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Hard anodizing of aluminum alloys and its effect on Bal Seal® performance

Technical Report

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Contents

1.0 Summary

This report describes various coatings for aluminum, including its processes, engineering properties, advantages, disadvantages, and effects on Bal Seal® performance in dynamic applications.

Aluminum alloys are used in applications that require light weight, corrosion resistance, and ease of fabrication. Applications include controls, actuators, and valves used in aircraft, marine, transportation, food processing, and other environments. Compared with other structural metals, aluminum and aluminum alloys have very low hardness and low resistance to wear, abrasion, and corrosion. However, a surface coating can provide a hard or corrosion-resistant surface.

Hard anodizing of aluminum per MIL-A-8625, Type III, is effective at improving hardness and wear resistance. Hard anodizing creates a hard surface obtained by the electrochemical conversion of aluminum to aluminum oxide. MIL-A-8625, Types I and II, are for the improvement of corrosion resistance or the application of a porous base for dyes, sealants, or paints.

The focus of this report is MIL-A-8625, Type III, on hard anodizing and its engineering properties when used in contact with Bal Seal® spring-energized seals in dynamic applications. This report gives a brief description of MIL-A-8625, Types I and II, for informational purposes only. It also describes an Alodine® coating that leaves a conductive, corrosion-inhibiting finish.

2.0 Description of Three Types of Aluminum Anodizing

The basic reaction in all anodizing processes is the conversion of the aluminum surface to aluminum oxide, and the part is the anode in an electrolytic cell. The three anodizing processes are as follows:

Type I: Chromic, in which the active agent is chromic acid

Type II: Sulfuric, in which the active agent is sulfuric acid

Type III: Hard anodizing, which uses sulfuric acid only or with additives

The principal military specification, covering the three anodizing processes, is MIL-A-8625 (anodic coatings for aluminum and aluminum alloys). The main difference in the three types of processes is the thickness of the coating produced.

Type I produces a thin, dense, low-porosity coating about 0.00005 in. (0.00127 mm) to enhance corrosion resistance.

Type II coatings may range from 0.00010 to 0.00100 in. (0.00254 to 0.0254 mm). This acts as a better base for dyes, paints, and pigments due to greater thickness and higher porosity than Type I coatings. Both Types I and II are also used for decorative purposes, such as architectural structures, household items, and automobile trim.

The coating thickness produced by Type III processes ranges from 0.0005 to 0.0045 in. (0.0127 to 0.1143 mm), with the typical thickness being 0.0020 in. (0.0508 mm). The added thickness and weight of Type III coatings provide a wear and abrasion-resistant surface. Table 1 shows a comparison of properties produced by the three types of anodizing.

Table 1: Comparison of three main types of anodizing per MIL-A-8625

Properties	Type I Chromic Acid	Type II Sulfuric Acid	Type III Hard Anodize
Coating Thickness	0.00005–0.00030 in. 0.001–0.007 mm	0.0001–0.0010 in. 0.002–0.025 mm	0.0005–0.0045 in. 0.012–0.114 mm
Effect on Surface Finish	minimal roughening	minimal to slight roughening increase	slight to moderate roughening
Hardness Increase	minimal	moderate	“file hard” (60 to 65 HRC)
Wear Resistance	poor	minimal	excellent
Coating Porosity	very low	medium to high porosity	high porosity
Corrosion Resistance	good	good (excellent when sealed)	good
Color, as Coated (Class 1, non-dyed)	colorless to purplish gray	colorless to yellowish gray	light gray to brown or black
Paint Base or Dye Base Properties	poor	good	good
Application or Special Features	Produces a thin, dense, non-porous coating for corrosion resistance.	A thicker, more porous coating makes a better base for paint or dye.	The purpose is to increase wear resistance; it is not suitable for high cycle loads.

