EFFECT OF DIFFERENT BACKING PLATE ON THERMO-MECHANICAL MODELLING OF FRICTION STIR WELDING IN ALUMINIUM ALLOY AA 2014

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Abstract: This research aims to experimentally explore the thermal histories and temperature distributions in a workpiece during a friction stir welding (FSW) process involving the butt joining of aluminum AA 2014 T6. K- Type thermocouples are used to measure the temperature histories during FSW at different locations on the workpiece in the welding direction. Successful welding processes are achieved by appropriately controlling the maximum temperatures during the welding process. Regression analyses by the least squares method are used to predict the temperatures at the joint line. A second-order polynomial curve is found to best fit the experimental temperature values in the thickness direction of the workpiece. A three-dimensional thermal model for Friction Stir Welding (FSW) is presented. Series of welds were made by friction stir welding (FSW) with various backplates made out of materials ranging from low diffusivity Asbestos to high diffusivity copper in order to reveal the effect of back plate diffusivity on the joint microstructure and properties. The peak temperatures and cooling rates can be used to explain the microstructure evolution during cooling in different regions of the weld. The results of the simulation are in good agreement with that of experimental results.

IndexTerms **- Friction stir welding, Finite element modelling, ANSYS, Maximum temperature, Effect of back plates diffusivity.**

I. INTRODUCTION

Aluminium alloys show good resistance to corrosion, and have better stiffness/weight and strength/weight properties than steel (Ashby, D.R.H.1998). Friction Stir Welding (FSW) is a relatively new welding process, patented in 1991 by (Thomas, 1991). FSW process has several advantages over fusion welding process. A schematic diagram illustrating the process of FSW is shown in Figure 1. The rotating tool is plunged vertically into the work piece, and, after a short pre-heating dwell, is traversed along the joint line, after which it is retracted vertically. The tool shoulder is the most important means of generating heat during the process, and it prevents material expulsion and assists material movement around the tool. A successful weld is produced when the correct tool design and operating parameters (down force, welding speed and rotation speed) are used for a given material (Mandal, 2005).

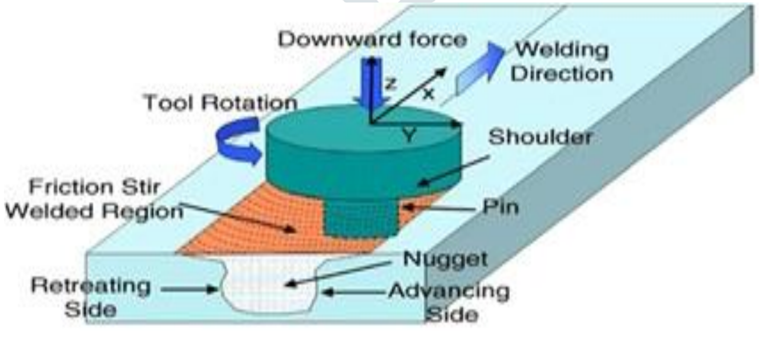


Figure 1: Schematic drawings of friction stir welding (Mishra & Ma, 2005).

II. LITERATURE SURVEY

A detailed literature survey was carried out towards the theoretical and experimental studies on modelling of friction stir welding process. (Chao & Qi, 1998) formulate the heat transfer of the FSW process into two boundary value problems (BVP)—a steady state BVP for the tool and a transient BVP for the work piece. Two commercial finite element software – ABAQUS and WELDSIM – to simulation the heat transfer and fluid flow during friction stir welding process. The heat transfer model was formulated as a boundary value problem where the heat input was divided into 2 parts, the tool (Q3) and the work-piece (Q1). The authors reported that 95%

of the heat produced through the friction between the tool and the work-piece flowed to the work-piece whereas only 5% dissipated to the tool. (Chen & Kovacevic, 2003) present a three-dimensional model based on finite element analysis is used to study the thermal history and thermo mechanical process in the butt-welding of aluminium alloy 6061-T6. The model incorporates the mechanical reaction of the tool and thermo mechanical process of the welded material. (Hwang et al, 2008) experimentally explore the thermal histories and temperature distributions in a workpiece during a friction stir welding (FSW) process involving the butt joining of aluminium 6061-T6. Different types of thermocouple layout are devised to measure the temperature histories during FSW at different locations on the workpiece in the welding direction. Successful welding processes are achieved by appropriately controlling the maximum temperatures during the welding process. In present work experiments were carried out using AA2014-T6, to investigate the influence of backing plate material on weld joint temperature.

