Al SLURRY COATING FOR Cd REPLACEMENT FOR AIRCRAFT COMPONENTS

A. Agüero, C. Blanco, M. García and M. Gutiérrez.

National Institute of Aerospace Technology (INTA)
Ctra. de Ajalvir, Km 4,
28850 Torrejón de Ardoz, Madrid. Spain
garciamam@inta.es

Cadmium has been widely used as a coating to provide sacrificial corrosion protection for steels and excellent lubricity for threaded applications. However, it is a toxic metal and a known carcinogen which is plated from an aqueous bath containing cyanide salts. For these reasons the use of cadmium is regulated by stringent worker exposure and environmental limitations.

Al-slurry coatings have been developed as an alternative to replace cadmium coatings during the project "Replacement for Toxic Coatings and Coating Processes for Aeronautic Components" (RAMPE) in which INTA as well as several Spanish aeronautics companies and institutions participate. The coatings have been characterized by optical and electron microscopy and porosity analysis has also been carried out. Results of salt fog corrosion exposure, fluid corrosion (immersion), humidity resistance, as well as coating-substrate and paint-coating adhesion indicate that Al-slurry coatings are an excellent alternative for Cd replacement.

Keywords: cadmium replacement, coating, slurry, aluminium, corrosion.

1. INTRODUCTION

Cadmium plating is widely use on aircraft for the corrosion protection of airframe components and fasteners manufactured from steel [1]. The advantages of cadmium plating are well known: effective corrosion barrier coating, particularly in the marine environments frequently experienced by aircraft, and its high lubricity. The main disadvantage associated with the use of cadmium is the high toxicity of the metal and its compounds. The poisonous nature of cadmium salts causes stringent controls of the disposal of effluent from plating operations and the levels of cadmium that may be discharged into the environment are extremely low. Over the past decade, environmental and worker health regulations affecting cadmium use have been promulgated in Europe [2] and in many other countries including the USA [3,4] and Japan. These regulations have increased the costs associated with cadmium coating application and cadmium-bearing waste disposal, created liability risks and restricted markets for certain cadmium-coated products. Thus, viable cadmium replacements must be identified. An important requirement is that the replacement coating should provide sacrificial corrosion if the substrate become exposed [5-10].

Aluminium coatings may be produced by a variety of methods [11-14]. The more usual method is a physical vapour deposition (PVD) method called ion-vapour deposition (IVD) [15,16]. Aluminium coatings may also formed by another vapour technique, chemical vapour deposition (CVD) [17]. The application of slurries is also an alternative low cost, easy to apply process to deposit aluminium. Slurries are suspensions of particles (metallic or ceramic) on a binder solvent system that can be applied on a substrate by means of a brush or by spraying. After application, the coated specimen is subjected to a curing heat treatment to eliminated liquids and set the coating.

Within the frame of the project "Replacement for Toxic Coatings and Coating Processes for Aeronautic Components" (RAMPE) partially funded by the Spanish Ministry of Education and Science, aeronautical companies and institutions have investigated commercial Al-slurry coatings for Cd replacement.

In this work, the Al coating deposition technique as well as its characterization is described. Moreover, its behaviour has been evaluated by a series of tests based on the North-American Joint Cadmium Alternative Team (JCAT) Protocol [18]. These include salt fog and fluid immersion corrosion testing, humidity resistance, as well as coating-substrate and paint-coating adhesion.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

Specimens of AISI 4340 steel (Fe, C: 0.38-0.43, Cr: 0.70-0.90, Mn: 0.60-0.80, Mo: 0.20-0.30, Ni: 1.65-2.00, Si: 0.15-0.30, Al: 0.007, P: 0.035 (max.), S: 0.04 (max.) wt.%) were obtained from Corus, United Kingdom.

Commercial Al slurry was obtained from Gebr Morant GmbH, Germany.

