MECHANICAL PROPERTIES OF AlSi10Mg PLATES PRODUCED BY SELECTIVE LASER MELTING WITH DISSIMILAR AUTOMOTIVE ALUMINUM ALLOYS BY FRICTION STIR WELDING

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Abstract

Welding of components processed by additive manufacturing (AM) to conventionally produced components become important for industrial applications. Among AM production methods, selective laser melting method provides number of advantages such as use of various type of materials, increased functionality, relatively low cost and the production of smooth surface components ready to use.

Within the scope of this study, preliminary research studies were carried out to demonstrate the feasibility of similar and dissimilar friction stir welded AlSi10Mg plates produced by selective laser melting. Mechanical performances in terms of tensile and hardness values of similar and dissimilar welded joint combinations of AlSi10Mg plates were investigated. In order to determine welding defects, macro/micro structural characterization was performed on welding zones. The similar friction stir welded of AlSiMg10 exhibits of up to 75% of the base metal. In dissimilar friction stir welded joint strength were obtained obtained up to 55% of the base metal.

Keywords: Dissimilar Friction Stir Welding, Selective Laser Melting method, AlSi10Mg, hardness

1. INTRODUCTION

Friction Stir Welding (FSW) of aluminum alloys is one of the widely studied topics in the literature. The major works in the literature on this subject have mainly focused on FSW of alloys produced by conventional process routes; see the important review and book on the subject by Mishra and Ma [1], Mishra and Mahoney [2]. The investigations on employing FSW for joining or repairing AM AlSi10Mg parts are very limited in literature [3,4]. Du et al. [1] have found that by increasing the friction stir welding (FSW)heat input, the elongation of the AlSi10Mg joints increases considerably. However, the ultimate tensile strength was decreased by approximately 44 %. Rashanth et al. in 2014 investigated the FSW of Selective Laser Melting (SLM) fabricated Al-12Si components [5] and Nahmanya et al. in 2015 investigated the electron beam welding of SLM fabricated AlSi10Mg components [6].

In recent years, SLMed Al-Si alloy has received increasing attention due to its high corrosion resistance, high specific strength, and good flowability properties. There are many studies in the literature focusing on optimization of processing parameters [7,8], dimensional accuracy and surface roughness [9], microstructure and mechanical properties [10-15]. However, only a few studies have been conducted so far on the weldability of parts printed by SLM technology.

In this study, preliminary research studies were carried out to demonstrate the feasibility of similar and dissimilar friction stir welded AlSi10Mg plates produced by SLM. Mechanical properties of similar and dissimilar welded joint combinations of AlSi10Mg plates were compared.

2. EXPERIMENTAL PROCEDURES

2.1 Material properties and method

Chemical composition and the mechanical properties of the aluminum alloys used in this study were shown in **Table 1** and **Table 2**, respectively. The SLM experiments were conducted on SLM® system solutions 280 2.0 machine. The spot size of the laser was about 80 µm. All plates were fabricated in an argon atmosphere with the concentration of O_2 controlled below 100 ppm. All plates were also fabricated under the same processing condition and the porosity was controlled below 0.2%. The production was done at 700W laser power and 60 µm layer thickness.

Table 1 Chemical composition of the aluminum alloys used in this study (wt%)

Alloy	Fe	Si	Cu	Mn	Mg	Zn	Cr	Ti	Ni	Pb	Sn	Al
AlSi10Mg	0.5	11.00	0.05	0.45	0.45	0.10	-	0.15	0.05	0.05	0.05	rest
AA5754	0.4	0.4	0.1	0.5	3.2	0.2	0.3	0.15	-	-	-	rest
AA7075	0.5	0.4	1.7	0.3	2.6	5.5	0.24	0.20	-	-	-	rest

Table 2 Mechanical properties of materials

Alloy	Tensile strength (MPa)	Elongation (%)	Micro hardness $Hv_{0.5}$
AlSi10Mg	421	8	123
AA5754 H111	210	24	55
AA7075 T6	543	10	150

The rotating pin (pin Ø = 1.80 mm) was y pushed into the dissimilar sheets until the pin tip entered (tool offset) 0.1 mm into the plates. The shoulder diameter of the tool used was 6 mm. A friction welding machine with pressure control function was preferred in order to prevent the effect of plate thickness changes and fixture/equipment deformation during the welding process.

