

A Review of Friction Stir Welding Process Parameters on Various Aluminium Alloys

Diljot Singh Sekhon¹, Er. Rajdeep Singh², Er. Nirmaljeet Singh Virk³

Research Scholar, Department of Mechanical Engineering, Punjabi University, Patiala, India¹

Assistant Professor, Department of Mechanical Engineering, Punjabi University, Patiala, India²

Assistant Professor, Department of Mechanical Engineering, Chandigarh University, India³

ABSTRACT: Friction stir welding is a solid state joining process in which a particularly designed rotating tool, which is inserted between the two sides of the sheets which need to be welded, and the tool is moved along the length of the joint. FSW is discussed here in this paper along with its working principle, micro structural features, process parameters and its benefits. Aluminium and its alloy's mechanical and metallurgical properties and process parameters of FSW which effect their properties are also discussed in this review. Apart from this, the paper also studied the different approaches used in previous studies to examine the properties of different aluminium alloys affected by different approach regarding FSW. In friction stir welding different types of tool profile used but square tool profile provide a better strength in the joint. There is less research done for study the effect of different tool pin profiles on a material Al 6101-T6. So to reduce the gaps in study in FSW we have to concentrate on the important parameters and do research on it properly.

KEYWORDS: Friction stir welding (FSW), Al 6101-T6, Microstructure, Metallurgical properties

I. INTRODUCTION

1.1 FSW (Friction stir welding)

The difficulties start occurring in joining of aluminum alloys and different metals by frequently used technologies such as in fusion welding, so to solve these difficulties a newly developed welding technology friction stir welding (FSW), is created and patented in 1991 by Wayne Thomas at TWI (The Welding Institute) Ltd. in UK. Friction stir welding is a solid state joining process in which a particularly designed rotating tool, which is inserted between the two sides of the sheets which need to be welded, and the tool is moved along the length of the joint. The tool produced the frictional heating and plastic deformation in the welding zone along the joining of the work piece length basis for welding. The friction stir welding is a solid state joining process means no melting of a material take place during the process. The main parameters in friction stir welding are welding speed, tool rotation speed, tool shoulder diameter and tool pin length, tool pin diameter.

1.2 Working Principle

The schematic diagram for friction stir welding (FSW) is shown in Figure1. The non- consumable tool has a circular section beside at the end where there is a threaded probe is present. The junction between the cylindrical portion and the probe is known as the Shoulder. The probe inserted in the work piece where the shoulder touches with the top surface. The friction stir welding is working on the principle that when a rotating tool which has a pin (and shoulder) is penetrated between the very small root gap of the two aluminium plates due to circular motion of tool heat is produced due to friction. The heat produce by rotation of tool the melting of the plates occur. Just before the melting point of the material, the joining process starts. So, the process is called solid state welding process. The CNC (computer numerical controlled) vertical milling machine is preferred for a better result or closer to accurate result.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor & UGC Approved Journal)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

1.3 Microstructural Features

The solid-state nature of the FSW process, applied with its unusual tool and asymmetric nature which results in a highly characteristic microstructure. The microstructure can be categorized into the following zones:

- Stir Zone** (also called nugget or dynamically recrystallized zone) is a region of heavily deformed material which is aggressively affected by the location of the pin during welding.
- Flow Arm Zone** is on the top surface of the weld and consists of material that is dragged by the tool shoulder from the retreating side of the weld, near the rear side of the tool and deposited on the advancing side.
- Thermo-Mechanically Affected Zone (TMAZ)** occurs on both sides of the stir zone. In this region, the temperature and strain are lower and the effect of welding on the microstructure is correspondingly less.

