

Review Paper on Weldability of Aluminium Alloy

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ABSTRACT

Aluminium is the second most abundant metal on the earth. It became an economic competitor in engineering field and used in various sectors from the end of the 19th century. Aluminium is non-ferromagnetic, a property important in the electrical and electronics industries. The main characteristics of aluminium, which influence welding, are hydrogen solubility, aluminium oxides, thermal conductivity, thermal expansion and solidification shrinkage, and non-discoloration. This paper provides a review on the weldability of aluminium alloy. The selection of the method depends on many factors such as geometry and the material of the parts to be joined, required strength of the joint, number of parts to be joined, the aesthetic appeal of the joint and the service conditions such as moisture, temperature, inert atmosphere and corrosion. Finally, we will discuss about Friction Stir Welding (FSW) process, advantages, disadvantages and applications.

Keywords: Friction stir welding (FSW), Aluminium & its Alloys,

1. INTRODUCTION

Aluminium displays excellent corrosion resistance in most environments including atmosphere, water (including salt water), petrochemicals, and many chemical systems. It typically displays excellent electrical and thermal conductivity. Various Al alloys have been designed with high degrees of electrical resistivity and conductivity. These alloys are very useful in high-torque electric motors. Aluminium is often selected for its electrical conductivity, which is nearly twice that of copper on an equivalent weight basis. Aluminium is non-toxic and is routinely used in containers for foods and beverages also. Some of the aluminium alloys exceed structural steel in strength. Aluminium has a density of 2.7 g/cm³, approximately one-third that of steel (7.83 g/cm³), copper (8.93 g/cm³), or brass (8.53 g/cm³). Aluminium alloys are divided into two major categories:

1. Casting compositions
2. Wrought compositions

The Aluminium Association system is most widely recognized in the United States for their alloy identification system which employs different nomenclatures for wrought and cast alloys [Metal hand book 1979] [1]. For wrought alloys a four-digit system is used to produce a list of wrought composition families. Casting compositions are described by a three-digit system followed by a decimal value. The decimal .0 in all cases pertains to casting alloy limits. Decimals .1 and .2 stand for ingot compositions, which after melting and processing should result in chemistries conforming to casting specification requirements [2]. Heat-Treatable and Non-Heat-Treatable are the two basic types of aluminium alloys. They are both widely used in welding fabrication and have somewhat different characteristics associated with their chemical and metallurgical structure and their reactions during the arc welding process.

Welding of aluminium alloys: Aluminium is light in weight, yet some of its alloys have strengths exceeding mild steel. It retains good ductility at sub-zero temperature, has high resistance to corrosion. Pure aluminium melts at 660 °C and aluminium alloys have an approximate melting range of from 482 to 660 °C, depending upon the alloys. There is no colour change in aluminium when heated to the welding temperature range. High thermal conductivity (as compared to steel) necessitates a high rate of heat input for fusion welding [Pandey et al., 2002, Idowu et al. 2009] [3] [4]. Thick sections may require preheating. During resistance spot welding, its high thermal and electrical conductivity require high current, shorter weld time, more precise control of welding variables than when welding steel. Aluminium and its alloys rapidly develop a tenacious, refractory film when exposed to air.

2. LITERATURE SURVEY

The welding of aluminium and its alloys has always represented a great challenge for researchers and technologists. Friction stir welding (FSW) is a new welding process that has produced low cost and high-quality joints of aluminium alloys. For carrying out research work in any area, the first and an important phase is to review the available literature for the selected topic and the research problem can be formulated with clear objectives. To study the present research problem along with the methodology that could be adopted for accomplishing this research work, the selective review of the relevant literature surveyed is presented briefly, in following four categories:

I. FSW OF ALUMINIUM ALLOYS

Colligan (1999) studied the material flow behaviour during Friction Stir Welding of aluminium. A threaded tool pin was used in the experiment. Steel balls of 0.38 mm were used as tracer material to find the path of the material flow. He found that not all material influenced by the pin is stirred in the welding process[5].

