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FSW NUMERICAL SIMULATION OF ALUMINIUM PLATES BY SYSWELD - PART II

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Abstract: Friction Stir Welding (FSW) is one of the most effective solid state joining processes and has numerous potential applications in many industries. The simulation process can provide the evolution of physicals quantities such as temperature, metallurgical phase proportions, stress and strain which can be easily measured during welding. The numerical modelling requires the modelling of the complex interaction between thermal, metallurgical and mechanical phenomena. The aim of this paper is to describe the thermal-fluid simulation of FSW using the finite element method. In the theoretical part of paper heating is provided by the material flow and contact condition between the tool and the welded material. Thermal-mechanical results from the numerical simulation using SYSWELD are also presented for aluminium alloy.

KEYWORDS: Friction Stir Welding (FSW); aluminium alloy; Finite element method; thermo-fluid model

1 Introduction

Friction stir welding (FSW) is a relatively new joining technology which was developed and patented in 1991 by The Welding Institute (TWI), in the United Kingdom [1]. This is a solid state welding process providing good quality of butt and lap joints. The FSW process has been proved to be ideal for creating high quality welds in a number of materials including those that are extremely difficult to weld by conventional fusion welding. A schematic of friction stir welding process is illustrated in Fig. 1.

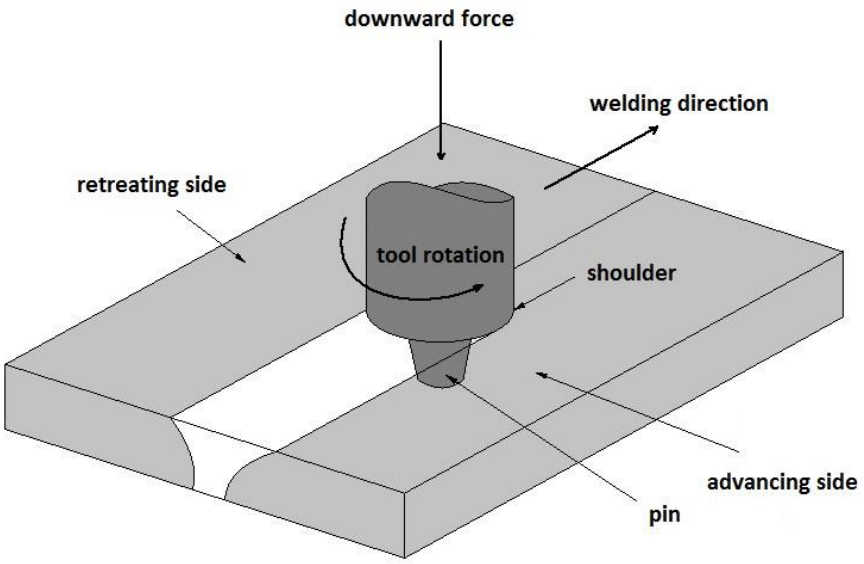

Fig. 1. Schematic diagram of FSW

The welding zone is completely isolated from the atmosphere during the welding process. The advantages of this type of welding are minimized formations of voids in the welding zone, so that welding defects and large distortions commonly associated with fusion welding are minimized or avoided. This welding technique is extensively applied to the aerospace, automobile and shipbuilding industries [3, 4, 5, 6].

2. Solution of Friction Stir Welding in SYSWeld

For the numerical solution we used the SYSWeld software with the FSW (Friction Stir Welding) module. The FSW module solves the weld joint in the three steps. This step is in the Fig. 2.

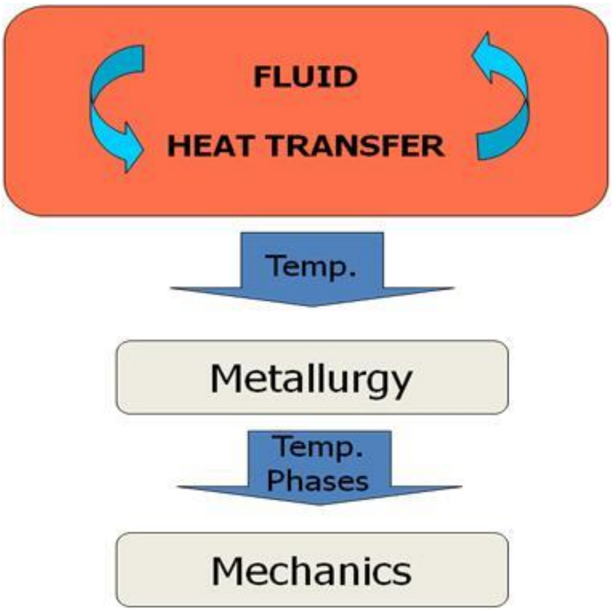

Fig. 2. Step solution using the FSW module in SYSWeld

The flow and heat transfer computation are strongly coupled in the FSW module. The Units for the solution are fixed as follow:

