THE EFFECT OF PIN LENGTH AND COMPRESSIVE FORCE IN DOUBLE SIDE FRICTION STIR WELDING ON BENDING STRENGTH OF AA1100

Sukma Satriawan[1*], Agus Setiawan[2], Dwi Pebrianti[3], Zainah Binti Md. Zain[4]

[1,2]State Polytechnic of Malang, Indonesia
[3]International Islamic University Malaysia
[4]Universiti Malaysia Pahang, Malaysia

*Author Email: sukmasatriawan@gmail.com, agus.setiawan@polinema.ac.id , dwipebrianti@iium.edu.my , zainah@ump.edu.my

Article Information

Manuscript Received 2023-07-26
Manuscript Revised 2024-04-06
Manuscript Accepted 2024-04-07
Manuscript Online 2024-04-08

ABSTRACT

Many new welding methods have emerged to improve connection results, including friction stir welding (FSW). FSW is a welding method that is widely used in welding aluminium alloys. FSW method on AA1100 aluminium material has not yet obtained the maximum bending strength so it is necessary to study the improvement of the quality of FSW joints using the welding method on both sides or double side friction stir welding (DFSW). This study aims to determine the effect of pin length and downward force on double side friction stir welding (DFSW) on the bending strength of AA1100 aluminium . The independent variables of this study are pin length (1.5 mm, 2 mm, 2.5 mm) and downward force (30 kg, 35 kg, 40 kg, 45 kg). The controlled variables are shoulder diameter of 25 mm, machine table translational speed of 10 mm/min, spindle rotation speed of 1750 rpm, base plate temperature of 250ºC, and AA1100 plate thickness of 3.6 mm with butt joint type welding connection model. The method used in this research is experimental using the factorial design of experiment (DOE) data analysis method. The results of this study indicate that pin length and downward force have a significant effect on the bending strength of DFSW welded joints on AA1100. The maximum bending strength value of the welded joint was 289.59 MPa at a pin length variation of 2 mm and a compressive force of 35 kg. The percentage of weld defects including tunnel and flash in welded joints with maximum bending strength is identified as the least and the micro test results also show the least FeAl3 particle grains.

Keywords: Aluminium AA1100, bending strength, double side friction stir welding, downward force, pin length

1. INTRODUCTION

Currently, the era of industrial revolution has entered the 4.0 stage. In the face of progress in the era of industrialization, science and technology related to the production process and material connection are also experiencing rapid development. This is characterized by the emergence of many new methods that have been found to solve material joining problems that expect maximum material strength and can reduce operating costs.

Friction stir welding (FSW) is a solid-state welding technique that was discovered in 1991 and has since gained attention in various industries [1]–[3]. Here are some key points about FSW:

- FSW is a non-consumable electrode welding process that joins materials without melting them, making it suitable for dissimilar metal/alloy joining [4], [5].

- It is used in applications such as shipbuilding, aerospace, automotive, and general fabrication due to its ability to produce excellent mechanical properties with less distortion [6]–[8].

- The process has been utilized for joining materials like duplex stainless steel, aluminum alloys, and copper, demonstrating its versatility [9]–[11].

- FSW is considered effective for joining high-strength aerospace aluminum alloys and other high-temperature metallic alloys that are challenging to weld using conventional fusion welding methods [12]–[14]

While the abstracts provide valuable insights into the applications and materials involved in FSW, they do not delve into specific details about the process itself, such as the tool stirring action, material flow, and thermal and kinetic fields [15]–[17]

Therefore, for a comprehensive understanding of FSW, additional sources beyond the provided abstracts may be necessary.

Aluminium and its alloys are one of the metals that are widely used in the manufacturing industry because they have various advantages including relatively light weight, good formability, corrosion resistance, and tensile strength can be increased by cold working or heat treatment and have a low melting point [18]–[20]. The use of aluminium

, especially type AA1100 in the industrial world, is widely used for reservoir tanks, pipes and others. In general, aluminium connections use the rivet and TIG welding methods. Both of these connections are very limited when viewed from several aspects, for example, rivet connection results will increase thickness, use added material and there is also material wasted from the rest of the drilling. As for TIG welding, it requires control of the straightness of the joints to obtain high-quality welding results. When viewed from the technology being developed, it is not effective [21], [22].

