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Welding of AlSi10Mg Alloy Produced by Additive Manufacturing to AA5083 by Friction Stir and Mechanical Properties Investigation

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Abstract- Nowadays, with the widespread use of additive manufacturing applications, it has become important to join the parts obtained from this production method with other materials. In this study, it was aimed to investigate whether the AlSi10Mg alloy produced by additive manufacturing can be joined to the AA5083 alloy, which is widely used in industrial applications, by friction stir welding (FSW) method. In this status, sheets produced in dimensions of 200x50x4 mm^3 were used. FSW was performed using a tool with triangular pyramid geometry with a travesting at 85 mm x min^{-1}, rotation speed of 800 rpm, and pressure force of 7 kN. The tilt angle of FSW tool was kept constant at 2°. FSW was performed using A tungsten carbide (WC) tool consisted of a shoulder with the diameter of 18 mm and the 30° cone angle. After the FSW, the specimens were taken from the joint areas to investigate the structural and mechanical properties. It is observed that a very fine-grained structure emerges in the mixing region. The tension test specimens were taken from the FSW zone parallel to the welding direction by wire-electron discharge machine (EDM). Tensile tests were performed using the shape of a dog-bone specimen which in accordance with the ASTM E8. The tests were carried out using a tensile tester at $1x10^{-3}$ s^{-1} strain rate. Evaluations were performed by comparing the findings with the base materials.

Keywords: Additive Manufacturing, Friction Stir Welding, AlSi10Mg, AA 5083, Tensile test

I. INTRODUCTION

Selective laser melting (SLM) is a powder bed fusion that melts powder layer by layer with a laser beam and is a widely used additive manufacturing technique. This technique has remarkable advantages such as short forming cycle and high forming accuracy [1, 2]. Therefore, SLM is a low-polluting method to produce mechanical parts than conventional methods which have high energy consumption and long production cycles such as casting, forging, rolling. Aluminum alloys have the advantages of good formability, high strength, and low density. They are widely used in fields such as aerospace, automobiles, and construction areas [3]. Among the aluminum alloys produced by the additive manufacturing method, AlSi10Mg alloy stands out [4, 5]. In the literature, a hierarchical microstructure consisting of ~10 µm sized grains and ~500 nm sized cells within individual grains has been seen in SLM AlSi10Mg alloys, resulting in high strength and high strain hardening capacity [6]. Welding of SLMed components have become a conspicuous subject in industrial application as allow for fabrication of hybrid structures with complex geometries, and huge sizes [8]. Researchers have very recently begun to investigate the weldability of SLM-AlSi alloys [8, 9]. These studies revealed that friction stir welding (FSW) is a convenient process for joining Al–Si10–Mg components. However, FSW

considerably affects mechanical properties in the weld zone. In addition, studies focus on joining the AlSi10Mg alloy, which is an additive manufacturing product, with the same alloy using FSW. The novelty of this study is on the joining of as-casted Al5083 alloy with FSW by additive manufacturing and its possible effects on mechanical properties.

II. Materials and Experimental Procedures

In this study, AlSi10Mg and Al5083 plates were used to be joined with FSW. Samples with dimensions of 200 x 50 x 4 mm^3 were prepared with machining from these plates. These plates subjected to the FSW were fixed by the shoes on the upper table of the hydraulic assembly given in Figure 1. FSW was carried out using a special processing tool (Figure 2) with 800 number of revolutions (rpm), traversing at 85 mm/min and pressure force of 7 kN. Hardness measurements were carried out using a Vickers micro-hardness tester (Struers Duramin, Denmark) under a constant load of 500 g and a dwell time of 10 seconds. Tensile tests were performed using the dog-bone shape sample which in accordance with the ASTM E8. Tensile tests were carried out using a tensile tester (Instron-3382, USA) at 1 x 10-3 s-1 strain rate. The fracture surfaces of tensile samples were analyzed employing SEM (Zeiss EVO LS10, Germany).

