EXPERIMENTAL AND NUMERICAL STUDY OF FRICTION STIR SPOT WELDING FOR 2024 ALUMINUM PLATES

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ABSTRACT

Friction stir spot welding (FSSW) is a relatively new welding process that may have significant advantages compared to the fusion processes as follows joining of conventionally non-fusion weldable alloys, reduced distortion and improved mechanical properties of weldable alloys joints due to the pure solid-state joining of metals. In this paper, a three-dimensional model based on finite element analysis is used to study the thermal history in the spot-welding of aluminum alloy 2024. The model take place the thermomechanical property on the process of the welded metals.

The thermal history and the evolution results with numerical model at the measured point in the friction stirred spot weld have a good matching, then the prediction of the temperature history from the numerical model in the welded plates is acceptable.

The experimental results of measuring the shear force of the welded plates show that there is a good agreement with the increase of the rotational speed of the tool with shear force.

الخلاصة

اللحام النقطي بالخلط و الاحتكاك من طرق اللحام الحديثة نسبيا والتي تمتاز عن غيرها من طرق اللحام ألانصهاري بالاتي: إمكانية لحام السبائك الغير قابلة للحام ألانصهاري، تقليل التشوه وتغير المواصفات الميكانيكية للسبائك الملحومة لأنها تعتبر من طرق الربط بالحالة الصلبة للمعادن. في هذا البحث تم إنشاء نموذج ثلاثي الأبعاد بطريقة العناصر المحددة لغرض دراسة السلوك في تغيير درجة الحرارة في القطعة الملحومة باللحام النقطي لسبيكة الألمنيوم 2024. النموذج اخذ بنظر الاعتبار تأثير الخواص الميكانيكية الحرارية في عملية اللحام على المعادن الملحومة.

تم الحصول على نتائج متقاربة بين القياس العملي لدرجة الحرارة في نقطة مع النتائج المستحصلة من النموذج الحسابي، لذا يمكن القبول بنتائج سلوك تغير درجة الحرارة المتوقعة من قبل النموذج الحسابي.

النتائج العملية لقياس قوة القص للحام أظهرت أن هناك توافق جيد مع زيادة السرعة الدورانية لعدة اللحام مع قوة القص.

KEYWORDS: Friction stir spot welding, Numerical simulation, ANSYS program, Aluminum 2024.

INTRODUCTION

Friction stir welding (FSW) is a solid-state welding process invented out at TWI (Cambridge, United Kingdom) in 1991 [Ayad M. Takahakh 2010]. Friction stir welding (FSW) is a solid state joining process, which is particularly adapted for difficult to weld high strength aluminum alloys (e.g. the 2XXX and 7XXX series). [Thomas W.M., et al. 1991] from The Welding Institute, TWI, patented the FSW process. A hard cylindrical tool with a threaded pin and a shoulder rotates and slowly plunges into the joint line between two workpieces butted together. Friction and stirring generate heat dissipation so that the metal pieces do not reach their melting point. The material is plastically deformed and transferred from the leading edge to the trailing edge of the tool, leaving a solid phase bond between the two pieces when the tool is moved along the joint line [D. Jacquina, et al. 2011].

Friction Stir Spot Welding (FSSW) is a process developed recently and has been studied for applications in automotive, aeronautic and other industries. This welding technology is quite similar to Friction Stir Welding process (FSW), and the main difference is the type of joint. In FSSW, the plates form a lap-joint and the tool penetrates the plates only in a point. In the FSW process the plates are positioned in a butt-joint configuration and the tool moves towards the joint direction [Malafaia, A. M. S., el al., 2010].

EXPERIMENTAL WORK

Lap shear specimens clamped with fixture as shown in fig.1, and friction stir spot welding were prepared using 2024 alloy, 100x25x3.8 mm plates and 30x25 mm overlap. The welding process was performed in a CNC milling machine fig.1 with difference rotation speed 700 and 900 rpm at constant preheating time, plunging time, stirring time and depth as shown in table 1. To carry out the FSSW process two aluminum plates were placed overlap on flat steel plate. These two plates were then clamped with special clamps so they would not separate during welding process, a thermocouple was fixed by hand during the welding process to measure the temperature in the point at the end of the lap plates shown in fig.1.

A 25 mm in diameter flat tool with a pin of 7 mm length and 5 mm in diameter were employed. The material used was special tool steel X38 Cr MoV 51 (DIN 1.2343).

