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# Influence of Process Variables and Finite Element Analysis on Friction Stir Welded Dissimilar Alloys

**Madhusudan M[1], Shridhar U Kurse[2], S P Shanmuganatan[1], Jacob John[1]**
[1]Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru, India
[2]Department of Automobile Engineering, New Horizon College of Engineering, Bengaluru, India

## ABSTRACT

Welding Technology is a vital manufacturing process used to join metal alloys. Friction stir welding (FSW) is a solid-state welding technique in which metal is heated to plasticized state due to the friction and stirring action of the non-consumable tool over the surface of the base metals, resulting in sound weld. In the present work, influence of various process parameters on dissimilar welding of AA 6061 T6 and AA7075 T651aluminium alloys is investigated in order to improve the mechanical strength properties. Conical and cylindrical tool pin profiles are chosen to perform butt welding. The process parameters considered for the study to determine the ultimate tensile strength (UTS) and elongation of the six welded joints are tool geometry, rotational spindle speed of about 600,800 and 1000 RPM and feed rate of about 30,45,60 mm/min respectively. Finite Element Analysis, parametric model with base weld plates and the tool is performed using ABAQUS. It is observed that irrespective of the process parameters cylindrical tool rendered the better tensile and elongation property in contrast to the conical tool.

Keywords : AA6061 T6, AA7075 T651, FSW, UTS, Elongation, ABAQUS.

## I. INTRODUCTION

In aerospace industries, heat treatable aluminium alloys finds wider application because of its higher ductility and good strength. Friction stir welding is a new welding process influencing the industry where heat due to the friction is combined with forging pressure to produce defect free high-strength joints. [1]. FSW is comparatively a new welding process potentially proven in joining materials which are conventionally difficult to weld. Friction stir welding process renders the scope of welding elements at high productivity with flat geometry. Light metal alloys, aluminium based metal matrix composites (MMCs) and dissimilar metals can be welded by using FSW process [2]. Friction stir welding is concerned with joining of thermally softened material heated by friction due to sliding contact with a heat resistant material in the form of a pin rotating at a high speed. The softened material is pushed to the advancing zone by the shoulder of the tool in contact with the work piece. Normally the tool is fed to the full depth over the butt joint of the work piece parts.

Finite Element Methods (FEM) are numerical techniques in which approximate solutions to boundary value problems for differential equations are obtained. This method involves variation methods to reduce error functions and to produce stable solutions. A lot of tiny straight lines and small elements with finite length can be connected by FE methods including procedural steps in case of solving complex equation within the domain under observation [3]. After welding process, FSW simulations performed on Altair's Hyper Weld can predict the temperature distribution at different zones for different parameters. Process modelling input have to be discussed in terms of geometric parameters, process parameters and material parameters considered during the friction stir welding process [4].

During FSW process, the heat transfer into two boundary value problems (BVP)-a steady state BVP for the tool and a transient BVP for the workpiece is formulated. Finite element analyses were carried out to determine the heat flux generated from the friction to the workpiece and the tool. Transient finite element analyses models the friction stir welding process. Heat transfer analysis exhibits the heat generated from the friction between the tool shoulder and the workpiece. The tool holding time and rotational speed are increased when there is a maximum temperature near the weld. As tool transverse speed increases, temperature decreases [5].

The element having three-dimension thermal conduction capability can be used for a three-dimensional, steady-state or transient thermal analysis. The element is defined by several nodes with temperature as single degree of freedom at each node and by the orthotropic material properties. The element can be replaced by an equivalent structural element for the structural analysis [6].

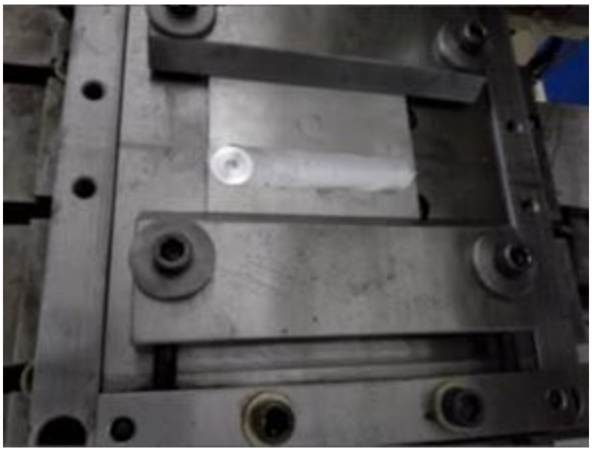
From the literature, it is observed that influence of different process variables on friction stir welded dissimilar alloys and Transient Finite Element analyses are investigated. Study of process parameters and Finite Element analysis involving cylindrical/conical tool are very limited especially at T6/T651 conditions. Hence, in the present study, the welding process variables effect on the mechanical properties like tensile strength and elongation have been investigated. Static Structural analysis is carried out to predict deformation, stress and strain at various zones.

