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INVESTIGATION OF SINGLE-PASS/DOUBLE-PASS TECHNIQUES ON FRICTION STIR WELDING OF ALUMINIUM

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ABSTRACT

The aim of this research is to study the effects of single-pass/ double-pass techniques on friction stir welding of aluminium. Two pieces of AA1100 with a thickness of 6.0 mm were friction stir welded using a CNC milling machine at rotational speeds of 1400 rpm, 1600 rpm and 1800 rpm respectively for single-pass and double-pass. Microstructure observations of the welded area were studied using an optical microscope. The specimens were tested by using a tensile test and Vickers hardness test to evaluate their mechanical properties. The results indicated that, at low rotational speed, defects such as ‘surface lack of fill’ and tunnels in the welded area contributed to a decrease in mechanical properties. Welded specimens using double-pass techniques show increasing values of tensile strength and hardness. From this investigation it is found that the best parameters of FSW welded aluminium AA1100 plate were those using double-pass techniques that produce mechanically sound joints with a hardness of 56.38 HV and 108 MPa strength at 1800 rpm compared to the single-pass technique.

Keywords**:** Friction stir welding; single-pass/ double-pass techniques; AA1100; microstructure; mechanical properties.

INTRODUCTION

Friction stir welding (FSW) is a novel solid-state welding technology that has been widely used for joining alloys and metals. The FSW process performs below the solidus temperature of the metals being joined and the use of filler material is not required as in conventional welding processes such as MIG welding [1-4]. It is also relatively easy to perform and produce a seamless joint. FSW produces welds that are high in strength, of good quality and release no fumes during the process, and is also energy efficient [5, 6]. During the FSW process, a non-consumable rotating tool with a pin and shoulder that provide ‘stir’ action is inserted into the abutting edges of the plates to be joined and will traverse along the joint line. The rotating tool moves along the weld line and develops frictional heating of the material, causing it to plasticize where it cools and consolidate to produce a high integrity weld [7-9]. Even so, there are still several defects that need to be addressed in FSW, such as worn holes, tunnels and ‘surface lack of fill’ defects at the weld joint of the aluminium alloy. These defects can lead to the degradation of the tensile properties and ductility strength of the welded material [10-14]. As the welded joint is the crucial part and is heavily affected by the proper selection of parameters, the proper technique of friction stir welding should be taken into consideration. Some attempts have been made on single-pass and double-sided FSW passes. Rohilla et al. [15] studied the effects of tool geometry on the mechanical properties of friction stir welding of AA6061 with 6 mm thickness for single- and double-sided friction stir welds. Mehra et al. [16] investigated the effect of the tool on the tensile strength in single- and double-sided friction stir welding of Al19000-H12. A comparison of single- and double-pass friction stir welding of skin-stringer aviation aluminium alloy was studied by He et al. [17]. Du Pont et al. [18] also investigated the characterization of the microstructural development and corrosion resistance of friction welds on SASS using double-pass techniques. Thompson et al. [19] studied the friction stir welding of thick section aluminium for military applications using single- and double-sided FSW. From all of the above studies, the double-pass results shows improvement and it is proved and confirmed that the joint strength and percentage elongation of the welds of double-sided joints are better than for single-pass joints. On the other hand, this study is also about the development of the FSW process in Malaysia, where conventional welding methods such as MIG and tungsten inert gas (TIG) welding are still widely used and the FSW process can be performed using a CNC milling machine. From the previous studies, using double-sided passes will increase the joint strength and reduce the bottom defects of the workpiece compared to single-pass welding. Hence an attempt has been made to look into the effects of using single-pass or double-pass techniques on the weld strength and defects that may arise during the welding process of aluminium sheets. The microstructure observation and mechanical properties of the weld joint are also investigated.

MATERIALS AND METHODS

Materials

The type of aluminium plate used in this study was AA1100 and had the chemical composition listed in Table 1. The plate was cut using a bandsaw machine with dimensions of 80 mm x 35 mm × 6 mm. It was then side-ground to provide a smooth surface, eliminate cutting burr and for accurate measurement. Meanwhile, the tool used for the FSW process was a mild steel type and was fabricated using a lathe machine to the required dimensions presented in Table 2. Figure 1 shows the tool design that was used in the FSW process and Table 1 shows the composition of the AISI 1018 mild steel [20]. A mild steel backing plate was used to support and hold the workpiece firmly to avoid slip-off between them or any forcing apart between the workpiece during the FSW process.

