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Effect of Pre/Post Heat Treatment on the Friction Stir Welded SSM 356 Aluminum Alloys

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Abstract. The butt joints of semi solid 356 were produced in as cast conditions by friction stir welding process (FSW). This experiment studied in pre/post heat treatment (T6) using the welding speed 160 mm / min with tilt angle tool at 3 degree and straight cylindrical tool pin. The factors of welding were rotating speed rates at 1320, 1750 rpm and heat treatment conditions. They were divided into (1) As welded (AW) joints, (2) T6 Weld (TW) joints, (3) Weld T6 (WT) joints, (4) T6 Weld T6 (TWT) joints, (5) Solution treated Weld Artificially aged (SWA) joints and (6) Weld Artificially aged (WA) joints. Rotating speed and heat treatment (T6) condition were an important factor to micro, macro structure of metal and mechanical properties of the weld. Increasing rotating speed and different heat treatment condition impacted onto tensile strength due to the defects on joints. Therefore the optimum welding parameter on joint was a rotating speed 1320 rpm, the welding speed 160 mm/min, heat treatment condition of Weld T6 (WT) which obtained the highest tensile strength 228.92 MPa, as well as, highest hardness of 98.1 HV.

Introduction

There are two types of semi-solid forming technology at the present. Rheo casting is one of them. It involves the preparation of semi-solid metal (SSM) slurry from liquid alloys and casting the slurry into a die for component manufacturing. In this work, semi solid metal was obtained from a new Rheo casting technique called Gas Induced semi-solid (GISS) [1,2]. It was clear that the joint between cast Al alloy has increasingly expanded in the usage of casting component in automotive such as suspension, driveline and engine parts. Conventional fusion welding of SSM aluminium die casting alloys is generally difficult due to the formation of blowholes in weld. In addition, the microstructure is also altered [3,4]. Therefore, a new welding method is required to overcome these problems. In recent year, friction stir welding (FSW) was developed as a solid conditions joining process in which materials are joined by the frictional heat [5]. This process is effective for the welding of aluminium alloys. However, only a limited number of studies have been carried out on SSM cast aluminium alloys. In the case of conventional A356 alloys, the mechanical properties of the joints are improved in comparison to the base metal [6]. Another study of ADC12 [7] shows that the stir zone is comprised of a fine recrystallized zone without dendritic structure. Previous studies also reveal that the strength of friction stir welds mainly depend on the heat treatment condition before and after joining [3, 6, 7, 9, 10, 12]. The aim of this work is to evaluate the effect that FSW has on the mechanical properties of the SSM 356 alloy in as cast and heat treated condition. Microstructure, hardness and tensile properties of the weld joint have been studied and the results are reported.

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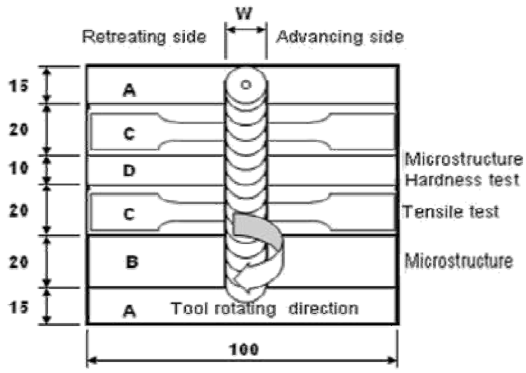
Materials and methods

The material used in this work was SSM 356 Al alloy which obtained from SSM squeeze casting technique. The chemical composition of SSM 356 is listed in Table 1. The friction stir welding plates were 100 mm in length, 50 mm in width and 4 mm in thickness. The cylindrical pin was used for friction stir welding. The diameter of the shoulder was 20 mm. The diameter and length of the pin were 5 mm and 3.3 mm, respectively. The welding tool was rotated in the clockwise direction and specimens, which were tightly fixed at the backing plate, were traveled, In this work, the welding speeds was 160 mm/min. The tool rotation speeds were fixed at 1320 and 1750 rpm, the tilt angle was 3˚.