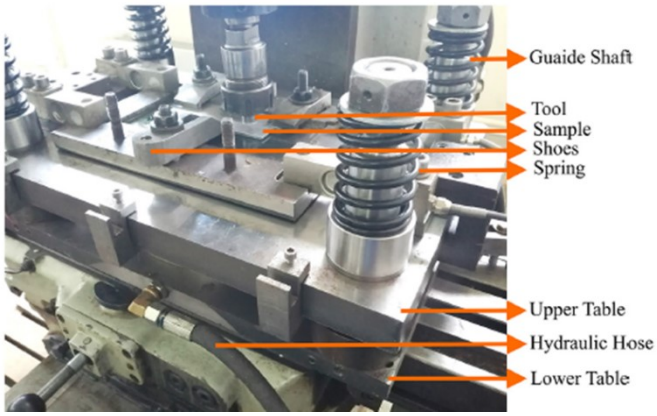


Fig. 1. Detail view of the friction stir welding setup [10].

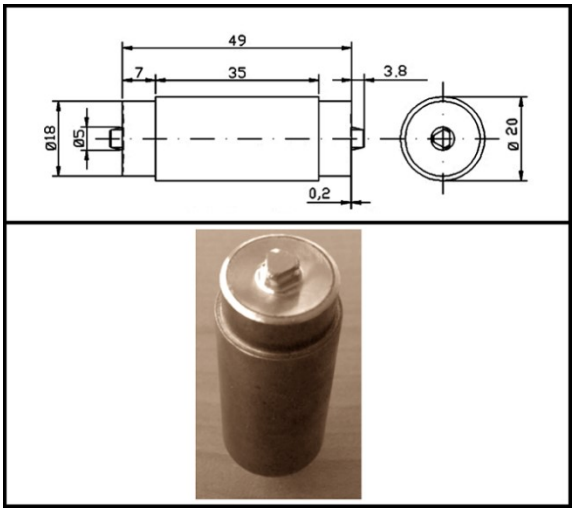


Fig. 2. Picture, geometry, and dimensions of the FSW tool

III. RESULTS AND DISCUSSION

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A. *Microstructure Analyses*

Figure 3 presents the optical microscope images of the cross section of the FSWed joints. The overview micrographs of welding zone reflect sound welds without any imperfections and hot cracks. In this case, the weldability of as-casted and additive manufactured alloys with this method are demonstrated. A basin-shaped weld with slight concavity is clearly observed for the FSW joints, resulting from the extreme deformation and frictional heating by contact with a shoulder during FSW [11]. Banding structures consisting of alternate material layers, namely the so-called “onion rings”, are noticeable in the nugget zone.

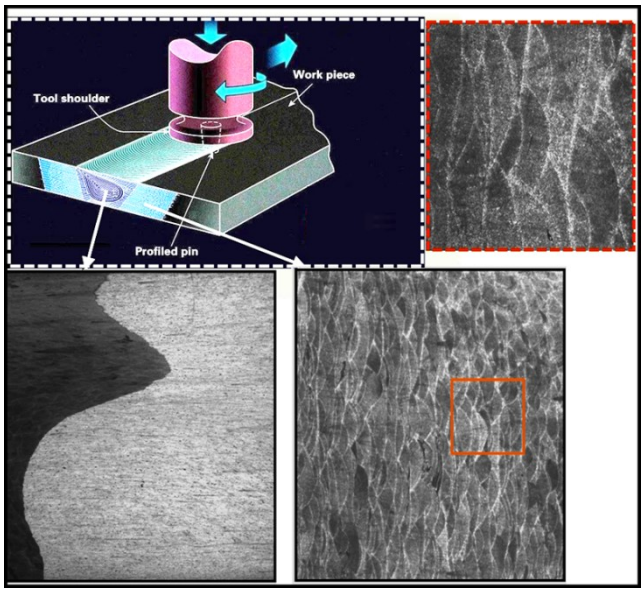


Fig. 3. Overview micrographs obtained by optical microscopy

B. *Mechanical Properties*

The microhardness profiles across the FSW zone from left to right are given in Figure 4. It can be seen the hardness values, the FSW is led to a softening in the weld nugget zone. The microhardness in the SLMed sample is about 72 HV0.5, which is 25% superior than welding zone with around 55 HV0.5. This situation in hardness is emphasized to be due to the dissolution and rearrangement, respectively, of the Si-rich network upon FSW [12]. It is also well-known that severe plastic deformation in FSW occurs an enhance in density of dislocation [13]. Due to this effect, higher hardness can be expected in the Nugget Zone compared to TMAZ, HAZ and base material.

