Variation of Micro Friction Stir Spot Welding (µFSSW) Parameters on Metallography with Similar Materials AA1100

Semuel Boron Membala, Onny S. Sutresman, Hairul Arsyad, Muhammad Syahid and Agus Widyianto

January 3, 2023

Variation of Micro Friction Stir Spot Welding (μFSSW) Parameters on Metallography with Similar Materials AA1100

S. B. Membala[1,4], O. S. Sutresman[2], H. Arsyad[2*], M. Syahid[2] and A. Widyianto[3]

[1]Graduate Student in Mechanial Enginering Departement Hasanuddin University. Jl. Poros Malino KM.6 Bontomarannu Gowa, 92171, Sulawesi Selatan, Indonesia
[2]Departement of Mechanical Enginering Hasanuddin University. Jl. Poros Malino KM.6 Bontomarannu Gowa, 92171, Sulawesi Selatan, Indonesia
[3]Department of Automotive Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
[4]Department of Mechanical Enginering Cenderawasih University. Jl. Kampwolker, Kelurahan Yabansai, Distrik Heram, Jayapura-Papua, Indonesia

E-mail: arsyadhairul@yahoo.com

Abstract. The Micro Friction Stir Spot Welding (m-FSSW) process is a metal plate welding technique with a relatively thin plate thickness. The advantages of this welding are the higher quality of the weld and the relatively low deformation. This study aimed to determine the effect of depth of penetration, dwell time, and tool geometry on the trend of material flow on the macrostructure of the welds produced in the Micro Stir Spot Welding (m-FSSW) technique using AA1100 thin aluminum plates. In this study, the parameters that are changed are the depth of the chisel, dwell time, and tool geometry. In this study, the parameters of the penetration depth were divided into 500 microns, dwell time was split into three lengths of time (300 ms, 500 ms, and 700 ms), and tool geometry was divided into two types of tool geometries (tool-1 and tool-2). In addition, the macro test was carried out to determine the depth of the weld, contour profile, and stretch macrostructure. The results of the macro test will be used to analyze the material flow relationship in each weld zone on the welding results of all existing parameters. Based on the results of the study, the effect of depth of penetration, dwell time, and tool geometry on the weld depth and metallography (hook width, hook height, and effective top sheet thickness) of welds using AA1100 thin plates is influential along with various tool geometries and the deeper the weld penetration and the longer stirring time, although the results are not always directly proportional.

Keywords: Micro Friction Stir Spot Welding, Aluminum, Metallography, Similar material

1. Introduction

Welding is a process of joining material with another material by heating the material to the welding temperature, with or without a change in pressure, and with or without the use of filler material or filler [1]. 1991 was the year of the discovery of one type of welding technique that utilizes heat from friction called Friction Stir Welding (FSW), which was discovered by The Welding Institute (TWI) in the United Kingdom [2, 3]. This FSW is suitable for application to aluminum materials. Friction Stir Spot Welding is a branch of Friction Stir Welding. Friction Stir Spot Welding (FSSW) is a welding technique in the Solid-State phase. FSSW in the stabbing process, uses a rotating chisel with a protruding pin geometry.

Conceptually, Micro Friction Stir Spot Welding (μFSSW) is very similar to the FSSW method, which differs only in the thickness of the material. FSSW is intended for materials whose thickness is less than 1 mm. Due to the penetration between the tool and the overlapping material, there is heat that causes the material to soften and coalesce, causing a joint in the weld zone. There are two types of connections in the FSSW method: complete metallurgical bonds and partially metallurgical bonds [4]. From the weld zone formed there is also the term "hook". This hook is a term for partial metallurgical bond [5], this hook can also be interpreted as a weld defect caused by the effect of tool stirring and creases in the FSSW weld zone. This hook is also one of the parameters of the success of a weld.

Yin, Y.H. et al. [6] have investigated the hook formation and mechanical properties of the AZ31 material in the Stir Spot Welding welding technique. Baskoro et al. [7] have also investigated the effect of HSS-based tools on the mechanical properties of welds using Response Surface Methods (RSM) with AA1100 Aluminum material. High Strength Steel is a type of material that can be used as a welding tool with the FSSW method. The tool geometry and the stitch's depth variation are important parameters in the FSSW process. Research on the effect of weld geometry and variations of puncture depth on μFSSW with AA5052 material on welds' mechanical properties and geometry has been carried out by Zhang et al. [8]. A similar study on the effect of the diameter width, and depth of the chisel (flat chisel or probeless tools) on μFSSW on AA1100 material on the mechanical properties and joint width has also been carried out by Baskoro et al [9]. Research on welding parameters has been carried out by A. S. Baskoro [9] as mentioned above regarding the effect of welding parameters and rotational speed of the tool in the μFSSW process using A1100 aluminum.