- Length: mm
- Temperature: °C or °K
- Stresses MPa
- Forces: N
- Energy: Joule

Conditions for creating a model of the thermo-fluid analysis using SYSWeld by the FSW module are as follow:

- Tool:
  - Axi-symmetric
  - Rotation axis Z
  - Centered on (0,0)
- Behavior laws
  - Norton Law for flow: $\sigma = K(T) \cdot \dot{\varepsilon}^{m(T)}$
  - Metallurgy: all SYSWELD models
  - Mechanics: all SYSWORLD models
  - Friction: t = m. (DV)R

where DV is the “gliding” velocity. Note that R=1 ensures a better convergence.

- Mesh: Tetrahedron elements for flow simulation.

3. Numerical solution by SYSWELD

The aim of this section is the numerical solution of friction stir welding using materials without phase transformation, e.g. Aluminium alloy AlMg4.5Mn0.7. In this section, we will be showing the whole process of numerical solutions in SYSWELD using the FSW module [3, 4].

3. 1. Experimental measurement of the thermal field

In the present work experimental measurements with transient temperature field were also carried out for the purpose of verifying the results of numerical simulations. Measurements were in the Welding Research Institute - Industrial Institute of SR directly on experimental equipment of the above mentioned department, with the cooperation by the staff of the Institute of Automation, Measurement and Applied Informatics, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. The chosen measurement method was thermography (Fig. 3) using a camera FLIR® SC660 camera.

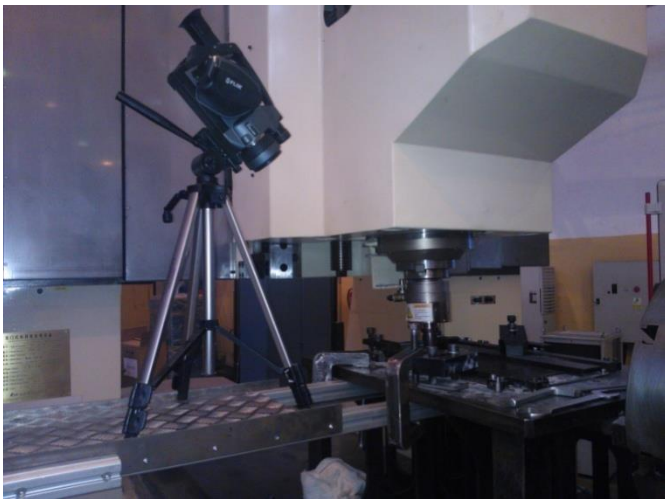

Fig. 3. Experimental measurement taken with a FLIR® SC660 camera.

In Fig. 4 the thermal field for experimental measurement is shown.

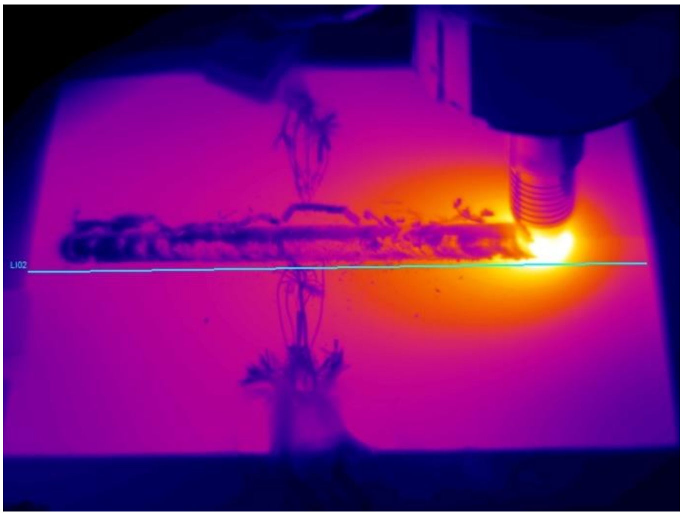

Fig. 4. Thermal field measured with a thermo camera

3. 2. Thermo-fluid analysis

The boundary conditions and finite element model with the results was presented in PART I of this article [2]. The result of the numerical solution of the thermal field with SYSWeld and the measurements taken with the camera are in a good agreement. The numerical result of thermal field is shown in the Fig. 5.

