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Effect of Process Parameters and Nano particles on Friction Stir Welding of Dissimilar Aluminium Alloys: Review

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Abstract - *Friction stir welding (FSW) is an advanced joining technique used in the industrial sector to connect various materials. It is a solid-state connection technology that utilizes a non-consumable tool to join work piece materials. FSW can be applied to similar and dissimilar materials, including ferrous, nonferrous, and polymers, enabling the development of sustainable products. It finds applications in the automobile and aerospace industries for lightweight designs and enhanced the performance. This paper comprehensively summarizes the most recent literature related to the friction stir welding of dissimilar aluminum alloys with nano-particle addition. The research field of the friction stir welding of aluminum with different alloys is analyzed and investigated from the aspects of welding technology, microstructure and mechanical properties, as well as innovations and improvements in the welding process. In view of the exploration status of this field, the authors put forward their views and prospects for its future, aiming to provide a basis for researchers in this field.*

Key Words: Aluminum alloys; Nano-particles; friction stir welding; Microstructure characteristics; Mechanical properties

1. INTRODUCTION

The challenges in metal joining technology are increasing in various industries, as new materials are being introduced and there is a need to develop innovative joining methods while ensuring the quality and strength of the products. One emerging trend in car development is the use of light alloys such as aluminum and magnesium in order to improve the efficiency and economy of automobiles. Friction stir welding (FSW) technology has been implemented in automotive production since 2012, providing satisfactory results in joining aluminum-steel alloys and offering benefits like improved driving characteristics and shorter production time.

On the other hand, there is growing interest in the welding of dissimilar materials due to the demand for complex parts and the need to maximize the advantages of different materials. Composite parts joined using dissimilar materials can meet various performance requirements while reducing costs. The welding of dissimilar materials is being employed in industries such as power generation, chemical, petrochemical, aerospace, transportation, electronics, and military. Examples include aero-engines, aerospace propulsion systems, metal ducting structures, and bimetal components for aerospace instruments.

When it comes to welding dissimilar materials, challenges arise due to the differences in their properties and behavior during welding. For instance, welding copper (Cu) and aluminum (Al) presents difficulties because of their significantly different melting points and limited mutual solubility. The formation of intermetallic compounds (IMCs) is common during welding, but thicker IMCs can cause diffusion and continuous thickening, affecting the performance of the joint. Additionally, oxidation and the difference in linear expansion coefficients between Al and Cu can lead to defects like cracks and stress in the welded joint.

In summary, while the challenges in metal joining technology are intensifying across industries, advancements in joining methods like friction stir welding have shown promising results in joining light alloys. Simultaneously, the welding of dissimilar materials is gaining importance due to its potential to optimize material advantages and meet diverse industry needs. However, addressing the specific challenges associated with dissimilar material welding, such as the formation of intermetallic compounds and managing differences in properties, remains a focus of research and development in the field.

1.1 Friction Stir Welding

FSW is a solid-state, hot-shear joining process in which a rotating tool with a shoulder moves along the butting surface of two rigidly clamped plates placed on a bucking plate as shown in Fig. 1. It was developed in the early 1990s by The Welding Institute (TWI) in the United Kingdom. FSW is particularly well-suited for joining aluminum and its alloys, although it can also be used for other materials such as copper, titanium, and some steels.

The process involves a non-consumable tool, typically made of a hard material like tungsten carbide, which is rotated and plunged into the joint between the two work pieces. The tool generates frictional heat as it rotates, softening the material without reaching its melting point. The softened material is then stirred together as the tool moves along the joint line.

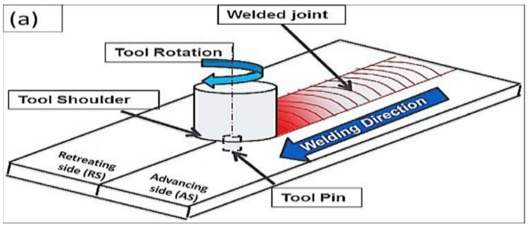

Fig -1: Schematic of The Friction Stir Welding Process [3]

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The key advantages of friction stir welding include:

- Reduced defects: FSW produces high-quality welds with minimal defects such as porosity, solidification cracks, or distortions. Since it is a solid-state process, there is no fusion or solidification, which eliminates issues associated with traditional welding techniques.

- Improved mechanical properties: FSW can create welds with excellent mechanical properties, including high tensile strength, fatigue resistance, and good corrosion resistance. The process refines the grain structure of the material, resulting in enhanced properties.

- Low distortion: FSW produces minimal distortion in the work pieces compared to traditional welding methods. The absence of molten metal reduces shrinkage and thermal stress, leading to less deformation.

- Joining dissimilar materials: FSW is effective for joining dissimilar materials that are difficult to weld using conventional methods. It allows for the joining of materials with different melting points and thermal properties.

- Environmental benefits: Friction stir welding is a more environmentally friendly process compared to conventional welding techniques. It does not require filler materials, and there is minimal or no release of fumes, gases, or spatters.

FSW has found applications in various industries, including automotive, aerospace, shipbuilding, and rail transportation. It is used for joining components such as panels, frames, heat exchangers, and structural members. Overall, friction stir welding offers several advantages over traditional welding methods, making it a versatile and reliable technique for joining metals.

2. LITERATURE SURVEY

Farhad Bakhtiari Argesi et al.[2021]: In a study on friction stir welding (FSW) of pure copper and AA5754 alloy, SiC nanoparticles were used to mitigate the negative effects of intermetallic compounds. Tensile tests, micro-hardness experiments, scanning electron microscopy, and X-ray diffraction analysis were conducted to analyze the joint properties. The best results were obtained with a travel speed of 50 mm/min and a rotation speed of 1000 r/min. The addition of nano-sized SiC particles reduced the grain size of aluminum and copper in the Nugget zone (NZ). The joint's tensile strength with SiC nanoparticles reached approximately 240 MPa, about 90% of the base aluminum strength. The micro hardness of the weld zone significantly increased from HV 160 to HV 320 with the addition of SiC nanoparticles. Higher heat generation in FSW led to increased formation of intermetallic compounds (Al_4Cu_9 and Al_2Cu).

