Studies on friction stir welding of Aluminum plates 2014-T6 and 6061-T6

A. T. V. Vara Prasad[1] & D. S. Chandra Mouli[2]

[1]*Department of Mechanical engineering, Mallareddy Engineering College (A)*
Secunderabad, Telangana-500100
Corresponding author: aakulavaraprasad963@gmail.com
[2]*Department of Mechanical engineering, Mallareddy Engineering College (A)*
Secunderabad, Telangana-500100
Corresponding author:dkmouli1986@gmail.com

Abstract: *The joining of dissimilar 6 mm thick aluminum plates for 2014-T6 and 6061-T6 was performed using the technique of friction stir welding(FSW).By using statistical approach optimized parameters for weld process have been obtained for joints. The process aimed at studying the effects of welding parameters on microstructure, tensile-strength and plate hardness. The concept of hexagonal tools was used to examine the effect of rotational speed and weld speed on micro structure and tensile property. The effect of welding speed on microstructures, the distribution of hardness and the tensile properties of weld joints are studied. By changing the process parameters more efficient and low defective weld joints are formed. The most prevalent factor is the fraction between both the shoulder of the tool and the diameter of the pin. It is evident from micro structural study that nugget region was dominated by advancing side material. At 6061 HAZ the hardness is found to be minimal, where weld joints are failed during the tensile studies at the ends of the HAZ.*

Keywords: **Friction stir welding, Dissimilar alloys, Al alloy 2014T6 and 6061T6, taguchi optimization method**

1. Introduction

1.1 Basic introduction regarding FSW

"Friction Stir Welding is a technique invented by Thomas for joining of novel material, in 1991, the welding center, TWI"[1]. "FSW has become one of the most important solid-state joining processes in recent years, and it consumes considerably less energy. Especially given the advantages they offer in design and manufacture over existing mechanical joining methods. Although a number of welding methods for airframe structures have been established, friction stir welding is an important candidate technique that is distinctive in being a low-energy, solid-state process"[2]. "FSW is a method of hot-shear joining in which a non-consumable, rotating device plunges through a rigidly clamped piece of work and travels along the joint to be welded" [3]. "The rotating tool is a cylindrical shape consisting of a shoulder and a pin; the profiled pin may be threaded or unthreaded while the length may be lower than the shoulder-extruding weld depth. The FSW process starts by plunging the tool into the joint until the shoulder is in contact with the work piece surface. The rubbing motion of the tool shoulder produces heat as the tool is moving along the joint. Shoulder is responsible for heat generation and the containment of the plasticized material in the weld region, while pin combines the material of the components to be welded, forming a joint" [4].

1.2. Working theory

The FSW mainly have four essential stages: The rotating tool reaches the surface of the metal work piece during the penetration or plunging process and pierce into the metal producing the primary heat. The residential method involves achieving the operating temperature needed to start the welding before a steady downward force between the tool and the work piece is achieved, which generates the energy of friction between them. This cycle goes on till the pressure force between both the FSW instrument and the surface of the metal working component slowly decreases, indicating that the temperature required to start welding has been reached. Complex thermo-mechanical operation includes the welding point. The constant frictional energy produces high temperatures at the joining of the plates which soften the material. As the tool goes forward in the direction of welding the material of both the joining work pieces are combines with each other with the help of the pin. The last step is the returning process. When rotating tool gets to the end of the joining line of the work pieces it retracts vertically. "The friction stir welding process is very effective method for mechanical improvement of semi solid metal Al alloy"[10]. The operational principles of the FSW process are shown in below figure

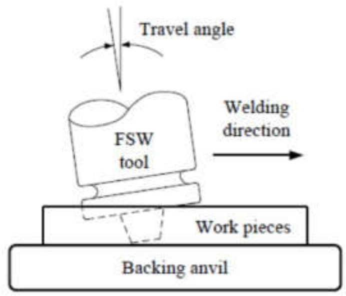


Figure 1.

