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Effects of welding parameters and post-heat treatment on mechanical properties of friction stir welded AA2195-T8 Al-Li alloy

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ABSTRACT

In this study, the effects of main welding parameters (rotation speed (ω) and welding speed (v)) on the microstructure, micro-hardness distribution and tensile properties of friction stir welded (FSW) 2195-T8 Al-Li alloy were investigated. The effects of T6 post-treatments at different solution and aging conditions on the mechanical properties and microstructure characteristics of the FSW joints were also investigated. The results show that with increasing ω and v, both strength and elongation of the joints increase first, and then decrease with further increase of ω and v. All the joints under varied welding parameters show significant strength loss, and the strength reaches only 65% of the base metal. The effect of T6 post-heat treatment on the mechanical properties of the joints depends on the solution and aging conditions. Two heat treatment processes (480 °C × 0.5 h quenching + 180 °C × 12 h, 520 °C × 0.5 h quenching + 180 °C × 12 h aging) are found to increase the joint strength. Furthermore, low temperature quenching (480 °C) is more beneficial to the joint strength. The joint strength can reach 85% of the base metal. Whereas both low temperature aging (140 °C × 56 h) and stepped aging (100 °C × 12 h + 180 °C × 3 h) processes decrease the joint strength. After heat treatment all the joints show decreased ductility due to the obvious grain coarsening in the nugget zone (NZ) and thermo-mechanically affected zone (TMAZ).

1. Introduction

Aluminum–lithium (Al-Li) alloys are considered to be the most ideal structure materials for aerospace and aircraft vehicles, due to their low density, high specific modulus and specific strength [1]. The latest generation of Al–Li alloys is the third-generation, and the most known ones are the weldalite alloys (includes AA2196, AA2098, AA2050 and AA2195 alloys), which are developed by Lockheed Martin and are applied to the Space Shuttle. Among these alloys, AA2195 achieved relatively high success, since it can reach high ultimate tensile strength (nearly 615 MPa) with a T8 temper [2].

However, aluminum alloys are difficult to join by fusion welding techniques, since welding defects such as crack and porosity can easily form during solidification of the welding pool. As a solid-state process, friction stir welding (FSW) can produce high-quality joints in heat-treatable aluminum alloys by avoiding melting and great heat input compared with fusion welding processes [3,4]. Studies also showed that FSW could effectively avoid loss of Li element as well as welding defects in Al–Li alloy joints, and thus better mechanical performance of the joints could be obtained [5].

It should be pointed out that FSW still generates considerable heat input in the joint. For age-hardened alloys, significant microstructural variations across the nugget zone (NZ), thermo-mechanically affected zone (TMAZ) and heat-affected zone (HAZ), in terms of distribution, size and density of the second phase precipitates dominate the joint strength [6]. Common observations in these three zones include over-aging, dissolution of strengthening phases and re-precipitation upon cooling [7].

In the third-generation Al–Li alloys, the relatively lower Li level, compared with the first- and second-generation alloys, and the addition of Cu and Mg play an important role in promoting the formation of the T1 (Al_2CuLi) metastable strengthening phase. The δ' (Al_3Li) phase is generally absent here when Li levels <1.3 wt.% [8]. Studies on 2195-T8 have shown that θ' (Al_2Cu) phase and the predominant strengthening T1 phase tend to dissolve towards the weld center, particularly under higher heat inputs [8], producing

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Table 1
Chemical compositions of 2195-T8 Al-Li alloy (wt%).

Cu	Li	Mg	Zr	Fe	Si	Al
3.97	1.05	0.40	0.11	0.15	0.025	Bal.

Table 2
Measured mechanical properties of 2195-T8 Al-Li alloy.

	Rolling direction	UTS (MPa)	YTS(MPa)	ε (%)
2195-T8	∥	577 ± 0.3	552 ± 0.3	6.4 ± 0.5
	⊥	565 ± 0.3	538 ± 0.3	6.3 ± 0.5

Note: UTS: ultimate tensile strength; YTS: yield tensile strength; ε: engineering elongation.

Table 3
Welding parameter combinations of FSW.

No.	Rotation speed, ω (rpm)	Welding speed, v (mm/min)	ω/v
1#	1500	500	3.00
2#	1800	500	3.60
3#	2100	500	4.20
4#	2300	500	4.60
5#	2600	500	5.20
6#	2100	700	3.00
7#	2100	600	3.50
8#	2100	400	5.25
9#	2300	548	4.20
10#	1800	429	4.20
11#	1500	357	4.20

Table 4
Schemes of different heat treatment processes.

