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Simulation of Material Flow and Heat Evolution in Friction Stir Processing Incorporating Melting

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ABSTRACT:

Friction stir processing (FSP) is a relatively new technology for microstructure refinement of metallic alloys. At high processing speeds, excessive heating due to severe plastic deformation and friction may result in local melting at the interface between the FSP tool and the work piece. In this work, a computational fluid dynamics (CFD) approach is applied to model material flow and heat evolution during friction stir processing of AZ31B magnesium alloy, taking into consideration the possibility of local melting in the stirring region. This is achieved by introducing the latent heat of fusion into an expression for heat capacity and accounting for possible effects of liquid formation on viscosity and friction. Results show that the temperature in the stirring region increases with the increase in rotational speed and drops slightly with the increase in translational speed. As liquid phase begins to form, the slope of temperature rise with rotational speed decreases and the maximum temperature in the stirring region stabilizes below the liquidus temperature at high rotational speeds. It is also shown that the formation of a semi-molten layer around the tool may result in a reduction in the shearing required for microstructure refinement.

Keywords: *friction stir processing, melting, computational fluid dynamics*

INTRODUCTION:

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. In addition to melting the base metal, a filler material is often added to the joint to form a pool of molten material that cools to form a joint that can be as strong, or even stronger, than the base metal.

Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding may be performed in many different environments, including in open air, under water, and in outer space. Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for centuries to join iron and steel by heating and hammering. Arc welding and oxy fuel welding were among the first processes to develop late in the century, and electric resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as the world wars drove the demand for reliable and inexpensive joining methods. Developments continued with the invention of Laser beam welding, Electron beam welding, Magnetic pulse welding (MPW), and Friction stir welding in the latter half of the century. Today, the science continues to advance. Robot welding is common place in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality.

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Friction Welding:

Friction welding is considered as a solid state welding process that generates heat through mechanical between a moving work piece and a stationary component, with the lateral force called "upset" to plastically displace and fuse the materials. Because of no melt occurs, friction welding is not actually a welding process but in a forge technique. used with metals and thermoplastics in a wide variety of aviation and automobile applications.

Advantage of friction welding is that it allows dissimilar materials to be joined. This is particularly useful in aerospace, where it is used to join lightweight strength steels. Normally the wide difference in melting points of the two materials would make it impossible to weld using traditional techniques, and would require some sort of mechanical connection. Friction welding provides a "full strength" bond with no additional weight.

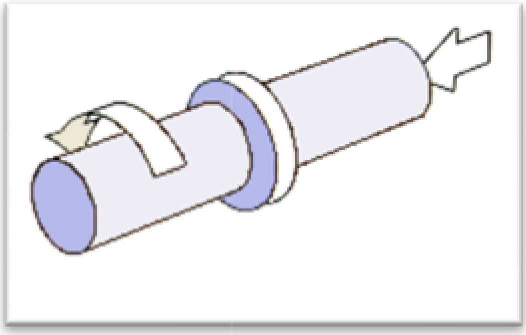

Fig- 1.1 Friction welding

Friction Stir Welding (FSW):

Friction-stir welding is relatively a new solid-state joining process (without melting of metal) that uses a third body tool to join two faying surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool.

It then mechanically intermixes the two pieces of metal at the place of the joint, and then softened the metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool). Friction stir welding is primarily used on Aluminium and most often non heat treatable alloys. Friction stir welding is a solid state joining method based on friction heating and local plastic flow in the joint region by stirring with a rotating tool pin. FSW is a solid-state joining process that creates high-quality, high-strength joints with low distortion and is capable of fabricating either butt or lap joints, in a wide range of materials thickness and lengths. In this process a rotating FSW tool is plunged between two clamped plates. The frictional heat causes a plasticized zone to form around the tool. The rotating tool moves along the joint line. A consolidated solid phase joint is formed.

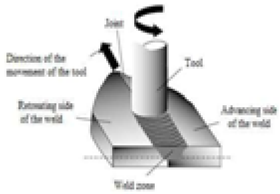

Fig- 1.2 Friction Stir Welding

FSW offers an excellent alternative to conventional fusion welding and provides good joint properties and a high degree of repeatability. It was soon found that apart from the aluminium alloys is also capable of joining a great number of other materials. These include Al, Pb, Mg, Ti, Cu, Zn, steels and especially hard to weld alloy. Many joints between dissimilar materials are possible.

Principle:

A constantly rotated non consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface.

Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld.

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FSW Tool Geometry:

Tool geometry has a great influence on resulting mechanical properties of the weld. It provides in-situ heating, stirs base material, and thus creates weld. There has been variety of tool shapes used. FSW can be performed with tool of a simple geometry yet having good mechanical properties .Advanced tool design provides intensified material flow in the stirred zone and better weld quality.

