Experimental Study on Microstructure of Friction Stir Welding of AA6061

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***Abstract*----Friction stir welding, a solid state joining technique, is widely being used for joining Aluminium alloys for aerospace, marine, automotive and many other applications of commercial importance. Friction stir welding (FSW) can produce better mechanical properties in the weld zone compared to other conventional welding techniques. Later the best composition of the material will be selected from test results and this will be used as the main tool in friction stir welding. The material which is to be welded is also made up of same composition used in the tool. Friction stir welding (FSW) can produce better mechanical properties in the weld zone compared to other conventional welding techniques the tool serves primary functions: (a) heating of workpiece, (b) deform the material (c) movement of deform material to produce the joint. Scanning Electron Microscopy test has been performed to study the microstructure of the FSW produced by our tool. Friction stir welding can be widely applied in Aircrafts, rockets, automobiles, robotics, etc.**

***Keywords*----metal matrix composites, microstructure, SEM test, friction stir welding**

I. INTRODUCTION

AA6061 is normal hardened aluminium alloy containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935. 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), tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

Fig. 1 AA6061 Raw Material

Friction Stir Welding is the most significant development in metal joining in a decade. In Friction Stir Welding no cover gas or flux is used, thereby making the process environmentally friendly, energy efficiency and versatility or it is a “green technology”. 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. In FSW no cover gas or flux is used and does not involve any use of filler metal so that the properties of the joints are improve compare to the parent metal. Friction stir welding can be applied to various types of joints like butt joints, lap joints, T butt joints, pipes and fillet joints with different thickness and different profile. FSW technique was initially developed for Al-alloys, it also has great potential for welding of Mg-, Cu-, Ti-, Al alloy matrix composites, lead, some steels, stainless steels, and different material combinations, particularly those with close melting temperatures and similar behaviour such as hot workability

Friction stir welding, a solid state joining technique, is widely being used for joining Aluminium alloys for aerospace, marine, automotive and many other applications of commercial importance. Friction stir welding (FSW) can produce better mechanical properties in the weld zone compared to other conventional welding techniques. In many applications, aluminium metals or sheets are joined by traditional methods like riveting, nailing, etc. By using Friction stir welding, instead of riveting, we can also weld the aluminium materials.

II. FRICTION STIR WELDING

Aluminum alloys are generally classified as non-weldable because of the poor solidification microstructure and porosity in the fusion zone. Also, the loss in mechanical properties as compared to the base material is very significant. These factors make the joining of these alloys by conventional welding processes unattractive. Some aluminium alloys can be resistance welded, but the surface preparation is expensive, with surface oxide being a major problem. The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys. The basic concept of FSW is simple. 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 till the shoulder contact the top surface of workpiece and traversed along the line of joint to produce the weld. The tool serves primary functions: (a) heating of workpiece, (b) deform the material (c) movement of deform material to produce the joint. The heating is accomplished by friction between the rotating tool and the workpiece and plastic deformation of workpiece. 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. As a result of this process a joint is produced in 'solid state'

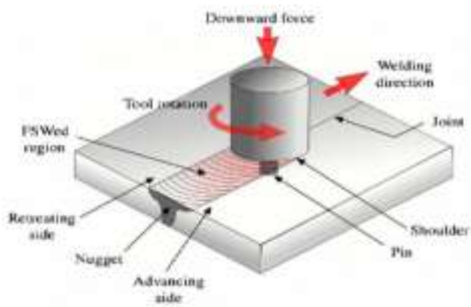

Fig. 2 Welding process

Friction Stir Welding is the most significant development in metal joining in a decade. In Friction Stir Welding no cover gas or flux is used, thereby making the process environmentally friendly, energy efficiency and versatility or it is a "green technology". 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. However, cost effective stirring tools are needed for welding some of these materials such as metal matrix composites and those with high melting temperatures, i.e. steels and titanium alloys. In this process, a specially consider important parameters, tool material, tool design, tool rotation, downward force and weld speed along the joint line, generating frictional heating that softens a material underneath the tool. The softened material flows around the tool through extensive plastic deformation and is consolidated behind the tool to form a solid-state continuous joint.

III. STANDARDS

ASTM: American Society for Testing Materials

ISO:International Organization for Standardization

Different forms and tempers of 6061 aluminium alloy are discussed in the following standards:

- ASTM B 209: Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate
- ASTM B 210: Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes
- ASTM B 211: Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire
- ASTM B 221: Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes
- ASTM B 308: Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles
- ASTM B 483: Standard Specification for Aluminum and Aluminum-Alloy
- ASTM B 547: Standard Specification for Aluminum and Aluminum-Alloy Formed and Arc-Welded Round Tube

ISO 6361: Wrought Aluminium and Aluminium Alloy Sheets, Strips and Plate.