3.0 Description of Alodine® Coating

An Alodine® coating provides a corrosion-resistant film where low resistance contacts are required. The reaction of chemicals on the surface of aluminum or aluminum alloy forms the chemical conversion coating known as Alodine®. Military specification MIL-DTL-5541 covers chemical conversion processes for military weapons systems. MIL-DTL-5541, Class 3 is specifically intended for electrical and electronic applications.

An Alodine® or chromate coating should be used in an application that requires a conductive finish, such as along the seam of an electromagnetic interference (EMI) shield. An anodized surface will not work in this application, because it leaves an insulating ceramic surface.

An Alodine® coating results from the non-electrolytic treatment of aluminum or aluminum alloy parts with an aqueous solution, producing a protective coating on the metal surface. The abrasion resistance of the Alodine® coating is very low.

4.0 Aluminum Anodizing Process

The basic process of producing anodic coatings on aluminum consists of making the treated part as the anode in a bath that contains an electrolyte such as sulfuric acid. The current density that passes through the part is regulated to overcome the passivity of the metal and to cause oxidation of the metal surface. The surface metal is converted to ceramic (aluminum oxide). As the oxide layer is formed, it penetrates the surface and expands outward because of the increased volume of the surface material as it takes on oxygen.

5.0 Purpose of Hard Anodizing

Hard anodizing produces a hard wear and an abrasion-resistant coating of aluminum oxide on the surface of aluminum alloys. The purpose of hard anodizing of aluminum is to increase hardness and wear resistance of the part.

6.0 Hard Anodizing to Improve Bal Seal® Performance in Dynamic Service

Bal Seal® performance is substantially improved when in contact with harder mating surfaces. An anodized surface results in lower friction and less wear to the seal material and to the shaft or bore surface.

6.1 Hardness

As the hardness of the mating surface increases, the adhesive force between the metal and the seal decreases, resulting in lower friction and less wear.

6.2 Surface Finish

Improving the surface finish of the hard anodized surface reduces abrasion of the Bal Seal®. Hard coatings can produce excellent finishes by honing.

6.3 Dry Film Lubrication

A dry film lubricant reduces friction, adhesion, and seal wear. Dry lubricants are introduced into the hard anodized aluminum in two ways: (1) by bonding or (2) by impregnation or infusion.

6.3.1. Bonding

Molybdenum sulfide or graphite is bonded onto the aluminum surfaces.

6.3.2. Impregnation or Infusion

Polytetrafluoroethylene (PTFE) is impregnated into the aluminum alloy during the hard anodizing process.

7.0 Engineering Properties of Hard Anodized Aluminum Coatings

In engineering, the primary purpose of a hard anodized coating is to improve the hardness and wear resistance. However, one should consider all coating properties for their effects on a particular application.

7.1. Nature of Film

The film coating produced on the surface of hard-anodized aluminum parts is aluminum oxide produced by electrochemical oxidation at the metal surface. The film is integrally bonded to the base metal and has an amorphous (non-crystalline) structure.