Kush Mehta et al. [2021]: Exit-holes in dissimilar aluminum-copper (AleCu) friction stir welds can be effectively repaired using probeless tools, which force the surrounding material to fill the cavity. The repair process involves two steps using probeless tools of different diameters. Experimental tests, including tensile tests, micro hardness measurements, scanning electron microscopy, and energy dispersive x-ray spectroscopy, were conducted to evaluate the effectiveness of the repair. Results showed that using probeless tools with shoulder diameters of 12 and 19 mm resulted in a repaired joint with ultimate tensile strength about 13% higher than steady-state weld bead samples. The hardness values of the repaired zone were within the range observed in previous studies on friction stir welding.

Mohammad Syahid Mohd Isa et al. [2021]: Friction stir welding (FSW) is a promising technique for joining dissimilar metals like aluminum and copper, allowing for the utilization of their unique properties. This comprehensive study summarizes various aspects of FSW between aluminum and copper, including process parameters, microstructural characterization, mechanical properties, and electrical characteristics of the joints. It also discusses the use of additives and new techniques to enhance the joint properties. The report delves into numerical modeling of FSW to understand the effects of process parameters on temperature gradients and microstructure evolution. The study concludes with recommendations for future research to advance and improve FSW studies between aluminum and copper.

F.M.Selamat et al. [2016]: This study focuses on the application of friction stir welding (FSW) for joining similar and dissimilar aluminum alloy plates. The welding parameters remained constant for both types of joints. Microstructure analysis revealed the presence of an "onion ring" structure in the nugget zone of similar joints, while dissimilar joints exhibited wavy and distorted patterns. Tensile tests showed that fractures occurred in the thermo-mechanically affected zone (TMAZ) for both types of joints. The tensile strength of the joints was lower compared to the base metals. Overall, FSW demonstrated potential for welding aluminum alloys, but further improvements are needed.

Tanvir Singh et al.[2020]: This study investigated the effect of adding novel nanoparticles to 2.5 mm thick 6061-T6 aluminum alloy sheets joined using Friction Stir Welding (FSW). The distribution of nanoparticles in different FSW zones was analyzed using optical and SEM micrographs. Vickers micro hardness tests focused on the nugget zone (NZ). Results showed that welds with Al2O3 nanoparticles had smooth surfaces, while TiO2 welds had rough surfaces with flash formation. Al2O3 welds had a more refined grain structure in the NZ, with homogenous nanoparticles dispersion, while TiO2 welds had clusters and larger grain sizes. Al2O3 welds had significantly higher NZ micro hardness (88Hv) compared to TiO2 welds (76Hv) and the base material (61Hv) due to grain refinement and uniform nanoparticles distribution in the NZ.

Ashwani Kumar et al. [2014]: Friction Stir Welding (FSW) is a joining process that utilizes plastic deformation rather than material melting. This unique characteristic makes it highly suitable for joining materials with varying mechanical properties, chemical compositions, and material structures. In this review, we aim to explore the feasibility of FSW as a technique for joining different materials and alloys, highlighting its advantages in achieving reliable and robust joints. By avoiding the need for melting, FSW offers enhanced control over the joining process, resulting in improved weld quality and integrity. With its versatility and potential for joining dissimilar materials, FSW emerges as a promising solution for various industrial applications.

Arun M et al. [2021]: Purpose – In structural applications, the utilization of dissimilar materials is crucial for withstanding diverse loads and imparting multifaceted properties to the final structure. Aluminum alloy materials are extensively employed in aerospace and marine industries due to their ability to offer high strength and protection against severe environmental conditions. This study aims to develop a novel material with exceptional strength to effectively withstand and overcome challenging environmental conditions. By exploring innovative approaches and incorporating advanced materials, the objective is to enhance the overall strength and durability of the developed material.

Kittipong Kimapong et al. [2005]: A5083 aluminum alloy and SS400 steel lap joint was made by using Friction Stir Welding (FSW) technique with varying process parameters such as rotational speed, traverse speed, and pin depth [8]. The different welding parameters resulted in distinct interfaces and significantly influenced the joint properties. Higher rotational speeds led to a decrease in shear load due to the formation of a thick FeAl3 intermetallic compound (IMC) at the interface. Increasing traverse speed increased shear load as the IMC thickness decreased, but excessively high speeds resulted in incomplete interfaces. Greater pin depth resulted in a thicker FeAl3 IMC phase and incomplete interfaces, adversely affecting the shear load of the joint.

Natrayan et al. [2021]: Friction Stir Welding (FSW) is an effective solid-state technique for joining Al-Zn-Mg alloys, which are widely used in various engineering applications. This research focuses on characterizing the unique mechanical properties of Al-Zn-Mg alloy reinforced with 1 to 3 wt% nano-SiC particles using a novel interlock friction-stir welding method. The chosen process parameters were a rotational tool speed of 1100 rpm, weld speed of 25 mm/min, and triangular pin profile. Tensile strength, yield strength, and hardness were evaluated according to ASTM standards, while XRD, optical, and scanning electron microscopy were used to study the microstructure of the weld joints. EDS analysis confirmed the presence of silica particles in the weld joints and their uniform distribution. Al-Zn-Mg with 3 wt% nano-SiC resulted the highest tensile strength, yield strength, and nugget hardness (191 MPa, 165 MPa, and 171 HV, respectively). The microstructures of the welds indicated a pinning mechanism resulting from the use of nano-SiC particles as reinforcement during friction stir welding.

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highlighting its advantages in achieving reliable and robust joints. By avoiding the need for melting, FSW offers enhanced control over the joining process, resulting in improved weld quality and integrity. With its versatility and potential for joining dissimilar materials, FSW emerges as a promising solution for various industrial applications.

Mahendra K C et al. [2019]: Friction stir welding (FSW) is an advanced joining technique used in the industrial sector to connect various materials. It is a solid-state bonding process that utilizes a non-consumable tool to join workpiece materials. FSW can be applied to similar and dissimilar materials, including ferrous, nonferrous, and polymers, enabling the development of sustainable products. It finds applications in automotive and aerospace industries for lightweight designs and improved performance. This paper aims to research and analyze the influence of critical parameters in FSW, focusing on different material combinations such as ferrous, non-ferrous, and dissimilar materials. The welding parameters affecting FSW operations and their impact on mechanical properties are discussed, including tensile testing, hardness inspection, and macro/micro structural evaluations. The potential application of FSW in polymeric materials is also suggested for further research.

Nikitha Veligotskyi et al. [2022]: This study focuses on the application of friction stir welding (FSW) for joining dissimilar aluminum alloys, specifically AW 5083 and AW 6082. The welding process was conducted at different weld speeds, and the resulting joints were subjected to metallographic analysis, hardness testing, and destructive static tensile tests. When using the lowest weld speed, an inadequate mixing of materials led to a noticeable gap at the joint and reduced joint strength. However, at medium and high weld speeds, the joints exhibited mechanical properties comparable to the base material. Metallographically, the bond between the materials displayed a defect-free interface.

