ANALYSIS AND FABRICATION OF ALUMINUM ALLOY AA6061 BUTT JOINT USING FRICTION STIR WELDING

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ABSTRACT

Aluminum alloy 6061 is widely accepted in the fabrication of light weight structures required in the field of Aeronautical and Automobile industries as high strength to weight ratio. Compared to friction stir welding process is an emerging solid state joining process in which the material that is being welded does not melt and recast. In this process the welding defects which are expected in fusion welding processes which is routinely using for joining structural aluminum alloys can be eliminated. This process uses non-consumable tool to generate frictional heat in the butting surfaces. The welding parameters tool pin profile plays a major role in deciding welding quality.

In this project an attempt is made to understand the effect of welding speed and tool pin profile in friction spot stir welding process in joining of in aluminum alloy 6061. Five different tool pin profiles such as straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square are used to analysis the welding joints using Pro/Engineer software for modeling and ANSYS for analysis. Experimental work is conducted with tool pin which got optimum results in analysis with software, by using milling machine. Parameters such as feed in mm and spindle speed in (RPM) are identified as process parameters for experimental work.
1. INTRODUCTION FRICTION STIR WELDING:

Friction stir welding (FSW) is a solid-state welding process that gained much attention in research areas as well as manufacturing industry since its introduction in 1991 (TWI). The main feature of a solid-state welding process is the non-melting of the work materials which allows a lower temperature and a lower heat input welding process relative to the fusion welding process. Friction stir welding is used for critical applications, because it produces strong and ductile joints. The process is most suitable for components which are flat and long (plates and sheets) but also it can be used for pipes, hollow section and position welding.

The friction stir welding make it possible to join light weight materials such as aluminium alloy, magnesium alloy, copper and titanium alloys which are very difficult to weld by conventional welding. These clear advantages have greatly increased the usage of these materials in structural applications. In addition, FSW also makes possible to produce sound weldment in all aluminum alloys series that are not possible to be welded using conventional method,

FSW consumes considerably less energy. No cover gas or flux is used, thereby making the process environmentally friendly. joining does not involve any use of filler metal and therefore any aluminum alloy can be joined without concern for the compatibility of composition, which is an issue in fusion welding. FSW does not produce sparks or flames. FSW is considered to be 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 process provides proven good quality and strong weldment with inexpensive and lesser number of equipment, eliminates the use of filler metal and improved weldability. Due to these factors FSW has successfully been employed in aerospace, automobile and ship building industries..

1.1 Principle of Operation

Friction stir welding was invented by TWI, Cambridge in 1991. Friction stir welding involves the joining of metals without fusion or filler materials it produced a plasticized region of materials.

In FSW, a cylindrical-shouldered tool, with a profiled threaded/unthreaded probe (nib or pin followed by shoulder) is rotated at a constant speed and fed at a constant traverse velocity into the joint line between two pieces of sheet or plate material, which are butted together. The parts have to be clamped rigidly onto a backing bar in a manner that prevents the abutting joint faces from being forced apart. The length of the nib is slightly less than the weld depth required and the tool shoulder should be in intimate contact with the work surface. The nib is then moved against the work, or vice versa. Frictional heat is generated between the wear-resistant welding tool shoulder and nib, and the material of the work pieces. The maximum temperature reached of the order of 0.8 of the melting temperature. The tool has a circular section except at the end where there is a threaded probe or more complicated flute the junction between the cylindrical portion and the probe is known as the shoulder. The pin
penetrates the work piece whereas the shoulder rubs with the top surface. The heat is generated primarily by friction between a rotating-translating tool and the work piece, the shoulder of which rubs against the work piece.

FSW process involves four phases which are plunging phase, dwelling phase, welding phase and finally exit or retract phase. The figure 1.1 explains the principle involved in friction stir welding [1].

Friction Stir welding has a number of advantages over other joining methods. FSW uses no filler material and uses less energy.

This process is suitable in ship building and marine industries for manufacturing panels for decks, sides, bulk heads and floors, hulls and super structures, helicopter landing platforms, marine and transport structures and container bodies [2].

In aerospace industry uses FSW for manufacturing of wings, fuselages, empennages, cryogenic fuel tanks for space vehicles, aviation fuel tanks, and repair of faulty MIG welds. In railway for production of rolling stock of railways, underground carriages, trams

Friction stir welding is being used increasingly to replace fusion-welding techniques when aluminum alloys are involved to reduce weight. The main advantage is being low distortion and the ability to weld easily [3].

