ISSN: 2278 – 7798
*International Journal of Science, Engineering and Technology Research (IJSETR)*
*Volume 5, Issue 12, December 2016*

# A REVIEW: JOINING OF ALUMINIUM TO MAGNESIUM ALLOYS AND COPPER BY FRICTION STIR WELDING

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***Abstract*— Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991. Friction stir welding (FSW) is a relatively new solid-state joining process. This joining technique is energy efficient, environment friendly, and versatile. In particular, it can be used to join high-strength aerospace aluminum alloys and other metallic alloys that are difficult to weld by conventional fusion welding. FSW is considered to be the most significant development in metal joining in a decade and is a ‘‘green’’ technology. Welding of dissimilar alloys is difficult due to variation in thermal and physical properties of parent metal. Joining of dissimilar alloys is possible by various Fusion and solid state welding techniques. However, fusion welding techniques are not suitable due to melting related defects, such as porosity and formation of brittle intermetallic. Diffusion welding is time consuming process while their limitation of parent metal thickness incase of ultrasonic welding. Therefore, Friction stir welding is most suitable technique of joining dissimilar alloys among all techniques. This paper looks at the review, on joining of dissimilar aluminium alloy to magnesium alloy and aluminium alloy to pure copper by friction stir welding process discussed.**

**Keyword: Friction stir welding, aluminium alloy, magnesium alloy, copper alloys**

## I. INTRODUCTION

Friction stir welding (FSW) is an innovative welding process commonly known as a solid state welding process. This opens up whole new areas in welding technology. It is particularly appropriate for the welding of high strength alloys which are extensively used in the aircraft industry. Mechanical fastening has long been favored to join aerospace structures because high strength aluminum alloys are difficult to join by conventional fusion welding techniques [1]. Its main characteristic is to join material without reaching the fusion temperature. It enables to weld almost all types of aluminium alloys, even the one classified as non-weldable by fusion welding due to hot cracking and poor solidification microstructure in the fusion zone. FSW is considered to be the most significant development in metal joining in a decade and is a “green” technology due to its energy efficiency, environment friendliness, and versatility [2]. The key benefits of FSW are summarized in Table 1[3].

**Table 1**: Key benefits of FSW

| Metallurgical benefits | Environmental benefits | Energy benefits |
|---|---|---|
| • Solid phase process<br>• Low distortion of work piece<br>• No loss of alloying element<br>• Absence of solidification cracking | • No shielding gas required<br>• No surface cleaning required<br>• Eliminate grinding | • Improved materials use allows reduction in weight<br>• Deceased fuel consumption in light |

## II. PROCESS PRINCIPLE

The basic concept of FSW is remarkably simple. A nonconsumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line. For process brief knowledge of advancing sides and retreating sides required. The FSW tool rotates in the counterclockwise direction and travels into the page (or left to right). The advancing side is on the right, where the tool rotation direction is the same as the tool travel direction (opposite the direction of metal flow).