Friction Stir Welding (FSW) was invented at The Welding Institute (TWI) UK in 1991 as a solid-state welding technique applied to aluminium alloys, in the FSW welding process does not involve the use of filler metal and therefore any aluminium alloy can be joined without regard to compositional compatibility which is a problem in fusion welding [23]–[25].

Previously, two-sided friction stir welding research has been carried out using 1100 H14 Aluminium material. The results of double-sided welding are better than usual welding [26], [27].

One of the factors that reduce the strength of the material as a result of welding is to withstand bending loads, this is especially true for components that are joined by the welding process because the bending strength is much smaller than the construction without welding and it should also be noted that bending failures in welds can occur under compressive loading conditions [28], [29].

The maximum bending strength of friction stir welding results can also be known from observations of the microstructure of the joined material, especially in 1100 series aluminium alloy materials in the nugget / stir zone area FeAl3 boundaries are numerous with Al matrix sizes tending to be small and soft [30]–[32].

Based on the background described above, to obtain an optimal double side friction stir welding connection, further research is needed on the effect of pin length and pressing force on double side friction stir welding on the bending strength of AA1100.

2. RESEARCH SIGNIFICANCE

Connections on aluminium materials need to receive more attention because currently, the industrial world is competing to create lightweight and strong products. Over time, the industry is also required to remain environmentally friendly. Therefore, Friction Stir Welding (FSW) can be an alternative method for connecting materials (welding) on aluminium. The connection results from FSW have not yet obtained optimal results, so further research needs to be done.

3. RESEARCH METHODS

The installation scheme of the DFSW research on the bending strength of AA1100 is in Figure 2 as follows.

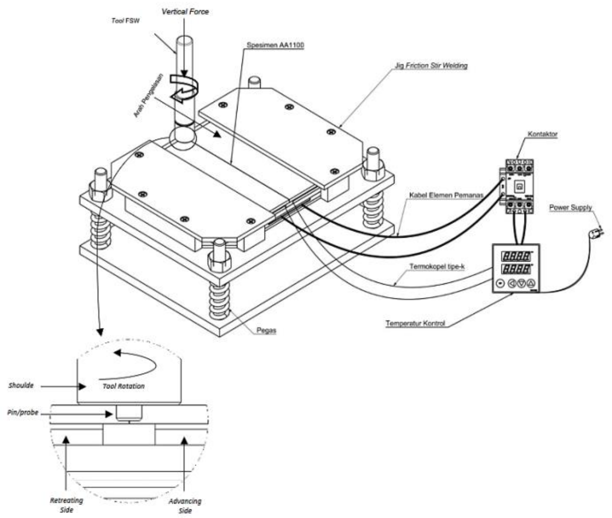

Fig 1. Setup of Research Installation

In this research, the material joined by the DFSW welding process is Aluminium Alloy 1100 (AA1100) with a size of 150 x 100 x 3.6 mm each. The DFSW process uses a milling machine where the translational speed parameter is 10 mm/min and the spindle rotation is 1750 rpm. The DFSW tool is made of AISI H13 steel. The size of the shoulder diameter is 25 mm and the pin diameter is 5 mm with the tool tilt angle set at 0°. Using a heating element with 500 Watts of power placed inside the JIG DFSW heating plate. The function of the heating element is to heat the material at the beginning of the welding process. The width of the heating plate is 10 mm and the heating plate temperature is controlled at 250°C. For bending testing using the ASTM E190-14 standard [6] which can be seen in Figure 3.