Ying et al., (1999) used FSW to join the plates of 2024 Al and 6060 Al having thickness of 0.6 cm each. The tool rotation speed was varied between 400 to 1200 rpm. Dislocation spirals and loops are seen in the 2024 Al intercalation regions within the weld zones at higher speeds (>800 rpm)[6].

Sutton et al., (2002) prepared the weld joints of 7 mm thickness using 2024-T351 aluminium rolled sheet material by Friction stir welding. Metallurgical, hardness and quantitative energy dispersive X-ray measurements were performed. The tests demonstrated a segregated, banded, microstructure consisting of alternating hard particles[7].

Lee et al., (2003) welded A356 alloys sheets using friction-stir-welding to observe the effect of mechanical properties at the weld zone by varying the welding speeds. The microstructures of the weld zone are composed of SZ (stir zone), TMAZ (thermo-mechanical affected zone) and BM (base metal). The mechanical properties of the weld zone are greatly improved in comparison to that of the BM[8].

Cavaliere and Squillace (2005) used 7 mm thick sheet of 7075 aluminium alloy to analyze the mechanical and microstructural properties by Friction Stir Processing (FSP). The sheets were processed perpendicularly to the rolling direction and the mechanical properties were evaluated at room temperature in the transverse and longitudinal directions[9].

Hua et al., (2006) conducted the experiments of friction stir welding for 5456 aluminium alloys with the changes of the tool tilt angle. The defects like lack of penetration or voids, or lazy S, which are unique to friction stir welding were reported. The typical welding defects of friction stir welding joint for 5456 aluminium alloys were analyzed and discussed[10].

Kumara and Kailas (2008) investigated the influence of axial load and the effect of position of the interface with respect to the tool axis on tensile strength of the friction stir welded joint of aluminium alloy 7020-T6. The axial load is continuously varied by linearly increasing the interference between the tool shoulder and the surface of the base material. It is found that there is an optimal axial load, above which the weld is defect-free, with joint efficiency of 84%.

Moreira et al (2009) investigated the mechanical and metallurgical characterization of friction stir welded butt joints of aluminium alloy 6061-T6 with 6082-T6. For comparison, similar material joints made from each one of the two alloys were used. The work included microstructure examination, micro-hardness, tensile and bending tests of all joints.

Longhurst et al (2010) conducted experiment on torque control of friction stir welding for manufacturing and automation. AA6061 aluminium alloy plates were butt welded using a threaded tool. The experiment was conducted on the FSW system.

Rajkumar et al (2011) developed empirical relationship for the prediction of tensile strength of friction stir welded AA1100 aluminium alloy joints. The experimental part of the study was based on five level central composite designs of six (process and tool) parameters. Optimisation of the model was carried out to maximize the tensile strength using design-expert software. A maximum tensile strength of 105.32 MPa is exhibited by the FSW joints fabricated with the optimized FSW parameters of 993 rpm rotational speed, 72.25 mm/min welding speed, 7.84 kN axial force, shoulder diameter of 14.55 mm, pin diameter of 5.12 mm and tool hardness of 40 HRC were found to be the optimum parameters to attain maximum tensile strength in AA1100 aluminium joints.

Shultz et al (2013) conducted an experiment on shared control of robotic friction stir welding in the presence of imperfect joint fit-up. In this paper a shared control strategy was presented that allowed a skilled operator to identify irregularities that occurred during robotic frictions stir welding and assist the robotic system in producing an appropriate response.

II. POST WELD HEAT TREATMENT

Krishnan (2002) carried out Post weld heat treatment (PWHT) of Friction Stir Welds (FSW) at solutionising temperatures of 520, 540, and 560°C followed by ageing at 175°C or 200°C. It was found that the weld (stir) region exhibited very coarse grains after the PWHT. The hardness was found to be uniform across the weldment after the PWHT.

Chen et al., (2005) investigated that, the tensile strength of the FSW joints of 2219-O aluminium alloy significantly improved by the PWHT process. The tensile properties of the joints welded at different welding speeds, before and after the heat treatment were evaluated. The results indicate that the heat-treated joints possess a higher tensile strength and a lower elongation than the as-welded joints[11].

