IVD Aluminum Coating and Application of the Process at Boeing – St. Louis

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1. What is IVD?

Ion Vapor Deposition (IVD) is a physical vapor deposition process for applying pure aluminum coatings to various substrates, the 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.

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.

Figure 1. Extended Length IVD Aluminum Coater at Boeing – St. Louis

Figure 2. Barrel Coater Installation

2. What properties make up IVD?

The properties that are important for the IVD aluminum coating are:

- Adhesion
- Appearance
- Composition
- Corrosion resistance
- Coverage
- Substrate integrity
- Thickness

These properties were initially defined in MIL-C-83488, the military specification for High Purity Aluminum Coatings. Today, these properties are still carried forth in the Detail Specification for aluminum coatings, MIL-DTL-83488 (Reference 1). Table 1 briefly describes the above important characteristics. Tables 2 and 3 augment the discussion by defining the corrosion resistance and thickness requirements. The reader is encouraged to read MIL-DTL-83488 for additional details concerning each characteristic.

3. How is IVD utilized to improve or benefit materials in aerospace?

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. However, cadmium is toxic, is a carcinogen, and is on the EPA 17 list as a substance for reduction or elimination from the workplace. 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. For high-strength steel applications, cadmium platings must be baked for 24 hours to alleviate hydrogen embrittlement concerns.

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 (Reference 2). 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 (Reference 3). 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 (Reference 4). The cadmium

TABLE 1. IMPORTANT PROPERTIES FOR THE IVD ALUMINUM COATING/PROCESS

Properties	Brief Explanation*
Adhesion	The coating shall not show separation from the base metal at the interface when examined at a minimum magnification of approximately four diameters. The interface between the aluminum and the base metal is the surface of the base metal before coating.
Appearance	The high purity aluminum coating shall be smooth, fine-grained, adherent, uniform in appearance, free from staining, pitting, and other defects. The coating shall show no indication of contamination or improper operation of equipment used to produce the deposit, such as excessively powdered or darkened coatings.
Composition	The composition of the aluminum coating shall not be less than 99.0 percent aluminum.
Corrosion Resistance	Test samples shall show no evidence of corrosion of the base metal after testing. (See Table 2 in this paper). Test panels shall be at least 3 inches wide by 6 inches long made of 4130 steel. The appearance of white corrosion products on the aluminum during the test period shall not be cause for rejection.
Coverage	The coating shall completely cover all visible surfaces, including roots of threads and sharp corners.
Substrate Integrity	The process used to deposit the coating shall not cause a temperature rise in the parts that could cause adverse reaction between the coating and the substrate or adversely affect the substrate.
Thickness	The thickness of the coating should be sufficient for its intended use. Class 3 coatings are typically 0.0003- to 0.0005-inch thick. Class 3 coatings 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. (See Table 3 for minimum coating thickness requirement for each coating class and for the types of aluminum coating applied.)
*	See MIL-DTL-83488 for a more detailed explanation.

TABLE 2. EXPOSURE TIMES FOR CORROSION RESISTANCE TESTS IN NEUTRAL SALT SPRAY TEST PER ASTM B-117

Class (Thickness of coating)	Test Period (hours)	
	Type 1 (As Coated)	Type II (With Supplementary Chromate Treatment)
1	504	672
2	336	504
3	168	336

TABLE 3. COATING CLASSIFICATIONS

Class	Coating Thickness	Type
1	0.0010 inch thick (0.026 mm) minimum	I – as coated
2	0.0005 inch thick (0.013 mm) minimum	II – with supplementary chromate treatment
3	0.0003 inch thick (0.008mm) minimum	

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 (Reference 5). 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 (Reference 6). 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 by reducing the hazardous waste stream and improving worker safety by decreasing potential exposure to cadmium products and plating solutions.

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.

IVD aluminum coatings offer other advantages to cadmium platings. IVD aluminum can be used up to 925^{o}F; whereas, cadmium is limited to 450^{o}F. IVD aluminum can be used on titanium where cadmium cannot because of solid metal embrittlement concerns. 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.

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 (Reference 3). 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.

4. What thickness is required for an adequate protectant as well as a weight reducer?

Depending on the application, IVD aluminum coatings are applied in the range of 0.0003 to 0.002-inch thickness. As noted in Table 1, Class 3 aluminum coatings are used for corrosion protection and/or dissimilar metal compatibility. Typically, Class 3 coatings are applied on fasteners or for other close-tolerance applications where thicker coatings would exceed dimensional tolerances. Class 1 coatings are used where dimensional tolerances are not a concern and where maximum corrosion resistance is needed. Class 2 coatings are used for additional corrosion protection, but where Class 1 coatings cannot be used because of dimensional tolerances. Also, Class 1 and Class 2 coatings are used for dissimilar metal compatibility.

Figure 3 shows graphically the corrosion resistance of panels and fasteners IVD aluminum and chromate conversion coated and tested to failure, red rust. Figure 3 encompasses about 900 data points for 4130 steel test panels representing hand-fixtured details and for alloy steel NAS 584 fasteners for barrel-fixtured details. For the test panels, there are 148 data points for Class 1 coatings, 167 for Class 2, and 56 for Class 3. For the test fasteners, there are 13 data points for Class 1, 237 data points for Class 2, and 284 data points for Class 3. The data in Figure 3 shows a good margin of safety for corrosion protection of coated parts versus Table 2 minimum specification requirements for Type II aluminum coatings. On the test panels, the average corrosion resistance of Class 1, 2, and 3, Type II, IVD aluminum coatings exceeds the requirement of MIL-DTL-83488 by 13.2, 5.8, and 2.4, respectively. For the test fasteners, the average corrosion resistance of Class 1, 2, and 3, Type II, IVD aluminum coatings exceeds the requirements of MIL-DTL-83488 by 12.2, 5.1, and 3.0, respectively. The close correlation between the test panels and fasteners provides an additional level of confidence in the test data (Reference 2).

