Chinese Journal of Aeronautics, (2017), **xxx**(xx): xxx–xxx

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

cja@buaa.edu.cn
www.sciencedirect.com

FULL LENGTH ARTICLE

Effects of different aging treatments on microstructures and mechanical properties of Al-Cu-Li alloy joints welded by electron beam welding

Shaogang WANG *, Yan HUANG, Li ZHAO

College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, China

Received 30 November 2016; revised 13 April 2017; accepted 15 June 2017

KEYWORDS

Al-Li alloy;
Electron beam welding;
Mechanical properties;
Microstructure;
Post-weld heat treatment

Abstract Post-weld single aging treatment (solution treatment at 510 °C for 1 h, water quenching, and aging at 155 °C for 16 h) and post-weld double aging treatment (solution treatment at 510 °C for 1 h, water quenching, aging at 155 °C for 16 h, and aging at 130 °C for 12 h) are carried out on Al-Cu-Li alloy joints by electron beam welding (EBW) respectively. The effects of aging treatments on microstructures and mechanical properties of welded joints are investigated. Results show that the mechanical properties of welded joints are obviously improved after both aging treatments. The strength coefficient of joints is increased from 0.64 in an as-welded condition (AW) to 0.90 after post-weld double aging treatment. Microstructure analysis shows that the precipitates of the fusion zone within grains and grain boundaries are less in the AW condition. After post-weld heat treatment (PWHT), a lot of fine needle-like phases T_1 (Al_2CuLi) precipitate in grain boundaries of the fusion zone, and more horseshoe-shaped β′ (Al_3Zr) particles precipitate within grains. In addition, grains of the fusion zone are refined after post-weld double aging treatment, which leads to an effect of grain refinement strengthening. Consequently, the mechanical properties of welded joints are greatly improved.

1. Introduction

Al-Li alloys have low density, high specific strength and specific modulus, excellent anti-fatigue performance, etc. When conventional aluminum alloys are replaced by these types of alloys in engineering structures, the weight of a component can be reduced by 10–15% and its stiffness can be increased by 15–20% respectively. Therefore, Al-Li alloys are the ideal

* Corresponding author.
E-mail address: sgwang@nuaa.edu.cn (S. WANG).

Peer review under responsibility of Editorial Committee of CJA.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.cja.2017.07.002
1000-9361

light-weight and high-strength structural materials for the aerospace field.[1–3] A welded structure instead of a riveted structure can further reduce the weight of an Al-Li alloy component, and welding is one of the important processing technologies to reduce production cost and improve production efficiency in the aircraft industry. Compared with the second-generation Al-Li alloys, the chemical composition of the third-generation Al-Li alloys has been adjusted, and their properties are further improved by increasing the element mass fraction of Cu/Li.[4]

In recent years, much research has been carried out on the welding process and weldability of Al-Li alloys. Calogero et al.[5] studied the weldability of Al-Cu-Li alloy 2198. It was successfully welded by using gas tungsten arc welding (GTAW), and many strip precipitates in big sizes were generated at grain boundaries and within grains of the joint. The Al-Li alloy 2A97 was welded by using gas metal arc welding (GMAW), GTAW, and laser beam welding (LBW), respectively,[6] and the microstructures of welded joints were analyzed. Results showed that there was no precipitate within fine equiaxed grains in welded joints, and the grain boundary had a eutectic composition. The amount of precipitates in the fusion zone was greatly decreased compared with the matrix alloy. Gao et al.[7] found that there were two main reasons for the strength decrease of 2198 Al-Li alloy joints by friction stir welding (FSW). On one hand, the decrease of the joint strength was because phase T_1 (Al_2CuLi) completely dissolved in the stir shoulder zone and the stir pin zone. On the other hand, the amount of phase T_1 decreased and the grain size changed obviously in the thermo-mechanical affected zone to generate stress concentration, which led to a decrease of the joint strength. Cui et al.[8] reported that the homogeneity of microstructure was improved in LBW joints of Al-Li alloys, and the hardness of joints increased by promoting more phases δ′ (Al_3Li) precipitated in weldment after PWHT.