Boz and Kurt [10] investigated the relationship between tool geometry and mechanical properties in FSW processes. Next, Zhang et al. [8] investigated the effect of welding parameters on temperature and material behavior in the FSW process. As a result, it was found that increasing the number of turns and decreasing the welding speed in tool welding increased the stirring effect and improved the quality of the FSW. Finally, Tran et al. [11] studied the effect of machining time on strength and failure models of two different types of FSSW between 5754-O and 7075-T6 aluminum plates. Their test results showed that both types of welds failed with longer processing times.

The tool geometry greatly affects the input energy, deformation pattern, puncture force, microstructure, and mechanical properties of the FSW joint. Rai et al. [12] reviewed and investigated several key aspects of FSW tools, including the tool selection process, geometry and toughness, tool degradation mechanisms, and process costs. Buffa et al. [13] studied the FSW process of aluminum alloys using the model developed by the authors. The research carried out in this paper describes the FSW process at different depths. The most important geometric parameter in the FSW tool design is the shoulder diameter, which is still being developed by trial and error.

Departing from the previous problem, further investigation of the defects in the weld results and regarding the material flow process in AA1100 thin plate welding is necessary. The thickness of the AA1100 plate is 0.32 mm and is joined by spot welding. Hence, the variation of μFSSW parameters such as penetration depth, dwell time, and tool geometry. After the welding process is complete, metallographic testing is carried out to determine the quality of the weld.

2. Experiment Method

This study uses a material similar to aluminum AA100 with micro-friction stir spot welding (μFSSW) with a thickness of 0.32. Testing of the chemical composition of the AA100 material was carried out using an optical emission spectrometer (OES), and the results are shown in Table 1. Before welding, both materials were cleaned with acetone to remove residual dirt and dust on the panel surface.

Table 1. Chemical composition (wt %) of AA1100

	Al	Zn	Mn	Fe	Si	Cu	Ti	Mg
AA1100	99.1	0.070	0.043	0.471	0.109	0.057	0.012	0.019

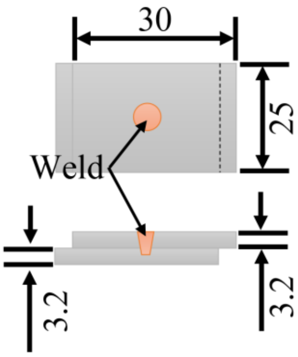

Figure 1. Metallographic test specimen dimensions

The welding used is μFSSW spot welding. Samples were prepared for triplicate metallographic examination. The dimensions of the metallographic specimen shown in Figure 1 are 30 mm long and 25 mm wide. The dimensions of the tools used for the μFSSW are shown in Figure 2. Two types of tools were used: pin 600 (Figure 2a) and two-stage shoulders (Figure 2b). The tool material used is high-speed steel (HSS) which is made by turning the machine. The stir point friction welding tool in this study uses a modified EMCO CNC TU-3A milling machine tensile tester with an accuracy of 0.01 mm. While the spindle used is a Mactec MT912 rotary drill with a die grinder specification of 6 mm and a spindle speed of 33,000 rpm. Table 2 shows the parameters of the μFSSW welding process used in this study.