III. EXPERIMENTAL SETUP

This experiment deals with a butt weld single pass welded joints of two identical plates made of AA 2014 T6 alloy. The FSW setup consists of 5mm thick plates, 100mm wide and 300mm long. The tool is made of HSS tool-steel having shoulder diameter of 18mm. The pin has a height and diameter of 4.7 mm and 4 mm respectively. Agilent data logger attached with k-type thermocouples for measuring the temperatures history in FSW. The chemical composition and mechanical properties of the base material are presented in Table 1 and Table 2, respectively. The setup consists of vertical milling machine with an indigenously designed fixture fabricated from the mild steel as shown in Figure 2. The detailed sketch of the thermocouple positions as shown Figure 3.

Figure 2: Experimental set up with data logger

Table 1 Chemical composition of AA2014 t6 aluminum alloy (%)

Fe	Si	Mn	Mg	Zn	Cu	Ti	Cr	Al
Max 0.7	0.5 to 1.2	0.4 to 1.2	0.2 to 0.8	0 to 0.25	3.9 to 5.0	0 to 0.15	0.1	Rem.

Table 2 Mechanical properties of aa2014 t6 aluminum alloy

Tensile Strength Mpa	Density (g/cm^3)	Thermal Conductivity (W/m.k)	Melting Point (^{0}C)	Hardness HRB	Specific heat (J/Kg. ^{0}C)
490	3.0	150	510	83	870

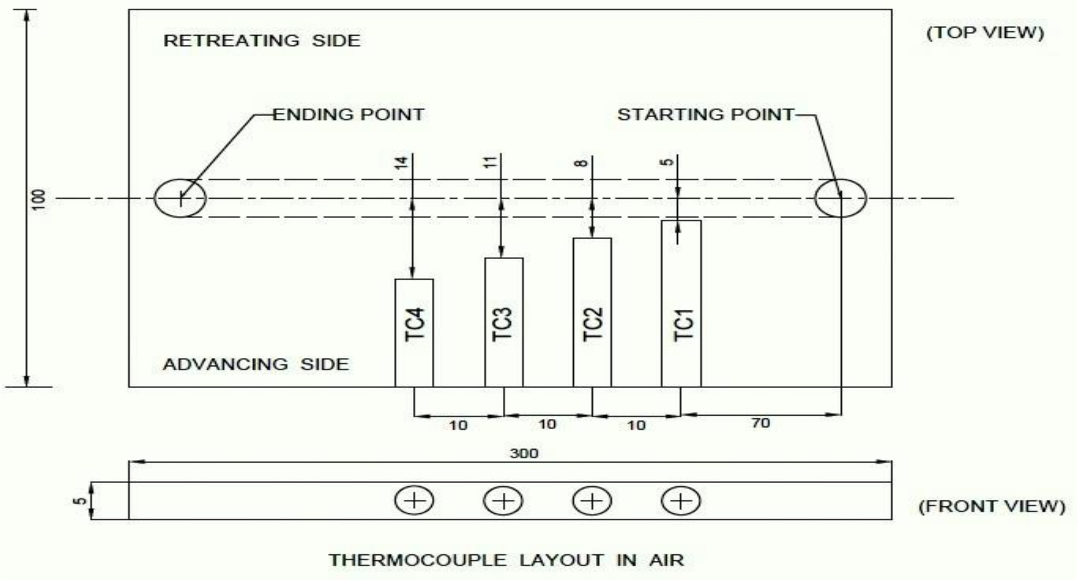
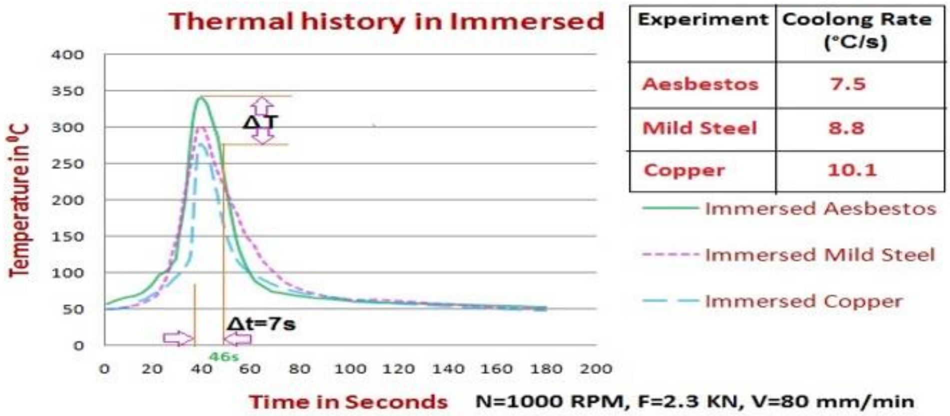