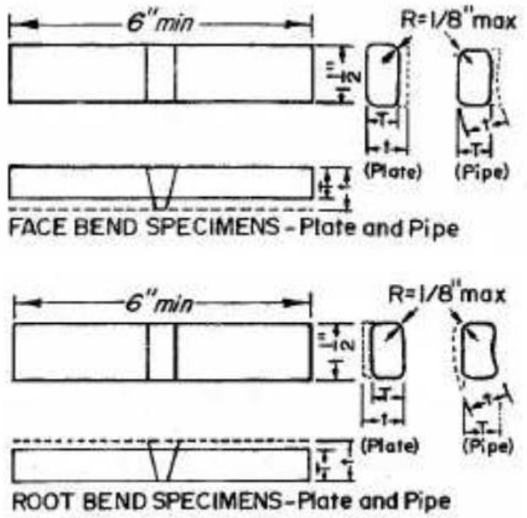

Fig 2. Bending test specimen according to ASTM E190-14

4. RESULTS AND DISCUSSION

Data obtained from bending tests of double Side Friction Stir Welding (DFSW) connection results on AA1100 as shown in table 1 as follows.

Table 1. Bending Test Result Data

PIN LENGTH (mm)	DOWNWARD FORCE (kg)	BENDING STRENGTH (MPa)				AVERAGE
		I	II	III	IV	
Parent Material		325,45	323,37	326,37	327,64	325,71
1,5	30	251,53	253,34	259,69	248,65	253,30
	35	283,21	286,50	281,45	284,16	283,83
	40	234,32	230,35	229,03	236,97	232,67
	45	219,59	217,37	224,34	216,54	219,46
2	30	269,21	261,05	263,77	266,49	265,13
	35	297,87	288,09	286,88	285,52	289,59
	40	260,66	254,63	249,80	247,35	253,11
	45	238,62	225,70	241,77	244,68	237,69
2,5	30	215,79	223,73	226,89	230,35	224,19
	35	243,18	235,65	235,23	242,27	239,08
	40	206,61	221,01	212,51	219,59	214,93
	45	206,61	202,13	195,51	199,34	200,90

The effect of pin length and compression force in DFSW on the bending strength of AA1100 joints can be seen in Figure 4, respectively.

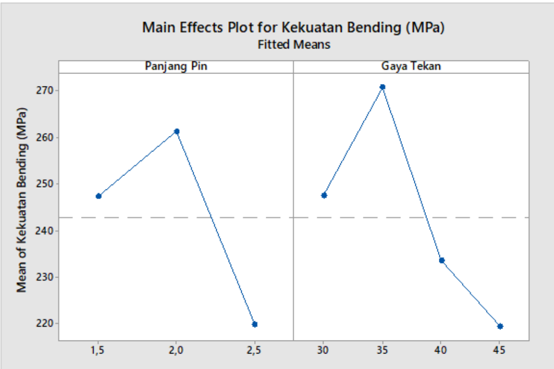

Fig 3. Graph of Effect of Pin Length and Press Force on Bending Strength

From Figure 4, it can be seen that the variation in pin length affects the bending strength which is characterized by a difference in bending strength between variations in pin length. The 1.5 mm pin length variation has an average bending strength of 247.32 MPa and the 2 mm pin length variation has the highest bending strength of 261.38 MPa. Then in the 2.5 mm pin length variation, the bending strength decreased to the lowest value with an average of 219.78 MPa. It is suspected that this is due to the proper stirring and forging process in the 2 mm pin length variation so that the heat generated is more stable.

In the compressive force graph, the bending strength value rises at a compressive force of 30 kg to the highest value at a compressive force of 35 kg and then there is a decrease in the bending strength value up to a compressive force of 45 kg. The lowest bending strength value is found at 45 kg compressive force which is 219.35MPa and the highest bending strength value at 35 kg compressive force is 270.84 MPa.

