A&M ENVIRONMENTAL TECHNOTES

August 2002 Volume 7, Number 3

IVD Aluminum Coating

Application of the Process at Boeing-St. Louis

Ion Vapor Deposition (IVD) is a physical vapor deposition process for applying pure aluminum coatings to various substrates, or parts, mainly for corrosion protection. The process is applied in a vacuum vessel of various sizes, called an Ivadizer®. To prevent contamination of the pure aluminum coating from oxygen and water vapor in the atmosphere, the aluminum coating is applied to the substrates in a vacuum. Also, by operating in a vacuum, the boiling point of aluminum is decreased from its atmospheric boiling point.

Fig. 1: Extended Length IVD Aluminum Coater at Boeing-St. Louis

Since IVD aluminum is a replacement for cadmium plating, the largest use of IVD aluminum is for corrosion protection of ferrous alloy parts. The IVD aluminum-coating process is in use at all of the Air Force Air Logistics Centers, at all Navy Rework Facilities and at several Army Depots. At military installations, most parts coated are steel alloy parts for corrosion protection. A wide variety of parts are coated, such as: trunnions, cylinders, retainers, caps, retainer rings, spacers, strikers, springs, bolts, brackets, standoffs, links, flap tracks, rings, outboard actuators, strut terminals, blower impellers, stops, screw assembly ballnuts, plates, housings leg bolts, fasteners, nuts, covers, housings, etc. However, there are some non-ferrous parts coated for dissimilar metal protections, such as copper-alloy bushings.

In this process, the substrate, or part being aluminum coated, is the cathode of a high-voltage system. A negative potential of 500 to 1500 volts DC is applied to the part. Aluminum is evaporated from resistively heated elements or from an aluminum slug by electron beam evaporation. Specifically, aluminum alloy wire is fed into a resistively heated source called a boat in the IVD aluminum coater. The boat is made from a special composite material having the proper electrical characteristics to get sufficiently hot with current flowing through it yet not erode rapidly or create hot spots. Also, the boat has sufficient strength to withstand stresses imposed on it at operating temperature.

The aluminum is evaporated from the boat in a process similar to water boiling or evaporating out of a pan. The vaporized aluminum, a gas, spreads out into the vacuum vessel coating the part and the shell of the vacuum vessel in the vicinity of the boat. The hot aluminum vapors condense to form an aluminum coating on the parts in exactly the same manner that water would condense on a metal plate held above a pan of boiling water. A part placed above the evaporating aluminum becomes hot. Heating of the part is primarily due to the heat of condensation that develops whenever a gas, water or aluminum, changes state(s) from a gas to liquid for water or from a vapor (gas) to liquid to solid for aluminum. In the case of aluminum coating, there is also some heating of the part from radiation off the hot boat. In a rack-type coater with a moving evaporator system, the radiant heating of the part is smaller and less significant than the heat of condensation of aluminum onto the part.

IVD aluminum coaters have been developed that are suited for specific applications. A rack-type coater is primarily used for coating large parts. A picture of a typical rack-type IVD aluminum coater is shown in Figure 1. A coater designed for handling large volumes of small parts is called a barrel coater. Barrel coaters are typically used for coating small cylindrical-shaped parts such as fasteners, bolts, pins, nuts, rivets, etc. A picture of a typical barrel coater is shown in Figure 2.

The thickness of the coating should be sufficient for its intended use. Class 3 coatings are typically 0.0003- to 0.0005-inch thick and are used where corrosion protection and/or dissimilar metal compatibility is needed for close tolerance or threaded parts. Class 1, 0.001-inch minimum, and Class 2, typically 0.0005- to 0.00099-inch, are used where corrosion protection and/or dissimilar metal compatibility are needed for structural and functional ferrous and non-ferrous alloy parts. Class 2 coatings are generally specified when Class 1 coatings exceed dimensional tolerance requirements.

Both the aluminum coating and the IVD process are environmentally clean. As evidence, aluminum is used without concern in our everyday lives. It is used as skins on aircraft, as siding on houses, in automobile parts, and in cookware. The IVD aluminum coating is essentially pure aluminum, being deposited from 1100 aluminum alloy.

Cadmium, on the other hand, is a heavy metal and is toxic to the environment and ultimately to humans. Once it escapes into the environment, it can find its way into the water supply or food chain. Also, electroplated cadmium processing presents additional hazards. Cadmium electroplating is typically applied in an alkaline bath containing cadmium oxide dissolved in a sodium cyanide solution. In addition to the cadmium exposure, environmental, health, and safety concerns arise with use of the cyanide bath.