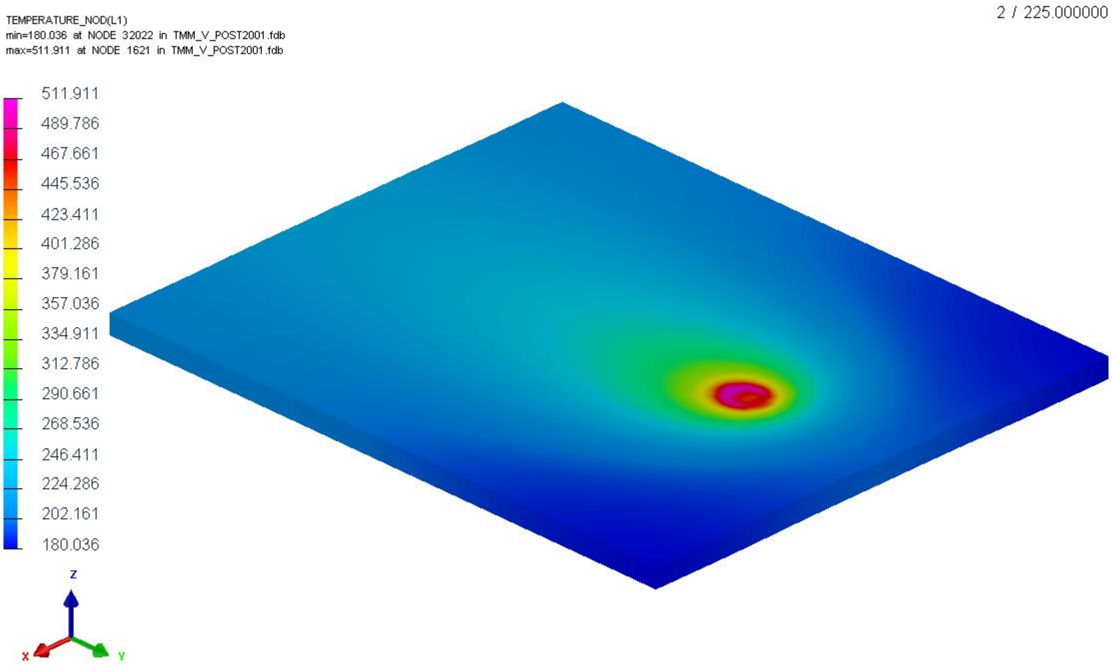

Fig. 5. Temperature field at time 225 s

3. 3. Thermo-mechanical analysis

The boundary conditions for the mechanical analysis are shown in Fig. 6. For the solution the thermal field from thermo-fluid analysis was used. The finite element model is shown in Fig. 7, which consists of 63261 elements and 70340 nodes.

