Parameter Optimization and Thermo-Mechanical Modelling of Friction Stir Welded Al 5083 to High Strength Low Alloy Steel and its Analysis

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***Abstract*-Friction stir welding (FSW) is the most remarkable welding technology that has been invented and developed in the last decade. It is a solid-state welding process in which a rotating tool is driven into the material and translated along the interface of two or more plates. This technology has been successfully used to join materials that are considered difficult to be welded by fusion welding methods. The present work deals with a simulation campaign aimed at the evaluation of the thermal and mechanical properties of Al 5083 and High strength low alloy steel plates joined by friction stir welding. The butt joints were obtained by varying the welding parameters, namely, tool rotating speed and feed rate. In this paper, a three-dimensional model created with the help of ANSYS 14.1 is proposed to study the thermal history and stress distribution in the weld and, subsequently, to compute mechanical forces. The proposed model includes a coupled thermos mechanical modelling. The standard tool was a very simple device of EN31 steel, with a flat shoulder and a cylindrical pin. The quality of the joints was evaluated and optimized in terms of joint strength at different rates of welding speeds and tool rotational speeds. The joint strength is also optimized for single pass and multi passes and also compared with the strength of base materials. The stress distribution and thermal distribution were also studied.**

Keywords –FEM, Cutting temperature, Chip formation, Hardened Steel, Temperature Distribution

I. INTRODUCTION

FSW is a technology developed by the welding institute (TWI) in 1991[1]. For development of technologies in material processing, knowledge about material behaviour at various process parameters is required specially in case of FSW. It's a solid state welding technology and has become a unique technique in joining many hard to weld metals like aluminium alloys and dissimilar metals. When compared to conventional welding techniques FSW has advantages like low distortion, lowdefect, no melting and can join both thick and thin sections. Nowadays the technology has been widely used in shipbuilding, aerospace and automobile industry.

Since it is a new technique, many questions need to be answered to understand the mechanism of FSW.Xu et al[1,2] developed a numerical model to analyse the thermomechanical features of FSW process. Joining of aluminum alloy to steel by friction stir welding TakehikoWatanabe∗,HirofumiTakayama, Atsushi Yanagisawa(2006) [5]. The authors tried to butt-weld an aluminum alloy plate to a mild steel plate by friction stir welding, and investigated the effects of a pin rotation speed, the position for the pin axis to be inserted on the tensile strength and the microstructure of the joint. The role of friction stir welding tool on material by K. Kumar, Satish V. Kailas (2007) The results show that there are two different modes of material flow regimes involved in the friction stir weld formation; namely "pin-driven flow" and "shoulder-driven flow". These material flow regimes merge together to form a defect-free weld.

Different from works that have been done by researcher's, the joining of a Al 5083 to HSLA is done by varying the process parameters like Rpm of the tool and traverse speed to get the best joint strength. The thermal distribution and stress distribution is also studied and the joint strength is compared for single pass and multi pass welds. The general finite element code–ABAQUS 14.5 is used to study the effect on the variations in welding parameters and the various thermal and stress distribution of FSW. The pin rotational speed being used is 100,250 and 500 Rpm and the traverse speed used are 16, 25 and 40mm/min.

II. MODEL DESCRIPTION

In FSW, the work piece material in front of the tool is pushed aside by the pin and then is forced to flow around the pin, so large plastic flow develops around the rotating tool. In order to model the contacting surface properly and

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handle mesh distortion during large plastic deformation, a thermo-mechanical finite element method based on the arbitrary Lagrangian technique are employed. The tool material employed for the stir welding is EN 31 tool steel. The tool is having a shoulder and pin diameter as 18mm and 6 mm respectively. And the length of pin of tool is fixed as 2 mm. The plates used for joining are High strength low alloy steel and aluminium 5083. The dimensions of the two welding plates are 100mm in length (along the welding line), 150mm in width and 5 mm in thickness. The three dimensional geometry is divided into eight node hexahedron elements. The mesh consists of 32,190 nodes and 25,520 elements. The effect of temperature on yielding is considered explicitly.