Table 1. Nominal chemical composition of aluminium wrought alloys and mild steel (composition%).

UNS Number	Si	Fe	Cu	Mn	C	S	Ni	Zn	P	Each	Total
AA1100	1.0	+Si	0.05-0.20	0.05	-	-	-	0.1	-	0.05	0.15
AISI 1018	-	99.3		0.90	0.20	0.05	-	-	0.04	0.05	0.15

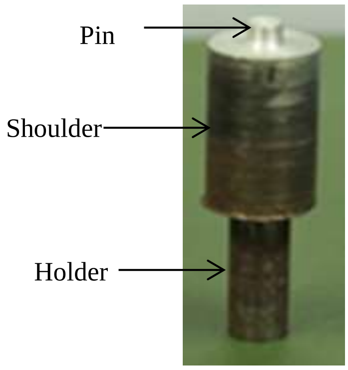

Figure 1. FSW tool design.

Table 2. Tool dimensions.

Pin	Values (mm)
Pin length,	5.5 (Single-pass), 3.0 (Double-pass)
Tool shoulder diameter, D	18
Pin diameter, d	6
Holder diameter	8
Holder length	36
Shoulder length	10

FSW Process

The FSW process was carried out using the VF6 CNC Milling Centre machine. The process was performed by using a first group with the single-pass (Group A) technique followed by the second group with double-pass (Group B) techniques, at three consecutive values of rotational speed: 1400 rpm, 1600 rpm and 1800 rpm respectively. Figure 2 shows the clamping in the CNC milling machine for the FSW process. The FSW tool is clamped in the CNC milling machine anvil.

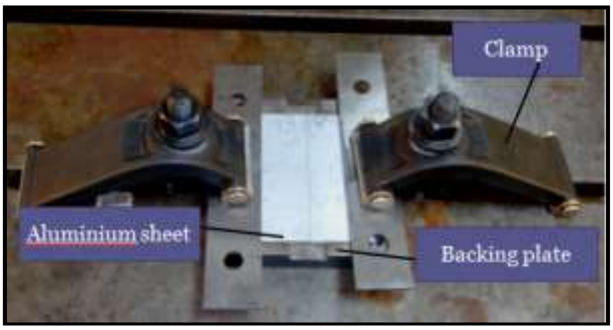

Figure 2. Clamping in CNC milling machine.

Sample Characterization

For microstructure analysis, the specimens were ground with 240, 320, 400 and 600 grit papers in increasing order. To remove scratches, specimens were then polished using 6 and 0.05 μm polishing plates and were lastly etched by immersion in NaOH solution. The microstructure of the welded specimens was observed using an optical microscope (Motic Images Plus 2.0 software). The hardness value was investigated using a Vickers hardness test machine (MMT-X7), while the tensile strength of the welded specimens was investigated using a tensile test machine (INSTRON). The dimensions of the tensile specimen are a rectangular shape using the ASTM E8 standard.

RESULTS AND DISCUSSION

Weld Appearance and Microstructure

Figure 3 shows the FSW welded samples and cross-sections for the single-pass (Group A) and double-pass techniques (Group B) with different rotational speeds of 1400 rpm, 1600 rpm and 1800 rpm respectively. For both groups, the best weld appearance is produced at 1800 rpm, because the joint surface is clear of burr and 'surface lack of fill' defects and has a smooth surface compared to the 1400 rpm and 1600 rpm samples [10]. Group B samples show a better weld appearance and have fewer defects compared to Group A. The weld appearance is proportional to the heat input being supplied during the FSW joints. From Figure 3(A), the 'surface lack of fill' defect is caused by an insufficient flow arm formation across the top surface and not enough forge pressure. Another defect that occurred is surface galling, which is due to the material sticking to the tool pin and the low travelling speed. These defects can reduce the strength of the weld joints but can be prevented by increasing the axial force pressure and increasing the rotational speed so that the stirring action between materials will smooth the formation of the flow arm at the weld line [10].