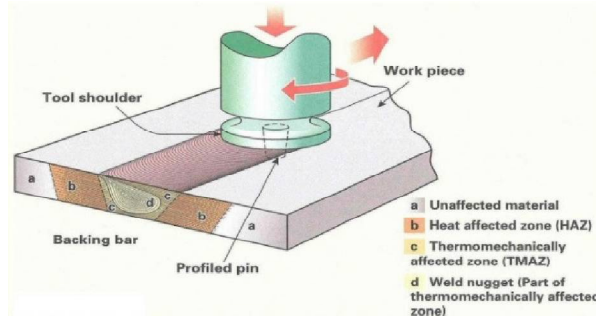


Figure 1.2 Different zones of welded specimen

(d) **Heat-Affected Zone (HAZ)** is mostly common to all welding processes. As it is indicated by the name, this region is affected by the thermal cycle but it is not deformed during welding.

1.4 FSW PROCESS PARAMETERS

During the research on the field of friction stir welding (FSW), a number of parameters are used by several researchers and their calculation of the effect of parameters on FSW. The present study aims to examine the effect of the following parameters:

- Tool pin profile** – This is the first parameter used in the present work on friction stir welding and it plays a crucial role because by changing the tool pin profile we are getting better results in butt welded joint plates.
- Tool rotational speed** – The second parameter that is used in the present work of study is the tool rotational speed. In this work by varying the tool rotational speed a number of different kinds of results are generated.
- Tool traverse speed** – The third parameter is the tool feed or welding speed of a tool that is measured in mm/minute in this present work.
- Tool shoulder** – Tool shoulder is the fourth parameter that is applied in the present work. It is also very much an important parameter because the lower part of the shoulder is rubbing against the upper surface of the joining plates.

1.5 ADVANTAGES OF FRICTION STIR WELDING

In general, FSW has only a less amount of defects and is very unbiased to variations in parameters and materials. A number of possible benefits of FSW over conventional fusion-welding processes have been identified as:

- Good mechanical properties in the welding constrain.
- Improved safety due to the un-availability of toxic fumes or the splash of molten material.
- Simply automated on simple milling machines with less setup costs and less training required.
- Can operate in all directions (horizontal, vertical, etc.), as there is absence of weld pool.
- Usually, good weld appearance and minimal thickness over/under-matching, therefore decreasing the need for expensive machining after the welding.

1.6 ALUMINIUM ALLOY

Aluminum alloys have a critical role in urban industry sectors. Aluminum has a comparably low cost, lightweight metal that can be treated with heat for fairly high strength levels, and its ease of fabrication leads to less costs. It has a high strength-to-weight ratio and also performs efficiently from cryogenic temperatures to moderate temperatures. The

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor & UGC Approved Journal)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

disadvantage of high strength aluminum alloys involves a low modulus of elasticity and low elevated temperature capability and corrosion susceptibility.

1.7 ALUMINIUM 6101-T6

Alloy 6101 is eminent in full line bus conductor extruded products. As a heat treatable wrought alloy 6101 is most effectively suited for applications involving modest strength and maximum electrical conductivity. It is similar to alloy 6063, but with minor chemistry changes which elevated electrical conductivity. This alloy available in various temper conditions and as a result, manufacturer does not have to worry about additional heat treating. The varieties in temper provide different strengths, formability and electrical conductivity levels which required for flexibility of design. It is necessary to check in the material Safety data sheet (MSDS) for proper safety and handling precautions when processing on 6101 alloy. This is comfortably extruded and it has better machinability than 1XXX alloy series. Alloy 6101 offers good weld ability, bend ability, formability, corrosion resistance and electrical as well as thermal conductivity.

Temper - T6 means Solution heat treated and artificially aged.

1.7.1 PROPERTIES OF AL 6101-T6

Despite the fact that the production of Aluminium is highly energy intensive and its alloys are the most widely used engineering materials beside to iron and steel because of their functional and economical competitiveness. The properties of aluminium alloys hugely dependent on structural features and can alleviate multifold by alloy chemistry, heat treatment and thermo-mechanical processing. This can be possible with the deep insight into the physical metallurgy of aluminium alloys. The basic benefits of Al 6101-T6 are following :

- Light weight (1/3 density of steel).
- Resistant to weather.
- High reflectivity.
- Aluminium alloys can equal the strength of steel.
- High elasticity: properties do not deteriorate at low temperature.
- Conducts electricity & heat comparable with copper.
- Excellent founding properties.