R N Shubhavardhan et al. [2017]: Friction Stir Welding (FSW) is an advanced solid-state joining technique that offers the advantage of joining dissimilar materials with disparate physical and mechanical properties, which are challenging to weld using conventional fusion welding methods. Tensile shear testing is commonly employed to assess the mechanical strength of friction stir lap (FSL) welds under static loading conditions, with fracture strength (σLap) being the widely accepted strength parameter. In the case of dissimilar metals with significant differences in melting temperatures, FSL welding establishes a metallurgical bond by forming interfacial intermetallic compounds. However, these intermetallic compounds are typically brittle and lack ductility, thereby potentially compromising the fracture strength of the welds. This research aims to investigate the influence of FSW parameters on the interface structure and how the resultant interface structure impacts fracture behavior in Al-Steel and Al-Ti FSL welds.

Rocio Saldaña-Garcés et al. [2020]: Friction Stir Welding (FSW) is a solid-state joining process that welds lightweight materials like aluminum and magnesium alloys without melting them. In their work, AA6061-T6 and AZ31B-H24 alloys were joined using Friction stir welding with different parameters: rotational speeds of 400, 800, 1200, and 1600 rpm, welding speeds of 30 and 60 mm/min, and tilt angles of 1° and 3°. Microstructure analysis revealed dissimilar welds achieved by placing AA6061-T6 on the advancing side under two conditions: without a tool offset (welding speed: 30 mm/min, rotational speed: 400 rpm, tilt angle: 1°) and with a tool offset (welding speed: 30 mm/min, rotational speed: 1200 rpm, tilt angle: 3°). Intermetallic compounds Al_3Mg_2 and $Al_{12}Mg_{17}$ were observed in the stir zone. Joint M7 had varying hardness (76-129 HV) and tensile strength (88.2 MPa), while joint M3 exhibited hardness (95-153 HV) and tensile strength (18.95 MPa).

S. Hassan et al.[2015]: In this research paper, the dissimilar A319 and A356 cast aluminum alloy plates joined by friction stir welding (FSW) microstructure and mechanical properties of were studied. The influence of tool rotational and welding speeds, as well as post-weld heat treatment (PWHT), was examined. PWHT involved solutionizing at 540°C for 12 hours followed by aging at 155°C for 6 hours. The welded zone (WZ) exhibited higher hardness compared to the parent alloys in the as-welded condition. Increasing the tool rotational speed and/or reducing the welding speed resulted in increased hardness at the WZ. Conversely, the PWHTed specimens showed lower hardness at the WZ compared to the parent alloys. Increasing the tool rotational speed and/or reducing the welding speed led to decreased hardness at the WZ in the PWHTed condition. Tensile testing revealed that fractures occurred on the A356 side with minimal hardness for the as-welded specimens, while fractures occurred at the WZ for the PWHTed specimens. Increasing the rotational speed reduced both tensile strength and yield strengths but improved the joint's ductility.

2.1 Problem Definition

The problem in friction stir welding (FSW) can be defined as follows:

FSW involves the joining of materials through a solid-state welding process, without melting the materials. However, there are several challenges associated with FSW that need to be addressed:

- Defects and imperfections: FSW can result in defects such as voids, porosity, and inadequate bonding between the materials. These defects can negatively impact the mechanical properties and structural integrity of the welded joint.

- Heat generation and dissipation: During FSW, heat is generated due to the friction between the rotating tool and the work piece. Efficient heat generation and dissipation are crucial to avoid excessive heat-affected zones, material softening, and distortion.

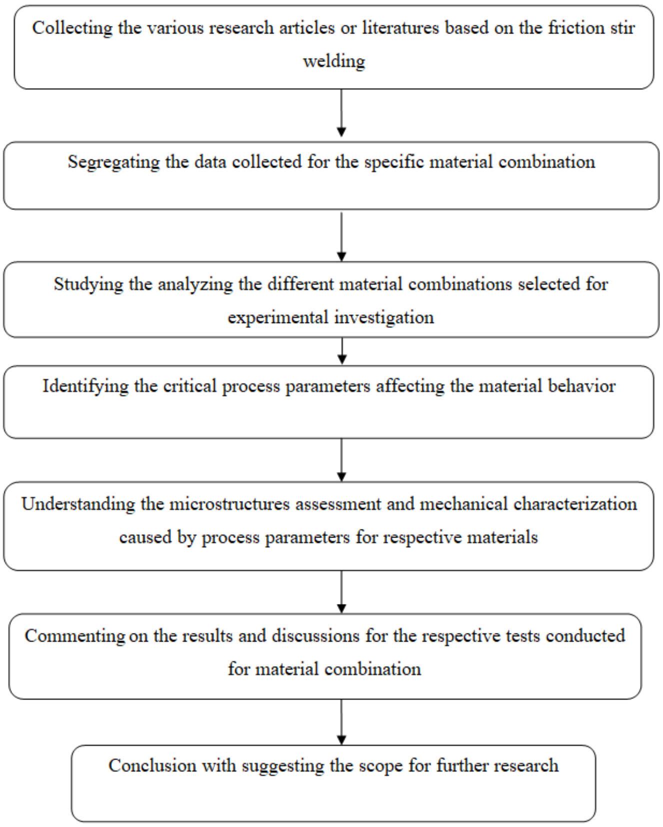
- Material compatibility: FSW is often used to join dissimilar materials with different mechanical properties, chemical compositions, and material structures. Ensuring proper compatibility between the materials is essential to achieve a strong and reliable joint.
- Process optimization: The selection and optimization of process parameters, such as rotational speed, traverse speed, and tool design, play a crucial role in determining the quality of the weld. Finding the optimal set of parameters for specific material combinations and joint configurations is a complex task.
- Microstructure changes: FSW can induce changes in the microstructure of the welded materials, such as grain refinement, intermetallic formation, and texture alterations. Understanding and controlling these micro structural changes are important to achieve desired mechanical properties in the welded joint.

Addressing these problems in friction stir welding requires advanced research, process optimization, and material-specific considerations to ensure high-quality, defect-free welds with optimal mechanical properties.

3. OBJECTIVES

- To study the various dissimilar materials used in friction stir welding.
- To study the effect of process parameters used in the friction stir welding.
- To study the effect of reinforced Nano particles on material behavior.
- To study the microstructure of the weld joint.
- To study the material characterization of various mechanical testing.
- To identify the scope for further investigation in dissimilar materials combination.

