An General Review of Joining of Al and its Alloys by Fusion and Solid-State Welding Processes

T. Pavan Kumar, S.Timothy

Abstract: ***Among all the non-ferrous materials, aluminium is widely employed in various aerospace, defence and industrial applications. The natural qualities, of aluminium and its alloys, like lightness, electrical and thermal conductivity, corrosion resistance, suitability for surface treatments, the diversity of the alloys and intermediates, ease of use, recycling make them usable in many applications. The applications demand the manufacturing of components by a superior manufacturing process, so that the products will be without any defects. Welding is one such process which is widely used in fabrication of aluminium components. Both fusion and solid- state welding processes are employed in the manufacturing of aluminium components. An attempt is made in this paper to take an overview of some fusion welding and some solid-state welding processes to weld Al and its alloys with a focus on the process parameters of these processes, tools used, micro structure of the welded specimens, thermal profiles, strength of joints and heat treatment. This is an attempt understand and summarize the issues related to welding of aluminium and its alloys.***

Keywords: Process Parameters, Microstructure, Aluminium.

I. INTRODUCTION

Pure aluminium is relatively soft. Generally, it cannot meet the demands made on advanced materials for high yield stress and high temperature performance as strength should not be lost at increased working temperatures and processing temperatures [1]. It is possible to some extent to meet these demands by means of alloying and heat treatment. The typical alloying elements in aluminium are copper, magnesium, manganese, silicon, tin and zinc. Alloying elements are selected based on their effects and suitability [2]. Based on the type of alloying element, the aluminium alloys are divided into 8 groups. They are 1xxx, 2xxx, 3xxx, 4xxx, 5xxx, 6xxx, 7xxx, 8xxx. Each alloy system is metallurgically distinct. Furthermore, different alloys within the given class may have different properties and characteristics. As a result processing for each alloy may vary. Aluminium and aluminium alloy are gaining huge industrial significance because of their excellent combination of mechanical, physical and tribological properties. One of the major routes of fabrication of theses alloys for various application in welding. Joining of aluminium and its alloys was never an easy task due to the various problems. This paper is an attempt to take an overview of problems associated with welding of aluminium and its alloys employing various conventional fusion welding techniques and solid state welding techniques.

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II. WELDING PROCESSES

A. Gas Tungsten Arc Welding (GTAW)

GTAW is also known as Tungsten Inert Gas (TIG) welding. It is the welding process, in which heat is generated by an electric arc struck between a tungsten non-consumable electrode and the work piece as shown in "Fig.1". The weld pool is shielded by an inert gas (Argon, helium, Nitrogen) protecting the molten metal from atmospheric contamination. The heat produced by the arc melts the work pieces edges and joins them. Filler rod may be used, if required. Automation or mechanization of the TIG process can have a number of benefits. These include the ability to use faster travel speeds, resulting in less distortion and narrower heat affected zones [3].

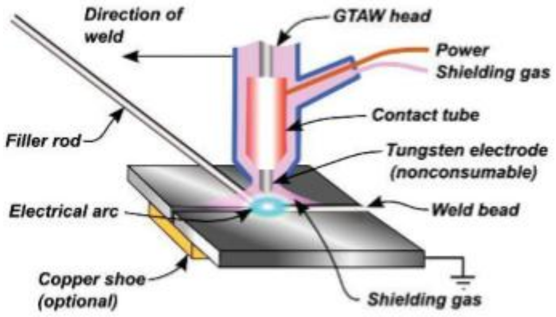

Fig. 1: Schematic of TIG Welding

B. Gas Metal Arc Welding (GMAW)

GMAW is also known as Metal Inert Gas (MIG) welding. The GMAW process was developed in the 1950s.In this process an electric arc forms between a consumable wire electrode and the work piece metal(s), which heats the work piece metal(s), causing them to melt and join as shown in "Fig.2". The weld area is shielded by an external source, such as argon, helium, carbon dioxide, or various other gas mixtures. The consumable bare wire is fed automatically through a nozzle into the weld arc. This process is used as a highly efficient process for welding various types of metals [4]. The basic GMAW process includes three distinctive process techniques they are Short Circuit (Short Arc), Globular Transfer and Spray Arc Transfer. The GMAW process is flexible in its ability to provide sound welds for a very wide base material type and thickness range. And this process is dominant today as a joining process among the world's welding fabricators. Despite its sixty years of history, research and development continue to provide improvements to this process.

