Influence of Friction Stir Welding Rotation Speeds In dwell phase on the Temperature Distribution of AA6061-T6 Aluminum Alloy Weldment

Rasheed Nema Abed
College of Engineering, Al-Nahrain University, Baghdad, Iraq.

Abstract

Friction Stir welding (FSW) parameters, which play a vital principle, that impact on the mechanical, microstructural properties of the weldment because of the warmth produced by the contact between the instrument and work-piece, An AA6061-T6 aluminum composite plate with measurements (186*150*4) mm^3 welded through various rotational paces 800, 1000, 1200 and 1450 rpm, the created heat measured through thermocouples embedded in study zones of the Weldment, a Finite Element model have been executed by utilizing ANSYS 12.1 bundle charges to ponder the temperature appropriation amid stay stage, the outcomes demonstrates a decent assention between the after effects of exploratory and hypothetical tests. The most extreme temperature measured at this condition was 0.71 from the liquefying temperature of the sample at a maximum rotational speed of (1450) r/min.

Keywords: Friction Stir Welding, FE Model, Temperature distribution.

1 Introduction

Friction Stir welding (FSW) was developed in 1991 by the welding foundation (TWI), Cambridge, United Kingdom (UK) [1-3]. FSW has risen as a dependable technique to joint high quality 6xxx arrangement aluminum composite and this symbol indicate that the last two digits represent the purity of the metal and The second digit indicates modifications in impurity limits [1, 4-6]. These aluminum compounds are by and large named non-wieldable amalgam as a result of the poor cementing microstructure and porosity in the combination zone. Additionally, the misfortune in mechanical properties when contrasted with the base material is exceptionally huge. The fundamental idea of FSW is strikingly basic. A non-consumable pivoting apparatus with an exceptionally outlined stick and shoulder is embedded into the adjoining edges of sheets or plates to be joined and navigated along the line of joint as appeared in figure (1). The apparatus serves two essential capacities: warming of workpiece, and development of material to create the joint. The warming is expert by contact between the apparatus and the workpiece and plastic distortion of workpiece. The confined warming mollifies the material around the pin and mix of hardware pivot and interpretation prompts development of material from the front of the pin to the back of the pin. As an after effect of this procedure a joint is delivered in "strong state" [1, 4]

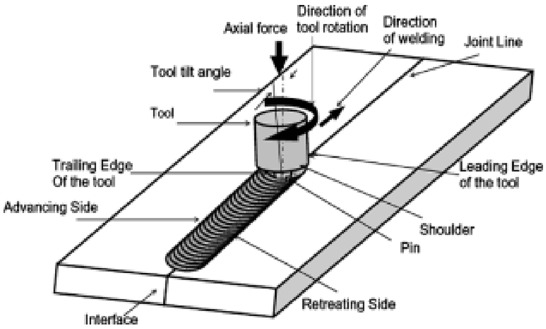


Figure (1): Schematic diagram shows terminology of friction stir welding process [14].

A few reports have been concentrated on the microstructural attributes and mechanical properties of FSW for aluminum compounds [1, 2, 6-10]. Numerous insights about the temperature dispersion have been distributed for FSW [1, 10]; some of these subtle elements were formed by utilizing the limited component models [11-13]; then Muhammed Abdul. M demonstrate that aluminum compound (7020-T53) can be welded utilizing (FSW) process and express the ideal welding parameters in the rotational velocity 1400rpm and 40mm/min travel speed which give the most extreme welding productivity (83%), expanding rotational rate the smaller scale hardness increments in weld zone because of diminishing the grain size[14]; Muhammed Abdul. M foresee numerical transient temperature dispersion in Al7020-T53 plates that were welded by erosion blend welding strategy for propelling velocity of 40mm/min and rotational rate of 1400rpm[15]; Muhammed Abdul. S. M anticipate numerical warm circulation in (Al7020-T53). Plates that were welded by rubbing mix welding strategy in which impact of hardware (propelling) travel velocity and turn speed [16]; H. FUJII examined of the FSW of 6061-T6 aluminum combination, with the accentuation set on the pliable properties and crack areas of the joints welded with various welding parameters. The outcomes for these studies are utilized as a pattern for the present study.

In present study a three-dimensional limited component model (3D-FEM) utilizing ANSYS 12.1 package was produced for butt welded AA6061-T6 aluminum combination in FSW to assess the warm history in butt welded joints and its consequences for mechanical properties on this specimen.

