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Effect of adhesive quantity on failure behavior and mechanical properties of fiber metal laminates based on the aluminum–lithium alloy

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ABSTRACT

The effect of adhesive quantity on the failure behavior and mechanical properties of fiber metal laminates based on the aluminum–lithium alloys (NFMLs) was investigated to optimize the manufacture process and further recognize the interface interaction. The NFMLs with different adhesive quantities (0 g/m^2, 20 g/m^2, 40 g/m^2, 60 g/m^2) were prepared primarily. Then, the influence of adhesive quantity on the interlaminar, tensile, flexural and fatigue properties of NFMLs was studied respectively. Also, the failure behaviors of NFMLs under different loading conditions were revealed. The results indicated that the adhesive layers significantly enhanced the interlaminar properties of the NFMLs within the investigated quantities. Moreover, the reasonable adhesive quantity also greatly improved the mechanical properties of the laminates, while an excessive amount deteriorated the performance. For the different properties, the peak values appeared under different adhesive quantities. Besides, the changing mechanical properties followed with the variation of failure mode. From the engineering perspective, the adhesive quantity of 40 g/m^2 is optimal to achieve the excellent performance of NFMLs.

1. Introduction

Fiber Metal Laminates (FMLs) combine the outstanding fatigue resistance and high strength of fiber reinforced composites with the ductility of metal alloys [1,2]. As the second generation of FMLs, Glare is composed of alternating layers of 2024 aluminum alloy and glass fiber reinforced epoxy [3,4]. It possesses excellent fatigue and impact resistance, good residual and blunt notch strength, as well as convenient manufacture and repair, leading to its wide application in the fuselages and wings of large aircrafts [5]. The Airbus A380 has obtained a weight saving of nearly 794 kg by using Glare in upper fuselage skin [6,7].

Generally, 2024-T3 aluminum alloy are used as the metal layers of conventional Glare. However, in recent years, many kinds of novel aluminum alloys, especially the aluminum–lithium alloys, offer low density and high specific strength and stiffness as compared to conventional 2xxx and 7xxx series aluminum alloys [8,9]. The novel fiber metal laminates based on the aluminum–lithium alloys (NFMLs) significantly improve the damage tolerance of Glare [10].

It is extremely important to spray the adhesive layers or at least a primer layer on the metal surface in the manufacture of FMLs [11]. The adhesive layer determines the interfacial bonding strength between the prepregs and metal layers, which significantly contributes to the whole performance of the laminates [12]. Usually, the epoxy adhesive system is mainly used in Glare family [13]. Different from the epoxy in prepregs, the chosen epoxy adhesive system possesses lower strength but higher toughness. The adhesive layers with a reasonable quantity undoubtedly improve the interlaminar properties, strength and fatigue of the FMLs owing to the enhanced interfacial bonding strength. However, an excessive amount of the adhesive reduces the volume fraction of the glass fibers in the whole laminates, which is adverse to the mechanical properties of FMLs. Hence, how to deal with the two contradictory factors is the key point. Furthermore, the adhesive quantity changes the interface state as well as the failure behaviors of FMLs. The importance of adhesive layers in FMLs is mentioned in many researches [14–16], however, the related mechanism was few discussed or reported in details. Wilson GS [17] investigated the effect of adhesive layer thickness on fatigue crack growth (FCG) of generalized fiber metal laminates and hybrid materials. The results indicated that adding adhesive to the interface improved the delamination growth rate of FMLs, and that this

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Table 1
Chemical composition of the novel aluminum–lithium alloy (wt.%).

Li	Cu	Mg	Ag	Zr	Mn	Zn	Al
0.7	3.7	0.7	0.34	0.11	0.29	0.32	The rest

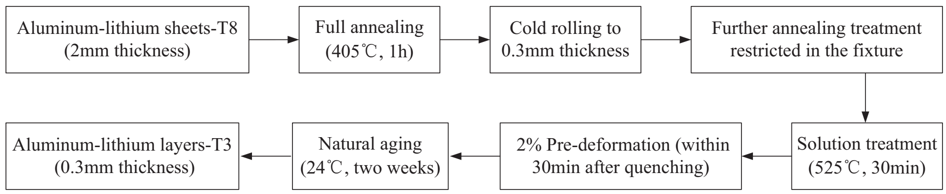

Fig. 1. The preparation process of aluminum–lithium layers.

