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Improvement of aluminum lithium alloy adhesion performance based on sandblasting techniques

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ABSTRACT

In this study, the aluminum lithium alloy (Al-Li alloy) sheets were subjected to sandblasting treatments using different parameters, and the specimens then were bonded as single lap joints with FM94 adhesive. The surface morphology, surface free energy, and shear strength of the specimens were investigated and analyzed, to comprehensively study how sandblasting can enhance the shear strength of Al-Li alloy joints. The results show that an increase in sandblasting pressure and abrasive size leads to an increase in surface roughness, which contributes to the surface wettability and adhesion performance of the substrates. The bonding properties between Al-Li alloy and FM94 adhesive can be greatly improved by sandblasting treatment, a moderate surface roughness is found to yield better wettability and stronger shear strength.

1. Introduction

Al-Li alloy is a new type of aluminum alloy, which has high strength, good fracture toughness, and good corrosion resistance compared to other similar aluminum alloy, it is specially used in the aerospace industry. Conventional combinations of aluminum alloy usually involve riveting, bolting, and welding the material together; however, rivets and bolts add extra weight to the equipment, which go against the lightweight requirements, and welding operations can easily produce deformations and cracks in the material. Bonding technology offers excellent features, such as a large bonding area, adaptivity to different materials and thicknesses, lighter weight than mechanical methods, and lesser residual stresses than welding [1,2]. With the improvement of adhesive performance, bonding technology has been more widely used [3,4]. The strength and durability of bond joints are significantly affected by the surface treatment of the materials; therefore, determining an effective, non-polluting, and economical method to apply surface treatment is an issue in urgent need of a solution. Surface treatments have often been used to enhance adhesion strength and bonding performance, and these treatments are usually applied by mechanical, chemical etching, and anodization methods [5–9]. Among these methods, anodization and chemical etching are highly effective at removing organic contaminants and surface oxide films; however, they require strong acids, expensive equipment, and a complex series of processes. Mechanical sandblasting may be the most direct and effective method to achieve the aforementioned goals because of its unique advantages, which include no material size requirements, no complicated operating procedures, no pollution, and lower operation costs. Sandblasting can enhance the adhesive strength of bond joints by modifying the surface roughness and mechanical properties of its substrates, this process and different associated parameters, such as grit type and size [10–12], sandblasting distance [11,13], sandblasting pressure [13,14], and angle of sandblasting [15–17], have been studied by many researchers. Pan et al. [18] investigated the relationships between grit size and bond strength, their results showed that large grit sizes can improve surface roughness, and greatly enhance the peel strength of bonding joints. However, larger grit sizes were found to have minor effects on shear strength. Rudawska et al. [14] studied the effect of sandblasting pressure and abrasive material on the adhesion properties of steel, they found that surface properties are more affected by abrasive material type rather than pressure. Horodek et al. [19] studied the stainless steel subjected to sandblasting with different pressure and time, they found that pressure has more effect on the surface roughness rather than time. Recent works have mostly focused on the surface morphology and adhesion strength achieved by sandblasting at different parameters [20–23], a systematic understanding of the mechanism of sandblasting as applied to enhance bond strength has yet to be achieved or presented.

The purpose of this study is to obtain a greater understanding of the mechanism of bonding strength as improved by sandblasting and study the bonding properties between FM 94 adhesive and Al-Li alloy. In this work, the surfaces of Al-Li alloy sheets were treated using different

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

Fe	Si	Cu	Mn	Mg	Ag	Zn	Li	Zr	Ti	Al
0.028	0.014	3.64	0.29	0.71	0.32	0.36	0.68	0.12	0.026	Bal.

sandblasting parameters, and then the specimens were bonded with FM94 film adhesive. The surface morphology, contact angles, surface free energy, and adhesion characteristics of the specimens were then analyzed.

2. Materials and methods

2.1. Materials

Al-Li alloys have good mechanical properties and are widely used in aerospace and other industries. In this study, 100 mm × 25 mm × 2 mm Al-Li alloy sheets (Al-Li-S-4, Aluminum Company of America) were selected for testing, and their chemical compositions are listed in Table 1. FM 94 adhesive film (Cytec Company of America) is a solid modified epoxy film adhesive which is suitable for bonding metals such as aluminum alloy or steel. The adhesive film has a nominal weight of 293 g/m^2 and a thickness of 0.25 mm. Patterns of FM 94 film adhesive should be cut as required and applied smoothly to the sample surface to prepare single-lap joints. After assembly, the joints were cured for 60 min in an oven at 121 ± 3 °C at a pressure of 0.28 MPa.