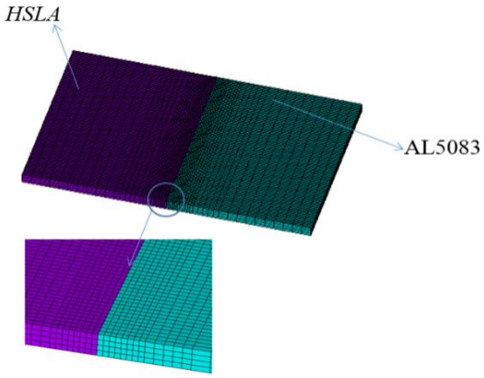

Figure 2.1 Element type: Solid 226, with 32,190 nodes and 25,520 elements

2.1 Contact Pair between the Plates

A standard surface-to-surface contact pair using TARGE 170 and CONTACT 174, as shown in the following figure. To achieve continuous bonding and simulate a perfect thermal contact between the plates, a high thermal contact conductance (TCC) of 300 W/m^2 °C is specified.

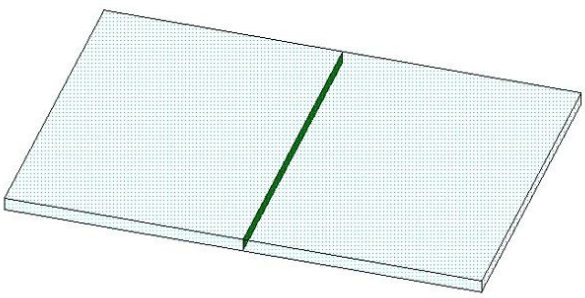

Figure2.2 Contact pairs

2.2 Boundary conditions

At the boundaries of the plates, material particles move with a constant speed ***v*** relative to the pin, in the direction opposite to the translational movement of the pin. Pin rotates with an angular velocity ω. An axial load is applied on the shoulder to prevent the upsurge of the material.

For thermal Boundary Conditions, a high overall heat-transfer coefficient (about 10 times the convective coefficient) of 300 W/m^2 °C is assumed for the conductive heat loss through the bottom surface of the work piece. An initial temperature of 25 °C is applied on the model.

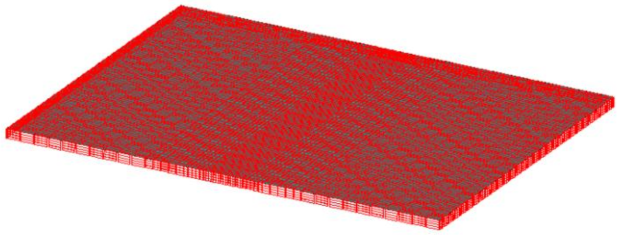

Figure 2.3 Sides and top of the plates are exposed to air with HTC=30 W/m^2 and bottom surface to backing plate with HTC=300W/m^2

For mechanical Boundary Conditions, the work piece is constrained in vertical direction as shown in figure 4.4.

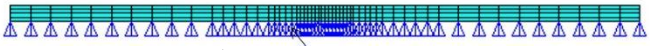

Figure 2.4 Bottom of the plate is constrained in vertical direction

2.3 Temperature Field

The heat generated at the interface between the pin and the work piece in FSW is the driving force to make FSW successful. The heat flux must keep the maximum temperature in the work piece high enough so that the material is sufficiently soft to be stirred but low enough so the material does not melt. The limitation of the PC computing power makes a fully thermomechanical analysis difficult to be completed. The maximum temperature created by FSW ranges from 80 to 90% of the melting temperature of the welding material, as measured by Tang et al.and Colegrove et al. [6]. Due to the limitation of the melting temperature, there are no big differences between the approximate temperature field being used in the computation and the practical one in the manufacture.

III.PARAMETERS USED

Plates of High strength low alloy steel (HSLA) and A5083 aluminium–magnesium alloy, 5mm thick, were welded. The tensile strength of A5083 base metal is about 275MPa. The shape and dimension of both plates is rectangular and is of 100mm in length and 150mm in width and 5mm thick. Welds were made with a clock-wisely rotating pin at rotation speeds of 100,250 and 500 rpm. The pin transverse speed used was 16,25and 40 mm/min. Al plate was located on the right as shown in figure 4.5.

