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Design and Experimental Investigation on Weld Characters tics of Friction Stir Welding For Different Tool Profiles and Speeds Of Al-6063 Alloy

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ABSTRACT

Friction stir welding is a solid-state joining process, mainly used for joining Aluminium alloys. The aluminium alloys are generally classified as Non-Weldable because of the poor solidification microstructure and porosity in the fusion zone. The advantage of this process over other commercial techniques is that the material is being welded without bulk melting. The weld joint is fundamentally free from defects and displays excellent mechanical properties compared to conventional fusion welds. The work has been carried out to study properties of weldment like tensile strength, microstructure which defines the mechanical properties and grain size of weld region. Aluminium alloy of grade 6063 is selected for the present work with tool different tool profiles, different rotational speeds of the tool two transverse speeds. Two tool profiles are selected and effectively comparison results are summarized. The weld parameters like tool geometry which can change the weld quality are selected as a major parameter here. Higher tool rpm with low welding speed resulted in finer grain structure leading to higher strength as well as higher ductility of welded joints. In order to simulate the welding process, combination of thermal and mechanical effects needs to be considered. Appropriate finite element software will be used to perform the finite element analysis of the FSW in order to predict residual stresses, temperatures, normal stresses and distortions of the welded structure.

KEYWORDS: Friction Stir Welding, Aluminium 6063, Tool Profile, Rotational Speed, Simulation.

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1. INTRODUCTION

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. The process is carried out by plunging a rotating tool made of a wear-resistant and high temperature resistant material into the material to be joined and translating it along the desired weld line. The heat generated by friction at the tool surface and plastic dissipation in the deforming regions of the work pieces soften the material to a plasticized state. It is then extruded around the tool and consolidates to form a weld. It must be emphasized that there is no bulk melting of the material.

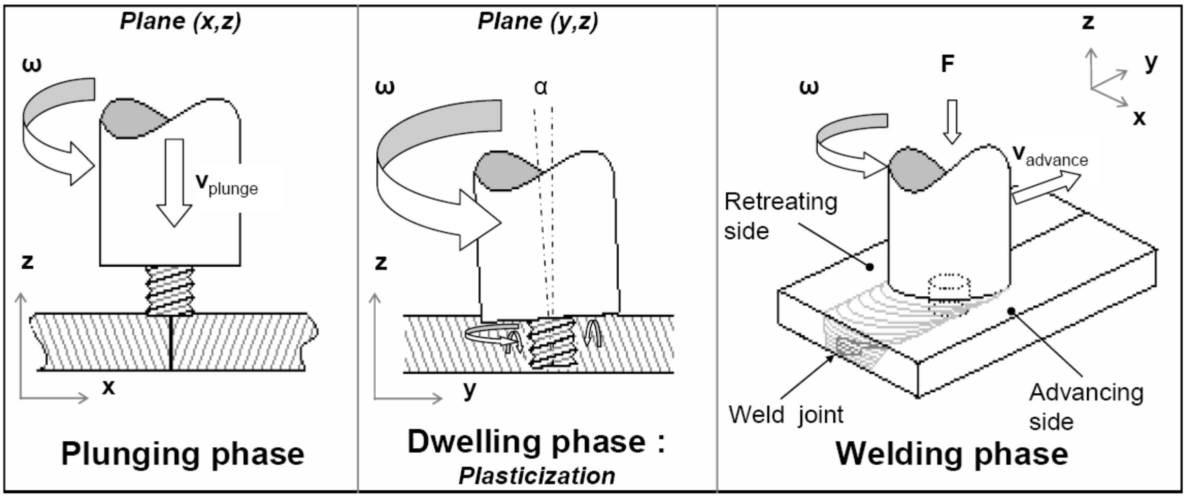


Fig 1.1 Phases in FSW welding

Friction welding is considered as a solid-state welding process that generates heat through mechanical friction between moving work piece and a stationary component, with the addition of a 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 a forging technique. Due to the similarities between these techniques and traditional welding, the term has become common. Friction welding is used with metals and thermoplastics in a wide variety of aviation and automotive applications. The combination of fast joining times (on the order of a few seconds), and direct heat input at the weld interface, yields relatively small heat-affected zones. Friction welding techniques are generally melt-free, which avoids grain growth in engineered materials, such as high-strength heat-treated steels. Another advantage is that the motion tends to "clean" the surface between the materials being welded, which means they can be joined with less preparation. During the welding process, depending on the method being used, small pieces of the plastic or metal will be forced out of the working mass (flash). It is believed that the flash carries away debris and dirt.

