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Friction Stir Welding of Two Al Plates Using Heated HSS tool

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Abstract: ***Friction welding is a class of solid-state welding processes that generates heat through mechanical friction between a moving work piece and a stationary component, with the addition of a lateral force called upset to plastically displace and fuse the. In this paper, HSS material was chosen as a tool which is heated to 750^{0}c before joining two Al plates using Lathe machine. Joining between two plates takes place while moving the plates fixed in the jig from one end of joint to other end. Experiment has been conducted based on three process parameters, namely, shoulder diameter, tool rotational speed and travel speed. A mechanical property like Tensile strength has been found to be 232.7MPa, the hardness of base metal is 50.7 HV***

Keywords: Lathe machine, Friction stir welding, HSS tool, heat treatment, tensile strength.

1. Introduction

FSW is an innovative solid-state joining process invented and patented by The Welding Institute, in 1991, in which a non-consumable rotating cylindrical tool with a shoulder and a specially designed pin, harder than the material to be welded is inserted into the butt lines of the base metal plates and subsequently travelled along the joint line. Heat is generated by the rubbing action of tool-shoulder part against the work piece makes it soft and plastically deforms, transverse movement of tool-pin while rotating against the part facilitates the joining along the interface line of two pieces Technically, because no melt occurs, friction welding is not actually a welding process in the traditional sense, but a forging technique, however, due to the similarities between these techniques and traditional welding, the term has become common. Friction welding is used with metals and thermoplastics. There are different types of friction welding such as Rotary Friction Welding, Inertia Friction Welding, spin welding, friction surfacing, Friction Stud Welding, Linear Friction Welding, Friction transformation processing, Friction stir welding.

2. Friction Stir Welding

Friction stir welding is a solid state welding process, is the newest addition to friction welding (FRW), a solid state welding process. Solid state welding, as the term implies, is the formation of joints n the solid state, without fusion. Solid state welding includes processes such as cold welding, explosion welding, ultrasonic welding, roll welding, and forge welding.

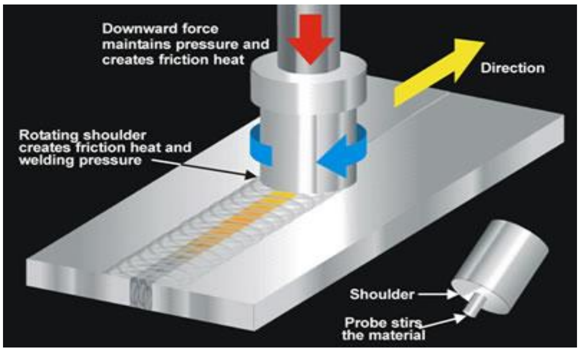

Figure 1: Friction Stir Welding

3. Working Principle

In friction stir welding (FSW) a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the joint line between two pieces butted together. The parts have to be clamped onto a backing bar in a manner that the abutting joint faces from being forced apart. Frictional heat is generated between the wear resistant welding tool and the material of the work pieces. This heat causes the latter to soften without reaching the melting point and allows traversing of the tool along the weld line. The maximum temperature reached is of the order of 0.8 of the melting temperature of the material. The plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged by the intimate contact of the tool shoulder and the pin profile. It leaves a solid phase between the two pieces.

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. 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.

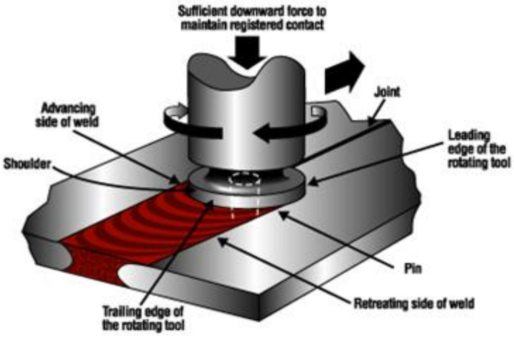

Figure 2: Friction stir welding process

3.1 Alloys

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 2.1 Mechanical properties are given in Tables 2.2

Table 2.1: Composition of AA 6061

Element	Al	Si + Fe	Mg	Cu	Mo	Other elements
Weight %age	97.56	0.8	0.15	0.15-0.40	0.05	0.15max

Table 2.2: Mechanical Properties

Name of the Al Alloy	Yield Strength in MPa	Ultimate Strength In MPa	Elongation %	Hardness in HV
AA 6061	110	207	16	75

Figure 4: Aluminium specimens before FSW

4. Variables in Friction Stir Welding

FSW involves complex material movement and plastic deformation. Welding parameters, tool geometry, and joint design exert significant effect on the material flow pattern and temperature distribution, there by influencing the micro structural evolution of material. In this section, a few major factors affecting FSW/FSP process, such as tool geometry, welding parameters, joint design are addressed. The strength of friction stir welding depends on the following three parameters. They are;

1. Shoulder diameter
2. Tool rotational speed
3. Travel speed
4. Feed rate
5. Depth of penetration

4.1 Factors Affecting Weld Quality

- Deformation characteristics of the metal
- Angle of tool
- Traversing speed of the tool
- Spinning speed of tool
- Pressure applied by the pin tool

Research is going on to combine the above factors in order to control the process in a better way.

5. Experimental Work

5.1 Experiment Set Up

Lathe Machine:

A lathe is a machine tool which rotates the work piece on its axis to perform various operations such as cutting, sanding, knurling, drilling, or deformation, facing, turning, with tools that are applied to the work piece to create an object which has symmetry about an axis of rotation.

A lathe fixture consists of a base, location and clamping devices. A lathe fixture can be fixed to the lathe either by holding in the chuck jaws or fixing to a face plate.

