EtI ENGINEERING AND
TECHNOLOGY
IN INDIA

Volume 7 | Issue 1 | April, 2016 | 1-7
e ISSN-2230-9284 | Visit us : *www.researchjournal.co.in*
DOI : 10.15740/HAS/ETI/7.1/ 1-7

ARTICLE CHRONICLE :
Received : 24.10.15;
Revised : 01.03.16;
Accepted : 10.03.16

RESEARCH ARTICLE

Analysis of welded joints using friction stir welding, metal inert gas and tungsten inert gas

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ABSTRACT

In this paper, a comprehensive practical study in mechanical properties and cost welding of welded Aluminum 6061 pipe using three different types of welds, Metal Inert Gas (MIG), Tungsten Inert Gas (TIG) and Friction Stir Welding (FSW) with rotation speed (1800 RPM) and travel speed 4mm/min. The mechanical properties of the weld have been also investigated using the hardness, elongation and tensile tests. The microstructure of the welds, including the nugget zone and heat affected zone, has been compared with these three methods using optical microscopy and the basis of heat input in weld joint. The results show that FSW improves the mechanical properties of welded joints compare Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG), respectively.

KEY WORDS : Friction stir welding (FSW), Metal inert gas (MIG), Tungsten inert gas (TIG), Aluminum alloys

How to cite this Article : Khourshid, A.M. and Sabry, Ibraheem (2016). Analysis of welded joints using friction stir welding, metal inert gas and tungsten inert gas. *Engg. & Tech. in India,* **7** (1) : 1-7.

INTRODUCTION

Due to the affinity of aluminum for oxygen, it cannot successfully be arc welded in an air Environment. If fusion welded in a normal atmosphere oxidization readily occurs and this results in both slag inclusion and porosity in the weld, greatly reducing its strength. To overcome these problems one of the most common ways of welding aluminum has been to use the electric arc process whilst shielding the weld pool with an inert gas, so called metal inert gas welding. This method produces good welds, but more recently solid-state methods for welding the material have been developed, one of these being friction stir welding. The following report examines the geometry, macrostructure and microstructure of three types of butt welds made by these processes (*en.wikipedia.org, www.weldwell.co.nz*).

Friction Stir Welding (FSW) is a process in which the welds are prepared with the help of a tool having a profiled pin. In this welding process the material does not reach to its melting point and the welds are made in the plastic stage condition by applying an axial force on the stirred work material keep halt with the help of the fixtures. The process involves plastic deformation and welding of the material, but at a temperature below the melting point. The combination of heat generated by friction and consequent plastic deformation being the main causes of fusion. Although a relatively new process, it has shown considerable potential for welding what was considered difficult-to-weld materials and dissimilar ones. The resultant welds exhibit high static and dynamic mechanical properties (Karunakaran, 2012; Raveendra and Kumar, 2015; Sakthivel *et al.*, 2011).

The friction stir process is suitable for butt, lap and T joints, requiring little material preparation, no filler material and in the case of materials like aluminum, no shielding gas. Prior to joining the material the pieces have to be rigidly fixed with the faces to be welded abutted to each other, a backing plate is also required (Yuri *et al.*, 2000).

EXPERIMENTAL PROCEDURE

The chemical composition and mechanical properties of Al 6061 aluminum alloys cylindrical parts used in the present study as delivered by the Miser Aluminum company are given in Tables (A-B). Three welding methods TIG, MIG and FSW are used in the study. The different welding parameters are shown in the following Table (C-D) and filler metal show in Table E.

Table A : Chemical composition (weight %) of Al6061

Weight %	Al	Si	Fe	Cu	Min	Mg	Cr	Zn	Ti
6061	Ball	0.4	0.70	0.15	0.15	0.9	0.04	0.25	0.15

Table B : The mechanical properties of Al6061

Alloy	σ_{UTS} M pa	EL%	VHD
6061	252.690	8	86

Table C : Process parameters Used in TIG and MIG

Process	Filler size	Current (A)	Voltage (V)	Travel speed (mm/min)
MIG	1.2	180	20	194
TIG	1.2	170	20	100

Table D : Process parameters used in FSW

Process	Rotational speed (RPM)	Heel plunge depth (mm)	Travel speed (mm/min)
FSW	1800	4	4

Table E : Chemical composition (wt %) of filler material

Filler (MIG, TIG)	Si	Mg	Cu	Fe	Mn	Zn	Ti
AA 4043	5.0	0.005	0.3	0.8	0.05	0.1	0.2

Tool friction stir welding:

The tool design is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. It is better that the material is high carbon tool steel, strong enough, tough and hard wearing, at a temperature welding (Zeng *et al.*, 2006 and Plaintively *et al.*, 2011).