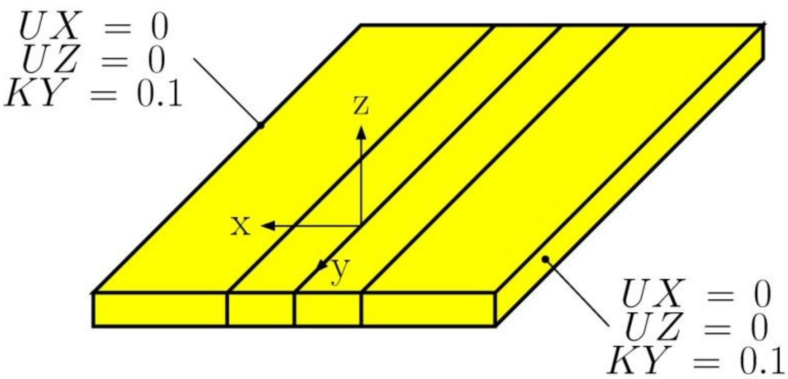

Fig. 6. Boundary condition for mechanical solution

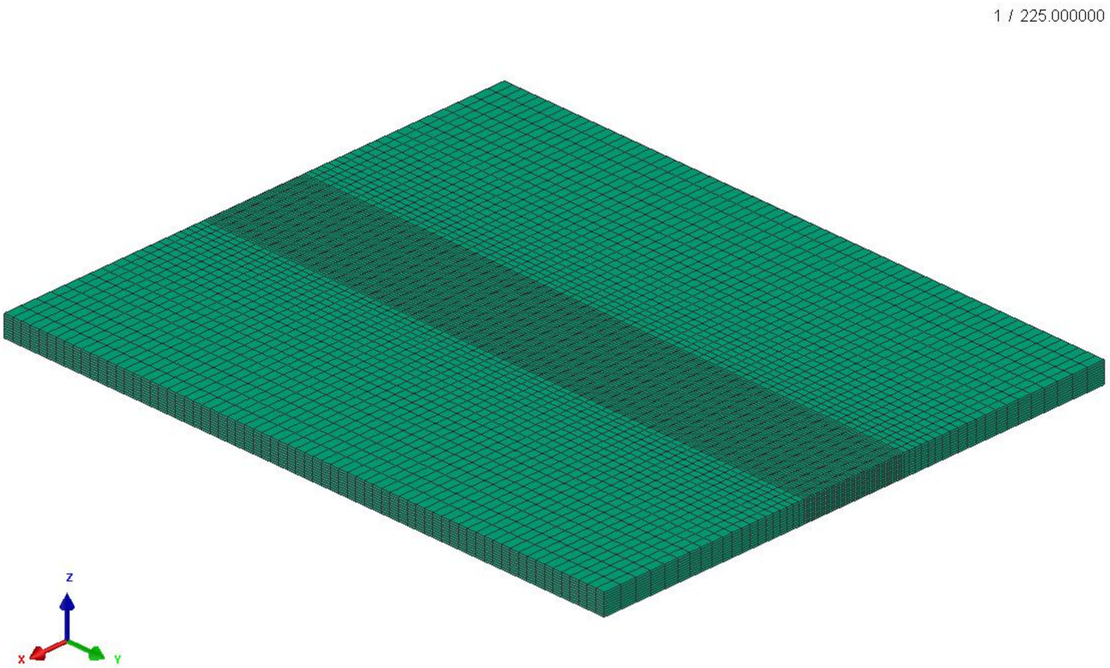

Fig. 7. Finite element model for the thermo-mechanical analysis

Mechanical properties are very important for solving the residual stress state, and therefore they have been the focus of our attention. Mechanical properties of the material AlMg4.5Mn0.7 were taken from literature. The mechanical properties (modulus of elasticity, thermal expansion, yield stress) used for numerical simulation of FSW of two plates from material AlMg4.5Mn0.7 are shown in Tab. 1. and Tab. 2.

Table. 1. Mechanical properties of material AlMg4.5Mn0.7

Temperature [°C]	Young's modulus [MPa*10^4]	Poisson ratio [-]	Coefficient of thermal expansion [1/K*10^{-6}]
20	7.000	0.33	22.0
120	6.950	0.33	25.4
220	6.500	0.33	26.5
320	5.600	0.33	27.8
420	4.930	0.33	29.9
587	3.000	0.33	32.5
644	0.100	0.33	35.5
2447	0.100	0.33	37.2

Results from thermo-mechanical analysis are presented from the Fig. 9 to Fig. 10.

Table. 2. Yield stress of material AlMg4.5Mn0.7

Temperature [°C]	Yield stress [MPa]
20	210
50	200
100	185
150	155
200	110
250	80
300	55
350	40
400	30
450	18
500	10
587	5
600	5
650	5