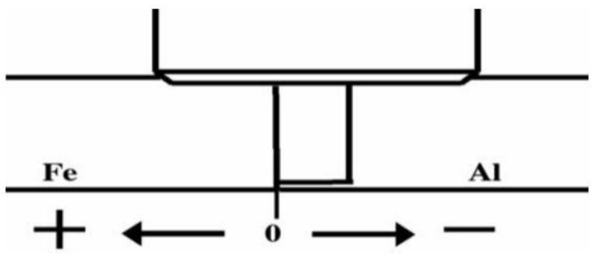

Figure 3.1 Schematic illustration to explain the relationship between the pin position and the coordinate.

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Now the runs were simulated in the software for all the welding speed and rpm combinations. From this the most appropriate welding speed and rpm combination and tested experimentally to obtain the maximum joint strength.

IV.RESULTS AND DISCUSSIONS

4.1 The Effect of Pin Rotation Speed and Traverse Speed on Strength of Joint

In the first place, the surface and cross-sectional structure of welds were examined when the pin rotation speed was varied under zero pin offset .The relation between the strength of the joints for different sets of pin rotation speed and traverse speeds is shown in table 4.1.

TOOL RPM-TRAVERSE SPEED COMBINATIONS	AREA OF CONTACT %	AVERAGE CONTACT PRESSURE (MPA)
100-16	100%	28.98
100-25	100%	29.15
100-40	99%	28.91
250-16	100%	72.61
250-25	100%	72.75
250-40	99%	72.61
500-16	39%	172.42
500-25	47%	151.86
500-40	47%	151.86
MULTIPASS (250-25)	100%	73.52

When the pin rotation speed was 100 rpm and for all the welding speeds, the welding was so slow and due to the lack of heat generation. Consequently, about a quarter of the weld line was welded and the remainder of the weld joined only the surface region of the weld. Therefore, there was incomplete fusion between HSLA and Al, so that the strength of these specimens was low. A pin rotation speed of 250 rpm made a good joint, showing the maximum strength of about 72.75 Mpa and the area of contact is 100% which means a complete welding of the weld line path were obtained. At pin rotation speeds of 500 a, the surface morphology of the welds was similar to that of the 250 rpm case. However, as indicated by the lower value of area of contact is seen which shows incomplete welding. The welding was not completed to make a tensile test specimen. According to the above results, a pin rotation speed of 250 rpm with welding speed 25mm/ was adopted as an optimal rotation speed in welding experiments, thereafter.