2 Model Description:

The instrument that utilized as a part of erosion blend welding was created from an apparatus steel marked as high speed steel (ρ=7800kg/m^3), specific heat Cp=500J/kg.^{o}C and warm conductivity (k=40W/m.^{o}C) and is warmth treatment incorporates warming the metal to 1020 ^{o}C for 30 min and afterward air cooling to room temperature. The device had a sunken shoulder (2.5^o), while the instrument pin is made barrel shaped with a right hand strings of (1) mm pitch and have a round base .the general stature of the pin is (3.85 mm), (4mm) in measurement and shoulder breadth is (18mm) appeared in fig(2). The instrument is viewed as an unbending strong, and the work piece is viewed as a malleable material portrayed with versatility, pliancy and dynamic solidifying impact.

Figure (2): schematic diagram explain the shape of the welding tool.

3 Experimental procedure

The base material utilized as a part of this study is AA6061-T6 aluminum composite, which is falsely matured to crest hardness and it has high quality warmth treatable combination with a higher quality, then it has great consumption resistance and great weld capacity, Aluminum amalgam A6061 is a precipitation hardenable Al–Mg–Si compound, which is utilized as a part of aviation and vehicles commercial ventures for basic applications. This is accomplished by arrangement treatment and controlled maturing. The concoction piece and the mechanical properties of this compound are recorded in table (1).

Table (1): Chemical composition wt. % of 6061-T 925 Al-alloy

Al	96%
Cr	0.18%
Ti	0.08%
Zn	0.1%
Mg	1.1%
Mn	0.09%
Cu	0.2%
Fe	0.45%
Si	0.5%

The workpiece with measurements (186 x150x4) mm^3 is a butted and clipped inflexibly on the carbon steel backing plate for welding. A FSW apparatus produced using HSS with a 4 mm pin distance across, 18 mm shoulder width and 3.85 mm pin length. The welding procedures were led utilizing vertical processing machine at four diverse rotational velocities, commonly; 800, 1000, 1200 and 1450 rpm. In all examinations the apparatus edge was settled 2.5^o and the grinding weight was held steady.

One K-sort thermocouple was utilized to assess the temperature inside of the welded plate at the best welding conditions. The thermocouple with 1.8 mm external sheath distance across was installed in 2 mm gaps, and after that satisfied the opening with aluminum powder. The thermocouple was implanted at 2 mm from the rotational pin under the shoulder around 3 mm in the propelling side, appeared in figure (3a-b).

Amid of the penetration stage, the turning device pin enters into the work-piece until the apparatus shoulder comes contact with the work-piece.

Convection heat exchange coefficient with sponsorship plate (300W/m^2 k), convection heat exchange coefficient (30W/m^2 k), encompassing and introductory temperature (To=298 ^{o}K), grating coefficient (μ=0.4), (hub load=2kN), Heat generation (Q=331watt) utilized as data welding parameters as a part of the limited component computation with their relating vertical power in the work-piece anticipated, This graph demonstrates the temperature measured from FSW process for various apparatus rotational speed normally; 800, 1000.1200 and 1450 rpm with the time.in fig. (4).

In this graph we draw the outcomes that get from the test in the lab and this outcome express the temperature that deliberate by the thermocouple to clarify the variety of temperature with the time in various rotational velocities.

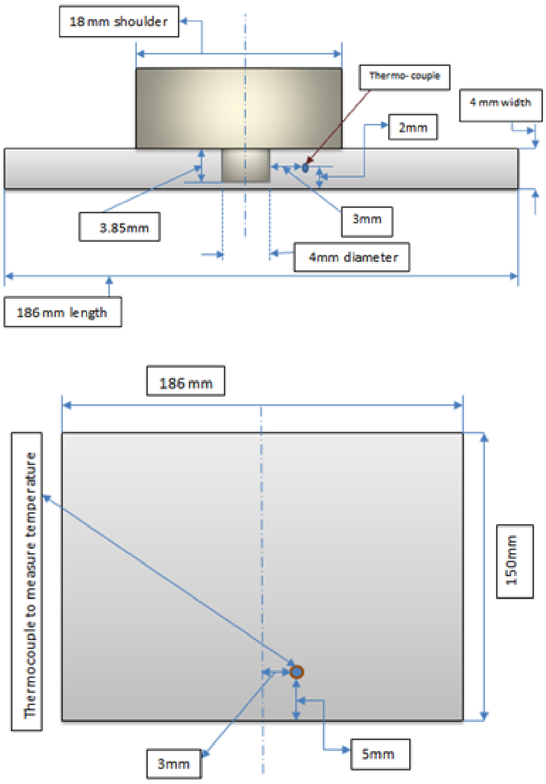


Figure (3) Locations of the inserted thermocouple

Experiments are behavior under various welding rotational velocity keeping in mind the end goal to utilize the vertical burdens and temperature results for check of the precision of the displayed ones. Four cases are considered with varying apparatus rotational rates (800rpm, 1000rpm, 1200rpm and 1450rpm). The plates are readied to quantify the temperature at infiltration of welding instrument by utilizing one thermocouple, its position as appeared in figure (5).

