MECHANICAL PROPERTIES OF THICK AND THIN AA1100 WELDED USING BOBBIN FRICTION STIR WELDING

M.K.A.M. Kassim[1], M.K. Sued[1] and D.J. Pons[2]

[1]Fakulti Kejuruteraan Pembuatan,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2]Department of Mechanical Engineering,
University of Canterbury, Christchurch,
8041, New Zealand.

Corresponding Author's Email: [1]kamil@utem.edu.my

Article History: Received 21 December 2018; Revised 19 April 2019; Accepted 4 September 2019

ABSTRACT: This study is to investigate the mechanical properties of thick and thin material welded using Bobbin Friction Stir Welding technique. The material that used for this study was Aluminium Alloy 1100 with the thickness of 3mm and 6mm. The aim of this study is to identify the process sensitivity for different material thickness. Different tapered shoulder was tested in this study and the spindle speed and welding speed were varied. There are two sets of parameters used which are 900 rpm and 310 mm/min; and 1440 rpm and 190 mm/min for spindle speed and welding speed respectively. The welding process was done by CNC Milling Machine. The welded products were tested using tensile test, micro hardness, and XRD analysis. The result shows that low spindle speed and higher travel speed produce good weld. This only can be produced with small tapered angle on the shoulder of the tool that represents the best tapered angle used in this study. If not, defect such as open tunnel, teared material at tool entry and void will be produced. However, the welding for thin materials is challenging and for different material thickness, optimized parameter should be used for high strength weld.

KEYWORDS: *Friction Stir Welding; Bobbin; Material Thickness; Welding Parameters; Mechanical Properties*

1.0 INTRODUCTION

Friction stir welding (FSW) is one of the solid state joining welded that produce weld by applying heat and pressure. This heat is produced from the mechanical friction rubbing between the surface of the tool and the material to be welded. FSW itself divided into two types which are conventional friction stir welding (CFSW) and bobbin friction stir welding (BFSW). Bobbin tool has a double-sided shoulders configuration which contacts both top and bottom surfaces of the workpiece material, whereby CFSW only have a single shoulder. It is stated that BFSW provide more advantages compared to the CFSW [1]. The main advantage is that, bobbin tool produced high friction heat that useful for fast welding speed. Through this approach, material readiness is improved; hence, it will improve the weld quality [2]. BFSW is an alternate method in order to overcome the difficulties that have been encountered by CFSW. The example of improvement is the elimination of the anvil and the potential of root defects in the weld product. Anyhow, early studies such as in [3] have stated that BFSW is difficult to weld thin plate materials (material thickness below 6mm [3]). In general, parameter setting for similar material at different thickness should only require a simple adjustment involving the heat generation and dissipation. The challenges should be minimized to produce the weld. However, during welding thin materials, two main problems found were the tearing of the workpiece edge and the accumulation of a solid mass of material within the gap of the bobbin shoulder. Both of these conditions represent bad or poor quality of welding [3]. During this condition, defects such as tunnel formation and flash are produced. The issue that occurs provide a low weld quality to the welded product when tested using tensile test.

Apart from the issue of material thickness, the BFSW challenge is its approach. The presence of two shoulders of BFSW and the full penetration of the pin, affect the stirring mechanism of weld formation. This contributes to different sensitivities of tool features, process variables and parameters setting compared to the CFSW process [4]. For example, the two shoulders of BFSW tool generate most of the heat [5], therefore because of the bottom shoulder no anvil (support) is required. Without anvil, axial force that produced by tool pressing the material to be welded (in CFSW), generally not applicable for BFSW. This leads to, minimum support requirements in BFSW [4-5]. On the other hand, BFSW tool interference (compression between the plate and the tool) creates the similar force as in axial force in CFSW. This principally relates to the tool design, i.e. the shoulder angle. Besides that, the changes of the principle will require process parameters (spindle speed and travel speed) to be adjusted. The high heat generated through double shoulder, should be taken as an advantage to increase the travel speed, but the amount of travel force during the welding process will also rise. Tool breakage will possibly happen.