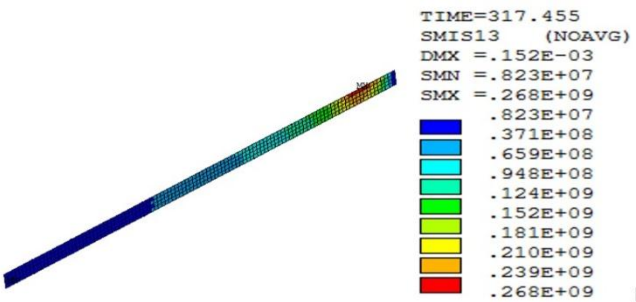

Figure 4.1 Contact pressure plot for 250-25 combination

4.2 The Effect of Pin Rotation Speed and Traverse Speed on Temperature Distribution

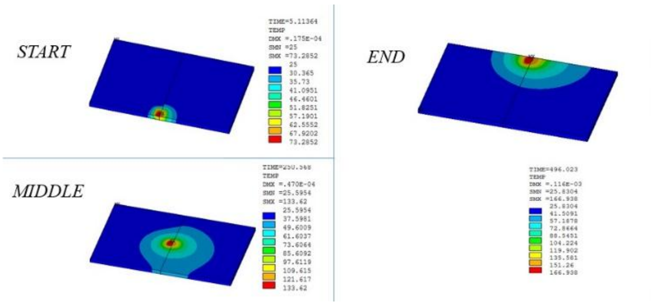

Fig 4.2 Temperature distribution for100rpm-16mm/min

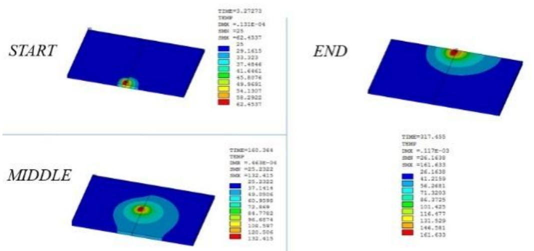

Fig 4.3 Temperature distribution for100rpm-25mm/min

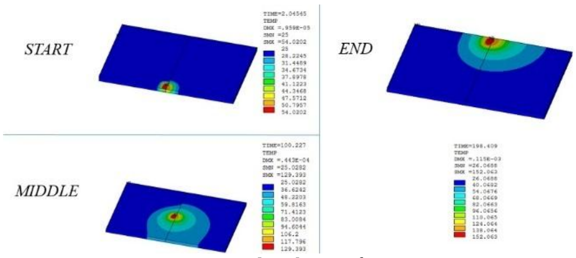

Fig 4.4 Temperature distribution for100rpm-40mm/min

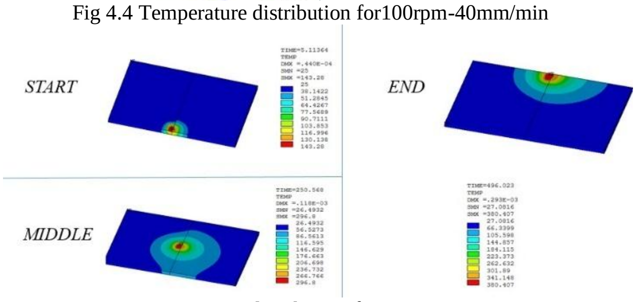

Fig 4.5 Temperature distribution for 250rpm-16mm/min

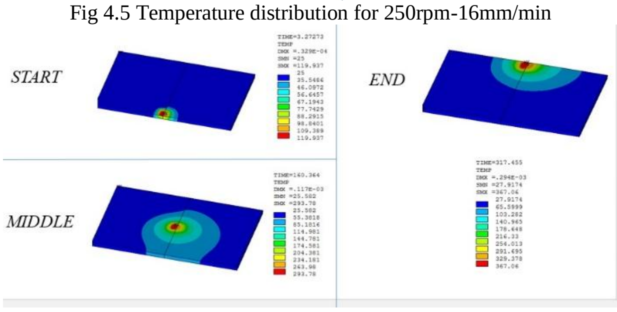

Fig 4.6 Temperature distribution for 250rpm-25mm/min

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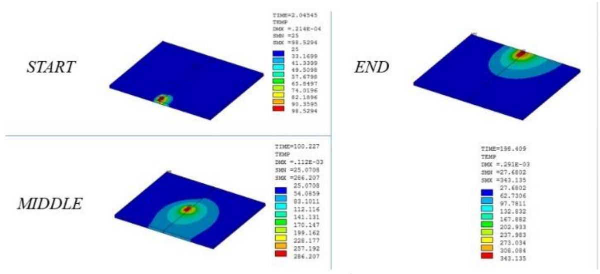