## II. EXPERIMENTAL PROCEDURE

6.35 mm thick sheets of 6061-T6 and 7075- T651 Aluminium (Al) alloys were cut into samples with a width of 70 mm and a length of 130 mm. The dissimilar welding was performed on a 3 Ton FSW machine as shown in figure 1

(a) and (b). Table 1 and 2 shows the constituents and properties of selected alloys.

(a)



(b)

The FSW process is illustrated schematically in figure 2.

TABLE 1. Chemical compositions of alloys.

| Elements | Mg | Si | Fe | Cu | Cr | Zn | Mn | Ni | Ti | Pb | Sb | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AA6061T6 | 1.03 | 0.6 | 0.570 | 0.253 | 0.242 | 0.137 | 1.105 | 0.03 | 0.02 | 0.02 | 0.05 | Bal. |
| AA7075 T651 | 2.536 | 0.12 | 0.306 | 1.091 | 0.186 | 6.185 | 0.041 | 0.029 | 0.050 | 0.022 | 0.044 | Bal. |

TABLE 2. Mechanical properties of alloys

| Alloys | Tensile Strength (MPa) | Elongation (%) | Hardness (HV) |
|---|---|---|---|
| AA 6061 T6 | 298.28 | 15.47 | 111.65 |
| AA 7075 T651 | 556.09 | 17.86 | 171.65 |

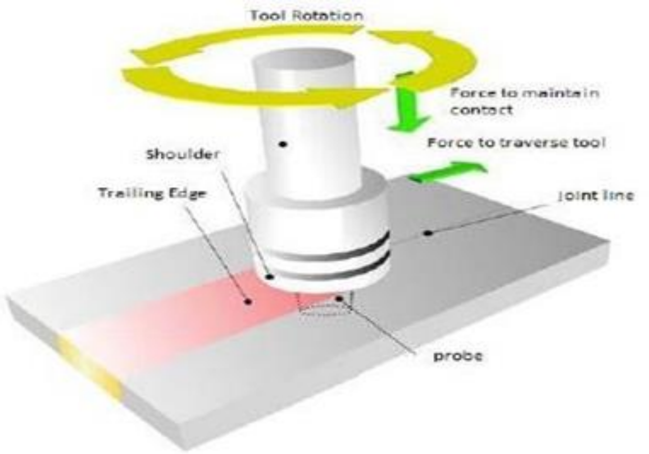
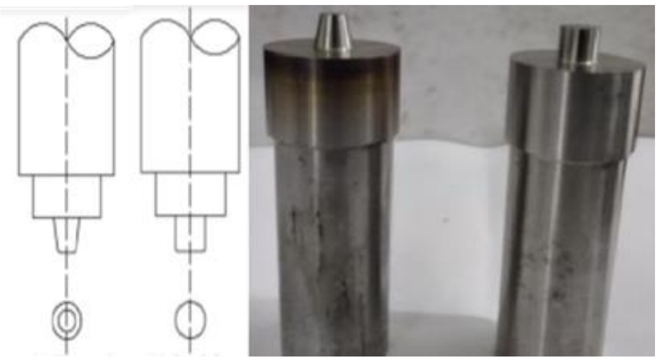



Fig 2. Schematic view of Friction Stir Welding (FSW) process [4]

The tool rotating at desired speed is plunged with shoulder contacting the surface at the beginning of the joint with appropriate depth. The tool continues to rotate as it traverses the entire length and then retracts. The frictional heat emanating during the process initiates the plasticization and subsequent consolidation of the material furthering the formation of fine- grained structure. Thereby resulting in a complete weld from one end of the material to the other end [7]. The conical and cylindrical pin profiles were selected to carryout the experiments. The schematic and photographic views of the tool pin is shown in figure 3 (a-c).



(a) (b) (c)

Fig 3. (a) Conical Tool, (b) Cylindrical Tool, (c) Photographic view of the tools used

The operating variables used in the study is shown in Table 3.

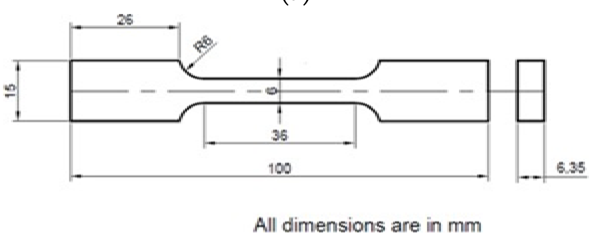
TABLE 3. Operating input parameters

TABLE 2. Mechanical properties of alloys

TABLE 1. Chemical compositions of alloys.