The plate as appeared in figure (6) is readied to quantify the temperature at point utilizing thermocouple as appeared as a part of figure, where K Type thermocouple was utilized 1mm diameter. The area of thermocouple in the work-piece is appeared in fig. (5). Thermocouple associated with read transient temperatures are recorded amid FSW process.

4 Finite element model:

The Finite Element Method (FEM) offers an approach to take care of complex continuum issues by subdividing it into a progression of straightforward interrelated issues. Limited component technique (FEM) is most ordinarily utilized as a part of numerical examination for getting inexact answers for wide assortment of building issues the warm and mechanical reactions of the material amid grinding blend welding procedure are researched by limited component reenactments. In this study, a nonlinear, transient three-dimensional warmth exchange model is produced to decide the temperature handle the limited component models are parametrically assembled utilizing APDL (ANSYS Parametric Design Language) gave by ANSYS® [18]. The models are then accepted by contrasting the outcomes and test thermocouples information.

The present warm investigation, the work-piece is coincided utilizing a block component called SOLID70. The component is characterized by eight nodes with temperature as single level of opportunity at every hub and by the orthotropic material properties.

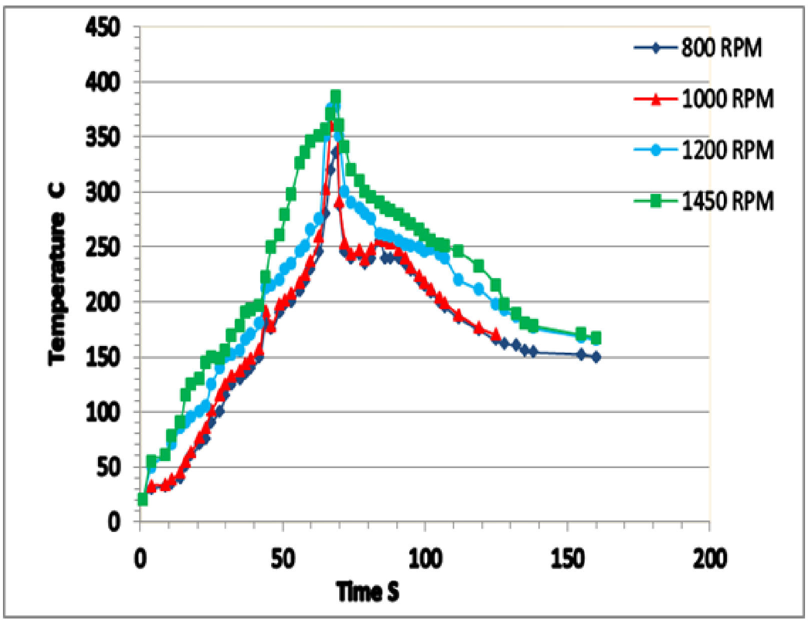


Figure (4): Experimental temperature distribution in dwell phase during the FSW process.

Figure (5): Temperature recorder by thermocouple position on work-piece

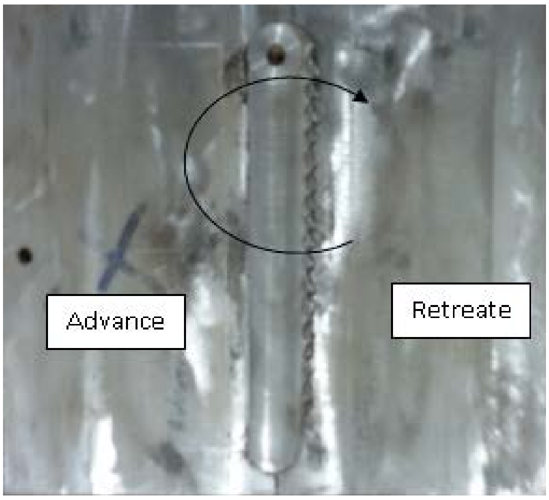


Figure (6): The experiment workpiece

5 Thermal Model:

The principle heat source in FSW is by and large thought to be the grating between the turning apparatus and the welded workpieces, and the chilly work in the plastic distortion of the material in the region of the device. In the present concentrate a few suspicions made in warm investigation model were as per the following:

i) Heat era is because of grinding as it were;
ii) Heat exchange by radiation is unimportant and
iii) The both welding sides are symmetric.