Till now, there is no best parameter and guidelines for BFSW. The BFSW approaches change the FSW sensitivity that needs attention for a stable process. The material thickness is believed an unsung parameter or covert variables. There are no studies directly focus on the material thickness issue. In order to overcome the problem, the study of the different type of thickness for the bobbin friction stirs welding process need to be carried out. Therefore, it is important to find the most suitable parameters that can eliminate these challenges. This study is very important for the industry to grow in positive ways, especially for automotive and aircraft industries. The best parameters suggested will help the industry to achieve a good weld quality [6] with effective use of resources.

2.0 METHODOLOGY

The type of alloy used in this work was Aluminium Alloy 1100 with the thickness 3mm (thin) and 6mm (thick). Table 1 shows the composition of the aluminium alloy. In general, Aluminium Alloy 1100 series has the 110 MPa UTS. The material was cut to 140mm x 140mm. Butt joint weld configuration was used.

Table 1: Chemical composition of aluminium alloy 1100 series

Si	Fe	Cu	Mn	Zn	Others-Each	Others Total	Al Min
0.95 Si + Fe		0.05 - 0.2	0.05	0.1	0.05	0.15	99

Figure 1 illustrates the tool used in this investigation, while Table 2 shows the dimension of the tool. Material that used to fabricate the bobbin tool is tool steel, H13. This material is made up of Chromium-Molybdenum that commercially for tooling applications. H13 is selected due to its toughness and the thermal stability. The important criteria for the tool are the angle of the shoulder that will be able to reduce the amount of flash during the welding process. For this study, two sizes of bottom shoulder angle were used that were 5° and 7° tapered. The top shoulder remains flat as illustrated in Figure 1.

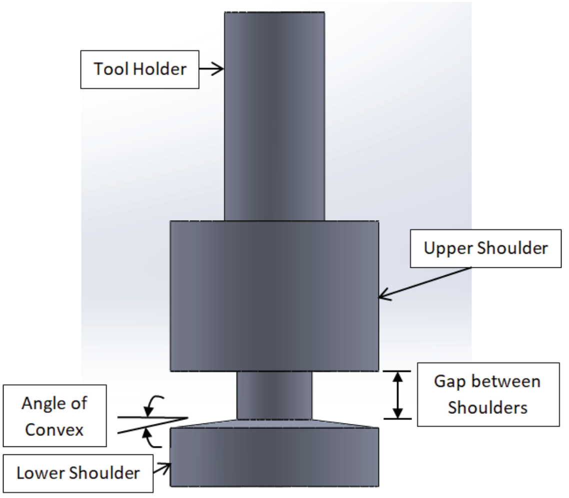

Figure 1: Drawing of bobbin tool

Table 2: Dimension for bobbin tool

Measurement	Dimension
Tool holder	25 mm
Tool holder diameter	12 mm
Shoulder diameter	25 mm
Shoulder gap	5.8 mm
Pin diameter	9 mm
Thickness of upper shoulder	18 mm
Thickness of lower shoulder	8 mm
Angle of convex shoulder	5° and 7°

The 3-axis Haas CNC milling machine was used as the FSW machine. The machine has 14.9 kW vector drive with a 20hp of machine capability. In order to identify the acceptable parameters (able to create butt joint), pilot test has been conducted earlier. Many parameters have been tested and it is quite challenging to obtain functional parameters for both thick and thin materials. This is because there is no information on literatures about the parameters for thin plate material. Table 3 shows the parameters that selected in this study.

