ARPN Journal of Engineering and Applied Sciences

©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

THE CHARACTERISTIC OF TEMPERATURE CURVES FOR FRICTION STIR WELDING OF ALUMINIUM ALLOY 6063-T6 PIPE DURING TOOL PLUNGING STAGE

Azman Ismail[1], Mokhtar Awang[2], Mohd Afendi Rojan[3] and Shaiful Hisham Samsudin[2]

[1]Institute of Marine Engineering Technology, Universiti Kuala Lumpur Malaysian, Lumut, Malaysia

[2]Departmental of Mechanical Engineering, Universiti Teknologi PETRONAS, Tronoh, Malaysia

[3]School of Mechatronics Engineering, Universiti Malaysia Perlis, Pauh Putra, Malaysia

E-Mail: azman@unikl.edu.my

ABSTRACT

Friction stir welding (FSW) is originally designed to cater to metals which are difficult to weld such as aluminium. This solid state joining process utilizes frictional heat produced by the high rotating tool to soften and stir (joint) these adjoining sections together without utilizing filler metal or shielding gas. The present study analyzes the characteristic temperature curves during the plunging stage of this high rotating tool. About four (4) points of selected location on both advancing and retreating side were measured by K-type thermocouples and recorded using a NI Signal Express on a laptop. It was found that the advancing side gave higher temperature curves compared to the retreating side.

Keywords: friction stir welding, AA6063-T6 Pipe, temperature curves, thermocouple, NI signal express.

INTRODUCTION

Friction stir welding is a solid state joining process which is originally invented to cater for difficult-to-weld materials such as aluminium alloys [1-2]. Nowadays, with substantial research done, it can be used to weld harder materials such as steel and titanium [3-4]. FSW is a well-known manufacturing process especially in aerospace and petrochemical sector [5-6]. FSW is considered as a green process which produces no arc and fumes, and requires no filler metals and shielding gas.

The operating range of FSW is performed below the melting temperature where the high rotating tool plunges into the joint line, softens the adjoining metals and stirs to join both metals together soundly with fundamentally defect-free cross-sectional welded joints. The stirring action causes the area to deform into several sections such as intensively deformed stirred zone (SZ), thermo-mechanically affected zone (TMAZ), heat affected zone (HAZ) and base metal (BM) as shown in Figure-1 [1].

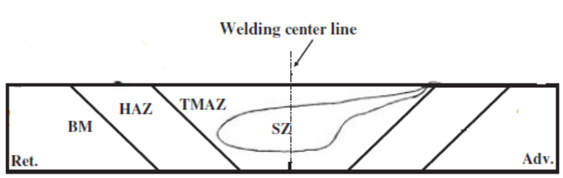

Figure-1. Layout at transverse cross section of welded joints.

The frictional heat of the high rotating tool softens the adjoining sections and materials starts to flow around the probe, transferring the materials from advancing to retreating and vice versa in order to form the joining. With operating below the melting points, defect-free weld can be achieved and the mechanical properties of welded joint exhibits better characteristics than fusion arc welding [1, 6]. The present study analyzed the characteristic temperature curves for friction stir welding of pipe during the plunging stage of this high rotating tool at required rotational speed.

MATERIAL AND METHODS

The friction stir welding was carried out on several sets of two AA6063-T6 pipe with the outside diameter of 89mm, nominal wall thickness of 5mm and length of 40mm each. These pipes were then secured tightly onto a customized orbital clamping unit (OCU) which acts as a jig in this experiment setting. This OCU was fixed securely onto a Bridgeport 2216 CNC milling machine. The utilization of OCU was to hold the pipes tightly during the friction stir welding process, rotated the pipe slowly at the required travel speed and lastly ensured easy removal of pipe samples after the welding process.

A H13, surface-hardened high carbon steel tool with a shoulder diameter of 20mm, pin's diameter of 5mm and pin's length of 3.8mm was used in this experiment setting. The experimental setup with the 4 units of K-type thermocouples were attached on it as indicated in Figure-2. The tool was offset at 6mm forward from the centerline as shown in Figure-3. The offset position was to ensure

VOL. 11, NO. 1, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.
www.arpnjournals.com

and maintain the maximum surface contact between the tool's shoulder and pipe during full weld cycle. At the same time, the plowing effect towards the joining or contact area was established in order to eliminate weld defects.