The neighborhood heat created (dQ) between the shoulder and workpiece surface on a basic zone from a separation (r) can be computed as [11]:

$$dQ = 2\,\pi\,\mu\,F_n\,\omega\,r^2\,dr \quad \ldots\ldots\ldots\ldots (1)$$

Where: μ =Coefficient of erosion shifts with temperature. In this model, a powerful μ (0.3-0.5) is considered. Fn= is pivotal burden typical to shoulder and ω is radial speed of the device.

Introductory condition for the figuring is:

$$T(x, y, t) = T_o \quad \ldots\ldots\ldots\ldots (2)$$

Introductory temperature of workpiece was thought to be barometrical temperature (To) 300 ^oK.

Vitality equalization at work surface requires other limit conditions. Particular warmth streams (qs and qp) were supplied from shoulder and stick over immediate surface of workpiece. All surfaces were presented to environment, where heat misfortune qcon. Happens going with to convection. Convective limit condition for all surfaces presented to the air is:

$$-k\,(\partial T/\partial n)_p = h(T-T_o) \quad \ldots\ldots\ldots\ldots (3)$$

Where n is normal condition vector of boundary.

All surfaces presented to climate were distributed uniform convection environment (h) of 30 $W/m^2\ ^oK$.

Workpiece surface in contact with back-plate is approximated to convection condition with a viable (h) of 300 $W/m^2\ ^oK$.

Temperature subordinate warm properties of AA6061-T6 aluminum amalgam are outlined in figure (7).

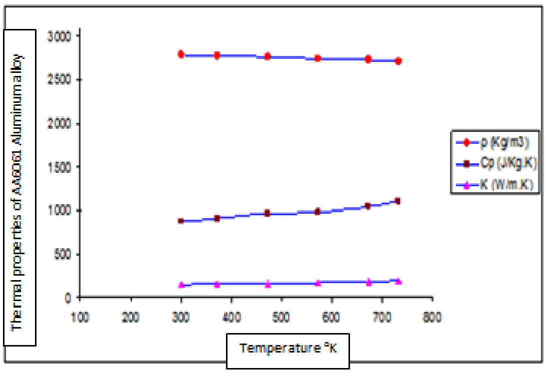


Figure (7): Thermal properties of AA6061-T6 aluminum alloy [19]

6 Results and Discussions:

Amid the entrance stage, the turning instrument pin enters into the work-piece until the apparatus shoulder comes contact with the work-piece.

convection heat exchange coefficient with support plate (300W/m2k) , convection heat exchange coefficient(30W/m2k), encompassing and beginning temperature (To=298K), slip element (δ=0.6), erosion coefficient (μ=0.4), (pivotal load=2kN) , Heat generation(Q=331watt) utilized as info welding parameters as a part of the limited component figuring with their comparing vertical power in the work-piece anticipated in fig.(5) the plasticization of material under the instrument increment with expansion rotational velocity and with abatement in apparatus cross rate coming about the decrease of vertical force.

The limited component reproduction couples the moving apparatus with the work-piece furthermore considers the warm impact of the underlying instrument pin entrance before begin of the weld.

Fig.(8a-e) present cross-sectional perspectives of the figured temperature forms in the work-piece and device at various time amid the entrance. The cross-sectional perspectives graphically represent the temperature history of the work-piece and the apparatus amid the pin penetration.

The most noteworthy temperature is seen in the focal point of the weld area stretching out down from the crown surface to the test root side, following the revolution of the shoulder and the test (pin) contributes the most elevated warmth flux in this locale. The generally higher warmth dispersal through the contact surface between the welded plate and the sponsorship plate as contrasted and the top surface the top surface of the plate causes the temperature form in the weld chunk region the take after a "V" shape.

This is a result of the moderately higher convection coefficient at the base surface of plate as contrasted and the top surface.

Fig.(9) demonstrates that the entrance of welding device in the work-piece, temperature increments with expansion apparatus infiltration when instrument pin enter into the work-piece indicates warm dissemination when the device enters in work-piece (starting the welding process), then begin moving of the device along welding line to end position of welding (haul out) and cooling of work piece. The temperature dissemination affected by warmth conduction between the work piece with installation and by convection, radiation surrounding travel speed additionally has impact on temperature conveyances build travel speed diminish temperature history. fig.(10) demonstrate the mesh element of the plate that utilize in FSW.

The outcomes as a rule, because of a blend of disintegration, coarsening and reprecipitation of fortifying hasten amid FSW [4], or limited disfigurement [7]. The main arrangement of welding parameters utilizing turn rate of 800 rpm, this examination was rehashed for other pivot paces of 1000, 1200 and 1450 rpm.