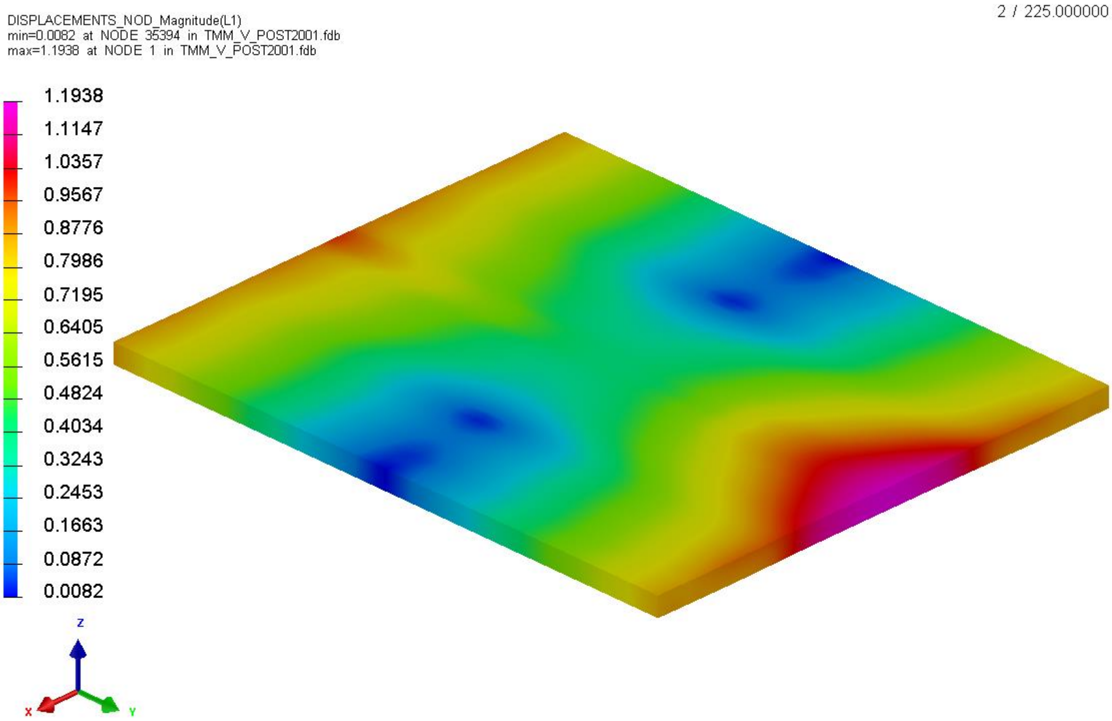

Fig. 8. Displacement vector sum field

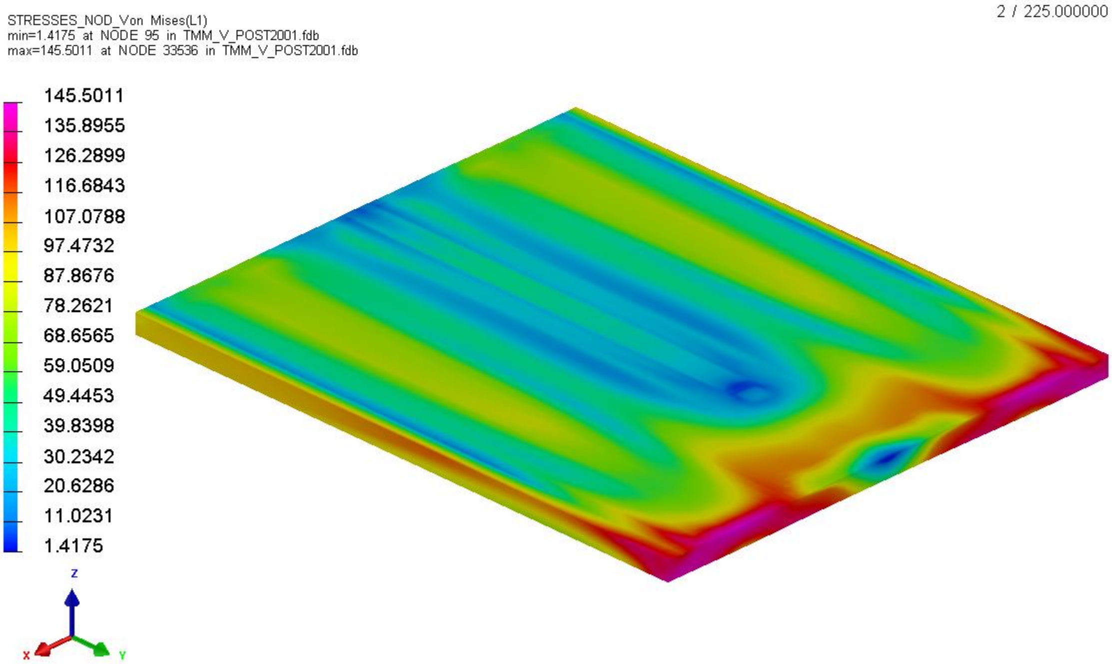

Fig. 9. Von Mises stress field

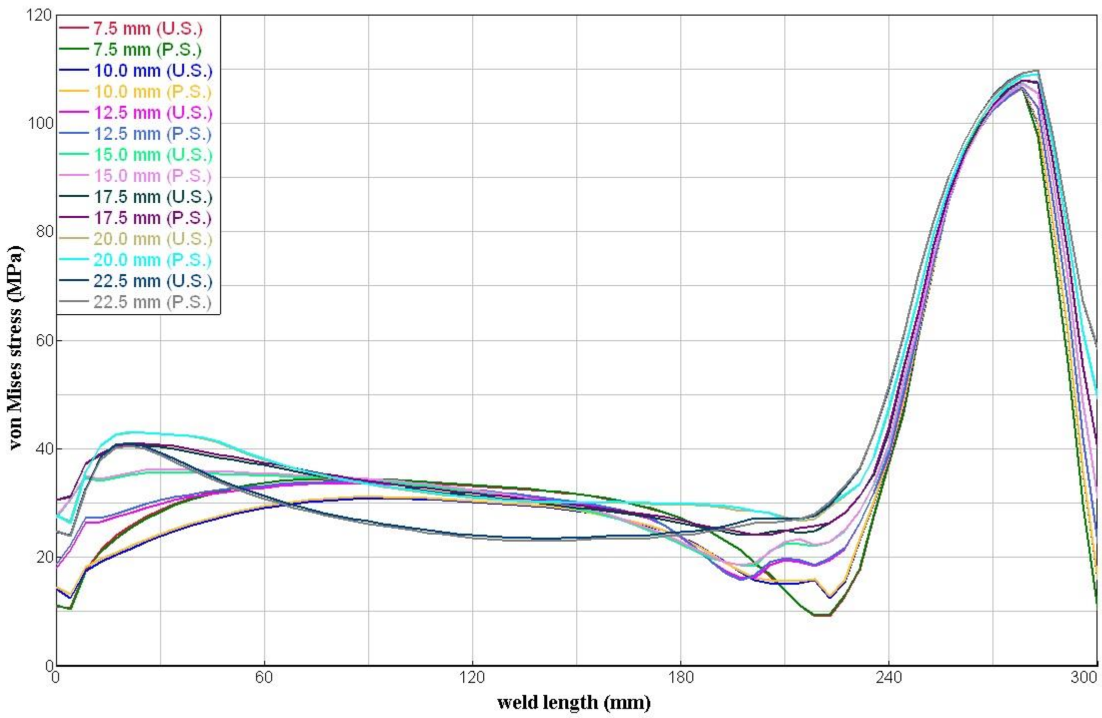

Fig. 10. Graph of von Mises stress in selected points

4. Conclusion

In this paper the experimental measurement of a thermal field taken with a FLIR® SC660 camera with is presented. The result is presented in Fig. 4. In section 3.2 the numerical solution of the thermal field is presented with the thermo-fluid analysis using the SYSWeld software and the FSW module. The result of the numerical solution of the thermal field calculated with SYSWeld and measured with the camera are in a good agreement. Maximum temperature is 511,911 °C at time 225 s in Fig. 4.

Results from the thermo-mechanical analysis are presented in Fig. 8, Fig. 9 and Fig. 10. In Fig. 8 the result of displacement vector sum with the maximum value 1.19 mm at time 225 s is shown. In Fig. 9 the result of von Mises stress at time 225 s is shown. The maximum value of stress is 145.5 MPa.

In Fig. 10 the graph of von Mises stress at a selected point from the weld line in the progress side (sign. P.S.) and suppressed side (sign. U.S.) is presented.

A three-dimensional thermo-mechanical model including the mechanical action of the shoulder and the thermo-mechanical effect of the welded material is developed for the FSW of an Al-alloy, in order to build a qualitative framework to understand the thermo-mechanical process in FSW. Modeling and measurement of the temperature and stress evolution in the FSW of AlMg4.5Mn0.7 Al alloy is conducted, and the experimental values validate the efficiency of the proposed model.

Acknowledgements

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