Fig 4.7 Temperature distribution for 250rpm-40mm/min

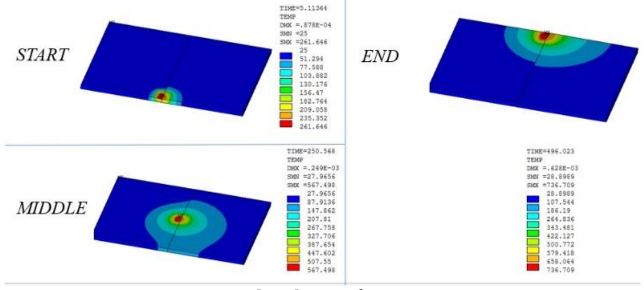

Fig 4.8 Temperature distribution for 500rpm-16mm/min

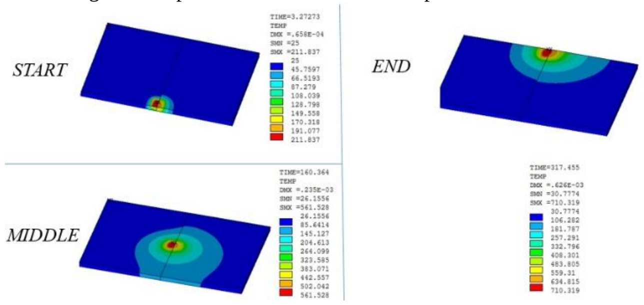

Fig 4.9 Temperature distribution for 500rpm-25mm/min

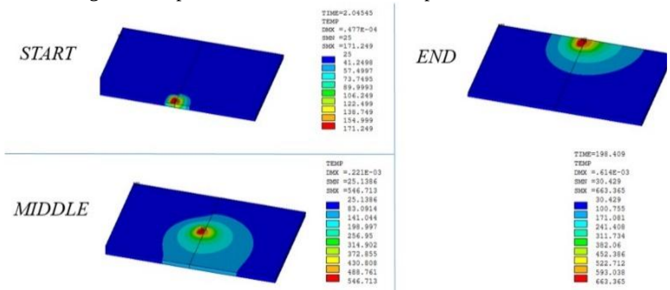

Fig 4.10 Temperature distribution for 500rpm-40mm/min

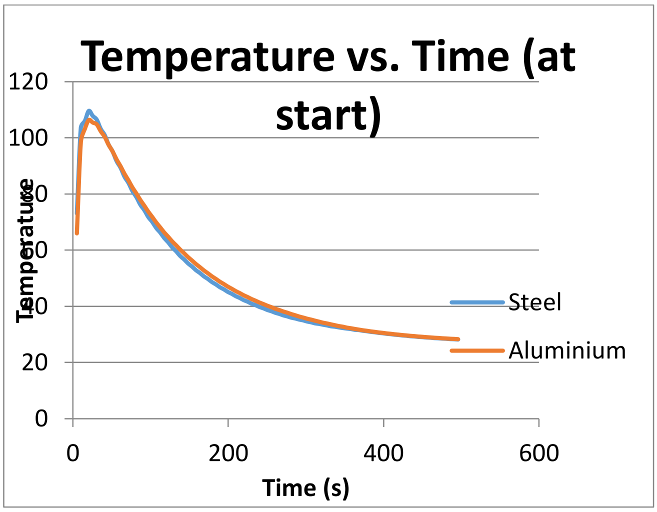

Fig 4.11 Temperature time plot at start

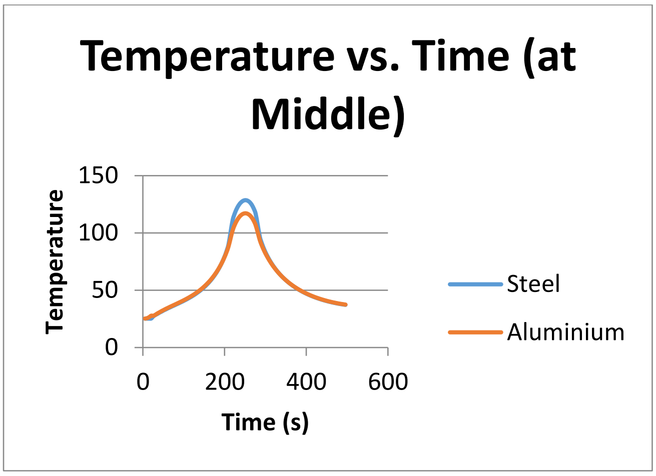

Fig 4.12 Temperature time plot at middle

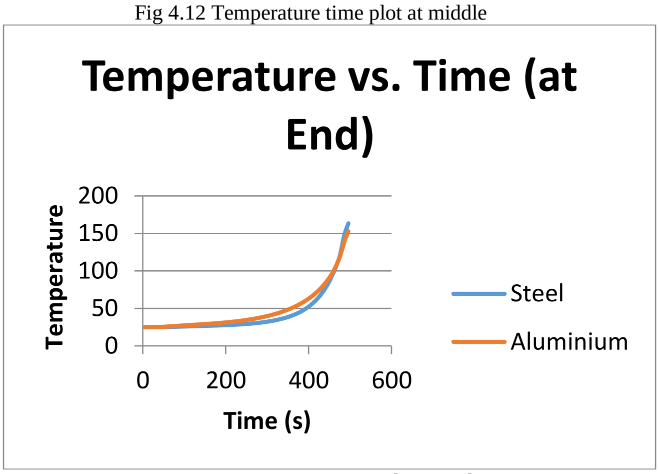

Fig 4.13 Temperature time plot at end

As we see from all the above figures of thermal distribution from the beginning till end for all the different times the distribution shows a common factor, there is a higher thermal distribution on the AL 5083 metal than that of HSLA. This is because of the higher thermal conductivity value of aluminium when compared to steel. And the highest value of temperature is seen at the end of the weld as the tool and the work pieces has undergone a lot of frictional heating till the end time