It is trusted that, to acquire top notch FSW welded joints with high mechanical properties, i.e. high welding effectiveness, the principle welding parameters (turn speed) must be precisely chosen to adjust the impact of every parameter on the measure of warmth data amid mix welding. A large portion of the FSW joints fizzled at warmth influenced zone (HAZ) on the propelling side. This is predictable with different reports on FSW of aluminum compounds, who found that the crack of FSW of warmth treatable aluminum composites for the most part happens in the HAZ, i.e. the mildest zone in the FSW joints because of noteworthy coarsening of the encourages and the improvement of free accelerates zones (FPZ). The best welding effectiveness was accomplished at 1450 rpm, with the goal that this welding condition was taken to develop the warm model.

Amid the infiltration stage, the pivoting pin enters into the work-piece until the apparatus shoulder interacts with the work-piece. The entrance time is roughly 69 sec. Figure (8) presents cross-sectional perspectives of the ascertained temperature shapes in the work-piece and apparatus at various times amid the penetration of the pin.

There is a decent understanding between the deliberate and ascertained temperature shows with the created model for the forecast of temperature history is palatable results.

Tentatively result demonstrates the temperature ahead of time side is higher than withdrew side in light of the fact that the plastic disfigurement around instrument moving from development side to withdrew side extra to contact heat under the shoulder that gives higher temperature the computational results. In this way, the slipping rates on the withdrawing and the front sides are lower than the ones on the trailing and propelling sides. This is the reason that the warmth fluxes on the trailing and the propelling sides are higher, which prompts the way that the temperatures are higher in this area for both slim plates. The outcomes at the position of the thermocouple in the reproduced warm profile toward the end of the weld procedure are contrasted and the exploratory results as appeared in figures (11-12).

It can be seen that the experimental peak temperature about 0.71 of the aluminum melting temperature during FSW and that confirms to observation of R. S. Mishra [4], who concluded the maximum temperature observed during FSW of various aluminum alloys is found to be between 0.6Tm and 0.9Tm which is within the hot working temperature range for those aluminum alloys.

7 Conclusions

- The numerically determined temperature fields match well with the experimental data. The maximum temperature during the FSW is at the weld line and within the tool shoulder. The maximum temperature determined from the simulation is 659 ^{o}k, was 0.71 from the liquefying temperature, which is significantly less than the melting temperature of 6061-T6 aluminum alloy at 925 ^{o}K.
- Temperature distribution increase with rotation speed increase because the amount of heat generation resulting from high speed.

- Numerical results (Tmax = 626 °K) agreement with measured data (Tmax = 659 °K) (error 8.5 %); at 1450 rpm

.

8 References

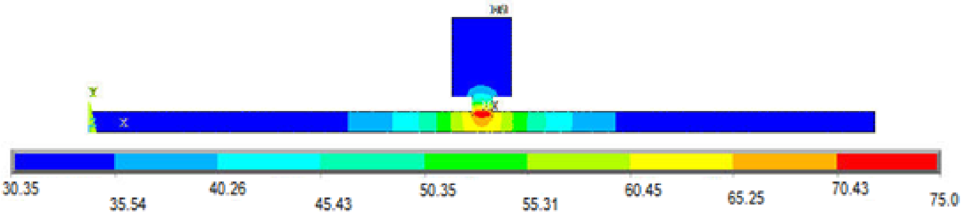
1-Christian B. Fuller, Murray W. Mahoney, Mike Calabrese, Leanna Micona, "Evaluation of microstructure and mechanical properties in naturally aged 7050 and 7075 Al friction stir welds", Journal of Materials Science and Engineering, November 2009, pp. 2233-2240.

2- N. T. Kumbhar and K. Bhanumurthy, "Friction Stir Welding of Al 6061 Alloy", Asian J. Vol. 22, No. 2, 2008, pp. 63-74.

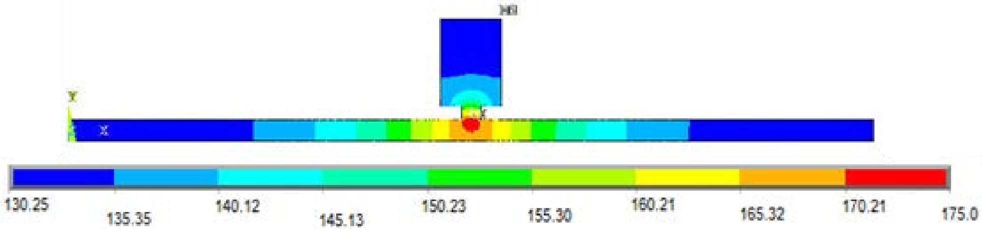
3- G. M. Xie, Z. Y. Ma and L. Geng, "Development of a fine-grained microstructure and properties of a nugget zone in friction stir welded pure copper", Script Material, April 2007, Vol. 57, pp. 73-76.

