Mechanical Characterization of Friction Stir Spot Welded Dissimilar Joints using Simulation Analysis

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***Abstract* - Dissimilar material joining has been receiving high importance in automobile, aerospace and other sectors. Friction stir spot welding has more advantages than conventional fusion joining process as it is a solid state material joining process. In this paper mesh analysis of dissimilar joints of 5X series aluminium alloy and commercial copper by friction stir spot welding process has been done. The analysis was conducted using two geometries of friction stir spot welding non-consumable tool, one with a specific probed pin with cylindrical shoulder and another with a flat pin less cylindrical tool. The stress induced in the top and bottom plates of the joints were analyzed thereby evaluating the overall quality and strength of the joint.**

Keywords—Dissimilar materials, friction stir spot welding, simulation, mechancial properties.

I. INTRODUCTION

Aluminum alloys and copper materials are desired to be joined due to the unique special properties they possess individually. Owing to differences in thermal properties, conventional joining methods create lots of issues like interstitial compound formation that are undesirable which causes crack initiation and propagation. Friction stir spot welding is used for joining dissimilar materials which have difference in mechanical and metallurgical characters.

It is a three step process involving plunging, dwell and retraction using a non-consumable rotating tool at a high rpm to frictionally induce the required thermal energy for softening the materials to be joined. M. Felix Xavier Muthu et al., successfully joined aluminium and copper using friction stir spot welding and conducted microstructural analysis on the fabricated joints [1].

Finite element analysis and simulation analysis had been done for evaluating the joint geometry and process. Vinayak Malik et al., investigated using finite element simulations, the effect of changes that were incorporated in the geometry of friction stir welding non-consumable tool on the joints [2].

In friction stir spot welding, the non-consumable rotating tool at high rpm plunges forcibly into the joint plates. It creates both mechanical and thermal stress and disturbances which softens the material. The amount of deformation that is seen on both plates which are in lap configuration depends on the amount of plunge depth of the non-consumable tool [3, 4].

In previous literatures, software had been extensively used for evaluation of friction stir welding and its processes [5, 6]. Kheireddine, et al had found that ABAQUS is better than other simulation software that are commercially available [7].

In this paper, investigation of the effect of plunge depth on the deformation of the lap configuration work pieces made of aluminium and copper has been conducted using simulation analysis. Aluminium alloys and copper alloys have excellent conductance and thermal properties. They offer better corrosion resistance than other materials in volatile environments.

II. INVESTIGATIONS

A. BASE MATERIALS

The base materials chosen for this investigation are 5 series aluminum alloy and commercial copper alloy. The two of the materials are of thickness 1.5mm. The dimensions of the test specimen are 100mm by 30 mm. they are placed in a lap configuration. The base materials which are sized are shown in Fig. 1.

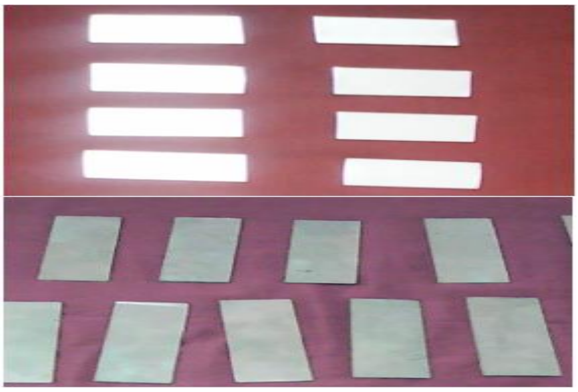

Fig. 1. Raw materials aluminum alloy and commercial copper

Fig. 2. Assembly of lap configuration of the joint

The sized materials are placed with an overlap of 30 mm over one another for welding.

The aluminium alloy is placed on the top configuration and copper is place on the bottom side. The assembly is elucidated shown in Fig. 2.

A tool made of hard grade steel which is not consumed in the welding process is used in this study. Two different tool geometry is used. One is with a pin probed cylindrical tool with a cylindrical pin of diameter 6 mm, pin length 1.5 mm, cylindrical shoulder length of 100 mm and 16 mm diameter. Another tool is a pin less flat cylindrical probe less tool with diameter 12mm. The assembly of the tool in the rotating spindle of the friction stir spot welding apparatus and the lap joints placement are indicated in Fig. 3.

