ELSEVIER

Progress in Organic Coatings 52 (2005) 217–226

PROGRESS IN ORGANIC COATINGS

www.elsevier.com/locate/porgcoat

Protection of aluminum alloys from filiform corrosion by low-temperature plasma interface engineering

Q.S. Yu*, H.K. Yasuda

Center for Surface Science and Plasma Technology, Department of Chemical Engineering, University of Missouri-Columbia, Columbia, MO 65211, USA

Received 22 July 2004; received in revised form 13 December 2004; accepted 14 December 2004

Abstract

This study investigates the filiform corrosion resistance of chromate-free coating systems fabricated on aluminum alloys by low-temperature plasma interface engineering. The aluminum alloys investigated include AA2024-T3 ([2B]), AA7075-T6 ([7B]), Alclad AA2024-T3 ([2A]), plate stock AA2124-T851([2P]), plate stock AA7050-T7451 ([7P]), and ion vapor deposition (IVD) Al-coated AA2024-T3 ([2I]), IVD Al-coated plate stock AA2124-T851([2PI]), IVD Al-coated plate stock AA7050-T7451 ([7PI]). Direct current (DC) cathodic plasma processes including plasma treatment and plasma deposition were used to create the water-insensitive adhesion of organic coatings to aluminum alloys. With appropriate application to aluminum alloys, DC cathodic plasma coatings of trimethylsilane (TMS) combined with argon plasma post-treatment provided tenacious and water-insensitive adhesion between the water-borne, chromate-free spray primers and aluminum substrates. These chromate-free coating systems, when tested by filiform corrosion test, showed superb resistance to filiform corrosion. Filiform corrosion test was found to be a good measure of water sensitivity of the coating interfaces.

Keywords: Aluminum alloys; Low-temperature plasma; Primer coatings; Filiform corrosion; Wet adhesion

1. Introduction

This paper is a follow-up to a series of four papers dealing with corrosion protection of aluminum alloys by low-temperature plasma coating systems based on system approach interface engineering (SAIE) concept [1–4]. The SAIE concept adopted in this series study emphasizes that the corrosion protection of a metal depends on the overall corrosion protective behavior of an entire system. Based on SAIE concept, low-temperature plasma interface engineering was used to tailor various interfaces to optimize overall corrosion protection properties of the coating system. The main objective of the study was to explore alternative corrosion protection methods for aircraft aluminum alloys by means of an environmentally benign process without using any environmentally hazardous heavy metal, such as chromate, used in chromate conversion coatings and chromated primers. A full introduction to the subject with background information can be found in the first of the four papers [1].

In the series of four papers that we previously presented [1–4], the corrosion protection properties of the plasma coating systems created without using any hazardous heavy metals were mainly investigated and evaluated by performing sulfur dioxide (SO_2) salt spray test (ASTM G 85-94-A4) [5] and Prohesion salt spray test (ASTM G 85-94-A5) [5]. The experimental data collected from about three-thousand aluminum panels evidently showed that excellent corrosion protection can be achieved by this approach because most of plasma engineered coating systems outperformed in many cases or at least performed comparably to the chromate coated controls through the corrosion tests.

The corrosion test results of scribed primer coated panels by above mentioned salt spray tests, indicated that the corrosion extended beyond the cut-edges reflects mainly the corrosion induced de-lamination of primer [6]. The

---

* Corresponding author. Tel.: +1 573 882 8076; fax: +1 573 884 4940.
E-mail address: yuq@missouri.edu (Q.S. Yu).

0300-9440/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.porgcoat.2004.12.004

electro-chemical corrosion protection, such as by means of chromate conversion coating and primer with corrosion inhibitors, slows down the corrosion reactions through reducing the corrosion driving force and as a result the corrosion induced de-lamination. The system approach interface engineering does not include electro-chemical corrosion inhibitor, but creates tenacious water-insensitive adhesion of primer to the substrate metal. Thus, in this approach, the corrosion resistance solely depends on the tenacious water-insensitive adhesion of corrosion protecting coating system.

It has been known that filiform corrosion is common on aluminum alloys under organic coatings [7–9]. Filiform corrosion is a type of corrosion that occurs on metal substrates underneath coatings and is characterized by a definite threadlike structure and directional growth (ASTM D2803 para. 3.1.1) [10]. This type of corrosion usually starts at coating defects or at cut-edges following anodic undermining or cathodic de-lamination as corrosion mechanisms. The metal/coating interfacial adhesion particularly adhesion under wet conditions (or simply wet adhesion) has been considered to be the critical factor in controlling filiform corrosion attack [9].