Table 1 Chemical Compositions (mass %)of SSM 356 Base Material

Alloy	Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Ni
Base Material	Bal.	7.74	0.57	0.05	0.06	0.32	0.01	0.05	0.02	0.01

In order to study the influence of pre/post weld heat treatment on microstructure and tensile properties, the welded joints were grouped into six different categories, namely, (1) As welded (AW) joints, (2) T6 Weld (TW) joints, (3) Weld T6 (WT) joints, (4) T6 Weld T6 (TWT) joints, (5) Solution treated Weld Artificially aged (SWA) joints and (6) Weld Artificially aged (WA) joints. The process of T6 consisted of solution treatment at 540^{O}C for 8 hours and then water quenching before artificial aging at 165^{O}C for 12 hours [8]. The welded joints were sliced using a power hacksaw and then machined to the required dimensions in Fig. 1. The test pieces were cut in the cross-section direction, ground, polished and then etched with Keller's reagent. The macrostructure and microstructure were observed by optical microscopy. The tensile test was carried out at room temperature using an Instron-type testing machine with cross-head speed of 1.67x10^{-2} mm/s.

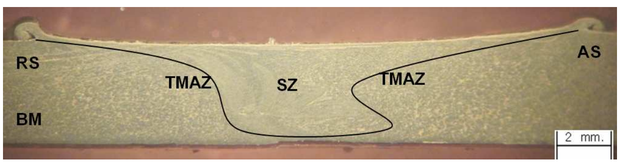


Figures 1 The location of the specimens (A) Discard, (B) Microstructure,
(C) Tensile Test and (D) Hardness Test

Experimental Results and discussions

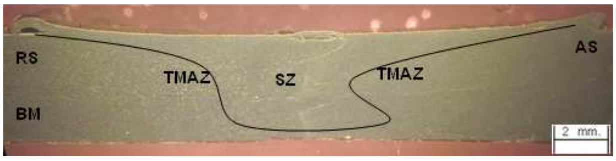
Macrostructures

Fig. 2 shows the cross-section of a FSW joint. The cross-section of the joint displays three microstructurally distinct regions: the Base Metal (BM), the Stir Zone (SZ), and the Thermo Mechanically Affected Zone (TMAZ) the Advancing Side (AS) and the Retreating Side (RS) are also revealed for the joint. Details of the precipitate variation in each zone are given below.



Figures 2 The Cross Section of FSW Joint

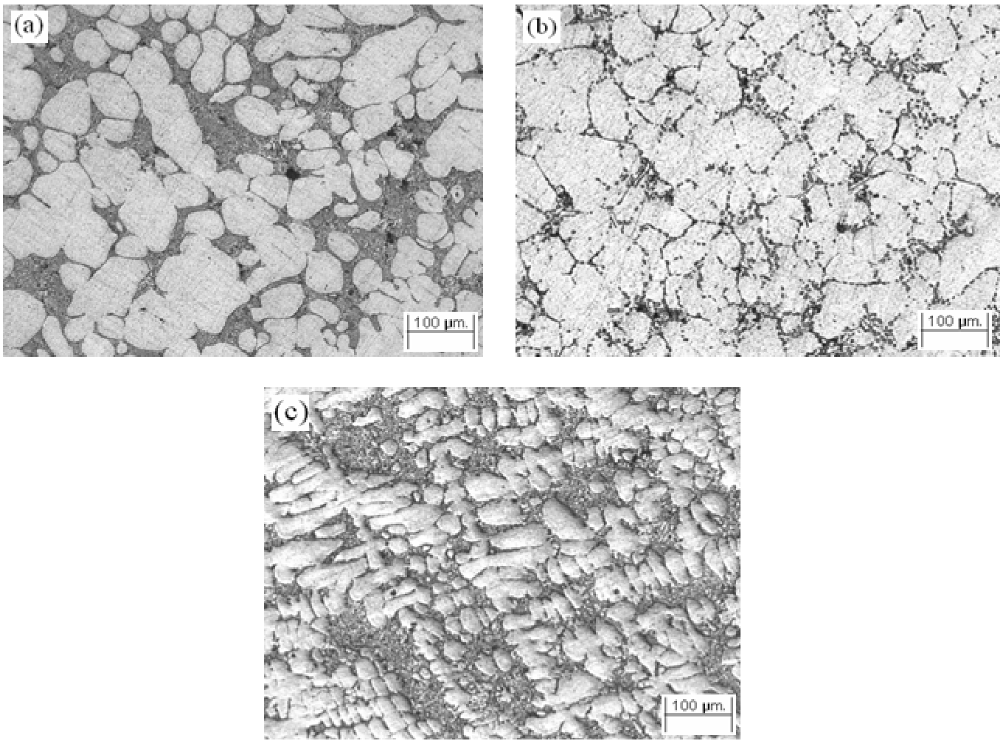
The joints obtained from AW, TW, SWA and WA indicated sound macrostructure. No crack was observed. The FSW process almost transforms the equiaxed grains in the base metal to fine grains in the stir zone. The TMAZ lies beside the SZ. The grains of the TMAZ are distorted due to plastic deformation. On the other hand, the cross sectional macrograph of the joints subjected to T6 after welding (WT and TWT) displayed cracks in the stir zone as depicted in Fig. 3. In addition, the image also showed blistered surface.