Friction heat between two sliding/rotating surfaces is employed in this process to form a joint. The pieces to be joined are clamped in chucks. One chuck rotates against a stationary one. Pressure is used to generate enough heat to reach a bonding temperature within a few seconds. At this stage the rotation is stopped and pressure is retained or increased to complete the weld. To accommodate awkward or very long parts, an intermediate slug or disc is rotated in between the sections to be joined.

Friction welding is also used with thermoplastics, which act in a fashion analogous to metals under heat and pressure. The heat and pressure used on these materials is much lower than metals, but the technique can be used to join metals to plastics with the metal interface being machined. For instance, the technique can be used to join eyeglass frames to the pins in their hinges.

1.1 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.

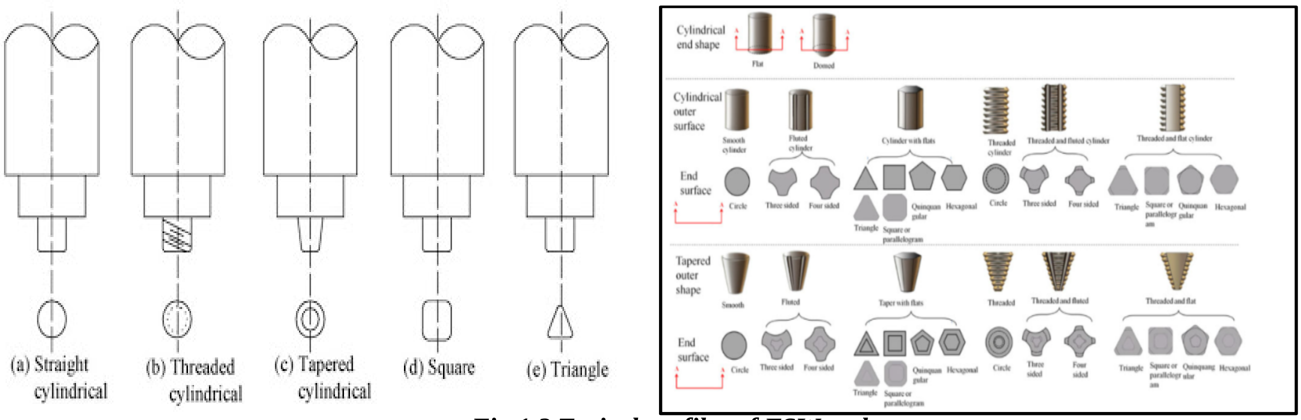


Fig 1.2 Typical profiles of FSW tool

1. EXPERIMANTAL PROCEDURE

Vertical axis NC milling machine (Specifications of NC Milling Machine: Vertical Axes NC Axes Machining Center, Model: NC-3T, Spindle Range: 760-3100 rpm, Tool Material: H13, Movement: 610 X 450 mm and Bed size: 800 X 500 mm) is converted Friction Stir welding Machine with proper setup.