Cadmium has excellent corrosion resistance and good wear resistance, paint adhesion, and lubricity characteristics. Cadmium platings have been the corrosion resistance finish of choice in the aerospace industry for many years. For high-strength steel applications, cadmium platings must be baked for 24 hours to alleviate hydrogen embrittlement concerns. Since cadmium is toxic and is a carcinogen, it is on the EPA 17 list as a substance for reduction or elimination from the workplace. On the economic side, a suitable replacement can both reduce life cycle costs associated with ratcheting environmental regulations and with hazardous waste collection, storage, disposal, and record keeping.

Fig. 2: Barrel Coater Installation

Unlike cadmium, aluminum is environmentally clean, nontoxic, and safe for operating personnel to handle and use. From February 1988 to August 1992, Boeing – St. Louis conducted a three-phase program to verify that IVD aluminum can replace cadmium processing across-the-board at the Air Force Air Logistics Centers (ALC).

In Phase I of the Air Force Contract C87-101602, “The Substitution of IVD Aluminum for Cadmium,” a database handbook was compiled for Air Force ALC use. The database handbook summarized technical information pertaining to IVD aluminum coating and cadmium plating from extensive testing at Boeing – St. Louis and other military/industrial test sources.

In Phase II, data was generated and process development was directed at “areas of concern” applications. “Areas of concern” include coverage of internal surfaces, lubricity, and erosion resistance..

In Phase III, a state-of-the-art IVD aluminum coater was installed at the Warner Robins Air Logistics Center (WR-ALC). The coater was used to demonstrate that IVD aluminum was acceptable as an across-the-board replacement for the toxic cadmium-plating process. During Phase III, over 100 cadmium-plated parts were converted to aluminum coating.

Figure 3 shows the front and rear barrel halves for C-130 Propeller Hubs IVD aluminum coated, glass bead burnished, and chromate conversion coated at WR-ALC. The glass bead burnishing and chromate conversion coating of the aluminum coating produces a pleasing yellow-gold color. Chrome plated areas on the rear barrel half were not coated.

The cadmium plating line was closed at the WR-ALC. Substitution of IVD aluminum coating for cadmium plating benefited WR-ALC by reducing the hazardous waste stream and improving worker safety by decreasing potential exposure to cadmium products and plating solutions.

Based on the successful program at the WR-ALC, two programs were implemented by the Sacramento Air Logistics Center (SM-ALC). The first effort was titled, "Ion Vapor Deposition Aluminum Qualification Tests." Boeing – St. Louis assisted SM-ALC with qualification of IVD aluminum for all of the alloy steel applications at Sacramento that required cadmium plating. The second effort was titled, "Expanded Ion Vapor Deposition (IVD) Aluminum Program." The effort was to develop and demonstrate the applicability of the IVD aluminum-coating process to three new-metal alloys, namely, alloys of copper, titanium, and stainless steel.

Fig. 3: C-130 Propeller Hub Barrel Halves IVD Aluminum Coated

During these programs, IVD aluminum was demonstrated as a successful cadmium-replacement finish on over 350 previously cadmium-plated steel parts. The IVD aluminum-coating process was qualified for use on copper-based, stainless steel, and titanium-based alloys. The cadmium plating line was closed at the SM-ALC. Again, the substitution of IVD aluminum coating for cadmium benefited SM-ALC similarly to that at the WR-ALC.

In tests comparing the corrosion protection of cadmium versus aluminum, the following findings are applicable:

- In acid salt fog tests per ASTM G85, aluminum coatings are vastly superior to cadmium platings.
- In neutral salt fog tests per ASTM B117, cadmium platings are equal to or better than aluminum coatings.
- In outdoor exposure tests, aluminum coatings are equal or superior to cadmium platings.

In most industrial or military applications of either cadmium or aluminum, the atmospheric conditions tend to be acidic due to power generating plants or use of fossil fuels containing sulfur. Long use and multitudes of tests have amply demonstrated that IVD aluminum is a logical and thoroughly tested substitute for cadmium plating for corrosion protection of steel alloy parts. Since aluminum coatings are applied in a vacuum vessel and no hydrogen is generated at the cathode of the high-voltage system, a hydrogen embrittlement relief bake is not required. Therefore, elimination of the 24-hour embrittlement relief reduces processing flow time in the shop for aluminum-coated steel parts.

