



Review

Problems and issues in laser beam welding of aluminum–lithium alloys



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ABSTRACT

Aluminum–lithium (Al–Li) alloys are very attractive for potential aerospace applications due to their lower density, higher specific strength and rigidity, better corrosion and fatigue crack growth resistance properties, compared to conventional aluminum alloys. Laser beam welding (LBW), being an advanced joining method, has already been approved for applications involving aluminum alloys. However, there are still a number of problems and issues to be answered and solved in LBW of Al–Li alloys. In this review, the properties of Al–Li alloys and the characteristics of LBW are introduced, the formation and prevention of the main weld defects such as porosity and hot cracking are discussed, and then the weld microstructure and the joint mechanical properties are described in highlight. At the end, an outlook on future trends is presented.

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1. Introduction

Structural design and manufacturing of modern flight are significantly stressed on the weight reduction and the damage tolerance improvement in consideration of increasing its payload, reducing fuel consumption and emissions and improving safety and reliability [1,2]. Thus, advanced lightweight structural materials with excellent fatigue crack growth resistance property are the favorable choice. In addition, adopting welded integral structures to replace riveted differential ones can further reduce structural weight [3,4].

Aluminum alloys containing the element lithium have increasingly received considerable attention as replacements of conventional aluminum alloys in aerospace applications due to their lower density, higher specific strength and elastic modulus, better properties of anti-fatigue crack growth and corrosion resistance [5–8]. The use of high strength Al–Li alloys instead of conventional aluminum alloys can reduce the structure weight by 10–15% and increase the rigidity by 15–20% [9]. In addition, Al–Li alloys are preferable to carbon fiber composite materials from the aspects of production and maintenance costs. Therefore, Al–Li alloys have increasingly become the materials of choice in the aerospace industry [10].

Arc welding, being a common joining method of metals and alloys, is widely used in manufacturing industries. However, most of aluminum alloy structural parts in aircraft body and wings are still joined by riveting at present. The reason is that serious mechanical property degradation and great deformation in arc welding of aluminum alloys, which caused by great heat input, make welded structures cannot meet the requirement of aircraft performance.

LBW is considered as a promising welding method for products of aluminum alloys. Due to the tight focusability and high power density of the laser beam, LBW offers numerous advantages: a high welding speed, a narrow and deep weld, a small heat affected zone (HAZ), good mechanical properties and low structural distortion. Moreover, its excellent propagation ability and accessibility make the laser beam a powerful tool to weld three dimensionally complicated structures. Thus, the structural integrity can be largely improved and the structural weight reduced through the optimization of materials and structures [11,12]. It was reported that LBW has been successfully used as an alternative to riveting in manufacturing lower fuselage panels of aluminum alloys in Airbus. Improvements in product quality and properties, cost and weight saving, are achieved through a modification of structure design, a simplification of the manufacturing process, and the elimination of additional elements such as rivets and sealants [13–15].

The first article on LBW of Al–Li sheet, written by Lin, was published in 1988 [16]. After that, much progress has been made by various authors all over the world. However, there are still a number of problems and issues to be answered and solved for applications. This paper will review the main problems and issues in LBW of Al–Li alloys in detail. Firstly, Al–Li alloy category and LBW processes are briefly introduced. Secondly, the generation and prevention of porosity and hot cracking usually encountered in the laser weld are highlighted. Thirdly, the weld microstructure and the joint mechanical properties are further demonstrated. Finally, an outlook on future trends is presented.

2. Aluminum–lithium alloys

Lithium is the lightest metal element. It has been found that adding 1% lithium to aluminum reduces the alloy density approximately by 3% and increases the elastic modulus by about 6% [9]. At the early stage, Al–Li alloys were designed, mainly focused

on the reduction of material weight like alloys 8090 and 2090 to replace the conventional alloys 7075 and 2024. However, this commercial application is not realized due to their anisotropy and lower ductility. Afterwards, a series of new type Al–Li alloys has been developed, concentrated on improvements in strength, ductility and weldability. It has been found that the Li addition within the range of 1.1–1.3 wt.% can provide the maximum strength of alloys while both the yield stress and tensile stress drop when the Li content is above 1.3 wt.% [17]. At present Al–Li alloys have entered into applications as alternative materials in the aerospace industry [18]. Some typical Al–Li alloys are listed in Table 1 [8].

The first aluminum alloy containing Li, called the Scleron alloy, was developed in German in 1924. The pilot application of Al–Li alloys in the United State in the 1950s was the alloy 2020 developed by Alcoa. However, this alloy was only used for a short time and was discontinued because of its poor ductility and fracture toughness, high notch sensitivity and rapid fatigue crack growth rate.

In the late 1960s, the first Al–Mg alloy with Li added (alloy 1420) was developed in the Soviet Union. Now it is widely used in the world and is considered to be one of the most mature Al–Li alloys. In addition, alloys 1421, 1423 and 1424 were formed on the basis of alloy 1420. Afterwards, in 1989, the Soviet Union exploited alloys 1430, 1440, 1450 in succession. Later, a novel high strength Al–Cu–Li alloy 1460 with the addition of Sc as a new alloying element was developed in Russia by modifying the Cu and Li contents in Al–Li–Cu–Zr alloy. Russia now preliminarily has its own Al–Li alloy series containing high strength, moderate strength and weldable Al–Li alloys.

In the 1970s, the western countries have focused on the development of Al–Li alloys once again, influenced by the global energy crisis and by the successful applications of Al–Li alloys in the Soviet Union. In the early eighties, alloys 8090 and 2091 were introduced in western European countries to take the place of alloy 2024, and alloy 2090 was developed as a replacement for alloy 7075 in the United States. Those alloys, containing richer Li, approximately 2–3 wt.%, are much better than alloy 2020 in elastic modulus and density, but there are still some deficiencies of low ductility, poor corrosion resistance and anisotropy.

In the late 1980s, exploration of Al–Li alloys concentrated on further improvements in strength, ductility and weldability. Some new type Al–Cu–Li alloys have occurred with irreplaceable advantages such as high toughness (e.g. alloys 2097 and 2197), anti-fatigue crack growth (e.g. C-155 alloy) and high strength weldable (e.g. alloy 1460 and the Weldalite series alloys) Al–Li alloys. In such new Al–Cu–Li alloys, the content of Li is further decreased, the ratio of Cu to Li increased and other alloying elements added, such as Ag, Mn, Zn and Sc. The most typical ones are the ultra-high strength Weldalite series containing Ag, produced by American Reynolds Company and Martin Maritta Company cooperatively. Among all those alloys, alloy Weldalite-210 is found to be the best in terms of weldability and combination of strength and fracture toughness [19].

3. Characteristics of laser beam welding

LBW is an advanced joining technology developed in the recent decades. In general, there are two LBW modes: thermal conduction welding and deep penetration (or keyhole) welding, as seen in Fig. 1. At present, there are mainly three types of industrial lasers for welding: CO₂ lasers with a wavelength of 10.6 μm, solid state (rod, disk and fiber) lasers of 1.03–1.07 μm, and semiconductor lasers of 808–940 nm. These types of the lasers are responsible for different welding phenomena and results due to their differences in wavelength, power and beam quality.

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