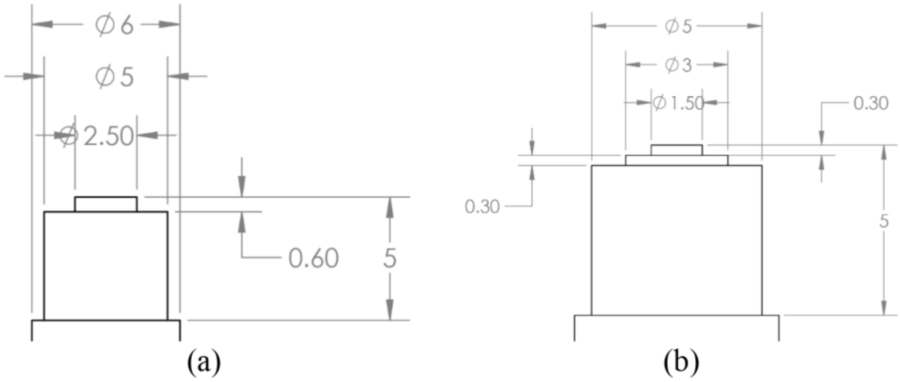

Figure 2. Tool dimensions of (a) pin 600 and (b) two-stage shoulder

Table 2. Parameters process of μFSSW

No.	Plunge rate (mm/s)	Plunge depth (microns)	Tool	Dwell time (milliseconds)
1	0.4	400	Tool 1	300
2				500
3				700
4			Tool 2	300
5				500
6				700

Metallographic examinations carried out included the macrostructure and microstructure of the weld. The sample is cut and then subjected to metallographic preparation including grinding, polishing, and etching. In addition, the macrostructure was observed with a digital microscope (Dino-Lite AM 4115 series) and the microstructure with an optical microscope (Oxion Inverso OX 2153-PLM).

3. Results and Discussion

3.1. Macrostructure

Macrostructure testing was conducted to determine the width and height of the hook formed, the direction of the hook formed, and the effective thickness of the top sheet of the weld. Meanwhile, microstructure testing was carried out to determine the boundaries between the μFSSW welded areas.

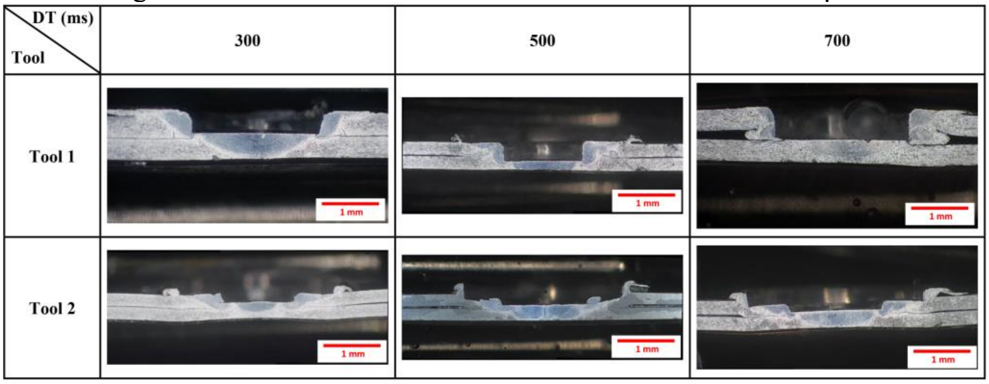

Figure 3. Macrostructure with Al-Al material in several variations of dwell time and tools

Figure 3 shows the results of observing the macrostructure with Al-Al material in several variations of dwell time and tool geometry. It can be seen that the geometry of the tools affects the material flow of the aluminum material. At the same time, the diameter of the weld will be wider if the stirring time is prolonged. Visually it can be seen that it produces a fairly good weld at a dwell time of 500 ms. Flash also appears at the edges of the weld for all variations of welding parameters. The effect of shoulder diameter on thermal cycling, peak temperature, power, and torque on the FSW process is very complex and needs further study. The criteria of the tool design process for the shoulder diameter based on the principle of maximum torque for traction have been proposed and tested [13].

3.2. Microstructure

Microstructural observations were carried out on various parameters of μFSSW, namely dwell time and tool geometry. While the plunge depth used is constant at 500 microns. Microstructural observations in the center of the weld and the weld edges on the left and right sides. The things that were observed were changes in structure, flash, hook formed and cracks.