Compared with other welding processes, electron beam welding (EBW) has some advantages, such as large weld depth to width ratio, small deformation of workpieces, high welding efficiency, stable weld performance, easy adjustment to welding parameters, good technological adaptability, and so on. Therefore, it has great advantages to weld Al-Li alloys. However, since it is similar to other fusion welding processes, the strength coefficient of an Al-Li alloy joint welded by EBW is still not high, because the formation of precipitates in the fusion zone is insufficient during the welding process. In order to further improve the microstructures of Al-Li alloy joints by EBW, so as to increase the mechanical properties of welded joints, in present work, two kinds of post-weld heat treatments including single and double aging treatments are carried out on welded joints respectively, and the effects of different aging treatments on microstructures and mechanical properties of joints are investigated.

2. Experimental material and procedure

The base metal is Al-Cu-Li alloy plate (condition T8) with a thickness of 4 mm, and the chemical composition is as follows (wt%): Al-3.2Cu-1.0Li-0.5Mg-0.4Ag-0.35Zn-0.11Zr-0.5Mn. The tensile strength of the base metal is 416.6 MPa. A welding sample is prepared with a dimension of 200 mm × 110 mm × 4 mm. A butt joint is used which is welded along the longitudinal direction with an LARA52 type vacuum EBW machine. A circular scanning pattern is used, with a scanning amplitude of 2%, and a scanning frequency of 500 Hz. The optimized welding parameters are determined as the following: vacuum degree 5×10^{-4} Pa, working distance 20 mm, accelerating voltage 50 kV, electron beam current 17 mA, welding speed 300 mm/min, and beam focus current 412 mA. As a result, a sound joint is obtained, and no welding defects such as crack and pores are found in weldment. After welding, joint samples are divided into three groups: (1) without heat treatment, namely in the as-welded condition (AW); (2) with post-weld single aging treatment, namely solution treatment at 510 °C for 1 h, water quenching, aging at 155 °C for 16 h, and then air cooling; and (3) with post-weld double aging treatment, namely solution treatment at 510 °C for 1 h, water quenching, aging at 155 °C for 16 h, aging at 130 °C for 12 h, and then air cooling.

The microstructures and mechanical properties of welded joints before and after heat treatment are investigated respectively. The microstructures of joints are observed by using an MM6 type optical microscope. The tensile strengths of joints are tested by using a CMT-5105 type universal electronic machine with a maximal loading capacity of 10 kN. The dimension of a tensile sample is shown in Fig. 1, and the tensile speed is 1 mm/min. The hardness measurement is performed by using an HXS-1000 A type hardness tester with a load of 200 g and a holding time of 15 s. The tensile fracture morphology of joints is observed by using a Quanta 200 type scanning electron microscope (SEM). The precipitates in weldment are observed by using an FEI Tecnai G2 type transmission electron microscope (TEM).

3. Results

3.1. Microstructures of welded joints

Metallographic specimens of Al-Cu-Li alloy joints are prepared in the following steps: grinding, polishing, and etching (Keller etchant: 1 mL HF + 2.5 mL HNO_3 + 1.5 mL HCl + 95 mL H_2O). The optical micrographs of welded joints in different zones are observed respectively. The microstructure of the base metal is shown in Fig. 2. It can be seen that the microstructure of the base metal is rolled grains, which presents the distribution of a long strip shape.

The microstructures of the weld metal before and after PWHT are shown in Fig. 3. In the AW condition, the microstructure of the fusion zone is an as-cast structure due to rapid solidification, and the fusion zone consists of a mixed microstructure including equiaxed grains and dendrites, as shown in Fig. 3(a). Because the active element Li contained in Al-Cu-Li alloy is adsorbed on the surface of heterogeneous nucleation, it can activate nucleation and slow down the

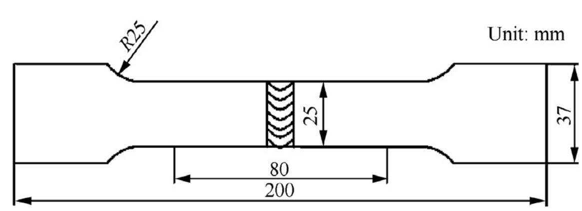

Fig. 1 Dimension of a tensile sample for Al-Cu-Li alloy joints.