Table 3: Parameter setup

Specimen Name	Thickness (mm)	Spindle Speed (rpm)	Welding Speed (mm/min)
A	3	1440	190
B	3	900	310
C	6	900	310
D	6	1440	190

For the welded plate, three tests were conducted that were visual inspection, mechanical test and X-Ray Diffraction (XRD). For visual inspection, it was conduct based on the appearances of the welded product. The result of the visual inspection is for the tool design selection (tapered angle) that has been applied for this study. For mechanical test, the tensile and microhardness test were conducted. Tensile test is to investigate the weld strength. ASTM E8-04 ISO 6892 is used as the reference standard. For the Microhardness test, maximum load of 0.025kg [7] was used with the Vickers hardness. In order to obtain overall hardness, 20 points were recorded from the centre of the weld towards the base material at the retreating side of the specimen. XRD was conducted to make sure the materials are similar based on the phase identification of a crystalline material. The observation explains the depth information about the crystalline compounds that include the identification and quantification of crystalline phase [8].

3.0 RESULT AND DISCUSSION

Figures 2 and 3 show the weld when different tapered shoulders were used (pilot test). The weld was conducted on both; 3mm and 6mm; thickness of material. It is observed that large tapered angle (Tool 1) could not develop acceptable weld. Defect such as open tunnel can be clearly seen in Figure 2(A) and Figure 3(A). This happens when there is less compression force on the welding area, hence material stirring and heating is not efficient. This causes no material joining at the advancing side of the material. Worse weld was recorded for thin material when large tapered was used as Figure 2(A). The join was unable to be form but cutting effect at the advancing side (AS) is produced.

High vibration can also be observed during the welding of thin plate material when using Tool 1. This means that the joining process is not in a rigid condition. Rigidity during welding is important because the degree of freedom movement disturb material stirring [9]. The condition is erratic when coupled with tool deflection which occurred during welding [10]. Therefore, to gain acceptable weld for this study, Tool 2 with a small tapered; 5˚ tapered; are used for the rest of this study. This are because of the higher compression force, higher heat generated, and good stirring effect that can be offer from small tapered angle.

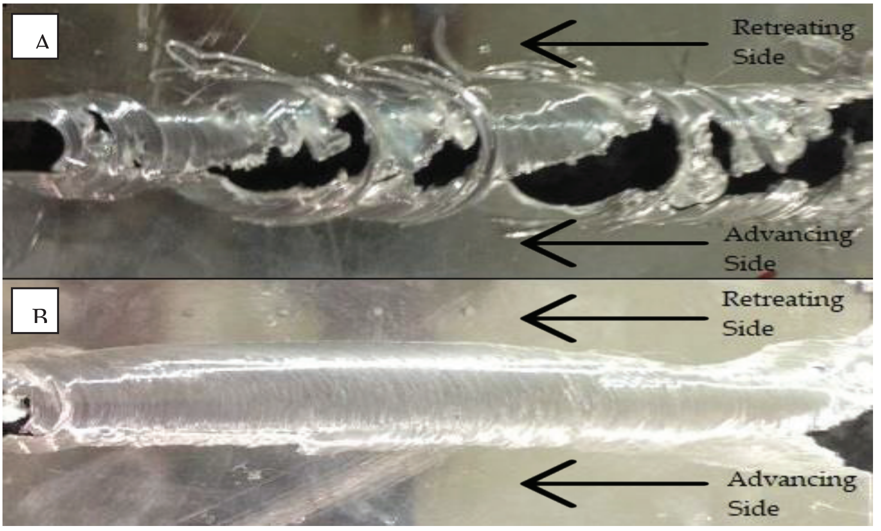

Figure 2: Welding quality for 3 mm thickness plate: (A) Tool 1 with 7° tapered and (B) Tool 2 with 5° tapered