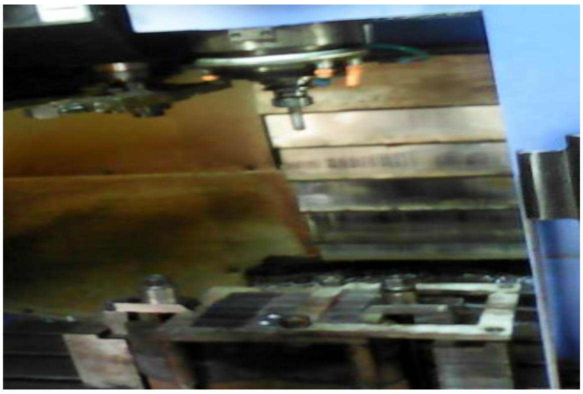

Fig. 3. Friction Stir spot welding apparatus with tool spindle and clamping fixtures

The process parameters which determine the strength of the friction stir spot welding are found from previous literatures and investigations. Tool rotational speed, dwell time of the tool after plunge, plunge depth are the friction stir spot joining process parameters that are identified for determining the joint quality. The dimensions of the material and tool are given in Table 1.

TABLE 1. Dimensions of raw material and tool

Materials	Dimensions in mm		
Aluminium plate	Length – 100	Breadth – 30	Thickness – 1.5
Copper plate	Length – 100	Breadth – 30	Thickness – 1.5
Tool 1 Probed pin	Shoulder dia – 16	Pin dia – 6	Pin length – 1.5
Tool 2 Pin less	Shoulder dia - 12	Pin dia – NA	Pin length - NA

B. *SIMULATION SOFTWARE*

In this study, Abaqus simulation software has been used. Andres Anca et al investigated simulation of fusion welding processes using finite element analysis method, in which mechanical analysis, non-steady state heat transfer analysis were done to predict the thermal and mechanical phenomena [8].

In this investigation, a model of the two tools and the joint plates with cohesive elements are created and the stress analysis is done when the plunge of the tool occurs. The plunge of the rotating tool is given a maximum of 2.2 mm whereby the tool shears the top plates and the bottom plates. The effect of plunge and the stir of the materials and the effect of the heat generated due to the plunge are studied.

From literature studies the feasible limit of the process parameters are fixed and the simulation done accordingly. The tool rotational speed is fixed not lower than 800 rpm below which enough stir of the region does not occur and not more than 1500 rpm above which charring and unusual vibration occurs.

The plunge depth is fixed not less than 1.2 mm, below which actual weld of the joint does not occur due to improper penetration and not more than 2.2 mm above which the very big keyhole becomes prominent. In the case of cylindrical probed pinned tool, the shoulder reduces that amount of flash that is created and extruded out.

But in the case of pin less flat cylindrical tool, the absence of probed pin allows the entire tool to penetrate uniformly from periphery to center and the amount of flash is more. So while using pin less flat tool, the maximum depth of plunge is taken to be 2.0 mm. The material properties used for the aluminium alloy, copper plate and tool are given in Table 2.

TABLE 2. Important mechanical properties

	Density	Elastic Modulus	Poisson ratio
	g/cm^3	GPa	
Al	2.66	70	0.33
Cu	8.8	120	0.34
Tool	7.8	210	0.27

C. *ANALYSIS*

Two tool geometry are created with appropriated dimensions. The first pin less tool is created with a shoulder diameter of 12 mm and shown in Fig. 4.

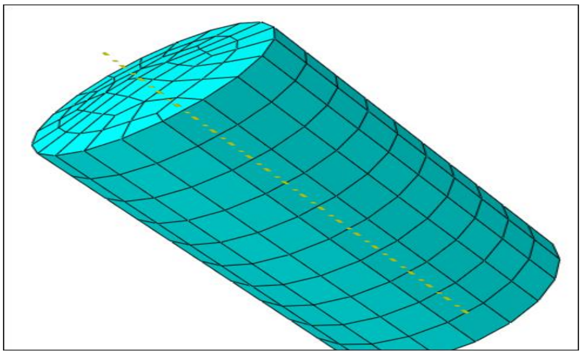

Fig. 4. Pin less tool

A pin probed tool of shoulder diameter 16 mm and pin diameter 6 mm, with a pin length of 1.5 mm is created and shown in Fig. 5.

