RESEARCH ARTICLE OPEN ACCESS

Characterization And Study of Friction Stir Welding of AA6101 Aluminum Alloy

S. K. Aditya[1], Dr. M. C. Majumdar[2],Dr. N. R. De[3]
[1] *Associate Professor In Mechanical Engineering Department, NSHM Faculty Of Engineering &Technology, Durgapur.*
[2] *Professor In Mechanical Engineering Department, National Institute Of Technology, Durgapur*
[3] *Professor In Mechanical Engineering Department, Dr. B. C. Roy Engineering College, Durgapur.*

ABSTRACT

Friction stir welding (FSW) combines two plates by frictional heating at the interface with the localized plastic deformation within the material. In friction stir welding heat is generated by the friction between rotating tool shoulder and the plates to be welded. The heat thus generated results in thermal softening of the material. The softened material is then forced to flow by the translation of the tool from the front to the back of the pin. There it cools, consolidates and results in joint formation. In the process, strength of the joint and percentage elongation varies from the parent material. AA6101 is equivalent to AA 6061 and AA6063. At present AA6101 is used by the electrical industries only. A detailed experimental study has been done on AA 6101 to its utility as an Aluminum alloy for structural fabrication.

Keywords:-FSW, Aluminum alloys, Tensile strength,

I. Introduction

Friction stir welding is one of the new entrants to the solid state joining techniques, which have made remarkable progress in welding technology. Friction Stir Welding (FSW) is a new joining process invented by The Welding Institute (TWI) in England and patented in 1991 and is essentially a solid state joining process, widely used for the welding of light and difficult-to-weld metals and their alloys like aluminum, magnesium, copper etc. Recently, its applications have been extended to the welding of high melting point materials such as various types of steels, Ti alloys, Ni-based super alloys, the welding of metal matrix composites and polythene. Welding of Aluminum and its alloys by fusion process are very difficult as aluminum has high affinity to oxygen. Friction stir welding being a solid state joining process is suitable for welding of aluminum and its alloys. There are various types of Aluminum alloys.

The composition of aluminum alloys are regulated by Classification for wrought aluminum alloys: EN Systems ENAW XXXX

1XXX Al of 99% minimum purity
2XXX Al - Cu alloys
3XXX Al - Mn alloys
4XXX Al - Si alloys
5XXX Al - Mg alloys
6XXX Al - Mg - Si alloys
7XXX Al - Zn - Mg alloys
8XXX Miscellaneous alloys, e.g. aluminum-lithium alloys
EN Systems EN AW - 6XXX eg 6061 and 6063

This group of heat-treatable alloys uses a combination of magnesium and silicon (magnesium Silicide) to render it heat-treatable. These alloys find their greatest strength, combined with good corrosion resistance, ease of formability and excellent ability to be anodized. Typical alloys in this group include 6061, 6063, 6082 are used for building structure applications, land and transport applications and sometimes used as electrical application for its high electric conductivity.

Friction Stir Welding Process :-

The Process Friction Stir Welding (FSW) is a simple process in which a rotating cylindrical tool with a shoulder and a profiled pin is plunged into the adjoining plates to be joined and traversed along the line of the joint. The plates are tightly clamped on to the bed of the FSW equipment to prevent them from coming apart during welding. A cylindrical tool rotating at high speed is slowly plunged into the plate material, until the shoulder of the tool touches the upper surface of the material. A downward force is applied to maintain the contact. Frictional heat, generated between the tool and the material, causes the plasticized material to get heated and softened, without reaching the melting point. The tool is then traversed along the joint line, until it reaches the end of the weld. As the tool is moved in the direction of welding, the leading edge of the tool forces the plasticized material, on either side of the butt line, to the back of the tool. In effect, thetransferred material is forged by the intimate contact of the shoulder and the pin profile. It should be noted that, in order to achieve complete through-thickness welding, the length of the pin should be slightly less than the plate thickness, since only limited amount of deformation occurs below the pin. The tool is generally tilted by 2-4°, to facilitate better consolidation of the material in the weld. Upon reaching the end of the weld, the tool is withdrawn, while it is still being rotated. As the pin is withdrawn, it leaves a keyhole at the end of the weld. This is the main disadvantage of FSW and few variants are being used to overcome this aspect.

