Experimental Comparison of the MIG and Friction Stir Welding Processes for AA 6061(Al Mg Si Cu) Aluminium Alloy

Anjaneya Prasad. B, Prasanna. P

***Abstract*—** Aluminum alloys are welded using both metal inert gas (MIG) and friction stir welding (FSW). Mechanical properties like tensile strength, hardness and impact strength for both welding processes are evaluated for AA6061 aluminum alloy. The results indicate that, the microstructure of the friction stir weld is different from that of MIG welded joint. The weld nugget consists of small grains in FSW than those found in MIG weld. The tensile strength of the weld joints can be increased using FSW instead of MIG welding. The heat affected zone (HAZ) of FSW is narrower than that of MIG welding.

***Keywords*—** Friction stir welding, Metal inert gas welding, Alluminium alloy, Mechanical Properties
.

I. INTRODUCTION

ALUMINUM alloys are light-weight, have relatively high strength, retain good ductility at subzero temperatures, have high resistance to corrosion, and are non-toxic. They have a melting range of 482^0C to 660^0C, depending upon the alloy. Properties of Aluminum alloy AA6061is given below. Table 1,2 gives the properties of the material used in the present study.

TABLE I
CHEMICAL COMPOSITION OF AA6061-T6

Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Others	Al
0.8-1.2	0.4-0.8	0.7	0.15-0.40	0.25	0.15	0.15	0.04-0.35	0.05	balance

It is impossible in practice to stop the tenacious oxide film formed due to oxidation at exposed surfaces. It can nevertheless be welded because the oxide can be dispersed by the action of a welding arc, although fragments of oxide may become entrapped into the weld. Resistance spot welding of aluminum is difficult (though not impossible) because the oxide film can cause uncontrolled variations in surface resistance. Unlike iron, aluminum has only one allotropic form. Hence there are no phase transformations which can be exploited to control its microstructure. The main methods by which it can be strengthened include deformation, solution-hardening, or by introducing precipitates into the microstructure. The heat introduced by welding can severely disrupt the deformed or precipitation- hardened alloys. In order to avoid these difficulties a new technique i.e Friction stir welding was developed in 1991 at Cambridge, UK. It can weld all aluminum alloys, including those that cannot normally be joined by conventional fusion welding techniques such as aluminum-lithium alloys. Dissimilar aluminum alloys can also be joined, for e.g. 5000 to 6000 series or even 2000 to 7000 series.

TABLE II
MECHANICAL PROPERTIES OF AA6061-6

Temper	Ultimate tensile Strength (Mpa)	0.2% Proof stress	Brinell Hardness	Elongation(%)
0	110-152	65-110	30-33	14-16
T1	180	95-96		16
T4	179	110		
T6	260-310	240-276	95-97	9-13

Friction stir welding has enjoyed worldwide interest since its inception because of its advantages over traditional joining techniques. Essentially, FSW is a local thermo-mechanical metal working process with additional adiabatic heating from metal deformation that changes the local properties without influencing properties in the remainder of the structure. As mentioned later, the pin and shoulder of the tool can be modified in a number of ways to influence material flow and micro-structural evolution.

A rotating tool with pin and shoulder is inserted in the material to be treated, and traversed along the line of interest (Figure 1). During FSW, the area to be processed and the tool are moved relative to each other such that the tool traverses with overlapping passes until the entire selected area is processed to a fine grain size. The rotating tool provides a continual hot working action, plasticizing metal within a narrow zone while transporting metal from the leading face of the pin to its trailing edge. The processed zone cools without solidification, as there is no liquid and hence a defect-free re-crystallized fine grain microstructure is formed.

Anjaneya Prasad. B, is with JNT University Hyderabad, Hyderabad, AP, India (corresponding author’s phone:919441124725; fax: 914023057787 ; e-mail: baprasadjntu@gmail.com).

Prasanna. P, is with JNTUH College of Engineering, Hyderabad, AP, Idia (e-mail: prajntu@jntuh.ac.in).