4- R. S. Mishra and Z. Y. Ma, "Friction stir welding and processing", Materials Science and Engineering, August 2005, pp. 1-78.

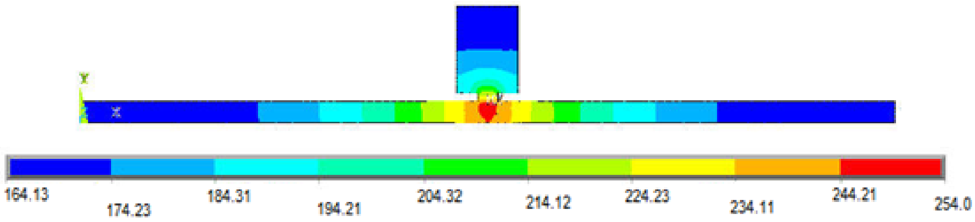
5- K. Kumar. Satish V. Kailas, "On the role of axial load and the effect of interface position on the tensile strength of a friction stir welded aluminum alloy", Materials and Design, January 2007, Vol. 29, pp. 791-797.



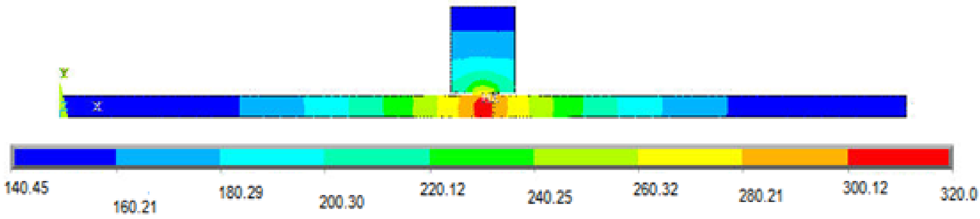
(a)Temperature °C / 14 sec



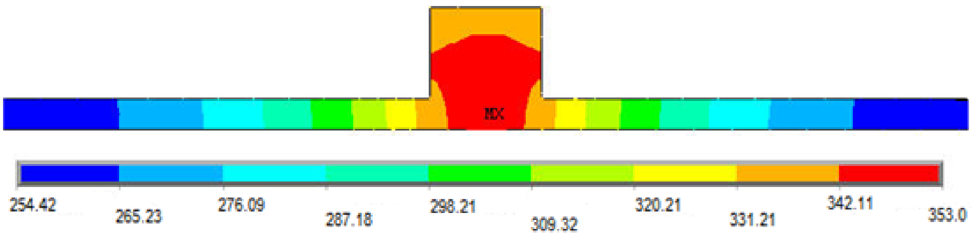
(b)Temperature °C / 42 sec



(c) Temperature °C / 51 sec



(d)Temperature °C / 58 sec



(e) Temperature °C / 69 sec

Figure (8): Temperature-time history for tool and work-piece during tool penetration

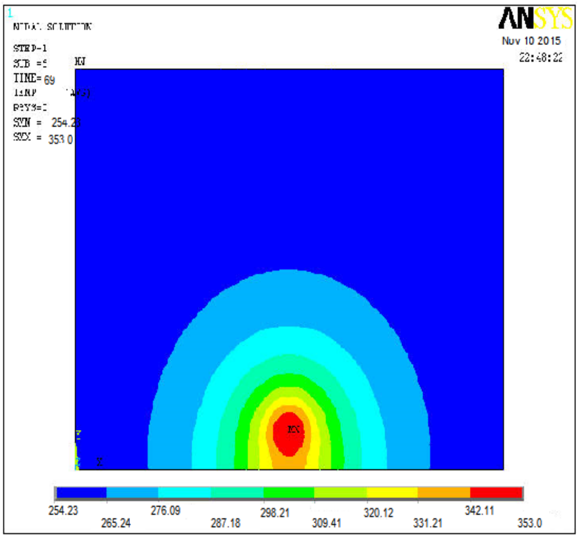


Figure (9): numerical results for temperature Distribution at time 69 sec (Dwell) at 1450rpm

