

# Non Linear Finite Element Analysis of Friction Stir Welding Process for Aluminium 6063 Alloy- A Review

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**Abstract**— Friction Stir Welding (FSW) is rather a recent technique that uses a non-consumable rotating welding tool to generate frictional heat and plastic deformation at the welding point while the material is in solid state. The principal advantages are lower distortion, absence of melt related defects and high joint strength. Tool design and material plays a vital role in addition to the important parameters like tool rotational speed, welding speed and axial force. This paper attempts to predict numerically both the temperature distribution during friction stir welding process of 6063 aluminum plates and the result in thermal residual stress by sequentially coupling the thermal histories into the mechanical model assuming of elastic-perfectly plastic metal behavior in accordance with the classical metal plasticity theory. The commercial code ANSYS 14 is used in Thermo mechanical modeling of FSW of aluminum 6063. Heat input from the tool shoulder and the tool pin are considered in the FEA model. A moving heat source with a heat distribution simulating the heat generated from the friction between the tool holder and the work piece is used in the heat transfer analysis.

**Key words:** Friction stir welding, finite element, three dimensional modeling

## I. INTRODUCTION

Welding is one of the oldest processes to join metals. It is carried out by use of pressure or heat or both and with or without addition of a filler metal. The joining of two metals takes place at the initial boundary surfaces and bonding strength is determined by the atomic forces in the weld. The strength of weld is equal to or greater than that of the parent metals, and it is enhanced by the addition of filler metal. Welding results in rigid permanent joints and hence the welded part becomes a single entity. Proper selection of welding process and metals results in high strength properties and minimal number of components.

A weld is defined in the Australian standards [AS2812] as “a joint in a material, produced by means of heat or pressure or both in such a way that there is continuity in the nature of the metal between the parts. A filler metal, the melting point of which is of the same order as that of the parent metal may or may not be used”.

## II. LITERATURE SURVEY

Clamping fixtures for FSW have the built in requirement to react the forces generated by the welding machine, which can be thousands of pounds both axial to the pin tool and wildly varying (in magnitude and sign) in the plane of the weld. Since fusion welding involves comparatively miniscule physical forces, the clamping used is typically less robust, and can be designed solely for optimal distortion mitigation. This much larger minimum clamping requirement for FSW may be part of the reason the friction

stir welds are lower in distortion than fusion welds. Clamping plays a key role in counteracting welding induced distortions. Moving the clamps closer to the weld centerline increases this effect. Increasing clamping force will limit distortion, but above a certain threshold, has diminishing returns. Residual stress from welding is the primary source of deformation in welded panels. Especially in thin sections, when the residual stress level exceeds the buckling limit of the weld.

## III. INFLUENCE OF CLAMPING FIXTURE IN FSW PROCESS

The influence of the different clamping forces on the distortion and residual stress of the welded plates was investigated by Richter-Trummer [13], (2012), and also found that higher clamping forces lead to lower distortion and a more uniform residual stress distribution through the thickness. The Higher clamping forces are also leads to a lower defect probability through the creation of gaps between the plate halves. In this paper, they use clamping forces level from 0 to 2500N such as 0, 500, 1000, 2000, 2500N. The power of the clamping condition on mechanical and metallurgical properties of friction stir welded joints was determined and as a general declaration it may be said that high clamping forces in the order of 2500 N may lead to better joint properties.

Fratini et al.[3], (2010) was describes new fixture is presented allowing obtaining effective FSW joints of titanium blanks. which were analyzed through mechanical and metallurgical tests highlighting the peculiarities of FSW of titanium alloys. The experiments are conducted by using 3 mm thick Ti-6Al-4V titanium alloy sheets 200 mmX200 mm in dimensions were welded jointly under different process conditions. In particular rotating speeds of 300, 500, 700 and 1000 rpm were preferred. Fixed advancing speed equal to 50 mm/min, nuting angle equal to 28 and tool shoulder dipping of 0.2 mm were considered for all the welds. A tungsten carbide tool with a 16 mm shoulder and a 308 conical pin, 2.6 mm in height and 5 mm in main diameter, was utilized. Both the back plate and the tool were cooled by a 2 l/min flow of water.