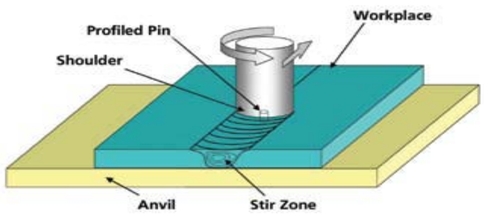

Fig. 1 Schematic of Friction Stir Welding

The concept of MIG welding was developed in the 1920s, but commercial exploitation did not begin until 1948. Initially it involved a high current density, small diameter metal electrode and inert gas for arc shielding. It was primarily used for welding aluminium, and the term MIG welding (metal arc inert gas) was employed. With advancements in the process, the term gas metal arc welding (GMAW) is now becoming a more common description, because both inert and reactive gases (particularly CO_2) are now employed1. MIG welding is a well-established way of joining various aluminium alloys, although some alloys, notably those in the 2XXX and 7XXX series, are difficult to fusion weld. MIG welding employs an electric arc, struck between the filler rod and the material being welded, to generate localised heat. The heat melts both the parent plate and the filler metal, mixing of the two occurs, and upon cooling fusion of them occurs. The filler wire is continually fed through to the weld pool; this is generally automated, thereby maintaining the arc length and the supply of filler material. Due to the reactive nature of aluminium, the arc is shrouded by an inert gas, generally argon, protecting the base metal from contact with oxygen, nitrogen or hydrogen. Figure 2 show a MIG welding set up.

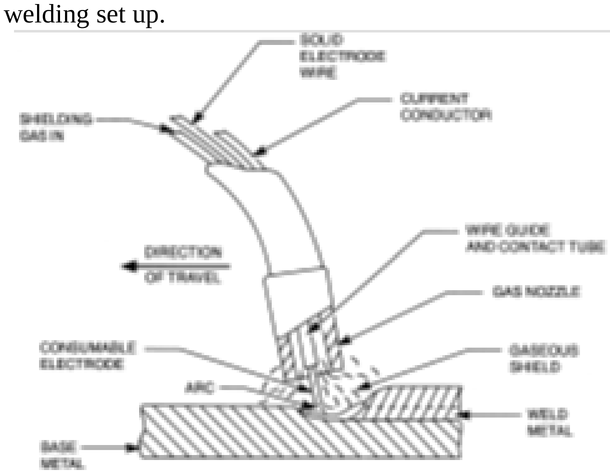

Fig. 2 Metal Inert Gas Welding Process

II. LITERATURE SURVEY

Friction stir welding (FSW) is a solid state welding process which was developed and patented by the welding institute (TWI-UK) for ferrous and non-ferrous materials. The process is repeatable, can be monitored , and does not **produce** major safety hazards , such as fumes or radiation. The FSW process can be implemented with a conventional milling machine. The FSW tool is generally made with a profile pin which is contained in a shoulder with larger diameter than that of the pin as seen in the figure. The tools are manufactured from a wear resistant material with a good static and dynamic properties at elevated temperatures. A properly designed tool permits up to 100m of weld to be produced in 5mm thick aluminium extrusions. The tool is shaped with a large diameter shoulder and a small diameter profiled pin that first makes contact as it is plunged into the joint region. The plates to be welded are fixed rigidly to prevent the joint faces from being forced a part as the probe passes. Through and along the seam. For thick plate welding , usually a pilot hole of smaller diameter than that of the profiled pin is drilled at the start to assist the plunging of the tool. The depth of penetration is controlled by the length of the profiled pin. Below the shoulder of the tool. The initial plunging friction contact heats the adjacent metal around the probe as well as a small region of material underneath the probe , but the friction between shoulder and material interfaces generates significant additional heat to the to the weld region. In addition to generating heat, the shoulder of the tool also prevents highly plasticized material from being expelled from the welding region. The thermally softened and heat-affected zone takes up a shape corresponding to that of the over-all tool geometry. The heat affected zone is much wider at the top surface and tapers down towards the tip of the tool. The combined friction heat from the profiled pin of the shoulder creates a highly plasticized condition around the immersed probe. This plasticized material provides a hydro-static affect as the rotating tool moves along the joint, which helps the plasticized material to flow around the tool. It then coalesces behind the tool as the latter moves along the weld line. For butt joining, the length of the pin approximates to the thickness of the work-piece. If the weld is done from one side. For a double-sided weld the length of the pin is approximately equal to half of the welded plate thickness. The onion-ring the structure of the nugget is typically of I quality stir welding in which no porosity or internal voids are detectable. In macro-sections of good quality welds, the nugget is visible at the center of the weld, as shown schematically in the figure 1. Outside the nugget, there is a thermo-mechanically affected zone, which has been severally, plastically deformed under shows some areas of partial green refinement. The main application of FSW is in the production of long-straight welds i9n aluminium alloy plates, extruded aluminium profiles, and tailored blank. Lightweight aluminium alloys are used widely in applications such as aerospace and transportation (ship-camels, frames of high speed railways and automobile parts) . The joints obtained with FSW reduce up to 30% the involved cost compared to mechanical fastening together with a weight reduction of 10%. On the other-hand, traditional welding processes present a series of disadvantages when applied to aluminium alloys.[1-20]