4. METHODOLOGY



Collecting the various research articles or literatures based on the friction stir welding

Segregating the data collected for the specific material combination

Studying the analyzing the different material combinations selected for experimental investigation

Identifying the critical process parameters affecting the material behavior

Understanding the microstructures assessment and mechanical characterization caused by process parameters for respective materials

Commenting on the results and discussions for the respective tests conducted for material combination

Conclusion with suggesting the scope for further research

5. STUDY ABOUT FRICTION STIR WELDING OF DISSIMILAR ALUMINUM ALLOYS

Friction stir welding (FSW) of dissimilar aluminum alloys involves joining two or more aluminum alloy sheets or plates with different compositions using the FSW process. FSW is a solid-state welding technique that uses frictional heat generated by a rotating tool to join materials without melting them. The process offers several advantages over traditional fusion welding methods, including improved mechanical properties, reduced distortion, and enhanced weld quality.

When it comes to dissimilar aluminum alloy welding, FSW has shown promise in overcoming the challenges associated with conventional fusion welding techniques. The primary challenges in dissimilar alloy welding arise from the differences in melting temperatures, thermal properties, and metallurgical behavior of the alloys involved. These differences can result in defects, such as cracks, solidification defects, and intermetallic compound formation, which can compromise the integrity and performance of the weld joint.

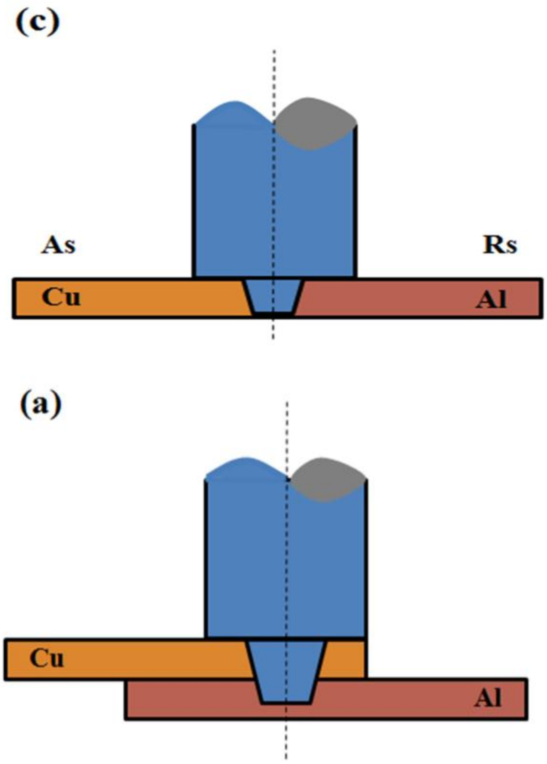
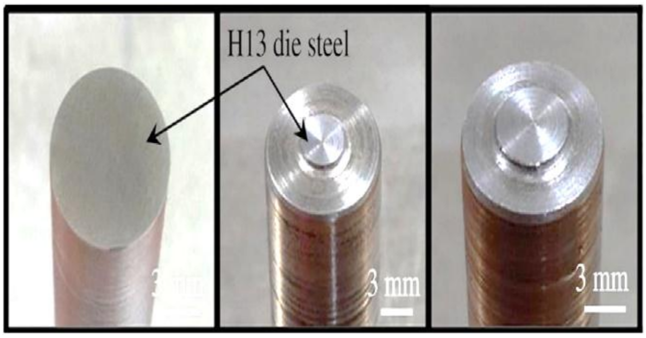


Fig -2: BUTT and LAP JOINT CONFIGARATION

FSW addresses these challenges by utilizing a rotating tool with a specially designed geometry. The tool consists of a shoulder, which provides downward pressure, and a threaded or cylindrical pin, which generates frictional heat and facilitates material mixing. The tool plunges into the joint line between the two work pieces, creating frictional heat that softens the material and allows for plastic deformation. As the tool moves along the joint line, it mechanically stirs and forges the material, resulting in a solid-state bond.



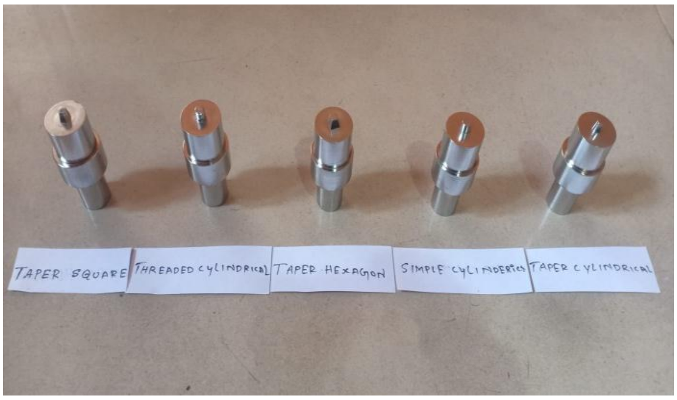


Fig -3: DIFFERENT TOOL PROFILES

Table -1: Chemical composition of the material used (wt%)

Base Material (wt%)	Ti	Si	Fe	Mn	Mg	Cr	Zn	Ni	Cu	Al
AL2024	0.025	0.22	0.21	0.41	1.65	0.12	0.02	-	3.54	Bal
AA5083 AA6061	0.05 0.14	0.25 0.52	0.45 0.70	1.00 0.15	4.4 0.88	0.14 0.24	0.03 0.16	- -	- 0.39	Bal Bal
AA6061 AA5083	0.0195 0.055	0.615 0.076	0.304 0.13	0.045 0.63	0.901 4.34	0.19 0.064	0.054 0.035	0.013 0.003	0.258 0.032	Bal Bal
AA6061-T6 CU	0.03	0.5	0.3	0.12	1.03	0.11	0.08		0.1 99.9	Bal IMP
A5083 SS400	0.02 -	0.08 0.02	0.21 -	0.62 0.42	4.60 -	- P-0.21	0.01 C-0.15	- S-0.06	0.02 -	Bal -
AA6061-T6	0.0195	0.615	0.304	0.0454	0.901	0.19	0.954	0.013	0.258	Bal
AA5754-H1114 C10100	- Pb-0.0005	0.16 Ag-0.0025	0.14 0.001	0.33 As-0.0005	2.9 Sb-0.0004	0.12 -	0.09 0.001	- -	0.05 99.99	Bal -

To successfully weld dissimilar aluminum alloys using FSW, several factors need to be considered:

- Material Compatibility: The selected aluminum alloys should have compatible metallurgical properties, such as similar solidification temperatures, thermal conductivities, and mechanical properties. This ensures that the alloys can be adequately mixed and forged during the welding process.