2.2 Coating deposition

Samples to be coated were ground and vapour degreased prior to coating. The Al slurry was applied by spray gun and cured, and the coated samples were subjected to mechanical treatment (glass beading).

2.3 Characterisation

The samples were characterised by optical and electron microscopy (LEICA MEF4 and JEOL JSM6400 respectively) of metallographic polished cross sections. Porosity was measured by image analysis (Leica Materials Wokstation Software) was determined.

2.4 Tests procedures

2.4.1 *Bend adhesion*: this test evaluates the adhesion of the coating to the substrate. The specimens with the dimensions 100 x 50 x 1.5 mm were bent repeatedly, back and forth, to an angle of 180º until rupture of the basis metal occurred. The failure region was examined for separation or peeling of the coating with a magnifying glass.

2.4.2 *Wet tape paint adhesion*: this test evaluates the adhesion of a paint to flat surfaces coated with Al-slurry coating according to ASTM D 3359-02. The coated specimens with the dimensions 100 x 50 x 1.5 mm were painted with MIL-PRF-23377H, Type 1, Class N (no chromates), epoxy primer. The samples were immersed in water kept at room temperature and tested after 24 and 168 hours by applying and quickly removing an adhesive tape (3M 250).

2.4.3 *Unscribed and scribed salt spray fog corrosion resistance*: this test evaluates the ability of the coating to prevent corrosion of coated substrates exposed to a salt spray fog. The lower area of each specimen with the dimensions 150 x 75 x 1.5 mm was scratched with a cutter forming a "X" pattern. The scribed specimens were placed into a salt fog chamber to study the corrosion resistance of the coating according to ASTM B117. The duration of the corrosion test was 1000 hours. Failure is established when red corrosion products appear, not taking into consideration the sample edges.

2.4.4 *Fluid corrosion resistance*: This test evaluates the resistance of the coating to fluids commonly employed in aircrafts. The coated specimens with the dimensions 40 x 40 x 1.5 mm were immersed in each fluid for a period of 7 days. The specimens were inspected daily for signs of corrosion attack, coating removal and/or discoloration. The test was carried out in the following fluids:

- lubricant oil (MIL-L-23699)
- JP8 fuel (MIL-PRF-5624)
- hydraulic fire-resistant fluid (Skydrol LD-4)
- hydraulic fire-resistant fluid (Skydrol 500 B4)
- hydraulic fluid (MIL-PRF-87257)
- degreasing fluid (PD-680 Type II)
- de-Icing Fluid (three parts (v) propylene glycol: one part distilled water)
- stripping agent (Turco 6017)

2.4.5 *Humidity resistance*: this test evaluates the resistance of the coating to a humid environment. The specimens with the dimensions 40 x 40 x 1.5 mm were placed into a controlled temperature and humidity chamber and subjected to 10 temperature cycles (in each cycle the temperature was increased from 30 to 60º C with a 0.25 ºC/min ramp, hold at 60 ºC for 6 h and decrease to 30 ºC with a 3.75 ºC/hour). The relative humidity was 95 %. Failure was established when swelling or blisters appear.

3. RESULTS AND DISCUSSION

3.1 Characterisation and influence on mechanical treatment:

A commercial aluminium slurry was applied to AISI 4340 using a spray gun process and subjected to a curing heat treatment. The resulting coating is shown in fig. 1. The coating thickness was approximately 100 μm.

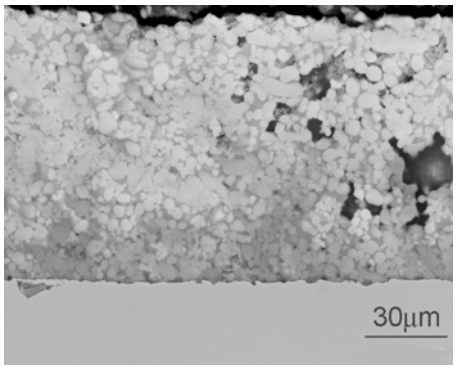


Figure 1. SEM cross section of Al-slurry coating.