He suggested penetration depth pin tool that about at least 90 per cent of the thickness of the work piece. We used two tools with flat shoulder, Tools was fixed on the spindle of the drilling. In the present study the tool length (L) (60mm), were 50mm, and two different pin lengths, pin diameter (d) (1 mm) and shoulder diameter (D) (10mm).

Friction stir welding process :

Two pipes to be welded were butted up against each other and clamped down using the fixture. Rotational speed and translational velocity of the tool are set in the adapted milling machine. Then rotates the tool and then slowly plunged into a workpiece along the interface of the sheets. Instrument creates the friction heat in the work piece until the plasticized material. The heat generated by the mechanical mixing process and the adiabatic heat within the material cause raised material to soften without reaching a their melting point. This is a great feature for friction stir welding. Once the material becomes plasticized the tool traverses along a weld line to bond the two materials together Plasticized material is deformed around the tool and is forged into place by the substantial downward axial force of the tool shoulder. The material then consolidates into the weld joint at the trailing edge of the tool leaving a solid phase bond between the two pieces (Khourshid *et al.*, 2011 and Khourshid *et al.*, 2015).

Tensile testing:

The tensile testing, also known as tension testing, is a fundamental science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength (UTS), maximum elongation (EL %) (Khourshid *et al.*, 2015).

Vickers hardness testing :

The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not a pressure. The HV number is then determined by the ratio *F/A* where *F* is the force applied to the diamond in kilograms-force and *A* is the surface area of the resulting indentation in square millimeters (Zhang and Friedrich, 2003).

EXPERIMENTAL FINDINGS AND ANALYSIS

It is a visual inspection test, Visual inspection of the upper (external surface of welded specimens) showed uniform semicircular surface ripples, caused by the final sweep of the trailing edge of rotating tool shoulder over weld nugget, under the effect of probe overhead pressure. The presence of such surface ripples, known as onion rings Fig. (1-a) shows the surface appearances of the weld the interface between the crystallized nugget zone and the parent metal is relatively diffuse on the retreating side of the tool, but quite sharp on the advancing side of the tool and Fig. (1-b, c) external surface of finished pipe


(a) (b) (c)

Fig. 1 : External surface of finished pipe at (a) FSW (b) TIG (c) MIG

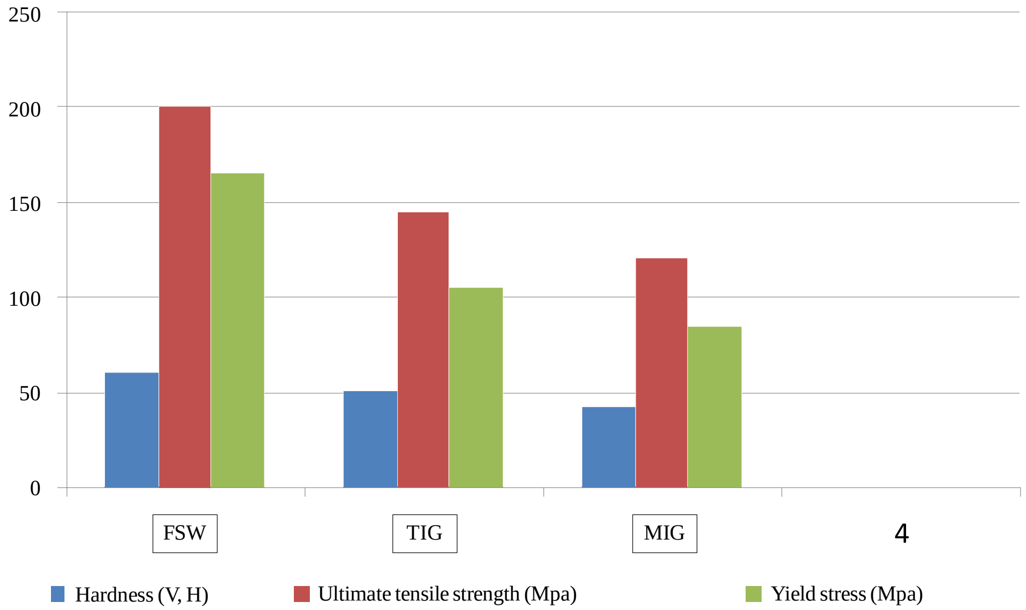

Fig. 2 : Tensile properties and hardness of different welded joint

As shown in Fig.(2 -3) the tensile test result.It is generally accepted that the FSW joints are exhibiting superior tensile properties, performances compared to MIG and TIG welded joints. The reasons for the better tensile performance of the FSW joints are the superior mechanical properties of the weld region.