- Tool Design: The tool geometry, including the pin profile and thread design, plays a crucial role in achieving a sound weld. The tool should be designed to promote effective material mixing and plastic deformation, enabling the formation of a homogeneous bond between the dissimilar alloys.

- Welding Parameters: Optimal welding parameters, such as rotational speed, traverse speed, and axial force, need to be determined for each specific combination of dissimilar alloys. These parameters affect the heat generation, material flow, and defect formation during the welding process.

- Intermetallic Compound Formation: Dissimilar aluminum alloys may form intermetallic compounds at the weld interface, which can affect the joint's mechanical properties. The formation and distribution of intermetallic compounds can be influenced by the welding parameters, material composition, and post-weld heat treatment.

Research and development efforts have been focused on understanding the fundamental aspects of dissimilar aluminium alloy welding using FSW and optimizing the process parameters to improve the quality and performance of the weld joints. Various techniques have been explored to enhance the properties of dissimilar FSW joints, including :

- Nanoparticles Reinforcement: Adding nanoparticles, such as SiC, Al2O3, and TiC, during the FSW process can improve the mechanical and tribological properties of the weld joints. These nanoparticles act as reinforcements and enhance the strength, hardness, wear resistance, and corrosion resistance of the joint.

- Hybrid Approaches: Combining FSW with other welding techniques, such as friction stir spot welding (FSSW), can create surface composites and tailor specific properties of the joints. By strategically placing the spot welds, different regions of the joint can have varying properties, offering flexibility in design and performance.

- Post-Weld Heat Treatment: Heat treatment processes, such as artificial aging or solution heat treatment, can be applied to the weld joint to modify the microstructure and improve the mechanical properties. This is particularly relevant for dissimilar alloys with significant differences in precipitation hardening response.

Table -2: Welding Parameter Considered

SL.NO	Tool rotational speed in RPM/min	Transverse speed in MM/min	Tilt angle of tool in Degrees	Thickness of weld material in MM
01	1000	100	3	5
02	1000	45	1	6
03	1500	50	2	6
04	1250	85	1	3
05	(1). 1600-2400 2000	50-90 70	4	2.5

6. RESULTS AND DISCUSSION

Research on the microstructure and mechanical properties of joints:

In the field of welding, researchers often analyze the microstructure and mechanical properties of welded joints through research methods in order to explore the mechanism of microstructure evolution, the formation and causes of defects, and the influence of parameters on mechanical properties during welding. In the previous studies on the Friction Stir Welding Aluminum (Al) dissimilar materials, researchers selected the welding technology and the appropriate welding parameter window based on the macroscopic morphology and tensile strength of the welded joint. They further analyzed and studied the microstructure and mechanical properties of the welded joint.

Based on the present research status, it can be concluded that current research is mainly focused on the following aspects in the field of Friction Stir Welding of Aluminium dissimilar alloys with reinforced materials:

- Microstructure of the joint: Researchers investigate the microstructure of the welded joint to understand the grain structure, phase distribution, and the presence of defects such as voids, cracks, or inclusions. The microstructure plays a crucial role in determining the mechanical properties of the joint.

- Interface Intermetallic Compounds (IMCs) of the joint: The formation and characterization of IMCs at the Cu-Al interface are of particular interest. Researchers aim to understand the composition, thickness, and distribution of these IMCs, as they can significantly influence the joint's mechanical properties.

- Tensile strength: The tensile strength of the welded joint is an important mechanical property that determines its structural integrity and load-bearing capacity. Researchers analyze the factors affecting tensile strength, such as welding parameters, heat input, and microstructural features, to optimize the welding process and improve the joint's mechanical performance.

- Micro-hardness: The micro-hardness of the welded joint is a measure of its resistance to indentation or deformation. Researchers investigate the correlation between microstructure and micro-hardness to gain insights into the strengthening mechanisms and deformation behavior of the joint.

In summary, the current research in the field of FSW of Cu and Al dissimilar materials primarily focuses on the microstructure of the joint, interface IMCs, tensile strength, and micro-hardness. These studies aim to improve the understanding of the welding process and enhance the mechanical properties of the welded joints

For practical applications.

6.1 Microstructure Characteristics

In the analysis of material structure and properties, the examination of microstructure is considered a fundamental research aspect that significantly influences mechanical properties. In existing literature, researchers have conducted observations and analyses of the microstructure in Al-Cu dissimilar Friction Stir Welding (FSW) joints using various techniques such as optical microscope (OM), scanning electron microscope (SEM), and transmission electron microscope (TEM). It is important to note that the authors will not provide a detailed explanation of these techniques in this paper but will rather focus on analyzing specific noteworthy cases.

The microstructures of commercially pure copper and AA5754-H114 alloy are shown in Fig-5 The microstructure of aluminum consisting of non-equiaxed grains, and the copper microstructure shows several annealed twins, as can be noticed within the copper grains. The grain sizes of aluminum and copper were 52 and 36 μm, respectively [1].

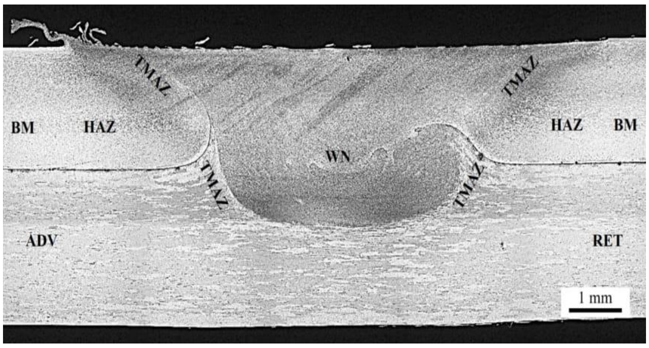


Fig -4: Various Regions For Friction Stir Weld Sample: WN/SZ, TMAZ, And HAZ[1]

Overall FARHAD BAKHTIARI ARGESI et al [1] stated that the microstructure of FSW could be categorized into three regions, including SZ, thermo-mechanical affected zone (TMAZ) and heat-affected zone (HAZ). These three regions for 1000-50p specimen are shown in Fig. 4, In the SZ, more refined grains are observed because of severe plastic deformation. The tool rotation caused the presence of elongated grains in the TMAZ. In the HAZ, the grains grow in FSW due to the heat generation and no plastic deformation.