1.7.2 TYPICAL APPLICATIONS OF AL 6101-T6 ALLOY INCLUDES

- Electrical bus conductor.
- Power transmission products (bar, beams, tubing and custom shapes).
- Power stations.
- Aircraft and aerospace structures.
- Boat building and ship building.
- Architectural and fabrication.
- Pipe and tubing.

II. LITERATURE REVIEW

M. B. Durdanovic et al., (2009), FSW was a promising welding technology from the same moment of its existence because of its easy use, low energy costs, being ecology friendly process and with no need for filler metal. FSW works in the solid state of weld metals and basic goals of the process are to generate thermal energy by friction on contact of FSW tool and welding pieces, which will soften weld pieces and stir it with solid metal into weld. FSW process has five main phases: plunging into weld pieces, dwelling, moving along joint line for the weld creation, final dwelling and pulling out of the welding tool from the weld. Generated heat is in proportion with large number of parameters, but most significant are contact pressure between tool – weld pieces and speed. Significant thermal energy is generated during FSW and there is mathematical model which describe these stages but still there are several inaccuracies of the

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor & UGC Approved Journal)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

model that give some differences between theoretical and experimentally determined amount of heat. **Gurmeet singh et al., (2011)**, Friction stir welding process is a promising solid state joining process with the potential to join low melting point materials, particularly aluminum alloys. The most attractive reason for this is the avoidance of solidification defects formed during conventional fusion welding processes. Tool rotational speed and the welding speed play a major role in deciding the weld quality. In the present work an effort has been made to study the effect of the tool rotational speed and welding speed on mechanical and metallurgical properties of friction stir welded joints of aluminum alloy AA6082-T651. The micro hardness profiles obtained on welded zone indicate uniform distribution of grains in the stir zone. The maximum tensile strength obtained is 263 MPa which is about 85% of that of base metal. Scanning electron microscope was used to show the fractured surfaces of tensile tested specimens. **L. Karthikeyan et.al., (2012)**, Aluminum AA 2011 and AA 6063 alloys are commonly used in various aerospace and marine applications. However welding of these alloys by conventional techniques is difficult. Friction stir welding (FSW) is a recent welding technique which has gained importance in welding dissimilar aluminum alloys. In this article aluminum alloys AA 2011 and AA 6063 were friction stir lap welded and their tensile and microstructural properties were evaluated. On evaluation it was found that sound weld joints can be produced using FSW. Moreover it was observed that welding strength improves with increased tool rotation speed. Optimum tool rotational speed for defect free nugget zone was found to be 1400 rpm and tool feed was found to be 60 mm/min. **S. Veerendra Prasad et.al., (2013)**, In this paper an attempt was made to maximize the tensile strength and hardness of friction stir welded AA 6082 - T6 aluminum alloy sheets. The experiments have been conducted using Taguchi experimental design and the samples have been prepared and welded by varying input parameters like tool rotation speed, tool traverse speed, depth of penetration and the optimum welding condition for maximizing tensile strength and hardness is determined. Tensile tests and Hardness tests are performed at room temperature were used to evaluate the mechanical properties of the joints. Tensile tests were performed by Universal testing Machine on weldments and hardness tests were performed on four weld regions (advancing side, retreating side, weld nugget and heat effected zone) by using Brinell Hardness Test apparatus. Test results show that tool rotation speed is dominant factor affecting tensile strength and hardness. Increase in tool rotation speed showed a decrease in hardness in HAZ. The effect of process parameters on tensile strength and hardness is evaluated and the optimum welding condition for maximizing the tensile strength and hardness is determined. **J. Stephen Leon et.al., (2014)**, Aluminium 6061 alloy is commonly used for construction of aircraft structures, such as wings and fuselages, more commonly in home built aircraft than commercial or military aircraft. Aluminium 6061 alloy generally present low weldability by traditional fusion welding process. The development of Friction Stir Welding (FSW) has provided an alternative improved way of satisfactorily producing weld joint in aluminium 6061 alloy. In FSW, the welding tool motion induces frictional heating and severe plastic deformation and metal joining process is done in solid state results, which results in defect free welds with good mechanical properties in aluminium alloy 6061. Unlike in traditional fusion welding, friction stir welds will not encounter problems like porosity alloy segregation and hot cracking, and welds are produced with good surface finish. In this paper, an attempt was made to investigate the impact of process parameters of FSW in the mechanical properties of the joint. **Shalin P. Marathe et.al., (2014)**, This research deals with the determination of the weld strength of the aluminum alloy of different grades in friction stir welding (FSW). The different grades of the plates are welded by the different tool geometry namely as tapered tool and the tapered threaded tool. During the welding the rotational speed of tool and feed rate of the tool are kept constant. Testing of the specimens is carried out by ASME –SEC-IX and the weld strengths are compared. As a result it is found that the threaded tool geometry gives the better weld strength and also the surface finish compare to the tapered tool geometry. **J.D.M. Costa et.al., (2015)**, Friction stir processing (FSP) is an emerging metalworking technique that can provide localized modification and control of microstructures in near-surface layers of processed metallic components. In this research the FSP was applied on Metal Inert Gas (MIG) T-fillet welds performed in 6082-T651 aluminium alloy plates of 6 mm thickness. FSP potential benefits were studied through micro structural analysis, hardness measurements, tensile strength and fatigue testing. Fatigue tests of unprocessed and processed MIG welded specimens were carried out under constant amplitude loading with stress ratios $R = 0$ and $R = 0.4$. Tensile testing results show that MIG welding reduces significantly the base material mechanical strength of the. However the friction stir post-processing does not promote an additional reduction of the MIG welds hardness and mechanical strength. **L.P. Borrego et.al., (2016)**, The friction stir processing is an adaptation of the friction stir welding process. The friction stir processing technique presents several characteristics, between which can provide localized modification and control of