The cross sectional view with the positioning of these 4 K-type thermocouples is shown in Figure-4. The tool was rotated at certain rotational speed, with plunge rate at 10mm/min, after the surface of tool's shoulder in contact with outer surface of pipe; the dwell time was set for 30s. Once completed, the tool was retracted to its original position as per before welding. The temperature data was experimentally recorded using NI Signal Express on a laptop for selected rotational speeds as shown in Table-1.

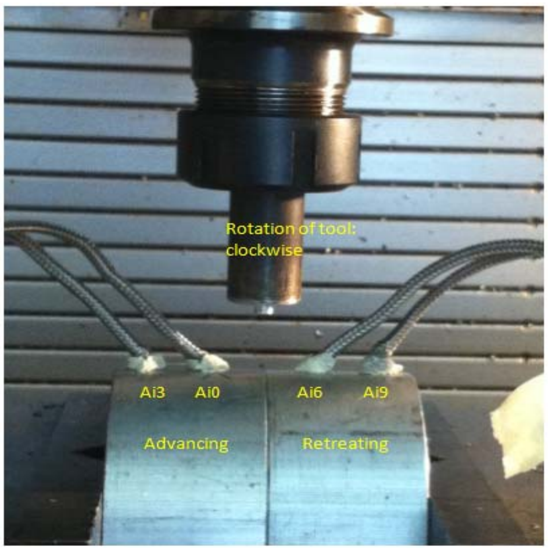

Figure-2. Experimental setup.

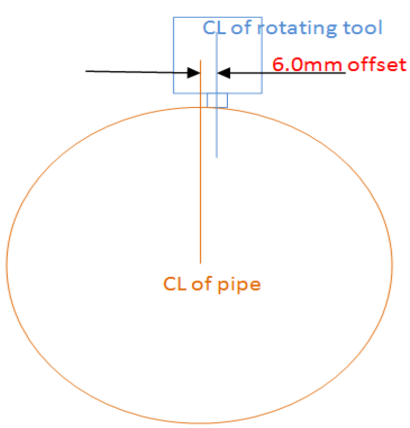

Figure-3. Side-view of offset tool.

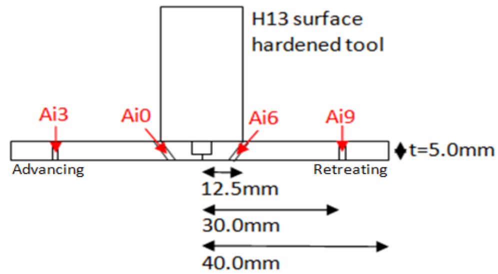

Figure-4. Cross sectional view and K-type thermocouples positioning.

The two thermocouples such as Ai0 and Ai6 were set on advancing and retreating side each at the 45^0 position each in order to be located at the nearest position towards the pin tool and below the tool's shoulder. The aim of this position was to get the temperature reading as nearest as possible towards the tool's pin. The two more thermocouples such as Ai3 and Ai9 were set to measure the temperature on HAZ section of advancing and retreating side each respectively. The gathered temperature was then plotted for comparisons.

Table-1. Welding parameters.

FSW sample	Rotational speed (rpm)	Plunge depth (mm)	Plunge rate (mm/min)	Dwell time (s)
FSW#1	900	4	10	30
FSW#2	1100	4	10	30
FSW#3	1300	4	10	30
FSW#4	1500	4	10	30
FSW#5	1700	4	10	30

RESULT AND DISCUSSIONS

Based on Figures 5-9, the temperature curves on the advancing side are higher (but still below the melting point) than the retreating side for all rotational speed settings. These findings are similar with that of Saad et al where it shows the same patterns of high temperature on advancing than the retreating side [1].

During the plunging stage at the rate of 10mm/min each, the increment of temperatures was detected. It took about 23s to reach full contact with the surface of shoulder for a plunging depth of 4mm. In order to complete the cycle for this experiment, it took about 54s. The temperature nearby the tool gave higher reading compared to HAZ section for the same side, advancing and retreating, with a higher temperature reading surely on advancing than the retreating side.