As discussed, FSW involves the intense stirring of the material at which formed four distinct zones, i.e. Weld zone/Stir zone(SZ), Thermo-mechanically affected zone(TMAZ), Heat affected zone(HAZ) and the Base metal (BM). The material in direct contact with the tool and shoulder at Stir zone will experience the highest temperature due to the frictional heat and the highest strain energy. In the Stir zone, the grain size is much finer than the base metals due to the dynamic recrystallisation. Depending on process parameters, the grain size can be reduced up to 96%. As a result, the microhardness and tensile strength of the SZ are the highest.

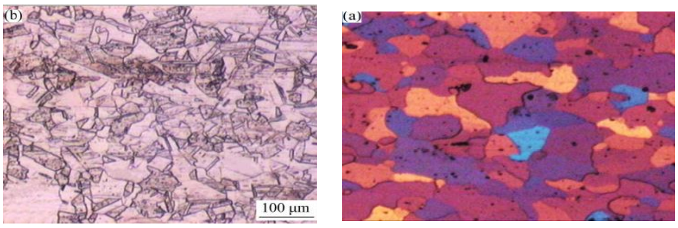


Fig -5: Microstructures Of AA5754-H114 (A) And Commercially Pure Copper (B)[1]

In some cases, a quasi-spiral shape can be observed in SZ, which is called an onion ring. Tongue et al. suggested that the complex material flows from the rotational and traversing tool movement producing alternating layers of high and average strain rate, which then deposit the stirred materials behind the pin. Next nearest zone to the tool is TMAZ, where high heat from the SZ flows and induces small deformation to the grain. However, lack of plastic strain, as compared in the Stir zone, limits the deformation of the grain structure. The material in this zone is also realised outwards in the direction of material flow. Moreover outward materials flow, called a flash defect, indicates the unsuitable parameters used during the welding process. In flash defect, removing material from the welding zone reduces the material intermixing, hence reducing the joint strength.

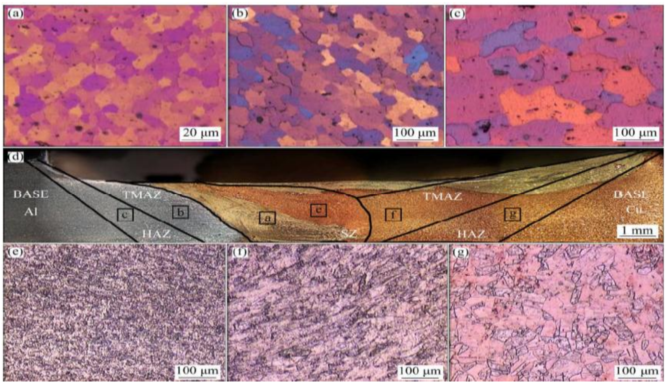


Fig -6: Various regions for 1000-50p sample: (a) SZ, Al; (b) TMAZ, Al; (c) HAZ, Al; (d) Macrostructure of joint; (e) SZ, Cu; (f) TMAZ, Cu; (g) HAZ, Cu[1]

In Heat affected zone, only the residual heat presents, and grain structure slightly deforms depending on the zone's temperature. On the other hand, the grain structure in the BM does not change since there is a lack of heat input and no strain energy in the region to induce any deformation. Therefore, the size of the three different affected zones can be controlled/maintained with suitable parameters. Fig-6 shows the different microstructural properties at different zones for the AleCu welded samples with the lap configuration.

In dissimilar friction stir welding of copper and aluminum with the addition of nano-particles, dynamic recrystallization, reinforcement of nano-particles, and heat generation influence grain size in the stirred zone (SZ). These factors compete to affect the grain size. Dynamic recrystallization causes the formation of new grains, reducing grain size. Reinforcement of nano-particles restricts grain boundary movement and promotes fine grain structure. Heat generation, primarily from friction between the sample and rotating tool, can lead to grain growth in the SZ. Increasing heat generation enhanced grain size and promoted the formation of intermetallic compounds (IMCs) like Al4Cu9 and Al2Cu in the stir zone (SZ).

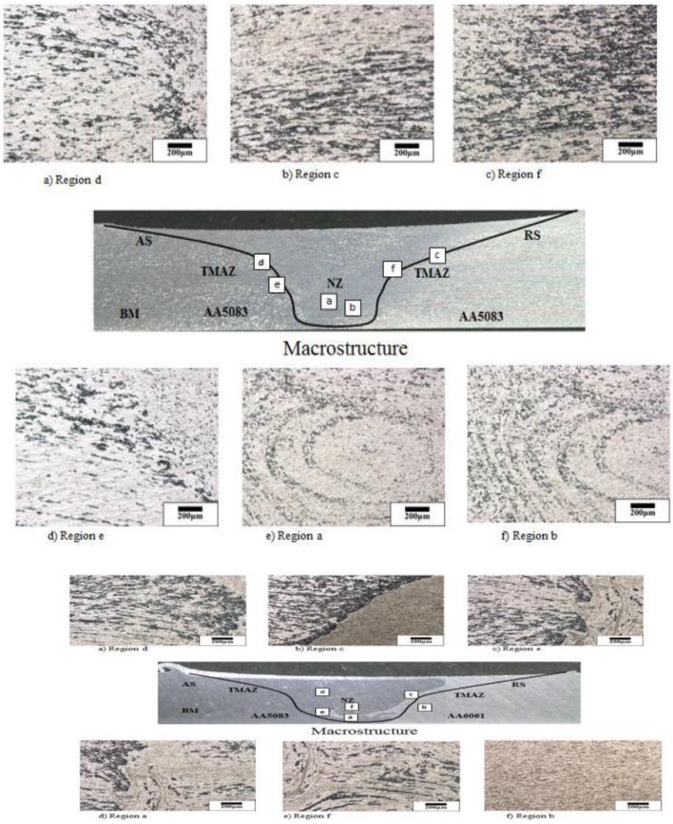


Fig -7: Microstructure Of Similar And Dissimilar Joints (AA5083-AA6061)[4]

With the addition of nano SiC particles, grain sizes of Al and copper in the weld zone reduced from 38.3 and 12.4 µm to 12.9 and 5.1 µm, respectively.