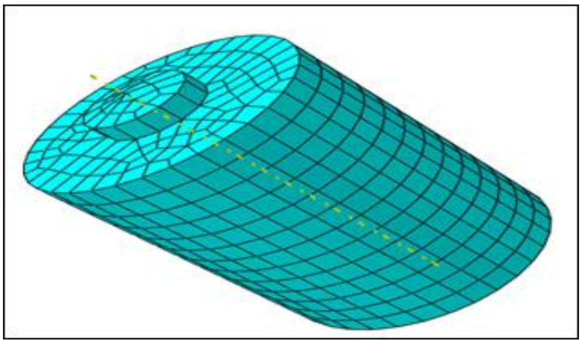

Fig. 5. Pin probed tool

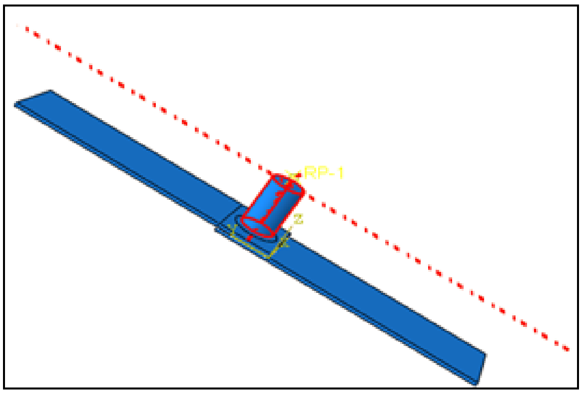

Fig. 6. Assembly representation of the tool with the two plates

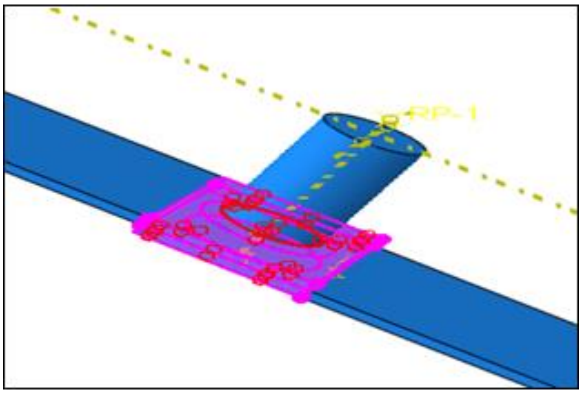

Fig. 7. Constraints defined for interactions

The two work pieces with length of 100mm, breadth 30 mm and thickness 1.5 mm are created and the material properties of the Aluminum alloy, commercial copper alloy and tool material are ascertained to the created part elements.

Interaction between surface of the non-consumable tool on the top surface of the top plate which is a frictional contact and pressure contact between the bottom surface of the top plate and top surface of the top plate are ascertained with constraints which is clearly given in Fig. 6.

Positional constraints and tie constraints are defined for the contact analysis between the tool tip through the top surface of the top plate and with the two plates which are held together. These are shown in Fig. 7.

The necessary boundary conditions are defined for clamping the top plate, bottom plate, restriction of movement of the tool in plunging direction. These are shown in Fig. 8 – 11.

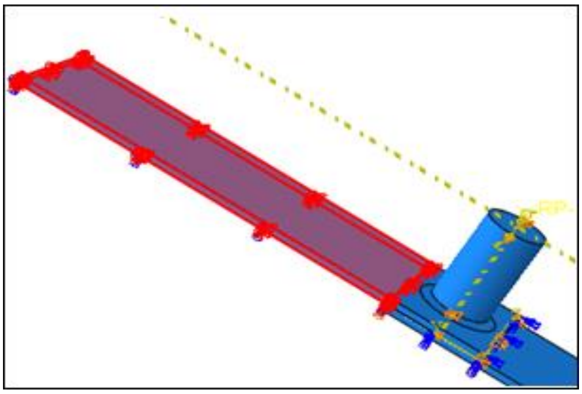

Fig. 8. Top plate clamping condition.

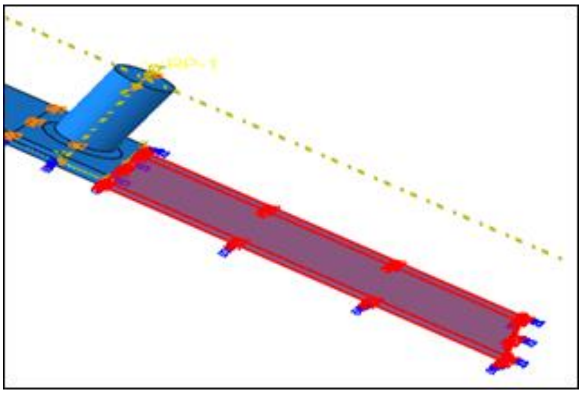

Fig. 9. Bottom plate clamping condition

The top clamp and bottom clamp boundary conditions are used for clamping the non-workable area of the plate are of 70 mm x 30 mm, where no actual weld process is done. Arresting these areas are required for ensuring proper plunge of the tool in the linear vertical direction.