III. EXPERIMENTAL DETAILS

The FSW was carried out on 3-axis CIMTRIX make computer numerical controlled milling machine with FANUC controller and is shown in fig3. The specification of the machine is given in table2. Computer Numerical Control milling machine is the most common form of CNC. CNC mills can perform the functions of drilling and often turning. CNC mills are classified according to the number of axes that they posses and these axes are labeled as X and Y for horizontal moment, and Z for vertical movement. CNC milling machines are traditionally programmed using a set of commands known as G codes represent specific CNC functions in Alpha numeric format.

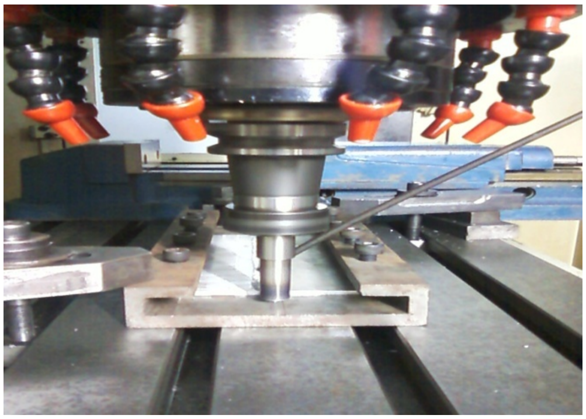

Fig. 3 CNC milling machine with tool and fixture

Although MIG welding is a well-established method for joining aluminum, it has several shortcomings. Weld porosity is more commonly detected in MIG welds in aluminum when compared to those undertaken in steel; this is due to the high solubility of hydrogen in the molten aluminum weld pool, but low solubility in solid aluminium. The higher thermal conductivity and expansion coefficients, and lower modulus of elasticity, result in greater shrinkage and distortion, again when compared to steel. A loss of strength also occurs in the heat affected zone (HAZ), in heat-treated alloys through over-ageing and in strain hardened alloys through annealing, resulting in the material properties differing between the weld metal, HAZ and parent plate. The MIG weld pool solidifies to form a reinforced area around the joint, commonly termed the weld bead. The weld bead leads to stress concentration effects and the failure of MIG welds frequently occurs due to crack initiation and growth along the weld toe. Within the weld bead grain growth on cooling results in columnar grains growing from the fusion zone into the weld bead and within the bead large equiaxed grains. To reduce the stress concentration effect, removal of the weld bead can be undertaken, but the processes is expensive. Similarly, the effect of microstructural changes can be reduced through the application of thermal processes. Residual stresses form due to the contraction of the weld metal on cooling. These are tensile and typically of yield magnitude at, and near to, the weld toe, in both the direction. Another set of aluminium alloy plates were butt welded(single-sided one joint) using the MIG process the plates were cleaned before the MIG welding procedure with a scrapper and acetone. In the MIG welding process, a MIG-350 type semiautomatic welding machine was used for welding the plates with the parameters of 240(+or-) A (Current) and 24(+or-1) V (voltage).A 4145 filler of 1.2mm diameter with a welding speed of 110mm per min was used to carry out the MIG welds. The hardness test gives an idea of the resistance to indentation of the weld metal .This is important with respect to components which have been built up and have to withstand abrasive wear. Hardness values can give information about the metallurgical changes caused by welding

IV. Results and Discussion

Macrographs of MIG and FSW welded joints of AA 6061 alloy are shown in figgure4&5. The surface appearance and roughness of the FSW weld is similar to the surface obtained by the milling process. The surface of the MIG welds is similar to the cast structure and has a rough surface. The Micro structure of the FSW is a refined structure, while MIG welds have a cast structure. The stirring effect of the FSW process gives a finer microstructure, while MIG welds gives a columnar crystalline structure is obtained. The stirring effect and refined structure improve the mechanical properties of the FSW joint.