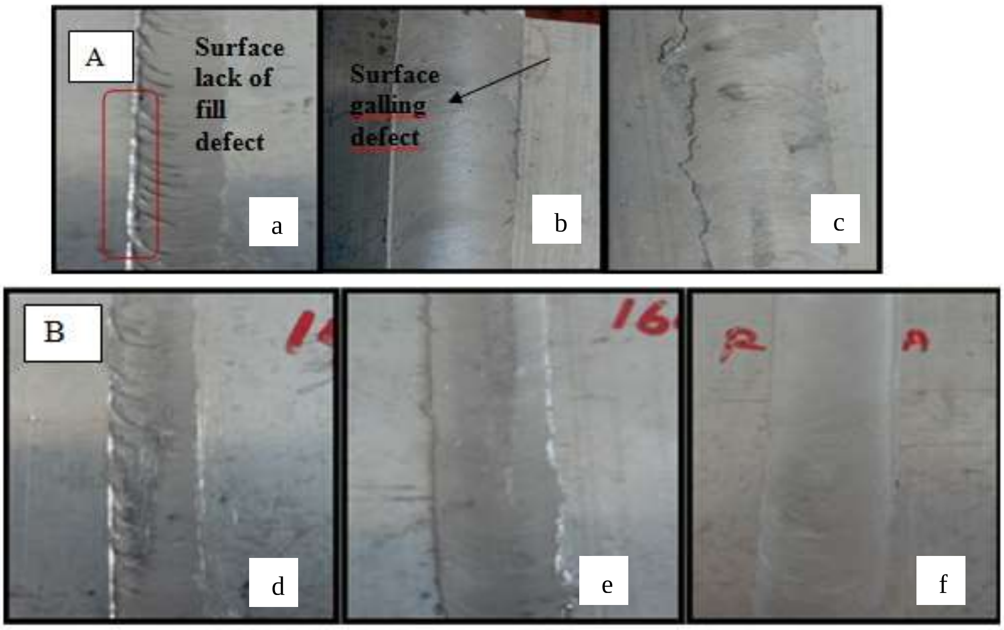

Figure 3. Weld appearance for Group A at rotational speeds of (a) 1400 rpm, (b) 1600 rpm, and (c) 1800 rpm, and Group B at rotational speeds of (d) 1400 rpm, (e) 1600 rpm, and (f) 1800 rpm.

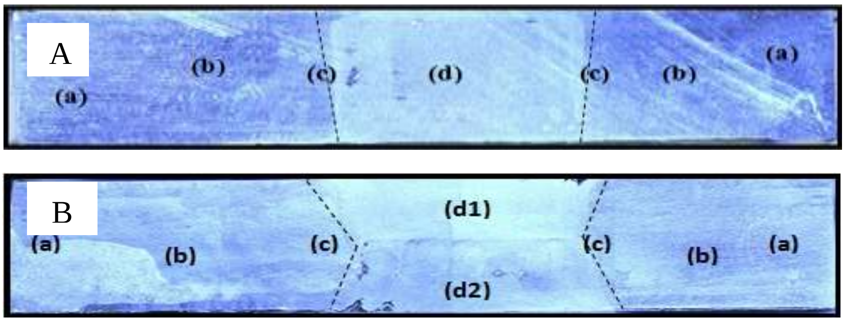

Figure 4. (a) Cross-section of FSW welded joints for Group A and (b) cross-section of FSW welded joints for Group B.

Figure 4 shows the weld regions for both Group A and Group B. Referring to Figure 4 (a) and (b), heat and deformation generated during FSW produce four micro-structural regions across the weld. These are the heat-affected zone (HAZ) shown as (b), thermomechanically affected zone (TMAZ) shown as (c), dynamically recrystallized zone or weld nugget shown as (d), and the unaffected material or base metal [21]. The outermost portion of the weld, HAZ (b), has been modified by the thermal field from the FSW welding process but there are no deformation changes in the grain structures. Adjacent to the HAZ is the TMAZ portion (c), where the material undergoes plastic deformation caused by the stirring action, in addition to the heat-induced microstructural changes [22]. At the fusion zone, mainly at the centre portion of the weld, the aluminium alloys have undergone significant grain refinement that is called the weld nugget or portion (d), which is about the size of the rotating pin of the tool. The unaffected, or base metal or portion (a), is material that is slightly heated but is not modified by the thermal field [23].