Fig 2.1 Vertical Milling Machine

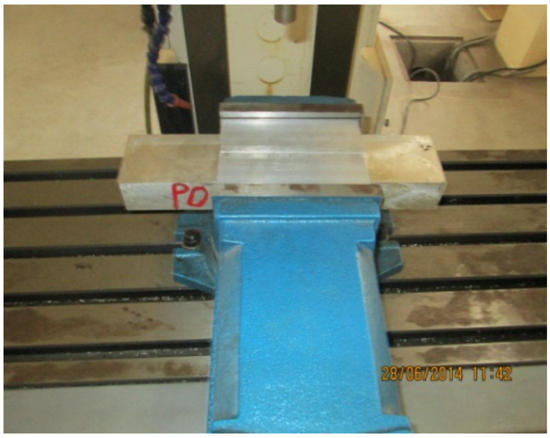


Fig 2.2 clamping of work piece on milling machine

2.1 Workpiece and Tool Geometry

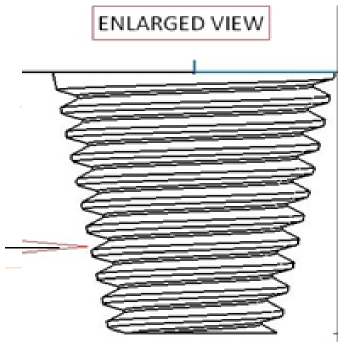
In this, two 6mm thick aluminium 6063 alloy plates are butt welded using Friction Stir welding using the Finite element simulation software DEFORM - 3D.

The geometry of each work piece includes:

Length of each plate = 150 mm, Width of each plate = 120 mm, Thickness of each plate = 6 m For the numerical analysis, as single block approach is used for Friction Stir Welding. The modeling of work piece is done as a single work piece.

Fig 2.3 Horizontal Slotted Pin

Vertical Slotted Pin



In this, for Friction Stir Welding of aluminium 6063 plates, H-13 Steel is used as the tool material. H-13 Steel is chromium, molybdenum, vanadium hot work tool steel which is characterized by high hardenability and excellent toughness. The molybdenum and vanadium act as strengthening agents. The chromium content assists H-13 to resist softening when used at high temperatures. H-13 offers an excellent combination of shock and abrasion resistance, and possesses good red hardness. It is capable of withstanding rapid cooling and resists premature heat checking. H-13 observed having good machinability, good weld ability, good ductility, and can be formed by conventional means.

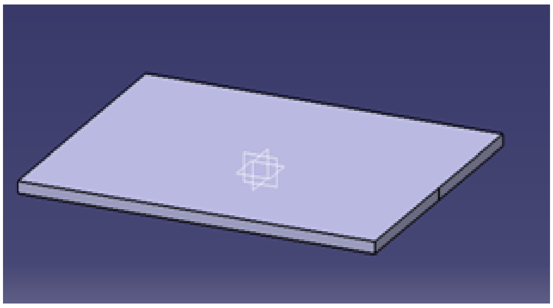


Fig. 2.4 Work piece Configuration

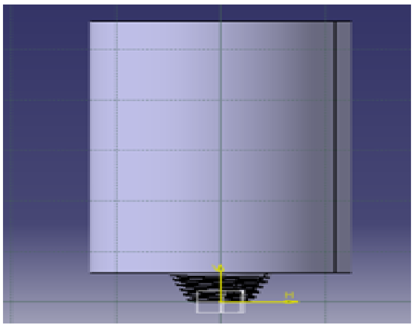
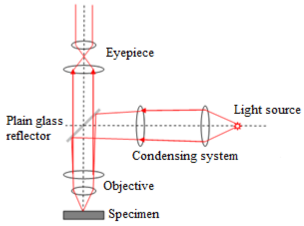


Fig. 2.5 Tool configuration

3. SOLUTION METHODOLOGY

3.1. Microstructure Of Fsw

Metallurgical microscope is the optical microscope, differing from other microscopes in the method of the specimen illumination.Optical Microscope- The image quality and its resolving power are mainly determined by the quality of the objective. The objective magnification depends on its focal length (the shorter focal length, the higher magnification).The eyepiece is the lens nearest the eye. The image is magnified by eyepiece in X 6, X 8 or X 10.



The total magnification of the microscope may be calculated by the formula:

$$M = L*E/ F$$

Where **L**- the distance from back of objective to eyepiece; **F** – the focal length of the objective; **E**- the magnifying power of the eyepiece. The common magnification of metallurgical microscope is in the range X 50 –X 1000.