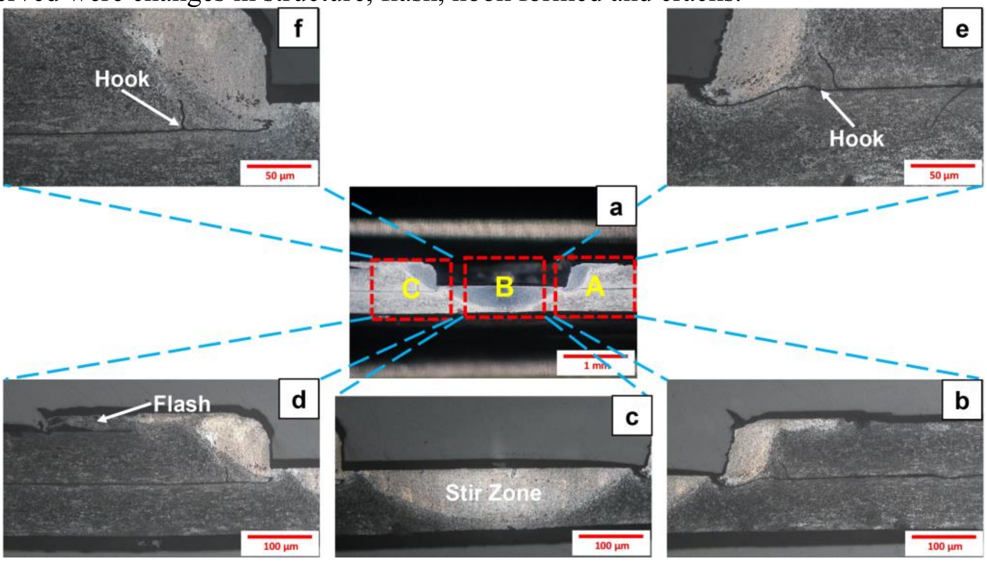

Figure 4. Metallography of Al-Al at dwell time 300 milliseconds and tool 1: (a) macrostructure, (b) microstructure of area A, (c) microstructure of area B, (d) microstructure of area C, and (e, f) microstructure with high magnification

Figure 4 shows the results of the macro and microstructure of Al-Al material at the dwell time parameter of 300 ms and tool 1. Welding defects in the form of flash began to appear on the left edge of the weld. The plunge depth used is constant, which is 500 microns. From the macro structure, the stir zone (SZ) area and the penetration depth (see Figure 4a) can be seen. A dwell time of 300 ms is the lowest parameter. This causes the heat generated also tends to be lower. Area A is further observed in the microstructure shown in Figure 4b. Area A is the weld area on the right side, where on the right side, no flash is formed. Area B is the SZ area which is right in the middle, as shown in Figure 4c. Based on the micro results, it can be seen that the two materials can be connected perfectly. Area C is the weld area on the left side, where flash appears, as shown in Figure 4d. Areas A and C are the sides of the weld, where extend or flash areas appear. The flow transition zone (FTZ) is observed at the edge of the weld, where friction occurs between the material and the shoulder pin tool. Furthermore, the stir zone (SZ) is also visible on the surface of the weld that rubs against the surrounding surface of the tool pin. If areas A and C are enlarged again, it can be seen that the hook formed on the side of the weld (see Figure 4 e,f).

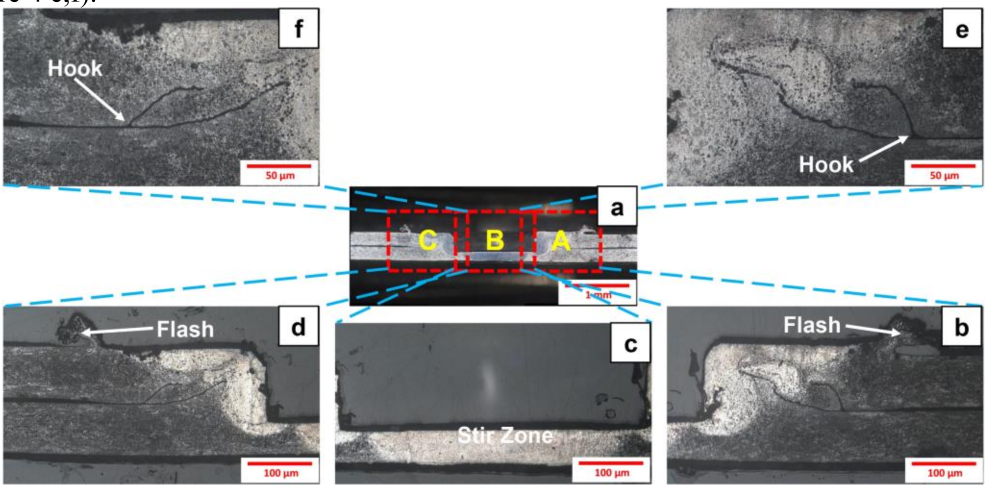

Figure 5. Metallography of Al-Al at dwell time 500 milliseconds and tool 1: (a) macrostructure, (b) microstructure of area A, (c) microstructure of area B, (d) microstructure of area C, and (e, f) microstructure with high magnification

Figure 5a shows the results of macro-structure observations for Al-Al material with a dwell time parameter of 500 ms and tool 1. The flash created on the upper plate is quite high, but some areas are not perfectly bonded. Microstructure observations were made in areas A and C, as shown in Figures 5b and 5d. In the middle area of the weld, you can see the rest of the upper plate which is attached to the lower plate due to friction with the tool. The SZ and TMAZ regions are visible on the bottom plate. Figure 5c shows the results of microstructure observations in area B. The hook formed tends to point upwards, and there are a few cracks on the left and right sides of the weld (see Figures 5e and 5f).

