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Research Article

An Experimental Approach to Study the Effect of Welding Parameters on Mechanical Properties of 6061 Al Alloys by Friction Stir Welding

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A B S T R A C T

Aluminium alloy 6061 is a structural material with exhibits good weldability, good damping capability and machine ability, is one of the most attractive material in applications of transportation and mobile electronics for effectively as a light weight. The structural application of Aluminium alloy involves welding and joining, which are difficult to weld using conventional welding processes. In 1991 a solid state joining process named Friction Stir Welding was developed and this technique has attracted considerable interest from the aerospace and automotive industries, since it is able to produce defect free joints particularly for light metals i.e. magnesium and aluminum alloy. In this investigation an attempt has been made to study the effect of friction stir welding parameters on mechanical and metallurgical properties of 6061 Al alloy. The selected material was welded using combination of different parameters i.e. tool rotational speed (1950 rpm and 3080 rpm), welding speed (20 mm/min and 40 mm/min) and tool shoulder diameter (18 mm and 20 mm). It has been observed that there was linear relationship between UTS and weld pitch. A maximum value of UTS i.e. 238.4 N/mm^2 was obtained at 3080 rpm with 40 mm/min and 20 mm tool shoulder diameter. This study also revealed an inversely proportional relationship between grain size and weld pitch. The fine and equiaxed grains were obtained due to dynamic recrystallization at higher value of weld pitch. It was also observed that excessive heat generation and insufficient flow of plasticized material at higher values of tool rotational speed, leading to formation of defects which ultimately results in failure of weld joints between SZ and TMAZ.

Keywords: Friction Stir Welding, Tool Rotation Speed, Welding Speed, Tensile Strength, Microhardness

Introduction

Friction Stir Welding (FSW) is a solid state welding process first discovered and patented by the Welding Institute of Cambridge UK in 1991 by Wayne Thomas [Casalino et al., 2014]. It has been since then the subject of a great deal of interest. As per a survey done by Prof. AP Reynolds, Guest Editor of Science and Technology of Welding and Joining journal, since 1996, more than 5% of all refereed journal articles related to welding have been friction stir welding articles and if the friction stir processing literature

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is included this number is even greater. FSW is a solid state joining process that uses friction generated by a rotating cylindrical tool to heat and plasticize metal on either side of a joint, creating a solid, functional weld. The joining does not involve any use of filler metal [Hirata et al., 2007]. Friction-generated heat is more effective at reorganizing the microstructure of metals and metal alloys than other forms of fusion welding, but FSW can be a much slower process. The process uses a rotating, non-consumable weld tool that plunges into the base material and moves forward. Friction heat caused by the rotating pin creates a plasticized tubular shaft around the pin. Pressure provided by the weld tool forces the plasticized material to the back of the pin, cooling and consolidation. Al alloy is difficult to weld by traditional methods, due to high thermal conductivity, resulting in defects like porosity, cracks etc [Xu et al., 2013]. Hence FSW is being increasingly used. The process is especially well suited to butt and lap joint in aluminium since aluminium is difficult to weld by arc process, but is very simple to weld by FSW. An emerging and very attractive technology to overcome such drawbacks is FSW. FSW consumes less energy and leads to decrease in material waste and to the avoidance of radiation and dangerous fumes. The energy efficiency, environment friendliness and versatility make the FSW a promisingly ecologic and green technology.

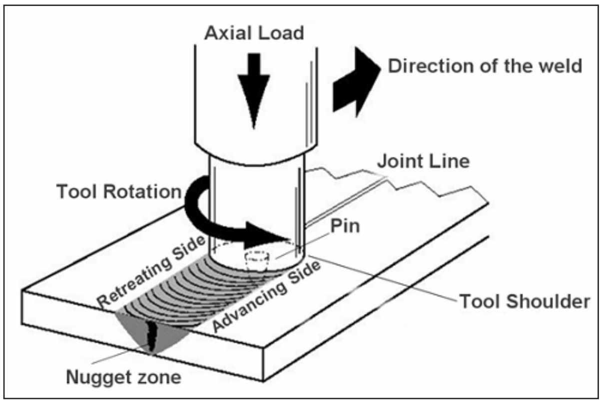

Figure 1.Schematic of Friction Stir Welding

Aluminium Alloy

Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required.

Alloys composed mostly of aluminium have been very important in aerospace manufacturing since the introduction of metal skinned aircraft. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium.

Aluminium alloy surfaces will keep their apparent shine in a dry environment due to the formation of a clear, protective layer of aluminium oxide. In a wet environment, galvanic corrosion can occur when an aluminium alloy is placed in electrical contact with other metals with more negative corrosion potentials than aluminium.