In this study, 2 mm thick sheets made of AlSi10Mg Al alloy powder were welded with 2 mm thick AA 7075 -T6 and AA 5754-H111 alloy sheets by CFSW (Conventional Friction Stir Welding) method. CFSW parameters are shown in **Table 3**.

Table 3 Welding parameters used in the study

Samples	Material 1	Material 2	Rotation speed (rpm)	Weld speed (mm/min)	Force (kN)	Tilt angle (°)
Sample 1	AlSi10Mg	AlSi10Mg	1800	300	4	3
Sample 2	AlSi10Mg	7075 T6	2000			
Sample 3	AlSi10Mg	5754 H111	1500			

In the friction stir welding method, besides the correct selection of the basic welding parameters, it is great importance to design a special pin that will provide sufficient heating and mixing during welding. For this reason, a tool (shoulder and pin) was designed and produced with literature knowledge and experience before welding. The visual figure of the tool design is shown in **Figure 1**.

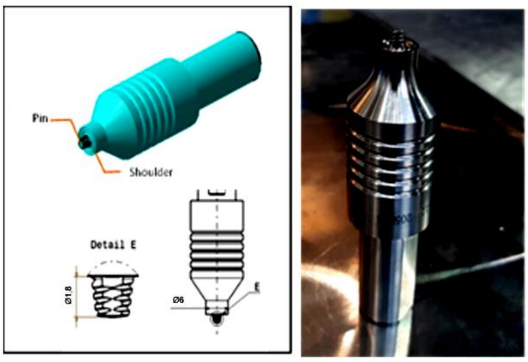

Figure 1 The FSW tool design

Figure 2 shows the welding jig and the welding seams after FSW operations.

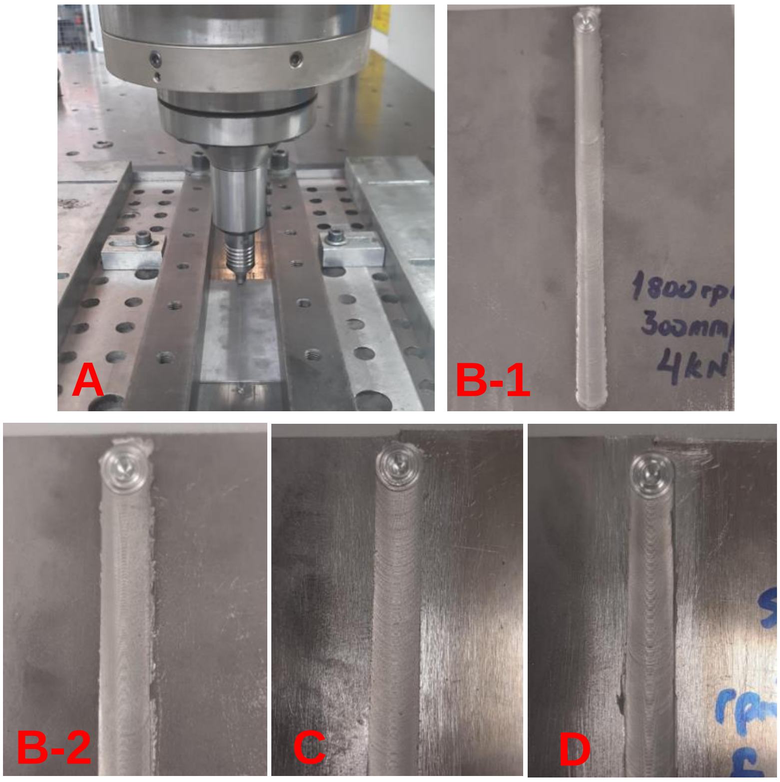

Figure 2 The plates were joined with a butt joint configuration as seen A. Macro images of the weld seams. (Sample 1 is B-1 and B2, Sample 2 is C and Sample 3 is D).