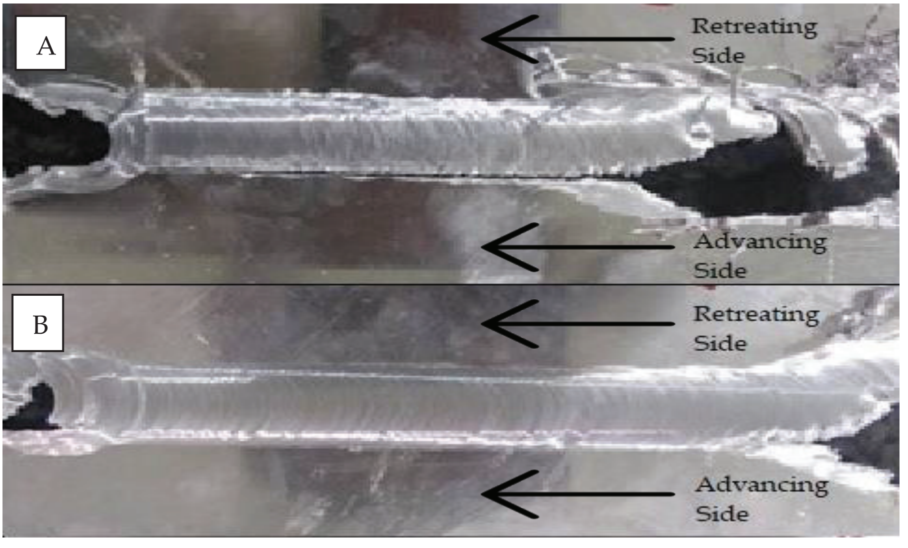

Figure 3: Welding quality for 6 mm thickness plate: (A) Tool 1 with 7° tapered and (B) Tool 2 with 5° tapered

Both Table 4 and Figure 4, represent the Ultimate tensile strength (UTS) for each specimen. Based on the result collected, it shows that for thin material specimen B has the higher tensile and for the thick material, specimen C produce the best weld strength. Both thick and thin produce similar pattern whereby slower spindle speed and higher welding speed produce better weld strength. The results indicate that when higher heat is introduced, better weld strength will be produced. The results also show that thin material break early and with minimum elongation. The reason is because of mass of material that smaller than thicker plate [11].

Besides that, UTS for base material is higher compared to the results. This is as expected because previous studies [4] recorded that for BFSW the weld strength produced is lower than the based material. The reason is because of the high heat generated by BFSW [12]. On the other hand, the approach taken was not based on optimised parameters and tool features. Cylinder pin and flat shoulder did not provide maximum mixing between materials which believed better tool design selection is required in improving the weld join. By analysing the broken specimen, it shows that all the specimens were broken at the advancing side of the tensile specimen. It is believed that tool deflected at the retreating side, hence minimum mixing produced at the advancing side. Most literatures agreed with the finding whereby tensile strength breaks at the advancing side because of the internal voids/tunnel due to tool deflection. The deflection is the effect of harder material at advancing side and low material reediness [13] due to low temperature at the advancing side.

Table 4: UTS for each specimen

Specimen	Specimen A	Specimen B	Specimen C	Specimen D
UTS (MPa)	36.11	38.89	75.09	74.74