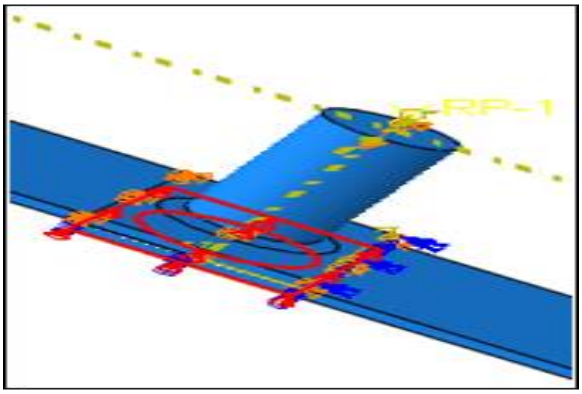

Fig. 10. Bottom supporting plate clamping condition

In all three directions the movements are arrested so that there is no slip or offset between the plates and with the tool surface and the top surface of the plate when the plunging action which takes place during the friction stir spot welding process.

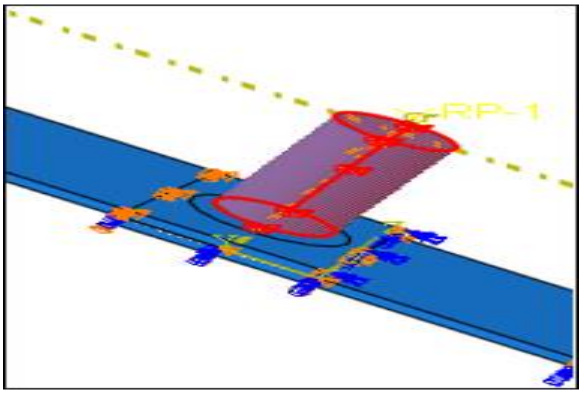

Fig. 11. Tool movement restriction in plunging direction

D. RESULTS

In both the assembly, one with pin less tool and the other with pin probed tool, the plunge is given at 1.2 mm in the negative Z direction with a rotational speed of 1000 rpm which is approximately 104 radians /sec. The stress distribution at the top surface of the pin less assembly is shown in Fig. 12.

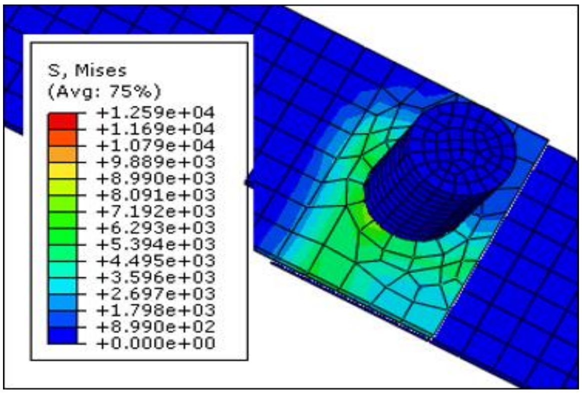

Fig. 12. Top view plunge with pin less tool

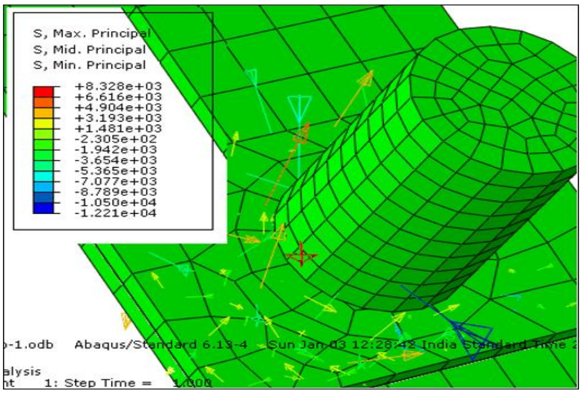

Fig. 13. Stress distribution using pin less tool.

Depending upon the profile of the plunging tool the stress distribution on the plates occurs.