Welded samples were first visually inspected within the scope of the following 4 items:

1) Whether or not any macro-scale surface defects are encountered in the weld seams
2) Whether burrs/corrugations are formed on the retraction side of the weld seams.
3) Whether or not there is a tunnel defect in the root parts.
4) Whether or not there is an open crack on the surface. When the samples seen in **Figure 2** were visually examined within the scope of these 4 items, no macro weld defects were found.

Welded samples were mounted from the cross-sectional area of the weld with an automatic molding press. Sanding and polishing processes were carried out with the standard metallographic method with a sanding and polishing device on the sample interfaces. After the friction stir process, specimens were cut into several sections, perpendicular to the welding direction. Specimens were mechanically polished first with 800, 1200 grit and 2500 grit SiC paper and then with 6 mm, 3 mm and 1 mm diamond paste. The final polishing of these specimens was accomplished using colloidal silica. After polishing, specimens were etched in a nitric Keller's solution at 273 K. After these treatments, they were prepared for optical microscopic observation. Sample surfaces were examined with a Nikon Epiphot 200 Inverted model optical microscope and macro-micro images were taken.

3. RESULTS AND DISCUSSIONS

3.1 Macro- and microanalyses

In FSW of similar materials, extensive grain refinement occurs due to dynamic recrystallization in the stir zone (SZ) resulting in fine-grained microstructures. The microstructural evolution in dissimilar friction stir welds is strongly influenced by the welding parameters, as the material flow has significant influence in the case of dissimilar material combinations compared to similar joints. Proper selection of all process parameters ensures adequate mixing of the base materials and produces a strong joint. When the microstructures taken from the weld zones are evaluated, grain refinement has been seen in the SZ of FSWed similar AlSi10Mg-AlSi10Mg and dissimilar AlSi10Mg-7075 joints in **Figures 3(a)** and **(b)** SZ-TMAZ and **Figures 4 (2)** and **(3)** SZ-TMAZ interface on. The microstructures of **Figure 3(f)**, **Figure 4(5)**, and **Figure 5(h)** are of the AlSiMg10 base metal of the joints and show the typical SLM microstructure. In **Figures 3(c)** and **(d)** shows stir zone of Sample 1.