No.	Heat treatment scheme
HT1	520 °C quenching for 50 min + 180 °C aging for 12 h
HT2	480 °C quenching for 25 min + 180 °C aging for 12 h
HT3	500 °C quenching for 25 min + 140 °C artificial aging for 56 h
HT4	500 °C quenching for 25 min + 100 °C aging for 12 h + 180 °C aging for 3 h

a U-shaped hardness profile with little recovery of strength at the weld center [9]. The joint properties were found to be insensitive to the welding conditions, owing to a loss of strength in the NZ from dissolution of T1 and θ' phases [10].

It is well known that the rotating speed (ω) and welding speed (v) are two main parameters during the FSW process, and the joint quality is determined largely by the ratio of rotating speed to welding speed (ω/v) [11]. Some researchers have analyzed the material flow of 2195-T8 during FSW using a marker insert technique. The effects of rotation speed and welding speed on material transport were investigated [12]. However, the relationship between the material transport and joint performance was not established.

Generally speaking, for heat-treatable aluminum alloys, with increasing ω/v, the heat input increases, promoting the softening of the NZ, TMAZ and HAZ, thus the joint performance would be deteriorated. Some research work showed that the strength of the welded joint decreases monotonously with increasing ω/v [13]; while others showed that the joint strength has a maximum value at medium ω/v [14]. Some research on FSW of 2060 Al-Li alloy also showed that with increasing rotation speed or decreasing welding speed, the strengths and elongation of the joints increase first and then decrease [15]. Up to date there is still no consistent conclusion on this issue. For FSW 2195 Al–Li alloy joints, investigations of the effects of welding parameters on the microstructure and mechanical properties are still highly desired.

Strength loss of welded joints for Al-Li alloys could not be efficiently reduced by optimizing welding parameters alone. Research on 2195-T8 and 2198-T8 showed that the tensile strength of FSW joints can only reach ~70% of the base metal even under optimized welding parameters [3,16]. Laser shock peening was investigated as a means for improving the tensile properties of the FSW joints. Some research work showed that the strength of 2195 Al–Li alloy joint can be increased by 11% by laser shock peening [17]. However, laser shock peening is a surface treatment technique, and therefore the improvement in joint strength for bulk metal is still limited.

Water cooling during FSW was reported to result in enhanced tensile strength in 5083Al-H19 alloy; however, the elongation seemed to be reduced [18]. For 2014Al-T6 alloy, no enhancement in the hardness in the lowest hardness zones and tensile strength of the FSW joint was found with water cooling [19]. On the other hand, post-heat treatment after welding has been proven to be a feasible way to improve the strength of FSW joints in heat-treatable aluminum alloys. It was also reported that the solution and aging processes can effectively promote the re-precipitation of strengthening phases in fusion welds, thereby increasing the joint strength but decreasing the ductility [20]. For Al-Li alloys, although post-heat treatment was also performed on the fusion welded joints [21], investigation on the post-heat treatment of FSW joints is lacking.

In this study, the effects of welding parameters (ω, v, ω/v) on the microstructure, mechanical properties of FSW 2195-T8 Al-Li alloy joints were investigated. T6 post-heat treatments at different solution and aging conditions were conducted with the aim to improving the joint strength.

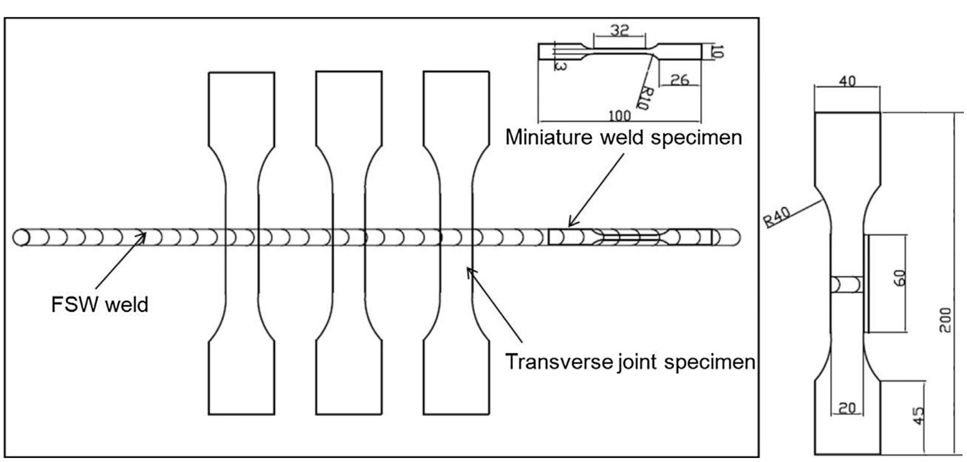

Fig. 1. Dimension of the tensile test specimens.