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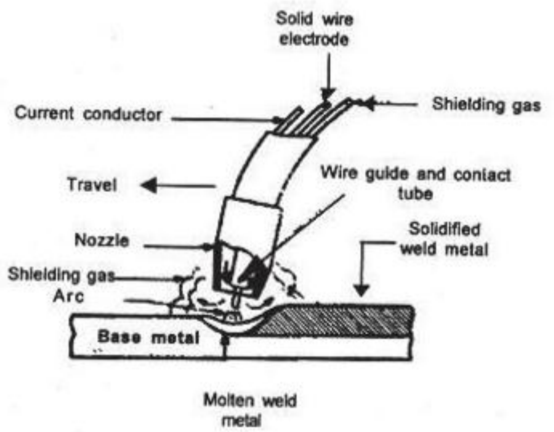

Fig. 2: Schematic of GMAW Process

C. Friction Welding

Friction welding is widely used solid state welding method for joining of similar or dissimilar metals. Friction welding requires rapid rotation of one component at high rpm and other component is brought into contact at high forging pressure to get upset as shown in “Fig.3”. Two pieces rotate in contact and heat necessary for welding is generated on friction plane. One important characteristic of friction welding is its ability to weld alloys and combination of alloys previously regarded as unweldable [5]

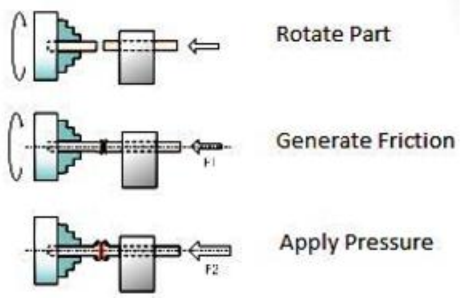

Fig. 3: Schematic of Friction Welding

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B. Friction Stir Welding

Friction -stir welding (FSW) is a solid-state joining process is used when the original metal characteristics must remain unchanged as much as possible and also the metal is not melted. It is primarily used on aluminum and most often on large pieces that cannot be easily heat-treated after welding to recover temper characteristics. A constantly rotated non consumable cylindrical- shouldered tool with a profiled pin is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material shown in “Fig.4”. The pin is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with the heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. It is demonstrated that FSW of aluminum is becoming an increasingly mature technology with numerous commercial applications [6].

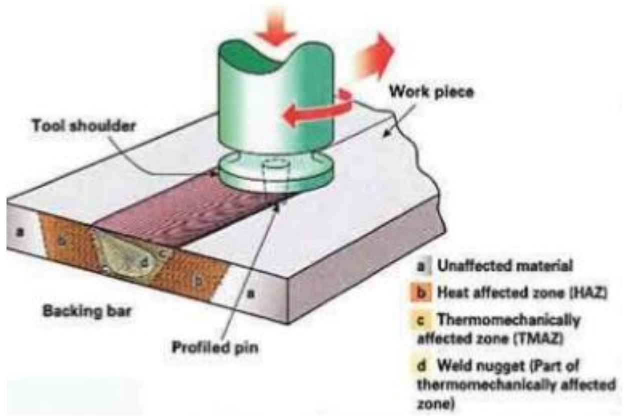

Fig. 4: Schematic of Friction Stir Welding

III. STUDIES ON SIMILAR METAL TIG ALUMINIUM WELDS

In TIG welding process, a non-consumable tungsten electrode is used to produce the weld. The weld zone is protected from the atmospheric oxidation by means of a shielding gas. This shielding gas may be argon or helium and a filler material is used to fill the gap between the work pieces. A constant-current welding power supply produces an electric arc between the tungsten electrode and the work piece. The primary functions of the arc are to supply heat to melt the work piece and any filler metal which may be necessary [7]. Rectifier supplies the power through a welding torch and is delivered to the tungsten electrode through it. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapours. Power source, type of current, gas flow rate, electrodes, filer wire, TIG Machines settings, and shielding gases are most important in determining arc stability, arc penetration and defect free welds.

Following is the brief overview of the findings of TIG welding of Al alloys: Lakshman Singh et al [8] considered welding current, gas flow rate and welding speed into account as input parameters.

They studied that keeping the gas flow rate constant and for different values of welding current, the front width and back width of weld bead increases linearly. And at constant current and increase in welding speed, the front and back widths decreased linearly.

Lakshman Singh et al [9] welded 5083 Al – alloy and they found that at constant current and voltage and with the increase in welding speed, the depth of penetration will increase until an optimum value which shows maximum penetration. Beyond an optimum value, there is a decrease in depth of penetration.