Regardless of the material in which a friction stir weld is performed, the resulting microstructure has two distinct zones that result from the welding process. The area of all three of these zones comprises what is commonly referred to as the Weld Affected Zone (WAZ). The first constituent of the WAZ is the Dynamically Recrystallized Zone (DXZ), also known as the weld nugget, which lies at the center of the weld along the weld seam. This zone is bordered on either side by the remaining two constituent zones, the Thermo Mechanically Affected Zone (TMAZ) immediately surrounding the DXZ, and the Heat Affected Zone (HAZ) surrounding the outside edges of the TMAZ All three constituents of the WAZ have distinct characteristics.

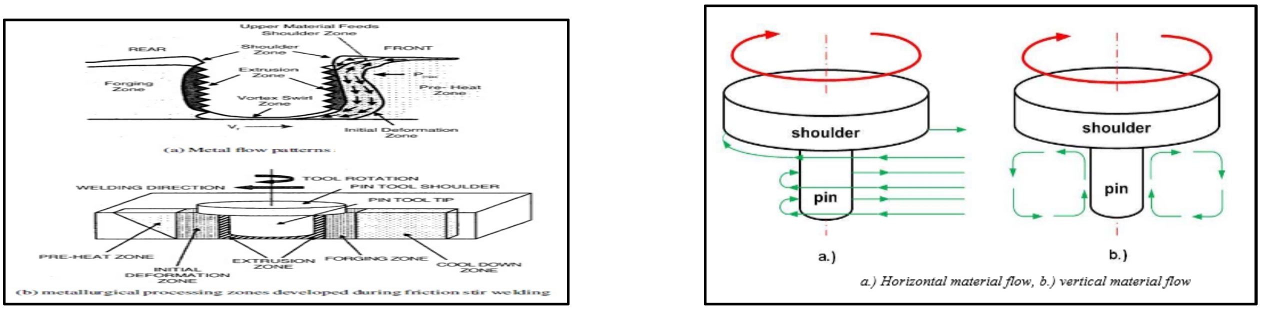


Fig. 3.1 Material Flow Pattern during FSW

3.2. Deform-3d

DEFORM-3D is commercial FEA software which uses Lagrangian implicit code designed for metal forming processes, was used to model the FSW process. The use of an implicit code versus an explicit one is a sort of inescapable choice being the latter better suited in order to correctly predict temperature evolutions and stress states.

DEFORM is a Finite Element Method (FEM) based process simulation system designed to analyze various forming and heat treatment processes used by metal forming and related industries. By simulating manufacturing processes on a computer,

1. Reduce the need for costly shop floor trials and redesign of tooling and processes
2. Improve tool and die design to reduce production and material costs
3. Shorten lead time in bringing a new product to mark