IV. EXPERIMENTAL PROCEDURE

Friction stir welding was performed on AA6061 plates of dimensions 100×50×5(mm). We have taken 4 plates of AA6061 of similar dimensions and two tools made of AA6061+6% Al_2O_3 and H13.

Table: FSW process parameters and tool nomenclature AA6061+6% Al_2O_3 Tool

Rotational speed (rpm)	710
Feed rate (mm/min)	30
Pin length (mm)	5
Tool shoulder diameter (mm),D	15
Pin diameter (mm),d	5.7
Tool holder diameter (mm)	22
Tool materials	AA6061+6% Al_2O_3
D/d Ratio of tool	2.63
Load	5000N
Tool Profile	Cylindrical Threaded

Fig. 3 AA6061 Metal Plates

After the preparation of setup for friction stir welding, first the welding fixture was properly clamped on the bed of Universal Milling Machine and after that workpiece was clamped on the welding fixture with the help of top clamps provided. Side supporting plates are used to support the workpiece or to restrict the movement of workpiece during the welding operation. After clamping of workpiece on welding fixture, tool was clamped in the spindle then starts the machine and impinge the tool into the workpiece up to the desired depth after that feed was provided to the bed and friction stir welding was performed.

Fig. 4 Experimental Setup of FSW

V. METHODS OF MICROSCOPY

(A) Optical

When a polished flat sample reveals traces of its microstructure, it is normal to capture the image using macrophotography. More sophisticated Microscopy microstructure examination involves higher powered instruments: optical microscopy, electron microscopy, X-ray diffraction and so on, some involving preparation of the material sample (cutting, microtome, polishing, etching, vapor-deposition etc.). The methods are known collectively as metallography as applied to metals and alloys, and can be used in modified form for any other material, such as ceramics, glasses, composites, and polymers.

Two kinds of optical microscope are generally used to examine flat, polished and etched specimens: a reflection microscope and an inverted microscope. Recording the image is achieved using a digital camera working through the eyepiece.

(B) X-Ray Micro-tomographic

Nondestructive testing of microstructure for biological materials is a challenge and computer micro-tomography is the current solution. In fact, CMT can be used for the evaluation of microstructure of many other materials also. CMT can be very expensive though, and for research purposes, it is a necessity to generate a three-dimensional microstructure from two-dimensional cross-sectional images of the material. This is an area of active research and pursued by many scientists.

(C) 3D compositional microstructure

Microscopic distribution of material compositions in a material sample can be obtained using a data constrained modeling technique together with quantitative X-Ray computed tomography. A software implementation of the technique is available.

(D) Electron microscopy

For high-resolution information on metallurgical microstructures, electron microscopic methods can be employed. This can allow for direct observation of atomic-scale features such as very fine precipitation reactions, dislocations or grain-boundary interfaces. Such methods may be critical in determining parameters such as solid state diffusivities.

(E) Atomic force microscopy

Atomic force microscopy is a powerful technique used to study the surface properties of materials. It relies on the interactions that can be observed between the surface of a material and the very fine tip (ideally one atom in diameter) of the AFM. This tip is mounted on a cantilever that will move in certain directions according to the surface’s charge, topography or composition. The information received can provide inside knowledge on the topography of the material, the dimensions of certain particles, the interactions between the different molecules, the mechanical properties of the sample (a bending test can be realized using AFM), as well as other properties such as the electrical and magnetic properties. The resolution of this technique is one of the best you can achieve using microscopy techniques. In fact, unlike other electron microscopy techniques such as SEM, STM and so forth, AFM provides a resolution in the range of Angstrom. This technique is therefore perfect for studying nanomaterials and is sometimes referred to as a single atom resolved technique. Another big advantage of this technique is the minimal sample preparation it requires. The data collection process it relies on is also quite simple. The movements of the cantilever are recorded using a photo detector and a laser that is deflected by the cantilever. These movements induce a change in the voltage of the photo detector which then transforms this signal into an image.

VI. SCANNING ELECTRON MICROSCOPE

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. The electron beam is scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum in conventional SEM, or in low vacuum or wet conditions in variable pressure or environmental SEM, and at a wide range of cryogenic or elevated temperatures with specialized instruments.

The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons that can be detected depends, among other things, on specimen topography. By scanning the sample and collecting the secondary electrons that are emitted using a special detector, an image displaying the topography of the surface is created.