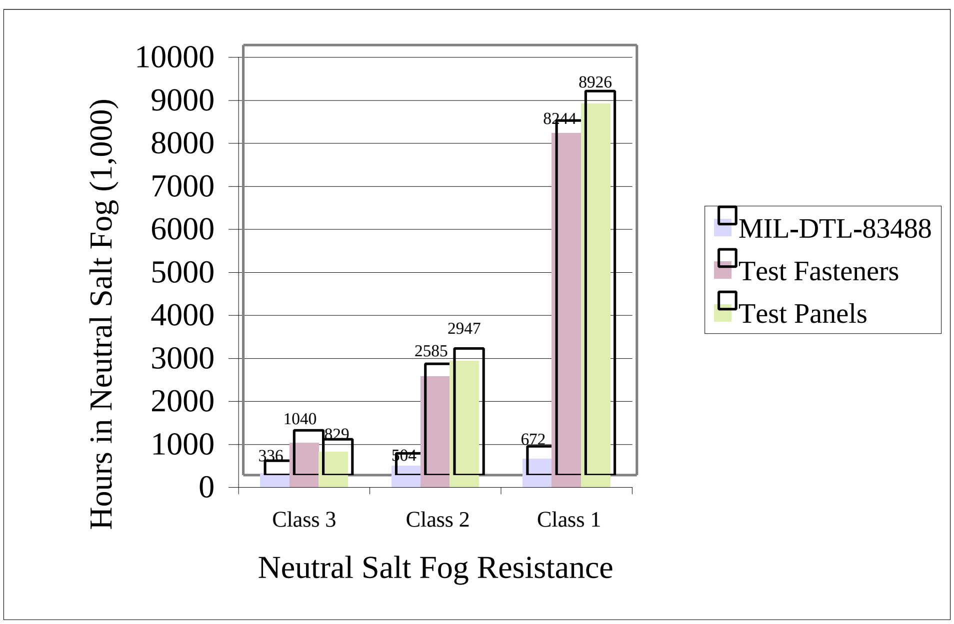

Figure 3. Average Corrosion Resistance of Different Parts Versus Minimum Requirements of MIL-DTL-83488

The bulk density of cadmium is nominally 3.2 times the bulk density of aluminum. From different plating baths, cadmium can be applied either as a dense plating, bright or dense cadmium, or as a porous plating, low embrittlement or porous cadmium. Bright cadmium is used for low-strength steel applications; whereas, low embrittlement cadmium is used for high-strength steel applications. Both platings are used in the aerospace industry. Bright cadmium's density is such that hydrogen cannot be relieved easily by baking. Low embrittlement cadmium is porous and allows hydrogen adsorbed in the steel during plating to be relieved during the subsequent bake at typically 375°F for 24 hours. The exact density of low embrittlement cadmium is not known.

The aluminum coating deposited on parts has a columnar-type structure. Like low embrittlement cadmium, it is not totally dense. Again, the exact density of the aluminum coating is not known.

The density of bright cadmium is probably approaching that of bulk cadmium. For fully dense cadmium and aluminum, a Class 1 cadmium plating, 0.0005- to 0.0007-inch thick, would be equivalent to a 0.0016- to 0.0022-inch thick aluminum coating in weight. If one assumes a density 80 percent of the bulk density for both finishes, a Class 1 cadmium plating, 0.0005- to 0.0007-inch thick, would be equivalent to about 0.0012- to 0.0018-inch thick aluminum coating in weight. The exact densities of low embrittlement cadmium or IVD aluminum have been stated as unknown. However, it is highly unlikely that the density of low embrittlement cadmium is nominally ? of the density of aluminum to achieve a 1-to-1 ratio for the applied finish densities. Although not specifically measured, this implies that replacing low embrittlement cadmium with aluminum for Class 2 or Class 3 resulted in a somewhat lighter part. Only for a thick Class 1 finish is it likely that the aluminum finish might equal or weigh more than the equivalent class cadmium finish. Therefore, there is generally no weight penalty for using thicker aluminum coating versus cadmium plating for the same coating class and sometimes even a net weight savings. Therefore, use of a Class 1 aluminum coating provides excellent corrosion protection to steel parts without any significant increase in weight compared to Class 1 cadmium plating. Class 1, Type II IVD aluminum should be specified whenever possible.

5. What is the typical coating thickness of IVD?

IVD is very adaptable for coating thickness needs. Typically, IVD aluminum coatings are applied in the range of 0.0003- to 0.002-inch in thickness. Class 3 IVD aluminum coatings, 0.0003- to 0.0005-inch thick, are applied to threaded or other close-tolerance parts for corrosion protection and/or dissimilar metal compatibility. The increase in total cycle time to apply a Class 1, 0.001-inch thick minimum coating versus a 0.0005-inch thick coating is small. Therefore, where maximum corrosion resistance is needed, a thicker coating can be applied very economically. Also, a thicker coating has an advantage for complex-shaped parts. Specifying a Class 1 coating ensures that hard-to-coat areas on complex-shaped parts get adequate coverage and coating thickness. Coating thickness requirements do not apply to contact points, recesses, internal threads, and other areas where a controlled deposit cannot be obtained, such as in corners of parts and in radius of intersecting surfaces. Most Class 1 coatings are typically in the 0.001- to 0.0018-inch thick range. If needed, coatings can be applied thinner than 0.0003-inch, but corrosion protection becomes compromised. Coatings can also be applied thicker, but stress buildup becomes an increasing problem affecting adhesion of the coating to the substrate above nominally 0.0025- to 0.003-inch thickness.