4. RESULTS AND DISCUSSION

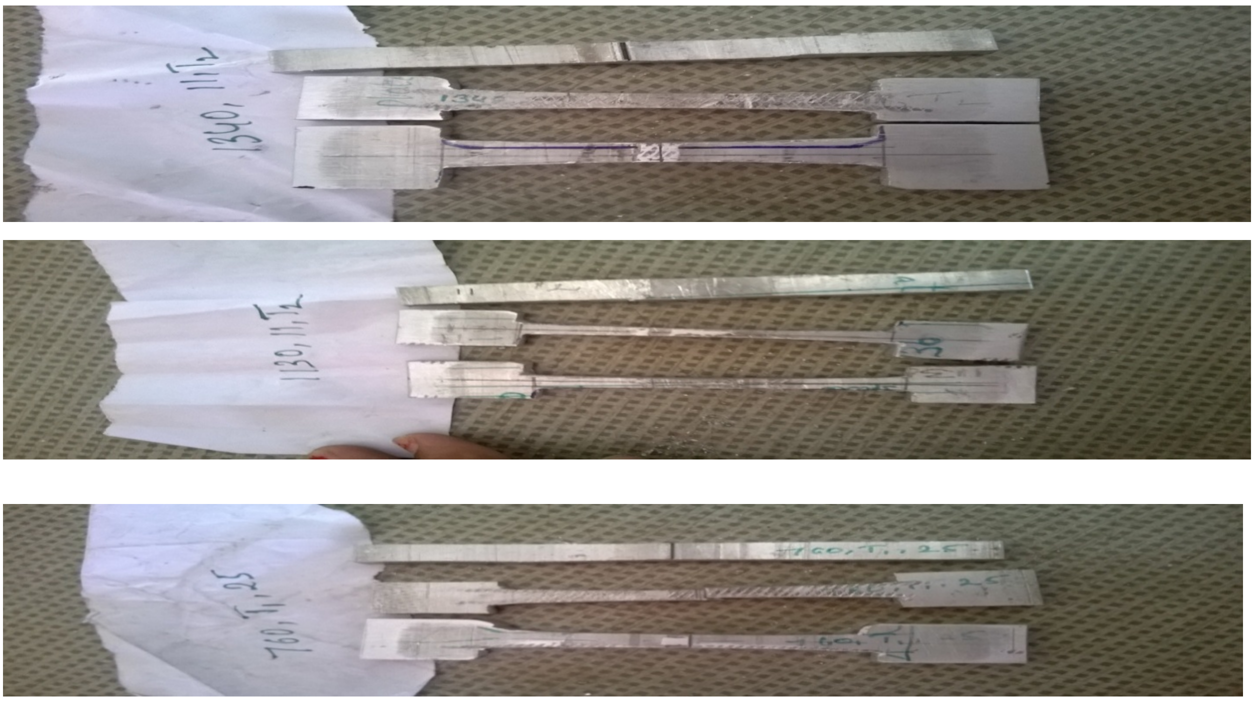


Fig. 4.1.Tensile testing sample

Table 4.1 Samples at various rpm and feed rate.

S. No	Tool	Tool RPM	Tool Feed Rate mm/min
1		760	760
2		760	760
3	Tool 1	1120	1120
4		1120	1120
5		1340	1340
6		1340	1340
7		760	760
8		760	760
9	Tool 2	1120	1120
10		1120	1120
11		1340	1340
12		1340	1340

4.1 Deform -3d Results

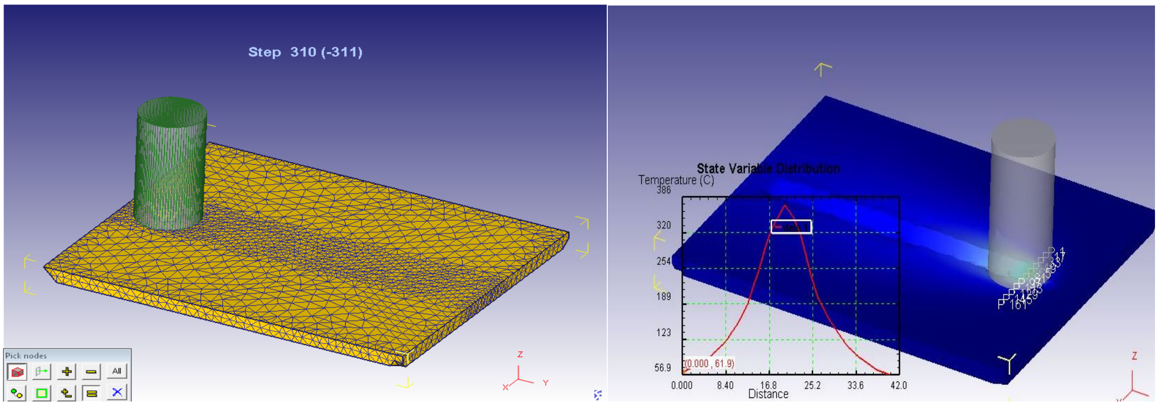


Fig. 4.2 Temperature Distribution

4.1.1 Stressc Distributation

DEFORM uses the von-mises stress to define the characteristic effective stress. In most metals, the effective stress is indicative of the onset of plastic flow. The effective stress is defined as

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$

Where,σ Effective stress and$\sigma_{1,}$ σ_2 and$\sigma_3$are principal stresses