In addition to IVD aluminum being used as a cadmium-replacement finish for corrosion protection of aircraft structural steel parts, IVD aluminum has been used extensively to protect the external steel surface of missiles from corrosion during storage. Also, IVD aluminum finds use as a cadmium-replacement finish for many small steel part applications, such as, fasteners, bolts, nuts, springs, rivets, etc. As noted in MIL-DTL-83488, IVD aluminum "can be applied to copper, titanium, and stainless steel alloys to provide corrosion compatibility with aluminum structure."

IVD aluminum coatings offer other advantages to cadmium platings. IVD aluminum can be used up to 925°F; whereas, cadmium is limited to 450°F. IVD aluminum can be used for space applications; whereas, cadmium platings cannot be used, because it sublimates in a vacuum environment. Where needed, IVD aluminum coatings can be polished to a mirror-like finish. Also, tests have shown that an IVD aluminum coating is superior to tin-plating for electromagnetic interference (EMI) uses.

IVD aluminum is acceptable for use on titanium parts; whereas, cadmium platings cannot be used because of solid metal embrittlement concerns. Also, titanium parts are coated with IVD aluminum to prevent galvanic corrosion of dissimilar parts. An example would be titanium structural or threaded parts in contact with aluminum alloys. Coating the titanium part with IVD aluminum eliminates the galvanic cell due to dissimilar metal contact. Barrel coaters are used to apply IVD aluminum to threaded titanium as well as threaded ferrous and stainless steel hardware for compatibility with aluminum structure in military aircraft.

IVD aluminum can be used in contact with fuels; whereas, cadmium cannot be used. IVD aluminum can be used in space applications, but cadmium cannot be used. Cadmium sublimates and plates out on other surfaces in a vacuum

An IVD aluminum coating is not as lubricious as cadmium plating. However, this concern is easily overcome with the use of suitable lubricants applied to the IVD aluminum coating. In Phase II of the Air Force Contract C87-101602, "The Substitution of IVD Aluminum for Cadmium," torque-tension data was generated for 15 installation cycles of reuse for various IVD aluminum/cadmium bolt finish, nut finish, and lubricant combinations. Most cadmium-replacement finishes, including IVD aluminum, have similar torque-tension characteristics with the use of a cetyl alcohol lubricant. Fifteen installation cycles of cadmium or IVD aluminum-coated nuts and bolts have very similar torque-tension characteristics when the finishes are lubricated with cetyl alcohol. (One installation cycle is installing the nut onto the bolt, tightening it to a specific torque value, and completely removing the nut off the bolt.) Additionally, the thickness of the cetyl alcohol lubricant is insignificant in comparison with the thickness of the IVD aluminum coating.

IVD aluminum can be applied to high-strength aluminum alloys to eliminate the fatigue debit associated with anodizing high-strength aluminum alloys. IVD aluminum provides satisfactory corrosion resistance and a weight saving resulting from elimination of an increase in aluminum part thickness to offset the fatigue debit.

The IVD aluminum coating process is easily performed. Boeing – St. Louis has used this process for over 25 years, and worldwide, others have used the process for the last 15 to 20 years. Examples are: IVD aluminum coating is in active use at all of the Air Force Air Logistics Centers and Navy Repair Facilities, and at some Army Depots; there are large finishing houses in the United States that have three or more machines applying IVD aluminum to both aerospace and commercial applications. A very successful commercial application of the process is providing corrosion protection to high-strength magnets for electronic applications. Other commercial applications involve coatings of fasteners, rivets, and other small parts.

Worldwide, there are over 12 IVD aluminum barrel coaters finishing an estimated 40,000 pounds of small parts per week. Worldwide, there is an estimated 2,000 to 4,000 large parts IVD aluminum coated in rack-type coaters per month.

The use of IVD aluminum produces a pristine, environmentally friendly, safe finishing system. It is a qualified and demonstrated across-the-board replacement for toxic cadmium-plating processes at Air Force Air Logistics Centers. IVD aluminum has allowed closure of the cadmium-plating lines at the Warner Robins Air Logistics Center, the former Sacramento Air Logistics Center, and contributed to the closure of the plating line at the Oklahoma City Air Logistics Center.

IVD aluminum, as a cadmium-replacement finish, is certainly improving our environment through the elimination of a hazardous waste stream and is a safe product to use and handle. It is truly a coating that is improving the world for the children of today and tomorrow

For further information, please contact Vernon Holmes, (314) 233-8665, e-mail: vernon.l.holmes@boeing.com