6. There is 25 years of proven experience with this technology. How has it advanced in recent years?

In the beginning, there was no long-term production experience with the IVD aluminum process, the aluminum coating, or equipment, other than from laboratory usage and evaluation. As would be expected, the IVD aluminum-coating process experienced its share of growing pains. The qualities of the applied coating, the application technique, and the equipment reliability have improved significantly. A few large and many small improvements have combined to make the coating/process better. The improvements generally arise from a better understanding of the parameters affecting the coating and their control, process equipment changes that improve the efficiency of the process, and better-trained workers. These improvements translate into improved efficiency and therefore profitability. Some improvements are small; such as, determining the vacuum pressure required (highest evacuation pressure) for consistent coating quality, use of larger evaporators, quick-change holders for the evaporators, better cooling of the evaporator holder, and establishment of preventative maintenance schedules. A few other larger improvements will be briefly discussed.

At the beginning, it was thought that most adhesion problems resulted from equipment or cleaning problems. Naturally, equipment must operate properly, and parts must be cleaned of shop oils or soils. However, equipment and cleaning can be perfect and still coating adhesion problems can arise, unless the process is understood. Control of the partial pressure of water in the vacuum system is key to good coating quality, coating adhesion, and an efficient process. Water vapor molecules are in the air and on all surfaces of the vacuum vessel prior to pumpdown. In the beginning, the evacuation or pumpdown times were much longer in the spring and summer than in winter due to the amount of water vapor in the air. The air can hold more water at the higher temperatures in the spring and summer versus winter. Also, the IVD aluminum coaters have a very large effective surface area on which water molecules can attach themselves or be adsorbed. The IVD aluminum coaters have stainless steel liners, shields, on the inside of the coater. During the IVD aluminum-coating process, aluminum coatings are deposited on production parts and the shields. The nucleation process results in aluminum coating being columnar in nature. Therefore, the effective surface area of these columns is much greater than the geometrical surface area of the coater. Also, there is evidence that some water is attached to the aluminum coating through water-of-hydration. Water on these surfaces slowly evaporates as the coater is evacuated. There is a large volume change in water as it changes from a liquid to a gas. Also, vacuum pumps do not pump water vapor efficiently at low pressures. Since production IVD aluminum coaters are not baked, this effectively means that water vapor molecules are coming off of the surfaces of the vacuum vessel at all times. In addition, when the internal surfaces are heated from glow discharge cleaning (discussed in more detail later) and from the condensation of the aluminum vapor, additional water vapor molecules are liberated from these internal surfaces. If the partial pressure of water becomes too high during evaporation and subsequent condensation of aluminum on the part, the coating has a higher and higher content of aluminum oxide in it. Unlike aluminum, which is flexible, aluminum oxide is brittle. If an aluminum oxide layer is formed near or on the surface of the substrate, coating adhesion is severely degraded.

Although troublesome, the adhesion problem is easily corrected through use of one or more of the following recommendations.

- The addition of a fast-cycle, water-vapor cryopump reduces pumpdown times by 50 to 70 percent. A Freon mixture is circulated through a copper coil, the cryocoil, placed in the top of the coater from a closed-loop refrigeration system located external to the coater. The coil is cold enough to freeze water-vapor molecules on it, but the cryocoil is not cold enough to freeze nitrogen or oxygen molecules on it. In addition to providing a faster pumpdown of the coater, the cryopump actively removes water vapor molecules from the coater during both glow discharge cleaning and during coating. This improves coating adhesion and coloration of the coating on the parts.

- Keeping maintenance schedules up-to-date ensures that aluminum coating buildup on the shields do not contribute significantly to the partial pressure of water vapor in the coater during the coating process. Remember, the surface area of the aluminum coating on the shield is many times the geometric surface area of the cylindrical shell of the coater. Also, the surface area is continually increasing as the coating thickness builds up on the shield. When the coater is opened to the room, water vapor molecules in the air are adsorbed on these surfaces and are chemically attached to the aluminum itself as water-of-hydration. During pumpdown, glow discharge cleaning, and coating, water molecules are continuously being liberated from the aluminum on surfaces in the coater. For this reason, the stainless steel shields in the coater must periodically have the aluminum coating stripped off them.

- Always pumping the coater down to less than or equal to 9×10^{-5} Torr ensures that the water vapor and oxygen partial pressures are low before introduction of argon back into the coater for the cleaning and coating steps of the process.

- Applying the initial coating layer quickly to the part by moving the boat rack at it maximum speed, prevents outgassing of water vapor from the walls of the coater to significantly change the partial pressure of water in the coater.