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor & UGC Approved Journal)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

microstructures in near-surface layers of processed metallic components in order to modify the correspondent mechanical behaviour. In this research MIG (Metal Inert Gas) welded butt joints, performed in 5083-H111 aluminium alloy plates with 6 mm thickness, were post-processed by friction stir processing. The friction stir processing effect was analysed performing tensile and fatigue tests, as well as microstructural analysis and hardness measurements. Fatigue tests were carried out under constant amplitude loading at a stress ratio $R = 0$ and with the load applied perpendicular to the weld bead. The hardness and mechanical strength of the welds were not significantly modified by the friction stir processing.

III. FINDINGS

The table below shows the findings of our review performed in above section. It includes the methods and processes used by different authors to evaluate the effects of FSW parameters on properties of aluminium alloys and their relative outcomes.

Table 1: Summary of literature review

Authors/ Year	Methods and Processes	Outcomes
M. B. Durdanovic et al., (2009)	FSW process has five main phases: plunging into weld pieces, dwelling, moving along joint line for the weld creation, final dwelling and pulling out of the welding tool from the weld.	Significant thermal energy is generated during FSW and there is mathematical model which describe these stages but still there are several inaccuracies of the model that give some differences between theoretical and experimentally determined amount of heat.
Gurmeet singh et al., (2011)	To study the effect of the tool rotational speed and welding speed on mechanical and metallurgical properties of friction stir welded joints of aluminum alloy AA6082-T651.	The maximum tensile strength obtained is 263 MPa which is about 85% of that of base metal.
L. Karthikeyan et al., (2012)	Aluminum alloys AA 2011 and AA 6063 were friction stir lap welded and their tensile and microstructural properties were evaluated.	It was found that sound weld joints can be produced using FSW. Moreover it was observed that welding strength improves with increased tool rotation speed.
S. Veerendra Prasad et al., (2013)	To maximize the tensile strength and hardness of friction stir welded AA 6082 - T6 aluminum alloy sheets.	Test results show that tool rotation speed is dominant factor affecting tensile strength and hardness. Increase in tool rotation speed showed a decrease in hardness in HAZ.
J. Stephen Leon et al., (2014)	Investigate the impact of process parameters of FSW in the mechanical properties of the joint.	The joint made from the FSW yielded superior tensile properties and impact strength due to the higher hardness and fine microstructure.
Shalin P. Marathe et al., (2014)	The different grades of the plates are welded by the different tool geometry namely as tapered tool and the tapered threaded tool.	It is found that the threaded tool geometry gives the better weld strength and also the surface finish compare to the tapered tool geometry.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor & UGC Approved Journal)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

