study on the fiber laser/TIG weldability of AISI 304 and AISI 410 dissimilar weld by G Casalino, A Angelastro, P Perulli, C Casavola [6] was observed The considerable increase in the amount of martensite is observed when the lower line energy decreases. This outcome indicates that the martensite formed at elevated temperatures had sufficient time to grow.

Baragetti and D'Urso [7] studied the tensile and fatigue behaviour of AA6060-T6 friction stir welded butt joints were investigated with a focus on the impact of tool geometry and feed rate. Butt joints were created using both a standard and a threaded tri-flute cylindrical tool featuring a flat shoulder. The study revealed that tool geometry played a role in influencing the strain at rupture, while the feed rate had an impact on microhardness. Additionally, it was observed that the specimens welded at a lower feed rate, using the unthreaded tool, demonstrated the most favourable fatigue behaviour.

Nishida et al. [8] applied Friction stir welding (FSW) was employed to create lap joints between thick plates of an A3003 aluminium alloy and SUS304 stainless steel. Non-destructive tests, including radiographic testing and ultrasonic testing, were conducted to assess the integrity of the welds.

Najafkhani et al. [9] applied Friction stir welding (FSW) was utilized to butt join a pure copper plate to a 316L stainless steel plate, with the stainless-steel plate positioned on the advancing side and the copper plate on the retreating side. They found that the weld nugget exhibited fine grains, while the Thermo-mechanically affected zone (TMAZ) of the 316L stainless steel displayed elongated grains. Coarse grains were observed in the Heat-affected zone (HAZ) of the pure copper. Additionally, it was noted that all welded samples experienced fractures originating from the HAZ of the copper, and the fractures exhibited a ductile behaviour. The weldment demonstrated a maximum Ultimate Tensile Strength (UTS) of 220 MPa and an elongation of 7%.

Table 1. Chemical compositions of the studied base materials (wt. %).

	C	Mn	Si	Ni	Cr	N	S	P	Fe
Steel	0.03	2	0.75	10	18	0.1	0.03	0.045	Balance
	Mg	Al	Si	Cr	Ni	Cu			
Copper	0.29	0.42	0.24	0.54	0.47	Balance			

Imani et al. [10] joined Friction stir welded (FSW) joints were created between 304L stainless steel and commercial pure copper plates, each having a thickness of 3 mm. Through trial-and-error, the researchers achieved the desired mechanical properties by setting the rotational speed at 1000 rpm and the welding speed at 14-112 mm/min. To produce defect-free welds between copper and steel, they adjusted the position of the pin from the butt line towards the copper side. The outcomes indicated that the weldment exhibited a maximum Ultimate Tensile Strength (UTS) of 171.3 MPa and an elongation of 6.8%.

Zhang and Wu [11] applied a A thermomechanical numerical model, fully coupled, was employed to investigate the impact of tool diameter on strain rate, temperature, and grain size in friction stir welding (FSW). The Zener Hollomon parameter was used to predict the grain size in the stir zone. The findings indicated that the influence of welding temperature on grain size was more significant than that of strain. Additionally, it was observed that a reduced shoulder size resulted in a smaller grain size in the stir zone.

M. Jafari1, M. Abbasi1, D. Poursina2, A. Gheysarian1 and B. Bagheri [12] Dissimilar metal weldments exhibit disparities in chemical, physical, and mechanical properties. Friction stir welding (FSW), a solid-state joining method, offers the capability to unite dissimilar metals without the defects associated with fusion welding. Utilizing response surface methodology (RSM), the optimization of welding parameters was carried out. The investigation determined that the process was notably influenced by traverse speed, rotational speed, and the cross term of traverse speed and rotational speed. Hardness values observed in the thermomechanical affected zone (TMAZ) and heat-affected zone (HAZ) were found to be lower compared to the weld regions.

Fig.1 Design and Dimension of the tool used for FSW.