These figures provide basic overview on the basic and advanced types of FSW tools

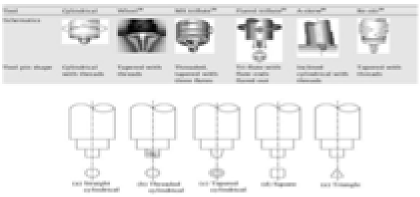

Fig- 1.6 Different Types of FSW Tools with Different Types of Tool Pin Shape

EXPERIMENTATION:

Friction-stir welding is relatively a new solid-state joining process (without melting of metal) that uses a third body tool to join two faying surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the joint, and then softened the metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool). Friction stir welding was invented by Wayne Thomas at The Welding Institute (TWI) of Cambridge in England in December 1991.

Friction stir welding is primarily used on Aluminum and most often non heat treatable alloys. Friction stir welding is a solid state joining method based on friction heating and local plastic flow in the joint region by stirring with a rotating tool pin.

FSW is a solid-state joining process that creates high-quality, high-strength joints with low distortion and is capable of fabricating either butt or lap joints, in a wide range of materials thickness and lengths. In this process a rotating FSW tool is plunged between two clamped plates. The frictional heat causes a plasticized zone to form around the tool. The rotating tool moves along the joint line. A consolidated solid phase joint is formed.

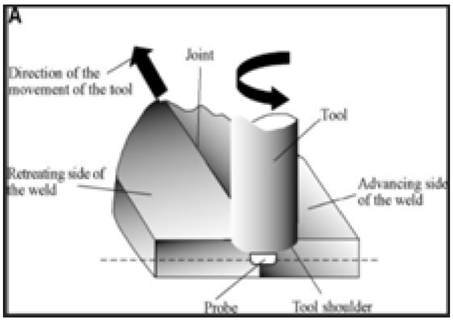

Fig- 1.0 FSW

Specification Of The Machine:

Spindle Taper - ISO 40
Spindle Speed - 3000rpm
spindle tilt angle +- 5deg
Z-axis thrust force 30KN(max)
Z-axis Travel - 300mm
X- axis Travel - 300mm
Y-axis Travel(manual) - 100mm(optional:Servo)
Table to spindle nose(min/max) - 100mm/400mm
Controller – Rexroth
Data Acquisition software - Spindle rpm, Torque axis force and velocity against time and distance

Weld able Material - Steel/Copper/Aluminium

- Liquid cooled tool holder
- temperature telemetry
- Tools for steel copper and aluminium
- Centralised lubrication
- Tilt head option
- 2 mode control Force control Position control

Fabrication and Heat Treatment of H13 Tool:

Machinability:

The machinability rate of H13 tool steels is nearly 75% of that of the W group tool steel.

Forming:

H13 tool steels are formed by using conventional methods.

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Welding:
H13 tool steels are readily weldable.

Heat Treatment:
H13 tool steels are preheated to 816°C (1500°F). Then the steels are directly heated by increasing the temperature to 1010°C (1850°F) followed by holding for 15 to 40 minutes. The steels are then air-quenched.

Forging:
H13 tool steels are forged at 1079°C (1975°F). For this type of steels, forging below 898°C (1650°F) is not preferable.

Work Piece Materials:
The work pieces used in this processing are AA6061 & AA6063. These work pieces are taken because AA6061 is less corrosive resistance than any other alloys & AA6063 has better corrosive resistance than 6061. So to make better corrosive resistance, we taught to weld with AA6063.

AA6061:
Aluminum alloy 6061 is the second most popular of the 2000-series aluminum alloys, after 6061 aluminum alloy. It is mainly used in the aerospace industry. It is easily machined in certain tempers and among the strongest available aluminum alloy as well as having high hardness. It is commonly extruded and forged. The corrosion resistance of this alloy is particularly poor.

Infrared thermometer:
An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured. They are sometimes called laser thermometers if a laser is used to help aim the thermometer, or non-contact thermometers or temperature guns, to describe the device's ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined. Infrared thermometers are a subset of devices known as "thermal radiation thermometers".

The most basic design consists of a lens to focus the infrared thermal radiation on to a detector, which converts the radiant power to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature. This configuration facilitates temperature measurement from a distance without contact with the object to be measured. As such, the infrared thermometer is useful for measuring temperature under circumstances where thermocouples or other probe type sensors cannot be used or do not produce accurate data for a variety of reasons.

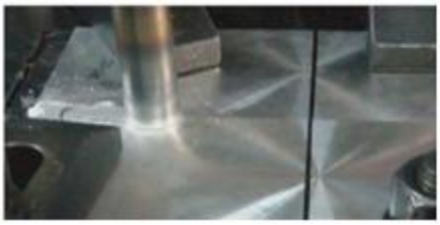

Fig-3.11 Processing of friction stir welding

The temperatures were recorded using infrared thermometer during welding process.

