Ion Vapor Deposited Coatings for Improved Corrosion Protection

Applying highly-adherent aluminum coatings onto metals is recognized as a replacement for cadmium...

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The aerospace industry recognizes the application of a highly adherent, continuous aluminum coating onto metallic substrates using ion vapor deposition (IVD) techniques as a replacement for electroplated cadmium.

Vacuum deposition as a method of applying metallic films onto both metal and non-metal substrates is a mature and well-established industry. Its origins coincide with the emergence and growth of the electronics and aerospace industries. IVD of aluminum improves on this traditional technology.

The McDonnell Douglas Corporation, McDonnell Aircraft Division, undertook the commercial development of IVD technology, at its St. Louis, Missouri, facility. The coating system was developed during the 1960’s in order to supply a functionally equivalent or better replacement for cadmium electroplating when its negative environmental impact was first recognized.

The growth of IVD is illustrated by the more than 70 installations worldwide, including facilities in Japan, Europe, Australia, Canada and the U.S.

Process. The IVD process is similar in sequence to conventional plating operations, requiring preparation, processing, and finishing operations in order to correctly process parts.

The preparation stage consists of a degreasing operation to remove gross contaminants prior to an aluminum oxide (A1203) blast treatment that textures the part’s surface and removes solid contaminants. The preparation stage also includes required
FOCUS: Vacuum Deposition

masking operations. Suitable, low out-gassing masking tapes or metal foils are typical materials used.

Parts are racked or barrel loaded prior to charging the IVD vacuum chamber. The vacuum vessel is evacuated to a pressure of 8 x 10^-5 Torr to purge the system prior to backfilling with Argon to 2 x 10^-2 Torr. At this pressure, parts are subjected to a glow discharge cleaning or sputtering operation. A high negative potential is applied between the parts being coated and the evaporation source. The argon gas in the chamber ionizes and creates a glow discharge around the parts, bombarding them with positively charged ions. This ion bombardment of the part surface acts as a final cleaning operation prior to coating.

The evaporator boat systems contained within the vacuum chamber are heated and continuously fed with aluminum wire. The aluminum evaporates and passes through the glow discharge where it combines with the ionized argon and is transported to the part. Pure aluminum is plated on the part, providing a uniform, dense, adherent coating.

Following the coating operation, post treatment operations are performed. To make the aluminum coating more dense, parts are glass bead peened using a No. 10 glass bead. This operation also serves to polish the coating and improve appearance. It also improves the coating’s corrosion resistance. Glass bead peening also serves as a 100-pct quality-control check on the coated part. Any flaw in coating adhesion is highlighted by this operation.

The final post treatment operation is a conventional chromate conversion coating that prepares the aluminum surface for finishing and improves corrosion resistance.

**Equipment.** The IVD aluminum coating is applied in a steel vacuum chamber. Other equipment includes a pumping system, parts racking or barrel tumbling device, evaporation source and high-voltage power supply (Fig. 1). The system uses conventional vacuum technology components that are controlled with a microprocessor-based control system. The system monitors sequencing, alarms, process timing and data recording functions.

**Coating Properties.** Coating adhesion is a function of the surface preparation and cleaning prior to coating. IVD takes advantage of glow discharge cleaning to achieve excellent adhesion of coating to substrate.

Table I shows results of adhesion tests conducted using a Sebastian pull tester on studs bonded to IVD-coated test panels. Two panels were tested for each coating thickness and substrate material.

IVD provides excellent coating coverage and uniformity. It is not limited to line-of-site coverage and can produce coatings several mils thick. The IVD aluminum coating does not build up or run off sharp edges, regardless of thickness. The uniformity of IVD aluminum on regular surfaces is approximately +/- 10 pct of the median thickness. IVD
aluminum coating thickness on the edge of a detail is virtually the same as that of the body of the detail.

During coating deposition, aluminum vapor is partially ionized in the glow discharge that envelops the coated part. This phenomena creates a columnar structure within the coating. The glass-bead post-treatment operation makes the coating denser and also polishes the finished surface. Tests conducted at McDonnell Douglas using BT-10 glass beads at 40 psig produced a surface roughness of approximately 50-70 microinches. Smoother coatings can be obtained by reducing the pressure and/or media size.

IVD aluminum can be used in applications where service temperatures are considerably higher than that allowed for cadmium. IVD aluminum can be used at temperatures up to 925°F without any adverse effects. There is no concern with embrittlement problems as is the case with cadmium on high strength steels at above 450°F.

IVD aluminum with a supplemental chromate conversion coating is electrically conductive. The coating meets the requirements specified in MIL-C-81706 for the electrical contact resistance of aluminum alloy panels. This specification requires that an aluminum alloy substrate treated with a Class-three material per MIL-C-5541 shall not have a contact resistance greater than 5,000 microhms per sq inch as applied, and 10,000 microhms per sq inch after exposure to five pct salt spray for 168 hrs. The electrical measurements are made with an electrode pressure of 200 psi applied to the treated area. IVD aluminum has approximately 48 pct of the conductivity of the bulk 1100 series alloy.

The aluminum coating exhibits the same alloy composition as basic 1100 series aluminum alloy evaporant. This alloy and cadmium have similar electrolytic pct of the conductivity of the bulk 1100 series alloy solution potentials, -0.83 and -0.82v, respectively, when measured against the standard calomel electrode. Since mild carbon steel has a solution potential of -0.58v, both IVD aluminum and cadmium provide corrosion protection in aqueous environments.