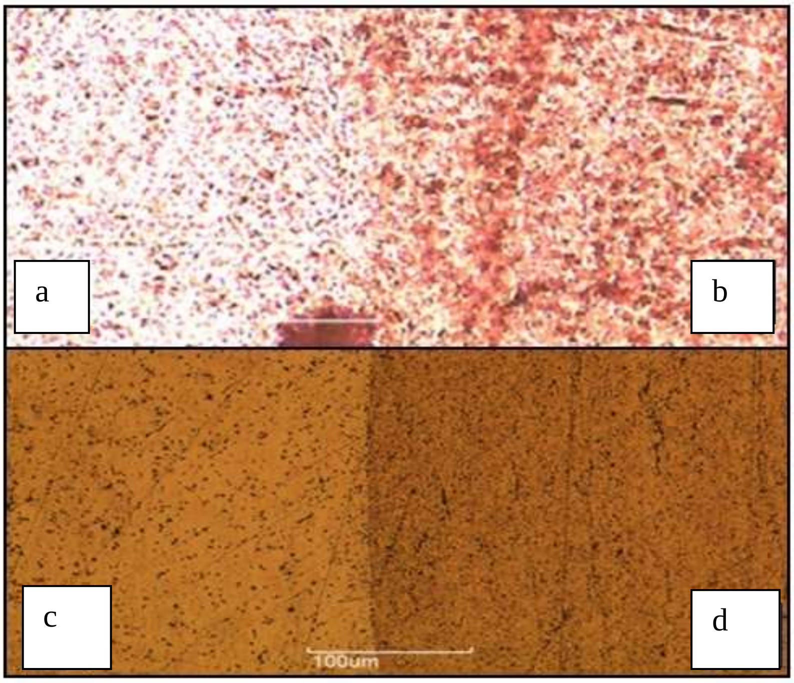

Figure 5. Microstructure of (a) TMAZ and (b) weld zone for Group A, and (c) TMAZ and (d) weld zone for Group B.

Mechanical Properties

The microstructure analysis was conducted to reveal the grain structure of the weld joints. The microstructure of the TMAZ and weld zone was taken in the weld cross-section of Group A and Group B respectively, as shown in Figure 5. It was observed that Group A (Figure 5a) had a coarser TMAZ grain size compared to Group B (Figure 5(c)). The grain structure of Figure 5(d) is seen to be finer than Figure 5(b) and it shows that full crystallization takes place in this zone, where heat generated from the interaction of the pin tool has deformed the grain boundaries [10]. As well as the differences between Group A and Group B, according to the differences of grain structure, unclear formation of grain structure deformation can be seen in the specimens. This is due to the chemical composition of the aluminium AA1100, which is pure aluminium content and is non-heat-treatable [24].

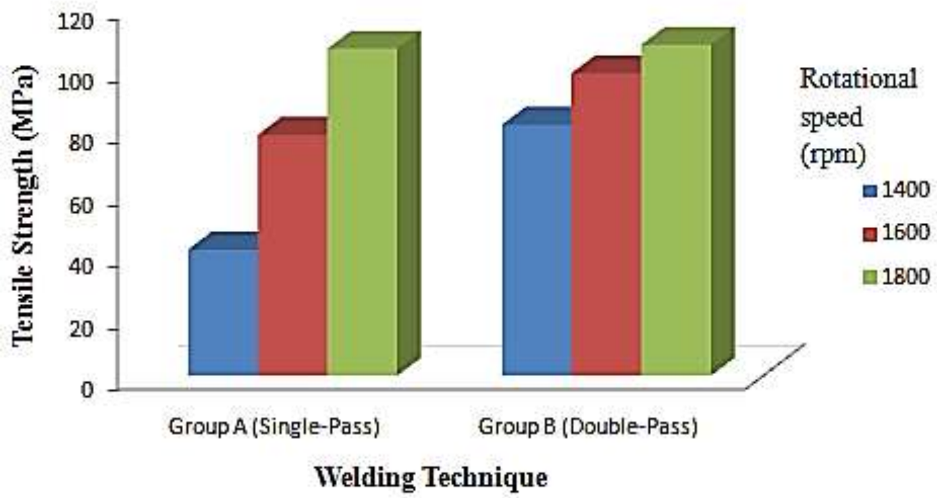

Figure 6. Comparison of tensile strength of Group A and Group B at different rotational speeds.

Tensile tests and Vickers hardness tests were conducted for mechanical properties analysis. Figure 6 shows the results of the tensile test for Group A and Group B. From the graph, it can be observed that Group B has higher tensile strength than Group A. Even at the rotational speed of 1800 rpm, the double-pass results in a slight increase in the tensile strength value, which is 108 MPa compared to the single-pass that obtains 106 MPa. At low rotational speed, the low tensile strength values are due to the 'surface lack of fill' defect and voids that exhibit higher crack propagation, which results in fracture. The tensile strength of both groups at 1800 rpm is higher due to the absence of any obvious defects. It can be concluded that, as the rotational speed increases, the tensile strength increases because higher tool rotation generates a higher temperature because of higher friction heating and results in more intense stirring and mixing of the materials [25, 26]. Group B also show better tensile values compared to Group A.