Fig-3.12 Recording temperature during FSW

Fig-3.13 Processing setting

RESULTS & DISCUSSIONS:
Tool wear is key issues for the Friction Stir Welding (FSW) & a consequence of prolonged contact between the tool and the harder reinforcements. Tool wear

describes the gradual failure of cutting tools during welding. It is a term often associated with tipped tools, tool bits, or drill bits that are used with machine tools. In order to quantitatively asses the tool wear, the percent variation in tool size is used as evaluation index, i.e. Valuation = (original size-measured size) / (original size) *100%.

So in this process of experimentation, the tool wear was calculated for each and every weld with the help of a digital vernier caliper. And with these readings we found that the tool wear for the weld is approximation 0.2mm.

Fig-4.1 Before Welding

Fig-4.2 After Welding

Consider first weld for evaluation index.
Valuation = (original size – measured size) / (original size) * 100%
Valuation for first weld = (5.8-5.7) / (5.8) * 100%
=(0.1)/ (5.8) * 100%
=1.724%
=(0.3) / (5.8) * 100%
=5.1724%
= (0.5) / (5.8) * 100%
=8.6207%

Consider fourth weld for evaluation index
Valuation = (original size- measured size) / (original size) *100% Valuation for fourth weld = (5.8-5.1) /(5.8) *100% = (0.7)/ (5.8) *100%
= 12.068%

Consider sixth weld for evaluation index
Valuation = (original weld- measured size) / (original size)* 100%.
Valuation for sixth weld = (5.8-4.6) / (5.8) * 100%
= (1.2) / (5.8) * 100%
= 20.69%

From the table -4.2, we can find the evaluation index gradually varying from first weld to the next progressive welds. The difference between the evaluation index values also varying from first weld to the next progressive welds and from the table 4.2 we observe that the maximum evaluation index value is seen at the last weld and the minimum evaluation index is seen in the first weld.

Graphical Representation:

Stress vs strain

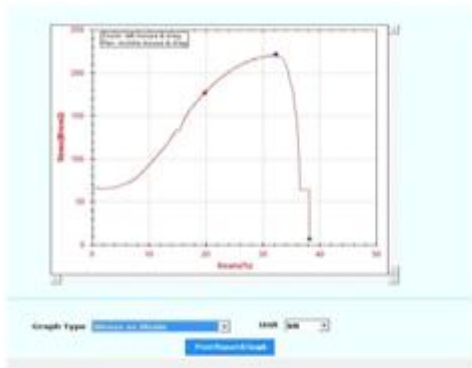

Fig 4.8 Tensile report on AA6061-6063 900rpm-40mm/min

Wear testing measurement

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact. As the wear is a surface removal phenomenon and occurs mostly at outer surfaces, it is more appropriate and

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economical to make surface modification of existing alloys than using the wear resistant alloys.

Weight Loss

The alloy and composite samples are cleaned thoroughly with acetone. Each sample is then weighed using a digital balance having an accuracy of ± 0.1 mg. After that, the sample is mounted on the pin holder of the tribometer ready for wear test. For all experiments, the sliding speeds are adjusted to 2 and 4 m/s.

The specific wear rate for the material were obtained by W=▲w/LÞF where W denotes specific wear rate in mm^3/N-m, ▲w is the weight loss measured in grams ,L is the sliding distance in meters ,Þ is the density of the worn material in g/mm^3 and F is the applied load in N.

HARDNESS TEST CALCULATIONS:

Aluminum and other softer alloy are frequently tested using 100kg test force and a 10 or 5mm carbite ball.Therefore the typical range of brinell testing in this country is 500 to 3000kg with 5 or 10mm carbide ball.

Modeling And Simulation:

Effect of tool rotational and welding speed on plastic strain is studied and insight is given on asymmetric nature of FSW process. Temperature distribution on the work piece and tool is predicted and maximum temperature is found in work piece top surface. The researchers have performed a three dimensional Finite Element Analysis (FEA) of thermal history in FSW by using Johnson–Cook material and damage models in ABAQUS/Explicit.The researchers have developed a 3D visco-plastic model of FSW to estimate temperature history and Material flow and validated the same with experimental data. They have assumed the material as a non-Newtonian fluid and allowed the flow stress to vary as a function of Temperature and strain rate. The recommended sequence for designing a manufacturing process using DEFORM 3D ,the defined proposed process, Is final forged part geometry, Material ,Tool progressions Starting workpiece/billet geometry, Processing temperatures, reheats, etc. To we have to gather the required Material data, Processing condition data, Using the DEFORM pre-processor, input the problem definition for the first operation, and submit the data for simulation, Using the DEFORM post-processor, review the results, and repeat the pre-process-simulate-review sequence for each operation in the process, If the results are unacceptable, we have to use engineering experience and then judgment is given to modify the process and then simulation sequence is repeated. For importing the geometry of Tool and Workpiece initially we have to draw the sketches. Sketches are done by using CATIA V5 R20 according to our dimensions i.e. 60mm * 6mm *100mm for work piece. For Tool, the dimensions are as follows- shoulder diameter of 20mm, shoulder length of 46mm, tool pin upper diameter of 6mm, and tool pin lower diameter of 3mm. With these diameters a tool is designed using catia tool. Then the catia model in .stl format is saved for importing in DEFORM 3D.

