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MAGNESIUM IN THE AEROSPACE INDUSTRY

1.0 Introduction

Magnesium and its alloys, hereinafter magnesium alloys, are lighter than aluminum and, as such, they should be extremely attractive in aerospace applications. This, however, is not the case. While magnesium alloys find extensive use in the automotive industry, they are infrequently used in the aerospace industry. In general, the level of usage in the aerospace industry, especially in airframe applications, is well below potential levels, due to real and perceived problems and the attendant construction mandates against such use. [(1)] Inasmuch as the FAA is involved, however, the undersigned is not aware of any document that specifically prohibits the use of magnesium alloys in the aviation industry. The purpose of this document is to point out some precautions for the fabrication and use of magnesium alloys.

2.0 Precautions

The problems in using magnesium alloys stem from their low melting points (around 1200 F) and their reactivity (inadequate corrosion resistance). Below is a brief account of the problems that may be encountered during fabrication and during usage. Users, however, are urged to consult magnesium alloy producers for advice regarding specific situations.

2.1 During Fabrication

The most highly publicized problem with magnesium alloys, the fire hazard / risk during machining and grinding, stems from the relatively low melting points of these alloys. Fires would result only if the alloys are heated to temperatures around their melting points. In roughing cuts, the chips are generally thick and are not likely to get hot enough to ignite. However, the thin chips, produced in the finishing cuts are more likely to heat up and ignite. Similarly, the dust produced in grinding can ignite, even explode, if heated to melting temperatures.

The fire hazard / risk issue is real, but it does not represent an insurmountable problem. It is advisable to follow NFPA 480. [(2)] The hazard can be eliminated by utilizing common sense and by observing some cardinal rules. The rules include, but are not limited to: avoiding fine cuts, dull tools, high speeds, idling in contact with the workpiece and sparks; using proper tool design to avoid heat build up; avoiding the accumulation of chips and dust on machines and cloths, and; using coolants. Mineral oils are the typical coolants used for magnesium alloys. Water base coolants are not used since they reduce the salvage value of the scrap and increase the risk of fire. The literature gives no explanation as to why it is so. It could be that said adverse effects are the result of the reaction: $Mg + H_2O \rightarrow MgO + H_2$ (see Appendix); oxide formation would reduce the salvage value and the hydrogen would increase the fire risk. Another possibility is the hydroxide reaction; specifically, $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$. According to ASM Handbook, vol. 2, 1961, p. 1081, magnesium hydroxide [$Mg(OH)_2$] can form at ambient temperature, in water / moisture containing salts, especially those salts containing chlorine or sulfur atoms. The salts destroy the passive layer, leading to an acceleration of general corrosion and pitting rates. The cited reference further indicates that the hydroxides tend to react with the environment and transform to more stable compounds, such as carbonates (hydrated or basic) or sulfates of magnesium. Still, the conversion of magnesium to compounds would lower the salvage value of the scrap and the generated hydrogen would increase the fire risk.

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[1] *For example the use of magnesium and its alloys is prohibited in many military aircraft, such as the F-18.*
[2] *NFPA: National Fire Protection Association.*

A fire hazard / risk can also exist during heat treatment, if the solution heat treatment temperatures of certain alloys are exceeded. Qualified heat treaters should, therefore, be sought and the heat treat ovens should be religiously surveyed. Normally, magnesium alloys are quenched in forced or still air after solution treatment. Occasionally, however, a water quench is used to develop desired properties in certain alloys, especially in thicker gage products; glycol or oil quenches can develop similar properties. There appears to be no prohibitions on the use of water for quenching.

Welding can also present a fire risk if the hot / molten metal comes in contact with air. Shielding by inert gas or flux is, therefore, required. The most widely used fusion welding methods are GTAW (gas tungsten arc welding) and GMAW (gas metal arc welding). In these methods, the inert gases of choice are argon, helium or mixtures thereof. Electron beam welding, performed in vacuum, is another fusion welding method that has been used in recent years. The use of industry's veteran fusion method, oxyfuel [(3)] gas welding, for magnesium alloys is not advisable, unless special or proprietary gases, specifically intended for the purpose, are used. Solid state welding methods may be used for magnesium alloys. One such method, friction stir welding, has gained acceptance in recent years.

2.2 During Usage

2.2.1 Fire: Service temperatures should be well below alloy melting points; otherwise the fire hazard of 2.1 above might materialize. The undersigned is aware of one accident where a magnesium alloy component is suspected of having started the engine fire that lead to the fatal crash of the DC-3 aircraft of Rick Nelson, the famous pop star, on 31 December 1985. This particular aircraft was built during the Second World War, when aluminum shortages forced the use of magnesium alloys as replacements in some applications.