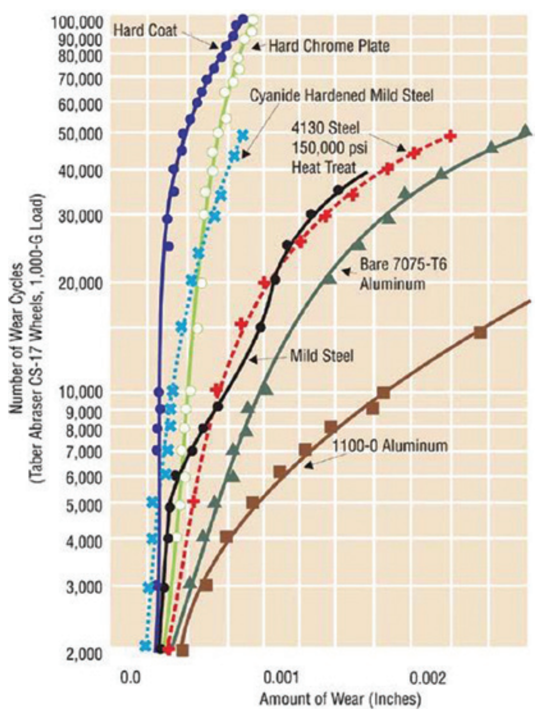
7.2. Hardness

Indentation tests cannot determine accurate hardness values because of the soft aluminum substrate. Scratch tests show the surface hardness to be between 7 and 9 on the Mohs scale, equivalent to 60–65 Rockwell C, which is comparable to that of hard chrome-plated steel or cyanide-hardened mild steel.

7.3. Wear Resistance

Figure 1 shows results of wear testing on various materials compared with hard anodized aluminum.

Figure 1: Wear Resistance of Hard Anodized Aluminum vs. Other Metals



Numbers of wear cycle on a Taber® Abrader using CS-17 wheels with 1,000 gram load

7.4 Adherence of Coating

The film adheres strongly to most aluminum alloys, especially those containing magnesium. The poorest adhesion is on alloys containing zinc. For best coating adherence, use alloy 6061-T6.

7.5 Coefficient of Friction

Hard coatings have a lower coefficient of friction than the metal substrate. Friction can be further reduced by the application of a dry film lubricant bonded to the surface. Hard anodized surfaces running in contact with PTFE-based Bal Seal® materials will eventually become impregnated with PTFE, reducing friction between the anodized surface and the seal.

7.6 Corrosion Resistance

The hard coating is inert and resists attack from atmosphere, humidity, and salt spray environments. Dry film lubricants enhance the corrosion resistance of the coating by filling the pores and forming a protective film on the surface. Sealants are not recommended, because the sealing process reduces hardness and wear resistance.

7.7 Coating Porosity

The electrolytic solution used in hard coating has a solvent effect on the coating in which the coating's porosity increases as the processing time increases. Certain alloying elements in the substrate (such as copper) increase the coating porosity.

7.8 Coating Ductility

Hard anodized coatings are brittle with low ductility and fatigue strength. A hard anodized surface cracks under impact loads or high flexural stresses.

7.9 Crazing (Cracking) of Coating

The thick oxide coating has a different coefficient of thermal expansion than the aluminum substrate. As a result, the coating develops fine hairline cracks after the parts are removed from the cold processing bath and allowed to warm to ambient temperature. This phenomenon, known as crazing, appears to have no detrimental effect on other coating properties.

7.10 Effect of Coating Thickness on Surface Properties

As the thickness increases beyond 0.002 in. (0.0508 mm), porosity increases while hardness and wear resistance decrease. The film closest to the metal substrate has the highest density and hardness and the lowest porosity. Applying a coating thickness of 0.002 in. (0.0508 mm) is optimal to obtain high hardness and wear resistance. Thicker coatings are not practical due to the decreased surface properties. A procedure for obtaining excellent hardness and surface structure properties is to apply 0.002 in. (0.0508 mm) thick hard coating, then remove 0.001 in. (0.0254 mm) to expose a harder, denser section of coating.

8.0 Effects of Hard Anodizing on Dimensions and Surface Finish

When designing parts to be hard anodized and preparing parts before coating, the following important points should be considered:

8.1. Dimensional Changes Due to Penetration and Buildup of Coating

Hard anodized coatings have different dimensions than other coatings. With electrodeposited coatings, the coating is only built on top of the item's surface. With anodized coatings, half of the coating thickness penetrates the substrate surface, while the other half is a growth on top of the item. Therefore, a 0.500-in. (12.7 mm) outside diameter item with a 0.002-in. (0.0508 mm) per side coating will measure a 0.504-in. (12.8016 mm) outside diameter for an electrodeposited coating, and only a 0.502-in. (12.7508 mm) outside diameter for an anodized coating.