N.F.M.Selamat et al. Observed that, Smooth surface welding on the joints depended on sufficient heat input applied during the FSW process, which was related to the transverse and rotational speed. From the micro structural study it is observed that the formation of 'onion ring' structure was found in the nugget zone of similar joints, while wavy and distorted patterns appeared in dissimilar material joints. Kittiong et al. proposed that, Increasing the rotational speed decreased the shear load of the joint due to producing a thick FeAl3 intermetallic compound (IMC) at the interface. When traverse speed increased, the shear load increased due to IMC thickness at the interface decreased, however, when the speed was so high, an incomplete interface was formed. The increased pin depth forms a thick FeAl3 IMC phase and an incomplete interface that directly deteriorated the shear load of the joint.

A. S. Hassan,et al. The average size of the Si particles increases with increasing the tool rotational and the reduction of welding speeds. No coarsening in the size or change in the distribution of primary Si particulates was observed at the welded regions after heat treatment. Dissimilar FSW of cast Al alloys A356 and A319 produced an irregular shaped regions in the WZ. These regions have structure and composition different from the two base alloys. Several combinations between the tool rotational and welding speeds led to different regions at the WZs with several chemical compositions. Rocio Saldaña-Garcés et al, There result suggests that when placing the Aluminium alloy on the retreating side, aluminum is not able to deform enough to be blended with the Mg alloy, which can be elucidate by the less deformation of the material on the retreating side.

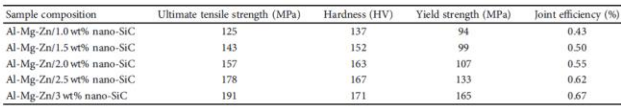
6.2 The Study of Tensile Strength and Micro-Hardness

Tensile strength is the most basic mechanical property of the FSW of Cu–Al dissimilar materials, whether in the lap or butt joint forms. Researchers took the tensile strength as the most basic standard to judge the mechanical properties. In every experiment, the strength of the welded joint was tested. They mainly recorded the tensile strength, the tensile fracture position of the specimen and observed the fracture morphology by using SEM. Because the basic conditions of each experiment are different, whether it is the thickness, the material of the specimen, or the welding parameters of the test, the results obtained are all different, and there is no regulation to follow. Therefore, the authors will not enumerate the results of each tensile test in this paper, but there are several results that are worth thinking about and will be of further help in the following research.

Farhad Bakhtiari Argesi et al. commercially pure copper plates 99.99 wt.% (C10100 OFHC) and 5754-H114 Al alloy were used for the FSW with a thickness of 4 mm. Microhardness of the friction stir welded copper–aluminum joints was directly related to the amount of reinforcing SiC nano-particles, intermetallic compounds, and grain size. The highest microhardness of SZ in the absence of SiC nano-particles was HV120, which significantly increased to HV320 in the presence of SiC nano-particles, for the 1000-100p specimen. The synergic effect of SiC nano-particles and IMCs resulted in an increase in the microhardness peak. The highest tensile strengths were obtained in joints prepared by 50 mm/min travel speed and 1000 r/min rotation speed, as it was 239 MPa (i.e., 92% of the strength of aluminum base).

Addition of the reinforcing SiC nano-particles, increased the tensile strength from 169 to 239 MPa. The addition of the SiC nano-particles led to fine grains size in the SZ and increased both the pinning effects and the tensile strength. The highest tensile strengths were obtained in joints prepared by 50 mm/min travel speed and 1000 r/min rotation speed, as it was 239 MPa (i.e., 92% of the strength of aluminum base). Addition of the reinforcing SiC nano-particles, increased the tensile strength from 169 to 239 MPa. The addition of the SiC nano-particles led to fine grains size in the SZ and increased both the pinning effects and the tensile strength.

L. Natrayan et al. in their work, Al-Zn-Mg alloy reinforced with 1 to 3 wt% of nano silicon carbide used and results Al-Zn-Mg/3 wt% nano-SiC (sample 5) shows better yield strength, tensile strength, and hardness. The highest tensile strength was reported as 191 MPa, and hardness was reported as 171HV.



Sample composition	Ultimate tensile strength (MPa)	Hardness (HV)	Yield strength (MPa)	Joint efficiency (%)
Al-Mg-Zn/1.0 wt% nano-SiC	125	137	94	0.43
Al-Mg-Zn/1.5 wt% nano-SiC	143	152	99	0.50
Al-Mg-Zn/2.0 wt% nano-SiC	157	163	107	0.55
Al-Mg-Zn/2.5 wt% nano-SiC	178	167	133	0.62
Al-Mg-Zn/3 wt% nano-SiC	191	171	165	0.67

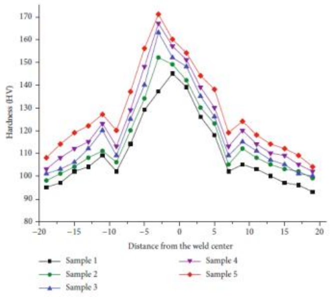
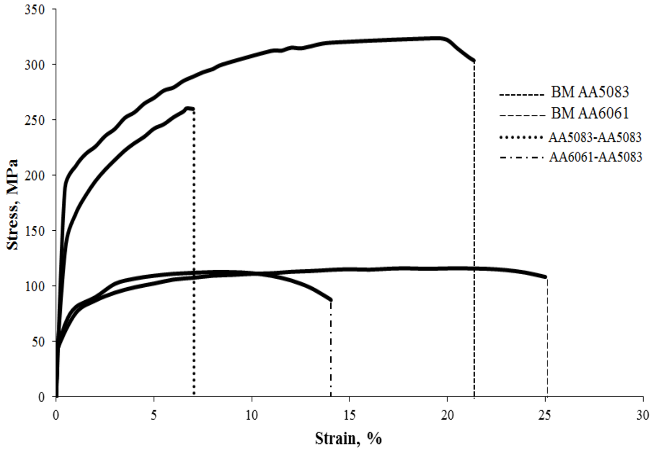


Fig -8: Mechanical properties of weld and hardness profile graph[9]

N.F.M. Selamat et al. similar and dissimilar 5 mm aluminium alloy plates used in there work and following results are obtained, Micro-hardness indentation exhibited different hardness profiles, in which low hardness was obtained at the welding centre. The Similar joint plots hardness at the base metal as 90HV and reduced to 76HV at the weld centre. Meanwhile, AA6061-AA5083 resulted reduced micro-hardness at the welding centre from 80HV to 35HV due to the mechanical properties of AA6061 on the retreating side(RS) . The welding efficiency of AA5083- AA5083 was 77% from AA5083 base metal, whereas the efficiency of joint AA6061-AA5083 was 93% and 34% compared to AA6061 and AA5083, respectively. For future studies, it is suggested to use different types of pin for the same welding parameters to compare the weld-ability of joints.