Vural et al.[15], (2007) was examined the effect of welding fixture used to prevent the distortions during cooling process utilize a robot controlled gas metal arc welding method on cooling rate and distortions of welded structures. A welding fixture is designed based on welding parameters, which are affecting distortions and remaining stresses, such as a welding speed and reverse distortion are taken into consideration. To conduct the experimentation square shaped hollow sections prepared from AISI 1020 steel are used for the material. The power source used in experiments can create 16 – 400 A current and provide 100% duty cycle up to 250 A. The solid wire was EN 440-G3Si1 with in 0.8 mm diameter. defending gas was 80%

Ar+20%CO<sub>2</sub> with 12 liter/min flow rate. After analysis of six specimens, inversely proportional to the welding speed, distortions are increased by increasing heat input, as expected.

Pushp kumar baghel.[1](2012) describes about the fixture design, which are designed by using AutoCAD software keeping certain belongings in view like groove of fixture to be such that it accommodate both assistance plate and metal plate to be welded, then development of fixture is prepared using AutoCAD drawing. The forces that act on the base plates as a result of transversal and rotational movement of the tool can be summarize and built into clamping design. This fixture has the flexibility to weld Stainless Steel 304 plates of various thicknesses.

Indira Rani et al.[6], (2011) investigated about the frictional heat and plastic deformation at the welding position while the material is in solid state. Probe diameter is varied from 5mm-3mm. The diameter of the shoulder is 10 mm. Two Aluminum plates of size 75X150mm were perfectly clamped in a milling machine bed on a backup plate. FSW butt welds were obtained by varying the process parameters within the range. In annealed condition and T6 condition the welding was done at different process parameters 800 rpm, 15 mm/min and 800rpm, 10 mm/min. So it can be concluded that in annealed condition tool rotation speed 800 rpm and welding speed 10 mm/min and 15 mm/min are the best parameters. The tool rotation speed 1000 rpm and welding speed 10 mm/min are the optimal parameters in 'T6' condition. In this paper the effect of different parameters on the mechanical properties of the butt welded joint AA6061 is analyzed.

Anand Raghu et al.[12],(2004) investigated about the effect of clamping sequence on workpiece location fault is modeled systematically for a fixture– workpiece system where all major compliance sources and fixture geometric error. An algorithmic procedure designed to understand how forces and deformations change as clamps are applied sequentially is presented. The model is developed in order to capture the steps involved in part loading and clamping when the final position and direction is obtained. This section gives an overview of the compliance models developed for the fixture workpiece system. The nonlinear optimization problem was solved in MATLAB. The fixture–workpiece form presented captures the effect of clamping sequence on part position in the fixture. A key assumption that the reaction force at the locator contrasting the clamp applied in one step of the clamping sequence stays fixed during the application of subsequent clamps. Comparison with experiments shows that the average prediction errors in workpiece location and reaction forces are 22.1% and 29.9%, respectively.

#### IV. FINITE ELEMENT ANALYSIS OF FSW PROCESS

Kadirgok et al.[4], (2013) investigate the process of friction stir welding (FSW) by using finite element method (FEM). The welding capability of many different materials by this method has been investigated by using numeric and analytical methods. In this method, a finite element (FE) model was developed for welding process with friction stir welding of AZ31 magnesium alloy. This computational model was performed by the software of DEFORM 3D finite element in different speeds such as 960, 1,964, and

2,880 rpm rotational speeds and in 10 and 20 mmmin<sup>-1</sup> transverse speeds. The best results are obtained both experimental and simulation studies under a rotation speed of 1,964 rpm and a transverse speed of 20 mmmin<sup>-1</sup>. In this work, it was seen that sensible in temperature took place on the workpiece with increase in transverse speed. The increase in transverse speed causes an increase in the material amount moved per rotation. During the FSW process, the amount of material increases because of extruded toward back of work pieces.

Hamilton. C et al.[5],(2008) investigate the thermal model of friction stir welding for Aluminium alloys was developed. that utilizes a new slip factor based on the power per unit length of weld. The slip factor is derived from an empirical, relationship observed between the ratio of the maximum solidus temperature to the welding temperature and the welding energy. Different grades of Aluminium alloys are used such as AA6082-T6, AA7108-T79, etc. For energy levels in excess of 2000 J/mm, the model captures the increasing persuade of slip between the tool and workpiece as the maximum welding temperature approaches the solidus temperature of the alloy. The energy levels between 800 and 2000 J/mm, the thermal model shows excellent agreement with the experimental data. The model, however, does not take into account heat generation from plastic deformation; therefore, the energy levels less than 800 J/mm, the predicted temperatures decrease more rapidly than experimentally observed.