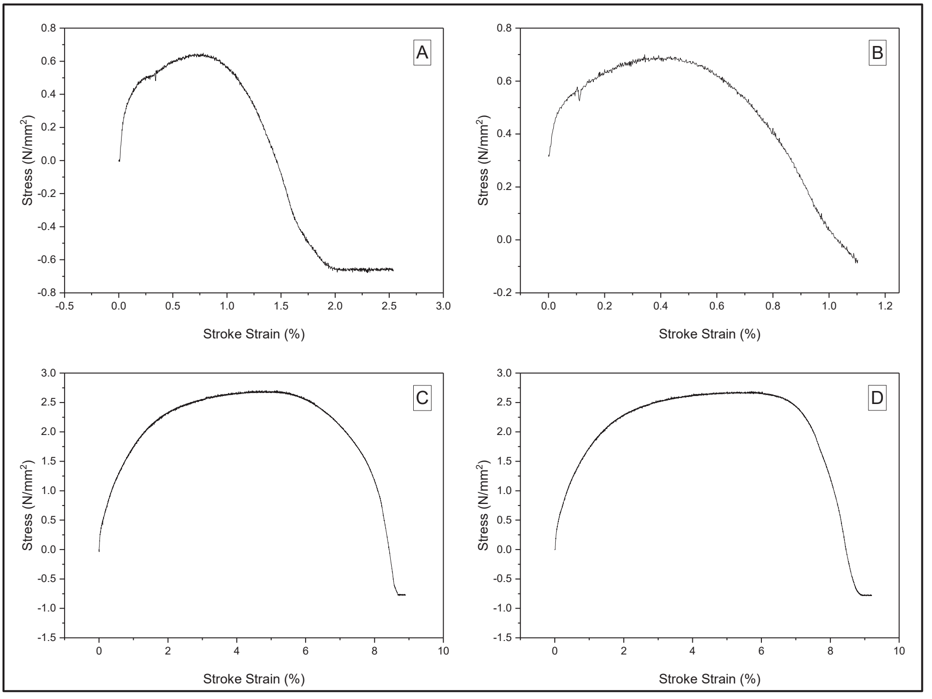

Figure 4: UTS graph: (A) Specimen A, (B) Specimen B, (C) Specimen C and (D) Specimen D

Figure 5 shows the hardness measurement for each specimen. The graph shows that welding area has low hardness and increased towards the base material. When heat is subjected to the material, grain growths take place that reduces the hardness. The heats generate at the same place and cause the material less crystalline which are more brittle. Specimen A and D are having higher spindle speed with a lower welding speed compare to specimen B and C that set to have lower spindle speed with higher welding speed. The increase of the advancing speed will cause plastic to deform and heat treatment that will overcome the dynamic recrystallization [14]. From the results it is found that specimen B and C have higher hardness value. The result agreed with the tensile strength test, hence specimen B and C are the best set of parameters in this study based on the taken approach.

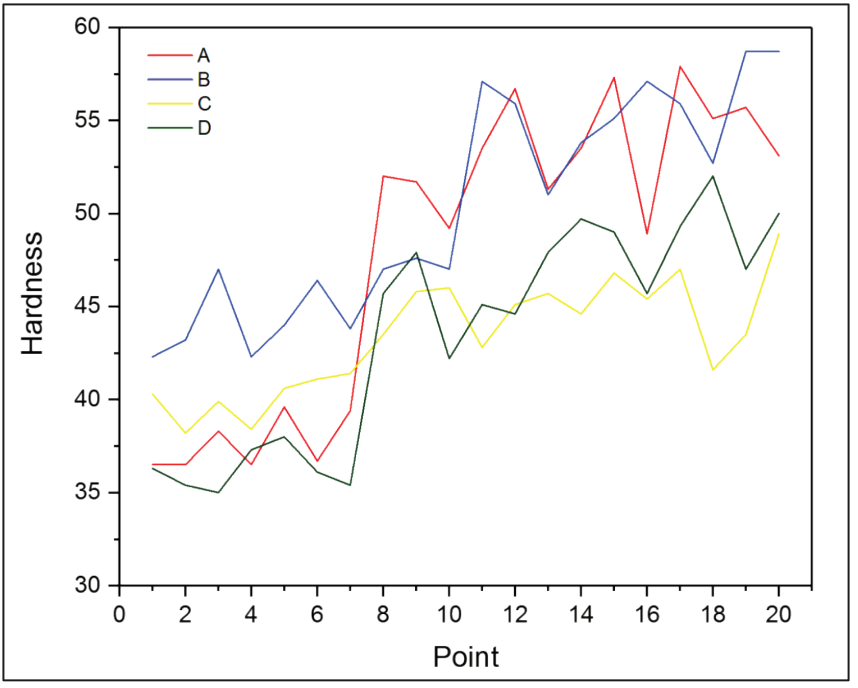

Figure 5: Hardness graph for each specimen

Table 5 and Figure 6 show XRD peak data for each specimen and graph for XRD analysis respectively. Based on the result obtained, the pattern of the XRD graph shows that at all specimens having element of Aluminium (Al). It shows that at 2θ axis, the highest peak was at point 38.476. While for the other point was at 44.725, 65.103, 78.237, and 82.445 deg. By comparing based on the thickness of each material, it shows that specimen A has highest peak which represent the crystallinity of the material for thin material and for thick material specimen C have higher crystallinity. This test confirms that the material is an Aluminium based composition that eliminates the possibility of different materials.