K. M Eazhil et al [10] used Taguchi experimental design for determining the successful welding parameters. Pulse current, base current, Pulse Frequency are considered as working range process parameters and Shielding gas, Shielding gas flow rate, Electrode diameter, pulse ratio, pulse on time are constant process parameters. Based on ANOVA the contribution of each parameters are calculated. They found that pulse current is the most dominant factor followed by pulse frequency and base current are influenced in the ultimate tensile strength.

Pankaj C. Patil [11] concluded that using TIG welding uniform welding of aluminium alloy possible. By optimizing and controlling welding parameters (like welding current, gas flow rate, welding speed) welding defects get totally avoided.

Swapnil S. Ingle [12] welded Aluminium Alloy 6082 by TIG welding and analyzed that there is a agreement between the simulation and experimental thermal profile as shown in "Fig.5" it can be predicted that that stress profiles and deformation got by simulation must match with experimental profile.

As the experimental methods for measuring residual stresses are costly and time consuming, FEM is enough for getting better results with negligible variation to that of experimental results so Simulation process can be carried out where welding applications deals with complex products.

IV. STUDIES ON SIMILAR METAL MIG ALUMINIŪM WELDS

MIG welding has four modes or MIG welding transfer types for the wire to hit the joint.

They are Short circuit, Globular, Spray, Pulsed spray. Aluminium is much softer metal so the feed wire must be larger and also feeding aluminum welding wire during gas-metal-arc-welding (GMAW) presents a challenge because the wire is softer than steel, has a lower column strength, and tends to tangle at the drive roll.

Aluminum is also a better conductor of heat, so welding aluminum requires more control over the power supply and the feed rate of the electrode.

Jyoti Prakash et al[13] welded aluminium alloys using different shielding gases and concluded that the high helium content gases are used for GMAW welding on thicker materials and GTAW welding with DCEN. Pure argon can be used for both GMAW and GTAW welding and is the most popular of the shielding gases used for aluminum. The helium content gases are usually more expensive. welding speeds can be increased by using helium and/or helium/argon mixtures.

E. Mahdi et al[14] attempted an investigation on effects of MIG welding on the corrosion and mechanical properties of AA 6061 T6.

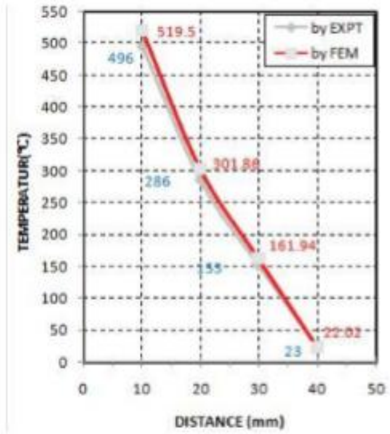

Fig. 5: Comparison of simulation and experimental thermal profiles [12]

Fig. 6: Extent of corrosion on BM and HAZ [14]

They found that Pitting corrosion is dominant on both BM and HAZ and the HAZ was more susceptible to corrosion showing severe pitting corrosion comparing to the BM as shown in "Fig.

The hardness of the welded specimens was increased as we moved away from the weld centre and the welded specimens were shown to have lower torsion properties.

Chandan Kaushal et al[15] concluded that, different parameters are to be considered to know the behavior of weldments and their effects on mechanical properties as aluminium alloys are susceptible to large change in microstructure after the welding. Welding heat input was increased by increase in arc voltage and welding current.

In this study, metal inert gas (MIG) welding was used to join heat treatable extruded 6063 T6 aluminum alloys.

I.O. Oladele Msc et al[16] worked on Wrought (6063) aluminum alloy for investigation using MIG welding. The current and voltage is used as parameters current and voltage on microstructure, tensile strength, toughness and impact strength. Since in arc welding is directly related voltage and current, the two conditions are applied i.e. at constant voltage the current was I1=75A & I2=100A and at constant current the welding voltage was varied as V1=25V & V2=30V. Tensile strength is more when current is at 100A.Toughness property is found to be good at V1=25V and other are nearer to it. Hardness is more at I1=75A & at V2=30V. The micro structure of I1= 75A shows that the constant MG2Si precipitation surrounding aluminum matrix leaded to fine particles are more responsible for high ultimate tensile strength & Hardness.

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From this it can be concluded that as current get increased heat input get increases & leads to better fusion of grains which give best possible mechanical properties (Ultimate tensile strength & hardness) and Change in current or voltage doesn't affect more on impact strength.

V. STUDIES ON SIMILAR METAL FRICTION ALUMINIŪM WELDS

Friction welding is used extensively in various industries. Heat in friction welding is generated by conversion of mechanical energy into thermal energy at the interface of work pieces during rotation under pressure.. This process can be used to join different types of ferrous metals and non-ferrous metals that cannot be welded by traditional fusion welding processes. The process parameters such as friction pressure, forging force, friction time and forging time play the major roles in determining the strength of the joints. FSW of aluminium is becoming an increasingly mature technology with numerous commercial applications[17].