During the IVD aluminum coating process, the coater is first evacuated to 9.0×10^{-5} Torr or less. Then, the coater is backfilled with argon and controlled at nominally 1×10^{-2} Torr. Abar Ispen has simplified the system for controlling the pressure in the coater during cleaning and coating parts. Previously, feeding in a constant flow rate of argon and modulating the large high-vacuum value controlled the pressure in the coater. This was achieved by using a specially designed electronic control circuit that took the pressure measurement (equivalent voltage) in the coater and combined that with a reference voltage to generate an error signal (voltage). The error signal was applied to a hydraulic system to precisely position the high-vacuum value to maintain a specific pressure in the coater. This system has a constant flow rate of argon and a variable conductance to the diffusion pump. With Abar Ipsen's system, the hydraulic system is eliminated. The high-vacuum value is either fully open or closed. The electronic press control board is replaced with a Honeywell pressure controller. Again, a pressure measurement (equivalent voltage) in the coater is combined with a reference pressure (voltage) in the pressure controller to generate a signal sent to the mass flow controller. The pressure controller's output to the mass flow controller modulates the flow rate of argon into the coater to control the pressure. With Abar Ipsen's system, the flow rate of argon is variable and the conductance to the diffusion pump is constant. The system is reliable and trouble-free.

Abar Ipsen has fully automated the complete IVD aluminum-coating system for a large IVD aluminum coater that entered production at Boeing – St. Louis in October 1998, Figure 1. The coater has a coating area of 75 square feet, 5-feet wide by 15-feet long, 50 percent larger than previous IVD aluminum coaters. Since the coater is larger, a larger cryopump coil and refrigeration system was installed. In addition, the system has two, 32-inch diffusion pumps backed by a 1600 CFM blower and 500 CFM mechanical pump. As in other rack coaters, the evaporator, boats, are on a boat-rack system that move from the front of the coater and return at speeds adjustable from nominally 10 to 70 inches/minute. As in other rack coaters, seven evaporator stations use ¾-inch wide evaporators. Although the system can be operated manually, if desired, the IVD coater is operated in the automatic mode. IVD operators control the operation of the coater from a large, touch-screen display. Before the coating cycle starts, the IVD aluminum-coating operator addresses a menu to input the operating parameter to coat the parts. The menu is retained for future use for similar parts. Pumpdown, glow discharge cleaning, IVD aluminum coating, cooling of parts, when required, and venting of the coater to atmospheric pressure is all automatic. Importantly, Abar Ipsen successfully automated the IVD aluminum-coating process. Automation of the coating cycle is achieved by monitoring and controlling the power to the evaporators, boats, as Boeing has been doing manually for years. Full automation of the coating system with all of the associated controls and meshing with the automated pumping systems, pressure control, high-voltage, boat-rack speed, and wire-feed rate is considered an outstanding achievement. After 2 ½ years of operation on two shifts, the automated coating/pumping system is reliable and produces quality a coating on the production parts.

7. What are typical aerospace components that are coated with IVD?

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. (Reference 5 and 6). However, there are some non-ferrous parts coated for dissimilar metal protections, such as copper-alloy bushings, (Reference 6).

Selected aluminum alloys are also IVD aluminum coated for corrosion protection and to eliminate a fatigue debit associated with the anodize process for aluminum parts. Anodizing is applied to aluminum alloy parts for corrosion protection and provides an acceptable surface for paint adhesion. However, anodizing of high-strength aluminum alloy parts can cause the surface to have microcracks, which are stress risers for fatigue. IVD aluminum is a soft coating and therefore not subject to microcracks. When an IVD aluminum coating is chromate conversion coated, the paint adhesion on the part is excellent. Other aluminum parts IVD aluminum coated are defined as maintenance critical. Maintenance critical parts are those located in assemblies that would require a major overhaul to replace them. IVD aluminum coatings can be used for applications where an electrically conductive surface is needed, such as, electrical bonding and grounding and for Electromagnetic Interference Compatibility (EMIC). A Type II, IVD aluminum coating does not experience a gradual increase in contact resistance that other electrically conductive coatings can have. Many structural interfaces require electrical continuity to meet EMIC needs. IVD has been shown to be better than electroplated tin in that electroplated tin joints corrode, electrical resistance at the interface increases, and its effectiveness for EMIC is lost. IVD aluminum corrodes less, has better adhesion to aluminum than tin, and retains the low electrical resistance needed. Table 4 shows the performance difference between electroplated tin and IVD aluminum after one-year shipboard exposure in a corrosion environment (Refernece 7).

TABLE 4. IVD ALUMINUM FOR EMI COMPATIBILITY

Finished Parts With One Year Exposure to Shipboard Conditions	Resistance Before Exposure (milli-ohms)	Resistance After Exposure (mili-ohms)
Electroplated Tin	0.03 – 0.05	200,000
IVD Aluminum	0.25 – 1.3	0.32

8. What is the process, and what steps are required to perform the process?

The IVD aluminum-coating process is the method for applying a corrosion resistant aluminum coating to parts for corrosion protection of the underlying metal substrate. It provides protection against galvanic corrosion by preventing dissimilar metal contact by IVD aluminum-coating copper, titanium, and stainless steel alloys in contact with aluminum structure.

Although the IVD aluminum-coating process is performed in a vacuum system, the process is very simple: load parts, pumpdown, clean, coat, and unload parts. Specific, processing steps for coating steel parts are as follows:

- Load production parts onto a parts rack.
  - Parts are suspended from a screen with hooks of sufficient length to position the parts nominally 10 inches above the evaporators (boats).
- Install the parts rack into the IVD coater.
  - The parts rack is on an air-floatation dolly, which is easily moved up to and docked to the coater. The parts rack is easily rolled onto matching rails in the coater that position the parts rack and its suspended parts at a specific distance above the boats.