2. Literature Review

- "Liu Hui performed 2219 aluminum alloy underwater friction stir welding to improve the weld properties. During normal friction stir welding, which is significantly involved in reducing the hardness, coarsened grain was achieved. Due to the precipitates dissolved in the matrix, high-density dislocations and refined grain structures were formed in submersed friction stir joint. This leads to improved welding properties, such as hardness and tensile strength"[6].
- "Basil Darras addressed AZ31 magnesium alloy friction stir processing under natural and submerged conditions and its inherence to tensile properties, grain structure, power consumption and thermal fields. For FSP in the air, average grain size of 18.9 µm, 15.9 µm, and 13.3 µm was achieved, submerged respectively in hot water and cold water. In cold water conditions more grain refining was achieved"[7].
- "Huijie Zhang demonstrated that 2219-T6 aluminum alloys had a submerged friction stir welding. In this, the most important parameters are rotational and welding speeds which affect the tensile strength of the welded sample. The ultimate tensile strength of 360 MPa in optimized condition was obtained via SFSW. This value of SFSW tensile strength is 6 per cent higher than the normal FSW"[6].

3. Experiment Materials And Methods

3.1. Materials

The friction stir welding technique can be successfully welded to a range of materials, including low - melting metals and higher melting metals. A broad variety of materials are able to weld by using FSW, including Al, Al alloys, Fe alloys, Cu alloys, brass, Mg alloys, Ti alloys, Ni alloys, Ag and Au. FSW does not only combine related metals but also dissimilar metals.

Al-2014-T6: 2014 can be used as a high-strength casting material for different uses. It contains a fairly high volume of copper, and is thus less resistant to corrosion. Adequate anti-corrosion treatment when exposed in a corrosive environment is required.

Al-6061-T6: This type of alloy has outstanding strength and resistance to corrosion, and is used as a material of the structures. 6061 has improved strength by adding small amounts of Cu. Although its corrosion resistance is somewhat lower, it has an excellent casting property and is therefore used for rivet materials and small car components. If the hardness is 254N / mm2 or higher and deflection is not a issue in design, the advantage of the allowable stress equal to that of SS400 steel is. 6063 is low in strength but has an excellent extrusion property. So it is used as a material of structure that does not have to be as strong as 6061.

Table-1 Mechanical Properties about AA2014-T6 alloy

Young's Modulus (GPa)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation (%)	Toughness (MPa/m²)
73	414	190-480	13	19

Table- 2 Physical Properties about AA2014-T6 alloy

Density	Hardness	Melting Range	Thermal Conductivity	Sp.Heat
Kg/mm³	BHN	°C	W/m-k	J/Kg-°C
2.8	135	507-638	154	0.88

Table-3 Chemical Composition about AA2014-T6 alloy

Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
90.4-95	Max 0.1	3.9- 5	Max 0.7	0.2- 0.8	0.4-1.2	0.5-1.2	Max 0.15	Max 0.25

Table-4 Mechanical Properties about AA2014-T6 alloy

Young modulus (GPa)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation (%)	Toughness (J/mm3)
68.9	276	310	17	80.7

Table-5 Physical Properties about AA2014-T6 alloy

Density	Hardness	Melting Range	Thermal Conductivity	Sp.hea t
Kg/mm3	BHN	°C	W/m-k	J/Kg- °C
68.9	107	582- 652	167	0.896

Table-6 Chemical Composition about AA6061-T6 alloy

Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
95.8-98.6	0.04-0.35	0.15-0.4	Max 0.7	0.8- 1.2	Max 0.15	0.4- 0.8	Max 0.15	Max 0.25

3.2. Tool design:

During the improvement of the FSW process it was realized that the tool design is crucial to the production of sound welds. The working tool is one of the most critical components of FSW operation. The tool consists of different design specifications according to work types, which material to be plate or sheet thickness. The tool contains shoulder and profile pin. The shoulder takes place at the base of the pin profile and pin pace penetrates only through the working materials. The tool shoulder purpose is to monitor the material flow and during operation the pin deforms the grain size of the working material.

