Frank Altmayer, MSF, AESF Fellow
AESF Technical Director
Scientific Control Laboratories, Inc.
3158 Kolin Ave.
Chicago, IL 60623-4889
E-mail: mfconsultant@msn.com

Magnesium

Dear Advice & Counsel,
I'll be the first to admit that I know absolutely nothing about magnesium. Unfortunately, I'm now in charge of the production of a part that is cast magnesium, and when we salt-spray these parts, they quickly corrode. Why is our magnesium casting so poor in corrosion resistance?
Signed, Cal Craig

Dear Cal Craig,
I have looked at the magnesium parts you submitted and find them to be in a "normal condition" after salt spray. Bare magnesium does not hold up well in salt spray, because the metal is highly active (more than aluminum) and is easily converted to corrosion products. As per our discussion over the phone, the following is some basic information on magnesium.

Magnesium

While some magnesium is found in ingot form on the ocean floor, most magnesium is produced by extraction of magnesium chloride from sea water. The magnesium chloride is reduced to magnesium by electrolysis. Magnesium is the world's lightest structural metal. It is typically alloyed with aluminum, manganese, zinc, thorium, and/or zirconium for increased strength.

- Magnesium alloys can be anodized, conversion coated, painted, electroplated, or mechanically finished.
- Magnesium can be cast by sand, die, permanent mold, and precision investment methods. Most commonly, magnesium is extruded or rolled into sheet, plate and strip. It can be formed by drawing, bending, or spinning, and is forgeable by press and hammer equipment.
- Magnesium alloys and their corrosion products present no (or low) toxicity hazard.
- Magnesium is considered the easiest of all metals to machine, but it can catch fire if not carefully handled. Magnesium dust and small particles can catch fire and/or explode because the metal rapidly combines with oxygen when given an opportunity. Therefore, machining and grinding must be carefully conducted.

Other significant characteristics of magnesium include good stability in atmospheric exposure and resistance to attack by many chemicals, including alkalis, chromic and hydrofluoric acids, and such organic chemicals as hydrocarbons, most alcohols (except methanol), phenols, amines, esters and most oils. Magnesium is rapidly attacked by methanol and cannot be used in applications where magnesium alloys are exposed to solutions containing even small amounts of methanol.

Magnesium (and alloys) are nonmagnetic, have relatively high thermal/electrical conductivity, and good absorption characteristics for vibration and shock.

Magnesium is a very active metal that corrodes rapidly in the presence of many corrosives, including saltwater and most galvanic cells. Bare magnesium that is to be put into service in a corrosive environment requires a protective coating. Protective coatings that are commonly applied include the following.

1. Chromate Conversion Coating

Numerous chromate conversion treatments are in the literature. ASTM D1732 covers this process, as does MIL-M-3171. Chromate conversion coatings are typically used as either undercoats to promote paint adhesion, or as stand-alone films for corrosion protection in storage and in mildly corrosive environments.

2. Anodizing

The mechanism of the anodization of magnesium is significantly different from that for aluminum, in that it occurs in alkaline solutions and by way of a sparking process. At potentials over a given voltage (usually near 50V DC) sparks form on the surface of the magnesium anode. These sparks move over the surface and, where they travel, a film is produced. The film results from a chemical reaction between the magnesium alloy, oxygen, the electrolytes and other components of the anodizing bath.

Because of the temperatures reached in a spark, there is a significant number of excited species available to contribute to the chemical and electrochemical reactions. The phases involved include liquids, dissolved species, gases from electrolysis and boiling, and the solid electrode. Physical processes, such as fusion, can also occur at this temperature. The process is, therefore, very complex, and the variables that contribute to the film formation are somewhat difficult to isolate.

Most anodizing treatments provide a hard, corrosion-resistant coating on the magnesium. The one exception is "galvanic" anodizing, referred to as Chemical Treatment No. 9.* The other anodizing treatments include Chemical Treatment No. 17,* HAE, and Cr-22. Magnesium anodizing is covered under MIL-M-45202.

3. Electroplating

Successfully plating magnesium alloys is an even greater challenge than aluminum. Magnesium alloying constituents can form localized cathodic/anodic sites that may have low hydrogen over-voltage potential, resulting in hydrogen evolution during processing for plating. Magnesium parts often exhibit surface contamination from manufacturing processes, such as polishing and buffing. Differences in surface composition and potential can result in skip plating, if pre-plate procedures are inadequate.

Processing steps for plating magnesium parts are similar to those for processing aluminum, but the solutions used are sig-

* *Dow Chemical Company*

nificantly different. Magnesium has a thin skin of oxides containing graphite and other localized inclusions. The acid pickle (30-60 sec at room temperature) and activation step (30-120 sec at room temperature) must remove this skin for successful plating to occur.

Following cleaning, parts may be pickled in either the chromic acid or phosphoric acid pickles. An activation step, consisting of 20 vol% phosphoric acid and 100 g/L of sodium acid fluoride ($NaHF_2$), follows the acid pickle and precedes the immersion zinc. The immersion zinc is operated at 155-160°F. The pyrophosphate assists the formation of an adherent zinc deposit on magnesium by reacting with any surface oxides, dissolving and complexing them. Fluoride is present to control the deposition rate. Zincate immersion time is typically two min, but may take up to 15 min. No benefit from "double zincating" magnesium alloys has been reported.

A stainless steel tank and heating coil are typically used. Close control of the narrow pH window is very important.

The initial cyanide copper strike is operated at low current density (5-10A/ft^2). No gassing should occur, or blistering may result. After two min, the current may be doubled. Periodic reverse (30 sec forward, followed by 15 sec forward, 3 sec reverse), has been proven to provide superior results.

Magnesium Uses

Magnesium is used in aircraft parts, textile machinery parts, printing machinery parts, hand trucks, grain shovels, gravity conveyors, foundry equipment and other products in the materials-handling field that require low weight-to-strength ratio. The portable tool industry utilizes magnesium castings for chain saws, drills, impact hammers, grease guns and many other manually handled articles. Household goods, office equipment, cameras, golf clubs, luggage, and transportation vehicles are other examples of common applications.

Magnesium Nomenclature

The standard nomenclature for magnesium alloys was adopted in 1948 and is explained as follows:

- First two characters: Identify the main alloying elements. Example: AZ= Aluminum & Zinc. Other letters: B=Bismuth, C=Copper, D=Cadmium, E=Rare earth, F=Iron, H=Thorium, K=Zirconium, L-Beryllium, M= Manganese, N=Nickel, P=Lead, Q=Silver, R-Chromium, S=Silicon, T=Tin.
- Next two characters: Indicate the percent of the main alloying elements. Example, AZ31= 3% Al, 1% Zr.
- Next character: Separates different alloys containing the same percent primary elements. Example: AZ91A vs. AZ91B differ in copper content, but have the same amounts of primary alloying elements.
- Dash and next two characters: Indicates surface condition, similar to aluminum nomenclature. Example: AZ31A-T6 = Solution heat treated and artificially aged.

I hope the above is helpful. If you need more information and/or help, don't hesitate to contact me. *P&SF*

***Note to our readers**: Our past articles on lead reporting under the TRI listed the wrong factor for conversion of lead to lead hydroxide. One pound of lead is converted to 1.12 pounds of lead hydroxide in an alkaline cleaner or in waste treatment. Thanks to Dr. Paul Chalmer of the NMFRC for pointing out this error.*