In a typical SEM, an electron beam is thermionically emitted from an electron gun fitted with a tungsten filament cathode. Tungsten is normally used in thermionic electron guns because it has the highest melting point and lowest vapor pressure of all metals, thereby allowing it to be electrically heated for electron emission, and because of its low cost. Other types of electron emitters include lanthanum hexaboride (Lab 6) cathodes, which can be used in a standard tungsten filament SEM if the vacuum system is upgraded or field emission guns (FEG), which may be of the cold-cathode type using tungsten single crystal emitters or the thermally assisted Schottky type, that use emitters of zirconium oxide.

The electron beam, which typically has an energy ranging from 0.2 keV to 40 keV, is focused by one or two condenser lenses to a spot about 0.4 nm to 5 nm in diameter. The beam passes through pairs of scanning coils or pairs of deflector plates in the electron column, typically in the final lens, which deflect the beam in the x and y axes so that it scans in a raster fashion over a rectangular area of the sample surface.

VII. RESULTS AND DISCUSSIONS

After performing Friction Stir Welding on the plates, $1cm^3$ of welded area is cut and SEM test has been performed on the Samples.

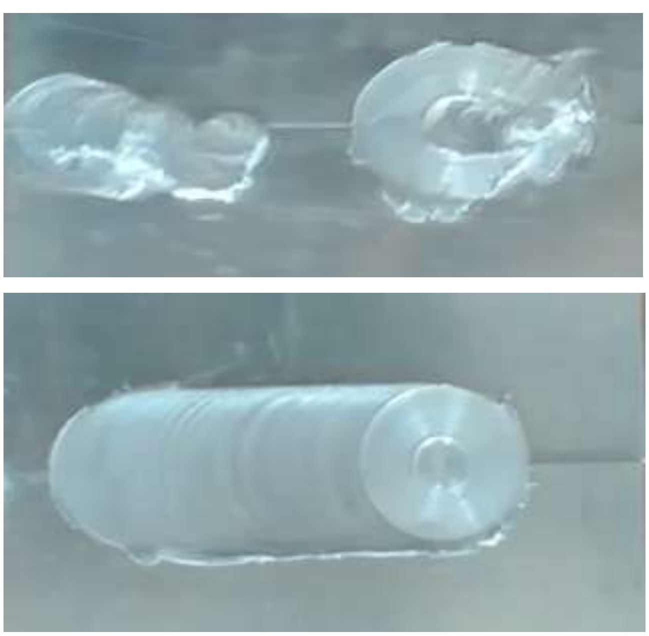

Fig. 5 Friction Stir Welded area

Scanning Electron Micro scoping test was performed on the samples to find whether any tool particles were melted and distributed in welded area during Friction Stir Welding, this test also determines the changes in grain size of non- welded region and Friction Stir Welded region.

SEM Test has been performed under following conditions:

- Filament use: Tungsten
- Voltage supplied : 20kV
- Magnification Range :100 to 10000
- Sample size : $1cm^3$

Fig. 6 Weld zone Samples

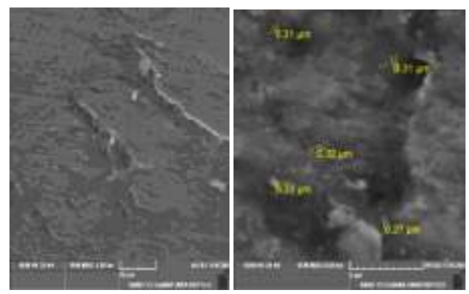

Fig. 7 Microstructure of FSW weld zone

The result of the Microstructure of FSW with AA6061+ 6% Al_2O_3 Tool as follows:

- The microstructure of sample welded byAA6061+ 6% Al_2O_3 tool clearly shows that some tool particles were distributed over the welded area. This is due to the meltdown of the tool profile due to high temperature at the welding zone.
- It is also noticed that the friction welding was not reached the bottom of the plate (the opposite side of the welded side)
- We can state that the weld produced by this tool is as strong as the weld produced by other tools when compared with other ceramic tools.
- We also predict that the weld is non- corrosive, may possess good strengths.
- We can conclude that the present work done is partially successful and paved a way to the further research in using similar materials for both tool and workpiece, which can be done by heat treatment, coating of tool, etc.

VIII. CONCLUSION

The conclusions were made from the present investigation are as follows:

- It was observed that in the friction stir welding process selection of tool material and design of tool is an important task.
- The results of the SEM Test results were studied and compared with each other.
- Finally, we conclude that the welding done by AA6061+ 6% Al_2O_3 tool is partially successful and this work paved a way for the future research on the use of similar material for both workpiece and tool which can be done by various methods like heat treatment, coating with other particles, etc.

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