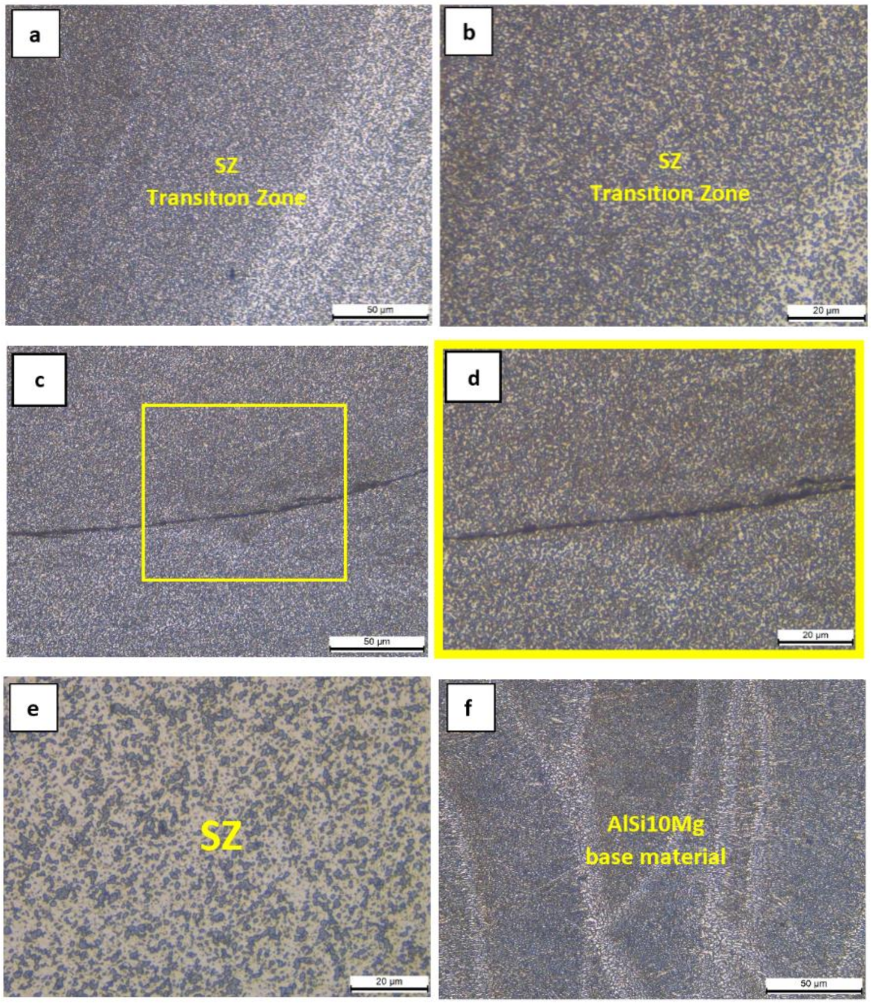

Figure 3 Microstructure images of the Sample 1 welding zone; The Stir Zone-HAZ transition zone at different magnifications (a, b), the s-line formation at the Stir zone centre (c, d), grain growth in the transition zone (e) and the base metal microstructure (f)

Generally, the pre-existing oxide films might cause pore formation in the fusion weld of the SLM Al-Si alloys. But for FSW method, **Figures 3(c)** and **(d)** are reported to be comprised of an array of oxide particles observable at low magnifications. The joint line remnant is also referred as kissing-bond, lazy S, lazy Z, or S-line defect [16-18].

The surfaces of SLM plates were observed rather rough (**Figure 4**). It is well known that aluminium alloys require various surface pre-treatments before welding in order to reduce the influence of surface oxide film. In Sample 1, an S-line defect was found to occur in the centre of the SZ (Stir Zone) along the cross-section (in the area where forehead to forehead positioned plates interfere).