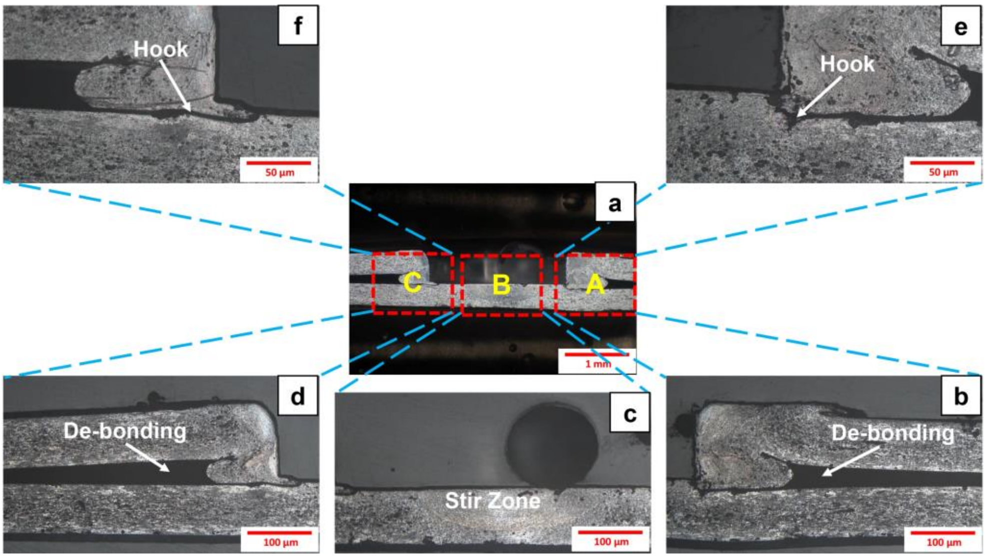

Figure 6. Metallography of Al-Al at dwell time 700 milliseconds and tool 1: (a) macrostructure, (b) microstructure of area A, (c) microstructure of area B, (d) microstructure of area C, and (e, f) microstructure with high magnification

Furthermore, macro-structural observations were carried out on Al-Al material with a dwell time parameter of 700 ms and tool-1, as shown in Figure 6a. The side area of the weld is not properly bonded because the top plate is lifted. The longer the stirring time occurs, the top plate can be lifted up in the area that is not exposed to the tool. The next observation is the microstructure in the middle area of the weld (area B) which is shown in Figure 6c. Based on these observations, the SZ, TZ and TMAZ areas on the bottom plate can be seen. The top plate blends with the bottom plate perfectly in the middle. The areas A and C, which are the weld edges of the right and left sides are observed in the microstructure and are shown in Figures 6b and 6d. Based on the figure, it can be seen that there is an area that is not well bound, which is next to SZ. The EXTD region was also observed in the non-bound region of the upper plate. While the flash formed is relatively lower. Figures 6e and 6f are high magnifications of the weld edge area on the left and right sides. In this picture you can see the direction of the hook formed from the welding results.