2.2. Surface treatment

The Al-Li alloy samples were degreased using an acetone solution in an ultrasonic cleaning machine (JP-020, China) for 10 min, then rinsed with distilled water and dried in air. The samples were then polished with sandpaper of mesh size 320 for 90 s using a sander to remove the surface oxides, and then degreased again using the abovementioned procedure to eliminate residual contamination. After degreasing, the samples were subjected to sandblasting (SHW1500220, China) with different treatment parameters. The sandblasting variables include three different abrasive sizes and pressures, which are listed in Table 2. The abrasive material was brown fused alumina and the three sizes selected for sandblasting were described by sieve mesh numbers of 30, 45, and 60, and correspond to the particle sizes of 600 µm, 355 µm, and 250 µm, respectively. The sandblasting pressure was set to 0.2 MPa, 0.35 MPa, and 0.5 MPa. The samples which were polished with sandpaper were also tested for comparison. The working distance was set to 100 mm, the sandblasting angle was set to 90°, and the sandblasting time was set to 40 s. After sandblasting, the Al-Li alloy samples were rinsed with distilled water and dried in an electric thermostatic drying oven (101-0 A, China) at 60 °C for 30 min. Twelve samples of each parameter group from Table 2 were prepared, of which eight samples were bonded as single-lap joints and the rest were used for the surface characterization test. The surface treatments were conducted at a temperature of 23 ± 1 °C and air humidity of 42 ± 3%.

2.3. Surface characteristics

The surface roughness parameters Ra, Rz, Rq, and Rt of the Al-Li alloy sheets were measured using a three- dimensional surface white-light profilometer (WYKO NT9100, Veeco Metrology Inc, America) with standard ISO 4287 requirements. A sampling length of 2.0 mm was examined and each specimen surface was measured at three different locations, four specimens of each treatment parameter were tested and the average values were obtained as the final results. The values of roughness and the images of the roughness profile were recorded and compared. The surface morphology of the Al-Li alloy sheets was examined using scanning electron microscopy (SEM, TESCAN, MIRA3).

Table 2
Different parameters of sandblasting.

parameters	samples									
	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-0
Abrasive size	30	30	30	45	45	45	60	60	60	320
pressure(MPa)	0.2	0.35	0.5	0.2	0.35	0.5	0.2	0.35	0.5	sandpaper

2.4. Surface free energy

The adhesion of liquids to the tested materials can be described by the work of adhesion W_a, which represents the work needed to produce a surface unit due to separation of the examined liquid and material W_a can be calculated using Young's equation (Eq. 1) [24,25]:

$$W_a = \gamma_L(1 + \cos\theta) \tag{1}$$

Where W_a is the work of adhesion, γ_L and θ represent the surface free energy and contact angle of the tested liquids.

W_a can also be defined by dispersive (γ^d) and polar (γ^p) components of the examined liquids and materials from Eq. (2) [24,26]:

$$W_a = 2\sqrt{\gamma_S^d \gamma_L^d} + 2\sqrt{\gamma_S^p \gamma_L^p} \tag{2}$$

Where γ_S^d and γ_L^d represent the dispersive of examined materials and liquids respectively, γ_S^p and γ_L^p represent the polar of examined materials and liquids.

Surface free energy can be determined by the contact angle of the measured liquids. Generally speaking, a smaller contact angle indicates higher surface free energy and better adhesion properties. Surface free energy can be calculated using Eq. (3) and Eq. (4). Eq. (3) can be derived from Eq. (1) and Eq. (2), and Eq. (4) was obtained from the literature [24,27,28]:

$$\gamma_L(1 + \cos\theta) = 2\sqrt{\gamma_S^d \gamma_L^d} + 2\sqrt{\gamma_S^p \gamma_L^p} \tag{3}$$

$$\gamma_S = \gamma_S^p + \gamma_S^d \tag{4}$$

According to Eqs. (3) and (4), to calculate the surface free energy of a solid surface, two different liquids with known surface free energies γ_L, and their dispersive γ_L^d and polar γ_L^p components are required. In addition, their contact angle values on the examined solid surface must be tested.

2.5. Shear strength test

After sandblasting, the Al-Li alloy sheets were bonded as single-lap joints using FM94 adhesive. The bonded area of the Al-Li alloy sheets was 25 mm × 12.5 mm; the adhesive film was cut into the corresponding size and affixed to the treated sample surface to form single-lap joints. The joints were then cured at 120 °C in an electric thermostatic drying oven (101-0 A, China) for 60 min under a constant pressure of 0.28 MPa, which was exerted on the joint area. The shear strength tests of the Al-Li alloy joints were conducted using an Instron 3369 testing machine according to the standard ASTM D1002-72 requirements. Four single-lap joints of each treatment parameter group from Table 2 were tested, and the average values were taken as the final results. The specific sizes of the single-lap joints and the modes of the test are presented in Fig. 1(a). Fig. 1(b) shows the three typical fracture modes of single-lap joints after the stretching test, the best failure mode is cohesive failure, which indicates that the substrates have a strong adhesion characteristic.