- Pump down the coater.
  - The door to the coater is closed and automatic pumpdown of the coater starts. Pumpdown continues until a pressure of nominally 9.0×10^{-5} Torr or less is reached.
- Backfill the coater with argon.
  - The coater is automatically backfilled with argon to a controlled pressure of 1×10^{-2} Torr.
- Apply a negative voltage to the parts.
  - High voltage is applied to the parts suspended from the insulated high-voltage screen for glow discharge cleaning. During glow discharge cleaning, the parts are bombarded with argon ions to remove minor oxides and gases adhered to the surface of the part.
- Coat the parts.
  - Power is applied to the boats; the boats are allowed to warm to operating temperature; aluminum wire is fed into them; and evaporation of aluminum out of the boats starts. During IVD aluminum coating, the evaporator (boat) rack moves from the front of the coater to the back and returns to the front. The number of cycles made at a constant wire-feed rate and at various boat-rack speeds allows coatings of any desired thickness to be applied.
- Cool boats and vent the coater.
  - After coating is complete, the boats are allowed to cool for 2 minutes and the coater is vented to atmospheric pressure.
- Remove the parts rack from the coater.
  - The air-floatation dolly is moved up to and docked with the coater. The parts rack is moved onto matching rails on the air-floatation dolly. The air-floatation dolly and parts rack are removed from the coater. The door of the coater is closed to reduce moisture adsorption from the air.
- Remove the aluminum-coated parts from the parts rack.

9. From experience while working with the IVD aluminum-coating process, what other applications would be acceptable for IVD?

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 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.

As previously noted, 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.

10. How is IVD aluminum environmentally friendly?

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 associated with cyanide products in the plating bath. 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.

Waste disposal is a major problem for the cadmium processes. Treatment of cadmium-plating solutions and rinse waters is required. This is usually a two-step process requiring the destruction of cyanide followed by precipitation of the cadmium. Both steps require separate tanks, instrumentation, chemicals, and labor hours. The effluent from these processes can be diluted or buffered to produce wastewater that meets pretreatment standards after the filtration of the precipitated cadmium compound. The remaining sludge must be dried, stabilized, and disposed in a hazardous waste disposal site. Even then, the environmental problems have not ended. Cadmium can be extremely hazardous if it enters the ground water system; the allowable concentration in wastewater is only one-fifth that for arsenic. As a result of these problems and the associated liability, disposal costs are high and are continuing to rise. Federal treatment standards for land disposal of cadmium-bearing sludge are stringent and subject to future modifications.

Processing and maintenance activities dealing with cadmium must all comply with OSHA Standards as well as EPA regulations. Inhaling small quantities of cadmium dust or fumes may cause a dry throat, cough, chest pain, headache, shortness of breath, and vomiting. More severe exposure could result in death. On 14 September 1992, OSHA established an Expanded Standard for cadmium, which limited the cadmium exposure to a single 8-hour time weighted average permissible exposure limit (TWA PEL) of 5 micrograms of cadmium per cubic meter (μg/m^3) of air for all cadmium compounds, including dust and fumes. An airborne concentration as low as 2.5 micrograms per meter (μg/m^3) as an average over 8 hours is the action level. Medical surveillance is generally required for all exposures at or above action levels for 30 or more days per year or for employees who are required to wear a respirator for cadmium exposure. Warning signs and step-by-step training is required. Initial representative full-shift monitoring is required for each job classification and work area. Regulated areas must be established for concentrations at or above the PEL. Processors are required to have a written plan to deal with emergencies. Change rooms with showers are required for exposure at or above the PEL. Private industry and military facilities alike are required to meet these stringent regulations which will add cost to working with cadmium processing and parts. The use of cyanide (HCN) solutions in the cadmium-plating process also has an impact on the safety in the work area. A toxic gas would be generated if an acid was inadvertently added to a HCN solution. The present OSHA Standard has a short-term exposure limit of 5 milligrams per cubic meter (mg/m^3) of HCN in air, and the Department of Transportation requires labeling to state "Poison A, Poison Gas, and Flammable" on all shipments of cyanide concentrate.

Conversely, aluminum is low in toxicity and is safe to handle, store, and dispose with standard shop practices. From the toxicity standpoint, OSHA regulates aluminum dust or powder only at the "nuisance dust" level.

11. Is IVD a surface coating?

Yes, IVD aluminum coatings are applied to the surface of a part. However, it is not limited to line-of-sight applications as is the case for most physical vapor deposition (PVD) coatings. Due to the higher pressure, nominally 1×10^{-2} Torr (10 microns), the mean free path for an evaporated aluminum atom to travel before collision with another gaseous atom is small being nominally 0.5 centimeters (about 0.2-inch). After the collision, the aluminum atom's direction is changed from that prior to the collision. The result is a scattering of the aluminum atoms being evaporated out of the boat. This action produces a more uniform coating on the substrate than for PVD coatings. Also, the scattering allows the backside of the part to be coated. Although the coating deposited will be thin, the coating wrap-around due to scattering will completely cover the back of a sheet up to nominally 24" by 24" in an IVD aluminum coater with the part 10 inches above the evaporators. This means that small parts do not need to be turned over for coating on their backside.

The IVD aluminum coating process is not limited to line-of-sight applications. However, it does have limitations regarding the ability to coat into deep recesses. Generally, the process will apply coating into recesses at least to a depth equal to twice the width or diameter of the opening. However, acceptable corrosion protection occurs only to a depth approximately equal to one times the diameter of the opening. Therefore, parts and lugs with holes open at both ends with a length-to-diameter ration of less than 2:1 can be coated with satisfactory corrosion protection. However, for parts with a bore or recess with a length-to-diameter ratio greater than 1:1 (or 2:1 if open at both ends) the IVD aluminum-coating thickness/coverage on internal surfaces may be inadequate. Boeing – St. Louis has demonstrated the effectiveness of both sacrificial-type and barrier-type supplemental protection systems for internal surfaces where the IVD aluminum coating could be marginal or inadequate (see Reference 3).