Figures 3 The Cross Section of Crack in FSW

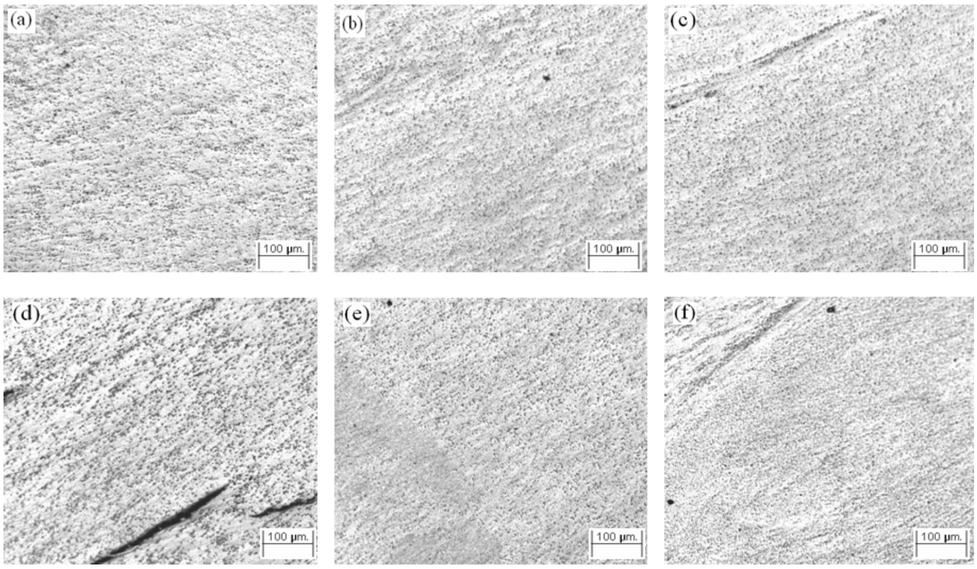
Microstructures

The microstructure of the base metal consists of primary phase α-Al and a eutectic mixture of Al and Si show in Fig. 4(a). The eutectic of the A356 is also characterized by phases containing Si, Fe and Mg. The shape of these constituents is elongated and irregular as in a typical eutectic structure [3, 10]. Microstructure of the T6 heat treatment of the base metal consists of α-Al globule. The irregular eutectic of the as cast material was converted into spherodized Si particles due to the solution treatment shown in Fig. 4(b). Microstructure of the base metal after aging is shown in Fig. 4(c). The α-Al phase was not spherical shape.