Figure 3: Detail sketch of thermocouple layout

IV. TEMPERATURE PROFILE

The temperature profiles under different backplates are shown in Figure 4. It should be noted that preliminary experiments were conducted to ensure the joint of excellent surface quality under the used welding parameters. Hence, the temperatures of the fixture were a little high, and thus the temperature in the measured workpiece was increased before welding. It is observed that with decreasing the back plate diffusivity the peak temperature remarkably increases, which increases by 40°C with changing the back plate from copper to Mild steel and by 62°C from copper to Asbestos. Furthermore, the cooling rate is defined as ΔT/Δt, where ΔT is the temperature difference between the peak temperature and the temperature at 46 s, Δt, is the time span between these two temperatures (see figure 4). Therefore, it can be calculated that the cooling rates are about 10.1°C/s, 8.8°C/s and 7.5°C/s under the back plates of copper, steel and Asbestos, respectively.



Experiment	Coolong Rate (°C/s)
Aesbestos	7.5
Mild Steel	8.8
Copper	10.1

Figure 4: Temperature profile under different backplates

The peak temperatures and cooling rates can be used to explain the microstructure evolution during cooling in different regions of the weld. Based on the above-mentioned analysis, it can be concluded that the back plate with high diffusivity effectively decreases the heat input to the joint during FSW.

V. THERMAL MODELLING OF FRICTION STIR WELDING

The purpose of the thermal model is to calculate the transient temperature fields developed in the work piece during friction stir welding. In the thermal analysis, the transient temperature field *T* which is a function of time *t* and the spatial coordinates (*x*,y,z), is estimated by the three dimensional nonlinear heat transfer equation (Thomas, 1991)

$$k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+Q_i=C\rho\frac{\partial T}{\partial t}$$

(Thomas, 1991)

Where *k* is the coefficient of thermal conductivity, Q_i is the internal heat source rate, *c* is the mass-specific heat capacity, and *ρ* is the density of the materials [Chao & Qi 1998].

VI. SIMULATION RESULTS AND DISCUSSION

6.1 Boundary conditions for thermal model

The workpiece 300×50×5 mm was modelled using finite element package ANSYS. In case of Air Based on Nusselt number formula, all the surfaces except at the bottom a convective heat transfer of 390.6 W/m2 °C was used for natural convection between aluminium and air. In friction stir welding, the work pieces were clamped over Mild Steel and clamped. A heat transfer will be 150 W/m2 °C to the bottom surface of the workpiece [22]. At every load step a set of elements in the shape of the tool are selected and calculated total heat flux 2436193.45 W/m2 was applied on the surfaces of the elements. Heat flux generated by tool shoulders Qs can be calculated using above equation [Rajamanickam, et al., 2009] where Ro = 0.009, Ri = 0.002, μ = 0.35 and (Schmidt & hattel, 2004) suggested that ratio of heat generated from the pin Qp and the heat generated from the shoulder Qs was 0.128. so, we can do similar calculation of finding convection heat transfer and total heat flux for other experiment of different backing plate.