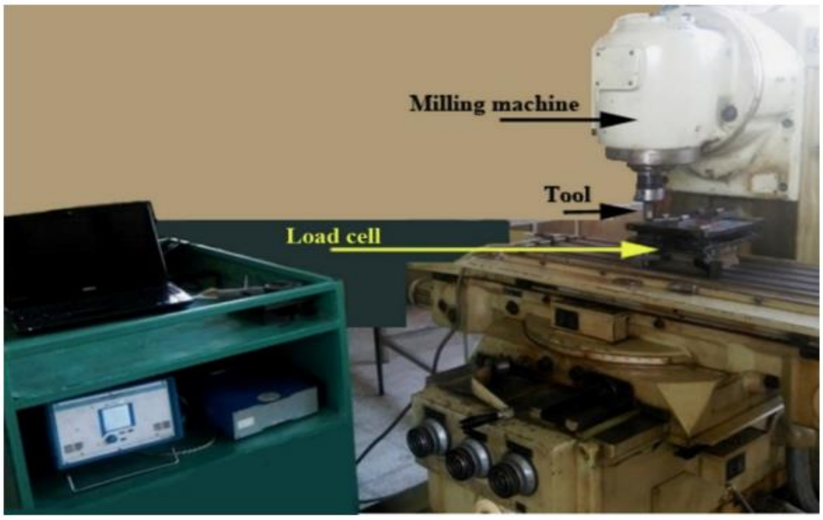

Fig.2 Set of the tools and machines used for FSW process in current Research.

Nickel from 304L steel diffused into the copper side during FSW.

H Nishida, H Kurashima, M Fujimoto, H Nishikawa [13] study the study is centered on the dissimilar lap joining of substantial plates composed of A3003 aluminium alloy and SUS304 stainless steel through the application of friction stir welding (FSW). Single-pass joints were effectively created, demonstrating commendable strength. Furthermore, multi-pass joints were successfully generated, with type III joints exhibiting reduced deformation and comparable strength to explosion bonded joints.

Table 2. Chemical compositions (mass %) and mechanical properties of A3003-H112 alloy

	Si	Fe	Cu	Mn	Zn	others each	others total	Al	TS (MPa)	YS (MPa)	El (%)
1)	0.23	0.37	0.14	1.1	0.02	<0.02	<0.03	Re	125	88	45.0
2)	0.22	0.45	0.12	1.1	0.01	<0.02	<0.03	Re	126	—	36.6

Remarks: 1) 11mm thick plates, 2) 40mm thick plates

The research findings indicate that the lap friction stir welding (FSW) technique can effectively realize large-scale structural joints between aluminium alloy and stainless steel through the optimization of joint shape and FSW configuration.

Sajjad Gholami SHIRI, Mohsen NAZARZADEH, Mahmood SHARIFITABAR, Mehdi Shafiee AFARANI [14] study concluded Copper emerges as a highly promising filler material for Gas Tungsten Arc Welding (GTAW) of copper to 304 stainless steels, presenting defect-free joints characterized by high tensile strength and excellent formability. These discoveries offer crucial perspectives for dissimilar metal welding, specifically in the application of copper as a filler material for GTAW. This research addresses a previously unexplored aspect in the literature, investigating the utilization of copper filler material for GTAW of copper to austenitic stainless steels. The outcomes hold significance for diverse industries in need of dissimilar metal joints.

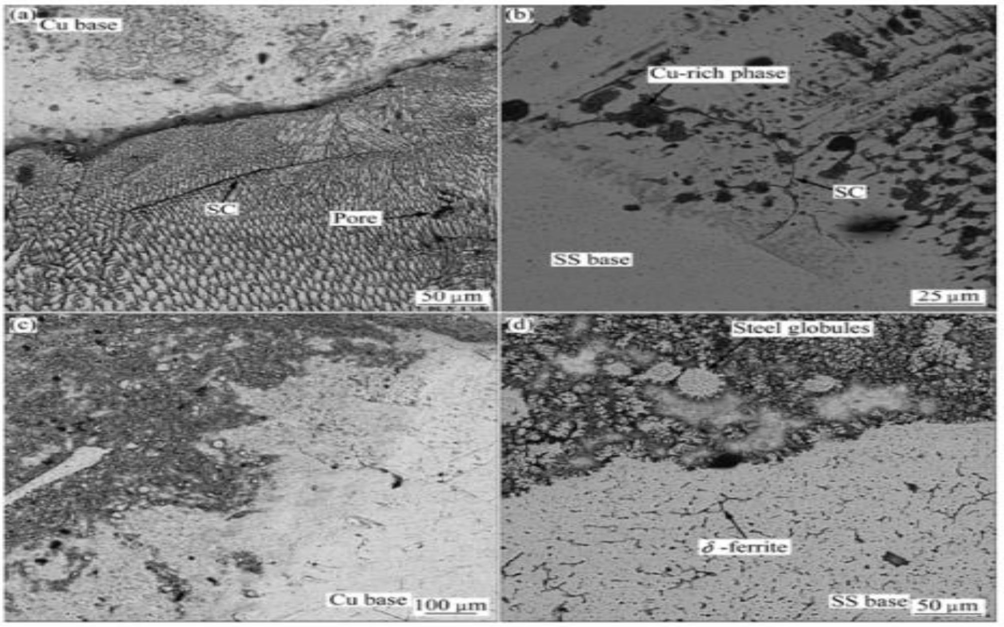

Fig.3 Microstructure of interfaces at copper and stainless side produced by Ni-Cu-Fe filler material.

joints. The results of the study provide actionable advice for welding dissimilar metals and underscore the suitability of copper as a filler material for Gas Tungsten Arc Welding (GTAW) applications.