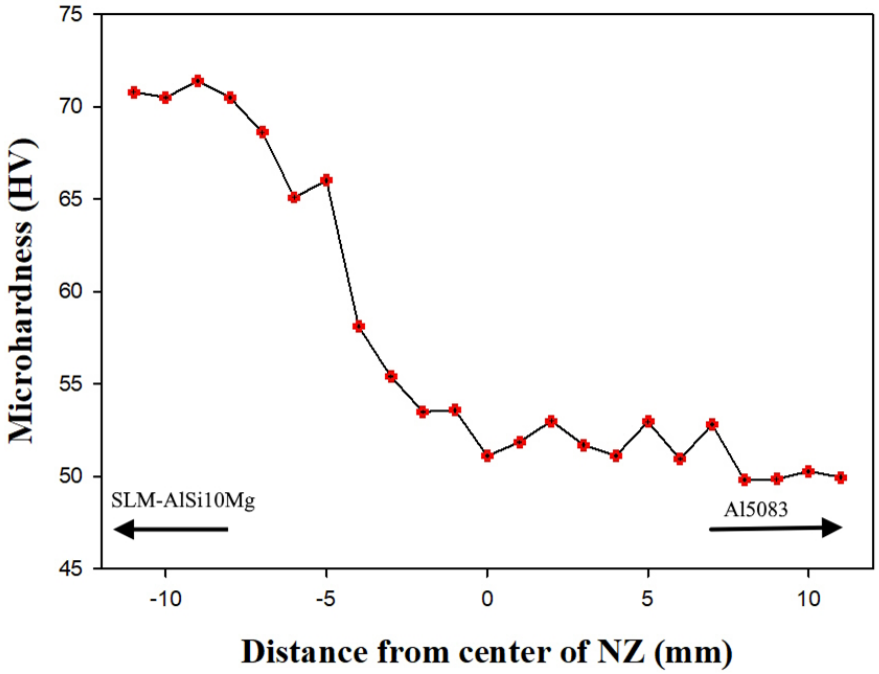


Fig. 4. Microhardness distrubition of FSW joints in SLMed AlSi10Mg and as-casted Al5083 alloys

In the literature, it is seen that the tensile strength value of SLMed AlSi10Mg alloy, which is about 323.6 MPa [14]. In Al5083, this value is determined as around 270 MPa [15]. Figure 5 presents the stress versus strain curves for the FSW joints. The FSW of SLMed AlSi10Mg and Al5083 alloys exhibits a UTS of 201.5 MPa together with an EI of 3.55%. The FSW joint produces a reduced UTS compared to the base materials, implying a joint softening phenomenon is still occurred during the FSW. However, the FSW joints possess a great strain hardening ability, contributing to the high tensile ductility. This is attributed the globularization of the Si-rich eutectic enhance ductility of SLMed AlSi10Mg alloys [16]. The fracture surfaces of the tensile samples are given in Figure 6. This fractograph reveals in eqiaxed dimples. This kind of failure can be due to nucleation of micro-voids at the tip of the cracks, their growth and coalescence by strong shear deformation [17]. Thus, the upper part in the Nugget Zone shows a ductile fracture mode, which is beneficial to improve the tensile ductility of the FSW joints.