Aluminium alloys are designated based on international standards. These alloys are distinguished by a four digit number which is followed by a temper designation code. The first digit corresponds to the principal alloying constituent. The second digit corresponds to variations of the initial alloy. The third and forth digits correspond to individual alloy variations. Finally the temper designation code corresponds to different strengthening techniques. The chemical composition is given in Table 1.

Table 1.Chemical Composition of AA 6061

Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
0.9	0.62	0.33	0.29	0.17	0.06	0.02	0.02	Bal

Material and Methods

Material

6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called “Alloy 61S,” It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use.

It is commonly available in pre-tempered grades such as 6061-O (annealed) and tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

One very common aluminum alloy that could benefit from use of FSW joints is the Al6061 alloy used in the transportation industry (Krishnan, 2002). This alloy is relatively inexpensive and has high strength and ductility. In industrial settings, this alloy is commonly MIG welded, laser welded, or riveted. However, these processes may be expensive and unreliable, degenerate macroscopic properties, or add weight. FSW offers a cost effective alternative, provided necessary research on FSW joints of Al6061 is performed. A proper selection of tool material and tool design plays a vital role to achieve good mechanical as well as microstructural properties with Friction stir welding process.

As a cooperative industrial effort under the sponsorship of AISI and SAE, a tool steel classification system has been developed in which the commonly used tool steels are grouped into seven major categories. These categories, several of which contain more than a single group, are listed in Table 2, with the symbols used for identification. Suffix numbers following the letter symbols identify the individual types of tool steels within each category. From to the various options of steels and alloys available it was necessary to select appropriate steel with specific characteristic behaviors that would apply to joining of 6061 Al. During the welding process the tool will reach temperatures in the range of 500 °C at tool tip depending on the type of material being welded. The tool material must have good hardness, toughness and wear resistant properties at elevated temperatures. A cold-work tool High carbon, high chromium oil hardened type steel tool that comprises of outstanding high temperature strength, high temperature toughness, high temperature wear resistance and good machine ability is selected for present work. This tool steel selection was also motivated by its cost and availability (Singh et al., 2013).

Method

The material used in this investigation was 210 mm × 210 mm x 6 mm in size. But the appropriate size for welding was 150 mm × 75 mm for friction stir welding. To make the plates of 150 mm × 75 mm cutting of original plates was done using power hacksaw. Sixteen plates of size 152 mm x 77 mm were cut to obtain eight friction stir welded joint with different parameters. Then cut edges are finished with filling operation so that interfaces can be properly matched. Parameters are given in Table 2.

Table 2.Specimen Number Specifications Followed throughout Study

S. No.	Welding speed (mm/min)	Rotational speed (rpm)	Weld pitch (mm/min rpm)	Tool shoulder Diameter (mm)
1.	20	1950	0.0102	18
2.	40	1950	0.0205	18
3.	20	3080	0.0064	18
4.	40	3080	0.0129	18
5.	20	1950	0.0102	20
6.	40	1950	0.0205	20
7.	20	3080	0.0064	20
8.	40	3080	0.0129	20

Result and Discussion

In this experimental work mechanical and microstructure properties of friction stir welding of AL 6061 alloy have been investigated and the main conclusion can be made as follow.

Base metal 6061 was found to exhibit the best characteristics for Friction Stir Welding .A significantly high UTS value of 238.4 N/mm^2 was achieved at high weld pitch of 0.0129 mm/min rpm with tool shoulder diameter of 20 mm due sufficient heat generation and material flow because of proper grain refinement and ductility.

With the different parameters of tool shoulder diameter, rotational tool speed and welding speed, the result of mechanical properties were observed. It was found that maximum value of UTS achieved with 3080 rpm tool rotation speed, 40 mm/min welding speed and 20mm tool shoulder diameter. The lower value of UTS 230 was achieved with 1950 rpm tool rotation speed and 18 mm tool shoulder diameter. UTS increased with increasing in welding speed which provided the high stir rate and also increased the size of TMAZ and HAZ region. There were also found the tunnel defect. The specimens broken were broken from the region between TMAZ and SZ.

Impact strength slightly decreased due to the tunnel defect and also due to high rotational tool the value decreased. There were high heat input and brittleness observed in the specimen.

Insignificant effect of welding parameters on the impact strength observed. But slight decrease in impact value was observed with increase in rotational speed, due to high heat generation which induces a small value of brittleness.

The microstructure of the weld can be divided into four regions which are stir zone, thermo mechanically affected zone and heat affected zone and base material respectively. There exists change of grain size due to the different difference in strain rate of material. The grain size increased with increase in welding speed and decreased with increasing of tool rotational speed. The base material and heat affected zone almost had the same grain structure observed. Micro hardness is the function of grain size. If the grain size increased the value of micro hardness decreased. The maximum value 106.2 Hv was observed with tool rotational speed and 20mm tool shoulder diameter. This was due to sufficient stir action.

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