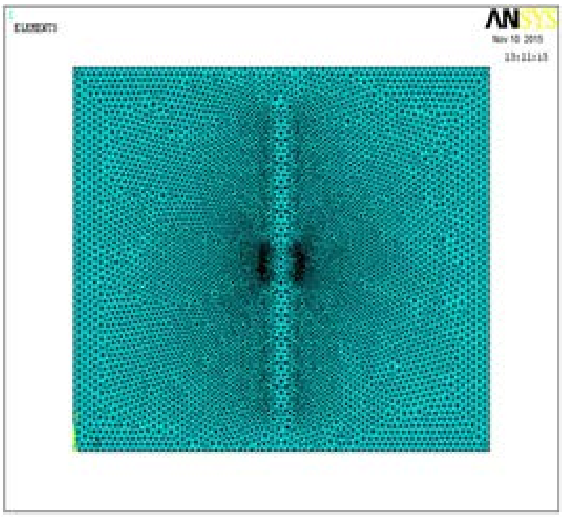


Figure (10): Mesh element for specimen

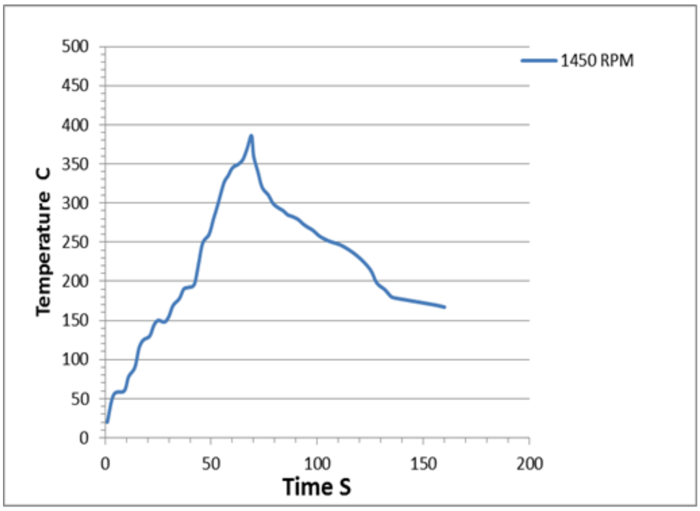


Figure (11): The experimentally of the modeled and measured temperature for thermocouple in 1450rpm

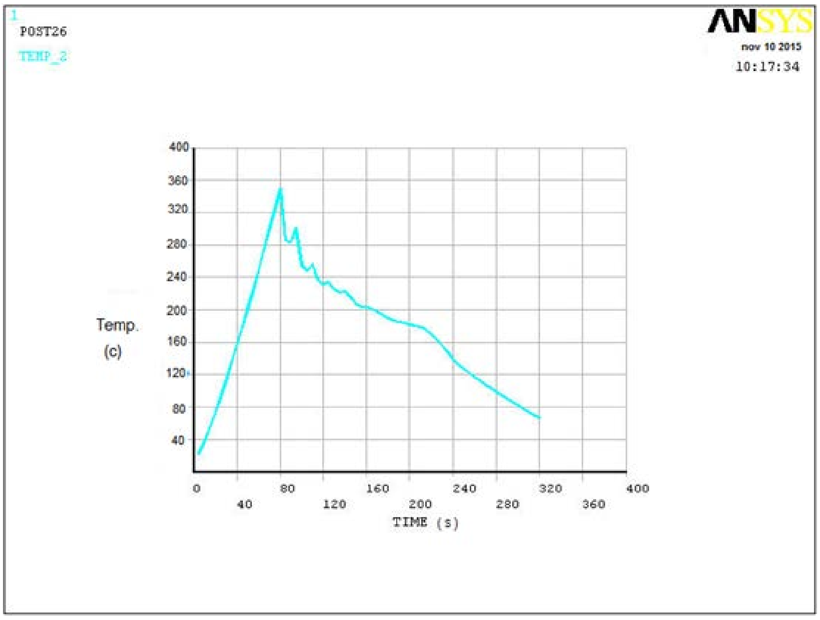


Figure (12): The FEM diagram for the temperature and time

6- M. A. Sutton, B. Yang, A. P. Reynolds, R. Taylor, "Microstructural studies of friction stir welds in 2024-T3 aluminum", Materials Science and Engineering, March 2002, pp. 160-166.

7- S. R. Ren, Z. Y. Ma, L. Q. Chen, "Effect of welding parameters on tensile properties and fracture behavior of friction stir welded Al-Mg-Si alloy", Script Material, Vol. 56, October 2006, pp. 69-72.

8- M. A. Gaafer, T. S. Mahmoud, E. H. Mansour, "Microstructural and mechanical characteristics of AA7020-O Al plates joined by friction stir welding", Materials Science and Engineering, August 2010, pp. 7424-7429.