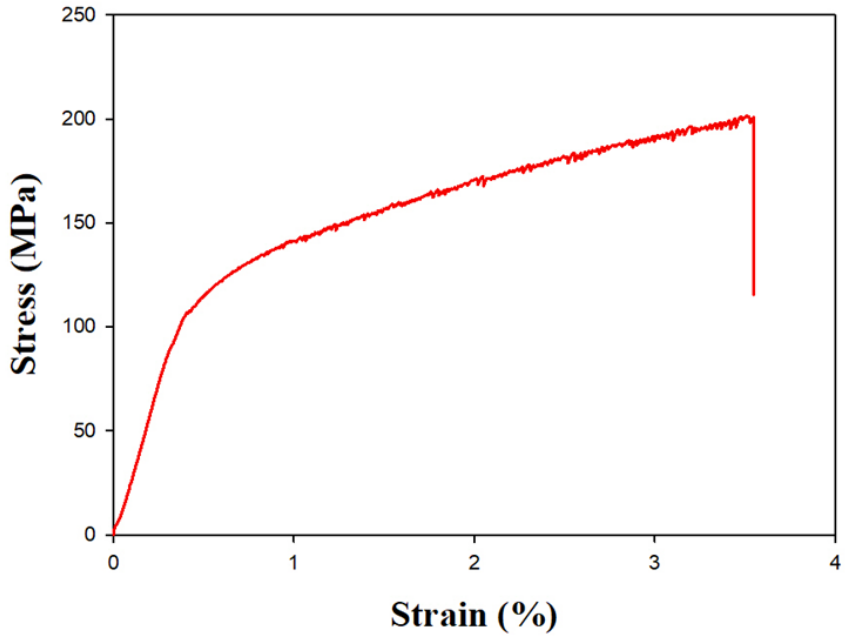


Fig. 5. Tensile stress and strain curve of the FSW joint

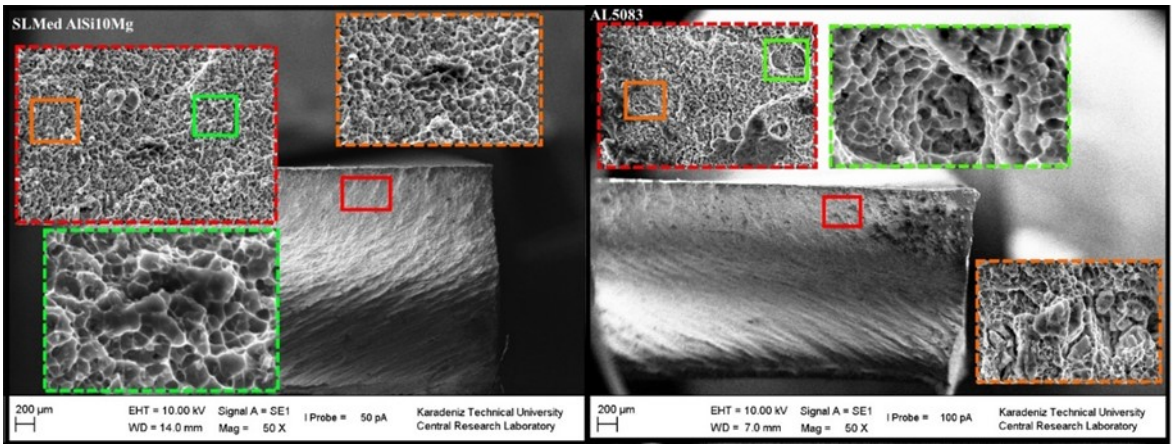


Fig. 6. Fracture surface morphology of the FSW joints

IV. CONCLUSIONS

Based on the above results and discussion, the following conclusions can be made from this work:

- With the welding parameters applied in the study, SLMed AlSi10Mg and as-casted Al5083 alloys can be joint using FSW.
- The hardness in the weld zone is slightly reduced, especially compared to SLMed AlSi10Mg.
- The FSW of SLMed AlSi10Mg and Al5083 alloys exhibits a UTS of 201.5 MPa together with an EI of 3.55%.
- In addition to the decrease in mechanical properties, an increase in ductility is observed.
- The weld zone characteristically indicates ductile fracture.

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REFERENCES

[1]. D. Herzog, V. Seyda, E. Wycisk, C. Emmelmann, Additive manufacturing of metals, Acta Materialia, 117 (2016) 371-392.

[2]. K. G. Prashanth, S. Scudino, H. J. Klauss, K. B. Surreddi, L. Löber, A. K. Chaubey, U. Kühn, J. Eckert, Microstructure and mechanical properties of Al–12Si produced by selective laser melting: Effect of heat treatment, Materials Science and Engineering: A, 590 (2014) 153-160.