Chen and Kovacevic.[2],(2003) proposed a three dimensional finite element analysis model to study the thermal history and thermo mechanical process in butt welding of aluminum alloy 6063. The model incorporated the mechanical reaction of the tool and thermo mechanical processes of the welded material. The friction between the material, the probe and the shoulder was built-in the heat source. X-ray diffraction technique was used to measure the residual stresses developed in the measured results and the plate was used to validate the efficiency of the proposed model. From the study, it was reported that fixturing discharge to the welded plates affected the stress distribution of the weld.

Zhu and Chao, et al.[16], (2004) presented three-dimensional nonlinear thermal and thermo mechanical simulations using finite analysis code – WELDSIM on 304L stainless steel friction stir welded plates. Initially, a heat transfer problem was formulated as a standard boundary value difficulty and was solved using the inverse analysis approach. The total heat input and the heat transfer coefficient was estimated by fitting the measured temperature data with the analytical model. presently, the transient temperature outputs from the first stage were used to determine residual stresses in the welded plates using a three dimensional flexible plastic thermo mechanical model. Convection and radiation were assumed to be responsible for heat defeat to the ambient on the surface. Their model provided good match between experimental and predicted results. They report that the residual stress in the welds after fixture release decreased significantly as compared to those prior to fixture release. They also reported that about 50% of the total mechanical energy developed by FSW machine was utilized into raising the temperature of the workpiece.

Soundararajan et al.[14],(2005) developed a finite element thermo mechanical model through mechanical tool loading considering a uniform value for make contact with conductance and used for predicting the stress at work piece and backing plate interface. The non-uniform contact conductance were defined from pressure circulation contours and used in predict the temperatures in the thermal model. The thermo mechanical model was then used in predicting the developed stresses.

Khandkar et al.[7],(2007) developed coupled finite element models to calculate residual stress in AA-2024, AA-6061 and SS 304L friction stir welds. In their models, the temperature record predicted by the thermal model was sequentially coupled to a mechanical model to review the residual thermal stresses developed during the welding. It was originate that clamping constraints and their locations had significant contained effects on the stress components in the unaffected base metal beyond the heat-affected zone.

Khandkar et al (2008) was developed in Input torque based thermal model for prediction of temperature in friction stir welds of Al-6063 alloy.in their model, the heat generated by tool rotation and linear traverse of shoulder and pin, has been connected with actual machine power input. This expected heat was applied as a moving heat to obtain the temperature distribution across the weld.

And also Li et al.[9], (2007) presented a semi coupled thermo mechanical finite element model containing both mechanical load and thermal load. Their model included an auto adapting heat source in the thermal model and fixtures were integrated in the mechanical model. They reported that in the case of 2024-T6 alloy, stresses at the receding side of the weld were smaller than those at the advancing side.

## V. ASSUMPTIONS

A number of assumptions have been made in mounting the finite element thermal model, which include:

- Work piece material is isotropic and harmonized.
- No melting occurs during the welding process.
- Heat transfer from the work piece to the clamp is negligible.

## VI. CONCLUSION

A 3D finite element analysis numerical model of the friction stir-welding process has been presented here to improve our accepting of the process and at the same time assess our modeling capabilities. The results of thermal and structural analysis which are computer-generated using ANSYS 14.0 are used to evaluate the residual stresses and overall deformation in the work-piece geometry. By using ANSYS 14.0, three dimensional analytical models are developed which are proved to be reliable and effective for welding simulation of FSW. Longitudinal stress values were found to be the highest compressive stress components. The residual stress of about 717Mpa and overall deformation of 1.173mm has been recorded for a butt joint of Al 6063.

## VII. FUTURE WORK

A three dimensional finite element analysis of the friction stir welding is to be carried out including the fixturing conditions (mainly clamps) and its influence on the residual

stresses and overall deformations will be studied. Also the clamping positions are to be optimized for a good quality weld. Genetic algorithm will be used as an optimization tool and also ANSYS 14.0 will be used for validation of results.

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