Figure 7 shows the Vickers hardness values at the weld zone for Group A and Group B, where similar trends of hardness values in the weld zone at different rpm were observed for both groups. From the graph, at the centre of the weld area, the hardness decreases with the decrease in rotational speed and the highest hardness values are

55.79 HV and 56.38 HV for Group A and Group B respectively. The rotational speed of 1600 rpm for both groups gives the lowest hardness value, possibly because of the insufficient heat input due to the poor welding technique at this speed, since there is a lack of references that could indicate the reason otherwise. At 1800 rpm in Group B, the hardness value is also higher than for Group A, which is due to the intense stirring and mixing action generated by the higher rotational speed, which increases the heat supplied to the weld zone [5].

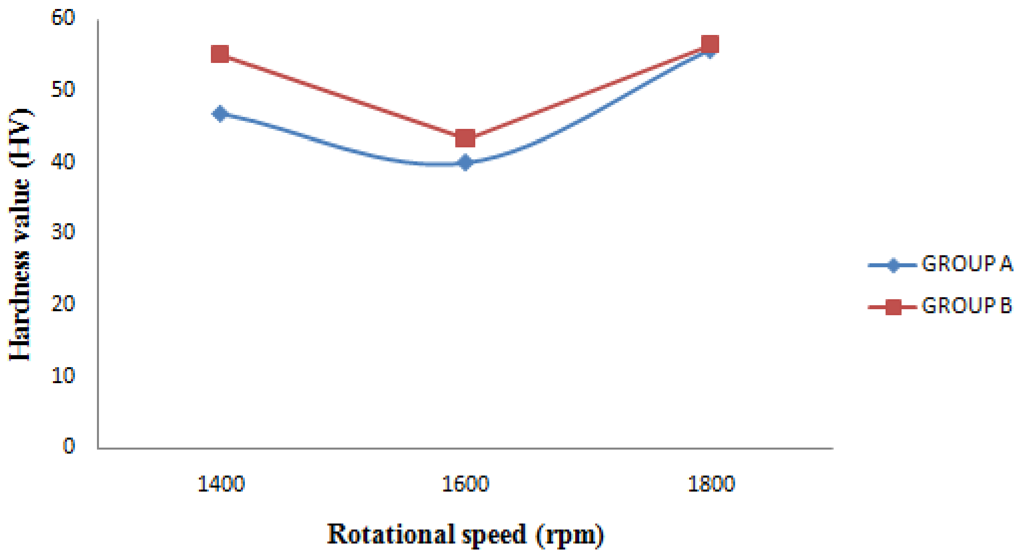

Figure 7. Summary of hardness values at weld zone for Group A and Group B.

CONCLUSIONS

A study of the FSW process using single-pass and double-pass techniques was successfully conducted and the following important conclusions were derived.

i) The weld quality and surface appearance at 1800 rpm resulted in a better surface appearance for both the single-pass (Group A) and double-pass (Group B). Finer grains are observed at 1800 rpm for Group B and have a slight difference in grain structure compared with Group A.

ii) The highest hardness value from the weld results is 56.38 HV from Group B, irrespective of the tool's rotational speed, and has improved the ductility of the weld. The tensile strength of Group B, at 108 Mpa, indicates the highest tensile value compared to Group A.

iii) The evolution of the microstructure and the properties of double-pass friction stir welded joints are recommended in future studies, since a greater variety of parameters need to be considered and it is more efficient compared to the single-pass technique.

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REFERENCES

[1] Godiganur V, Birabadar S. Comparison of friction stirs welding technique with conventional welding methods. International Journal of Research in Engineering and Technology. 2014; 03:572-6.

[2] Nuraini AA, Zainal AS, Azmah Hanim MA. The effects of welding parameters on butt joints using robotic gas metal arc welding. Journal of Mechanical Engineering and Sciences. 2014;6:988-94.

[3] Ishak M, Shah LH, Aisha ISR, Hafizi W, Islam MR. Study of resistance spot welding between aisi 301 stainless steel and AISI 1020 carbon steel dissimilar alloys. Journal of Mechanical Engineering and Sciences. 2014;6:793-806.

[4] Charde N. Characterization of spot weld growth on dissimilar joints with different thicknesses. Journal of Mechanical Engineering and Sciences. 2012;2:172-80.