Table 5: XRD peak data for each specimen

Specimen	Height (cts)
Specimen A	4051.35
Specimen B	3264.35
Specimen C	19111.83
Specimen D	15536.76

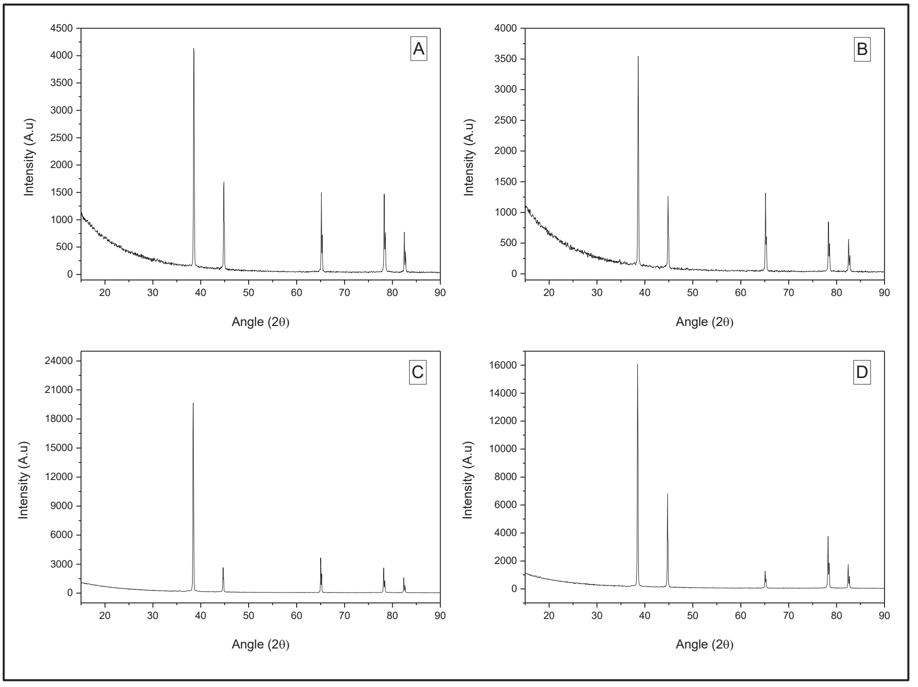

Figure 6: Graph of XRD analysis for each specimen

4.0 CONCLUSION

It shows that parameters that have been used for specimen B and C are completely acceptable compared to the specimen A and D. Both sets of parameters are producing best weld quality, but in term of mechanical properties, only one set of parameters will be acceptable. The best parameters are 900 rpm for spindle speed while 310 mm/min for welding speed. Controlling heat generation is important for BFSW, since the high heat generated will result poor welding. Once the heat generation during BFSW process are high, it will make the material less crystalline that are tending to be brittle. This experimental study has successfully conducted for welding different weld thickness. There are a few general conclusions that can be summarized which are:

i. To weld thin plate, it is challenging to use BFSW approach. Additional investigations are required to be conducted to explain and solve the situation.
ii. Large tapered on the shoulder is not suitable. This cause minimum heat generation and material stirring around the shoulder.
iii. Higher travel speed and low spindle speed produce low weld strength and hardness.

iv. Thin plate rigidity needs to be control for easy weld formation.
v. Different material thickness should use optimised parameters for better weld quality.

ACKNOWLEDGEMENTS

The author would like to thank the Universiti Teknikal Malaysia Melaka (UTeM) for the research grant PJP/2016/Proton/FKP-AMC/SO1502 and PJP/2017/FKP/H18.

