AN ANALYSIS OF ALUMINUM ALLOYS ON FRICTION STIR WELDING

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Abstract--This paper presents a review of friction stir welding of various aluminum and other metal alloys. Friction Stir Welding (FSW) technique was developed before two decades as a novel solid state joining process for Al alloys. Later, it has been developed and used for many other metals, composites and high melting alloys. The FSW process is applicable presently for welding of aluminium and magnesium alloys as well as other non-ferrous and ferrous materials like copper, steel, composites and dissimilar materials. Welding of heat treatable Al alloy by FSW gives better quality weld compared to other fusion welding process. The work done by the researchers in this field has been acknowledged in this paper.

Keywords: FSW, Aluminum alloy, Microstructure analysis, Mechanical properties

INTRODUCTION

The Friction Stir Welding (FSW) technique was invented by The Welding Institute (TWI) in 1991. FSW is a solid state new joining process that is presently attracting considerable interest. In this process the two pieces of metal are mechanically intermixes at the place of join, then often them so that the metal can be fused using mechanical pressure. In this welding process, a rotating welding tool is driven into the material at the interface of, for example two adjoining plates, and then translated along the interface. In this process, joining is done with the help of frictional heat generated at the faying surfaces of the two sheets to be joined with the specially designed rotating tool. In the FSW process, a special tool mounted on a rotating probe travels down through the length of the base metal plates in face-to-face contact; the interface between welding tool and the metal to be welded generates the plastically deformed zone through the associated stirring action. At the same time, the thermo-mechanical plasticized zone is produced by friction between the tool shoulder and the top plate surface and by contact of the neighbor material with the tool edges, including plastic deformation.
Although the work piece does heat up during friction stir welding, the temperature does not reach the point of the melting. The welded friction stir joint does not have the dendritic structure like conventional fusion-weld joint, cause of degradation of mechanical properties.

**Literature Review:**

1.1 FSW of similar aluminum alloys:

**a) 5052 aluminum alloy plates**

The research work was done by Yong-Jai Kwon et.al. in 2009 on Al5052-O aluminum alloy plates of dimensions 160mm*30mm*2mm and they used tool with 10mm shoulder dia., 4mm probe dia. & 1.7mm height of probe and tool was rotated in a clockwise direction at speeds ranging from 500 to 3000 r/min. The conclusions they drew were as follows:

- Defect free weld is successfully obtained at all tool rotation speeds.
- Onion ring structure is formed in friction stir welded zone (SZ).
- At all tool rotation speeds, the gain size in the SZ is smaller than that in the base metal.
- At all tool rotation speeds, the SZ exhibits higher average hardness than the base metal.
- At 500, 1000 & 2000 r/min, the tensile strength of the FSWed plates is similar to that of the base metal (about 204 MPa). The elongation is lower than that of the base metal (about 22%).

**Fig.3 Schematic representation of FSW process**

**b) AA7039 aluminum alloy**

The research work was done by Chaitanya Sharma et.al. in 2012 on Al-Zn-Mg alloy AA7039 with plate dimensions 300 mm*50 mm*5 mm. They performed experiment on vertical milling machine using welding speed of 75, 120 and 190 mm/min, and tool rotary speed of 410, 540, 635rpm. The FSW tool had shoulder diameter of 16 mm & cylindrical tapered pin diameter of 6 mm at top and 4 mm at bottom, 4.7 mm in length and anticlockwise threads of 1 mm pitch. Base material have 414 MPa tensile strength, 328 MPa yield strength, 15.1 % elongation and 135 HV hardness. The conclusions they drew were as follows:

- An increase in tool rotary speed and decrease in welding speed reduces zigzag line formation tendency. Average grain size of α- aluminium present in weld nugget decreases on increasing welding speed and decreasing rotary speed.
- The ultimate tensile strength, % elongation, energy absorbed and joint efficiency decrease with increase in welding speed and all above joint performance parameters increase with increase in rotary speed.
- The location of minimum microhardness zone in FSW weld joint of AA7039 alloy is significantly influenced by FSW process parameters. The minimum hardness region shifts from heat affected zone to weld nugget zone on increasing welding speed and decreasing the tool rotary speed.

**Fig.4 Tool for FSW**

2.2 FSW of dissimilar aluminum alloys:

**a) AA6082-AA2024 aluminum alloys**

The research work was done by P.Cavaliere et.al. in 2009 on AA6082 & AA2024 alloy plates of dimensions 200mm*80mm*4mm tool used was made of C40 steel of conical shape with 3.8 mm large diameter, 2.6 mm small diameter & 9.5 mm shoulder diameter. They performed experiment with rotation speed of 1600 rpm and by changing advancing speed from 80 mm/min to 115 mm/ min. The conclusions they drew were as follows:

- The vertical force was observed to increase as the travel speed for all the produced joints increases.
- The forces acting on the plates in the case of higher strength material (AA2024) positioned on advancing side of tool resulted higher with respect to corresponding welds with softer material (AA6082) positioned in advancing side.
Best tensile & fatigue properties were obtained for joints with AA6082 on advancing side & welded with an advancing speed of 115 mm/min.

b) 2024 – 7075 aluminum alloys

The research work was done by P. Cavaliere et al. in 2006 on 2024-7075 aluminum alloys plates of 2.5 mm thickness. The welding speed was set to 2.67 mm/s, the welding tool was fixed to the rotating axle in the clockwise direction while the parts, fixed at the backside, have been translated. The tool nib was 6 mm diameter and 2.5 mm long, a 20 mm diameter shoulder has been machined perpendicular to the tool axis; the tilt angle of the tool was set to 3 degrees. The conclusions they drew were as follows:

- The dissimilar 2024 and 7075 aluminum alloys in the form of 2.5 mm thick sheets have been successfully joined by friction stir welding.
- The micro hardness reaches a value of 150 HV in the center weld; the micro hardness profile increases in both 2024 and 7075 sides and then starts to descend after 2 mm from the center until reaching the hardness corresponding to the parent materials.