The temperature reached the highest value once in full contact between the surface's shoulder and pipe. The consistency of temperature reading depended on the contact between these 2 surfaces and also the

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.
www.arpnjournals.com

thermocouples. In order to maintain the accuracy of temperature reading, a special high thermal conductivity glue OMEGABOND (for thermocouple) as proposed by [3] should be utilized. The same temperature pattern occurred for all selected rotation speed of FSW#1 - FSW#5 in this experiment setting.

The materials flow on advancing side was severer than on the retreating side due to the movement of tool and pipe rotation against each other during the friction stir welding process. Therefore severe plastic deformation was caused which eventually gave rise of temperature on the advancing more than retreating side. The temperature increased when the rotational speed increased due to the severe plastic deformation caused by high stirring process [1-3, 5]. The increment of temperature tended to give similar increment pattern during the plunging mode on both advancing and retreating side respectively but started to give a distinguished temperature differences on both advancing and retreating within 30s dwell time. Within this dwell time, the outer surface of pipe should be in full contact with the tool's surface shoulder where the additional stirring process occurred on the outer surface of this pipe.

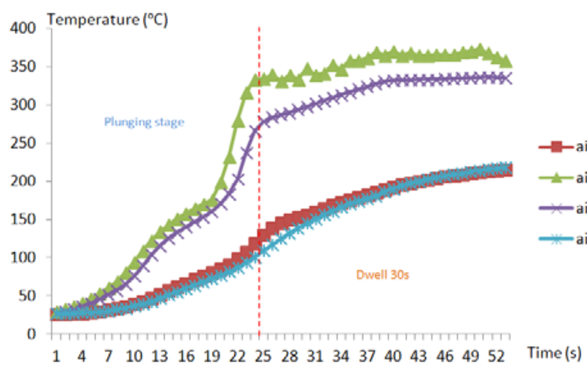

Figure-5. Temperature curve at rotational speed of 900 rpm.

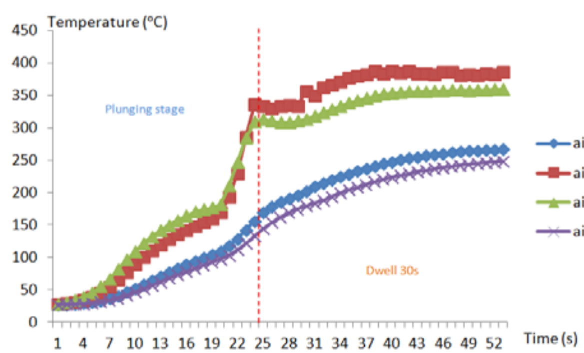

Figure-6. Temperature curve at rotational speed of 1100 rpm.

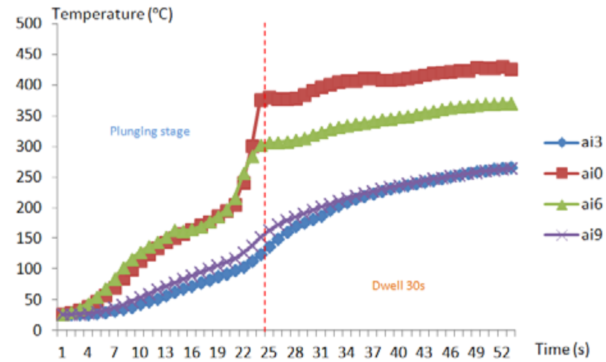

Figure-7. Temperature curve at rotational speed of 1300 rpm.

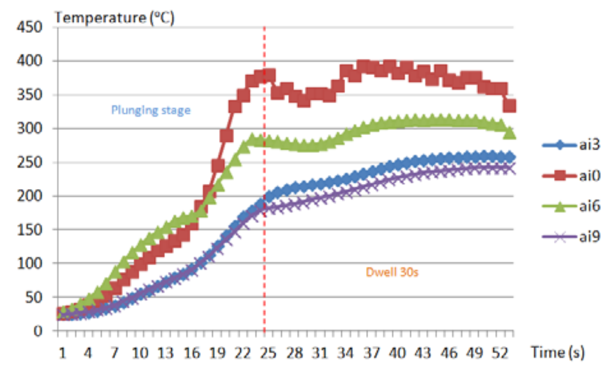

Figure-8. Temperature curve at rotational speed of 1500 rpm.