8.2. Surface Finish before and after Coating

Because of the method of coating growth method, the quality of the hard anodized coating improves with the quality of the surface finish before coating. The surface finish roughens slightly to moderately during coating, depending on the prior surface finish and the coating thickness. For example, a finish of 2 RMS prior to coating will roughen to approximately 4 RMS after a coating thickness of 0.002 in. (0.0508 mm) is applied. Approximately 0.0005 in. (0.0127 mm) of coating thickness should be allowed for machining after coating to obtain the desired finish, normally by honing.

8.3. Coating Sharp Corners, Edges, and Angles

Anodized coatings grow perpendicular to the surface from the treated surface. Therefore, voids occur on all sharp corners and edges. Thicker coatings accentuate these defects, and the coating has a tendency to crumble at these points. All edges and corners should be broken with a 0.005–0.050 in. (0.127–1.27 mm) radius to obtain a uniform coating.

8.4. Coating of Small Radius Parts

When coating a straight piece of aluminum, cracks form in the coating due to the expansion of the substrate under normal processing conditions. When coating small radius parts, the number of cracks increases due to the coating's radial growth.

8.5. Coating Inside Small or Deep Bores

Hard coating solutions are ideal for coating surfaces in hard-to-reach places such as small bores or deep blind holes. Because the coating thickness varies from the open end of a bore to the closed end of a blind hole, using auxiliary cathodes and agitating the bath inside deep recesses can help produce a more uniform coating.

9.0 Selection of Aluminum Alloy Substrate to Be Hard Anodized

All aluminum alloys can be hard anodized by one process or another. Results vary with certain alloys, depending on the composition and temper. However, for Bal Seal® applications, specifying one of the three wrought aluminum alloys shown in Table 2 is recommended.

Table 2: Mechanical properties of three heat-treatable wrought aluminum alloys

Properties		SAE-6061-T6 AMS-QQ-A-225/8 AMS4150	SAE-7075-T6 AMS-QQ-A-225/9 AMS4122, AMS4123	SAE-2024-T4 AMS-QQ-A-225/6 AMS4119, AMS4120
Tensile Strength: **(psi)**	**at 75 °F** **at 300 °F**	45,000 30,000	83,000 25,000	68,000 45,000
Yield Strength: **(psi)**	**at 75 °F** **at 300 °F**	21,000 21,000	73,000 21,000	47,000 36,000
% Elongation		12%	11%	20%
Brinell Hardness with 500 kg load, 10 mm ball		95	150	120
Density	**grams/cc** **lb/cu³**	2.70 0.098	2.80 0.101	2.81 0.102
Chemical Composition Typical Analysis	**Si** **Fe** **Cu** **Mn**	0.4–0.8 0.7 0.15–0.40 0.15	0.5 0.7 1.2–2.0 0.30	0.5 0.5 3.8–4.9 0.30–0.90
	Mg **Cr** **Zn** **Ti**	0.8–1.2 0.15–0.35 0.25 0.15	2.1–2.9 0.18–0.40 5.1–6.1 0.20	1.2–1.8 0.10 0.25 –
Others **Aluminum**	**max** **min**	0.15 95.85	0.15 86.75	0.15 90.90
Machinablility		fair	good	excellent
Corrosion Resistance		excellent	fair	poor to fair
Anodic Coating Quality		best density and wear resistance	good, but less wear resistance	poor, due to high Cu content
Special Features and Applications		• Lowest cost • Most versatile alloy • Very good corrosion resistance, but fair strength • General-purpose application	• One of the highest strength alloys • Used for highly stressed parts • Anodic coatings similar to 6061 • Applications requiring higher strength than 6061	• Good strength with very high fatigue resistance but lowered corrosion resistance • Used in aircraft structural components

9.1. Mechanical Properties of Various Alloys

Select the alloy for a specific application based on strength and other required properties and the anodizing characteristics of the alloys. Table 2 shows mechanical properties of the three wrought aluminum alloys.