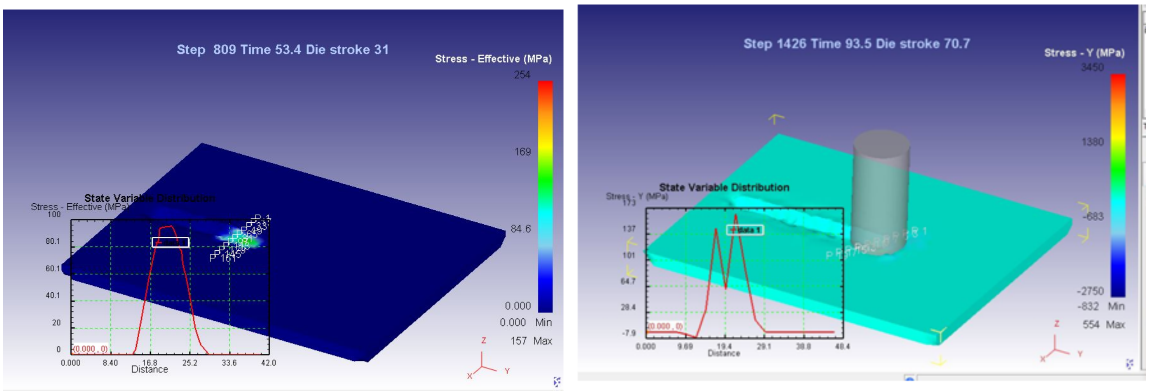


Fig 4.3 Effective stress distribution during welding

4.1.2 Effective Strains

It is useful to have a single characteristic strain value to describe the degree of deformation. DEFORM uses a common value during analysis known as the Effective or Von-Mises strain. The Effective Strain is defined as

$$\epsilon = \frac{1}{\sqrt{2}}\sqrt{[(\epsilon 1 - \epsilon 2)^2 + (\epsilon 2 - \epsilon 3)^2 + (\epsilon 3 - \epsilon 1)^2]}$$

Where ϵ - Effective strain and $\epsilon 1$, $\epsilon 2$ and $\epsilon 3$ are principal strains

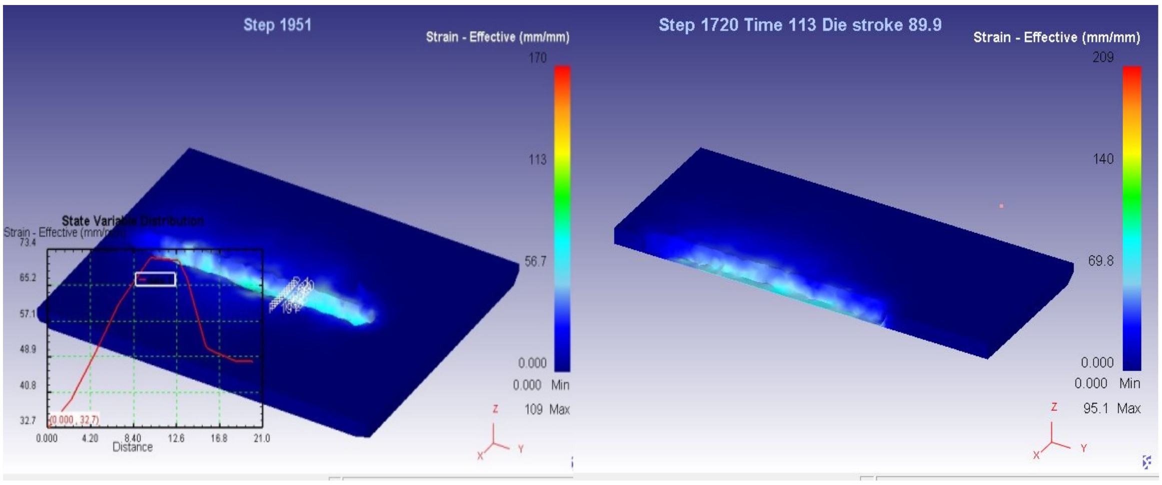


Fig 4.4 Effective strain distribution during welding

Table 4.2 Welding process parameters for horizontal slotted pin

S. No	Thickness of the plate(mm)	Tool rotational speed (rpm)	Tool transverse speed (mm/min)	Observation from tensile test (breaking zone)	Quality of weld
1	6	760	11	Middle of the weld zone	poor
2	6	760	25	Middle of the weld zone	poor
3	6	1130	11	Outside the weld zone	good
4	6	1130	25	Outside the weld zone	good
5	6	1340	11	Outside the weld zone	good
6	6	1340	25	Middle of the weld zone	poor