In order to reduce porosity the coating was subjected to glass beading. Fig. 2 shows the resulting microstructure. The coating thickness was reduced to approximately 70 μm.

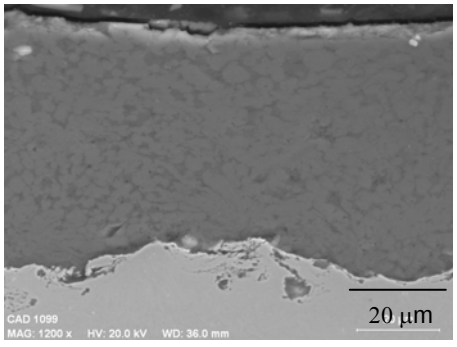


Figure 2. SEM cross section of a glass-beaded Al-slurry coating.

3.2. *Bend adhesion*: no separation or peeling of the coating was observed indicating satisfactory coating adhesion (fig. 3).

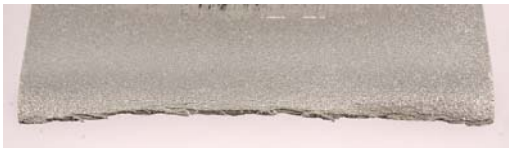


Figure 3. Ruptured Al-slurry coated specimen after bending several times 180º.

3.3 *Wet tape paint adhesion*: no evidence of paint or slurry coating detachment was observed when tape was peeled from a coated specimen painted with epoxy primer after having been immersed in water (fig. 4).



Figure 4. Al-slurry coated specimen painted with epoxy primer after tape removal

3.4 *Unscribed and scribed salt spray fog corrosion resistance*: red corrosion products appeared at 430 h in the specimens that were not glass beaded when exposed to salt fog corrosion, whereas the sample that was subjected to glass beading reached 1000 without evidence of red corrosion products, (fig. 5).



Figure 5a.



Figure 5b.

Figure 5. Influence of glass beading in corrosion resistance of Al-slurry: **(a)** without glass beading: 430 h in salt fog chamber, **(b)** with glass beading: 1000 h in salt fog chamber.

The glass beaded Al coating was scribed and tested reaching 1000 hours of exposure to salt spray fog without the appearance of red rust (fig. 6).



Figure 6. Al-slurry coated and glass-beaded sample exposed to unscribed and scribed salt fog corrosion test for 1000 h at 35 ºC.

3.5 *Fluid corrosion resistance*: the results indicate satisfactory fluid corrosion resistance after 7 days for all tested fluids, excepting the stripping agent. Cd coatings also fail in this fluid according the published results [19]) (fig. 7).



Figure 7a.

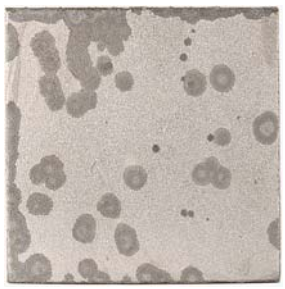


Figure 7b.

Figure 7. Al-slurry coated and glass-beaded sample after 7 days of immersion in: **(a)** most fluids, **(b)** stripping agent.

3.7 *Humidity resistance*: no swelling or blisters was observed after exposure to temperature cycles in a humidity chamber, indicating satisfactory humidity resistance.



Figure 8. Al-slurry coated and superficial glass-beaded sample after 10 temperature cycles in a humidity resistance chamber.

5. CONCLUSIONS

Commercial aluminium slurry coatings have been deposited and subjected to a series of tests. Glass beading after coating application is required in order to reduce porosity.
Preliminary testing studies indicate that Al slurry coatings have potential to replace Cd in aircraft components. Further tests, including axial fatigue, embrittlement and reembrittlement, and electrochemical analyses are ongoing or scheduled.

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