The microstructure in the weld region. The FSW process the welding zone would affected by the tensile fracture. In view of the heat input to the welding zone and HAZ is affected by the tensile properties showing in Fig.3.

In the process of TIG welding the fracture occurred in the HAZ. The tensile properties would not affect the welding zone,Because of the high welding strength. In the process of MIG welding has shown very poor tensile properties due to less welding strength. Post weld aging treatment has shown better improvement see Fig.3 a.

Optical micrographs of the fusion zone- nugget region of all the joints are displayed in Fig. 3. From the micrographs, it can be observed that the grain structure was columnar for MIG welds and fine axed for MIG. The structure increasingly coarser and columnar for TIG welds. Of this deformation leads to the formation of very fine equiaxed crystallized grains within the friction stir processed zone. Various dislocations with network structure observed in the crystallized

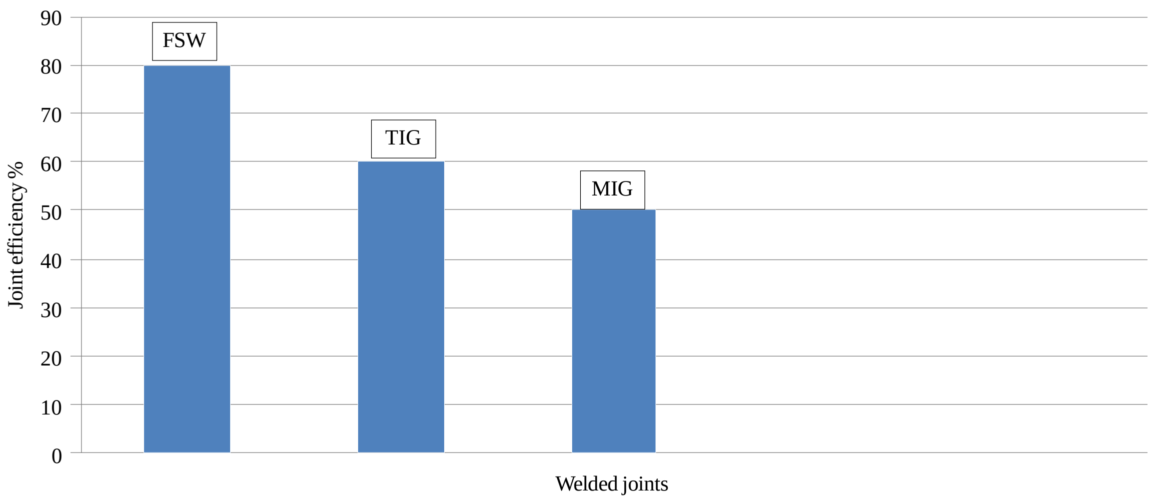

Fig. 3 : **Tensile properties and hardness of different welded joint**

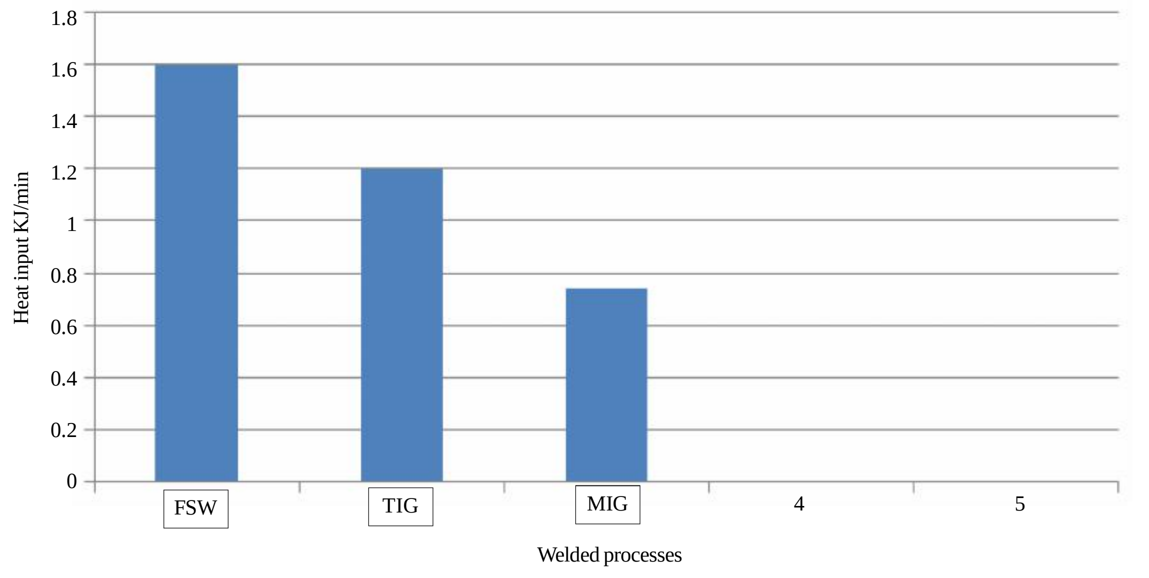

Fig. 3-a : **Tensile properties and hardness of different welded joint**

grains. High density of dislocation with network structure observed in many grains.

A minimum of hardness is located around 5mm from the weld center towards 6061. Relatively high hardness in all areas of welding joints compared with the heat affected zone (HAZ) and base metals (BM). The hardness is relatively high in the weld regions of all the joints compared to heat affected zone (HAZ)and base metal (BM). The value of low hardness in the weld region of MIG when compared to other welding process the post weld aging

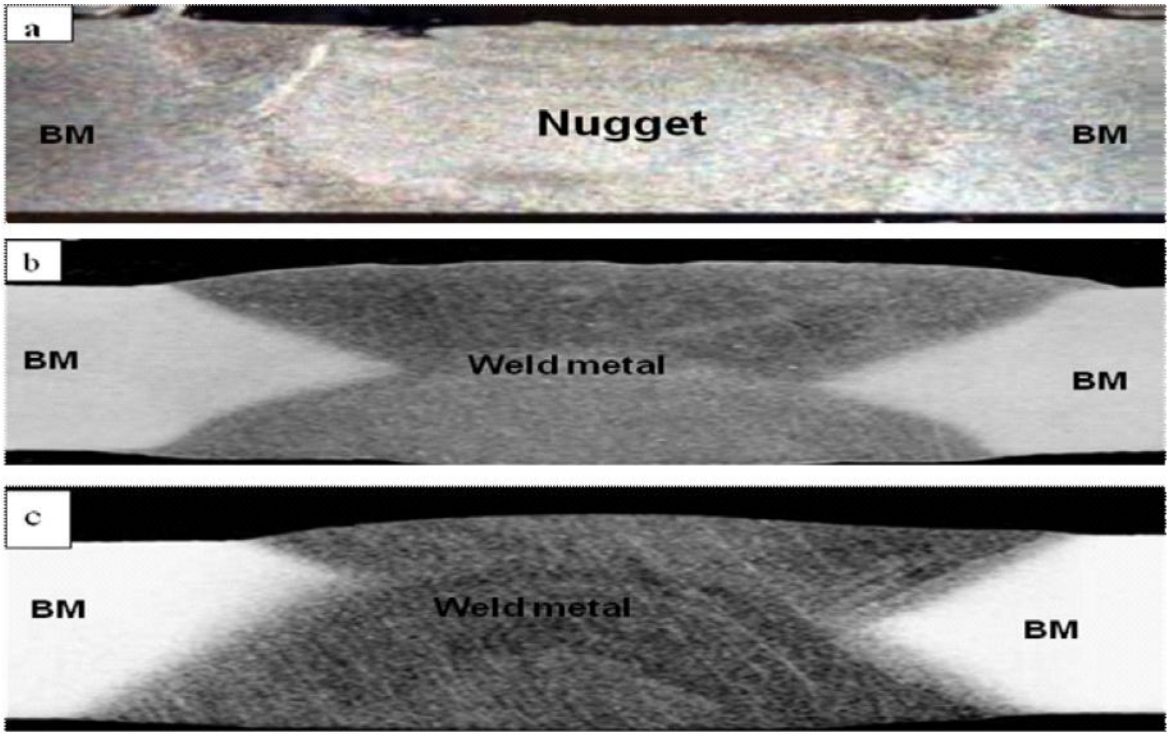

Fig. 4 : **Weld cross-section macro of Al pipe 6061 at (a) FSW (b) TIG (c) MTIG**