Table 4.3 Welding process parameters for vertical slotted pin

S. No	Thickness of plate (mm)	Tool rotational speed (rpm)	Tool transverse speed (mm/min)	Observation from tensile test (breaking zone)	Quality of weld
1	6	760	11	Middle of the weld zone	Poor
2	6	760	25	Middle of the weld zone	Poor
3	6	1130	11	Outside the weld zone	Good
4	6	1130	25	Middle of the weld zone	Good
5	6	1340	11	Outside the weld zone	Good
6	6	1340	25	Middle of the weld zone	Poor

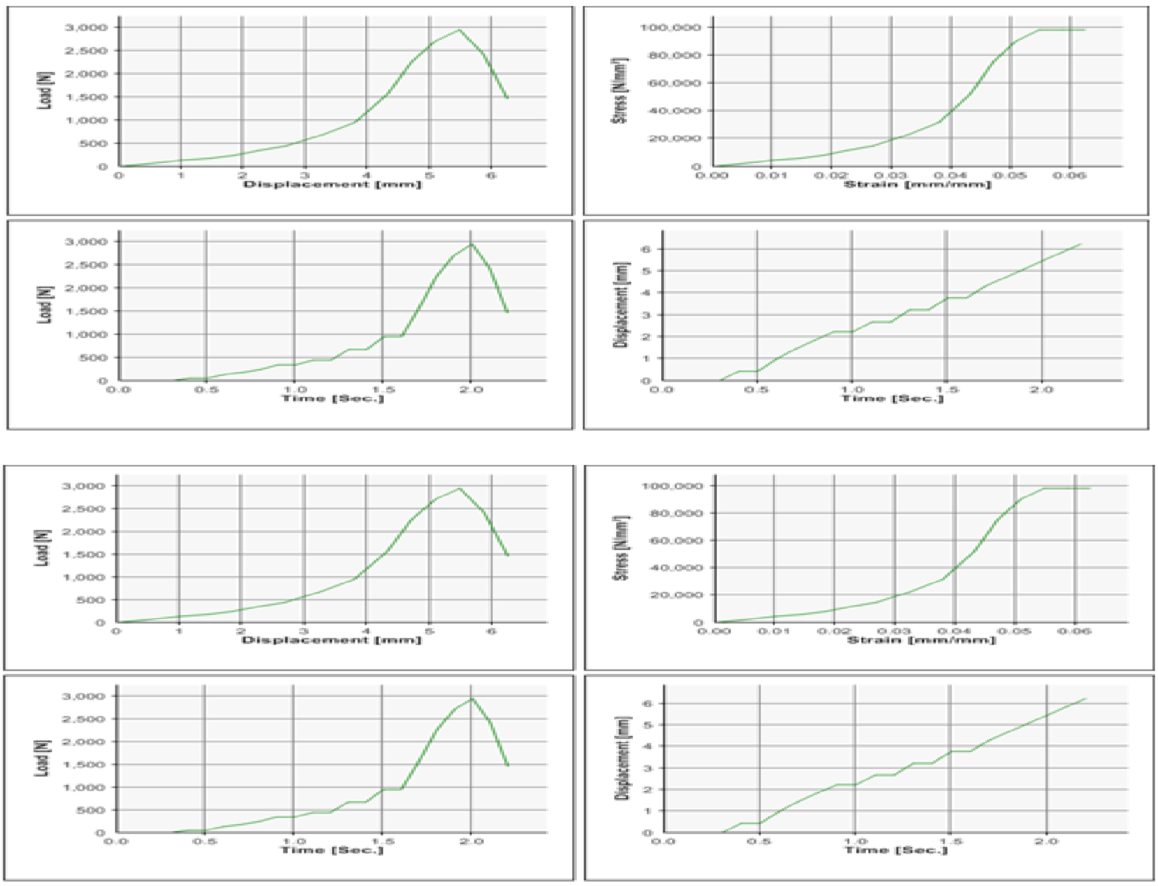
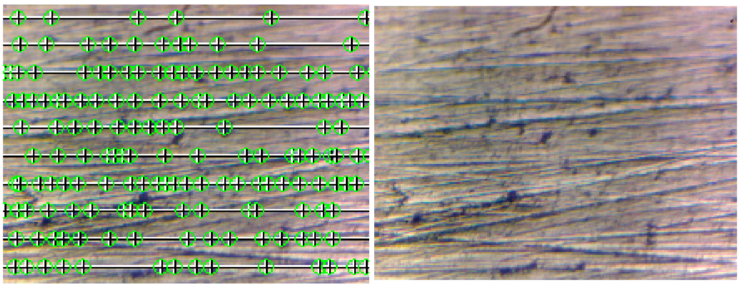