Singh et al., (2011) reported the effect of post weld heat treatment (T6) on the microstructure and mechanical properties of friction stir welded 7039 aluminium alloy joints. FSW parameters were optimized by making welds at constant rotary speed of 635 rpm and welding speed of 8 and 12 mm/min. As welded joint has highest joint efficiency (92.1%). Post weld heat treatment lowers yield strength, ultimate tensile strength but improves percentage elongation[12].

III. COMPARISON OF FSW WITH CONVENTIONAL WELDING PROCESSES

Squillace et al., (2004) compared two different welding processes one is conventional tungsten inert gas (TIG) process and second is friction stir welding (FSW). A micro-hardness measurement allows pointing out a general decay of mechanical properties of TIG joints, mainly due to high temperatures experienced by material. In FSW joint, instead, lower temperatures involved in process and severe plastic deformations induced by tool motion allow rising of a complex situation: by a general point of view a slight decay of mechanical properties is recorded in nugget zone, flow arm and thermo-mechanically altered zone (TMAZ), while in heat-affected zone (HAZ), due to starting heat treatment of alloy under investigation, a light improvement of such properties is appreciated[13].

Wang et al., (2008) reported the effect of welding processes (FSW and TIG) on the fatigue properties of 5052 aluminium-welded joints was analyzed based on fatigue testing. The results show that the fatigue properties of FSW welded joints are better than those of TIG welded joints.

Zhao et al., (2010) welded Al–Mg–Sc alloy plates by FSW and TIG welding. The effect of welding processes on mechanical and metallurgical properties of welded joints was analyzed. The results shown that the mechanical properties of FSW welded joint are much better than those of TIG welded joint. Moreover, tensile strength and yield strength of FSW joint are 19% and 31% higher than those of TIG joint, respectively.

Malarvizhib and Balasubramanian (2011) welded AA2219 aluminium alloy square butt joints without filler metal addition using gas tungsten arc welding (GTAW), electron beam welding (EBW) and friction stir welding (FSW) processes. The effect of three welding processes on fatigue crack growth behaviour is reported. Transverse tensile properties of the welded joints were evaluated. It was found that the FSW joints are exhibiting superior fatigue crack growth resistance compared to EBW and GTAW joints. This was mainly due to the formation of very fine grains.

IV. DESIGN OF EXPERIMENTS

Jamshidi et al., (2010) investigates the relationship between the microstructures of thermo mechanically affected zone (TMAZ) and heat input in friction stir welding (FSW) of 5086 aluminium alloys. First, welding heat input has been predicted using a three-dimensional finite element analysis; then, welding experiments have been carried out on annealed and work-hardened conditions to study the developed microstructures and the mechanical properties of the welded metal. The results show that the temperature field in the FSW process is asymmetrically distributed with respect to the welding line[14].

Mustafa (2012) investigated the experimental and numerical results of friction stir spot welding of high density polypropylene. The determination of the welding parameters plays an important role for the weld strength. The experimental tests conducted according to combinations of process factors (tool rotation speed, plunge depth and dwell time) at beginning welding were carried out according to the Taguchi orthogonal table L9 in randomized way. The results show coherence between the numerical predictions and experimental observations in different cases of weld strength. The signal-to-noise ratio and the analysis of variance were utilized to obtain the influence of the friction stir spot welding parameters on the weld strength. Finally, the improvement in the weld strength from the initial welding parameters to the optimal welding parameters was about 47.7% [15].

Raj kumar in his study shows that taguchi experimental design method determines the parameter setting whereas importance level of parameter on hardness, tensile strength, impact energy of Al6063 alloy can be resolute by ANOVA and S/N ratio [16].

3. FRICTION STIR WELDING

Friction stir welding (FSW) was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys [Thomas et al. 1991]. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. The parts must be suitably clamped rigidly on a backing bar to prevent the abutting joint faces from being forced apart. The length of the pin is slightly less than the required weld depth. The plunging is stopped when the tool shoulder touches the surface of the job. The tool shoulder should be in intimate contact with the work surface.