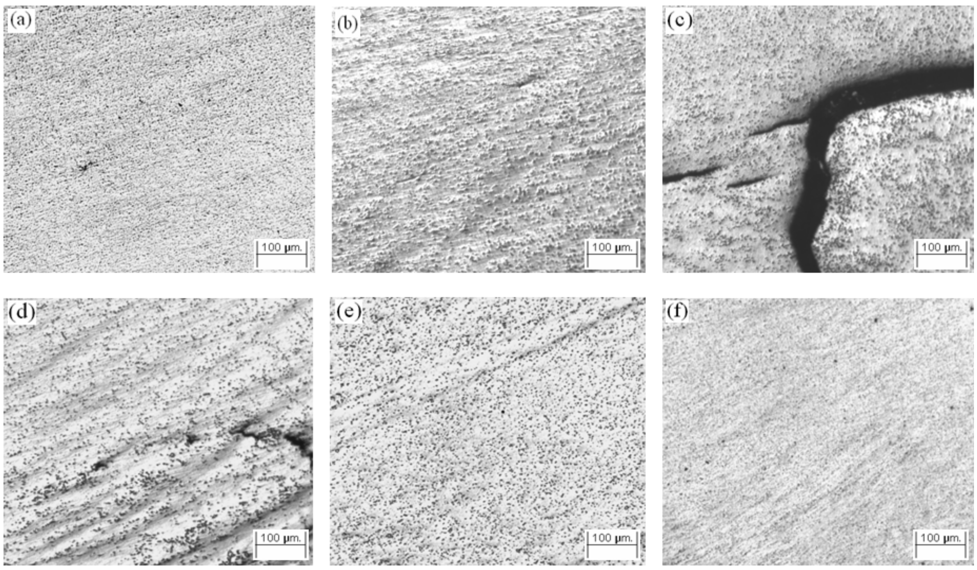


Figures 4 The microstructure of the base metals (a) As cast base metal (b) T6 heat treated base metal (c) Artificially aged base metal

The microstructure of the stir zone weld in Fig. 5 (a) showed that the weld contains fine structure and includes Si particles in the mixture of aluminum matrix dispersion regularly throughout the area. In the stir zone (SZ), the globular and eutectic phases disappeared. The Si particles are uniformly dispersed through out the stir zone. This is due to the friction between the shoulder and the pin to the base metal being welded. Cracks were observed in the stir zone of WT and TWT as shown in Fig.5 (c) and (d) which is influenced by heat treatment. Moreover, the SWA and WA revealed no crack in the stir zone.



Figures 5 The microstructure of the stir zone for the parameter 1,320 rpm, 160 mm/min
(a) As welded (AW) joints, (b) T6 Weld (TW) joints, (c) Weld T6 (WT) joints,
(d) T6 Weld T6 (TWT) joints, (e) Solution treated Weld Artificially aged (SWA) joints and
(f) Weld Artificially aged (WA) joints



Figures 6 The microstructure of the stir zone for the parameter 1,750 rpm, 160 mm/min
(a) As welded (AW) joints, (b) T6 Weld (TW) joints, (c) Weld T6 (WT) joints,
(d) T6 Weld T6 (TWT) joints, (e) Solution treated Weld Artificially aged (SWA) joints and
(f) Weld Artificially aged (WA) joints

In the case of 1750 rpm, the microstructure of the stir zone is shown in Fig. 6(a)-(f). It was found that the weld also contains fine structure and includes Si particles in the mixture of aluminum matrix dispersion regularly throughout the area similar to at 1320 rpm. This is the same reason as explained previously in the case of 1320 rpm. However, cracks were clearly observed in the case of WT and TWT compared to at 1320 rpm as depicted in Fig. 6 (c) and (d). The higher hardness caused greater cracks which occurred after heat treatment.

Hardness measurement

The micro-hardness of the joints is depicted in Table 2. The base metal of the WT (1,750/160) shows the highest average hardness 97.3 HV. The lowest hardness of the base metal which obtained from AW (1,320/160) is 36.4 HV.

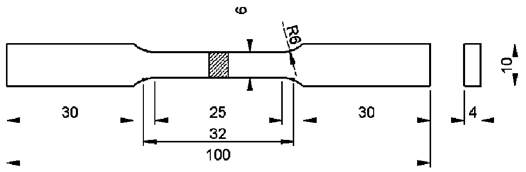
The hardness valves across the joint of each sample vary depending on the heat treatment. In short, the highest hardness of the stir zone was from WT (1,320/160) at the value of 98.1 HV and the lowest hardness of the stir zone was from AW (1,320/160) at the value of 39.1 HV. The lowest hardness of the AW (1,320/160) and AW (1,750/160) are similar.

Table 2 Micro-Hardness of SSM 356 Across of Friction Stir Welding

Joint		Hardness Testing			
		STIR ZONE	RSTMAZ	ASTMAZ	BM
1,320/160	AW	39.1	38.0	38.4	36.4
	TW	64.4	64.2	58.7	61.2
	WT	98.1	89.0	97.9	95.1
	TWT	91.4	90.4	97.0	86.7
	SWA	77.2	80.0	82.3	77.2
	WA	76.3	70.1	69.9	62.3
1,750/160	AW	40.9	39.7	41.3	38.4
	TW	68.4	69.7	62.7	61.8
	WT	93.8	90.5	100.4	97.3
	TWT	84.8	80.2	87.8	84.1
	SWA	72.7	71.9	75.4	78.1
	WA	71.0	72.3	65.9	61.7

Tensile measurement

The tensile weld specimens were prepared with the weld in the centre according to the dimension shown in Fig. 7. The tensile strength of the base metal in as cast and T6 is also shown in table 3.



