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Accelerated growth of oxide film on aluminium alloys under steam: Part II: Effects of alloy chemistry and steam vapour pressure on corrosion and adhesion performance

Rameez Ud Din *, Kirill Bordo, Morten S. Jellesen, Rajan Ambat

Department of Mechanical Engineering, Technical University of Denmark, Kongens Lyngby 2800, Denmark

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ABSTRACT

The steam treatment of aluminium alloys with varying vapour pressure of steam resulted in the growth of aluminium oxyhydroxide films of thickness range between 450 and 825 nm. The surface composition, corrosion resistance, and adhesion of the produced films were characterised by XPS, potentiodynamic polarisation, acetic acid salt spray, filiform corrosion test, and tape test. The oxide films formed by steam treatment showed good corrosion resistance in NaCl solution by significantly reducing anodic and cathodic activities. The pitting potential of the surface treated with steam was a function of the vapour pressure of the steam. The accelerated corrosion and adhesion tests on steam generated oxide films with commercial powder coating verified that the performance of the oxide coating is highly dependent on the vapour pressure of the steam.

1. Introduction

Aluminium and its alloys are widely used in the construction, automotive and aerospace industries because of their distinct properties, for instance light weight, low toxicity and valuable corrosion resistance characteristics [1,2]. Heat-treatable 6000 series aluminium alloys are heavily used in the automotive and construction industries owing to fuel efficiency, weight reduction, formability and strength [3,4]. The native oxide film of about 2–10 nm thick on an aluminium alloy, is stable in natural environments in the absence of chloride and provides natural corrosion resistance to the metal. Nonetheless the native oxide film has inadequate barrier properties for long term corrosion prevention of the underlying metal substrate, even after being further coated by organic protective coatings [5]. Therefore an intermediate layer of conversion coating is needed. The function of conversion coatings is to improve the corrosion resistance and build a base for subsequent application of organic coatings with improved adhesion [6]. An organic coating alone is permeable to water and other ions over long periods of time due to the micro-pores and diffusion through the molecular structure [7].

Although banned today due to carcinogenic issues [8], chromate-based conversion treatment [9] is the most protective conversion coating due to the re-passivation provided by the self-healing ability of chromate. A number of alternative conversion coatings are in use, however none of them have been proven to be as good as chromate-based conversion treatments. Alternative surface treatment techniques applied to aluminium alloys include Ti/Zr based conversion coatings, which are commercially available and include polymeric constituents. These coatings are applied by dipping or spraying to generate a 10–50 nm thick oxide film [10,11]. However the corrosion performance of these coatings has been shown to be inferior when compared to the chromate-based conversion coating treatment [12]. Other alternatives for chromate based conversion coating treatments include rare earth based inhibitors [13], organic polymer coatings [14], and phosphating process [15] with some additives for aluminium alloys [16]. These processes have some drawbacks, like e. g. polymers are difficult to work with unless used with chromates and use of rare earth inhibitors add to the cost. Phosphate based coatings individually or with addition of chromates provide good paint adhesion, but corrosion resistance is inferior to that of chromate-based conversion treatments [17]. Earlier studies [18–20] reported that steam based conversion coatings exhibit good corrosion resistance properties by reducing anodic and cathodic activities of aluminium.

The interaction of applied top coat with metal substrate is determined by the chemical and physical nature of pre-treated aluminium alloy surface. The adhesion provided by the mechanical interlocking is one aspect which depends on the surface morphology of the conversion coating [21,22]. The adhesion mechanism also depends on the acid/base

* Corresponding author.
E-mail address: rudin@mek.dtu.dk (R.U. Din).

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Table 1
Chemical composition of AA6060 in weight%, remainder Al.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.3–0.6	0.1–0.3	Max. 0.1	Max. 0.1	0.3–0.6	0.05	0.1	0.1

properties of the surface due to the possibility of forming chemical bonds with the top layer [23]. The organic molecules in the top layer will form chemical bonds with the conversion layer depending on the surface property. The presence of hydroxyl group is an important aspect due to the possibility of forming bonds by donating negatively charged oxygen [24]. Rider [25] reported that adhesion and durability of applied epoxy coating was affected by boiling water treatment of aluminium. Strålin and Hjertberg [26] found that the adhesion of ethylene vinyl acetate polymer with a pseudo-boehmite aluminium oxyhydroxide layer is stronger than with a dehydroxylated aluminium oxide.

In the present investigation aluminium alloy surfaces are treated with steam to generate relatively thick oxide layers. Part I of this paper describes in detail the microstructure, surface morphology, oxide growth mechanism and phase analysis of the steam generated oxide films as a function of steam parameters. This paper (Part II) studies surface chemistry and electrochemical behaviour of steam generated oxide films evaluated on Peraluman 706™ and AA1090. The acid salt spray, filiform corrosion resistance, and adhesion properties of the oxide films were examined according to relevant standards, and therefore using AA6060 alloy [27]. Moreover the adhesion properties of these oxide films were judged in dry and wet conditions by tape test. The oxide films were produced at different vapour pressures of steam and compared for the surface chemistry and corrosion performance.