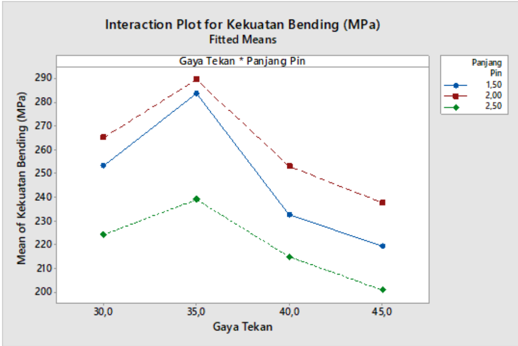

Fig 4. Interaction Plot

Figure 5 shows that there is a compressive force of 30 kg, 35 kg compressive force, 40 kg compressive force, 45 kg compressive force has a pattern that is almost the same but not parallel, namely an increase in bending strength value at a pin length of 1.5 mm to a pin length of 2 mm and then a decrease in bending strength value up to a pin length of 2.5 mm. From the interaction effect plot, it can be concluded that the interaction between pin length and compressive force on bending strength value is characterized by lines that are not parallel or different slopes in each variable. The highest bending strength value is found in the variation of 2 mm pin length and 35 kg compressive force which is 289.60 MPa while the lowest bending strength value is found in the variation of 2.5 mm pin length and 45 kg compressive force which is 200.90 MPa.

5. CONCLUSIONS

Based on the results of the research and discussion in the previous chapter, the conclusions are obtained, among others:

1. Pin length has a significant effect on the bending strength value of DFSW results on AA1100. In the 1.5 mm pin length variation, the average bending strength value is 247.32 MPa, in the 2 mm pin length variation, the highest average bending strength value is 261.38 MPa and in the 2.5 mm pin length variation, the bending strength value decreases to the lowest average value of 219.78 MPa.
2. Compressive force has a significant effect on the bending strength value of DFSW results on AA1100. In the variation of 35 kg compressive force, the average bending strength value was 270.84 MPa and in the variation of 45 kg compressive force, the bending strength value decreased to the lowest average value of 219.35 MPa.
3. The maximum bending strength of the welded joints of 289.59 MPa or 89% of the bending strength of the parent material was obtained from the interaction between the pin length of 2 mm and the compressive force of 35 kg. Macro observations showed that in this variation the least weld defects were identified and microstructure observations also showed the finest and most evenly distributed FeAl3 particle grains.

6. ACKNOWLEDGEMENTS

Thank you to all those who have supported this research process.

7. AUTHOR CONTRIBUTIONS

- Conceptualization: Sukma Satriawan, Agus Setiawan, Dwi Pebrianti, Zainah Binti Md. Zain
- Methodology: Sukma Satriawan, Dwi Pebrianti,
- Software: Sukma Satriawan, Dwi Pebrianti, Zainah Binti Md. Zain
- Validation: Agus Setiawan, Dwi Pebrianti, Zainah Binti Md. Zain
- Writing – original draft: Sukma Satriawan
- Writing – review & editing: Sukma Satriawan, Agus Setiawan, Dwi Pebrianti, Zainah Binti Md. Zain

8. REFERENCES

[1] M. Hasieber, M. Kranz, T. Löhn, M. Grätzel, A. Zemlicka, and J. P. Bergmann, "Effect of friction stir welding tool hardness on wear behaviour in friction stir welding of AA-6060 T66," *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.*, vol. 236, no. 6, 2022, doi: 10.1177/14644207211073055.

[2] N. Rajesh Jesudoss Hynes *et al.*, "An experimental insight of friction stir welding of dissimilar AA 6061/Mg AZ 31 B joints," *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 236, no. 6–7, 2022, doi: 10.1177/09544054211043474.

[3] R. Rudrapati, "Effects of welding process conditions on friction stir welding of polymer composites: A review," *Composites Part C: Open Access*, vol. 8. 2022. doi: 10.1016/j.jcomc.2022.100269.

[4] E. Kaygusuz, F. Karaömerlioğlu, and S. Akıncı, "A review of friction stir welding parameters, process and application fields," *Turkish Journal of Engineering*, vol. 7, no. 4. 2023. doi: 10.31127/tuje.1107210.

[5] H. Deng *et al.*, "Microstructure and mechanical properties of dissimilar NiTi/Ti6Al4V joints via back-heating assisted friction stir welding," *J. Manuf. Process.*, vol. 64, 2021, doi: 10.1016/j.jmapro.2021.01.024.