Figures 7 The Tensile Test Specimen

The joint tensile properties, such as yield strength, tensile strength, percentage of elongation and percentage of joint efficiency are presented in Table 3. The yield strength, tensile strength, percentage of elongation of the base metal in as cast and T6 is also shown for comparison. In addition, Fig. 8 shows the comparison of the tensile strength of each condition for better understanding.

From the results it is found that the highest yield and tensile strength was obtained from WT (1320/160) at the value of 183.1 and 228.9 Mpa respectively. However, the lowest yield and tensile strength was from WT (1750/160) at the value of 86.1 and 107.6 Mpa respectively. This is due to crack occurred after T6. It is assumed that heat treatment, in particular T6, should improve the joint strength if there is on crack after heat treatment. However, the results clearly showed cracks in case of TWT for 1320 rpm and 1750 rpm as well as WT for 1750 rpm.

Table 3 Tensile Strength of Semi-Solid Aluminum Casting SSM 356 and Friction Stir Welding

Joint		Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Joint Efficiency (BM) (%)	Joint Efficiency (BM T6) (%)
BM		134.9	168.7	5.3	-	-
BM T6		236.5	295.6	4.8	-	-
1,320/160	AW	133.3	166.7	3.3	98.8	56.4
	TW	94.8	118.5	3.0	70.2	40.1
	WT	183.1	228.9	2.6	135.7	77.4
	TWT	109.4	136.8	3.3	81.1	46.3
	SWA	170.3	212.9	3.5	126.2	72.0
	WA	120.5	150.6	3.9	89.3	50.9
1,750/160	AW	138.8	173.5	3.1	102.8	58.7
	TW	138.3	172.9	4.5	102.5	58.5
	WT	86.1	107.6	1.3	63.8	36.4
	TWT	114.7	143.4	1.5	85.0	48.5
	SWA	135.4	169.3	2.4	100.4	57.3
	WA	120.4	150.5	2.9	89.2	50.9

However, tensile strength in the case of TW (1,750 / 160) is 172.9 MPa which is higher than TW (1,320 / 160) of the value 118.5 MPa. This is due to the joining parameters such as rotation speed and welding speed resulting in improper pressure and heat of friction which affect the tensile strength [9-14].

Conclusions

The microstructure of the base metal consists of primary phase α-Al and a eutectic mixture of Al and Si The eutectic of the 356 is also characterized by phases containing Si, Fe and Mg. The shape of these constituents is elongated and irregular as in a typical eutectic structure. Microstructure of the T6 heat treatment of the base metal consists of α-Al globule. The irregular eutectic of the as cast material was converted into spherodized Si particles due to the solution treatment. Microstructure of the base metal after aging. The α-Al phase was not spherical shape.

The microstructure of the stir zone weld that the weld contains fine structure and includes Si particles in the mixture of aluminum matrix dispersion regularly throughout the area. In the stir zone (SZ), the globular and eutectic phases disappeared. The Si particles are uniformly dispersed throughout the stir zone. This is due to the friction between the shoulder and the pin to the base metal being welded. Cracks were observed in the stir zone of WT and TWT which is influenced by heat treatment. Moreover, the SWA and WA revealed no crack in the stir zone.

The hardness values across the joint of each sample vary depending on the heat treatment. In short, the highest hardness of the stir zone was from WT (1,320/160) at the value of 98.1 HV and the lowest hardness of the stir zone was from AW (1,320/160) at the value of 39.1 HV.

The average tensile strength of the T6 condition of pre heat weld is lower than the conditions post heat weld. The tensile strength of the conditions post heat weld WT (1,320/160) greater than WT (1,750/160) due to crack of the weld conditions WT (1,320/160) the amount that is less than. The tensile strength of the conditions pre heat weld TW (1,320/160) was lower than the TW (1750/160) Due to heat treatment (T6) the hard part is growing. Rotation speed and welding speed weld resulting in improper pressure and heat of friction less affect the tensile strength.

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