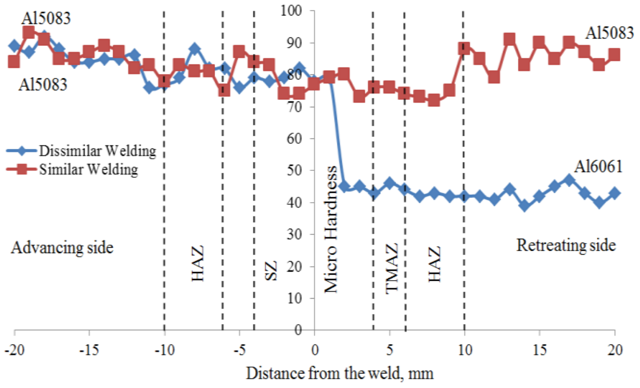


Fig -9: Tensile properties and hardness of weld joint[4]

A. S. Hassan et al. were used Two types of materials in the current investigation, typically, A356 (Al–Si–Mg) and A319 (Al–Si–Cu) cast Al alloys. The as cast FS WZs exhibited higher hardness values than both A319 and A356 base alloys. After the heat treatment, the welded regions showed lower hardness than the base alloys. In both as welded and PWHTed joints, the hardness at the WZs increases with increasing the welding speed and/or decreasing the tool rotational speed. The as welded FS joints exhibited better mechanical properties than the as cast A356 and A319 base alloys. However, the PWHTed joints showed lower mechanical properties than the heat treated base alloys. The maximum strength of the PWHTed joints was ,83% of the strength of the heat treated A356 base alloy. The PWHTed joints ultimate tensile and yield strengths decrease, however, the ductility increases, with increasing tool rotational speed and/or decreasing the tool welding speed.

Arun M et al. conducted experiment on aluminum alloy materials AA6061 and AA5083 were used as base materials in the form of plates of dimensions 200_100_6mm. The Friction stir welding of dissimilar AA6061–AA5083/La2O3 resulted in the maximum hardness value of 118 HV at SN region. This is 8.3% & 32.6% higher than AA6061–AA5083/CeO2 & AA6061–AA5083 materials correspondingly. This could be due to the higer hardness of La2O3 particles. Rocio Saldaña-Garcés et al., conducted study on AA6061-T6 and AZ31B-H24 alloys with different tilt angles and following results obtained. The higher hardness values (95-153 Hv) resulted in the M3 joint compared to the M7 weld (76-129 Hv), can be related to a higher amount of Inter metallic component. Under uniaxial tensile conditions, welds are fractured in the stir zone and exhibit a brittle behavior, which is results in defects such as lack of penetration, tunnel, insufficient mixing, and the presence of compounds Al3Mg2 and Al12Mg17 intermetallic compounds. The highest tensile strength is showed in the M7 joint (88.2 MPa), and the lowest (18.95 MPa) in the M3 weld. This behavior is related to a higher amount of Inter metallic component when using a higher rotational speed.

Tanvir Singh et al. Micro hardness distribution in the NZ for Al2O3/FSW welds is higher (88Hv) than TiO2/FSW welds (73Hv) which is attributed to the more intense uniform nanoparticle.

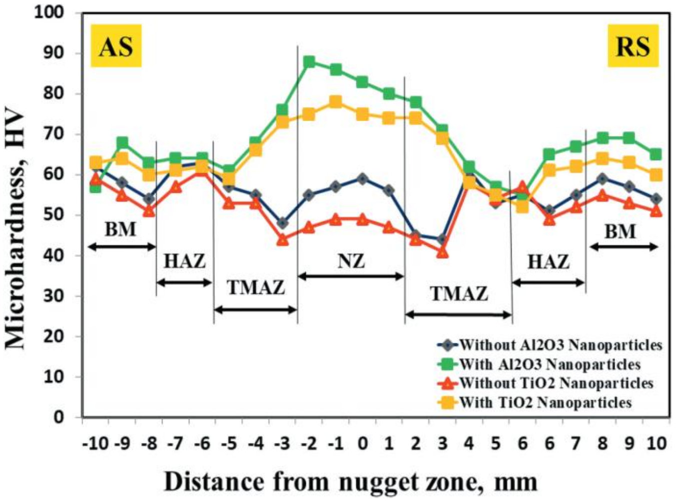


Fig -10: Microhardness of FSW welds with and without nanoparticles addition measured along the horizontal section of weldments on both sides of the weld centerline

Distribution in the NZ that causes grain refinement and in turn increase the hardenability. While the existence of nanoparticle agglomeration along with the NZ and HAZ for welds with TiO2 nanoparticles results in the occurrence of crack nucleation sites at the grain boundaries that leads to a decrease in the microhardness along the processed nugget zone.

7. CONCLUSION

Many researchers have been already carried out to demonstrate the extensive work on joining similar and dissimilar material and on FSW welding parameters, but very few investigations have been elaborated on nano particles addition, microstructure characteristics and mechanical properties

- With the adequate heat generation at higher tool rotational and lower transverse speed results in complete fragmentation of inter metallic components and nanoparticles in Al2O3/FSW welds compared to partial fragmentation occurred in TiO2/FSW welds.
- Intense uniform nanoparticles distribution in the NZ that causes grain refinement and in turn increase the hardenability.
- Increased participation Cu in NZ leads to the presence of large bulky fragments in the NZ impairing a sound material flow leading to formation of defects such as micro-voids and cracks observed.

- An increase in heat generation resulted in an enhancement in the grain size and significantly promoted the number of IMCs.
- Addition of the reinforced SiC nano-particles led to fine grains size in the SZ and increased both the pining effects and the tensile strength.
- Micro hardness of the friction stir welded joints was directly related to the amount of SiC nano-particles, intermetallic compounds, and grain size.
- Smooth surface welding on the joint depended on sufficient heat input applied during the FSW process, which was related to the transfers and the rotational speed.
- Pin rotation during the stirring process resulted in the formation of onion-ring and wavy distortion in the NZ for similar and dissimilar friction welding.
- Increasing the rotational speed of a tool decreased the shear load of the joint because the higher rotational speed.
- The addition of SiC with base material also improve the micro hardness valve, while the La2O3(lanthanum oxide) displays good tensile and wear resistance properties.

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