9.2 Anodizing Characteristics of Wrought Aluminum Alloys

Alloys low in copper or silicon (i.e., 6061-T6) yield the best results with anodizing. Alloys (i.e., 7075-T6) used when there is a required strength higher than 6061-T6 anodize almost as well. The presence of zinc in alloy 7075 lowers the adherence strength of the coating. Due to its high copper content, alloy 2024-T6 produces a less wear resistant coating with lower corrosion resistance, lower hardness, and higher porosity. As the purity of the alloy approaches pure aluminum, the coating's density and hardness increase while the roughening of the surface finish decreases.

9.3 Anodizing of Die Cast or Sand Cast Alloys

Die cast or sand cast alloys are generally not recommended. Their higher porosity and non-uniform surface composition results in coatings with excessive porosity. For best results, use heat-treatable wrought alloys with a T4 to T6 temper.

10.0 Quality Control of the Hard Anodizing Process

To achieve good results with hard anodizing, a high level of quality control must be maintained throughout the stages of surface preparation, processing, and finishing. Some areas to consider are listed below.

10.1 Surface Machining and Removal of Contaminants

Care should be taken to produce a smooth, clean surface before anodizing. Surfaces that are dirty, smeared, galled by a dull cutting tool, contaminated with lapping compounds, sandblasted, or not cleanly cut produce non-uniform coatings.

10.2 Quality Control of the Anodizing Bath

Bath conditions, such as processing time, temperature, pH level, agitation, and current density must be strictly controlled to obtain good results. Too much processing time increases coating porosity due to the solvent action the bath has on the coating. Excessively warm baths or lack of agitation may cause excessive coating porosity or other defects. A cold bath helps to increase electrical resistance, which produces densest possible coating.

Variations in the proper current density may cause poor results. If current density is too low, it cannot overcome coating resistivity and aluminum surface passivity. If current density is too high, the coating can be produced too rapidly, resulting in a higher porosity and lower hardness. It is important to select a vendor with a high level of quality control to produce the desired results.

11.0 Finishing Requirements after Anodizing

After hard coating, the following steps are required to finish the parts.

11.1 Honing to Proper Dimensions and Surface Finish

Because of coating buildup and roughening of surface finish, coated parts must be honed back to proper dimensions and surface finish. Coated parts should be 0.0005–0.0010 in. (0.0127–0.0254 mm) oversized to allow enough thickness to obtain the proper finish.

11.2 Dyeing of Parts for Color Coding

Dyeing consists of impregnating the pores of the anodic coating (before sealing) with an organic coloring material. This is necessary for seal applications to mark parts for color code identification.

11.3 Sealing of Coating and Effect on Corrosion and Wear Resistance

Sealing improves corrosion resistance, but decreases wear resistance. Use dry film lubricants to fill pores and improve corrosion resistance without lowering coating hardness. Do not seal coatings by boiling in deionized water or a hot aqueous solution of nickel acetate. Doing so lowers the hardness of the coating.

11.4 Stripping of Coating/Reanodizing

Hard-coated parts cannot be reanodized without first removing the coating to expose the metal substrate. Removing the coating with a fast-acting solvent rapidly removes the coating, but also attacks the substrate. A slow-strip solution dissolves only the coating.

12.0 References

1. *Metals Handbook*, American Society for Metals
2. Military Specification, Anodic Coatings for Aluminum and Aluminum Alloys, MIL-A-8625
3. Military Specification, Coatings, Anodic, Conventional for Aluminum and Aluminum Alloys, MIL-A-8625
4. *Mechanical Engineers Handbook*, Lionel S. Marks
5. WADC Technical Report 53-151, Study of Hard Coating for Aluminum Alloys, F. G. Gillig, Cornell Aeronautical Laboratory, Inc., Wright Air Development Center
6. *Military Handbook*, MIL-HDBK-132(ORD), Department of the Army Technical Bulletin TB-700-801D-1, Protective Finishes