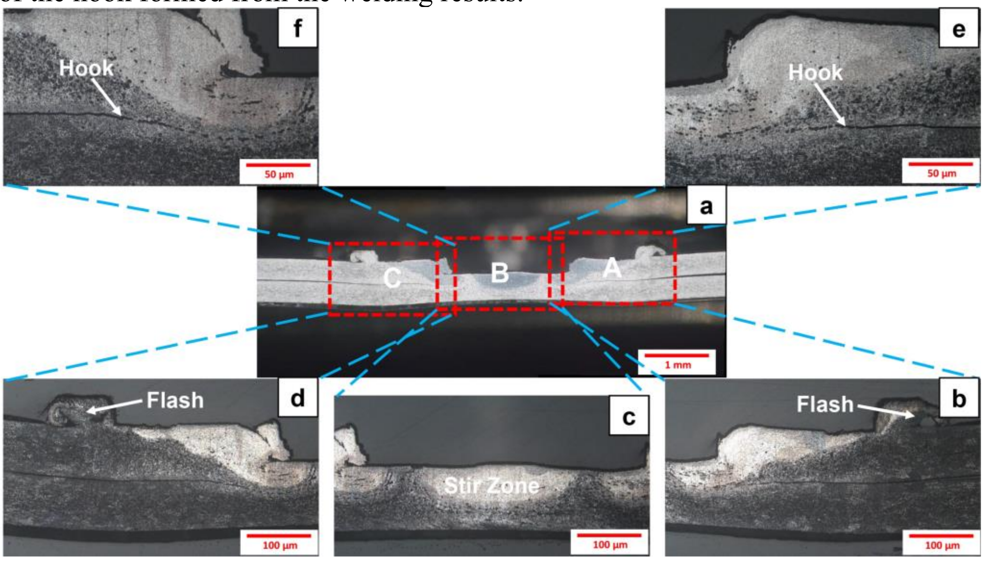

Figure 7. Metallography of Al-Al at dwell time 300 milliseconds and tool 2: (a) macrostructure, (b) microstructure of area A, (c) microstructure of area B, (d) microstructure of area C, and (e, f) microstructure with high magnification

Figure 7a shows the results of the macrostructure of the Al-Al material at the dwell time parameter of 300 ms and tool 2. Welding defects in the form of flash began to appear on the right and left edges of the weld. The depth of the puncture looks very shallow because the dwell time used is the lowest. This causes the heat generated to be lower and the weld penetration to become shallow. Area B is further observed in the microstructure shown in Figure 7c. Area B is the SZ area which is right in the middle. Based on the micro results, it can be seen that the two materials can be connected perfectly. The SZ region on the top plate and the TMAZ region on the bottom plate can be clearly observed. Figures 7b and 7d show the microstructure results in areas A and C. Areas A and C are the sides of the weld on the right and left sides, where extend or flash areas appear. The flow transition zone (FTZ) is observed at the edge of the weld, where friction occurs between the material and the shoulder pin tool.

Furthermore, the stir zone (SZ) is also visible on the surface of the weld that rubs against the surrounding surface of the tool pin. The hook formed leads to the bottom plate, as shown in Figures 7e and 7f. The relatively short stirring time causes the hook formed to point downwards.

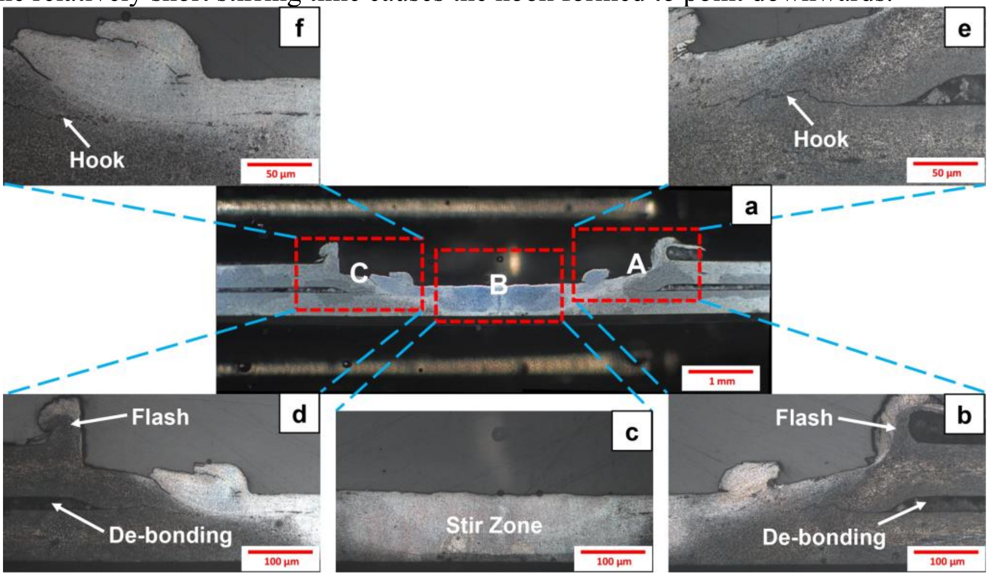

Figure 8. Metallography of Al-Al at dwell time 500 milliseconds and tool 2: (a) macrostructure, (b) microstructure of area A, (c) microstructure of area B, (d) microstructure of area C, and (e, f) microstructure with high magnification