2. FACTORS EFFECTING WELD QUALITY.
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. The major factors affecting FSW/FSP process are tool geometry, welding parameters, joint design. The strength of friction stir welding depends on the following three process parameters and they are spindle speed, feed rate and depth of penetration

2.1 Tool Rotation (rpm) And Transverse Speed (mm/sec)
There are two tool speeds of the tool vise tool rotation speed and traverses speed are to be considered in friction-stir welding. In order to produce a successful weld, it is necessary that the material surrounding the tool is hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool. If the material is too cool then voids or other flaws may be present in the stir zone and in extreme cases the tool may break. The amount of heat generated depends on torque and tool speed and formation of heat effected zone depends on
traverse speed and welding speed of the tool. The relationship between the welding speeds and the heat input during welding is complex. The excessively high heat input may be detrimental to the final properties of the weld that could even result in defects due to the liquation of melting-point phases. Proper selection of tool speed and welding speed resulting weld will have a sufficiently high heat input to ensure adequate material plasticity but not so high that the weld properties are excessively reduced.

For FSW, two parameters are very important such as tool rotation and tool traverse speed (n, mm/min) along the line of joint. The rotation of tool results in stirring and mixing of material around the rotating pin and the translation of tool moves the stirred material from the front to the back of the pin and finishes welding process. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material as will be discussed later. However, it should be noted that frictional coupling of tool surface with work piece is going to govern the heating. So, a monotonic increase in heating with increasing tool rotation rate is not expected as the coefficient of friction at interface will change with increasing tool rotation rate.

2.2 Tool tilt and Plunge depth:

In addition to the tool rotation rate and traverse speed, another important process parameter is the angle of spindle or tool tilt with respect to the work piece surface. The plunge depth is the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be a critical parameter for ensuring weld quality. Plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool. Tilting the tool by 2-4 degrees, such that the rear of the tool is lower than the front, has been found to assist this forging process. The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. On the other hand an excessive plunge depth may result in the pin rubbing on the backing plate surface or a significant undermatch of the weld thickness compared to the base material.

A suitable tilt of the spindle towards trailing direction ensures that the shoulder of the tool holds the stirred material by threaded pin and move material efficiently from the front to the back of the pin. Further, the insertion depth of pin into the work pieces is important for producing sound welds with smooth tool shoulders. The insertion depth of pin is associated with the pin height. When the insertion depth is too shallow, the shoulder of tool does not contact the original work piece surface. Thus, rotating shoulder cannot move the stirred material efficiently from the front to the back of the pin, resulting in generation of welds with inner channel or surface groove. When the insertion depth is too deep, the shoulder of tool plunges into the work piece creating excessive flash.

Preheating or cooling can also be important for some specific FSW processes. For materials with high melting point such as steel and titanium or high conductivity such as copper, the heat produced by friction and stirring may be not sufficient to soften and plasticize the material around the rotating tool. Thus, it is difficult to produce continuous defect-free weld. In these cases, preheating or additional external heating source can help the material flow and increase the process window. On the other hand, materials with lower melting point such as aluminium and magnesium, cooling can be used to reduce extensive growth of recrystallized grains and dissolution of strengthening precipitates in and around the stirred zone.
3. MODEL OF FSW TOOLS

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. Tool geometry is the most influential aspect of process development. The tool geometry plays a critical role in material flow and in turn governs the traverse rate at which FSW can be conducted. An FSW tool consists of a shoulder and a pin and has two primary functions: (i) localized heating, and (ii) material flow. In the initial stage of tool plunge, the heating results primarily from the friction between pin and work piece. Some additional heating results from deformation of material. The tool is plunged till the shoulder touches the work piece. The friction between the shoulder and work piece results in the biggest component of heating. From the heating aspect, the relative size of pin and shoulder is important, and the other design features are not critical. The shoulder also provides confinement for the heated volume of material. The second function of the tool is to ‘stir’ and ‘move’ the material. The uniformity of microstructure and properties as well as process loads are governed by the tool design. Generally a concave shoulder and threaded cylindrical pins are used.

It is desirable that the tool material is sufficiently strong, tough and hard wearing, at the welding temperature. Further it should have a good oxidation resistance and a low thermal conductivity to minimize heat loss and thermal damage to the machinery further up the drive train. Hot-worked tool steel such as AISI H13 has proven perfectly acceptable for welding aluminum alloys within thickness ranges of 0.5 – 50 mm but more advanced tool materials are necessary for more demanding applications such as highly abrasive metal matrix composites or higher melting point materials such as steel or titanium. Improvements in tool design have been shown to cause substantial improvements in productivity and quality [4-5].