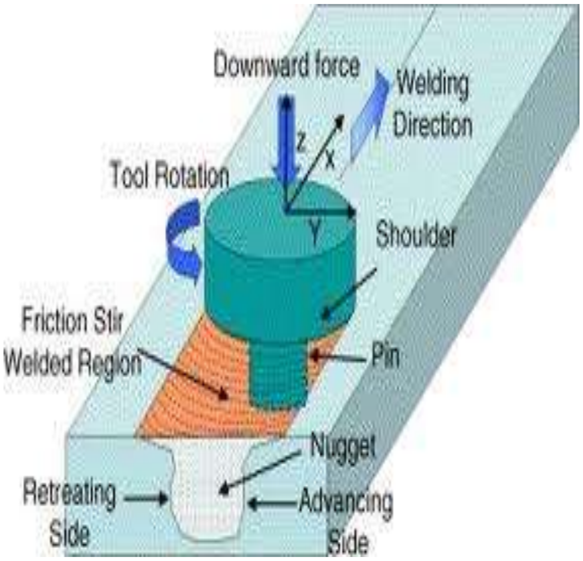

**Fig. 1** Schematic drawing of friction stirs welding [3]

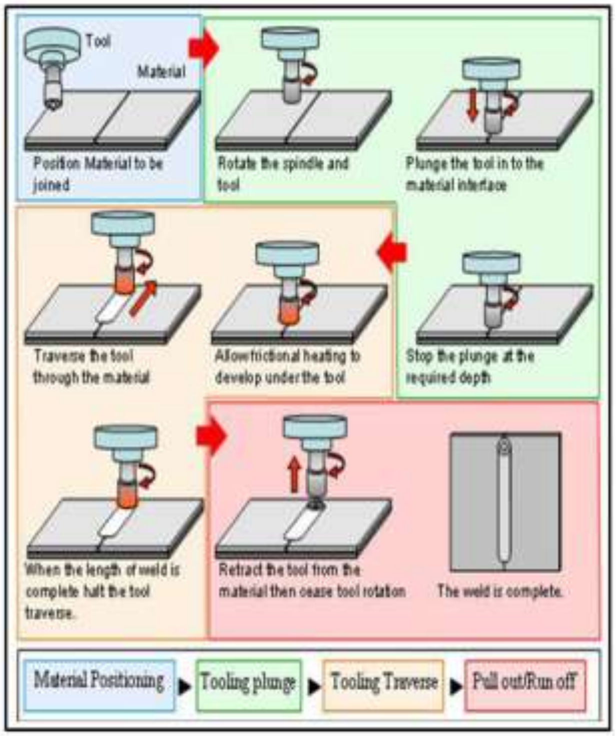

**Figure: 2** Process Diagram of Friction stir welding [3]

The retreating side is on the left, where the tool rotation is opposite the tool travel direction (parallel to the direction of metal flow).

## III. FSW MATERIAL COMBINATIONS STUDIES

### *3.1* FSW of Al alloy and Mg alloy

**SAAD AHMED KHODIR** et al [4] have studied the dissimilar joining of 2024-T3 Aluminum Alloy and AZ31 Magnesium Alloy by friction stir welding. They have been studied that the Increasing welding speed brought about a redistribution of phases in SZ where the regions occupied by 2024 Al alloy concentrated in the lower portion of SZ while AZ31B Mg alloy concentrated in the upper region beneath the tool shoulder. The laminated structure was formed in the SZ near the boundary between SZ and TMAZ on the advancing side of 2024 Al alloy regardless of the welding speed.

**Y.J.KWON** et al [5] investigated the FSW between Al and Mg alloy. The maximum tensile strength of about 132 Mpa was obtained for a 1000 rpm tool rotation speed.

**N.SAITO** et al [6] investigated the Joining of tailor welded blank of Al and Mg alloy by FSW. The maximum average tensile strength of about 143 MPa was obtained at 1400 rpm under the tool traverse speed of 100 mm/min, which was nearly equivalent to the joint efficiency of about 72%.

**YAN YONG** et al [7] have studied the Joining of 5052 Al alloy and AZ31B Mg alloy by FSW. They have been studied that the Complex flow pattern characterized by intercalation lamellae is formed in the stir zone.

**TAIKI MORISHIGE** et al [8] have studied the dissimilar welding of a 5052 Al alloy and AZ31B Mg Alloys by FSW. They have been observed that the FSW joints showed higher hardness in their stir zones than that of parent AZ31 alloy compare to laser welding because of Mg-Al inter metallic compound formation.

**VAHID FIROUZDOR** et al [9] have studied Formation of Liquid and intermetallics in Al-to-Mg Friction Stir Welding. They have been studied that intermetallic compounds in the stir zone were revealed by color etching and identified by X-ray diffraction (XRD), electron probe microanalysis (EPMA), and transmission electron microscopy (TEM) as $Al_3Mg_{13}$ and $Al_{12}Mg_{17}$.