6.2 Thermal modelling

During the penetration phase, the rotating tool pin penetrates into the workpiece until the tool shoulder comes in contact with the workpiece. In case of Air FSW is performed at a rotation speed of 1000 rpm, downward force of 2.3 KN and a welding speed of 80 mm/min, tool-to-work piece angle was maintained at approximately 2.5◦ and an effective plunge depth of 0.35 mm. The longitudinal view of calculated temperature filed distribution along the joint line at the end of process. Coordinate system is moved after each load step. At every load step a set of elements in the shape of the tool are selected and calculated total heat flux 2436193.45 W/m2 was applied on the surfaces of the elements. The obtained peak temperature is 404.22 °C using regression analysis and 392.406 °C using simulation shown in Figure. At welding time, t = 47.6 second. The variation in temperature with distance perpendicular to the weld line shown in Figure 5. The results of the simulation is in good agreement with that of experimental result. so, similar simulation in temperature with distance perpendicular to the weld line for as shown in Figure 6 and 7 under backing plate of Mild steel and Copper.

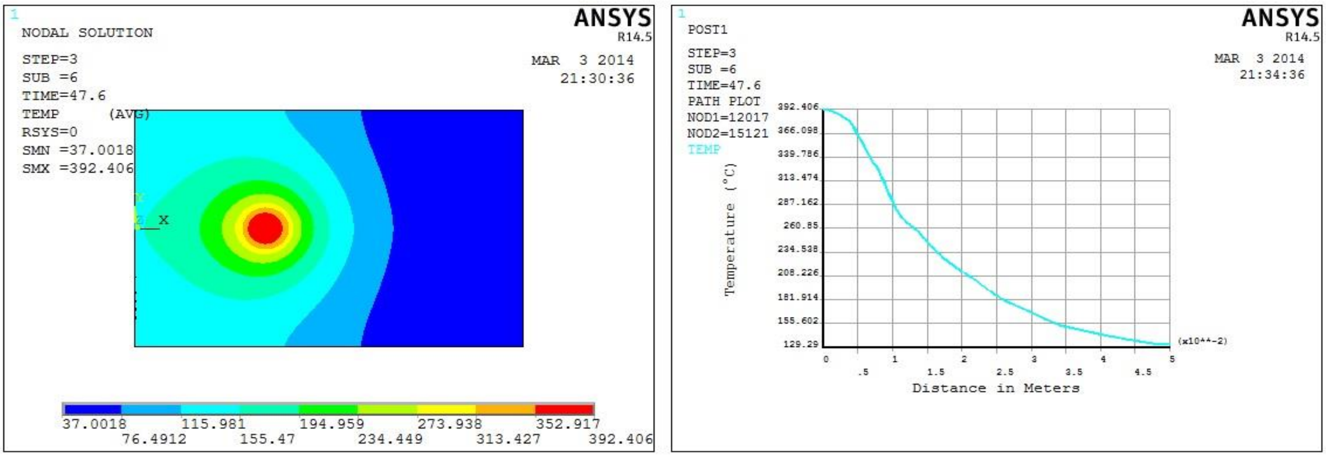


Figure 5: Temperature distribution on top surface of the workpiece and Temperature contours on thickness direction