The ANSYS is a package program that uses finite element method to calculate the numerical solution of complex problems whose analytical solution is tedious or not easy to achieve. The FSSW model depend on the assumptions that used to get the required results, the assumptions are

1- The element that is used in the analysis is three dimensional, 8 nodes, has a temperature as a degree of freedom and accepts the convection, conduction as a load in each face and heat generation on the volume of the element.

2- The plate metal has the following material properties (thermal conductivity, specific heat and density) which have different values with temperature as shown in table 2 [Kenneth C Mills 2002].

3- The heat generation in the model has a constant value in each four steps (preheating, plunging, stirring, drawing out and cooling) depends on calculations that based on the areas of contact, friction coefficient, rotation speed and the normal force which have approximate value (because the difficult of measuring) [Fulufthelo Masithulela 2009].

4- The heat convection coefficients (H) values are (100 W/m^2 C) for the bottom side of the plate and (10 W/m^2 C) for the top side of plate [Manthan Malde 2007].

5- The time period of each step is equal to the experiment case study.

The heat transfer conditions at specific areas and volume in the body are important to solve the problem. Heat transfer by convection takes place from top and bottom of the plate. Heat generation was taken place in the volume under the shoulder area as shown in fig.2.

RESULTS AND DISCUSSION

The FSSW process, similar to plunge phase of linear friction stir welding, provides frictional heating between the interface of the tool pin and the top sheet that effectively increase that hot workability of the specimens. With sufficient reduction in flow stress at temperature a combination of forging and stirring joints the two sheets without melting the base materials. Heat generation during the plunge phase softens materials that are mixed both axially about the tool and vertically through the thickness of the sheet interface [Y. Hovanski, et al., 2007].

The experimental results in sample 1 (700rpm) and numerical results are shown in fig.3 which represents the value of temperature have a small difference at the end of the stirring stage because the metal became very soft at high temperature then the heat generation will decrease whereas the numerical solution assumed constant heat generation at each stage.

As tool rotation speed increase from700 rpm to 900 rpm for a given preheating time, plunging time and depth, It will cause an increase in shear force (weld force) as shown in fig.4, Maximum lap shear weld failure force of 9500 N was obtained at tool rotation speed 900 rpm, because the increase in rotational speed to certain value leads to increase in temperature and material flow around the tool, as represented in the numerical model in fig.5 and

6 which show that the temperature distribution at 210 sec (maximum temp) for sample 1 (700 rpm) and sample 2 (900 rpm).

CONCLUSIONS

A three-dimensional thermal model including the thermomechanical effect of the weld material is developed for the FSSW of Al-alloy, in order to build qualitative framework to understand the thermomechanical process in FSSW. Modeling and measurement of the temperature evolution in the FSSW of 2024-T6 Al alloy is conducted, and the experimental values validate the efficiency of the proposed model. The good agreement between the prediction and measurement temperature at the point of the end of lap show that the temperature distribution at the prediction model is acceptable. The increase of the rotational speed from 700 rpm to 900 rpm for a fixed other parameters caused an increase mechanical properties of the weld joint.

REFERENCES

Ayad M. Takahakh "Effect of Tool Rotational Speed on Properties of 1060 Aluminum Friction Spot Stir welding" F.I.T. Scientific International Conference 2010.

D. Jacquina B. de Meesterb, A. Simarb, D. Deloisonc, F. Montheilleta, C. Desrayauda "A simple Eulerian thermomechanical modeling of friction stir welding "Journal of Materials Processing Technology 211 (2011) 57–65.

Fulufthelo Masithulela "Conceptual Design of a FSSW Machine for Joining Rails" M.Sc. research at University of the Witwatersrand, Johannesburg, 2009.

Kenneth C Mills "Recommended values of thermophysical properties for selected commercial alloys" Woodhead Publishing Limited 2002.

Malafaia, A. M. S, Milan, M.T., Oliveira, M. F., Spinelli, D. "Fatigue behavior of friction stir spot welding and riveted joints in an Al alloy" ScienceDirect Procedia Engineering 2 (2010) 1815–1821.

Manthan Malde " thermomechanical modeling and optimization of FSW" COMSEL News a technical computing magazine, www.comsel.com, 2007.

Thomas, W.M., E.D. Nicholas, J.C. Needham,. Friction-stir butt welding. GB Patent No. 9125978.8, International patent application No. PCT/GB92/02203(1991).

Y. Hovanski, M .L. Santellab, G. J. Grant, "Friction stir spot welding of hot stamped boron steel", Script materialila 57 (2007)873-876.

Fig.1 FSSW process using CNC machine in the workshop at Nahraien University represents the welded plates, clamping, tool, and thermocouple device.