Different cross sections of tool such as cylindrical, round taper tool, square, thread and triangular are designed using integrated Pro/ENGINEER CAD/CAM/CAE solution. ANSYS10 Software is used for the analysis of thermal temperature distribution in the tool and in work pieces at temperature of 703°C and thermal gradient by making models with pro-e. Temperature distribution, thermal flux model and thermal gradient are valued are analyzed by ANSYS at 770 rpm and 900 rpm of the tool at which the temperature 673°C and 703°C is reached [6-8].

| Table 3.1 shows thermal properties at 770 and 900 rpm for joining Aluminum (AA 6061) using FSW |
|---------------------------------------------|----------|-----------------|------------------|-----------------|
| Type of tool      | RPM  | Temperature distribution | Thermal gradient | Thermal flux   |
| Round Tool        | 770  | 673°C               | 5398             | 971             |
|                  | 900  | 703°C               | 6232             | 1122            |
| Round Taper Tool  | 770  | 673°C               | 5160             | 962             |
|                  | 900  | 703°C               | 5909             | 964             |
| Square Tool       | 770  | 673°C               | 5119             | 956             |
|                  | 900  | 703°C               | 6206             | 1053            |
| Thread Tool       | 770  | 673°C               | 5082             | 914             |
|                  | 900  | 703°C               | 1327             | 860             |
| Triangular Tool   | 770  | 673°C               | 4916             | 884             |
|                  | 900  | 703°C               | 5457             | 982             |
Table 3.2 Shows thermal properties at 770 rpm and temperature at 673°C for joining Aluminum (AA 6061) by FSW using ANSYS

<table>
<thead>
<tr>
<th>Type of tool</th>
<th>Temperature distribution</th>
<th>thermal flux model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical</td>
<td><img src="Cylindrical.png" alt="Image" /></td>
<td><img src="Cylindrical.png" alt="Image" /></td>
</tr>
<tr>
<td>Round Taper Tool</td>
<td><img src="Round_Taper.png" alt="Image" /></td>
<td><img src="Round_Taper.png" alt="Image" /></td>
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<tr>
<td>Square Tool</td>
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<td><img src="Square.png" alt="Image" /></td>
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<tr>
<td>Thread Tool</td>
<td><img src="Thread.png" alt="Image" /></td>
<td><img src="Thread.png" alt="Image" /></td>
</tr>
<tr>
<td>Triangular Tool</td>
<td><img src="Triangular.png" alt="Image" /></td>
<td><img src="Triangular.png" alt="Image" /></td>
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</tbody>
</table>

It is observed that while joining two Al 6061& 6082 material by friction stir welding process, from the analysis of ANSYS, it is found that cylindrical tool is having more thermal flux, thermal gradient and good weld properties than taper cylindrical, square, triangle and threaded tools. Hence it is concluded that High speed steel, cylindrical tool is selected for FSW [9-11].
4. METHODOLOGY

4.1 Selection of Material and Testing
Aluminium alloy AA6061 is a medium strength alloy with excellent corrosion resistance. It is used for joining by friction stir welding process. The aluminium materials are test for evaluating its mechanical properties as per is standard.

![Figure 4.1 Dumbell (IS Standard)](image)

![Figure 4.2 Dumbell after fracture by UTM](image)

The obtained dumbbell results on UTM are yield load: 10400N, maximum load: 11500N, yield Strength: 265.4 Mpa, tensile Strength: 293.4 Mpa.

Rolled plates of Aluminium alloy AA6061 of 3 mm thickness are cut into the required size (100mm x 50 mm x 3 mm) and machined by milling. Before the friction welding, the weld surface of the base material was cleaned. Plate edges to be weld were also prepared so that they are fully parallel to each other. This is to ensure that there is no uneven gap between the plates which may not result in sound welding. Secondly surface preparation was also done so that the surfaces of both the plates are of equal level and footing plates are of equal level and footing.

4.2 Experiment:
Semi automation milling machine with maximum speed 6000 rpm and 7-horse power was used for friction stir processing (fsw) of aluminum alloy. The work piece was clamped in the fixture firmly. The rotating pin is initially inserted into a predrilled hole, which will facilitate the startup of welding with tool tilt angle was 2 degree. The plates are joined with spindle speed of 770 rpm and travel rate of 75 mm/min. Result of this the two side plates are welded together. The process is repeated for tool travel rate of 90 mm/min for the tool speeds of 900 rpm. The plates are tested for visual inspection for voids, blow holes, cracks and other irregularities. Mechanical tests are also performed to study influence of speed and feed on hardness and tensile strength of the joint at different experimental conditions. The figures show the FSW processes for joining aluminium plates.