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4.3 The Effect of Pin Rotation Speed and Traverse Speed on Stress Distribution

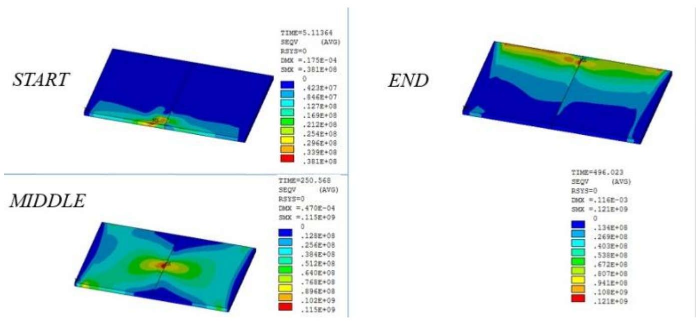

Fig 4.14 Stress distribution for100rpm-16mm/min

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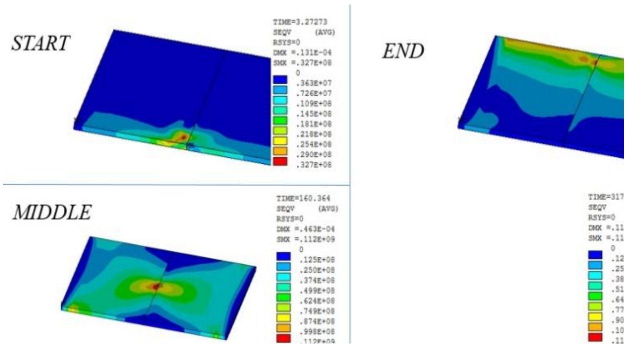