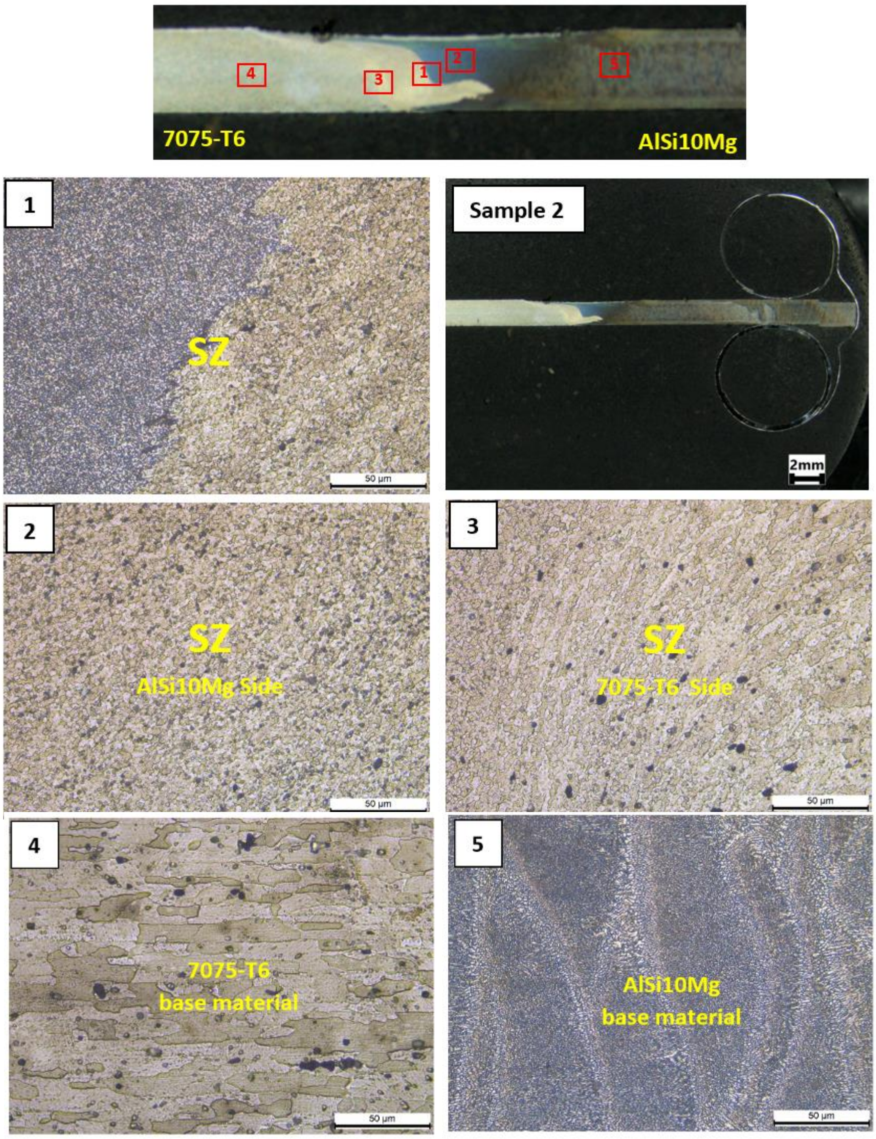

Figure 4 Macro- and microstructures of the Sample 2 welding zone. “1” nugget (weld zone), “2” nugget→AlSi10Mg transmission zone, “3” nugget→7075 transmission zone, “4” 7075-T6 base material, “5” AlSi10Mg base material

Figure 5 shows the stir zone and AlSiMg10 base metal microstructures of Sample 3. In the centre of the stir zone, 5754-H111 and AlSiMg10 alloys are easily separated from each other.

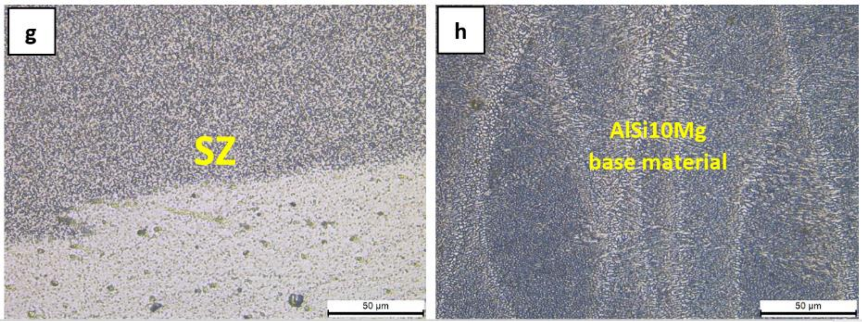

Figure 5 Macro- and microstructures of the Sample 3 welding zone. “g” nugget (weld zone), “h” AlSi10Mg base material

3.2 Microhardness measurements

Hardness profiles were obtained by Vickers microhardness measurements from one side of the weld zone to the other side of the weld zone. The hardness values were taken at 0.2 mm intervals. A sharp drop in hardness can be seen in the center of the nugget.