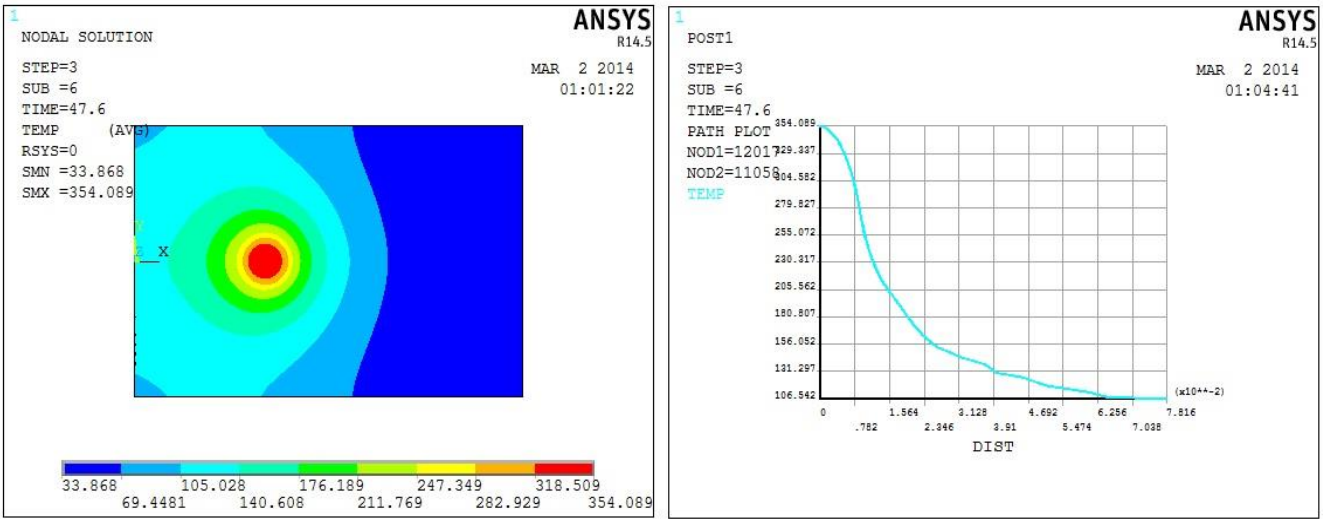


Figure 6: Temperature distribution on top surface of the workpiece and Temperature contours on thickness direction

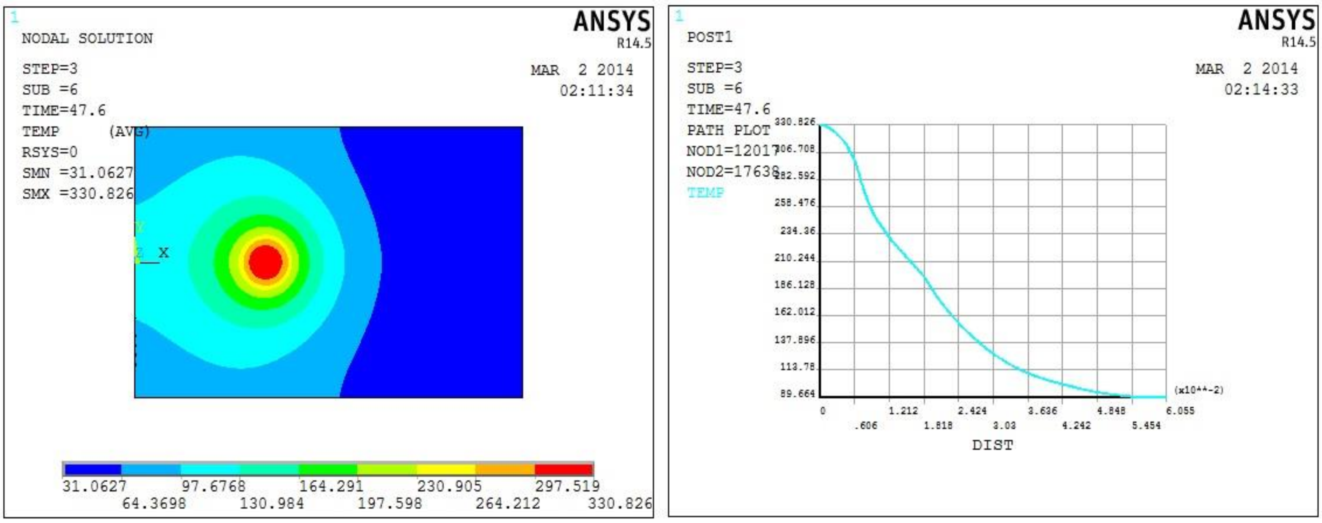


Figure 7: Temperature distribution on top surface of the workpiece and Temperature contours on thickness direction

6.3 Prediction of Residual stress:

Stress is developed in the tool and workpiece during the process of welding because of thermal heating and cooling leading to thermal stress and application of mechanical loading with tool rotation and movement leading to structural stress generation. The thermo-mechanical model used for predicting the stress at the bottom of workpiece with uniform contact conductance, is now used with the adaptive contact conductance.