[6] A. Heidarzadeh, M. Javidani, M. Mofarrehi, A. Farzaneh, and X. G. Chen, "Submerged dissimilar friction stir welding of aa6061 and AA7075 aluminum alloys: Microstructure characterization and mechanical property," *Metals (Basel).*, vol. 11, no. 10, 2021, doi: 10.3390/met11101592.

[7] M. S. M. Isa *et al.*, "Recent research progress in friction stir welding of aluminium and copper dissimilar joint: a review," *Journal of Materials Research and Technology*, vol. 15. 2021. doi: 10.1016/j.jmrt.2021.09.037.

[8] H. I. Khalaf, R. Al-sabur, M. E. Abdullah, A. Kubit, and H. A. Derazkola, "Effects of Underwater Friction Stir Welding Heat Generation on Residual Stress of AA6068-T6 Aluminum Alloy," *Materials (Basel).*, vol. 15, no. 6, 2022, doi: 10.3390/ma15062223.

[9] A. Chumaevskii, A. Amirov, A. Ivanov, V. Rubtsov, and E. Kolubaev, "Friction Stir Welding/Processing of Various Metals with Working Tools of Different Materials and Its Peculiarities for Titanium Alloys: A Review," *Metals*, vol. 13, no. 5. 2023. doi: 10.3390/met13050970.

[10] I. S. Zuiko, S. Malopheyev, S. Mironov, and R. Kaibyshev, "Dissimilar Friction Stir Welding of AA2519 and AA5182," *Materials (Basel).*, vol. 15, no. 24, 2022, doi: 10.3390/ma15248776.

[11] A. Dimopoulos, A. Vairis, N. Vidakis, and M. Petousis, "On the friction stir welding of al 7075 thin sheets," *Metals (Basel).*, vol. 11, no. 1, 2021, doi: 10.3390/met11010057.

[12] D. Ambrosio, Y. Morisada, K. Ushioda, and H. Fujii, "Material flow in friction stir welding: A review," *Journal of Materials Processing Technology*, vol. 320. 2023. doi: 10.1016/j.jmatprotec.2023.118116.

[13] S. H. Iftikhar, A. H. I. Mourad, J. Sheikh-Ahmad, F. Almaskari, and S. Vincent, "A comprehensive review on optimal welding conditions for friction stir welding of thermoplastic polymers and their composites," *Polymers*, vol. 13, no. 8. 2021. doi: 10.3390/polym13081208.

[14] B. Wang, P. Zhu, Y. Cao, L. Zhou, P. Xue, and L. Wu, "Effects of different friction stir welding processes on residual stress and deformation of Ti62A alloy joints," *J. Mater. Res. Technol.*, vol. 26, 2023, doi: 10.1016/j.jmrt.2023.08.308.

[15] A. Ghiasvand *et al.*, "Investigation of mechanical and microstructural properties of welded specimens of aa6061-t6 alloy with friction stir welding and parallel-friction stir welding methods," *Materials (Basel).*, vol. 14, no. 20, 2021, doi: 10.3390/ma14206003.

[16] P. Yu, C. S. Wu, and L. Shi, "Analysis and characterization of dynamic recrystallization and grain structure evolution in friction stir welding of aluminum plates," *Acta Mater.*, vol. 207, 2021, doi: 10.1016/j.actamat.2021.116692.

[17] M. Akbari, M. R. M. Aliha, and F. Berto, "Investigating the role of different components of friction stir welding tools on the generated heat and strain," *Forces Mech.*, vol. 10, 2023, doi: 10.1016/j.finmec.2023.100166.

[18] R. Beygi, I. Galvão, A. Akhavan-Safar, H. Pouraliakbar, V. Fallah, and L. F. M. da Silva, "Effect of Alloying Elements on Intermetallic Formation during Friction Stir Welding of Dissimilar Metals: A Critical Review on Aluminum/Steel," *Metals*, vol. 13, no. 4. 2023. doi: 10.3390/met13040768.

