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Effect of hot-humid exposure on static strength of adhesive-bonded aluminum alloys

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Abstract

The effect of hot-humid exposure (i.e., 40 °C and 98% R.H.) on the quasi-static strength of the adhesive-bonded aluminum alloys was studied. Test results show that the hot-humid exposure leads to the significant decrease in the joint strength and the change of the failure mode from a mixed cohesive and adhesive failure with cohesive failure being dominant to adhesive failure being dominant. Careful analyses of the results reveal that the physical bond is likely responsible for the bond adhesion between ***L*** adhesive and aluminum substrates. The reduction in joint strength and the change of the failure mode resulted from the degradation in bond adhesion, which was primarily attributed to the corrosion of aluminum substrate. In addition, the elevated temperature exposure significantly accelerated the corrosion reaction of aluminum, which accelerated the degradation in joint strength.

Keywords: Epoxide adhesive; Aluminum alloy; Hot-humid exposure; Static strength; Bond adhesion

1. Introduction

The use of adhesive is posed to increase dramatically for application to the next generation of vehicle structures as the use of lightweight materials (e.g., aluminum and magnesium alloys) [1–3]. In spite of this, the use of adhesive-bonded aluminum joints in vehicle structures has been limited, mainly due to the degradation of crashworthiness and structural durability caused by the hot-humid exposure [4,5].

In vehicle structures, the majority of the adhesive-bonded components is exposed to the environment of temperature and moist air. Previous studies revealed that if the exposure was over a significant period of time, the joint strength gradually declined [6] which was closely related to the water absorption of the adhesive-bonded joints [7,8]. Many studies [9–12] on effect of hot-humid exposure on the strength of the adhesive-bonded aluminum alloys showed that the hot-humid exposure significantly decreased the strengths of the adhesive-bonded aluminum joints. The strength degradation primarily resulted from that water absorption in the interface between adhesive and adherend, which resulted in the surface electrochemical corrosion of aluminum adherend, and consequently led to the degradation in the interfacial bond between adhesive and adherend. To improve the corrosion resistance of the adhesive-bonded aluminum joints, various surface treatments of aluminum were utilized. Lunder et al. [10] investigated the effect of surface pretreatment of aluminum alloys on the joint strength and found that the improvement in corrosion resistance of treated aluminum alloys significantly promoted the durability of the bonded joints. However, although these surface pretreatments improved the corrosion resistance of aluminum, there was still a slight decrease in joint strength,

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Table 1
Chemical composition (Wt. %) of Novelis X610-T4PD (X1.0) and X626-T4P (X0.9) aluminum alloys.

Substrate	Mg/%	Si/%	S/%	Ti/%	Mn/%	Al/%
X1.0	0.63	0.82	0.01	0.05	0.12	Balance
X0.9	0.46	1.14	0.01	0.02	0.12	Balance

and the treated aluminum in the overlap region was not corroded by the electrochemical reaction. Furthermore, the degradation mechanism of the adhesive-bonded aluminum alloys exposed to hot-humid environment has been still unclear.

In the present study, the effect of hot-humid exposure on the strength of the adhesive-bonded aluminum joints is investigated. The strength of the adhesive-bonded aluminum joint is evaluated using lap-shear joint configuration. Differential scanning calorimetry (DSC), contact angle measurement, surface free energy dispersive X-ray spectroscopy (EDS) and polarization corrosion test are utilized to analyze the degradation mechanism of adhesive-bonded aluminum joints exposed to hot-humid environment. Finally, the effect of elevated temperature in hot-humid environment on the corrosion resistance of the adhesive-bonded aluminum joints is discussed.

2. Experimental

2.1. Materials

1.0 mm thick bare Novelis X610-T4PD (hereafter referred to as **X1.0**) and 0.9 mm thick bare Novelis X626-T4P (hereafter referred to as **X0.9**) aluminum alloys (hereafter referred to as XX substrates) were used in this study. ***L*** adhesive (i.e., a bi-component epoxy-modified acrylic adhesive containing 0.25 mm diameter glass beads to control the bondline thickness) was selected to bond XX aluminum substrates. The main chemical composition of aluminum substrates were measured by X-ray fluorescence spectroscopy (Bruker AXS SRS 3400, Germany), referring to Table 1. The mechanical properties of aluminum substrates provided by supplier are listed in Table 2. Table 3 lists the mechanical properties of ***L*** adhesive provided by supplier.

2.2. Sample fabrication

All substrates were sheared into 25 mm × 100 mm samples which were cleaned by 1-1-1 trichloroethane. ***L*** adhesive was applied to the substrates, and the top sheet was set down upon the bottom sheet per the lap-shear joint configuration (hereafter referred to as XXL joint), as shown in Fig. 1. The adhesive-bonded samples were prepared as follows: (a) applying the adhesive on one of the two adherends using a hand-held injection gun, and positioning the adherends with and without dispensed adhesive using a fixture; (b) bringing the adherends together by a fixture under ambient laboratory conditions, and a pressure was applied via the fixture so that a bondline thickness of 0.25 mm can be maintained; (c) curing the samples in the oven as per the supplier's recommended curing procedure (i.e., 16 h at room temperature and then 20 min at 170 °C). The schematic diagram of adhesive bonding process for aluminum alloys is presented in Fig. 2. All finished samples were examined and the spew fillets around the edge of the overlap were retained to simulate real production conditions.

Table 2
Mechanical properties of Novelis X610-T4PD (X1.0) and X626-T4P (X0.9) aluminum alloys.

Substrate	Yield strength/MPa	Ultimate tensile strength/MPa	Total elongation/%
X1.0	119.9	228.6	21.9
X0.9	108.7	214.8	22.4

Table 3
Mechanical properties of *L* adhesive.

Material	Yield strength/MPa	Tensile strength/MPa	Elongation/%
L adhesive	3.7	8.9	28.6

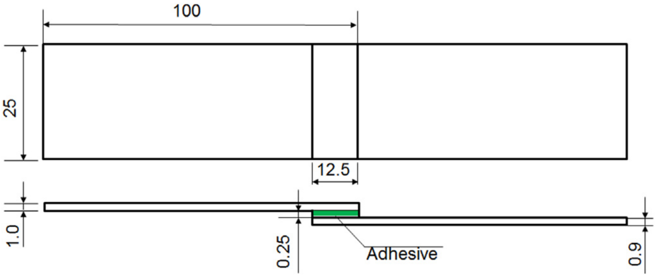

Fig. 1. Configuration of adhesive-bonded lap-shear joint (dimensions in mm).

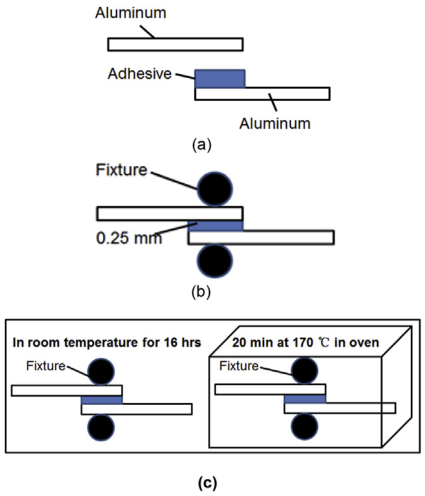

Fig. 2. Schematic diagram of adhesive bonding process for aluminum alloys (a) Applying adhesive and positioning the aluminum substrates (b) Pressure is applied by the fixture to maintain a bondline thickness of 0.25 mm (c) Curing the samples for 16 h at room temperature and then 20 min at 170 °C.