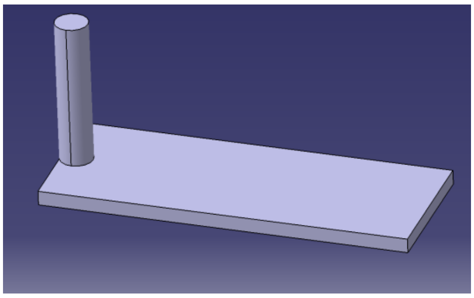

Fig1.0 model with Tool

Simulation Results:

Various temperatures obtained for AA60601 & AA6063 when they were made to run at 900 rpm, 1200 rpm, and 1400 rpm at feed rates of 40, 50, and 30 mm/min. These temperatures are plotted in graphical representation and they are compared between the results of manufacturing welds and DEFORM-3D tool weld.

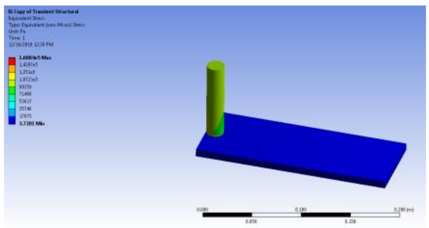

FIG.3.0EQIVALENT STRESS

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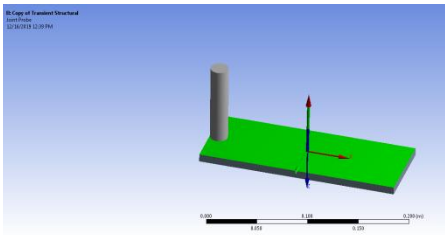

FIG.4.0 JOINT PROBE

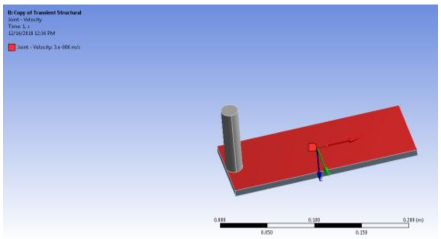

FIG.5.0 JOINT VELOCITY

TABLE 1.0 FORCE VALUES

S.No	Time [s]	Joint Probe (Total Force X) [N]	Joint Probe (Total Force Y) [N]	Joint Probe (Total Force Z) [N]	Joint Probe (Total Force Total) [N]
1	0.2	3.99E-06	8.19E-10	-25.447	25.447
2	0.3	0.3198	-2.65E-07	-25.447	25.449
3	0.4	0.33025	-2.09E-08	-25.447	25.449
4	0.5	0.32943	3.35E-11	-25.447	25.449
5	0.6	0.33025	1.34E-10	-25.447	25.449
6	0.7	0.32971	8.18E-10	-25.447	25.449
7	0.8	0.33007	5.54E-10	-25.447	25.449
8	0.9	0.32983	5.60E-10	-25.447	25.449
9	1	0.32999	7.24E-10	-25.447	25.449

Conclusions:

In this experimental study aluminium alloys namely Al 6061 & Al 6063 are welded using Friction Stir Welding. Welding of these alloys is carried out with different speeds such as 1400, 1200, 900 rpm. The parameters such as speed and feed rate are varied to obtain optimum values. Their mechanical properties such as tensile strength, hardness, impact resistance and surface roughness are investigated. Based on the results obtained, the following are the conclusions. For AA6061-6063 the best magnitude of tensile strength i.e. 143.06 N/mm^2was obtained at a speed of 900 rpm and feed rate of40 mm/min. The best magnitude of hardness i.e. 53.91 BHN was obtained at a speed of 1200 rpm and feed rate of 50mm/ min. The best magnitude of impact resistance i.e. 29.3 N-m was obtained at a speed of 1400 rpm and feed rate of 60mm/ min. The best magnitude of surface roughness i.e. 1.71µm was obtained at a speed of 1400 rpm and feed rate of 60 mm/ min. Moreover the obtained results are validated using DEFORM-3D simulation software and the temperature results are represented in the form of graphical representation. The results are validated according to the temperatures as parameters. With FSW dissimilar metals can be easily joined with sound results. When compared Tensile strength and hardness with base material an average of 60 % of the properties is obtained for similar welded joints.

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