Fig 4.15 Stress distribution for100rpm-25mm/min

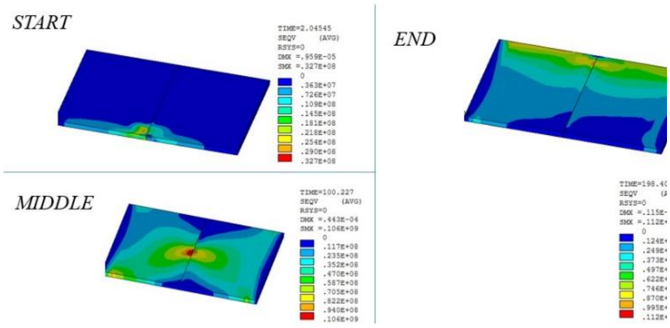

Fig 4.16 Stress distribution for100rpm-40mm/min

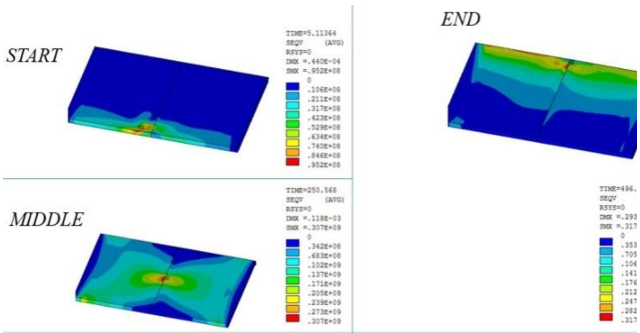

Fig 4.17 Stress distribution for 250rpm-16mm/min

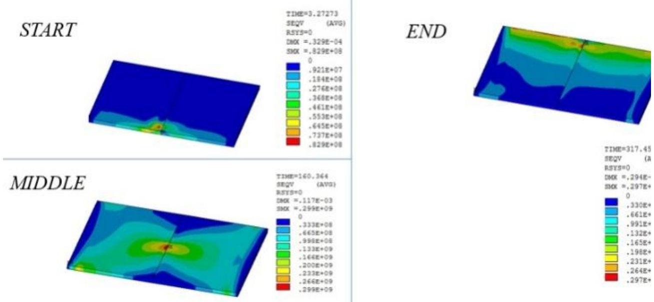

Fig 4.18 Stress distribution for 250rpm-25mm/min

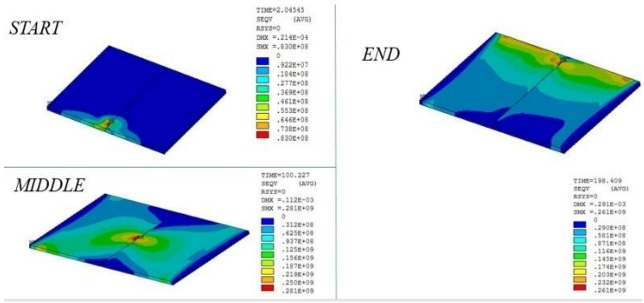

Fig 4.19 Stress distribution for 250rpm-40mm/min

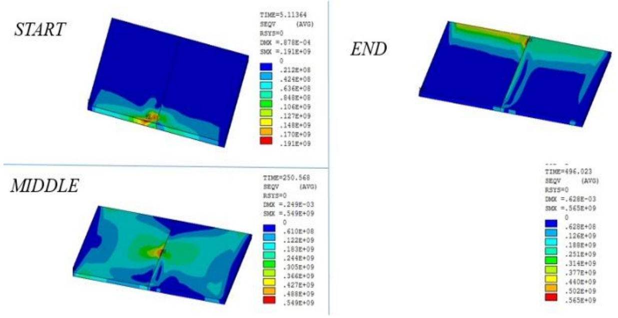

Fig 4.20 Stress distribution for 500rpm-16mm/min

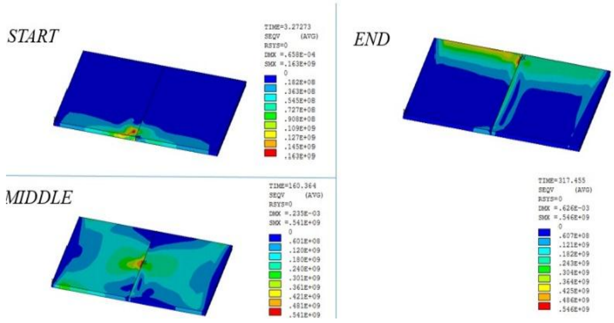

Fig 4.21 Stress distribution for 500rpm-25mm/min

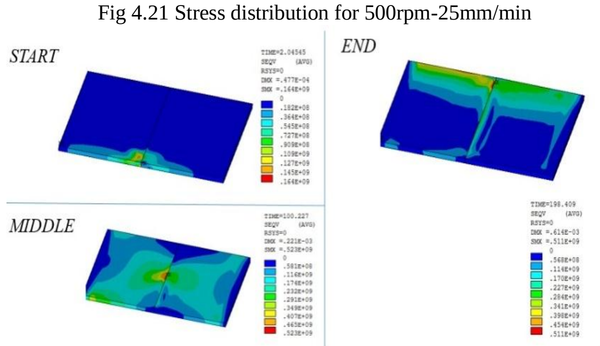

Fig 4.22 Stress distribution for 500rpm-40mm/min

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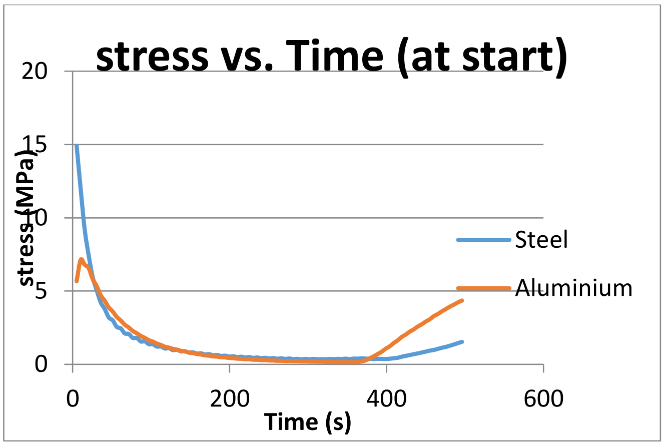