2.2.2 Reactivity: The problem of reactivity is twofold. First, magnesium alloys can react with oxygen to form oxides, and with water / moisture, even at ambient temperatures, leading to an increased risk of fire (see 2.1). Second, magnesium alloys are at the bottom (i.e., are the least noble) of the galvanic series, Table 1. As such, these alloys will form active galvanic couples, acting as corroding anodes, with all other metallic components in their proximity. To avoid all reactivity problems, it is advisable to use protective finishes, such as anodic coatings, and / or paint schemes (primers and paints). It needs to be acknowledged that chemically applied coatings (e.g., chromate conversion coatings) only offer limited term protection, and are water-soluble. In view of the risks involved, these coatings should be used only in conjunction with paint schemes. It is also crucial that designs be provided with adequate drainage, to prevent the accumulation of corrosive substances, such as water / moisture.

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APPENDIX
THERMODYNAMICS

According to Figure 7.7 of Swalin (Thermodynamics of Solids, John Wiley, 1962), the following reactions have the stated free energy (ΔG^O) values at room temperature:

$2Mg + O_2 \rightarrow 2MgO$ $\Delta G^O = -275$ kCal Reaction 1

$2H_2 + O_2 \rightarrow 2H_2O$ $\Delta G^O = -110$ kCal Reaction 2

The reverse of reaction 2 is,

$2H_2O \rightarrow 2H_2 + O_2$ $\Delta G^O = 110$ kCal Reaction 3

Adding reactions 1 and 3,

$Mg + H_2O \rightarrow MgO + H_2$ $\Delta G^O = -165$ kCal Reaction 4

Having a negative free energy value, reaction 4 can proceed spontaneously (i.e., without the addition of external energy) at room temperature

[3] *Typically, an oxyacetylene flame is used.*

GROUP NO.	METALLURGICAL CATEGORY	E.M.F. (VOLT)	PERMISSIBLE COUPLES[1]
1	GOLD, SOLID AND PLATED; GOLD-PLATINUM ALLOYS; WROUGHT PLATINUM	+0.15	
2	RHODIUM, GRAPHITE	+0.05	
3	SILVER, SOLID OR PLATED; HIGH SILVER ALLOYS	0	
4	NICKEL, SOLID OR PLATED; MONEL METAL, HIGH NICKEL-COPPER ALLOYS, TITANIUM	-0.15	
5	COPPER, SOLID OR PLATED; LOW BRASSES OR BRONZES: SILVER SOLDER; GERMAN SILVER; HIGH COPPER-NICKEL ALLOYS: NICKEL-CHROMIUM ALLOYS; AUSTENITIC STAINLESS STEELS	-0.20	
6	COMMERCIAL YELLOW BRASSES AND BRONZES	-0.25	
7	HIGH BRASSES AND BRONZES; NAVAL BRASS; MUNTZ METAL	-0.30	
8	18% CHROMIUM TYPE CORROSION-RESISTANT STEELS	-0.35	
9	CHROMIUM, PLATED: TIN, PLATED; 12% CHROMIUM TYPE CORROSION-RESISTANT STEELS	-0.45	
10	TIN-PLATE: TERNEPLATE; TIN-LEAD SOLDERS	-0.50	
11	LEAD, SOLID OR PLATED; HIGH LEAD ALLOYS	-0.55	
12	ALUMINUM WROUGHT ALLOYS OF THE DURALUMIN TYPE	-0.60	
13	IRON, WROUGHT, GRAY, OR MALLEABLE; PLAIN CARBON AND LOW ALLOY STEELS, ARMCO IRON	-0.70	
14	ALUMINUM, WROUGHT ALLOYS OTHER THAN DURALUMIN TYPE: ALUMINUM, CAST ALLOYS OF THE SILICON TYPE	-0.75	
15	ALUMINUM, CAST ALLOYS OTHER THAN SILICON TYPE; CADMIUM, PLATED AND CHROMATED	-0.80	
16	HOT-DIP-ZINC PLATE; GALVANIZED STEEL	-1.05	
17	ZINC, WROUGHT; ZINC-BASE DIE-CASTING ALLOYS: ZINC, PLATED	-1.10	
18	MAGNESIUM AND MAGNESIUM-BASE ALLOYS CAST OR WROUGHT	-1.60	

[1] MEMBERS OF GROUPS CONNECTED BY LINES ARE CONSIDERED AS PERMISSIBLE COUPLES, HOWEVER, THIS SHOULD NOT BE CONSTRUED AS BEING DEVOID OF GALVANIC ACTION. PERMISSIBLE COUPLES REPRESENT A LOW GALVANIC EFFECT. CONSULT M & P ENGINEER.

○ INDICATES THE MOST CATHODIC MEMBER OF THE SERIES. ● AN ANODIC MEMBER, AND THE ARROWS THE ANODIC DIRECTION.

Table 1: Electro-Motive Force (EMF) Series in moisture. At the top are the most noble (cathodic) members. The least noble members (the corroding anodes) are at the bottom. Magnesium and its alloys are at the bottom (#18). An EMF difference of 0.20 volt or more would activate galvanic action.