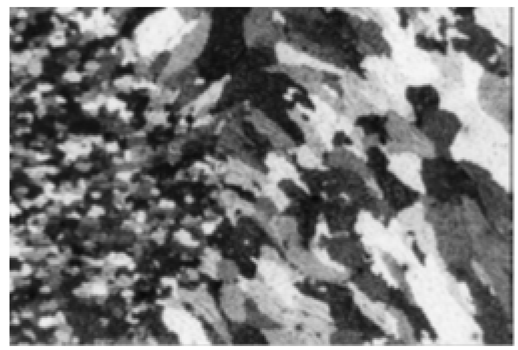

Fig. 4Microstructure of MIG Grains at weld Nugget zone(x400)

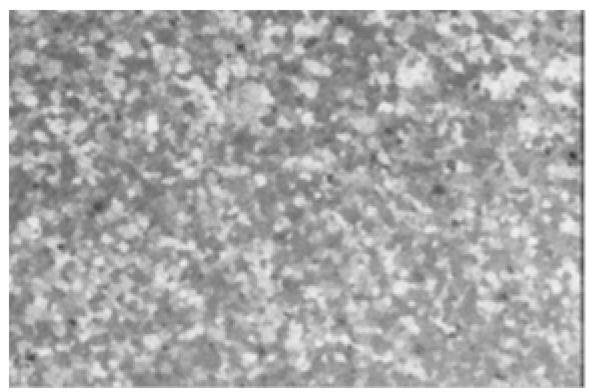

Fig. 5 Microstructure of FSW Grains at weld Nugget zone(x400)

The tensile strength of FSW, MIG and Base metal of AA 6061 alloy were 121, 95 and 145 N/mm ^{2}, respectively, as seen in the table III. The tensile strength of FSW was 17% lower than base metal. On the other hand, strength decrease was about 34% in MIG welded specimens**.** The results of the tensile tests show that 22% strength improvement can be obtained with the FSW process when compared with MIG. The tensile strength of the FSW joint is stronger than the MIG weld joint but lowers than the base metal.

TABLE III
COMPARISON BETWEEN MIG, FSW AND BASE METAL

Type of Weld	Tensile Strength (N/mm^2)
MIG	95
FSW	121
Base metal	145

TABLE IV
HARDNESS VALUES OBTAINED FROM THE MIG AND FSW PROCESSES

SI. No	Distance from the center of the weld zone(mm)	Hardness (HV) MIG	FSW
		Forward welding	Clock wise direction
1	-30	70 (L)	75(AS)
2	-20	65 (L)	70(AS)
3	-10	58(L)	65(AS)
4	0	62 (Center)	60(Center)
5	10	60 (R)	63(RS)
6	20	65 (R)	75(RS)
7	30	65(R)	75(RS)

L-Left hand side R – Right hand Side AS- Advanced Side RS-Retreating side Hardness distribution on the surface of the FSW and MIG welded joints perpendicular to the weld line is given in the table IV, which shows that the region where the hardness decreases is narrower for FSW and MIG welds. From this result, it is seen that the heat-affected zone of FSW is narrower than the MIG welded joints.

V.CONCLUSION

1. The microstructure of the FS weld is different to that resulting from the MIG process. The weld nugget consists of small grains in FSW , typically, 10 - 100 times smaller than those found in the MIG. The small grain size of the weld nugget would generally be considered beneficial to the mechanical properties of the material, although the reduction in dislocation density that have been reported may result in the effect of the grain size being reduced or diminished.

2. The tensile strength of welded joints can be increased using the FSW process instead of MIG.

3. Hardness change in the welded material is affected from the amount of the heat input during the welding process. Less heat input in the FSW process lowers the area where hardness changes. The heat-affected zone of FSW is narrower than the MIG process. The shoulder diameter of FSW and heat input during the welding process determines the width of the hardness.

4. Higher performance in production rate and quality, as well as decreasing production costs, can be obtained by FSW welding. The required pre-operations before the welding process are very limited in FSW. This feature of the FSW process saves consumable material time cost and improves the quality of welds.