N. Jeyaprakash, Adisu Haile, M. Arunprasath[15] This document functions as an all-encompassing guide to grasp the essential elements of TIG welding, emphasizing the enhancement of weld quality and the possibilities for future research in this domain.

Sachindra Shankar a, Kush P. Mehta, Somnath Chattopadhyaya, Pedro Vilaça [16] The significant benefit of incorporating aluminium in the automotive industry lies in its recyclable nature. Recycling aluminium results in nearly 90% energy savings. The joining of aluminium and magnesium is necessary for the roof and front part of the vehicle. The hybrid structure of aluminium and titanium contributes to weight reduction and enhanced strength. Fusion, solid-state, and hybrid welding represent the three common methods for joining aluminium to non-aluminium metallic alloys.

Due to notable differences in melting point temperature and coefficient of thermal expansion, fusion welding poses challenges when welding dissimilar materials such as Al-Cu, Al-steel, Al-Mg, and Al-Ti. Solid-state welding methods offer several advantages over conventional welding techniques.

Mohammad Syahid Mohd Isa [17] Magnetic pulse welding is the predominant solid-state welding technique for joining dissimilar metals. The frequently employed assisted methods for joining Al to non-Al metallic combinations include ultrasonic-assisted Friction Stir Welding (FSW).

Critical factors influencing the choice of tool material include tool wear rate, cost, and weld quality. Solubility between the metals to be joined is an additional factor affecting the welding of dissimilar metals. Friction Stir Welding (FSW) is recognized as one of the most viable welding technologies for achieving sound joints between Aluminium and Titanium. The hardness of the Al-Mg stir zone exhibits uneven characteristics and is considerably higher than the base metal. During the FSW of Al-Mg alloys, only two Intermetallic Compounds (IMCs) phases, Al_3Mg_2, and $Al_{12}Mg_{14}$, form.

Xue, Ni et al., [18], The study employed commercially available 1060 aluminium and pure copper plates measuring 300 mm × 70 mm × 5 mm. Friction Stir Welding (FSW) was conducted using a butt-welded configuration. The research investigated the impact of welding process parameters on surface characteristics, mechanical properties, and interface microstructure. Lowering the welding speed resulted in the formation of a regular, homogeneous, continuous intermetallic compound layer. Concurrently, cracks initiated quickly, leading to the development of a stacking layered structure at the Al–Cu phase interface at high tool rotation speed, influencing joint strength and mechanical properties.

Galvão et al., [19] used the base materials utilized were 5083AA (H111) and oxygen-free copper, each having a 1 mm thickness and arranged in a butt-welded configuration. Friction Stir Welding (FSW) was conducted, varying feed rate and tool rotation rate. The authors observed distinctive non-smooth characteristics, including the presence of a CuAl2 creamy layer near the tool shoulder and in the weld region.

Liu et al., [20] used the base materials consisted of 5052 AA (O condition) and pure copper (1/2H condition), both 3 mm thick. The authors observed favorable outcomes in joint appearance when using a copper plate on aluminium alloy (AS) under specific welding conditions: tool rotation of 600/1000 rpm, feed rate of 100 mm/min, and a tool offset of 0. At lower tool rotation speeds, superior hardness and increased ultimate tensile strength were achieved.

Liu et al., [21] used base materials was 5052 AA (H32 condition) and pure copper (1/2H condition) of 3 mm thick. The authors found that initially, the voids growth decreased at higher tool rotation. Increasing the tool rotation speed growth of the void's size also increases, and sub-layers of laminates volume at the welding joint interface were lowered.

Akinlabi and Stephen Akinlabi [22] used a Friction Stir Welding (FSW) involved a butt-welded configuration of 5754 AA and C11000 copper, each sized 600 mm × 120 mm × 3 mm. The FSW process was executed at a tool rotation speed of 600 rpm, with feed rates ranging from 50 to 300 mm/min. The investigation revealed that optimal Ultimate Tensile Strength and high-quality joint strength were attained specifically at a high feed rate of 300 mm/min and a small shoulder diameter of 15 mm.