Figure 8a shows the results of observing the macrostructure of the Al-Al material at the dwell time parameter of 500 ms and tool 2. The unbound area between plates is visible on the right and left sides of the weld. The flash that is formed is also quite high. This is because the tool's geometry has two stage shoulders with a long dwell time that causes the top plate to lift. Area B is further observed in the microstructure observations shown in Figure 8c. SZ, TZ, and TMAZ regions appear on the bottom plate. Furthermore, microstructure observations were carried out again in areas A and C as shown in Figures 8b and 8d. A slight crack beside the hook forms on the left side of the weld as shown in Figures 8e and 8f. The difference in microstructure can be seen from the area that rubs against the tool and the base metal.

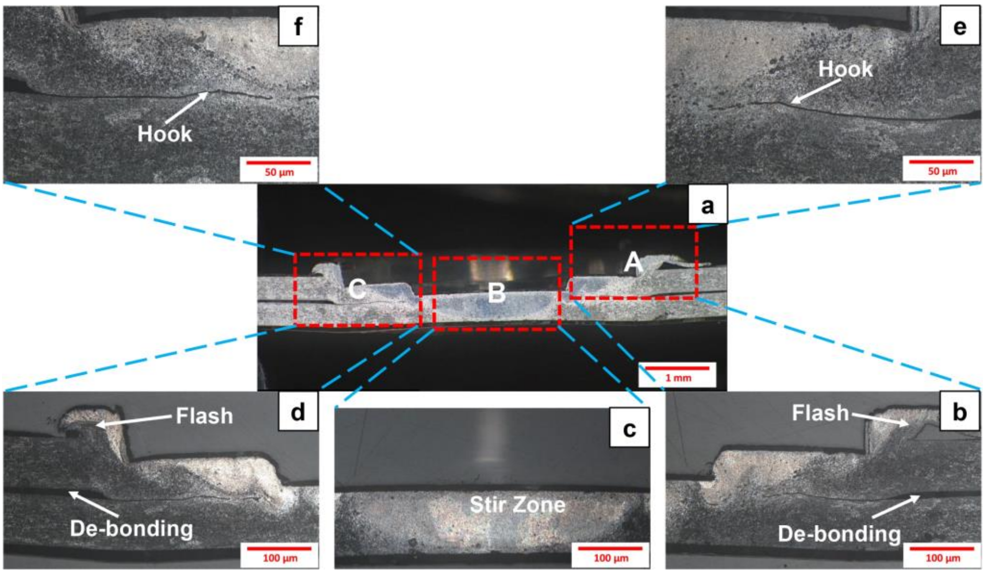

Figure 9. Metallography of Al-Al at dwell time 700 milliseconds and tool 2: (a) macrostructure, (b) microstructure of area A, (c) microstructure of area B, (d) microstructure of area C, and (e, f) microstructure with high magnification

Figure 9a shows the results of macro-structure observations on Al-Al material with dwell time parameters of 700 ms and tool 2. The side of the weld on the top plate is raised quite high and causes the area not to be appropriately bonded. This happens because the dwell time used is the highest, so the heat is higher and presses the top plate. So that the top plate that is not exposed to the tool will be lifted, but it also forms a flash. Microstructure observations in area B have been carried out; the results are shown in Figure 9c. The SZ and TZ regions can be seen on the bottom plate. The heat-affected area looks different in its microstructure. Then the left and right weld edge areas (areas A and C) were further observed for their microstructure and shown in Figures 9b and 9d. The EXTD, FTZ, SZ and TZ regions can be observed at the edges of the weld. The flash that is formed can be seen clearly due to friction with the tool. The hook formed on the weld side tends to point upwards, as shown in Figures 9e and 9f.

Based on the observation of the microstructure for all welding parameters, it can be seen that a flash appears on the edges of the weld. This is because some samples' top plate on the side of the weld is not properly bonded. The trend obtained from the macrostructural search results regarding the value of the hook width tends to decrease slightly from the weld results with a dwell time of 300 ms, then drastically increases the hook width in the weld results with a dwell time of 500 ms and 700 ms. This is in accordance with the literature written by Badarinarayan et al. [5], which states that the longer the stirring time, the wider the hook width and leads to the top. The value of the hook height starting from the end of the metallurgical connection or perfect connection to the point between the two materials is also decreasing. This is also in accordance with the existing literature. When viewed from the hook's direction, the weld hook with 500 ms turns towards the upper material or towards the stirring zone.