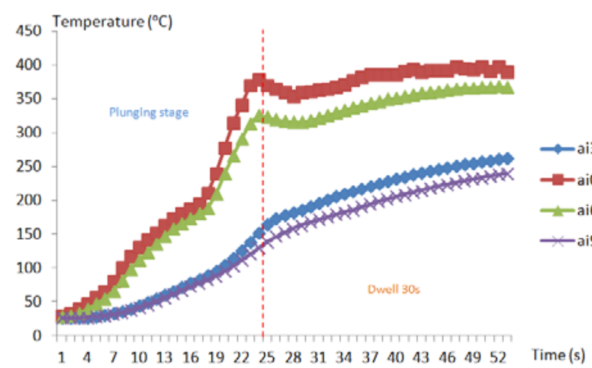

Figure-9. Temperature curve at rotational speed of 1700 rpm.

The rotation of tool and pipe gave an additional effect in determining this phenomenon whereby more materials flow to be pushed forward on the advancing side compared to when it was brought inside on the retreating side. The offset position of tool added additional

ARPN Journal of Engineering and Applied Sciences
©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

temperature at the wider contact related to the level of severity of material flow caused by this condition.

The nearest point towards the pin tool gave differences in the temperature between these two sides, whereas advancing gave more increment in temperature curves than the retreating side. The same temperature pattern occurred at the position 30 mm away from the centerline for both sides, whereby there was a slight increase in temperature on the advancing than retreating side.

CONCLUSIONS

Based on the temperature curves gathered from this experiment during the plunging stage, several conclusions can be made as follows:

a. The temperature increased with the increment of the rotational speed.
b. The advancing side gave higher temperature curves than retreating side, with the increment of rotational speed.
c. The temperature difference between advancing and retreating side at weld center varied from 5% to 25%.
d. The peak temperature on advancing side during 24s plunging stage was recorded at 1700 rpm for 378°C

ACKNOWLEDGEMENT

The authors would like to record special thanks to Dr Puteri Zarina Megat Khalid for her assistance during the writing of this article.

This study was funded by Majlis Amanah Rakyat (MARA) under MARA Product and Innovation Grant Scheme (SGPIM), MARA/UNI: 1/33/03/01/14 (3) and also Ministry of Higher Education Malaysia under Fundamental Research Grant Scheme No.9003-00411.

The research facilities provided by Universiti Teknologi PETRONAS (UTP) and Universiti Kuala Lumpur Malaysian Institute of Marine Engineering Technology (UniKL MIMET) were greatly acknowledged.

REFERENCES

[1] Saad Ahmed Khodir, Toshiya Shibayanagi and Masaaki Naka. 2006. Microstructure and Mechanical Properties of Friction Stir Welded AA2024-T3 Aluminum Alloy Materials Transactions, Vol. 47, No. 1, pp. 185 to 193, The Japan Institute of Metals.

[2] Lammlein DH, Gibson BT, DeLapp DR *et al*. 2010. Friction stir welding of small diameter pipe: an experimental and numerical proof of concept for automation and manufacturing. Proc Inst Mech Eng Part B: 1-16.

[3] Yuh J Chao, X Qi, W Tang. 2003. Heat Transfer in Friction Stir Welding - Experimental and Numerical Studies, Journal of Manufacturing Science and Engineering, Vol. 125, Transaction of the ASME. pp. 138-145.

[4] Defalco J, Steel R. 2009. Friction stir process now welds steel pipe. Weld J Am Weld Soc. 88 (5): 44-48.

[5] C. Hamilton, S. Dymek, and A. Sommers, 2010. Characteristic Temperature Curves for Aluminum Alloys during Friction Stir Welding, Welding Journal, Vol. 89, AWS. pp. 189s-194s.

[6] Kumar A, Fairchild DP, Macia ML *et al*. 2011. Evaluation of economic incentives and weld properties for welding steel pipelines using friction stir welding. In: Proceedings of the international offshore polar engineering conference. pp. 460-467.