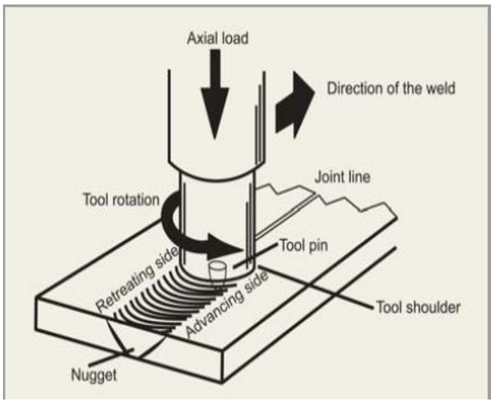
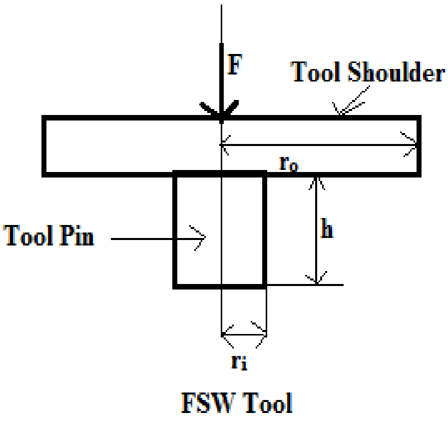


Fig.-1: Schematic diagram of the friction stir welding process



Process Technology

FSW is a solid state welding process performed at temperatures lower than the melting point of the alloy. The work pieces are rigidly clamped in a fixed position and a specially profiled rotating tool traversed through the joint line produces the friction heating. The tool is crushing the joint line, breaking up the oxide film by a mechanical stirring and forging of the hot and plastic material. The resulting joint exhibits a finer grain structure than the base metal. The FSW tools can permit over 1500 m of weld to be produced in 4 mm thick aluminum extrusions without changing the tool.

Process Parameters

In friction stir welding process, a number of process parameters have to be defined to get good, defect-free joints. The important process parameters are

- Tool rotation speed : Generate frictional heat, Mixing of material, breaking oxide layer.
- Axial Force: Frictional heat, contact between tool shoulder and work piece
- Tool traverse speed : Heat control, Appearance,
- Tool shoulder diameter : Frictional heat
- Tool geometry (cylindrical or conical) : plastic deformation, forging of weld material.
- Out of the above parameters Tool rotation, Axial force and Tool traverse have the major contribution in the friction stir welding.

Experimental Procedure :

The machine used for friction stir welding was a conventional vertical milling machine which was transformed into a friction stir welding machine by designing a fixture that makes the milling machine capable of performing friction stir welding, the friction stir welding machine.

The designing and fabrication of fixture for holding the work pieces on the machine was completed successfully. The fixture was fitted on the milling machine table to do the friction stir welding. The tool used for welding was designed to fit the taper of the vertical head of the milling machine and clamped rigidly with a nut at the other end. The tool has a shoulder diameter 18 mm and cylindrical probe of 6 mm diameter.

The rotational motion of the spindle is started and the tool is then got in contact with the surface of the plates and the probe is penetrated at the butt welded zone to a depth so that the shoulder of the tool is firmly in contact with the plate to be welded. The vertical force is applied at predetermined amount.

The tool is given some time as it rotates in contact with the surfaces to soften the material due to the frictional heat produced, this time is called dwell time, and after the dwell time the tool is given forward motion which formed the weld. The tool is withdrawn after the weld is fabricated, the process leaves a hole and the design of the weld is done in such a way that the part with the hole in it is cut and not used for the further processes with the welded plates. Efforts are on the way so that the hole can be avoided at the end.

Material chosen for the work is AA6101 to find an alternative of AA6061 and AA6063.

Chemical composition:

	Copper	Magnesium	Silicon	Iron max	Manganese	Others Chromium etc.	Solidus temp °C	Liquidus temp °C
AA6061	0.2	0.9	0.6	0.7	0.5	0.4	621	675
AA6063	0.1	0.7	0.5	0.6	0.3	0.4	632	670
AA6101	**0.1**	**0.7**	**0.5**	**0.5**	**0.1**	**0.1**	**635**	**658**

Table –1

Mechanical Properties:

	Density gm/cc	Melting point ^{0}C	UTS MPa	Yield Strength Mpa	Young's modulus Gpa	Elongation %	Poisson's Ratio	Specific heat $10^{-6}/^0$C	Conductivity W/mK
AA6061	2.7	641	281	241	69	10	0.29	19	152
AA6063	2.7	635	225	170	72	15	0.30	21	159
AA6101	**2.7**	**635**	**221**	**172**	**75**	**19**	**0.33**	**23**	**219**

Table – 2

Other properties:

	Density gm/cc	Melting point ^{0}C	UTS MPa	Yield Strength Mpa	Young's modulus Gpa	Elongation %	Poisson's Ratio	Specific heat $10^{-6}/^0$C	Conductivity W/mK
AA6061	2.7	641	281	241	69	10	0.29	19	152
AA6063	2.7	635	225	170	72	15	0.30	21	159
AA6101	**2.7**	**635**	**221**	**172**	**75**	**19**	**0.33**	**23**	**219**

Table – 3

Size of material : Length : 125 mm, Width: 50 mm
Thickness : 5 mm **Tool material :**
High carbon steel : Density = 7.8 gm/cc, Specific heat = 559 J/kg-K,
Thermal conductivity =40 W / m-K.
Material used for Fixture of job : Mild steel.
Tool dimension :

Tool shoulder radius r_0 = 18 mm, Tool pin radius r_I = 3 mm Height of Tool pin = 4.8 mm

The tensile test and % elongation test specimen are done on the fabricated welds according to the standards ASTM-E8-1983. The welds with holes are cut off and not used for the research purposes. The marked for right dimensions and cut by power saw machine to a width of 25 mm. Generally three tensile specimens are cut from each welded joints to ensure accuracy. The specimens are marked for identification, center of the weld is identified and 12 mm mark is made to facilitate the measurement of elongation after test sample breaks under tension.

The tensile testing was done in universal testing machine FUN 100 made by Fine Testing Co. with a capacity of 10 metric tons. It has mechanical grippers with serrated jaws for holding the test pieces without slip.

Characterization of the AA6101- T6 Friction Stir Welded Joints

Tensile Test of AA6101- T6 FSW joints

Transverse tensile specimens were tested in order to determine the tensile properties at room temperature for the AA6101-T6 alloy Base Material and for the FSW joints, for different energy inputs applied. Following the same procedure used earlier, specimens are obtained from the butt joined plates and BaseMaterial along the same direction, with the testing load position transverse to the welding direction and and rolling direction. The tensile properties for the nine welding conditions were studied. Test results are given in the following table for both UTS and % elongation.

AA6101 T6

			Tensile strength (Mpa)					Weld Performance	
Force (KN)	Rotational speed (RPM)	Speed (mm/min)	Trial 1	Trial 2	Trial 3	Average UTS(Mpa)	% elongation	Strength %	Elongation %
6	250	12	139.35	137.45	143.25	140.02	6.22	63.36	32.74
10	250	18	151.35	148.85	143.5	147.9	7.66	66.92	40.32
14	250	30	144.1	149.1	150.05	147.75	5.79	57.81	30.47
6	400	12	133.25	134.85	137.05	135.05	6.21	56.58	32.68
10	400	18	149.95	154.35	151.22	151.84	7.12	64.18	37.47
14	400	30	164.75	166.85	159.45	163.68	5.94	74.06	31.26
6	660	12	151.15	156.7	153.58	153.81	5.7	69.6	30
10	660	18	169.32	169.05	163.05	167.14	6.35	75.63	33.42
14	660	30	159.65	157.15	150.45	155.75	5.51	70.48	29

Table - 4

FSW joint shows highest performance of UTS to 75.63% of Base Material (BM) . However, average value of UTS is 68.33% of Base Material.Elongation basically shows an increase in the welded region, attaining maximum values in the Stir Zone(SZ) for all weld energy inputs. The higher elongationin the weld zones can be related to the superplasticity of grains in Stir Zone and recovered grains in Thermomechanically Affected Zone (TMAZ) and Heat Affected Zone(HAZ). Elongation values decreases to around 33.05% of Base Material.

The results shows that high heat input gives better weld performance. This may be explained as at high heat input the weld interface is more plasticized and at lower range of rpm throw of the material to the trailing end during welding. At high energy input level amount of strain energy develops at low level due to more plasticity of the material. At low energy input low rpm of the tool is unable to develop sufficient strain energy. This results lower welding efficiency. It is important to remark that fracture occurs in the retreating side and location close to the interface TMAZ/HAZ. The shift in falure location is basically to the stretching of the temperature gradient with the energy inputs. In this way critical temperature field shifts towards the BM away from the SZ. In addition, it is reported for a friction stir welding that fracture never occurred close to the original joint line, but mostly near the line where shoulder of the tool had touched the top side of the weld at 45^0 fracture, at the bottom side of the weld.

Hardness Test :

Hardness profiles are determined along the transversal cross section surface of the AA6101-T6 FSW joints for different conditions, following the procedure described in section Hardness measured transverse to the weld direction of AA6101-T6 of similar FSW joints produced with different conditions. The hardness measured along three different line i e near the starting point, middle of the length and lastly near the end point. Hardness also measured on both the sides of the weld i e advancing side and retreating side of the weld. The hardness is plotted as shown in the fig - 2 .