Rasheed Abdullah et.al., (2014)	The optimum parameters of burnishing process on Friction Stir Welded joints of Aluminum 7075 T6 alloy are investigated by testing the effect of different burnishing parameters i.e. Table speed, burnishing force, and transverse feed rate on Friction Stir Welded joints.	That good surface finish is achieved at low burnishing speed and transverse stroke with burnishing force around 200 N, high micro-hardness and high bending strength can be obtained at low burnishing speeds and low transverse stroke.
J.D.M. Costa et.al., (2015)	The FSP was applied on Metal Inert Gas (MIG) T-fillet welds performed in 6082-T651 aluminium alloy plates of 6 mm thickness.	The friction stir post-processing does not promote an additional reduction of the MIG welds hardness and mechanical strength.
L.P. Borrego et.al., (2016)	MIG (Metal Inert Gas) welded butt joints, performed in 5083-H111 aluminium alloy plates with 6 mm thickness, were post-processed by friction stir processing.	The hardness and mechanical strength of the welds were not significantly modified by the friction stir processing.

IV. CONCLUSION

An overview of FSW is discussed here in this paper along with its working principle, micro structural features, process parameters and its benefits. Aluminium and its alloy's mechanical and metallurgical properties and process parameters of FSW which effect their properties are also discussed in this review. Apart from this, the paper also studied the different approaches used in previous studies to examine the properties of different aluminium alloys affected by different approach regarding FSW. In friction stir welding different types of tool profile used but square tool profile provide a better strength in the joint. There is less research done for study the effect of different tool pin profiles on a material Al 6101-T6. So to reduce the gaps in study in FSW we have to concentrate on the important parameters and do research on it properly. The future research will focus on the two most important parameters, that is tool rotational and welding speed and tool pin profile.

REFERENCES

- [1] Afrin, N. Chen, D. Cao, X. and Jhazi, M. (2007), "Micro structure and tensile properties of Friction Stir Welded AZ31B magnesium alloy", Material Science and Engineering, vol.472, 2007, pp. 179-186.
- [2] Blignaulh, C. (2002), "Design, Development and Analysis of Friction Stir Welding process"
- [3] Cavaliere, P., Squillace, A., Campanile, G., Panella, F., 2006. "Effect of welding parameters on mechanical and microstructure properties of AA6056 joints produced by friction stir welding." J. Mater. Process. Technol. 180, 263–270.
- [4] Soron MC., Kalaykov I., "A robot prototype for friction stirs welding", IEEE, 2006, pp 1-5.
- [5] Kisset Z., Czigan T., "Microscopic analysis of the morphology of seams in friction stir welded polypropylene", Volume6, No.1, 2012, pp 54-62.
- [6] Kumbhar N.T., Bhanumurthy K. , " Friction stir welding of Al 6061 alloy", Asian J. Exp.Sci., Volume 22 , no. 2, 2008, pp 63-74.
- [7] Hamilton C., Dymek S., Sommers A., "Characteristics temprature curves for aluminium alloys during friction stir welding ", Volume 89, Sep 2010, pp 189-194.
- [8] Muruganadam D., Sreenivasan K.S., Kumar S.R. , " Study of process parameters in friction stir welding of dissimilar aluminium alloys ", International conference on industrial Engg. and operations management kualalumpur, Malasiya, January 22-24, 2011, pp 22-27.
- [9] Singh, G. Singh, K. and Singh, J. (2011), "Effect of process parameters on microstructure and mechanical properties in friction stir welding of aluminum alloy", Indian institute of metals.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor & UGC Approved Journal)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