Based on strength parameters and elongation, friction stir welded samples were evaluated. The samples were machined using Wire- Electric discharge machining as per ASTM B557M standard [8]. The tensile parameters was measured using INSTRON (MAKE-FIE) UTM machine. The welded specimens, tensile standard specimen, the machined tensile samples before and after testing are shown in figure 4 (a- d).

(a)




(b)

(c)

(d)

Fig 4. (a) Welded specimens, (b) Schematic view of tensile specimen, (c) Tensile samples before testing, (d) Tensile samples after testing

The experimental ultimate tensile strength (UTS) and % elongation of the welded samples are shown in Table 4.

TABLE 4. Experimental results

| | Runs | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| UTS (MPa) | 78.79 | 122.54 | 165.12 | 125.88 | 179.11 | 161.85 |
| Elongation (%) | 5 | 5 | 16.93 | 10.16 | 13.48 | 11.73 |

Tensile properties tends to improve with surge in feed rate and spindle speed up to a certain limit and drops as seen in figure 5. The friction stir welding adheres the process of combined plasticizing and stirring the material under the influence of the different tool geometries. The age hardened and solutionized nature of the parent metal, relaxation experienced over the surface owing to thermal heating /stressing may lead to reduced order of strength properties. With increasing speed, higher temperature induced in the zone results in softening and possibly declining nature of tensile strength. When compared to conical tool, cylindrical tool provide better contact of the tool with the surface providing better stirring effect, enhanced deformation and strain strengthening resulting in grain recrystallization which favors the strength property.

Tensile property increases with increase in feed rate. With increase in feed rate, the stirring waves traverses at a faster pace leading to sub- grain formation with the creation of dislocation site contributing to improved tensile

Elongation

The metallurgical studies for the welded samples were performed as per ASTM standard [9] with the help of MOTICAM 1000 microscope. The specimens from the welded samples were well- polished and etched with Keller's solution to unveil the salient traits of the microstructure.

## III. RESULTS AND DISCUSSIONS

The influence of spindle speed and feed rate on UTS and % elongation for two tool geometries is shown in figure 5.

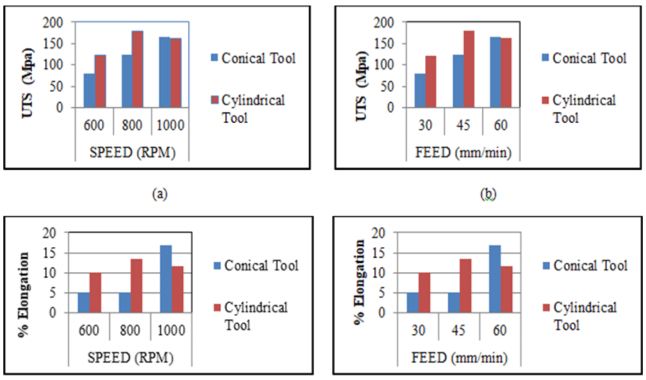



Fig 5. Infuence of (a) Speed on UTS, (b) Feed on UTS, (c) Speed on % elongation, (d) Feed on % elongation comes into play contributing to reduction in property [10].

More heat is generated in the weld surface at higher rotational speed and traverse feed, thereby effective recrystallization of grains takes place with overaging effect leading to higher ductlity. Beyond a certain limit, the elongation property drops down with increase in feed rate . At higher traverse feed, the time required for stirring is less which further reduces the efficiacious mixing of the stirred material and hence reduction in elongation [11].

## IV. INTRODUCTION TO FEA

The Finite Element Analysis (FEA) is a numerical method for solving problems of engineering and mathematical physics. This method is useful for problems with complicated geometries, loadings and material properties where analytical solutions cannot be obtained.

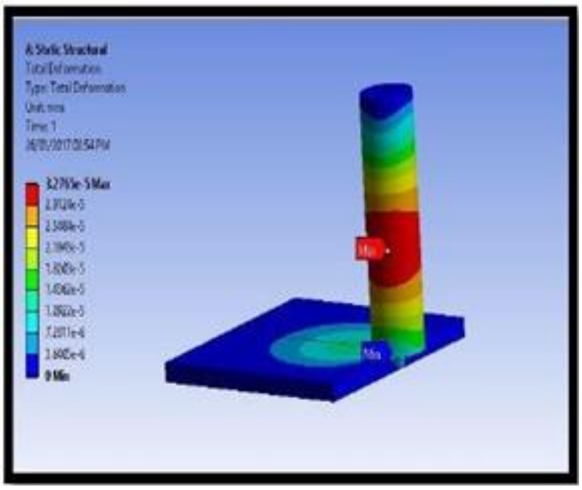
Discretizations involves dividing a model into an equivalent system of many smaller bodies or units (finite elements) interconnected at points common to two or more elements (nodes or nodal points) and/or boundary lines and/or surfaces.