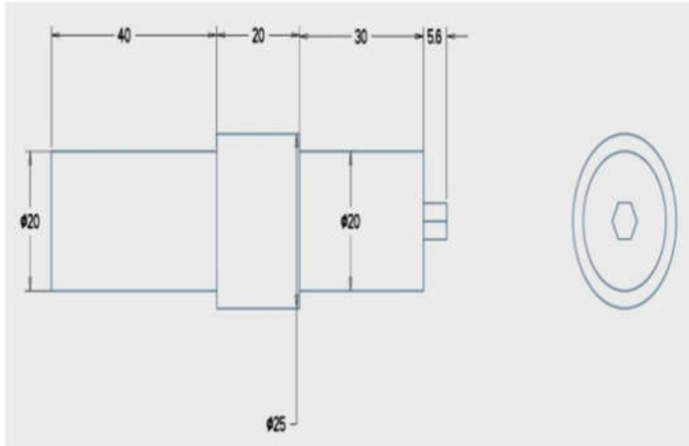


Figure 2 fsw tool design

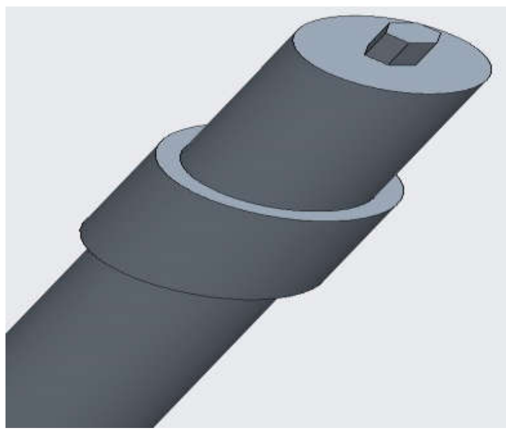


Figure 3 fsw tool design

3.3. Taguchi methodology

"Genichi Taguchi developed mathematical methods known as taguchi methods, and these methods are one among very effective DOE methods of experimental research. The quality of manufactured products can be used to enhance by using these technique and also these methods are recently applied to biotechnology, marketing and advertisement engineering. He first applied his methods was Toyoto. Robustness of the product, pioneered by Taguchi, uses experimental design to study the response surfaces associated with both the product means and variances to select suitable factor settings so that variance and bias are both small at the same time. Designing a quality product requires knowledge in making the response variable immune to unmanageable variation in the production system or client's requirements of using the item"[5]. In this study, there are 18 DOF's due to three independent parameters around three points, so that A L9 orthogonal array is used

4. Experimental Procedure

4.1. Workpieces

The FSW study is important in order to incorporate the welding of Al material into a broad range of industrial applications and to improve the use of environmentally sustainable production processes. Two dissimilar AA6061T6 and AA2014T6 Al plates with thickness about 6mm was butt weld by FSW along the joint line shown in Figure for the following experiments. The samples were cut lengthwise to 140 mm and width to 100 mm.

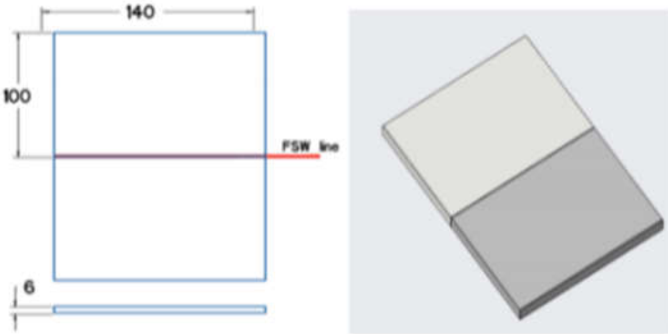


Figure: 4 butt-weld along line

The physical and mechanical property of the work pieces plays a major part in most areas like weldability and selection of the tool materials. Tables 1-6 outline the physical and mechanical properties of the aluminum sheets used in experiments. Table 3,6 shows the chemical compositions of 2014 and 6061 Al alloys. Vertical milling machine is used to do the welding process.