[19] C. Rathinasuriyan, E. Pavithra, R. Sankar, and V. S. S. Kumar, "Current Status and Development of Submerged Friction Stir Welding: A Review," *International Journal of Precision Engineering and Manufacturing - Green Technology*, vol. 8, no. 2. 2021. doi: 10.1007/s40684-020-00187-6.

[20] D. Shaysultanov, K. Raimov, N. Stepanov, and S. Zherebtsov, "Friction stir welding of a trip fe49mn30cr10co10c1 high entropy alloy," *Metals (Basel).*, vol. 11, no. 1, 2021, doi: 10.3390/met11010066.

[21] M. Arif, D. Kumar, and A. Noor Siddiquee, "Friction stir welding and friction stir spot welding of polymethyl methacrylate (PMMA) to other materials: A review," *Mater. Today Proc.*, vol. 62, 2022, doi: 10.1016/j.matpr.2022.02.621.

[22] M. M. El-Sayed, A. Y. Shash, M. Abd-Rabou, and M. G. ElSherbiny, "Welding and processing of metallic materials by using friction stir technique: A review," *Journal of Advanced Joining Processes*, vol. 3. 2021. doi: 10.1016/j.jajp.2021.100059.

[23] C. Vimalraj and P. Kah, "Experimental review on friction stir welding of aluminium alloys with nanoparticles," *Metals*, vol. 11, no. 3. 2021. doi: 10.3390/met11030390.

[24] H. Luo, F. Zhao, S. Guo, C. Yu, G. Liu, and T. Wu, "Mechanical performance research of friction stir welding robot for aerospace applications," *Int. J. Adv. Robot. Syst.*, vol. 18, no. 1, 2021, doi: 10.1177/1729881421996543.

[25] V. Patel *et al.*, "High-speed friction stir welding in light weight battery trays for the EV industry," *Sci. Technol. Weld. Join.*, vol. 27, no. 4, 2022, doi: 10.1080/13621718.2022.2045121.

[26] A. A. E. Sidhom, S. A. R. Naga, and A. M. Kamal, "Friction stir spot welding of similar and dissimilar high density polyethylene and polypropylene sheets," *Adv. Ind. Manuf. Eng.*, vol. 4, 2022, doi: 10.1016/j.aime.2022.100076.

[27] A. Heidarzadeh *et al.*, "Friction stir welding/processing of metals and alloys: A comprehensive review on microstructural evolution," *Progress in Materials Science*, vol. 117. 2021. doi: 10.1016/j.pmatsci.2020.100752.

[28] M. M. Z. Ahmed, M. M. El-Sayed Seleman, D. Fydrych, and G. Çam, "Friction Stir Welding of Aluminum in the Aerospace Industry: The Current Progress and State-of-the-Art Review," *Materials*, vol. 16, no. 8. 2023. doi: 10.3390/ma16082971.

[29] Y. Sun, W. Gong, J. Feng, G. Lu, R. Zhu, and Y. Li, "A Review of the Friction Stir Welding of Dissimilar Materials between Aluminum Alloys and Copper," *Metals*, vol. 12, no. 4. 2022. doi: 10.3390/met12040675.

[30] D. G. Mohan and C. S. Wu, "A Review on Friction Stir Welding of Steels," *Chinese Journal of Mechanical Engineering (English Edition)*, vol. 34, no. 1. 2021. doi: 10.1186/s10033-021-00655-3.

[31] H. Zhang and F. Khoshnaw, "Friction stir welding," in *Welding of Metallic Materials: Methods, Metallurgy, and Performance*, 2023. doi: 10.1016/B978-0-323-90552-7.00006-7.

[32] T. Prabaharan, M. B. S. Sreekara Reddy, A. Bovas Herbert Bejaxhin, Ramanan, V. Pothamsetty Kasi, and Jenaris, “Strain-cum-Deformation Analysis of Friction Stir Welded AA5052 and AA6061 Samples with Microstructural Analysis,” J. Mines, Met. Fuels, vol. 70, no. 10, pp. 140–150, 2022, doi: 10.18311/jmmf/2022/31214.