**M.A. MOFID** et al. [10] have studied the effect of water cooling during dissimilar friction stir welding of Al alloy to Mg alloy. They have been studied the air welded specimen had a relatively larger volume fraction of intermetallic compound, higher peak temperature in stir zone and significantly higher hardness in the weld center.

**P. POURAHMAD** et al [11] have studied flow and phase transformations were studied at the interface of dissimilar welding of Al 6013 to Mg by FSW.

**S. MALARVIZHI** et al [12] have studied influence of tool shoulder on mechanical and tensile properties of Al alloy and Mg alloy.

### 3.2 FSW of Al alloy and pure copper

**PRATIK AGRAWAL** et al [13] have studied the effect of welding speed on mechanical properties of AA 6063 Al alloy and pure copper. They have been studied that the Under higher rotation rates stacking layered structure developed at the Al–Cu interface, and crack initiated easily in this case, resulting in the poor mechanical properties.

**MONEER H. TOLEPHIH** et al [14] have studied the effect of tool offset and tilt angle on mechanical properties of AA2024 Al alloy and pure copper. They have been studied that the $2^o$ tilt angle gives higher welding strength than $0^o$ tilt angle.

**ESTHER T. AKINLABI** et al [15] have studied the effect of travel speed on joint properties of 5754 Al alloy and C11000 copper. They have been studied that the microstructural evaluation of the welds revealed that at a constant rotational speed and varying the traverse speed, better mixing of both metals and metallurgical bonding were improved at the lowest traverse speed.

**SUNIL PANDEY** et al [16] have studied the butt joining of 6101 Al alloy to pure copper by FSW. They have been studied the Tensile strength of weld is very poor as compare to both of the base metals and all welds were fail from nugget zone. The ductility of is also very poor and comparable to the base metals.

**ESTHER T. AKINLABI** et al [17] have studied the Fracture Location Characterizations of Dissimilar Friction Stir Welds. They have been observed that the It was observed that 70% of the tensile samples failed in the Thermo Mechanically Affected Zone (TMAZ) of copper at the weld joints.

## IV. MATERIAL CHARACTERIZATION STUDIES

Elongated grains along the rolling direction with a random distribution of second phase particles recognized as small black particles. The compositions of these particles were $CuMgAl_2$, $Cu_2\mathrm{Mn}Al_{20}$, and $Cu_2\mathrm{Fe}Al_7$.These grains with several hundred microns long and approximately 40–70 mm wide is lying along the transversal direction that is normal to the welding direction [6]. Dynamic recrystalization occurred in SZ due to the plastic deformation and thermal cycle effect caused by rotational tool [7].

**M.A.MOFID** et al. shows that complex intercalated flow patterns, in which recrystallized Mg and Al alloys are swirled together to form a complex mesh in the stir zone of the weld. The recrystallized Mg grains in this zone can be seen to be fine homogeneous and equi-axed [10].

**S.MALARVIZHI** et al. shows that the recrystallized grains at Mg side from the transition zone along with the intercalated flow patterns and prominent grain growth observed in the dynamically recrystallized Mg alloy in the transition region [12].

## V. MECHANICAL TESTING STUDIES

**SAAD AHMED KHODIR** et al. showed that the different regions like SZ, TMAZ shown in microstructure. In SZ grey and slightly dark grey regions were observed. The grey regions showed the irregular shape grains in which small fragments coming from Mg alloy side. While in TMAZ twins and elongated grains was observed. The grains are also equiaxed and recrystallized having a size equal to that in the SZ. Increasing welding speed the hardness distribution in HAZ and TMAZ of 2024 Al alloy on the advancing side but is less effective for AZ31 Mg alloy which is located on the retreating side. The hardness distribution in SZ is slightly effected by welding speed and the harness values varied from 65 to 220 Hv due to the presence of intermetallic compounds and microstructures occupied by either 2024 Al alloy or AZ31 Mg alloy [4].