Anbukkarasi and Kailas [23] used the base materials utilized were AA2024 and pure copper plates, each with a thickness of 5 mm. The welding technology employed a butt-weld configuration. The welding process involved distinct tool offset positions: threaded or plain tool pin profiles at both the interface and copper in the retrieving and advancing portions. The study concluded that superior mechanical properties were achieved when a homogenous, continuous, regular, and smooth interface weld was formed.

Medhi et al., [24] used Friction Stir Welding (FSW) involved a butt joints configuration with base materials chosen as AA6061-T6 and pure copper, both with a thickness of 3 mm. The FSW was conducted at a consistent tool rotation rate of 800 rpm, with the feed rate varied from 30 to 150 mm/min. The study revealed that an inhomogeneous distribution occurred at the nugget zone, impacting the hardness property. The highest tensile strength was achieved at a feed rate of 90 mm/min.

Eslami et al., [25] used the base materials comprised EN AW-1050A-H14 and EN CW008A-240, with aluminium blanks sized at 1300 mm × 100 mm × 4.7 mm. The authors determined joint efficiencies of 72%, and the ultimate tensile strength was measured at 10 kN. Improved tensile properties were correlated with reduced electrical resistance.

Zhang and Amir Shirzadi [26] used the base materials used were 5A06 AA and T2M pure copper, with plate dimensions of 300 mm × 100 mm × 2 mm. The study revealed excessive residual stress, and the highest tensile strength of 240 MPa was observed in the Thermo-Mechanically Affected Zone (T.M.A.Z.) of the aluminium alloy plate.

Jaina et al., [27] Friction Stir Welding (FSW) was applied with varying process parameters to join AA6082 and AA5083. The optimization techniques employed in this process included Taguchi, Grey Relational, and Weight Method. The study revealed that the highest ultimate tensile strength was achieved at a feed rate of 35 mm/min, tool rotation speed of 1200 rpm, and a shoulder diameter of 16 mm.

Bozkurt and Bilici [28] used the Friction stir spot welding in a lap joint configuration was employed to assess the impact of dissimilar alloy plates on their mechanical properties. Optimization techniques, specifically ANOVA and Taguchi, were utilized. The study revealed that in case (1), there was a 47% enhancement in the Lap shear tensile test, increasing from 3.55 to 5.28 kN. In contrast, in case (2), there was only a 1.1% improvement, rising from 5.29 to 5.64 kN.

Xue et al., [29] used Friction Stir Welding was applied in a lap welded configuration to join 3 mm thick aluminium and copper plates. The welding process parameters included a tool rotation speed of 600 rpm using an 8 mm diameter pin. The authors determined a tensile shear load of 2.6 kN, and the joints failed in the Heat-Affected Zone (H.A.Z.) of the aluminium plate. This failure occurred because the aluminium plates were fixed on the advancing side of the weld. Additionally, the hardness increased due to the strengthening effect of the Intermetallic Compounds in the Al–Cu phase.

Palanivel et al., [30] AA6351 rolled plates, each sized 100 mm × 50 mm × 6 mm, were employed in the study. Friction Stir Welding (FSW) was conducted in a single pass, and a mathematical model using Response Surface Method and ANOVA optimization techniques was developed. The findings indicated that the ultimate tensile strength exhibited an increase with higher feed rates and tool rotation speeds, followed by a decrease. On average, % elongation and yield strength demonstrated similar trends.

Jayaraman et al., [31] used The FSW configuration involved a square butt joint. Optimization techniques, including Taguchi and ANOVA, were employed to maximize and examine the effects of welding parameters on mechanical properties using the signal-to-noise ratio of the robust design method. The study revealed that the maximum tensile strength, approximately 147 MPa, was attained at a tool rotation of 1200 rpm, feed rate of 40 mm/min, and axial force of 4 kN.

III. CONCLUSION

TIG welding successfully joined 316 stainless steel and 99.9% pure copper plates, each 5 mm thick. The microstructure of the joint primarily comprises a coarse grain structure in the heat-affected zone (HAZ) of copper and an acicular type of grain growth in the HAZ of SS-316. Additionally, coronal-shaped SS-316 particles appeared at the fusion zone (FZ) of copper. Microhardness values obtained along the cross-section of the weld bead are predominantly influenced by the copper content in the solution. These values exhibit inconsistency at the weld face compared to the weld root. The measured tensile strength of the weldment is 143.7 MPa, with fracture occurring in the copper base metal zone whereas for Friction Stir Welding (FSW) parameters joining 304L stainless steel to copper. Results showed RSM's effectiveness, with smaller grain sizes in the weld region attributed to work hardening. Hardness enhancement was linked to grain size refinement, while nickel diffusion from steel to copper occurred. Strength and ductility decreased with increasing welding passes due to HAZ grain growth on the copper side.

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