In this study HSS material is used for welding tool, because HSS has high resistance thermal fatigue. The shoulder surface is flat with diameter is 20mm and the shape of the pin is -hexagonal with height of 5.7mm. The complete toll design is shown in the fig

Figure:5 hexagonal tool design as shown in figure 2,3

Table 7 outlines the weld parameters of this study. Due to its higher mechanical strength AA2014 plates were kept on the tool forwarding side and positioned the tool pin at centre of the weld line.The aluminum plate sets are fixed to machine firmly, using the parameters shown in the table 7 tests are made using different weld speed and tool rotation speed.

TABLE-7 below table shows Weld parameters used

Trail no.	Tool Rotation speed(rpm)	Tilt angle (°)	Weld Speed mm/min
1	900	0	20
2	900	1	25
3	900	2	30
4	1120	0	25
5	1120	1	30
6	1120	2	20
7	1400	0	30
8	1400	1	20
9	1400	2	25

For the study of micro-structure of the welded samples of different aluminum alloys they undergo series of grinding process and finally to a disk polishing machine where specimens finished their final stage of grinding, then on grinding surface Keller's reagent was used and cleaned with water for microstructure study. Optical microscopeused to evaluate the microstructure characterization.

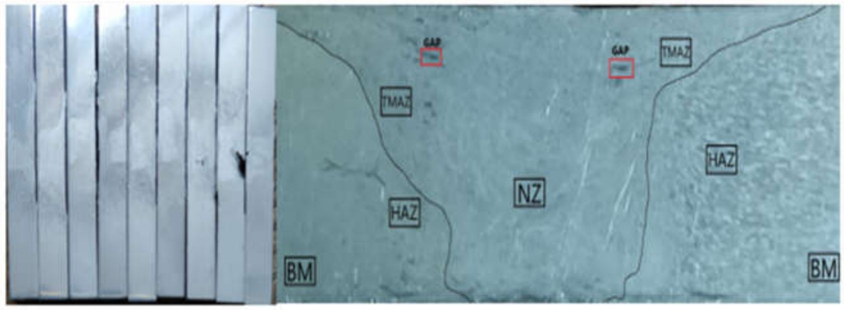


Figure:6 figure shows different zones in weld joint

The weld samples are made as per the ASTM E8 standards for tensile studies, and tensile tests are performed at a strain rate of 0.5mm/min. Micro hardness was performed at a load of 100gf with a dwelling time of 10secs and a distance of 0.25 mm through the weld.

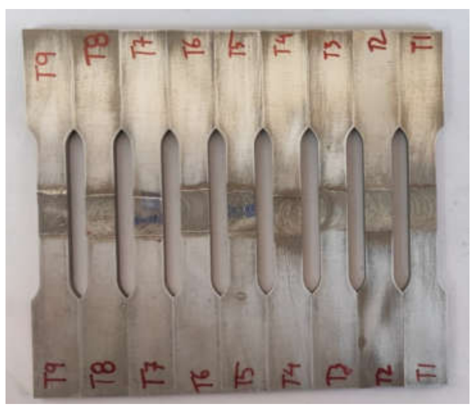


Figure:7 figure shows samples for tensile test

5. Result and Discussion

5.1. Microstructure

Below fig.6 shows the welded different material microstructure of various areas. Even if the weld passes through significant number of heat cycle, the main materials microstructure does not change significantly. The thermal cycle, on the other hand, HAZ is significantly influenced, that is visible from the microstructure. But, plastic deformation does not happen in the HAZ. Because of less heat produced and the plastic deformation in the process there is considerable growth in grain boundaries in the TMAZ area. It is also evident in the microstructure that the recrystallized zone (welded nugget) is separated by a distinct grain boundary from the deformed TMAZ areas. "The stirred zone is the dynamically recrystallized area, in which the material has undergone severe plastic deformation resulting in fine equiaxed grains"[8]. The word stirred zone is widely used in friction stir processing where the material is processed in appropriate volume. "Further to the weld nugget microstructure (Figure 6), it is obvious that the grains are highly refined, that may boost welding strength" [9]