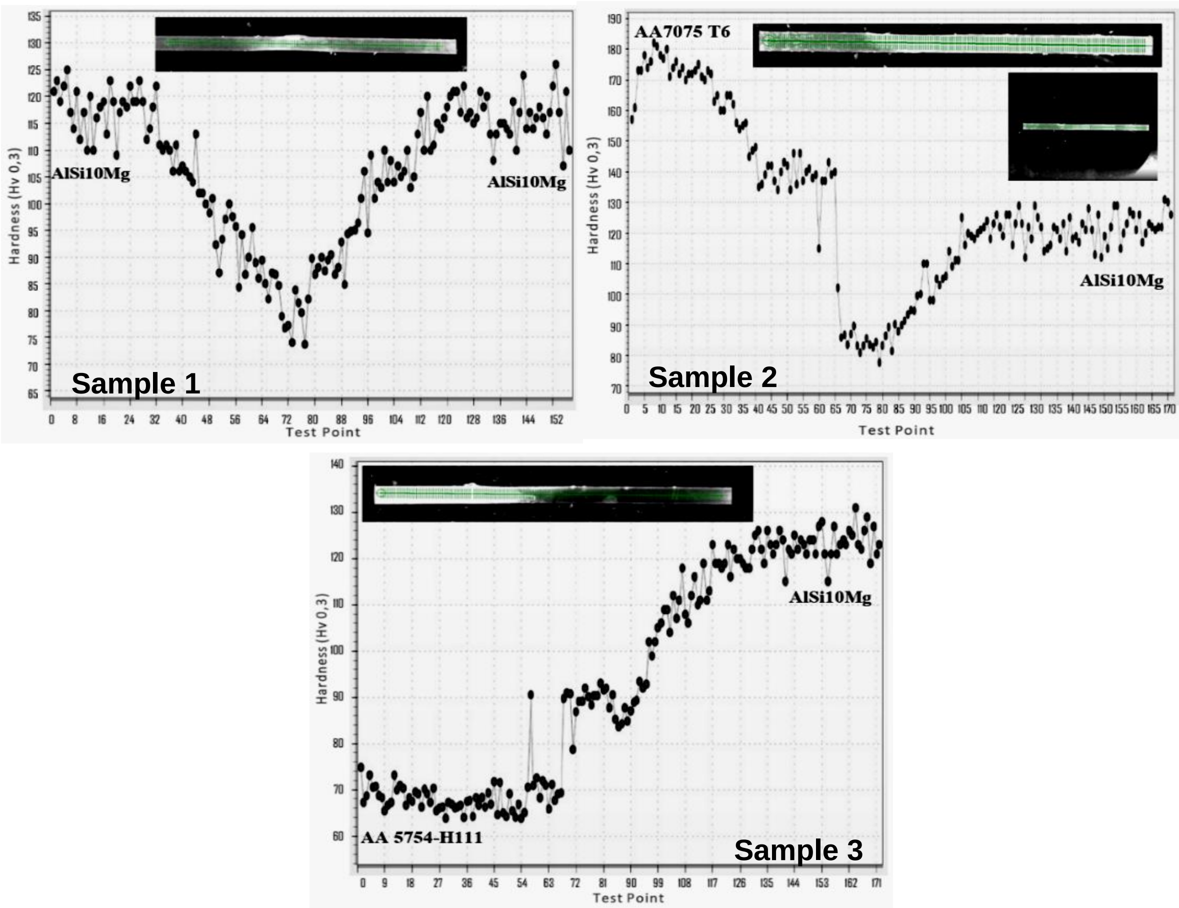

Figure 6 Graphs of microhardness measurement results of the weld zone

When the hardness values of Sample 1 are examined, it is seen that the hardness starts to decrease in HAZ and the lowest hardness values are measured in the weld metal. The hardness values of the advancing side of the sample were relatively higher than the retreating side. It is considered that the FSW parameter used for Sample 1 by reduced the supersaturation of Si in the Al matrix and destroyed the Si network, FSW reduced the hardness of the weld. The hardness of the weld zone decreases due to dissolution or coarsening of the strengthening precipitates. In the present case, the high hardness of the SLM-base metal is due to the supersaturated Al matrix with a large content of Si (11 wt%). As in this study, Prashanth et al [5] observed a softening in the nugget region, which shows a lower hardness than the parent material. In both cases, the parent material is a supersaturated Al matrix whose grains are surrounded by a Si-rich phase network. The matrix can be thought of as an aluminium alloy hardened in solid solution. In general, FSW for this type of alloy does not result in softening of welds, but rather an increase in hardness [1]. However, for the Friction Welding (FW)/Friction Stir Welding (FSW) process of SLM materials, two competing phenomena influence the final hardness of the ingot. On one side, by reducing the supersaturation of Si in the Al matrix and destroying the Si network, FSW tends to reduce the hardness of the weld. On the other hand, FW/FSW increases the hardness by its usual effect of grain refinement, porosity reduction, strain hardening and dispersion strengthening due to the homogeneous distribution of small particles.

3.3 Tensile test results

When the tensile test results are evaluated; It was determined that Sample 1 was broken from the stir zone, Sample 2 was broken from the AlSi10Mg HAZ and Sample 3 was broken from the 5754-H111 base metal region.