- [10] Rana B.R., Kamble L.V., Soman S.N., Mathane V.V. , “ To study the effect of welding speed on mechanical properties of friction stir welding of aluminium alloy ”, Journal of information ,Knowledge and research in mechanical Engg., Volume 02, issue 02, 2012, pp 417-423.
- [11] Karthikeyan L., Puviyasan M., Kumar S., Balamugundan B. , “ Experimental studies on friction stir welding of AA2011 and AA6063 aluminium alloy”, International journal of advanced engg. Technology, Volume 3, issue 4, oct- dec 2012, pp 144-145.
- [12] Kamat S., Kumar A., “An experimental investigation of mechanical properties of Al 6106-T6 alloy joined by friction stir welding and tig welding”, International journal of innovation in engineering and technology, volume3, oct 2013, pp 246-253.
- [13] Prasad S.V, Kumar B.V.R. , “ Optimization of process parameters in friction welding of AA 6082-T6 aluminium alloy”, International journal of advanced scientific and technical research, Volume 6, issue 3, Nov-Dec 2013, pp 818-831.
- [14] Singh N., Singh R., Lal H. , “ Experimental study of friction stir welding of aluminium alloy (A1100 & A6101) ”, International journal of advances in science and technology (IJAST), Volume 1, issue1, dec 2013, pp 1-7.
- [15] Leon J.S., kumar V.J. , “ Investigation of mechanical properties of aluminium 6061 alloy friction stir welding ”, American journal of mechanical Engg. And automation, 2014, pp 6-9.
- [16] Marathe SP, Bachubhai B.M, Padhumanish G.R , “ Experimental investigation of tapered and tapered thread tool for friction stir welding from different grades of aluminium alloy”, International journal of advance engineering and research developement (IAERD), Volume1, issue 3, April 2014, pp 1-6.
- [17] Abdullah R., Beithou N., “Burnishing effects on friction stir welding of Al alloy 7075-t6” ,Global journal of researches in engineering, volume 14, issue 3 version 1.0, 2014,pp 13-20.
- [18] Chowdhary, S.M. Bhole, D. and Cao, X. (2010), “Tensile properties of friction stir welded magnesium alloy, effect of pin thread orientation and weld pitch”, Material science and Engineering, vol. A527, 2010, pp. 6064-6067.
- [19] Devaraju A., Kumar A., Kumaraswamy A, Kotiveerachari B., “Influence of reinforcements (SiC and Al2O3) and rotational speed on wear and mechanical properties of aluminum alloy 6061-T6 based surface hybrid composites produced via friction stir processing” Material and Design, Vol. 3 , Oct,2013, pp 331-341.
- [20] Ericsson, M., Sandstrom, R., (2003), “Influence of welding speed on the fatigue of friction stir welds, and comparison with MIG and TIG.” Int. J. Fatigue 25, 1379–1387.
- [21] Mishra, R.S., Ma, Z.Y.,(2005), “Friction stir welding and processing.” Material Science and Engineering R 50, 1–78
- [22] Canalier, P., Squillance, A. and Panella, F. (2007). “Effect of welding parameters on mechanical and microstructural properties of AA6082 joints produced by friction stir welding.” Journal of Material Science and Technology. Pp 364-372.
- [23] Rhodes, C.G., Mahoney, M.W., Bingel, W.H., (1997), “Effects of friction stir welding on microstructure of 7075 aluminium.” Scripta Mater. 36, 69–75.
- [24] Scialpi, A. De Filippis, L.A.C. and Cavaliere, P. (2007), “Influence of shoulder geometry on microstructure and mechanical properties of Friction Stir Welded 6082 Aluminium alloy.” Material and Design. Vol. 28, pp. 1124-1129.