K. Boonseng et al [18] observed fine and homogeneous structures in the weld zone (WZ) this is due to thermal effect and in the thermo mechanicall affected zone (TMAZ), change is from globular structures to fine structures and after welding Mg_2Si phase particles were broken and the hardness is close to the hardness of base metal due to heating.

N. Bhanodaya Kiran Babu et al [19] observed the results of many researchers in which rotational speed, welding speed and axial force are considered as process parameters for welding AA 6061 Aluminium alloys in determining tensile properties by friction welding. They observed fine equiaxed grains and uniformly distributed very fine strengthening precipitates in the weld region. They also suggested that the higher tensile strength of these alloys, allows the manufacturer to use in the area of aerospace and automobile industries, where the high strength to weight ratio is important.

Al Faizal at al[20] carried out a study on friction welding process for Al 6063-T6 and 3D model of the rotary friction welding was made. They performed the tensile tests as shown in "Fig.7" which shows that the weld zone is stronger than the base metals, since the rupture occurred outside of the welding area and the quality of rotary friction welding is depend on rotating velocity of members.

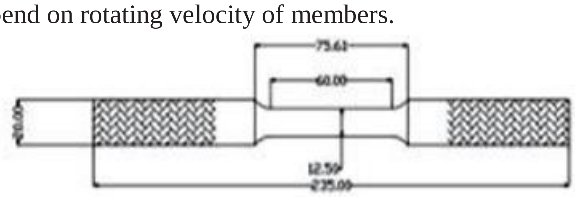

Fig. 7: ASTM Standard Tensile Specimen [20]

The length of work piece is reduced after welding due to high material penetration. The weld zone was divided into three regions based on the microstructure (center of weld and two HAZ). The center of weld had fine grains due to dynamic recrystallization with higher tensile strength and hardness. They concluded that the speed of rotating member affect the quality of weld and the study reveals for Al 6063-T6 after friction welding at 1200, 775 and 500 rpm the mechanical properties are remains almost same as that of parent material.

R.Sathish et al [21] investigated effects of friction welded corrosion behavior of dissimilar aluminum alloys of AA7075-T6 and AA6061 –T6. The welded samples are initially subjected to tensile test. Based on tensile strength the samples are subjected to potentiodynamic polarization resistance measurements in NaCl solution. It is observed that the parent metal wrought aluminum alloy found to corrode higher than the corresponding friction welded region of joints. Also the corrosion current and the corrosion rate are higher for the AA7075-T6 side compared to the AA6061-T6 side. The minimum and maximum corrosion rate was varied from 1.91 and 5.74 mm/year in different region. Micro structure study was conducted by optical microscopy to validate the results of the weld joints.

M.Y. Xie et al [22] stated that linear Friction Welding has tremendous potential for joining components from similar and dissimilar materials, avoiding material melting and introducing minimal distortion and only moderate levels of residual stress. They welded aluminium alloy specimens and found that the thermal mechanical process that occur during the LFW process lead to significant modification of the orientation distribution, but cause only moderate changes in the texture index.

VI. STUDIES ON SIMILAR METAL FRICTION STIR ALUMINIŪM WELDS

With recent developments in technology of friction stir welding, it is now possible to carry out dissimilar welding of various types of steels with alloys of aluminium, magnesium, copper, titanium and also other alloy combinations. Moreover, work pieces in the form of plates, sheets and hollow pipes can be welded by this method. Over a period of time developments in friction stir welding have led to different variants like friction stir processing, friction stir spot welding, friction stir channeling etc. Thus, it can be said that friction stir welding and its variants have brought a revolution in the field of solid state joining technology. In addition, friction stir welds can be accomplished in material is firmly held in place in a fixture [23].

P. Vijaya Kumar et al [24] Welded AA7075 Alloy Plates using FSW, they concluded that while joining these higher strength alloys, post weld heat treatment is necessary in order to stabilize the microstructure in the friction stir welded regions and this in turn has a potential to restore the corrosion resistance in sensitized weld zones to that of the parent metal. Than the other post weld treatments, the peak aged condition (T6) shown better mechanical properties.. In RRA the SCC resistance was good and also the strength was recovered nearer to the base metal strength.