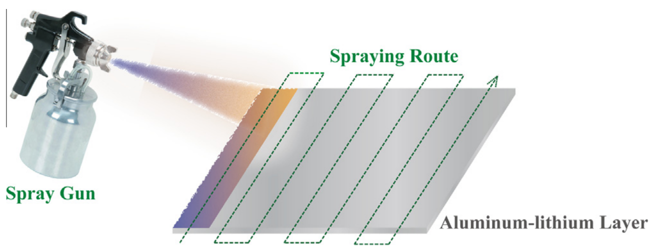

Fig. 2. The adhesive spraying of aluminum–lithium layers.

improvement was not in proportion to the adhesive layer thickness but reached a horizontal asymptote as the thickness was increased. He also claimed that the recommended thickness applied specifically to the FM94 adhesive system, similar studies could be undertaken for FMLs with other materials to optimize the interface. Meanwhile, the range of adhesive quantity could be enlarged to further reveal the related mechanism. Furthermore, similar research has been conducted by Roebroeks G, et al. [18] in the concept of CentrAl, which also mentioned that the adhesive between Glare and thick metal sheets significantly improved the FCG. Nevertheless, adhesive layer obviously affect the other properties as well.

From the engineering perspective, the optimized adhesive quantity can be obtained only considering the whole performance of the laminates, especially for a novel adhesive system. Besides, the effect of adhesive quantity on the failure behavior, under different loading conditions, is also necessary to be revealed which is helpful to further recognize the interface interaction of FMLs.

Therefore, this work tried to explore the effect of the adhesive quantity on the floating roller, interlaminar shear, tensile, flexural as well as the fatigue crack growth (FCG) properties of NFMLs. Moreover, the failure behaviors under typical loading conditions were also revealed to further recognize the interface interaction of NFMLs. Also, we focused on the optimized adhesive quantity of manufactured NFMLs from the engineering perspective.

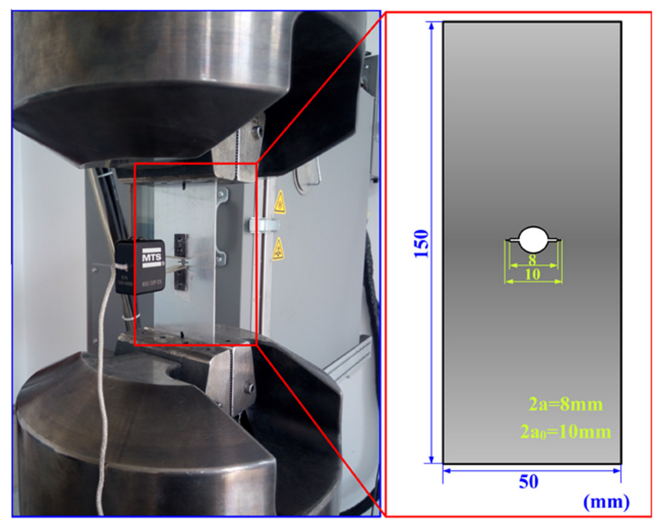

Fig. 4. The FCG test of NFMLs.

2. Experimental

2.1. The preparation of NFMLs

The used aluminum–lithium alloy was newly-developed in recent years, aiming at large commercial aircrafts. It belonged to the Al–Cu–Li family with a high Cu/Li ratio of 5.29. The nominal chemical composition of the aluminum–lithium sheets (2 mm thickness, T8 state) used in this study is given in Table 1.

Firstly, the 0.3 mm aluminum–lithium layers were prepared by a series of manufacture processes, shown in Fig. 1 [10]. Moreover, the surface treatment of the aluminum–lithium layers was conducted to achieve a better bonding with the fiber reinforced composites. The phosphoric acid anodizing (H_3PO_4 150 g/ml, 20 °C, 15 V, 15 min) was adopted to construct a rough surface.

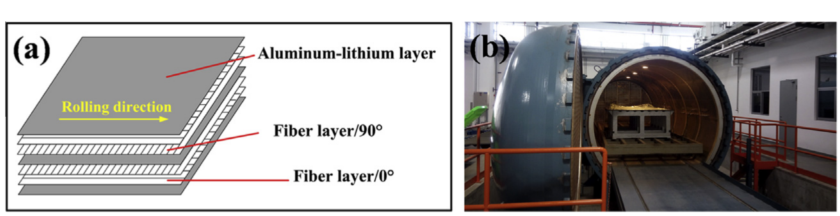

Fig. 3. The laminating designs and curing process of NFMLs: (a) laminating design; (b) objective graph of autoclave curing.