[5] Mishra RS, Ma ZY. Friction Stir Welding and Processing. Materials Science and Engineering: R: Reports. 2005;50(1-2), 1-78.

[6] Groover MP. Fundamentals of modern manufacturing: materials, processes, and systems. John Wiley & Sons; 2010.

[7] Nagasawa T, Otsuka M, Yokota T, Ueki T. Structure and mechanical properties of friction stir weld joints of magnesium allov AZ31. Essential Readings in Magnesium Technology: John Wiley & Sons, Inc.; 2014;517-21.

[8] Vural MO, A. Cam, G. Ozarpa,C. . On the friction stir welding of aluminium alloy EN AW 2024-O and EN AW 5754-H22. Archives of Materials Science and Engineering. 2007;28:49-54.

[9] Charde N. Effects of electrode deformation of resistance spot welding on 304 austenitic stainless steel weld geometry. Journal of Mechanical Engineering and Sciences. 2012;3:261-70.

[10] William J. Arbegast. Friction stir joining: characteristic defects. Advanced Materials Processing Center2003.

[11] Joshi V, Balasubramaniam K, Prakash RV. Study of defects in friction stir welded AA 5083 by radiography, ultrasonic and phased array ultrasonic. Proceedings of the National Seminar & Exhibition on Non-Destructive Evaluation. 2011; 1-7.

[12] Shah LH, Akhtar Z, Ishak M. Investigation of aluminum-stainless steel dissimilar weld quality using different filler metals. International Journal of Automotive and Mechanical Engineering. 2013;8:1121-31.

[13] Hariri A, Azreen P N, Abdull N, Leman AM, Yusof MZM. Determination of customer requirement for welding fumes index development in automotive industries by using quality function deployment approach. International Journal of Automotive and Mechanical Engineering. 2014;9:1609-19.

[14] Charde N. Microstructure and fatigue properties of dissimilar spot welds joints of AISI 304 and AISI 1008. International Journal of Automotive and Mechanical Engineering. 2013;7:882-99.

[15] Rohilla P, Kumar N. Experimental investigation of tool geometry on mechanical properties of friction stir welding of AA6061. International Journal of Innovative Technology and Exploring Engineering. 2013; 3(3),56-61.

[16] Mehra S, Dhanda P, Khanna R, Verma NSGS. Effect of tool on tensile strength in single and double sided friction stir welding. International Journal of Scientific & Engineering Research. 2012; 3(11), 1-6.

[17] He D, Yang K, Li M, Guo H, Li N, Lai R, et al. Comparison of single and double pass friction stir welding of skin-stringer aviation aluminium alloy. Science and Technology of Welding and Joining. 2013;18:610-5.

[18] DuPont JM, AR. Characterization of the microstructural development and corrosion resistance of friction weld on SASS alloys. Framset Research Activities Journal,Office of Naval Research. Retrived from http://www.lehigh.edu/~inemg/Framset/Research_Activities/JLP/SASS/SASS_6.htm; 2005.

[19] Thompson B, Doherty K, Niese C, Eff M, Stotler T, Pramann Z, et al. Friction stir welding of thick section aluminum for military vehicle applications. DTIC Online Document. Access No. ADA574537. Retrived from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA574537; 2012.

[20] Chen C, Kovacevic R. Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding. International Journal of Machine Tools and Manufacture. 2004;44:1205-14.

[21] Elangovan K, Balasubramanian V. Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy. Journal of Materials Processing Technology. 2008;200:163-75.

[22] Lohwasser D, Chen Z. Friction stir welding: From basics to applications. Cambridge: Woodhead Publisher; 2010.

[23] Li WY, Li JF, Zhang ZH, Gao DL, Chao YJ. Metal flow during friction stir welding of 7075-T651 aluminum alloy. Experimental Mechanics. 2013;53:1573-82.

[24] Hatch JE, Association A. Aluminum: properties and physical metallurgy. USA: ASM International; 1984.

[25] Zhang Q, Mahfouf M, Panoutsos G, Beamish K, Norris I. Multiple characterisation modelling of friction stir welding using a genetic multi-objective data-driven fuzzy modelling approach. IEEE International Conference on Fuzzy Systems. 2011;2288-95.

[26] Hussain AK, Quadri SAP. Evaluation of parameters of friction stir welding for aluminium AA6351 alloy. International Journal of Engineering Science and Technology. 2010;2,5977-84.