M. Koilraj [25] joined dissimilar AA2219-T87 and Al– Mg alloy AA5083-H321 using Friction Stir Welding (FSW) technique and they optimized the process parameters using Taguchi L16 orthogonal design of experiments. They considered rotational speed, transverse speed, tool geometry and ratio between tool shoulder diameter and pin diameter as process parameters. By using the optimum process parameters, they predicted the optimal value of tensile strength.

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Micro structural studies revealed that the material placed on the advancing side dominates the nugget region. According to the analysis of variance, the ratio between tool shoulder diameter and pin diameter is the most dominant factor in deciding the joint soundness while pin geometry and welding speed also played significant roles.

A.k. lakshminarayanan et al [26] RDE 40 aluminium alloy using FSW and evaluated tool rotational speed, traverse speed and axial force on tensile strength. Taguchi approach was applied to determine the most influential control factors which will yield better tensile strength of the joints of friction stir welded RDE-40 aluminium alloy. Through the Taguchi parametric design approach, the optimum levels of process parameters were determined. The results indicate that the rotational speed, welding speed and axial force are the significant parameters in deciding the tensile strength of the joint.

Prashant Prakash et al [27] welded AA 6061 Aluminium Alloy plates (150mm X 50mm X 6mm) using FSW as shown in"Fig.8". In this experiment it is observed that the process parameters like tool design, tool rotational speed, welding speed and axial force are the main parameters to produce the butt joint.

Fig. 8: Aluminium Alloy Plates [27]

Other parameters are important but sub sets of the main parameters like indentation time of tool cannot be too long or too short, materials of the tool and backing bars should have low thermal conductivity and tilt angle used should be between 00 to 30. It is also observed that more than 6mm thickness of work piece is possible to weld by friction stir welding butt. The condition is to design a different tool for different thickness. While designing tool, the tool tip length should be less than the thickness of the base material i.e. less than 0.25 to 0.8 times of the base the material thickness.

Saumil K.Joshi et al [28] stated that from last some years, there is some significant improvement in FSW process. According to them, the main requirement of FSW is good material flow and less flash formation during welding process where as various types of tool shoulder and pin geometry with different diameters have been designed as shown in "Fig.9" and for that effective shoulder geometry with optimum shoulder diameter are required. So, further work should be focused on deigning effective shoulder geometry with optimum shoulder diameter.

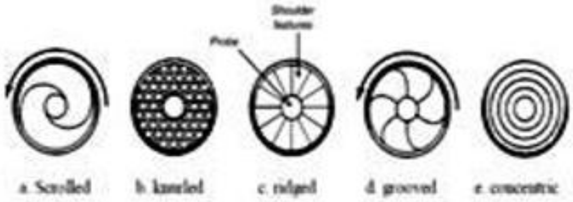

Fig. 9: Tool Shoulder Geometries [28]

K. Ramanjaneyulu et al [29] experimented on FSW with different pin profiles and observed that adiabatic temperature rise due to plastic deformation is significant in ensuring adequate plasticity of the material and also concluded that the rate of heat generation as well as peak temperature are relatively higher in casse of non - circular pin profiles, increasing with number of flats(i.e., square to hexagonal).The various tool pin profiles are presented in "Fig.10".

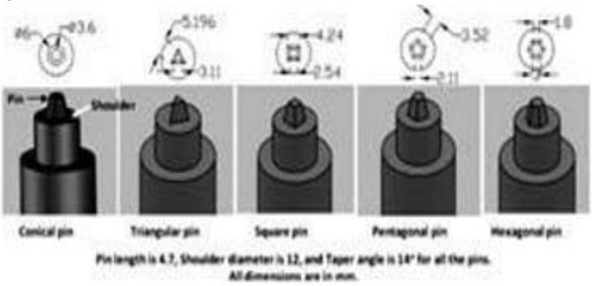

Fig. 10: Geometry of various tool pin profiles [29]

VII. CONCLUSIONS

From the literature survey, it can be concluded that welding of Al and its alloys can be performed by means of conventional fusion welding as well as solid state welding processes. But the nature of the joint will not be the same.

- ☐ While welding various alloys of Al using TIG welding, different process parameters like welding current, gas flow rate, welding speed, Pulse current, base current, Pulse Frequency are taken in to account in order to get a sound joint.
- ☐ Welding of aluminium alloys can be done using different shielding gases and concluded that the high helium content gases are used for GMAW welding on thicker materials and GTAW welding with DCEN. Pure argon can be used for both GMAW and GTAW.
- ☐ A study on friction welding process for Al alloy shows that the weld zone is stronger than the base metals.
- ☐ In FSW of Al alloys, rotational speed, transverse speed, tool geometry and ratio between tool shoulder diameter and pin diameter, axial force play an important role in obtaining the sound welds.

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