![Figure 4.3 FSW operation in progress](image)

![Figure 4.4 Al finished join tby FSW](image)
5. TESTING OF DEPOSITS
Primary inspections are for the qualitative analysis, used is evaluated after deposition to give status of the deposit, whether it is acceptable or not. The deposit is inspected for the physical appearance and damage. It is also inspected by visual inspection using magnifying glass for visible defects such as blisters, pits, roughness, and cracks or undercut areas.

Non-destructive testing methods have limitations for testing dissimilar metal joints. However ultrasonic testing with special probes and equipment can be used to detect the defects at the interface like lack of bonding and any cracks formed after friction surfacing. Surface defects like cracks and voids can be detected by dye-penetrant examination. Radiography technique is normally best suited for the detection of the volumenar kind of defects.

Visual examination is performed to reveals surface flaws, and is a valuable indication in weld quality. It is a simple, accessible, low-cost inspection method, but it requires a trained inspector. Visual examination only identifies surface discontinuities. A conscientious program of visual inspection before and during welding may reduce costs by exposing surface defects early in the fabrication process. The most important instrument in visual testing is the human eye. Hence, the visual acuity of inspector is prime importance aspect in visual testing. It can be natural or aided by other instruments like magnifying lenses.

Dye penetrant test is conducted on the stainless steel friction surfaced deposit according to the standard ASME Sec V SE 165. Liquid Penetration Test (LPT) is also generally called as Dye Penetration Test (DPT). In practice, the liquid penetrant process is relatively simple to utilize and control. The major advantages of penetrant testing include, portability, low cost, easy to use. Penetrant testing is a simple nondestructive testing method for detecting discontinuities that are open to surface such as cracks, seams, laps, cold shuts laminations, porosity and shrinkage. Hence this test is preferable for detecting any gaps between the deposit and substrate. The strength of the joint is determined by UTM. Microstructure of AA 6061 is conducted as per the standard IS: 7739 Part and its structure is shown in figure 4.5

![Figure 4.5 Microstructure at 100XL](image)

6. RESULTS AND DISCUSSION
When the deposit was observed under microscope it is found that the surface of the deposit is free of cracks, blisters, pits, roughness, or undercut problems, which are generally encountered in fusion welding process as in some magnitude or other.

The surface when observed carefully revealed that it is free of porosity, which indicates that the selected welding speed is correct and allow any entrapped gases if formed during the process escape. The nature of this solid state process eliminates this type of defect.

When the dry penetration test is conducted for the deposit, it is found that the surfaces are free of defects such as cracks or voids or holes. It indicates that the obtained joint is perfect.
On testing joint strength with UTM, it is found that maximum load: 10090 N and tensile Strength: 278.7 MPa. Which is nearer to 90% of the parent material

7. APPLICATIONS

FSW process benefits solid state joining method that has great advantage on light weight material such as aluminium alloy due to its thermal properties which make it difficult to be joined using conventional methods.

Heat generation and heat transfer play major role in determining the success of the joining process as well as predominantly establish the joint characteristics and properties.

It is observed that while joining two Al 6061& 6082 material by friction stir welding process cylindrical tool is having more thermal flux, thermal gradient and good weld properties than taper cylindrical, , square, triangle and threaded tools. It is found that from analysis results. Hence it is concluded that cylindrical tool is best suited for FSW

Friction surfacing has potential application in industries due to improved reliability and productivity, suitable for batch production, reduction in cost, superior quality and the achievement what was previously impossible. This process can also be attempted in the robotics for full automation.

Friction surfacing is the solid state welding process and it is confirmed that the problems associated with fusion welding are eliminated like porosity, inclusion and other defects normally formed while solidification of weld. The deposit has refined micro structure and with little distortion

This process can be performed in open air and not required any inert gases to prevent oxidation. This process is most suitable for the consumables which are having less thermal conductivity than substrate and poor sliding characteristics]. It is a clean welding process, does not require fluxes or other consumables and produces no fumes or spatters or harmful radiation

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Analysis and Fabrication of Aluminium Alloy AA6061 Butt Joint Using Friction Stir Welding