9- Husam Okuyucu, Adem Kurt, Erol Arcaklioglu, "Artificial neural network application to the friction stir welding of aluminum plates", Materialia and Design Vol. 28, August 2007, pp. 78-84.

10- Weifeng Xu, Jinhe Liu, Guohong Luan, Chunlin Dong, "Temperature evolution, microstructure and mechanical properties of friction stir welded of aluminum joints", Materials and Design, Vol. 30, September 2008, pp. 1886-1893.

11- N Rajamanickam, V Balusamy, P. R. Thyla and G Hari Vignesh, "Numerical simulation of thermal history and residual stresses in friction stir welding of Al2024-T6", Journal of Scientific and Industrial Research, Vol. 68, March 2009, pp.192-198.

12- V. Soundararajan, M. Valant and R. Kovacevic, "An overview of R&Ad. work in friction stir welding at SUM", Association of Metallurgical Engineering ", Vol. 669, pp. 275-294.

13- X. K. Zhu, Y. J. Chao, "Numerical simulation of transient temperature and residual stresses in friction stir welding of 304L stainless steel", Journal of Materials Technology, Vol. 146, October 2004, pp.263-272.

14- Muhsin. J. Jweeg, M. H. Tolephih and Muhammed Abdul. Sattar, "Influence of Tool Geometry on the Quality and Mechanical Properties of FSW Weldment for Al-alloy (7020-T53)", Nahrain University, College of Engineering Journal (NUCEJ) Vol.17 No.1, 2014 pp36-49.

15- Muhsin. J. Jweeg, M. H. Tolephih and Muhammed Abd. Sattar, "Theoretical and Experimental Investigation of Transient Temperature Distribution in Friction Stir Welding of AA 7020-T53", Journal of Engineering, Baghdad, Vol.18, June 2012, pp.693-709.

16- Muhsin J. J., Moneer H. Tolephih and Muhammed A. M., "Effect of Friction Stir Welding Parameters (Rotation and Transverse) Speed on the Transient Temperature Distribution in Friction Stir Welding of AA 7020-T53", ARPN Journal of Engineering and Applied Sciences, Vol. 7, No. 4, April 2012, pp. 436-446.

17- H. FUJII, M. MAEDA, K. NOGI, "Tensile properties and fracture locations of friction-stir welded joints of 6061-T6 aluminum alloy", JOURNAL OF MATERIALS SCIENCE LETTERS, No.22, 2003, pp.1061 – 1063.

18-ANSYS® Release12.1 Documentation, ANSYS Inc, 2009.

19- Chao, Y.J. and Qi, X.H., “Thermal and Thermo-Mechanical Modeling of Friction Stir Welding of Aluminum Alloy 6061-T6”. Journal of Materials Processing & Manufacturing Science, 7(2), 1998, pp. 215-233.

تأثير السرع الدورانية للحام الخلط الاحتكاكي في طور التغلغل على توزيع درجات الحرارة لسبيكة الالمنيوم (6061-T6)

رشيد نعمة عبد
كلية الهندسة, جامعة النهرين, بغداد - العراق

الخلاصة:

في هذا البحث تم دراسة تاثير طريقة لحام الخلط الاحتكاكي (FSW), و طريقة اللحام هذه تعمل كدور اساسي في تاثيرها على الخواص الميكانيكية والتركيب البلوري للعينة المستخدمة, بسبب الحرارة المتولدة نتيجة الاتصال بين العينة والصفيحة. العينة كانت عبارة عن صفيحة من سبيكة الألمنيوم (AA6061-T6) وكانت قياساتها المختبرية (186* 150* 4) ملم^3 وتمت عملية اللحام باربعة قيم لسرع دورانية هي (1450,1200,1000,800) دورة/دقيقة. وكمية درجة الحرارة الناتجة من اللحام الدوراني والتي كانت هي اساس هذا البحث تم قياسها بواسطة مزدوج حراري مغروس داخل الصفيحة وموصل الى قاريء الكتروني, وتم استخدام موديل للعناصر المحددة(ANSYS 12.1) للتوزيع الحراري لفهم الظواهر التي تقع خلال طور التغلغل لاداة اللحام في لحام الخلط الاحتكاكي. وكانت النتائج النظرية قد وضحت موافقة جيدة مع النتائج العملية المقاسة لدرجة الحرارة بواسطة المزدوج الحراري. وبينت النتائج ان اقصى درجة حرارة تم الوصول اليها هي (0,71) من درجة الانصهار للعينة عند اقصى سرعة دورانية وهي (1450) دورة/دقيقة.