12. What is considered a dense coating for IVD?

IVD aluminum is considered a dense coating, but it is not as dense as bulk aluminum. The IVD aluminum coating deposited on a part, at or near room temperature and deposition pressure, has a columnar structure. Generally, the smoother the surface of the part prior to application of the coating, the smoother and denser the resultant coating will be. However, for best adhesion of the coating to the surfaces of the part, some roughing of the surface is beneficial. The roughing is achieved by the normal chemical or mechanical cleaning of the part prior to IVD aluminum coating. Experience has shown that as the roughness increases prior to IVD aluminum coating, more early corrosion sites are noticed during corrosion resistance testing.

On steel, it appears that roughness of the part prior to IVD aluminum coating is as important or more important than coating density for resistance to corrosion. For example, a part grit blasted with 32-mesh aluminum oxide grit will show more corrosion sites than a similar part grit blasted with 220-mesh aluminum oxide grit, even when coated in the same load under the same conditions. The dense IVD aluminum coating replicates the surface being coated. Therefore, with the rougher surface, the IVD aluminum coating grows faster in thickness at high points than at low points on the surface of the part. (At the microscopic level of coating application, the rough surface can be thought of as consisting of mountains and valleys arising from the metal-cutting action of the grit blasting operation. Grit blasting produces folds in the metal surfaces, the mountains, and between the folds are the valleys.) Experience has shown that the best corrosion protection, coating adhesion, and least possible dimensional changes in the part occur with 220-mesh aluminum oxide grit on close tolerance parts, such as fasteners. For large steel parts, the best corrosion protection and coating adhesion is achieved with 120-mesh aluminum oxide grit. Even when parts are grit blasted with 16- or 32-mesh aluminum oxide, a Class 1 IVD aluminum-coated part will still easily pass the MIL-DTL-83488 corrosion resistance requirement of 672 hours without any evidence of red rust in a ASTM B117 neutral salt spray (fog) test. However, the part will show more white corrosion sites, than a similar part grit blasted with finer grit. As noted in Figure 3, the corrosion resistance of IVD aluminum-coated steel parts exceeds the Military Specification requirements. In Figure 3, the fasteners were typically grit blasted with 220-mesh aluminum oxide grit. The panels were mostly grit blasted with 120-mesh aluminum oxide grit.

Although not fully dense, the IVD aluminum coating’s density is not a deterrent to its widespread use. In the future, the coating may be made denser through application techniques that increase the ionization of the coating or perhaps surface modification of the deposited coating/substrate surface.

13. What type of load configuration do you use?

To better understand load configuration guidelines, a brief description of the coater and parts rack is presented.

The Boeing – St. Louis IVD coaters are rack-type coaters having a coating area of either 50 or 75 square feet. The parts rack is supported in the coater off ball-bearing wheels that set in a long track in the coater. The parts rack is easily rolled out of the coater onto matching tracks on an air-floatation dolly that can be moved up to and mated with the corresponding set of tracks in the coater. During loading and unloading of production parts from the parts rack, the air-floatation dolly is moved back away from the coater. The coater door is closed to reduce moisture adsorption, when not under vacuum.

In addition to the wheeled assemblies and rectangular frame of the parts rack, it consists of three major pieces, each nominally 5- x 10-feet for the standard 50 square-foot parts rack. The three pieces are as following from top to bottom:

- A top screen at ground potential.
- A center screen supported off insulators. During glow discharge cleaning and coating, a negative potential of several hundred volts is applied to it.
- A set of stainless steel sheets, nominally ? -inch thick, that has a uniform pattern of 1.5-inch diameter holes cut into them in a 4-inch pattern lengthwise and across the sheets. Since these sheets are heavy, they are cut into three pieces lengthwise for ease of handling. These sheets are often referred to as the “ground plane.” As implied by the name, these sheets are at ground potential.

The spacing between the center screen and top and bottom ground screens prevents the center screen from glowing during glow discharge cleaning. This allows maximum power from the high-voltage power supply to be applied to the production parts that are suspended from the center screen for cleaning prior to IVD aluminum coating, as explained further below. Hooks are pushed up through the 1.5-inch diameter holes and attached to the center screen using a small “J” on the end of the hook.

Since there is a 4-inch-hole pattern both lengthwise and crosswise, parts of just about any configuration can be hung on the parts rack. A part can be hung from one or a number of hooks, depending on the size, weight, and configuration of the part. If conducive, rods can be laid across hooks and large production parts can be laid on the rods. Since large parts are turned over and coated on both sides, fixture contact points are fully coated. Since the hooks attach the production parts to the center screen, the production parts are at negative potential of several hundred volts during processing.

The type of material being coated, whether steel or aluminum, must be considered when loading parts onto the parts rack. The following guideline should be employed during loading of parts for IVD aluminum coating.

- During IVD aluminum coating, the maximum temperature a part reaches will increase and the coating uniformity will decrease the closer the part is placed to the evaporators (boats). Therefore, whenever possible, the bottom surfaces of parts should be placed 10 inches above the boats for good coating uniformity and to reduce the heating effect on the parts.

- If aluminum parts are placed within 8 inches of the boats, they may be overheated.

- If steel parts are placed within 6 inches of the boats, they will have poor coating uniformity and may exhibit coating adhesion problems due to excessively thick coating on part edges.