Fig 4.23 Stress- time plot at start

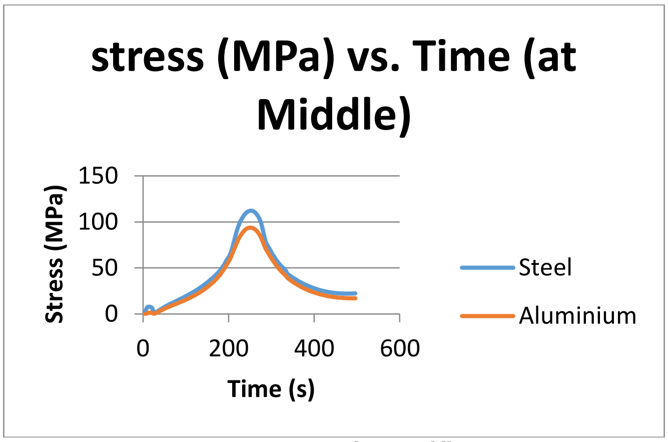

Fig 4.24 Stress- time plot at middle

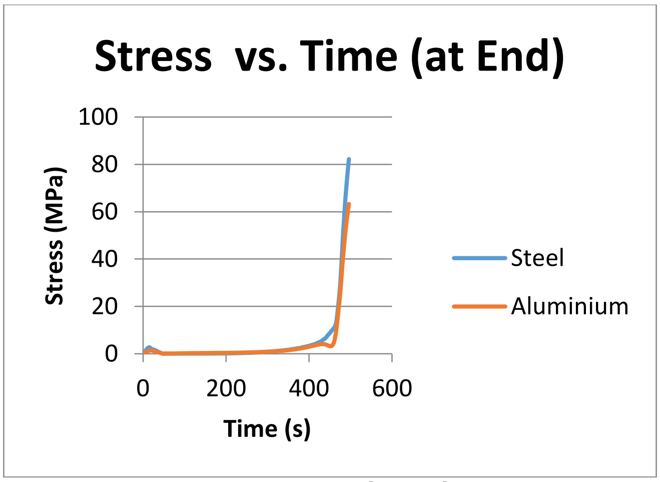

Fig 4.25 Stress- time plot at end

The value of stress is low at the beginning of the welding. This is due to the fact that at the beginning of the welding the area where the weld is taking place is free to expand. Whenever there is a possibility of free expansion there will be very low value of stress. As the tool moves along the weld line further the value of stress will keep on increasing and will reach the highest value at the centre as the expansion of the metal is getting more and more limited as the tool moves towards the centre. There is seen a sudden increase in the value of stress at the end of the weld for both HSLA and AL5083 due to thermal stresses.

V. CONCLUSIONS

The authors applied the friction stir welding to join aluminium alloy containing magnesium to steel. In this study, the effects of pin rotation speed and welding speed on the strength and the structure of a joint were investigated. The following results were obtained.

(1) There was an optimum rotation speed for a pin to make a sound joint. A lower rotation speed gave rise to the insufficient increase in temperature at the weld. At a higher rotation speed, the temperature increase was so excessive that the magnesium in the Al alloy burned, resulting in an unsound joint.

(2) The maximum strength of 72.75 MPa of contact pressure for the joint was obtained at the pin offset of 0.2mm toward steel at a tool rotation speed of 250 rpm and 25mm welding speed along the weld line.

(3) The value of stress is low at the beginning of the welding. This is due to the fact that at the beginning of the welding the area where the weld is taking place is free to expand. As the tool moves along the weld line further the value of stress will keep on increasing and will reach the highest value at the centre as the expansion of the metal is getting more and more limited as the tool moves towards the centre. There is seen a sudden increase in the value of stress at the end of the weld for both HSLA and AL5083 due to thermal stresses

(4) The values of temperature is low in the beginning because the temperature gets spread to the base plates at the beginning easily. On reaching the centre there is an increase in temperature due to increased temperature of tool and work piece.

(5) FSW proved to be an effective tool for joining of dissimilar materials.

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