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Molybdate-based conversion treatment for improving the peeling strength between aluminum foil and polypropylene grafted with glycidyl methacrylate

Chang-Sheng Liang, Zhong-Fei Lv, Ye-Ling Zhu, Shi-Ai Xu *

Shanghai Key Laboratory of Advanced Polymeric Materials, Key Laboratory for Ultrafine Materials of Ministry of Education, School of Materials Science and Engineering, East China University of Science and Technology, Shanghai 200237, China

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ABSTRACT

This paper describes an environment-friendly treatment for aluminum (Al) foil that can greatly improve the adhesion strength between foil with the polymer film to a similar extent as the traditional chromate–phosphate treatment. Al foil was treated with different methods, after which a modified polypropylene (PP) film (PP grafted with glycidyl methacrylate, PP-g-GMA) was directly joined with the treated Al foil by hot pressing. The T-peeling strengths of the Al/PP-g-GMA composites were measured, and the peeling strength of molybdate-treated foil was found to be approximately 10 times greater than that of untreated foil. The surface morphologies of the Al foils were observed by scanning electron microscopy and atomic force microscope, their chemical compositions were characterized by energy-dispersive spectroscopy. The hydrophilicities and surface energies of the treated Al foils were further evaluated by contact-angle measurements.

1. Introduction

Metal–polymer composites are widely used in aerospace, automobile, and packaging industries [1]. Among such composites, Al/polymer (Al/P) composites are attracting considerable research interest because of their desirable properties, such as low weight and excellent impermeability to moisture and air [2]. However, the low adhesive strengths of Al/P composites limit their applications. To overcome this problem, researchers have proposed various methods, such as polymer modification, metal treatment, and adhesive use [3–10].

Surface pretreatment of Al can effectively improve the adhesion and corrosion resistance of Al/P composites. This treatment can be divided into two main categories, namely, physical and chemical treatments. Physical treatments such as mechanical grinding and grit blasting are used to remove loose contaminated layers and to provide a rough surface for mechanical interlocking with an adhesive [11]. Chemical treatments such as chemical conversion treatment and electrochemical treatment can modify the surface by depositing a new coating layer designed to improve coupling with a given adhesive system [12–14]. Compared with physical methods, chemical conversion treatments are more effective and concise for achieving effective adhesion between metal and polymer.

To obtain a strong and stable bond between Al and polymer layers such as polypropylene (PP), the naturally formed surface oxide on Al must be removed and replaced with a new oxide layer that is continuous, solid, and corrosion resistant. The most successful and widely used treatments are chromate conversion coatings [15–19]. However, hexavalent chromate Cr (VI) is highly toxic, and its use has been limited by several European Union Environmental Legislation and Restriction of Hazardous Substances directives since 2006. Therefore, environment-friendly conversion coatings must be developed to replace traditional chromate treatments.

Low toxicity conversion coatings formed in non-Cr (VI) solution such as titanium, zirconium, Cr (III), and cerium salt baths are widely studied [20–23]. Molybdate-based conversion coatings are promising alternatives because of their low toxicity and good corrosion resistance properties similar to those of chromate-based coatings [24–29]. Yong et al. [24] analysed the corrosion protection of a molybdate/phosphate composite conversion coating on magnesium alloy. Karpakam et al. [26] prepared a polyaniline–molybdate coating on steel and investigated its performance as a corrosion barrier.

Some studies have reported on the treatment of Al foil with molybdate-based conversion solution [30–32]. In the present study, an Al foil was treated with a molybdate-based conversion solution, and a composite film of the treated foil with PP film grafted with glycidyl methacrylate (PP-g-GMA) was prepared by hot pressing. Results showed that molybdate-based conversion coatings can effectively improve the T-peeling strength of Al foil with PP-g-GMA film. To explore the underlying mechanism, the surface morphology of Al foil was

* Corresponding author.
E-mail address: saxu@ecust.edu.cn (S.-A. Xu).

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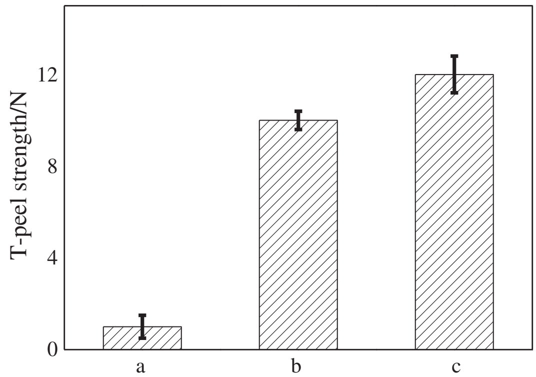

Fig. 1. T-peeling strengths of Al foil/PP-g-GMA composites with different pretreatments: (a) no treatment, (b) molybdate-based conversion, and (c) chromate–phosphate conversion.

observed by scanning electron microscopy (SEM) and atomic force microscope (AFM), the chemical composition was characterized by energy-dispersive spectroscopy (EDS). The hydrophilicity and surface energy of the coated Al foil were further evaluated based on contact-angle measurements.