- Spacing between parts is critical for satisfying minimum coating thickness requirement and the best coating uniformity. Therefore, the parts should be separated by a minimum of the height or thickness of the part.

- For best coating thickness uniformity, parts with dimensions of 6 inches or more should be oriented with the longest dimension parallel to the boats, rather than vertical.

- Most parts will require coating on two opposite surfaces to meet the minimum thickness requirement on exterior surfaces. Parts wider than 2 inches need both sides of the part to be coated for best coating thickness uniformity.

- Parts with recesses should be coated with the recesses toward the evaporators during coating of the first side of the parts for best coating adhesion, thickness, and uniformity.

- Hang 1- x 4-inch steel strips, used to determine the coating thickness on alloy parts that cannot be measured directly (examples: aluminum, copper, stainless steel, titanium, etc.), horizontally and even with the bottom of the production parts. Normally, the 1- x 4-inch strips are 10 inches above the top of the evaporators, as are the production parts. The steel strips should be used only once for thickness measurements. (However, they can be stripped and reused.) Clean steel strips, not coated, should be used whenever production parts are turned over for additional coating. Clean steel strips permit an accurate determination of the coating applied to each side of the production parts.

- A coating time of 24 to 28 minutes per side is required to obtain a minimum coating thickness of 0.001 inch in the center of a large part at a 10-inch evaporator-to-part spacing and for a wire-feed rate of 3.5 grams/minute (nominally 26.5 inches of 0.062-inch diameter aluminum wire) of aluminum into each evaporator. The 1- x 4-inch steel strip hung at 10 inches above the evaporators must have a coating thickness at least 1.6 times the minimum thickness requirement identified in Table 3 for the correct coating thickness in the center of a large part.

  Note: The above guideline for coating time was established by coating a flat, 17- x 17-inch steel panel on both sides and by replacing 1- x 4-inch steel strips when the part was turned over. (The thickness of the coating in the center of this panel is 0.001-inch minimum when the coating thickness on the steel strip is 0.0016-inch minimum. The 1- x 4-inch strip receives more coating than the large part due to coating wrap-around being more influential on coating thickness for the smaller part than the larger part.)

- For aluminum alloy parts, the total coating time must consist of several alternate coating and convective cooling cycles with gaseous nitrogen to prevent overheating of temperature-sensitive parts. Convective cooling should occur for a minimum of 5 minutes with the pressure in the coater at nominally 350 Torr at the end of 5 minutes of convective cooling. The gaseous nitrogen flow rate should be adjusted so that after nominally 2 minutes, the pressure in the coater has reached at least 270 to 300 Torr. (1 Torr is equivalent to a pressure of 1 mm of mercury (Hg). Therefore, atmospheric pressure at sea level is 760 mm Hg or 760 Torr.)

14. What is your experience in applying a dense, high-performance aluminum coating on aerospace components?

When parts are loaded and coated using the above guidelines, a dense, high-performance aluminum coating on aerospace parts is obtained. In addition to a pleasing appearance of the coating and satisfaction of coating thickness requirement, Boeing – St. Louis validates that a dense, high-performance coating has been properly applied. Validation is accomplished by verifying coating adhesion on 100 percent of the production parts and by performing monthly corrosion tests on panels coated with production parts. The validation process and results are further amplified as follows.

Rather than rely totally upon the standard bend-to-break and tape adhesion tests, Boeing – St. Louis performs a 100 percent non-destructive evaluation of coating adhesion on all production parts. This is accomplished by burnishing (peening) the applied IVD aluminum coating with No. 10 glass beads. During the burnishing process, shear stresses are imparted to the coating by the impinging glass beads. Any poorly adhering coating is easily lifted up and blown off. This test is more severe than the normal tape test often applied to production parts to verify coating adhesion. In addition, 100 percent of the part is inspected; whereas, only a limited surface area of a part would be tape tested. The glass-bead burnishing test can reveal areas poorly cleaned, improperly handled, load/fixture problems, or coater operational problems. Although a tough adhesion hurdle is imposed upon production, an adherent, high-performance coating is ensured.

Most parts are chromate conversion coated both for improved corrosion resistance performance and for assurance of satisfactory paint adhesion. Each month, two 4- x 6-inch steel panels for each of the three classes are coated with production parts in each IVD aluminum coater. The IVD aluminum-coated, glass-bead burnished, and chromate conversion coated panels are submitted for neutral salt fog tests as specified in MIL-DTL-83488. During 25 years of testing, over 2000 panels have been tested. During this time, only two panels have failed the MIL-DTL-83488 corrosion resistant requirement. Later, tests revealed that the panels did not have the required minimum coating thickness for the specific coating class on them. Likewise, laboratory corrosion tests to failure, red rust, of both 4- x 6-inch panels, 1- x 4-inch strips, and fasteners, Figure 3, demonstrates that the respective class of coating specified in MIL-DTL-83488 exceeds the minimum corrosion resistance requirements with a good margin of safety.

15. How does the ion vapor deposition process provide excellent adhesion and uniformity?

The secret to excellent adhesion of the IVD aluminum-coating process is dependent on the following factors:

- Parts are degreased and cleaned properly (important for adhesion).
- Parts are loaded in the correct configuration (important for uniformity).
- The coater is properly evacuated (important for adhesion and somewhat for uniformity).
- The parts are properly glow discharge cleaned (very important for adhesion).
- The coating is performed at the correct pressure (important for adhesion and uniformity).
- The IVD aluminum coating is applied properly (important for adhesion and uniformity).