Basic Design Principles for Turning or Lathe Fixtures:

1. To avoid vibration while revolving, the fixture should be accurately balanced.
2. There should be no projections of the fixture which may causes injury to the operator.
3. The fixture should be rigid and overhang should be kept minimum possible so that there is no bending action.
4. Clamps used to fix the fixture to the lathe should be designed properly so that they don't get loosed by centrifugal force.
5. The fixture should be as light weight as possible since it is rotating.
6. The fixture must be small enough so that it can be mounted and revolved without hitting the bed of the lathe.

Figure 3: Work Piece setup

Due to of the non availability of specialist machine for FSW process. A conventional Lathe machine was used to attempt the welding process as shown in the Figure 1. The machine must has the ability to apply significant pressure on z axis direction, wide range of spindle speed, enough space for its working table to holding the welding assembly and rigidly during the welding operation. The lathe machine used has rotational speed on the head that is suitable to fixing welding tool on it.

High speed steel material was used for welding tool. The cylindrical shoulder produces a mixture of frictional heating and forging pressure, most of heat generation related to the tool shoulder while the probe When descended to the part, the rotating pin contacts the surface producing frictional heating which softens a small column of metal. Shoulder diameter 20 mm and it fit to the holder of milling machine. Pin has conical shape start from diameter 5 mm to 3 mm and length of pin is 4.2 mm. Set of parameters were used as shown in the Table 2.3

6. Methods and Materials

Materials: Partially re-crystallized AA 6061 having the chemical composition as given in table 2.1 was used. The dimensions of the 6061 Al plates were 100 mm x 25 mm x 5 mm. A high-speed steel tool was used for welding 6061 Al alloy having different shoulder diameters and the combinations of rotational speed, welding speed and shoulder diameters are considered.

Figure 5: Aluminium specimens after FSW

6.1 Welding Parameters

The 6061 Al plates were welded using three different tool rotation speeds, tool traverse speeds and three shoulder diameters. These designed process parameters are given in table 2.3

Table 2.3: Process Parameters

Process Parameters	Rotational Speed(rpm)	Transverse Speed(mm/min)	Shoulder dia(mm)
1	680	7	20

6.2 Process Parameters

The friction stir welding process is dominated by the effect associated with material flow and large mechanical deformation, which in turn is affected by process parameters such as rotational speed, welding Speed, axial force and shoulder diameter.

6.3 Tensile Strength

Tensile Strength (TS) or ultimate strength is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract. The Tensile strength of the specimen is evaluated using a UTM machine shown in Figure5 .The quality characteristic of Tensile strength is 'Bigger the Better'.

The tensile test specimens are prepared the tensile tests for nine specimens are conducted they yielded a variety of results the ultimate tensile strength of the specimen is tested using Universal Testing machine. The tensile failure has occurred in between regions of heat affected zone and base metal. All nine specimens have been welded, and the tensile strength and hardness of all specimens are presented in table 3.1 and 3.2 respectively.

The tensile strength is measured using UTM for all the experiments. The strength is influenced by the tool rational speed and also traverse speed. At speed of 680 rpm, traverse speed of 7mm/min the tensile strength is found to be 190 N/mm^2. At lower speeds and lower shoulder diameter, the strength is found to be low.

Figure 6: Universal Testing Machine

Table 3.1: Tensile Strength

Experiment Trials	A	B	C	Tensile strength (N/mm^2)
1	680	7	20	232.7

6.4 Hardness

Vickers hardness profiles of the welded zones were measured on a cross- section perpendicular to the welding direction using a Vickers indenter with a 5kgf load for15 second. The hardness of base metal is 44.7 HV. For all nine experiments, hardness is measured and presented in table 3.2 More hardness is found to be at lower speeds and shoulder diameter of 18 mm.

Table 3.2: Hardness

Experiment Trials	A	B	C	Hardness
1	680	7	20	50.7

7. Conclusions

Based on the results of different researchers, the tensile strength of AA 6061 Aluminium alloy is discussed for optimum process parameters of rotational speed, welding speed and axial force. Superior tensile properties of FSW joints were observed, this is due to the formation of fine equiaxed grains and uniformly distributed very fine strengthening precipitates in the weld region. With a recent research developments in use of heat treatable aluminium alloys, it has been suggested that higher tensile.

Strength of these alloys, a manufacturer allow to use in the area of aerospace and automobile industries, where the high strength to weight ratio is important. The combination of the process parameters of 680 rpm tool Rotation rate (rpm), 7 mm/min welding speed and 18mm shoulder diameter has been predicted to give the Tensile Strength of 232.7 N/mm^2.Combination of the process parameters of 680 rpm tool rotation rate (rpm), 7 mm/min welding speed and 24 mm shoulder diameter has been predicted to give the hardness of 50.7

8. Scope of Future work

1. The research could be taken further by applying the same technique to other Aluminium alloys such as 5XXX and 7XXX which are the alloys used in the automotive industry. This could help the increase of use of the friction stir welding in the automotive industry.
2. Further investigations on the forces generated during single and multiple passes for different alloys at different conditions and for different process parameters might be very beneficial.
3. As the literature suggests that the fine grained friction stir welded aluminium alloys might exhibit improved strength as well as ductility, hence mechanical testing of these friction stir welded plates like high temperature tensile testing, micro hardness testing, deformation mapping etc. is another area of interest.
4. Further studies may be done, considering most of the welding parameters, on a wider range of values. Fatigue analysis, shear tests can be conducted.
5. Higher thickness aluminium plates can be welded by employing double sided FSW. One can try to use tools made of different materials to improve the quality of the joints.
6. Welding of materials like Copper, Titanium, and magnesium by using friction stir welding is another area of interest.

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