2. Experimental

2.1. Materials

The thickness of the Al foil AA 8021 used in this study was 40 μm. Ammonium molybdate, sodium fluoride, chromium trioxide and phosphoric acid were purchased from Shanghai Ling Feng Chemical Reagent Co., Ltd., China. PP-g-GMA was home-made in our laboratory, and its melt flow index (MI) was approximately 5 g/10 min. PP-g-GMA film with a thickness of 100 μm was prepared by mould pressing.

2.2. Surface pretreatment of Al

2.2.1. Molybdate-based chemical treatment

The substrates were first degreased at 40 °C in acetone for 10 min and subsequently immersed in an aqueous solution containing phosphoric acid (60 g/L), ammonium molybdate (6 g/L), sodium fluoride (2 g/L), and FN-44 (4 g/L, self-developed additive) at 40 °C for 1 min. Finally, the substrates were rinsed with tap water and dried in an oven for 1 h.

2.2.2. Chromate–phosphate conversion treatment

The substrates were first degreased at 40 °C in acetone for 10 min and subsequently immersed in a solution containing hexavalent chromium

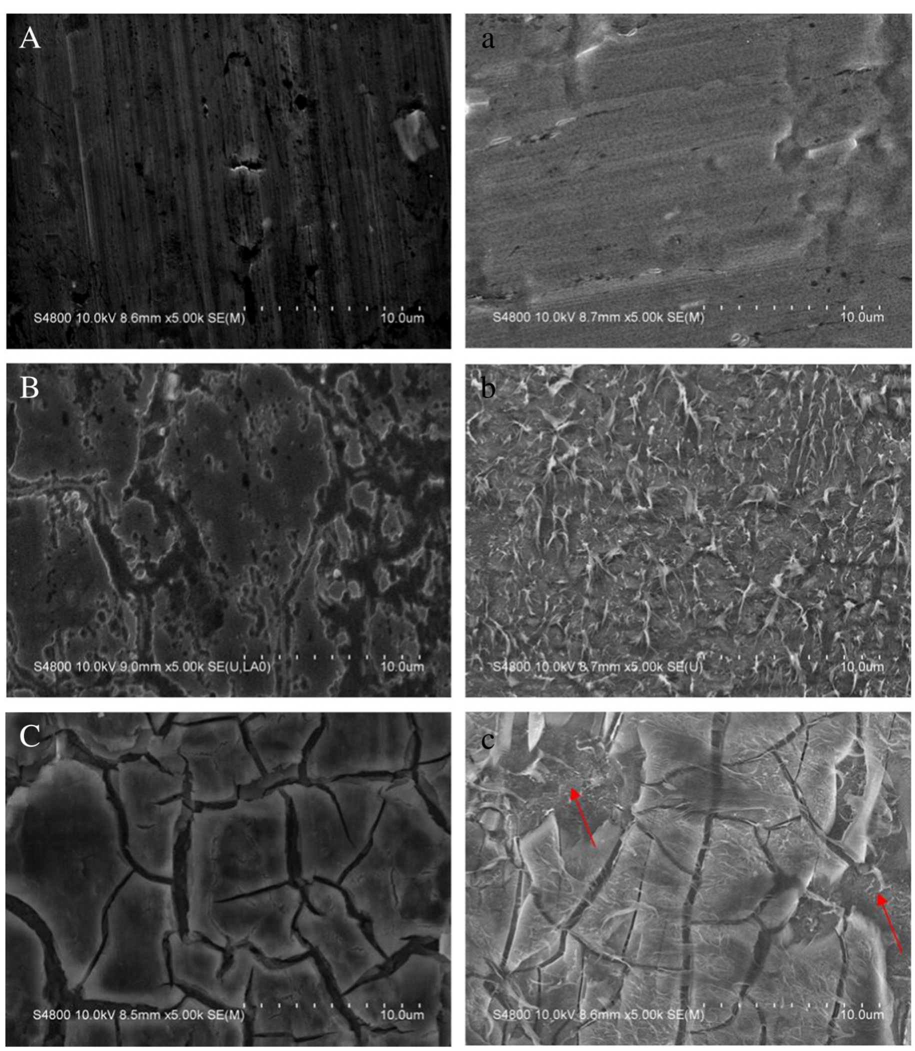

Fig. 2. Surface morphologies of Al foils before and after peeling with different pretreatment methods: (A, a) no treatment; (B, b) molybdate-based conversion; and (C, c) chromate–phosphate conversion.