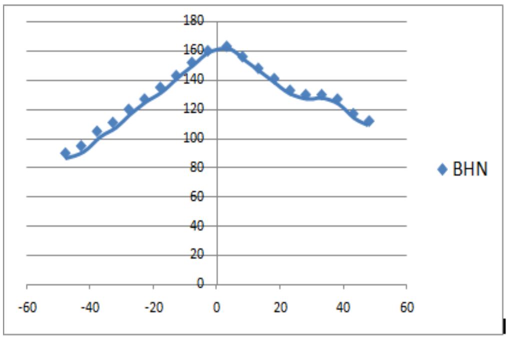


Fig – 2

II. CONCLUSION

In this study welding of AA6101 was successfully done and its results are quite encouraging. Lower rotational speed is useful for welding AA6101. Welding performance is almost similar to that of AA6061 and AA6063. Mechanical properties can be substantially improved by post weld heat treatment. The process parameters used can be optimized for obtaining highest strength at the joint. So AA6101 can be used in place of AA6061 and AA6063 for several light automobile structures which will reduce the cost of the product.

REFERENCES

[1]. D. M. Rodrigues et al : Influence of friction stir welding parameters on microstructural and mechanical properties of AA6016- T4 thin weld; Materials and Design 30 (2009), (pp1931- 1921)

[2]. Samir A. Emam& Ali EiDomiaty. A refined energy based model for Friction stir welding, World academy of science, engineering & technology, 53, 2009.(pp 1-7)

[3]. Diogo Marino Neto, Pedro Neto : Numerical modeling of fsw process: a literature review. Research paper of Mechanical Engineering Deptt, University of Coimbra, Portugal, (pp1- 23)

[4]. N. T. Kumbhar et al : Friction Stir Welding of Al 6061 Alloy ; Asian J. Exp. Sci. Vol 22, No.2, 2008; 63 - 74

[5]. Kareem N .Salloomi. et al : 3-Dimentional non-linear finite element analysis of both thermal & mechanical response Friction stir welded 2024-T3 Aluminum plate, Journal of Information Engineering & applications, 2013, Vol 3, No 9 (pp6- 11)

[6]. Selvamani S. T. et al : Heat transfer analysis during Friction stir welding of Al6061-T6 alloy, International journal for Engineering Research & Analysis, Vol. 1, Issue 4 (pp1453- 1460)

[7]. J. Adamowski, M. Szokodo, Friction stir welding of Al-alloy AW6082-T6 : AMME journal vol 20, Issue – 12, Feb 2007 (p 403- 406)

[8]. R. Palanivel et al : Development of mathematical model to predict the mechanical properties of Friction stir welded AA6351 Al- alloy, Journal of Engineering Science & Technology review 2011, 4 (1) (pp25- 31)

[9]. S. K. Tiwari et al : Friction stir welding of Aluminum alloys : A review, International journal of Mechanical, Aerospace, Industrial & Mechatronics Engineering 2013 , Vol 7 No. 12 (pp1342- 1347)

[10]. MohamadrejaNoorani et al ; Taguchi optimization of process parameters in Friction stir welding of 6061 Aluminum alloy, A review and Case study, Scientific Research engineering, 2011, 3 (pp144- 155)

[11]. H. F. Wang et al :Effect of Friction Stir Welding on microstructure and wear properties of 7072 Al-alloy, Indian journal of Engineering and Material science. Vol 21, Oct 2014 (pp557- 5620

[12]. R. Nandan et al : Improving reliability of heat transfer and materials flow calculations during FSW of dissimilar Al-alloys ; Welding Journal, Oct 2006, vol 86, (pp313s- 322s)

[13]. R. Soltysiak : Local strain analysis of friction stir welded 2024-T3 Aluminum joint under cyclic loading , Journal of Polish CIMAC, 2004, (PP 1- 8)

[14]. Sang& Sang et al : Liquation cracking of dissimilar aluminum alloys during FSW, Material transactions, Japan Institute of Metals, 2011 vol 52 no 2 (pp54- 57)

[15]. S. Feritti et al : Friction stir welding process optimization : Experimental methods Research done at DIEM , University of Bologna, Bologna.(pp1- 2),

[16]. S. K, Aditya et al : Analysis of Friction Stir Welding of Aluminum alloys and Optimization of welding parameters for maximum tensile strength; International journal Engineering Research and Application, Vol 5, Issue 5,(Part -5) May 2015, pp36- 43