[3]. S. A. Alla, V. Bianco, L. A. Tagliafico, F. Scarpa, Pathways to electric mobility integration in the Italian automotive sector, Energy, 221 (2021) 119882.

[4]. G. Çam, G. İpekoğlu, Recent developments in joining of aluminum alloys, Int J Adv Manuf Technol 91 (2017) 1851–1866.

[5]. X. Gu, J. Zahng, X. Fan, N. Dai, Y. Xiao, L.-C. Zhang, Abnormal corrosion behavior of selective laser melted AlSi10Mg alloy induced by heat treatment at 300 °C, Journal of Alloys and Compounds, 803 (2019) 314-324.

[6]. B. Chen, S. K. Moon, X. Yao, G. Bi, J. Shen, J. Umeda, K. Kondoh, Strength and strain hardening of a selective laser melted AlSi10Mg alloy, Scripta Materialia, 141 (2017) 45-49.

[7]. M. Nahmany, I. Rosenthal, I. Benishti, N. Frage, A. Stern, Electron beam welding of AlSi10Mg workpieces produced by selected laser melting additive manufacturing technology, Additive Manufacturing, 8 (2015) 63-70.

[8]. A. Ascari, A. Fortunato, E. Liverani, A. Gamberoni, L. Tomesani, New Possibilities in the Fabrication of Hybrid Components with Big Dimensions by Means of Selective Laser Melting (SLM), Physics Procedia, 83 (2016) 839-846.

[9]. A. Heidarzadeh, S. Mironov, R. Kaibyshev, G. Çam, A. Simar, A. Gerlich, F. Khodabakhski, A. Mostafaei, D. P. Field, J. D. Robson, A. Deschamps, P. J. Withers, Friction stir welding/processing of metals and alloys: A comprehensive review on microstructural evolution, Progress in Materials Science, 117 (2021) 100752.

[10]. H. Ghahramanzadeh Asl, S. C. Uzuner, U. Uzuner, Y. Sert, T. Küçükömeroğlu, The effect of friction stir process on the mechanical, tribological, and biocompatibility properties of AZ31B magnesium alloy as a biomaterial: A pilot study, 236 (2022) 1720-1731.

[11]. R. S. Mishra, Z. Y. Ma, Friction stir welding and processing, Materials Science and Engineering: R: Reports, 50 (2005) 1-78.

[12]. G. Moeini, S. V. Sajadifar, T. Wegener, F. Brenne, T. Niendorf, S. Böhm, On the low-cycle fatigue behavior of friction stir welded Al–Si12 parts produced by selective laser melting, Materials Science and Engineering: A, 764 (2019) 138189.

[13]. G. Çam, V. Javaheri, A. Heidarzadeh, Advances in FSW and FSSW of dissimilar Al-alloy plates, Journal of Adhesion Science and Technology, 37 (2023) 162-194.

[14]. L. Cui, D. Wu, Y. Chang, X. Guo, X. Wu, W. Shao, D. He, Microstructural evolution and mechanical property of friction stir welded joints in AlSi10Mg alloys fabricated by laser powder bed fusion, CIRP Journal of Manufacturing Science and Technology, 4 (2023) 228-243.

[15]. F. Heirani, A. Abbasi, M. Ardestani, Effects of processing parameters on microstructure and mechanical behaviors of underwater friction stir welding of Al5083 alloy, Journal of Manufacturing Processes, 25 (217) 77-84.

[16]. L. Zhao, L. Song, J. G. S. Macias, Y. Zhu, M. Huang, A. Simar, Z. Li, Review on the correlation between microstructure and mechanical performance for laser powder bed fusion AlSi10Mg, Additive Manufacturing, 56 (2022) 102914.

[17]. U. A. Khaliq, M. R. Muhamad, F. Yusof, S. Ibrahim, M. S. M. Isa, Z. Chen, G. Çam, A review on friction stir butt welding of aluminum with magnesium: A new insight on joining mechanisms by interfacial enhancement, Journal of Materials Research and Technology, 27 (2023) 4595-4624.