The tensile values of AlSi10Mg, 5754-H111 and 7075-T6 were obtained as 421 MPa, 210 MPa and 543 MPa, respectively (**Table 3**). Considering the relationship between the hardness plots and the tensile test results, a significant decrease in hardness (up to 75 HV) was observed in the stir zone (SZ) center of the FSW weld of similar AlSiMg10 materials on Sample1. It is assumed that the formation of S-line may also have an effect together with the decrease in hardness and cause the connection to exhibit rupture behavior from the stir zone center.

When the tensile test results of Sample 2 are evaluated, Sample 2 (**Figure 7**) was ruptured from the HAZ region of AlSiMg10 base metal transition.

The bond strength of AlSiMg10 was approximately 80% of the base material in Sample1, approximately 55% in Sample 2, and approximately 57% in Sample 3.

Table 3 Tensile test results

	Sample 1		**Sample 2**		**Sample 3**	
	Sample1-1	Sample1-2	Sample2-1	Sample2-2	Sample3-1	Sample3-2
Stress (MPa)	337.3	336.0	227.3	244.5	238.8	228.4
	336.6		227.8		241.7	
Elongation (%)	3.15	3.11	2.22	2.13	13.91	14.14
	3.13		2.18		14.02	
Break Zone	SZ	SZ	AlSiMg10	AlSiMg10	5754-H111	5754-H111

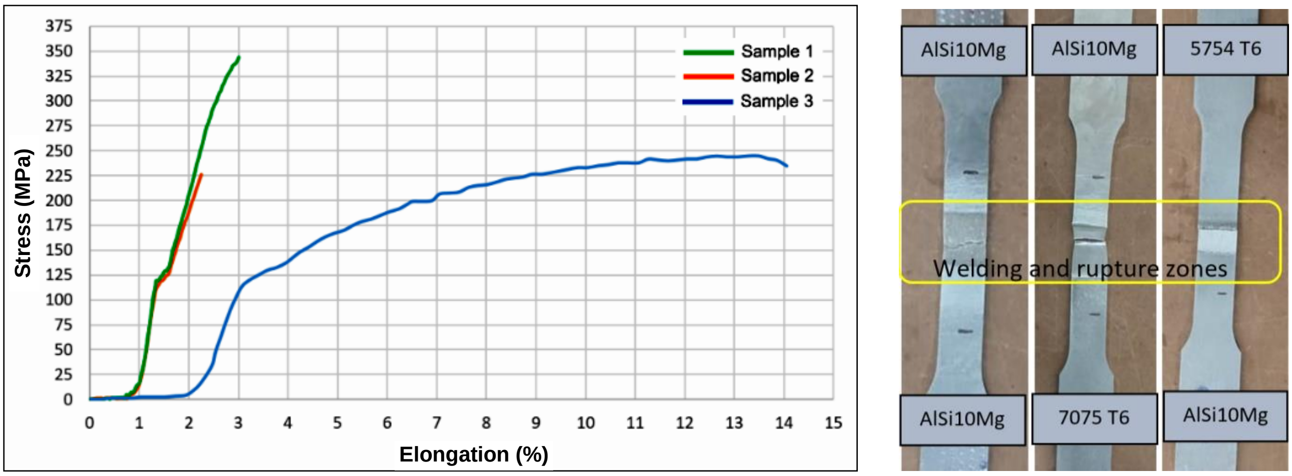

Figure 7 Tensile test result graph and broken tensile test specimens

4. CONCLUSION

- In this study, preliminary research studies were carried out to demonstrate the feasibility of similar and dissimilar friction stir welded AlSi10Mg plates produced by SLM. The test results are summarized as follows:

- Macro welding defect could not be observed by macro structural investigations.
- S-line formation was observed in Sample 1 stir zone by micro structural investigations.
- Stir zone in Sample 1 and Sample 2 has been reported as having lower hardness values than base metals.
- The bond strengths were obtained as; AlSiMg10 was approximately 80% of the base material in the Sample1, approximately 55% of the base in the Sample 2, and approximately 57% of the base in the Sample 3.

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