Table 1 Friction spot stir welding parameters.

Sample	Rotation speed (rpm)	Preheating time (sec)	Plunging time (sec)	Stirring time (sec)	Depth of pin plunging (mm)
1	700	30	120	60	7
2	900	30	120	60	7

NUMERICAL MODEL

Table 2 Thermal properties of Al 2024 [Kenneth C Mills 2002].

Temperature C	Density kg/m^3	Heat Capacity kJ/kg	Thermal Conductivity W/(m^2.C)
25	2785	850	175
200	2750	950	193
400	2707	1000	190
538	2674	1100	188
632	2500	1140	85

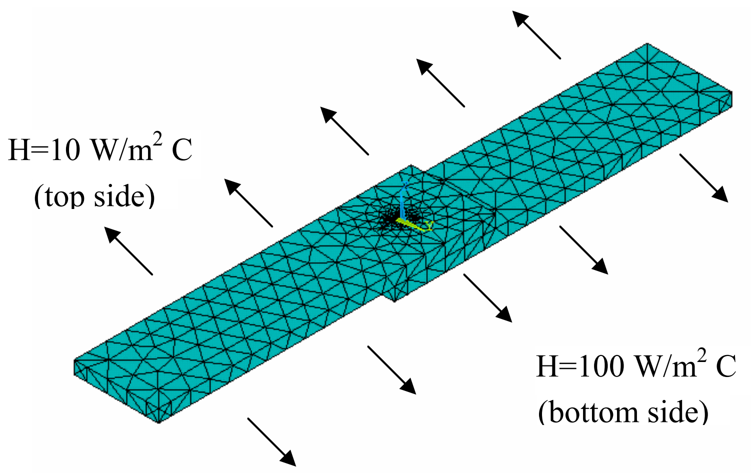

Fig.2 The mesh geometry with conditions of welding process.

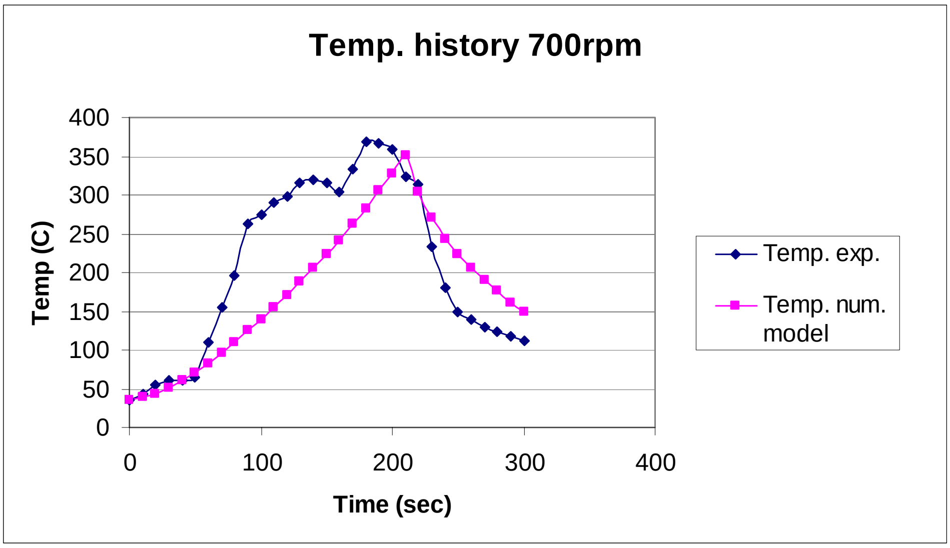

Fig.3 Temperature history comparison of exp. and num. models, sample 1 (700rpm).