It is important to recognize that filiform corrosion test does not include salts unlike most of corrosion test methods. If one accepts the interpretation that corrosion observed with corrosion tests with salts is the result of corrosion induced de-lamination of protective coating, filiform corrosion test that also use scribed coated samples is significantly different from corrosion test with salts. Filiform corrosion test could be viewed as the testing of water resistant adhesion of protective coating. Then, the system approach interface engineered corrosion protecting systems, which were prepared by low pressure plasma polymerization coating, are anticipated to show outstanding results.

In this study, an effort was made to extend the corrosion testing of plasma coating systems to filiform corrosion test. The corrosion protection performance of these coating systems created on various aircraft aluminum alloys was examined and evaluated by conducting filiform corrosion test.

2. Experimental

2.1. Materials and sample preparation

Al alloy panels of AA 2024-T3 sheet (denoted as [2B]), AA 7075-T6 ([7B]), Alclad 2024-T3 ([2A]), and Alclad 7075-T6 ([7A]) with dimensions of 7.62 cm by 15.2 cm by 0.081 cm were procured from Q-Panel Lab Products (Cleveland, OH). Al alloy panels of AA 2124-T851 cut from plate ([2P]) with dimension of 7.62 cm by 15.2 cm by 0.33 cm and AA 7050-T7451 cut from plate ([7P]) with dimension of 7.62 cm by 12.7 cm by 0.33 cm were prepared at Boeing, St. Louis, MO. Ion-vapor-deposition (IVD) [11,12] Al-coated Al alloy panels of AA 2024-T3 ([2I]), AA 2124-T851 cut from plate ([2PI]), and AA 7050-T7451 cut from plate ([7PI]) were prepared at Boeing, St. Louis, MO. Class I IVD (25 μm in thickness) was employed in this study. Chromate conversion-coated (Iridite 14-2) then chromated primer-coated (44-GN-72) aluminum panels (denoted as CC/A or CC/A1) that are typical to current aerospace industry usage were utilized as test controls in this study. These controls were also prepared at Boeing, St. Louis, MO.

The chromate-free spray primers were water borne Dexter 10-PW-22-2 (X) (Dexter Corporation, Waukegan, IL) and water borne Spraylat EWAE118 (D) (Spraylat Corporation, Chicago, IL). Both primers are epoxy-based paints with TiO_2 as white pigments. All the other materials used in the present study are identical to what was described in our previous publication [1]. Except for the plasma deposition step when the anode assembly was removed, the sample preparation procedures were the same as reference [1]. The sample identification codes and associated plasma conditions for sample preparation are summarized in Table 1.

2.2. Plasma reactor system and operation

Direct current (DC) cathodic polymerization and plasma treatment were carried out in a bell jar reactor, which was described in detail elsewhere [1]. The system was exactly the same as described in part 1, except when the anode assembly was removed and the grounded reactor wall was used as anode during the operation in certain situations explored. A pair of Al panels was placed inside the plasma reactor as the cathode (i.e., substrate for deposition). Plasma treatment by simple gases, such as oxygen or argon, was conducted in a flow system similar to that described in reference 1 [1].

To conduct plasma deposition in a closed reactor system, a new approach in this study, the reactor chamber was first pumped down to <1 mTorr. The reactor chamber was then isolated from the pumping system by closing the main valve located in between. Trimethylsilane (TMS) gas, controlled by an MKS mass flow meter (model 247C), was then fed into the reactor. After the system pressure reached a preset point, TMS gas feeding was stopped and DC power was then applied to initiate the glow discharge to start cathodic polymerization.

2.3. Application of primers

Primers were sprayed onto the substrates with an airbrush. After painting, primer-coated samples were cured according to the stipulations provided by the primer suppliers. After curing, the thickness of primer coatings was measured with an Elcometer 355 (Elcometer Inc., Rochester Hill, MI). The thickness of the primer coatings was controlled to be around 1.0 mil (25.4 μm).

2.4. Tests and measurements

A standard tape test (ASTM D3359-93B) was first used to evaluate the adhesion performance of the coating systems [13]. For stronger adhesion and especially wet adhesion, an