The region of maximum stress is where the tool comes in direct contact with the plates and the top surface region near the tool periphery is pulled down by the pushing action of the non-consumable friction stir spot welding tool. The stress distribution of the plunge of pinless tool is shown in Fig. 13.The changes in the mesh deformation during the course of plunge of pin less tool is shown in Fig. 14.

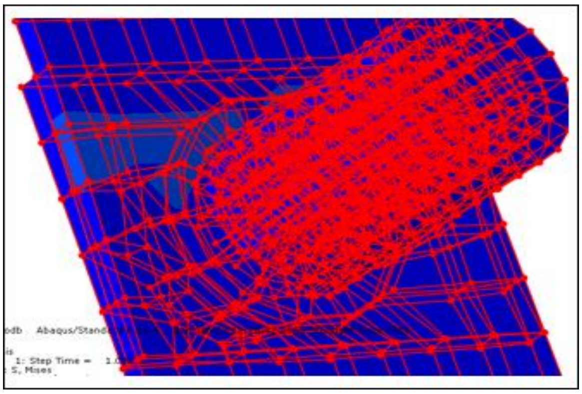

Fig. 14. Top view of mesh of pin less plunge.

Mesh deformation in the bottom side of pin less plunge is shown in Fig. 15.

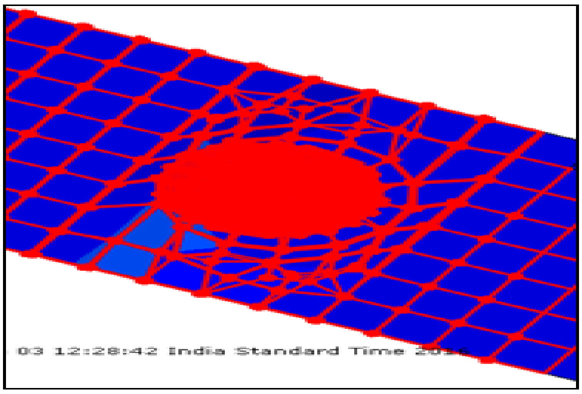

Fig. 15. Bottom view of mesh of pin less plunge

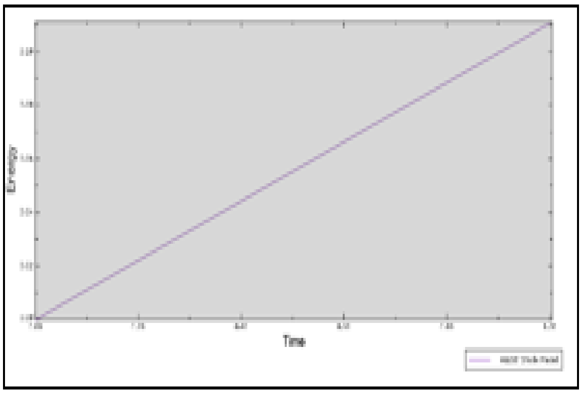

Fig. 16. Strain energy distribution for pin less probed tool.

During the plunging operation the top and bottom sheets are deformed mechanically and due to the various stresses and strains induced in the plates can be understood by the deformation in the mesh shape and sizes. The stress concentration effect is responsible for changes in the shape, size and texture of the material grain sizes which gets deformed.

The analysis using pinned tool from isometric view is given in Fig. 17.

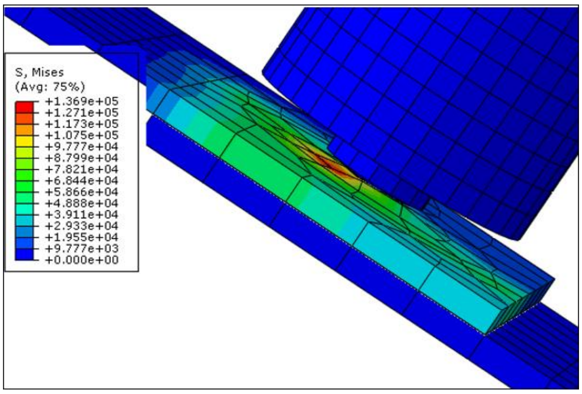

Fig. 17. Pin probed tool analysis top view.

The stress distribution is shown in Fig. 18.