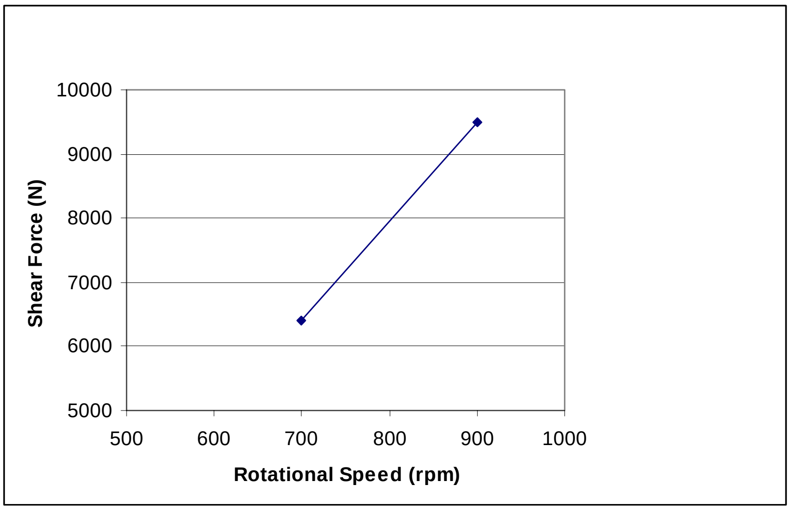

Fig. 4 Effect of rotational speed on the weld force that measured in the laboratory of Mech. Eng. Dep. at Nahraien University .

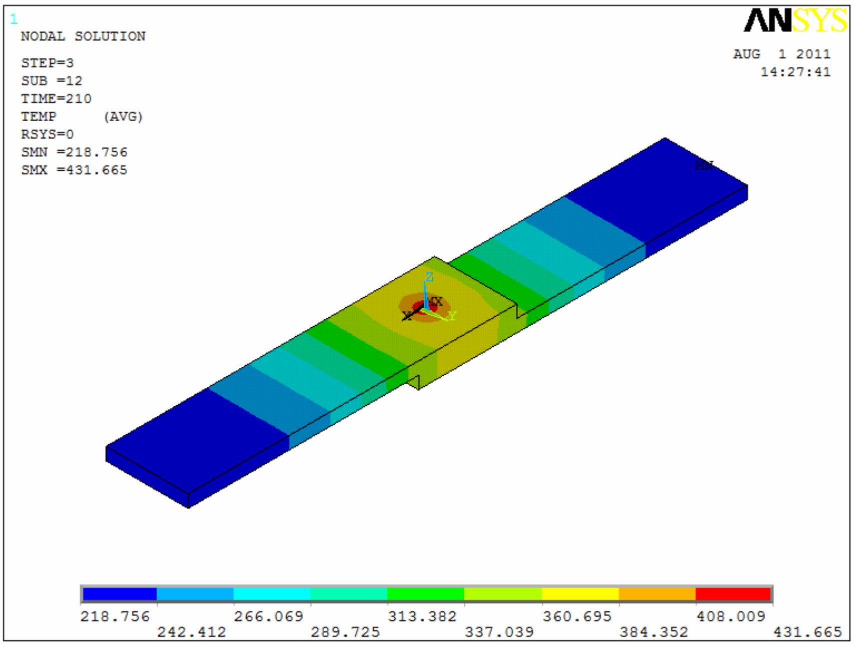

Fig. 5 The temperature distribution at 210 sec for 700 rpm.

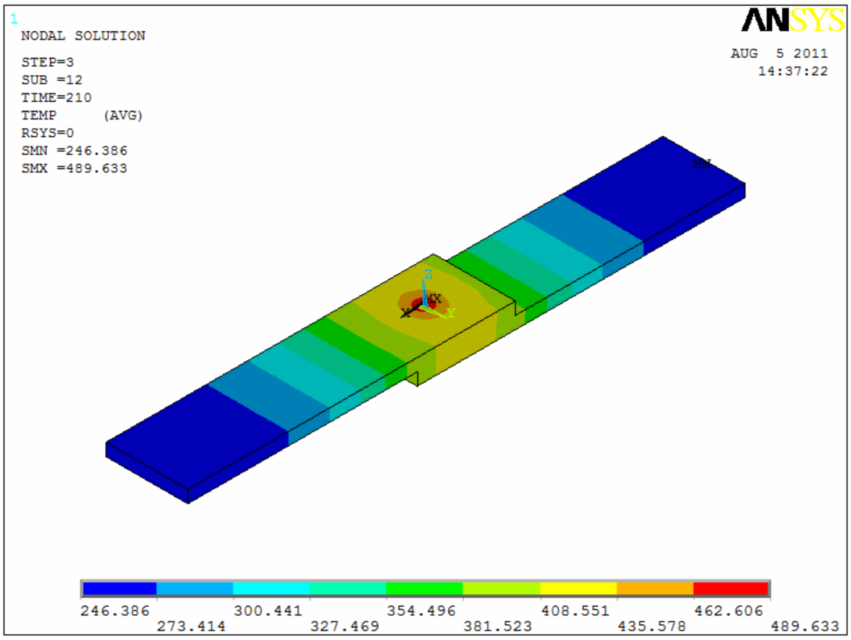

Fig. 6 The temperature distribution at 210 sec for 900 rpm.