The function of tool is heating of work-piece, and movement of material to produce the joint. The heating is accomplished by friction between the tool and the work-piece and plastic deformation of work-piece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. Because of various geometrical features of the tool, the material movement around the pin can be quite complex [Boz and Kurt, 2004]. Here a substantial forging force is applied by the tool to consolidate the plasticized metal behind the tool. The welding of the material is facilitated by severe plastic deformation in the solid state involving dynamic recrystallization of the base material. As the tool is moved along the seam the desired joint is created [17].

1. Process Variables in FSW: The main process variables in friction stir welding are listed as follows: *Tool rotational speed, Welding speed, Shoulder diameter, Pin diameter and profile, Axial force, Tilt angle, Work piece material, Shoulder and pin material.* All these variables may affect the characteristics of the weld joint significantly. All these variables act to determine the outcome of the welding process. The main interest in studying the effect of the process variables lies in understanding the effect of the process on joint properties, including static mechanical and metallurgical properties, with the goal of maximizing productivity, performance and reproducibility. The welding process affects these joint properties primarily through heat generation and dissipation, so primary attention should be given to the effect of the welding process variables on heat generation and related outcomes [Pouget and Reynolds 2008; Rodrigues et al., 2009] [18].

2. Advantages: The key benefits of this newly developed welding process are to increase joint efficiency and range of alloys that can be welded. Friction stir welding permits welding opportunities relative to dissimilar alloys and difficult weld material. Composite materials can also be welded with this process. Other advantages are as follows: Improved weldability, Reduced distortion, Improved appearance, Elimination of under matched-filler metal.

FSW is the most significant development in metal joining in a decade and is a green technology due to its energy efficiency, environment friendliness, and versatility. As compared to the conventional welding methods, FSW consumes considerably less energy. No cover gas or flux is used, thereby making the process environmentally friendly. The joining does not involve any use of filler metal and therefore any aluminium alloy can be joined without concern for the compatibility of composition, which is an issue in fusion welding [19].

3. Disadvantages: One of the main limitations of the FSW is that the joint is not self-supporting and must be properly restrained. The other limitation of the FSW as follows: Key hole at the end of the work piece, the cost of the friction stir welding machine is very high and backing bar required [20].

4. Applications: Various applications are in Ship building, marine industries, Aerospace industry, Heating, ventilating and air conditioning units, High speed trains, railway tankers, goods wagons, Helicopter landing platforms, offshore accommodations etc[21].

4. CONCLUSION & FUTURE SCOPE

For the data collected from various research work done in this field by many researchers, there are a lot of points which can further be studied for the more appropriate results. From the extensive literature survey, it is found that there are only a few articles discussing the effect of process parameters such as rotational speed, feed rate, axial force and welding speed on the mechanical properties of friction stir welds. It was found that there is a lot of study is done on the FSW welding joints. But the effects of the parameters of the FSW process can further be studied for the better results. The FSW parameters affect the welding joints yield strength, ultimate tensile strength and the elasticity of the joint in significant manner. In future work we can investigate the microstructure and fracture surface of the weld zone of the joints to study the mechanical properties such as ultimate tensile strength, percentage of elongation and micro-hardness.