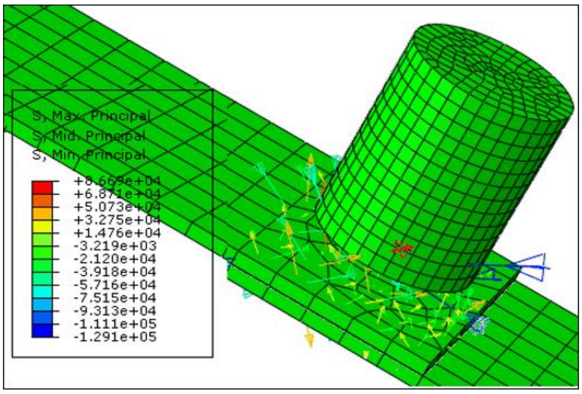

Fig. 18. Stress distribution of pin probed tool.

The mesh deformation during the plunging of pin probed tool is shown in Fig. 19.

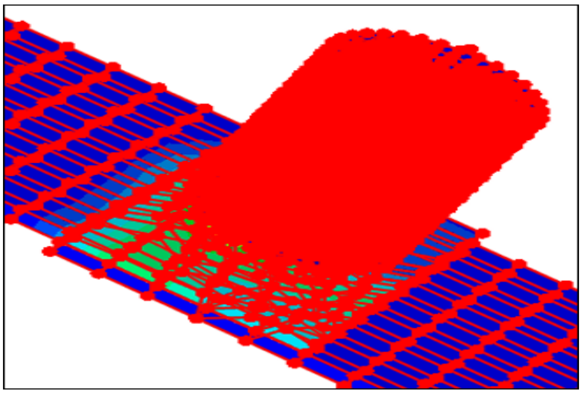

Fig. 19. Deformation along mesh of the top region using pin probed tool

The effect of the linear plunge using the pinned tool nomenclature is seen. The effect of pin is more pronounced than that of the shoulder plunge due to the contact of a lesser portion of the tool for the initial fraction of plunge of 1.5 mm. Mesh deformation in the bottom side of pin probed tool plunge is shown in Fig. 20.

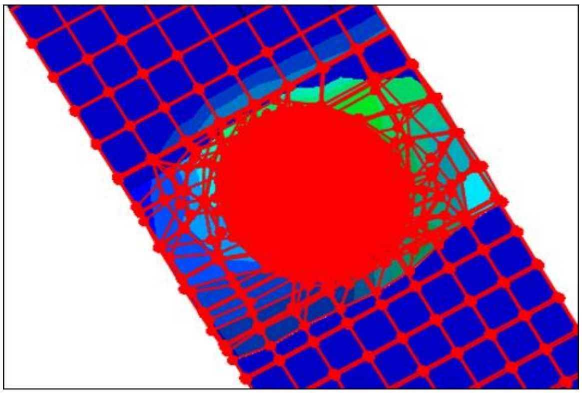

Fig. 20. Bottom mesh deformation using pin probed tool

Distribution of strain energy in pin less tool plunge is shown in Fig. 21.

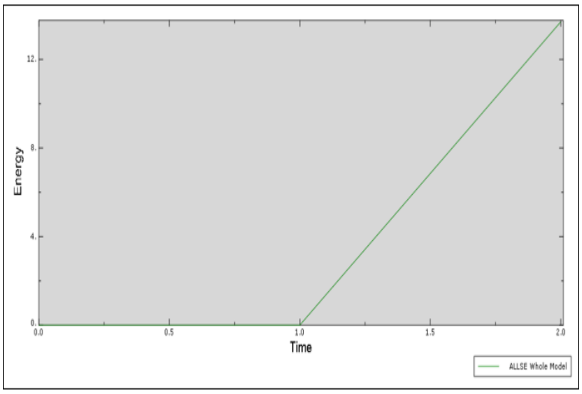

Fig 21. Distribution of strain energy using pin probed tool

The initial deformation is due to the plunge of the smaller area of the pin of 6 mm diameter till the pin length moves through the top plate. Then as the shoulder surface comes in contact with the plate, the deformation is produced with the whole of the diameter of 16 mm shoulder. The stress and deformation induced with the plunge of the pin probed tool is more pronounced with respect to the amount of stir that occurs due to the rotation of the tool.

E. CONCLUSION

Thus analysis of Friction stir spot welding of dissimilar joints of aluminium alloy and commercial copper alloy has been done using simulation software. The stress distribution along the surface and subsurface during the plunge of pin less tool and pin probed tool at an optimum plunge depth of 1.2 mm and tool rotational speed of 1000 rpm has been studied. The changes in stress and strain energy distribution were studied and the variations due to the change in tool geometry has been evaluated.

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