**Y.KWON** et al. showed that the simple bonded interface is clearly evident as zigzags near the center of SZ. No formation of a eutectic microstructure suggests that the dissimilar FSW was carried out in the solid state of the base metals. The maximum tensile strength was about 132 MPa, which was about 66% of the tensile strength of the A5052P-O alloy [5].

**N.SAITO** et al. showed in the SZ, the bonded interface was clearly evident with plastic flow pattern between the aluminum and magnesium alloys, although an onion ring pattern was not formed. During tensile testing, the FSWed TWBs were fractured in the SZ at the early stage of the plastic deformation. The joint efficiency of the TWBs exceeded 62%, and the maximum average tensile strength of about 143 MPa was obtained at 1400 rpm under the tool traverse speed of 100mm/min, which was nearly equivalent to the joint efficiency of about 72% [6].

**YAN YONG** et al. showed Microstructure of the base metal was replaced by equiaxed and fine grains in stir zone. At the top of the stir zone, 5052 and AZ31 alloys were simply bonded, while onion ring structure which consisted of aluminum bands and magnesium bands was formed at the bottom of the stir zone. The maximum value of microhardness in the stir zone was twice higher than that of the base materials. The fracture position located at a distance of 2.5 mm from the joint center leaning to the advancing side (aluminum side). Different intermetallic compounds observed in the microstructure and 61% joint efficiency obtained [7].

**VAHID FIROUZDOR** et al. shows that the presence of the eutectic structure of $Al_{12}Mg_{17}$ and (Mg) in the stir zones of lap and butt welds is clear evidence of liquid formation during FSW [9].

**M.A.MOFID** et al. shows that the XRD analysis shows these intermetallic phases are $Al_3Mg_2$ and $Al_{12}Mg_{17}$ and$Al_2Mg_3$. The stir zone of underwater welded specimen showed a much smoother interface and less intermixing. Due to a decrease of $25^oC$ in the peak temperature from a maximum of $403^oC$ in the case of air welded specimen to a maximum of $378^oC$ for welds made underwater, the formation of intermetallic compounds was suppressed significantly. Grain growth was not noticeable in the dynamically recrystallized Mg alloy in the stir region because of lower peak temperatures.

**P. POURAHMAD** et al. shows that the zigzag interfaces and intermetallic compounds founded in microstructure [10].

**S.MALARVIZHI** et al. have been observed that the maximum tensile strength of 192 MPa and the joint efficiency is 89% compared with the lower strength base metal. Complex intercalated microstructures in the weld zone, with swirls and vortices indicative of the flow pattern of the dissimilar metals [12].

**PRATIK AGRAWAL** et al. showed the proper mixing of Al and Cu in microstructure and many stacking layers structured were observed at interface at 1000 rpm. Constant hardness value 75 obtained at copper sides while at Aluminium side hardness value decrease 35 [13].

**MONEER H. TOLEPHIH** et al. showed onion ring and fracture occurred at interface [14].

**ESTHER T. AKINLABI** et al showed improved mixing of both metals was achieved at the lowest traverse speed due to low downward vertical force and high heat input. Higher Vickers microhardness was measured at the interfacial regions due to dynamic recrystallization and the presence of intermetallics. The average Ultimate Tensile Strength of the welds decreased as the welding speed increased [15].

**SUNIL PANDEY** et al. showed different regions, like TMAZ and Nugget Zone in microstructure. Microhardness in weld nugget is higher than base metal and no significant difference found in other regions. Tensile strength of weld is very poor as compare to both of the base metals and all welds were failing from nugget zone. The ductility of is also very poor and comparable to the base metals [16].

**ESTHER T. AKINLABI** et al founded that majority of the welds fractured in the advancing side of the weld. Most of the welds with low Ultimate Tensile Strength either have defects or the presence of intermetallic compounds at their joint interfaces. Fracture locations are dependent on the internal structures of the weld regions, either due to the presence of weld defects or the presence of intermetallic compounds in the joints [17].

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