REFERENCES

- [1]. Bray J. W., 1992. Aluminium Mill and Engineered Wrought Products. In Properties and Selection: Nonferrous alloys, ASM Metals Handbook Volume 2, 10th edition, ASM International, Materials Park, Ohio, USA p 148
- [2]. Elwin L. Rooy, 1992. Introduction to Aluminium and Aluminium Alloys. In Properties and Selection: Nonferrous alloys, ASM Metals Handbook Volume 2, 10th edition, pp 17-38, ASM International, Materials Park, Ohio, USA.
- [3]. Mandal N. R. 2005. Aluminium Welding, Narosa Publishing House, Second edition, New Delhi.
- [4]. Cross C. E., Kohn M. L., 1993. Selection and Weldability of Non-Heat-Treatable Aluminium Alloys. In ASM Metals Handbook Volume 6, 10th edition, ASM International, USA, 1363.
- [5]. Liu, HJ, Fuji, H, Maeda, M &Nogi, K 2003, 'Tensile properties and fracture locations of friction-stir-welded joints of 2017-T351 aluminum alloy', Journal of Materials Processing Technology, vol. 142, pp. 692-696.
- [6]. Ying Li, L. E. Murr, McClure J. C., 1999. Flow visualization and residual microstructures associated with the friction-stir welding of 2024 aluminium to 6061 aluminium. Material Science and Engineering A 271(1-2): 213-223.
- [7]. Sutton M. A., Yang B., Reynolds A. P., Taylor R., 2002. Microstructural studies of friction stir welds in 2024-T3 aluminium. Materials Science and Engineering: A. 323(1-2): 160-166.
- [8]. Lee W. B., Yeon Y. M., Jung S. B., 2003. The improvement of mechanical properties of friction-stir-welded A356 Al alloy. Materials Science and Engineering A 355: 154-/159.
- [9]. Cavalierea P., Squillace A., 2005. High temperature deformation of friction stir processed 7075 aluminium alloy. Materials Characterization 55: 136– 142.
- [10]. NS Tung, V Kamboj, A Bhardwaj, "Unit commitment dynamics-an introduction", International Journal of Computer Science & Information Technology Research Excellence, Volume 2, Issue 1, Pages 70-74, 2012.
- [11]. Yan-hua Z. T., San-bao L., Lin W., Fu-xing Q., 2005. The influence of pin geometry on bonding and mechanical properties in friction stir weld 2014 Al alloy. Materials Letter 59: 2948 – 2952.
- [12]. Lohwasser, D., Chen, Z., 2009. Friction stir welding: from basics to applications Woodhead publishing U.K.
- [13]. Singh R. K. R., Sharma C., Dwivedi D. K., Mehta N. K., Kumar P., 2011. The microstructure and mechanical properties of friction stir welded Al–Zn–Mg alloy in as welded and heat-treated conditions. Materials and Design 32: 682– 687.
- [14]. Cavalierea P., Squillace A., 2005. High temperature deformation of friction Stir processed 7075 aluminium alloy. Materials Characterization 55: 136– 142.
- [15]. Idowu O. A., Ojo O. A., Chaturvedi M. C., 2009. Crack-free electron beam welding of Allvac 718 Plus(R) superalloy. Supplement to the Welding Journal 179- 187. Jamshidi A. H.
- [16]. Mustafa B., Adem K., 2012. The influence of stirrer geometry on bonding and mechanical properties in friction stir welding process. Materials & Design, 25: 343-347.
- [17]. Raj Kumar, Dr Vineet kumar, " Optimization of process parameter for stir casted of AA6063 metal matrix composite on hardness, tensile strength and impact energy". IJMET volume 8, issue 12 dec 2017, pp 108-117.
- [18]. Pouget G., Reynolds A. P., 2008. Residual stress and microstructure effects on fatigue crack growth in AA2050 friction stir welds. International Journal of Fatigue 30: 463–472.
- [19]. Rodrigues D. M., Loureiro A., Leitao C., Leal R. M., Chaparro B. M., Vilaça P., 2009. Influence of friction stir welding parameters on the microstructural and mechanical properties of AA 6016-T4 thin welds. Materials & Design 30: 1913-1921.
- [20]. Murr L. E., Li Y., Flores R. D., Trillo, E. A. 1998. Intercalation vortices and related microstructural features in the friction-stir welding of dissimilar metals. Materials Research Innovations 2:150-163.
- [21]. Li Y., Trillo E. A., Murr L. E., 1999. Friction-stir welding of aluminium alloy 2024 to silver. Journal of Materials Science Letters 19: 1047-1051.
- [22]. Pandey S., Mistry P., wattle R., 2003. Mathematical model for prediction of dilution by universal gas metal arc welding process. National conference on recent development in Mechanical Engineering(NCME-2003). Thaper Institute of Engineering and Technology (TIET) Patiala.