Figure 8 shows active stress in longitudinal direction (X direction). It can be seen that the stress distribution in end of the plate is very less as it has not affected by thermal stress or by structural loading. In the area marked by C, it is observed that the tensile stress starts to increase due to the mechanical force in the horizontal direction and reaches maximum at the tool. The region behind the tool marked by D has a compressive stress with the maximum value right behind the tool. Due to the thermal expansion and constraint on the sides by the fixture results in compressive stress in this area. This stress extends till the region near the edge behind the tool.

Figure 8 the active stress in the transverse direction is shown (Y direction). There is very little tensile stress before the tool in the transverse direction as it is the stress development is due to tool movement along X axis which mainly affects stress creation in longitudinal direction. The area behind the tool has a high compressive stress because of the thermal stress leading to expansion of workpiece which is constrained by fixture on both sides. It should also be noted that the transverse stress is spread over a very larger area behind the tool compared to that in longitudinal stress as the end of workpiece right behind the tool is not constrained leading to free thermal expansion. In case of backing plate of Mild steel and copper similarly Stress distribution in longitudinal and transverse direction as shown in figure 9 and figure 10.

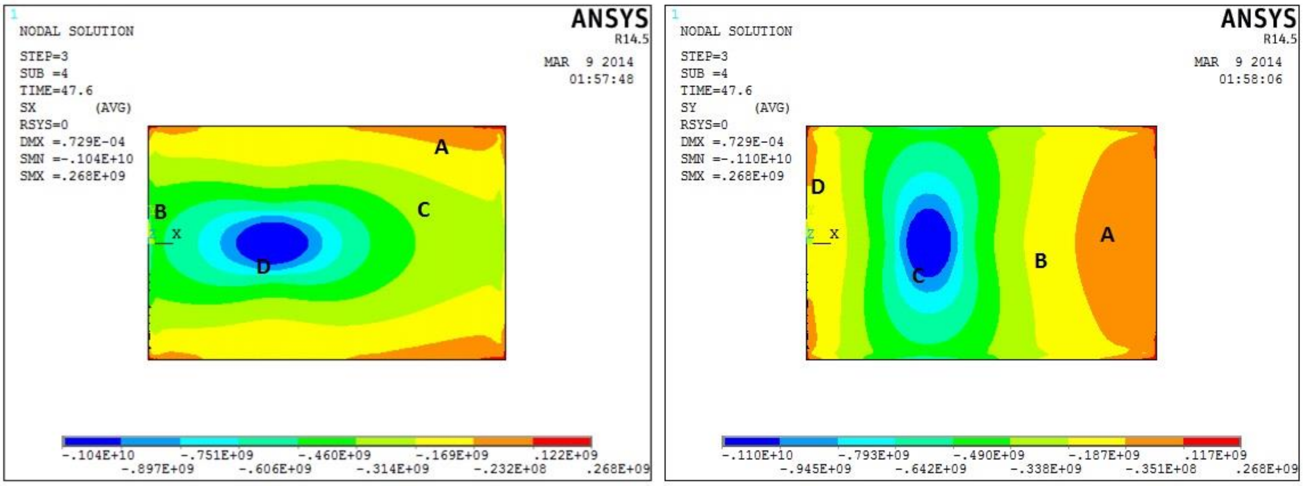


Figure 8: A variation of the residual stress in longitudinal and transverse direction