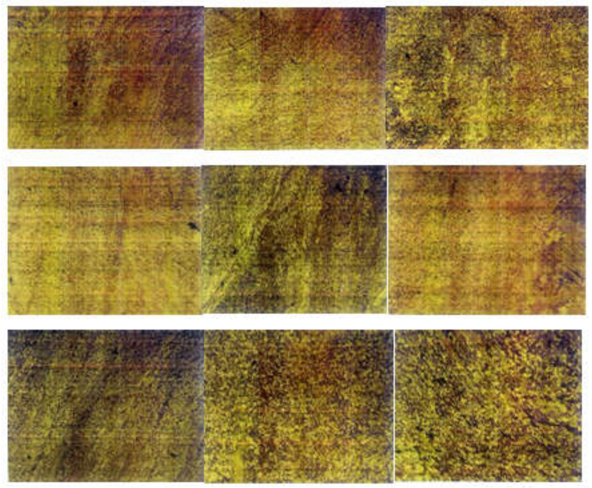


Figure:8 figure shows the microstructure results of the 9 test specimens

5.2. Tensile test

Using hexagonal pin, the highest weld strength was 184N / mm2 and 187 N / mm2. The fracture occurred at 6061 HAZ side as shown in fig 9. The welded specimen displays lower force as the tool rotating at low speed. Joint efficiency has been achieved by 80%. The welded specimens exhibit high strength when the weld speed with lower tool tilt angle is high.

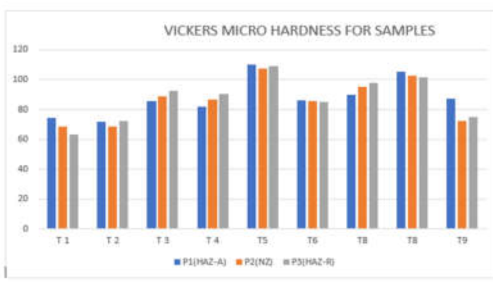
Figure:9 figure shows the tensile test result pieces.

Table:8 table noted the tensile test values

Test specimen number	Tensile strength values (N/mm²)
1	166.605
2	145.095
3	155.983
4	187.934
5	164.137
6	179.392
7	184.612
8	179..274
9	174.460

5.3. Hardness

Tests are conducted for Vickers hardness around diverse weld spacing zones of (1 mm). Hardness aggregate of 105.15 HV is obtained by this welding for hexagonal pin. At weld nugget area the durability is slightly lesser than AA2014; while, the durability is significantly greater than AA6061 material and thermo mechanically affected zone.



Graph: 1graph represents the hardness values in bar chart

Table: 9 hardness values of the table

Sample-no.	Hardness Values
T1	63.0, 74.5, 68.3 HV0.2
T2	72.2, 71.5, 68.8 HV0.2
T3	92.3, 85.4, 88.9 HV0.2
T4	90.3, 82.1, 86.8 HV0.2
T5	109.1, 110.3, 107.4 HV0.2
T6	85.1, 86.2, 85.4 HV0.2
T7	98.1, 89.7, 95.4 HV0.2
T8	101.7, 105.4, 102.8 HV0.2
T9	74.8, 51.3, 66.1 HV0.2

6. Conclusion

The Taguchi approach was used in this analysis to obtain optimized process parameters of AA2014T6 and AA6061T6 for FSW. In 2014T6 and 6061T6 aluminium alloys, the influence of rotating tool speed, speed at which welding is carried out and inclination angle of tool on the joint excellence was established. The tensile strength was found to be raised with the raise in speed from 900 - 1400 rpm. The raise in tool forwarding speed from 20mm / min to 30mm / min has also been found to increase the hardness. Visual inspection was understood from the trial and error methods that rotation speed of 900 rpm and below surface defects were extremely prominent and poor welding joints were developed. The FSW joint, manufactured with optimized parameter of 1120 rpm rotational speed, 0 tilt angle and 25mm / min weld speed, exhibited a higher tensile strength of 187.9 N / mm2. Rotation speed of the tool was the main contributing factor to the tensile strength.

7. References

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