Cleaning - Steel parts should be degreased and grit blasted with clean aluminum oxide grit. Fasteners and close-tolerance parts should be grit blasted with 220-mesh aluminum-oxide grit and limited to 40-psi grit-blasting pressure. Excessive grit-blasting pressure and time can change dimensional tolerances. Although aluminum parts may be grit blasted with 220-mesh grit and with pressures up to 60 psi, the preferred method is to chemically clean aluminum parts by degreasing, pickling to remove about 0.0001- to 0.0003-inch of aluminum and deoxidizing to remove any smut (include appropriate rinses between steps).

Loading - The correct load configuration has been discussed.

Pumpdown - The coater should be evacuated to less than 9.0×10^{-5} Torr before backfilling with argon. The more coating builds up on the shields in the coater, the lower the coater needs to be evacuated for proper adhesion. Experience at various coating sites has shown that shields need stripping of the aluminum coating after nominally 3 weeks of two shift operation or 6 weeks of one shift operation. A little extra time for pumping pays big dividends for adhesion.

Glow Discharge Cleaning - It is the main contributor to excellent IVD aluminum-coating adhesion. The parts are glow discharge cleaned by making them the cathode of a high-voltage system. Since the production parts are at a high negative potential, electrons are expelled from the parts. The electrons, on the way to the anode (the chamber at ground potential), collide with argon molecules ionizing them. The ionized argon, having a positive charge, is attracted to the negatively charged part. The ionized argon atoms are accelerated across the negative potential gradient and strike the part. The impinging ionized argon can be thought of as a gaseous blast of ions. These ions remove surface gases; the gas of importance being removed is water from molecules on the surface of the part. Also, some very minute amount of metal is removed. When the water molecules are dislodged from the surface, over time, they either are pumped away by the vacuum system or are frozen onto a very cold surface, a cryocoil, in most coaters. Glow discharge cleaning nominally occurs for 10 to 15 minutes. Also, glow discharge cleaning is performed during IVD aluminum coating. Glow discharge cleaning ensures a clean surface for the arrival of the first IVD aluminum atoms deposited on the production parts. A clean surface produces excellent coating adhesion. A properly applied coating has excellent adhesion; it will survive even an 80-psi glass-bead burnishing adhesion test. Another example is that if the coating is not stripped off chemically, the coating has to be eroded off steel parts by grit blasting with, typically, 120-mesh aluminum-oxide grit at 80 psi.

Coating - Although it is possible to IVD aluminum coat anywhere in the pressure range of nominally 5 to 20 x 10^{-3} Torr (5 to 20 microns or millitorr), experience has shown that the minimum coating time and best coating thickness distribution is when the coating is preformed at nominally 1 x 10^{-2} Torr (10 microns or millitorr).

Since the surface area for IVD aluminum coating is large in the rack-type coaters, typically 50 square feet, it is recommended to apply the coating onto production parts in layers. Coating layers are produced by the movement of the evaporation rack from the front of the coater to the rear and return (total travel distance of 20 feet in standard rack coaters). Each coating cycle gives two layers on the part. The desired coating thickness is obtained by making typically one to four coating cycles in the coater. Making coating cycles reduces heating of the parts and more importantly reduces moisture contamination of the coating environment by reducing the heating, and associated degassing, of the chamber shields and parts rack.

Special care needs to be exercised when aluminum parts are IVD aluminum coated. Unlike most steel parts, aluminum parts are temperature sensitive and can be overheated by improper coating procedures. Therefore, when aluminum parts are coated, the boat-rack speed generally needs to be increased, and the aluminum parts must be convectively cooled with gaseous nitrogen following glow discharge cleaning and after every coating cycle in the coater (Reference guidelines discussed for Question 13). For most aluminum alloy parts, weighing over 0.4 pounds, a boat-rack speed of 40 inches/minute or more, a wire-feed rate of 3.5 grams/minute of aluminum fed into the evaporator, and cooling of the parts after glow discharge cleaning and after every coating cycle will minimize heating of temperature-sensitive parts. However, it is the responsibility of the coating house to verify they have an acceptable coating procedure before coating production aluminum alloy parts. Safe procedures can be established by coating aluminum sheet stock or plate of the same size as the production part, a thickness equivalent to the minimum cross sectional thickness of any section of the production part, and the same aluminum alloy and heat treatment as the production part (preferred method). Alternately, coat only “one” of the first article (production) parts received to verify the coating procedure. Measure the hardness and electrical conductivity of the aluminum alloy part before and after IVD aluminum coating. The hardness and electrical conductivity must not drop below minimum acceptable values for that aluminum alloy and heat treatment. Also, if the hardness drops by more than two point Rockwell B, the coating procedure must be changed to reduce heating of the part. In no case is the drop of two points in Rockwell B the acceptance criteria for the aluminum alloy production part. Acceptance or rejection of aluminum alloy production parts is based on minimum acceptable hardness and electrical conductivity requirements for that particular aluminum alloy as stated in the appropriate document from the company desiring IVD aluminum coating of aluminum alloy parts. Several alternate coating and convective cooling steps will be needed to achieve the desired coating thickness on the production part.

Although aluminum alloy parts are temperature sensitive and can be overheated, safe IVD aluminum-coating procedures can be developed. Boeing – St. Louis has safely IVD aluminum coated over 250,000 aluminum parts. Again, it is the responsibility of the IVD aluminum-coating house to develop an acceptable coating procedure that does not affect material properties before IVD aluminum-coating production parts.

Conclusion:

Although the details shared may at first seem involved, 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.

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