Computer model of a material under FEA is stressed and analyzed for particular results. In new product design and existing product refinement, the concept of FEA is involved. Proposed design verified by an industry can reach customer specifications prior to manufacturing or construction. In structural failure, FEA determines the design modifications to arrive at new condition.

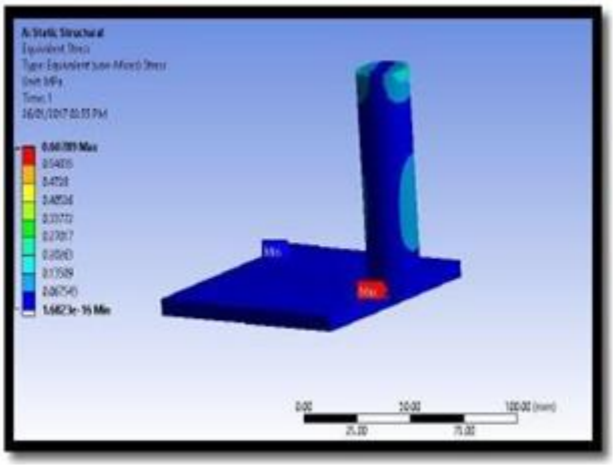
In industry, there are generally two types of analysis: 2-D and 3-D modeling.

2-D modeling is having more simplicity where normal computer performs analysis and tends to yield less accurate results whereas 3-D modeling obtains more accurate results with the ability to run on all the fastest computers effectively. The programmer can adopt numerous algorithms (functions) within each of these modeling schemes in which system behaves linearly or non-linearly. Linear systems are less complex and generally do not consider plastic deformation into an account. Non-linear systems consider plastic deformation into an account and capable of testing a material till failure occurs [12].

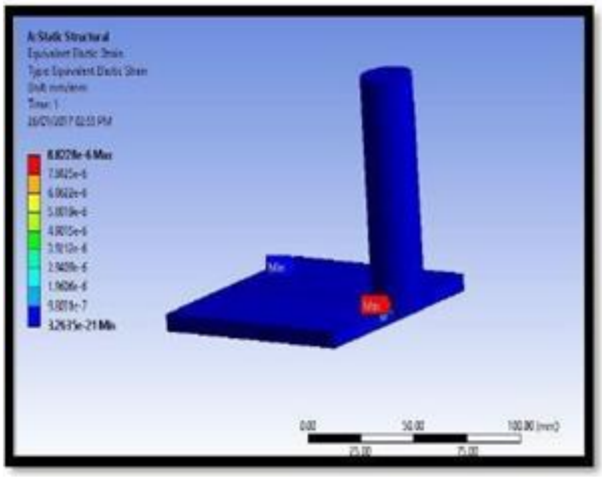
Structural analysis of FSW speed at 410 RPM is shown in figure 6 (a-c).



(a)



(b)



(c)

Fig 6. (a) Deformation, (b) Stress, (c) Strain [12]

TABLE 5. Static result table [12].

| SPEED(RPM) | DEFORMATION(mm) | STRESS(N/mm$^2$) | Strain |
|---|---|---|---|
| 750 | 0.00010961 | 2.0336 | 2.9151e-5 |
| 560 | 0.00006119 | 1.1339 | 1.6458e-5 |
| 410 | 3.276e-5 | 0.60789 | 8.8228e-5 |

From the above structural analysis carried on the circular tool rectifying deformation, stress and strain, it is noticed that as speed of the tool increases there is a relevant increase with respect to the stress valves.

## V. CONCLUSIONS

The following conclusions were arrived based on the investigation:

- Bounded by the stipulated attribute limits of feed rate of 45 mm/min and spindle speed of 800 rev/min are recommended to achieve good weld.
- Irrespective of the process parameters cylindrical tool renders better tensile and elongation property in contrast to conical tool.
- The increasing trend in feed/speed culminates in drift in tensile strength, then peaks up and finally attenuates.
- Maximum value of UTS and percentage elongation observed are 179.11 MPa and 13.48% respectively.
- Structural analysis is performed on the circular tool to verify the deformation and stresses.
- From the results, stress values increases by increasing the speeds of the tool.

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