![Micro hardness profile measured in the joints of the 2024–7075 FSW plates](image)

Fig.5

2.3 FSW of dissimilar metal alloys:

a) Magnesium and aluminum alloys

The research work was done by Y.J. Kwon et al. in 2008 on AZ31B-O & A5052P-O alloy plates of dimensions 160mm*30mm*2mm and they used tool with 10mm shoulder diameter, 4mm probe diameter & a height of 1.7mm. The tool was rotated in clockwise direction at speeds ranging from 800 to 1600 rpm & rotating tool was traversed at a constant speed of 300 mm/min. The conclusions they drew were as follows:

- For tool rotation speeds of 1000, 1200 & 1400 rpm defect free welds were successfully obtained.
- The mixed microstructure was formed near the bonded interface, in which magnesium and aluminium alloy particles were distributed in the A5052P-O & AZ31B-O alloy regions respectively.
- For the FSWed plates, the maximum tensile strength was about 132 MPa, which was about 66% of the tensile strength of the A5052P-O alloy.

b) ZK60 magnesium alloy and titanium

The research work was done by Masayuki Aonuma & Kazuhiro Nakata in 2012 on Mg-Zn-Zr (ZK60) alloy and titanium alloy plates of dimensions 150mm*50mm*2mm and tool used was made of SKD61 alloy steel and have 15mm shoulder diameter, 1.9mm probe length and 6mm probe diameter. Travel speed of tool was 50 mm/min. The conclusions they drew were as follows:

- Zn & Zr of alloying elements formed a thin reaction layer with titanium at the joint interface by friction stir welding.
- The tensile strength of the Ti and ZK60 joint increased with increasing the probe offset and reached to 237 MPa, at 1.5 mm offset, which was 69% of that of ZK60 base metal, and much higher than that of Ti and Mg joint, 135 MPa the probe offset 1.5 mm, though, in the Ti and Mg joint, little change was observed in the tensile strength with increasing the travel speed.

![Schematic illustration of joint arrangement in FSW](image)

Fig.6

2.4 FSW of other metal alloys:

a) Brass plates

The research work was done by Mr. Cemal Meran in 2006 on Brass CuZn30 plates of dimensions 120mm*60mm*3mm (L*W*H) and he performed the experiment at 2050 rpm. Base materials (CuZn30) have 360 MPa tensile strength, 215 MPa yield strength, 67% elongation.
and value of E is 110 kn/mm$^2$. The conclusions he drew were as follows:

- Evaporation of zinc & copper problem has solved.
- Colour of brass material did not change.

![Fig.7 Geometry and dimensions of stirrer](image)

b) copper metals

The research work was done by Y.W. Hwang et.al. in 2010 on Copper 11000 plates of dimensions 60mm*20mm*3.1mm and tool used was made of SKH9 high speed steel with length of pin 2.8mm and diameter of shoulder 12mm and he performed the experiment at 400 to 1200 rpm.

![Fig.8 Dimensions of the tool and pin](image)

The conclusions they drew were as follows:

- The appropriate temperature for a successful FSW process were found to be between 460$^0$ & 530$^0$ (4 thermocouples were used, two on advancing side of work piece, whereas two on retreating side).
- The tensile strength & the hardness at the thermal-mechanical affected zone (TMAZ) were about 60% of the base metal, whereas, the elongation can reach 3 times that of the base metal.

![Fig.9 Layout of the thermocouples inside the work piece](image)

c) Aluminum & titanium alloy

The research work was done by Yanni Wei et.al. in 2012 on aluminium 1060 and titanium alloy Ti-6Al-4V plates of dimensions 100 mm* 100 mm* 3 mm and they used tool with 25 mm concave shoulder diameter, 6 mm cutting stir pin diameter (made of tungsten carbide) and 3.2 mm insertion depth. The welding was performed at a rotation of 950 rpm and different welding speeds of 150 mm/min, 235 mm/min, 375 mm/min and 475 mm/min. The conclusions they drew were as follows:

- Aluminium 1060 and titanium alloy Ti-6Al-4V high strength lap joints were successfully obtained by FSW with cutting pin.
- There are many titanium scrapings distributed in aluminum near the interface. A swirl like structure with lighter and darker parts was observed.
- The failure load of the joint reached 1910 N at the welding speed of 300 mm/min, which was approximately equal to that of 1060Al base metal, and the ultimate fracture happened in Al metal that underwent thermal cycle provided by the shoulder during FSLW.

Conclusions

The effect of friction stir welding on aluminum alloy and some other metals has been studied in this paper with the help of notable research in this field. The various parameters were taken for different materials and effects were studied.

REFERENCES


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