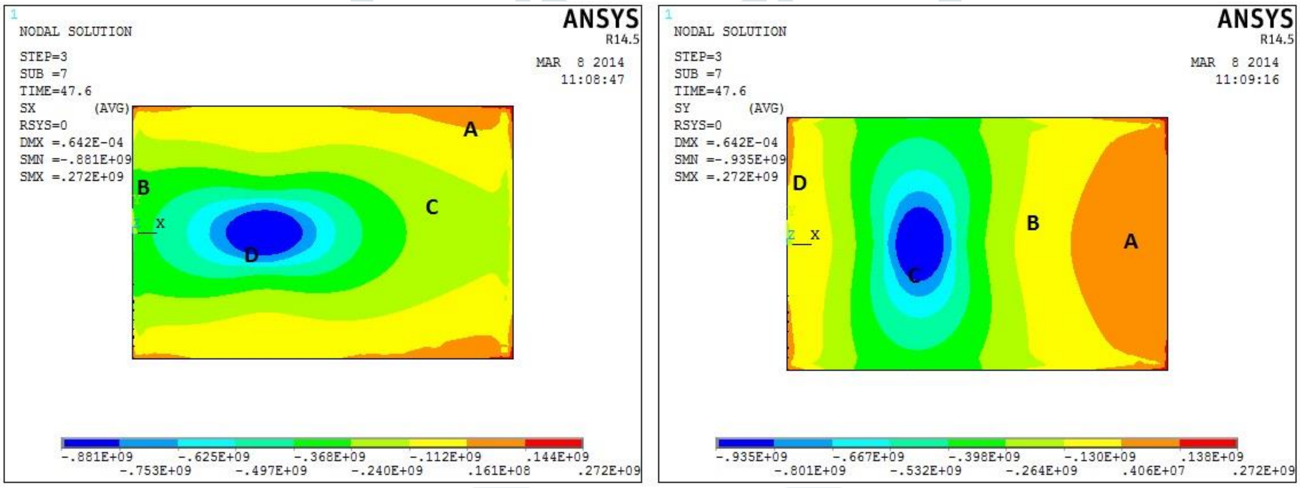


Figure 9: A variation of the residual stress in longitudinal and transverse direction

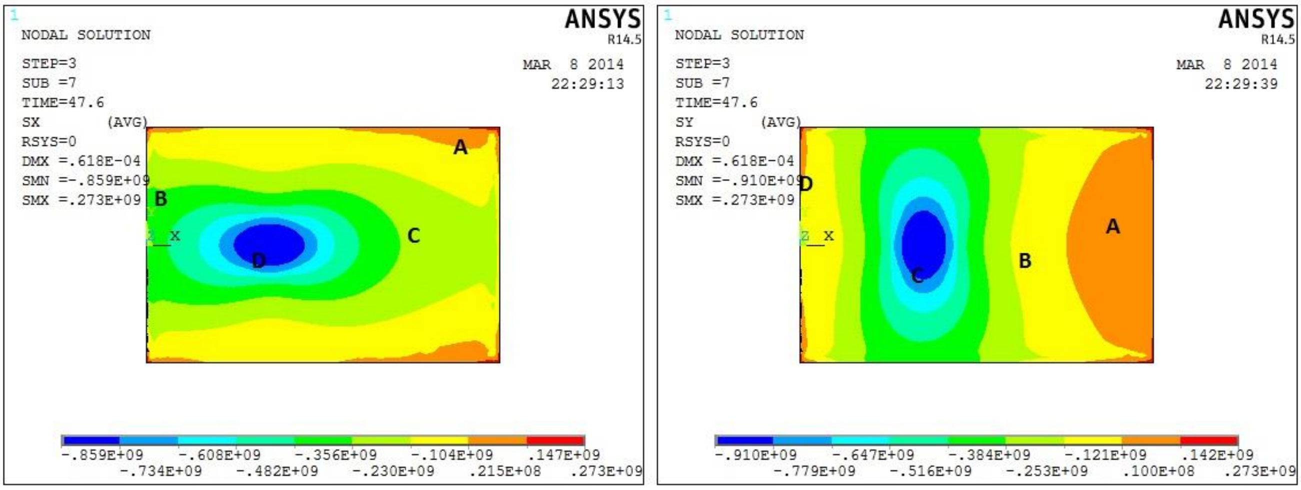


Figure 10: A variation of the residual stress in longitudinal and transverse direction

VII. CONCLUSION:

For determining the temperature at the interface of the tool shoulder and workpiece during the friction stir welding process, we have to relay on results of thermal simulation. The active stress in workpiece during the process leads to prediction of residual stress after the workpiece cools down and the clamps are removed. The dominant part of active stress is the thermal stress and its determination is based on the thermal model. The results of the simulation are in good agreement with that of experimental results.

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