Topcoats, such as paints, sealants and lubricants improve the performance of the underlying basecoat. For example, topcoats are used to improve corrosion resistance, improve erosion resistance, or change the coefficient of friction of a finish system. The application and successful performance of any topcoat is dependent on basecoat qualities such as coverage, uniformity, and adhesion. IVD aluminum is characterized by excellent adhesion, coverage and uniformity. Evaluation of the penetration of an epoxy primer into the columnar structure of an IVD aluminum sample by scanning electron microscopy indicated a skeleton of primer penetrating into the structure. This feature considerably enhances topcoat adhesion.

Both IVD aluminum and cadmium are soft coatings that are not particu-
larly well suited for erosion resistance when used alone. IVD aluminum outperforms vacuum-applied cadmium in resisting abrasive forces and diffused nickel-cadmium when subjected to an erosion/corrosion environment. Economically, IVD aluminum can be applied thicker than cadmium and, therefore, is more abrasion resistant than cadmium. Also IVD aluminum is well suited to accepting topcoats of abrasion-resistant materials.

The corrosion resistance performance of IVD aluminum has been compared to the various cadmium processes on alloy steel substrates. The comparisons have been made using neutral salt fog, acidic salt fog or outdoor environmental exposure. The testing led to the conclusion that IVD aluminum can replace all cadmium processes without exception (Tables II and III).

**IVD aluminum on steel** provides excellent “sacrificial” corrosion resistance without detriment to the strength levels of high-strength steel alloys. The absence of hydrogen embrittlement and stress corrosion cracking in these materials results in lower cost processing and higher usable strength levels.

**IVD aluminum on heat and corrosion-resistant alloys.** Historically, cadmium or nickel-cadmium deposited on Inconel, 300 and 400 series stainless steels, and the precipitation-hardening grades receive a nickel strike to prevent the substrate from attack during plating. A readily applied IVD aluminum coating provides galvanic protection for these alloys when used in structural applications.

The coatings can be used to provide oxidization and sulfur resistance up to 925F as coated and extremely high temperature resistance if diffused to form nickel and/or cobalt aluminides.

**IVD aluminum on magnesium.** IVD aluminum applied to a magnesium substrate can be used to replace anodic and conversion-type coatings as a pretreatment for paint or solid-film lubricants. This application maybe useful in overhaul situations where magnesium parts may be assembled with other materials.

**IVD aluminum on aluminum alloys.** The application of an IVD aluminum coating on aluminum-alloy components improves the corrosion performance of the part and eliminates the need for an anodizing treatment. The fact that the part need not be anodized allows for full use of the fatigue strength of the material.

The development of microcrystalline (rapid solidification) aluminum-based alloys for high-strength engineering performance has been restricted due to the inability to provide adequate wear and corrosion resistance using traditional finishing techniques such as hard anodizing. The high-alloying-element content in these materials leaves little pure aluminum available, since a coating allows the part to be treated as a pure aluminum product that readily accepts anodic or conversion finishes.

IVD aluminum is able to replace anodizing on aluminum alloys in situations where electrical continuity or
bond is required. This eliminates the need for “jumper” connections across anodized fittings.

**IVD aluminum on powdered metals.** Traditionally, sintered (powdered) metals have been a problem because they tend to absorb chemicals during wet processing. IVD aluminum, being vacuum applied, allows operators to deposit a uniform protective coating without entrapping fluids.

**IVD aluminum on bi-metallics.** Dual material components requiring corrosion protection while retaining their individual material properties are readily coated using IVD. The coating is not substrate sensitive, allowing for application over brazed connections.

The use of IVD aluminum is expanding from its traditional base. It provides solutions to engineering problems in fields as diverse as non-metallics and ceramics while helping to minimize environmental pollution in the finishing industry.

REFERENCES

1. **SCHEMATIC of an ion vapor deposition system**
**FOCUS: Vacuum Deposition**

### TABLE I—Adhesive Tensile Strength of IVD Aluminum Coating

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Tensile Strength (ksi)</th>
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<tbody>
<tr>
<td>Panel One</td>
<td>*10.18 9.32 *10.28 9.80</td>
</tr>
<tr>
<td></td>
<td>*10.27 9.85 *10.32</td>
</tr>
<tr>
<td>Panel Two</td>
<td>*10.30 8.80 9.94 9.66</td>
</tr>
<tr>
<td></td>
<td>**6.82 8.24 *10.31</td>
</tr>
</tbody>
</table>

* The Sebastian adherence tester has a nominal upper limit of 10 ksi. A recorded adherence value of greater than 10 ksi indicates that the stud/coating specimen interface did not fail.

** A microscopic inspection indicated that this specimen failed due to substrate surface roughness. The coating did not fail. The stud could not be bonded properly to the surface.

### TABLE II—Comparative Corrosion Resistance Performance

<table>
<thead>
<tr>
<th>Environment</th>
<th>IVD Aluminum</th>
<th>Electroplated Cadmium</th>
<th>Low-Embrittlement Cadmium</th>
<th>Vacuum Cadmium</th>
<th>Nickel Cadmium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Salt Fog</td>
<td>Good</td>
<td>Excellent</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Sodium Dioxide Fog</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Outdoor Exposures</td>
<td>Excellent</td>
<td>Good</td>
<td>Fair/Good</td>
<td>Fair/Good</td>
<td>Fair/Good</td>
</tr>
</tbody>
</table>

### TABLE III—IVD Aluminum Compared to Electroplated Cadmium

<table>
<thead>
<tr>
<th>Environment</th>
<th>Relative Protection by Fastener Finish Aluminum Countersink</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 pct Neutral Salt Fog</td>
<td>Cadmium Best</td>
</tr>
<tr>
<td>Sodium Dioxide Salt Fog</td>
<td>IVD Aluminum Best</td>
</tr>
<tr>
<td>Industrial Outdoor</td>
<td>IVD Aluminum Best</td>
</tr>
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