2. Experimental

2.1. Materials

The elemental composition of the aluminium alloys Peraluman 706™ and AA1090 was presented in Part I. The alloys were in the form of cold rolled sheets with a thickness of 1 mm and 0.5 mm respectively. All samples were cut from the sheet into 50 × 50 mm coupons. The commercial AA6060 aluminium alloy was used for industrial scale corrosion performance testing. The alloy specimens were cut from 1 mm thick sheet into 150 × 50 mm coupons. The alloy chemical composition obtained from the supplier data sheet is presented in Table 1.

2.2. Surface preparation

2.2.1. Treatment 1

All samples were degreased by dipping in 6 wt.% commercial Alficlean (pH = 9) aqueous solution for 2 min at 60 °C followed by rinsing in deionised water for 1 min and air drying at room temperature.

2.2.2. Treatment 2

Samples were subjected to alkaline etching treatment by immersing in an aqueous solution of 10 wt.% NaOH at 60 °C for 5 min, rinsing in deionised water for 1 min followed by desmutting in 69% vol. HNO_3 for 2 min. The specimens were then washed with deionised water and dried in air at room temperature.

2.3. Steam treatment

Samples from treatment 1 and treatment 2 were exposed to steam treatment in an autoclave. The surfaces of the specimens were exposed

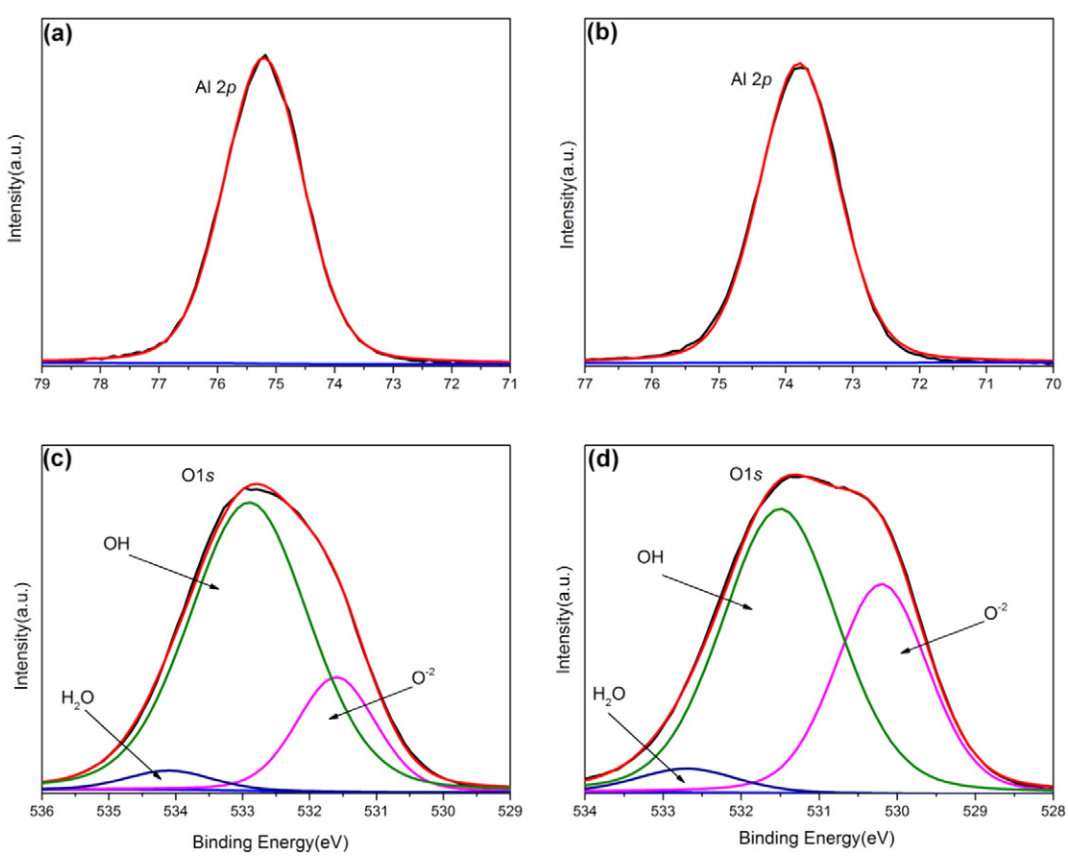

Fig. 1. XPS spectra of the Al 2*p* and O 1 *s* levels for the surface of AA1090 samples treated by steam for 30 s (a, c) and 10 min; (b, d) at 1.3 bar vapour pressure.