Fig 4.5 UTM machine and Test Report

Two samples of same rotational, welding speeds but of different tools are used for comparison. Grain size image of sample with rotational speed 760rm and feed rate of 11mm/min welded with horizontal slotted tool.



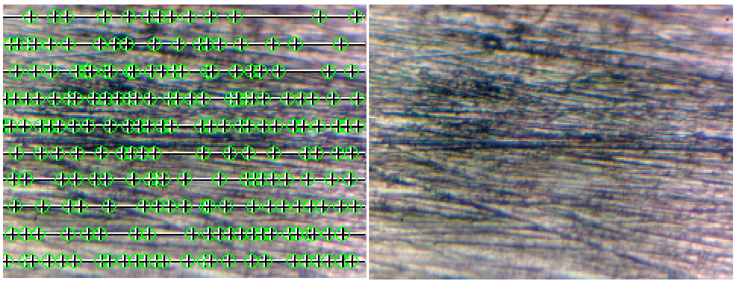
GrainSize analysis :Results Summary

Fields measured 1
Analysed Area 2.3237(sq mm)
Standard used ASTM E 1382

ASTM Grain size#	3.
Intercepts	162
Mean Int.length(um)	108.6528
Std dev.	.
95% CI	.
%RA	.

Fig 4.5 Grain size analysis of sample 1

Grain size image of sample with rotational speed 760rm and feed rate of 11mm/min welded with vertical slotted tool.



GrainSize analysis :Results Summary

Fields measured 1
Analysed Area 2.3237(sq mm)
Standard used ASTM E 1382

ASTM Grain size#	4.
Intercepts	211
Mean Int.length(um)	83.42067
Std dev.	.
95% CI	.
%RA	.

Fig 4.6 Grain size analysis of sample 2

5. CONCLUSION

Successful friction stir welding was achieved for 6063 aluminium plates which are being welded with tool different tool profiles namely; horizontal slotted pin and vertical slotted pin at 3 different speeds 760, 1130, 1340 and 2 different feeds 11, 25 respectively. Higher tool rpm with low welding speed resulted in finer grain structure leading to higher strength as well as higher ductility of welded joints. The tensile strengths of Friction Stir welds were found to be similar to that of base metal. Lower welding speed resulted in higher ductility exhibited through higher elongation. This indicates that lower range of weld speed is suitable for achieving superior mechanical properties.Usage of horizontal slotted pin led to the better stirring of material at weld zone which led to the finer grain size. The proposed methodology DEFORM-3D can accurately determine the temperature distributions for various work piece and tool profiles. The process simulation is done for friction stir welding for various welding parameters namely tool rotational and transverse speeds. The temperatures in the work piece are increasing with the increase in tool rotational speed whereas the temperatures are decreasing with increase in tool traverse or welding speed. The maximum temperatures are recorded at the locations close to the stirred zone and the temperatures keep on decreasing with increase in distance from the stirred zone.

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