4. Conclusions

This study completed the variation of Micro Friction Stir Spot Welding (µFSSW) welding parameters for AA1100-like materials. FSSW parameters include tool geometry (pin 600 and two-stage shoulder) and dwell time (300 ms, 500 ms, and 700 ms). The tool rotates at high speed of about 33,000 rpm and then presses the two materials. Based on the results of the study, the effect of dwell time and tool geometry on weld depth and metallography (hook width, hook height, and effective cover plate thickness) for welds using AA1100 sheet and various tool geometries and Weld depth results are not always directly proportional but increase penetration and stir time. At the same time, the diameter of the weld will be wider if the stirring time is prolonged. Visually, it produces a fairly good weld at a dwell time of 500 ms. Based on the observation of the microstructure for all welding parameters, the trend of the hook width values obtained from the microstructure search results shows a trend towards a slight decrease at a dwell time of 300 ms and a significant increase in the hook width of the weld results at dwell times of 500 ms and 700 ms.

Acknowledgments
This research is supported by the Automation and Manufacturing Systems Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia.

References
[1] J. G. Feldstein, "Welding and brazing qualifications," *ASME Boil. Press. Vessel Code,* vol. 2, pp. 189-225, 2002.
[2] W. M. Thomas, E. D. Nicholas, J. C. Needham, M. G. Murch, P. Templesmith, and C. J. Dawes, "Friction stir welding. International Patent Application No. PCT/GB92/02203 and GB Patent Application No. 9125978.8," *US Patent,* no. 5, pp. 460-317, 1991.
[3] W. M. Thomas and E. D. Nicholas, "Friction stir welding for the transportation industries," *Materials & design*, vol. 18, no. 4-6, pp. 269-273, 1997.
[4] H. Badarinarayan, Q. Yang, and S. Zhu, "Effect of tool geometry on static strength of friction stir spot-welded aluminum alloy," *International Journal of Machine Tools and Manufacture,* vol. 49, no. 2, pp. 142-148, 2009.
[5] H. Badarinarayan, Y. Shi, X. Li, and K. Okamoto, "Effect of tool geometry on hook formation and static strength of friction stir spot welded aluminum 5754-O sheets," *International Journal of Machine Tools and Manufacture,* vol. 49, no. 11, pp. 814-823, 2009.
[6] Y. H. Yin, N. Sun, T. H. North, and S. S. Hu, "Hook formation and mechanical properties in AZ31 friction stir spot welds," *Journal of Materials Processing Technology,* vol. 210, no. 14, pp. 2062-2070, 2010.
[7] A. S. Baskoro, G. Kiswanto, and W. Winarto, "Effects of high speed tool rotation in micro friction stir spot welding of aluminum A1100," vol. 493, pp. 739-742: Trans Tech Publ.
[8] Z. Zhang, X. Yang, J. Zhang, G. Zhou, X. Xu, and B. Zou, "Effect of welding parameters on microstructure and mechanical properties of friction stir spot welded 5052 aluminum alloy," *Materials & Design,* vol. 32, no. 8-9, pp. 4461-4470, 2011.
[9] A. S. Baskoro, A. Riyanto, M. F. Arifardi, and P. Rupajati, "Influence of Tools Diameters and Plunge Depth on Mechanical Properties of Micro Friction Stir Spot Welding Materials A1100," vol. 727, p. 012008: IOP Publishing.
[10] M. Boz and A. Kurt, "The influence of stirrer geometry on bonding and mechanical properties in friction stir welding process," *Materials & Design,* vol. 25, no. 4, pp. 343-347, 2004.
[11] V. X. Tran, J. Pan, and T. Pan, "Effects of processing time on strengths and failure modes of dissimilar spot friction welds between aluminum 5754-O and 7075-T6 sheets," *Journal of materials processing technology,* vol. 209, no. 8, pp. 3724-3739, 2009.
[12] R. Rai, A. De, H. Bhadeshia, and T. DebRoy, "friction stir welding tools," *Science and Technology of welding and Joining,* vol. 16, no. 4, pp. 325-342, 2011.
[13] 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.