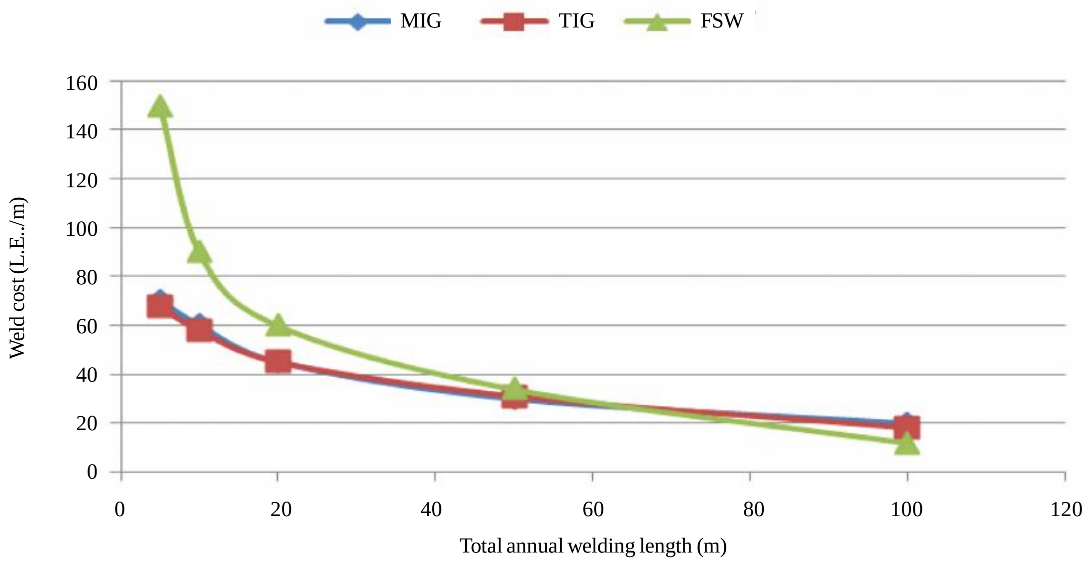

Fig. 5 : **Cost Comparison of TIG, MIG and FSW Welding**

treatment has enhanced the hardness of the weld region of all the joints.

Action has been compared between FSW, MIG and TIG In terms of the cost of the welding line .calculation sheet was developed for comparison of direct welding costs of virtually any three welding methods. The cost elements are: machine investment cost, license (only FSW), labour wages, tool (FSW only), filler material (MIG and TIG), energy, and shielding gas (MIG, TIG) (Hanninen and Mononen, 2004). The costs per weld meter calculated by ARC time, Oxide removal, Lifting and clamping,Lining check,Welding head positioning and Welding personnel protection In practice, welding cost calculations have to be made for each specific production case. Welding duty cycles were taken from the measurements in the Factories military training sector. Welding costs were calculated per meter of fabricated weld. Generally, MIG and TIG welding was more cost effective in small-volume production.As the annual production amount increases, FSW welding becomes more economical than MIGand TIG welding Fig. 5 with that, a cost comparison with lots of information shows the order of magnitude and the share of costs in different categories for a good overview information. It must also be stressed that none of the FSW process advantages, such as low distortion, high strength, uniform quality and improved occupational health issues, have been taken into account in the calculations due to the fact that no general valuation can be made for these issues

Conclusion :

– According to the joints by FSW show comparatively excellent mechanical properties when compared to TIG and MIG joint pipe, The Micro hardness values are higher in the weld region of FSW joints compared to MIG and TIG welded joint pipe.

– The FSW joint exhibited higher strength values compared to FSW joint pipe (88.5%), TIG joint pipe (60%) and MIG joint pipe (50%).

– FSW production time in the test evaluation was 79 per cent of the corresponding MIG and TIG production time.

– MIG and TIG welding was more cost effective in small-volume production.As the annual production amount increases, FSW welding becomes more economical than MIGand TIG welding.

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