REFERENCES

[1] W. Tang, X. Guo, J.C. McClure, L.E. Murr, A. Nunes, ‘‘Heat Input and Temperature Distribution in Friction Stir Welding,’’ Journal of Materials Processing and Manufacturing Science, 1988, vol-5 163–172.

[2] P. Colegrove, M. Painter, D. Graham, and T. Miller, ‘‘3 Dimensional Flow and Thermal Modeling of the Friction Stir Welding Process,’’ Proceedings of the Second International Symposium on Friction Stir Welding, 2000, June 26–28, Gothenburg, Sweden.

[3] Y.J. Chao, X. Qi, W. Tang, “Heat Transfer in Friction Stir Welding—Experimental and Numerical Studies, ASME J. Manufacturing Science and Engineering”, 2003, vol-25, 138–145.

[4] Y.J. Chao and X. Qi, “Thermal and Thermomechanical Analysis of Friction Stir Joining of AA6061-T6”, Journal of material processing and manufacturing sciences, 1998, 215-233.

[5] Frigaard, Grong, O.T. Midling, “Modeling of the Heat Flow Phenomena in Friction Stir Welding of Aluminum Alloys”, Proceedings of the Seventh International Conference Joints in Aluminum— INALCO ’98, Cambridge, UK, April 15-17, 1998, 1189-1200.

[6] Frigaard, Grong, O.T. Midling, “A Process Model for Friction Stir Welding of Age Hardening Aluminum Alloys”, Metallurgical and Materials Transactions A, Physical Metallurgy and Materials Science, vol. 32A, no. 5, May 2001, ASM International, pp. 1189-2000. 32A, 2001.

[7] A.P. Reynolds, W.D. Lockwood, T.U. Seidel, “Processing – Property Correlation in Friction Stir Welds”, Material Science Forum 331–337 (2000) 1719–1724.

[8] Colegrove, P. A., and H. R. Shercliff, 2003, “Experimental and Numerical Analysis of Aluminium Alloy 7075-T7351 Friction Stir Welds”, *Science and Technology of Welding and Joining*, vol. 8, no. 5, IoM Communications Ltd., pp. 360-368.

[9] M. Song and R. Kovacevic, “Numerical and Experimental Study of the Heat Transfer Process in Friction Stir Welding”, Proc. Instn Mech. Engrs, USA, Vol. 217 Part B: J. Engineering Manufacture.

[10] C.M.Chen, R. Kovacevic, “Finite Element Modeling of Friction Stir Welding – Thermal and Thermo-Mechanical Analysis”, International Journal of Machine Tools & Manufacture 43 (2003) 1319–1326.

[11] H Schmidt, J Hattel and J Wert, “An Analytical Model for the Heat Generation in Friction Stir Welding”, Modelling and Simulation in Material Science Engineering 12, 143–157, 2004.

[12] X.K. Zhu, Y.J. Chao, “Numerical Simulation of Transient Temperature and Residual Stresses in Friction Stir Welding of 304L Stainless Steel”, Journal of Materials Processing Technology 146, 263–272, 2004.

[13] J.C. McClure, W. Tang, L.E. Murr, X. Guo, Z.Feng, J.E. Gould, “A Thermal Model of Friction Stir Welding”, International Conference on Trends in Welding Research, 1998, vol-349, 156-165.

[14] P. Ulysse, “Three Dimensional Modeling of Friction Stir Welding Process, International Journal of Machine Tools and Manufacture 42 , 1549-1557, 2002.

[15] Vijay Soundararajan, Srdja Zekovic, Radovan Kovacevic, Thermo-mechanical model with adaptive boundary conditions for friction stir welding of Al 6061, International Journal of Machine Tools & Manufacture 45, 1577–1587, 2005.

[16] G. Buffa , J. Huaa, R. Shivpuri , L. Fratini, “A continuum based fem model for friction stir welding—model development”, journal of material science and engineering,A419, 389-396, 2006.

[17] Terry Dickerson, Qing-yu Shi, Hugh R Shercliff, “Heat Flow Into Friction Stir Welding Tools”, proceedings of 4th international symposium on friction sitr welding, USA, 14-16, 2003.

[20] Properties of Aluminum alloy by John Gilbert, Kautman