REFERENCES

[1] P.L. Threadgill, M.M.Z. Ahmed, J.P. Martin, J.G. Perrett and B.P. Wynne, "The use of bobbin tools for friction stir welding of aluminium alloys", *Material Science Forum*, vol. 638, pp. 1179-1184, 2010.

[2] H. Zhang, M. Wang, Z. Zhu, X. Zhang, T. Yu and G. Yang, "Improving the structure-property of aluminum alloy friction stir weld by using a non-shoulder-plunge welding tool", *The International Journal of Advanced Manufacturing Technology*, vol. 87, no. 1-4, pp. 1095-1104, 2016.

[3] K.J. Colligan, A.K. O'Donnell, J.W. Shevock and M.T. Smitherman, "Friction Stir Welding of Thin Aluminium Using Fixed Gap Bobbin Tools", in Proceedings of the 9th International Friction Stir Welding Symposium, Huntsville, Alabama, 2012, pp. 1-17.

[4] R.S. Mishra and Z.Y. Ma, "Friction stir welding and processing", *Materials Science and Engineering: R: Reports*, vol. 50, no. 1-2, pp. 1-78, 2005.

[5] A. Arora, A. De and T. DebRoy, "Toward optimum friction stir welding tool shoulder diameter", *Scripta Materialia*, vol. 64, no. 1, pp. 9-12, 2011.

[6] M. Guillo and L. Dubourg, "Impact and improvement of tool deviation in friction stir welding: Weld quality and real-time compensation on an industrial robot", *Robotics and Computer-Integrated Manufacturing*, vol. 39, pp. 22-31, 2016.

[7] S.S. Entezami and M. Honarpisheh, "A study on the hardness of 7075 and 5052 aluminum alloys in the equal channel angular rolling process", *Bulletin de la Société Royale des Sciences de Liège*, vol. 85, pp. 879-889, 2016.

[8] C.M. Chen and R. Kovacevic, "Finite element modeling of friction stir welding-thermal and thermomechanical analysis", *International Journal of Machine Tools and Manufacture*, vol. 43, no. 13, pp. 1319-1326, 2003.

[9] E.F. Shultz, E.G. Cole, C.B. Smith, M.R. Zinn, N.J. Ferrier and F.E. Pfefferkorn, "Effect of compliance and travel angle on friction stir welding with gaps", *Journal of Manufacturing Science and Engineering*, vol. 132, no. 4, pp. 041010-1-041010-9, 2010.

[10] M.K. Sued, D. Pons, J. Lavroff and E.H. Wong, "Design features for bobbin friction stir welding tools: Development of a conceptual model linking the underlying physics to the production process", *Materials and Design (1980-2015)*, vol. 54, pp. 632-643, 2014.

[11] F. Marie, B. Guering, D. Deloison, D. Aliaga and C. Desrayaud, "Investigation on Bobbin Tool Friction Stir Welding of 2000 Series Aluminum Thin Sheets", in Proceedings of the 7th International Symposium on Friction Stir Welding, Awaji Island, Japan, 2008, pp. 1-19.

[12] S. Karami, H. Jafarian, A.R. Eivani and S. Kheirandish, "Engineering tensile properties by controlling welding parameters and microstructure in a mild steel processed by friction stir welding", *Materials Science and Engineering: A*, vol. 670, pp. 68-74, 2016.

[13] B.S. Davidson and S. Neelakrishnan, "Influence of Friction Stir Welding Parameters on Tensile Properties of AA8011 Aluminium Alloy Plate", *Journal of Computational and Theoretical Nanoscience*, vol. 15, no. 1, pp. 93-98, 2018.

[14] Z. Boumerzoug and Y. Helal, "Friction Stir Welding of Dissimilar Materials Aluminum AL6061-T6 to Ultra Low Carbon Steel", *Metals*, vol. 7, no. 2, pp. 1-9, 2017.