A BRIEF REVIEW ON MG ALLOYS THEIR PROPERTIES AND APPLICATION

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ABSTRACT

Magnesium is the lightest of all light metal alloys and therefore is an excellent choice for engineering applications when weight is a critical design element. It is strong, has good heat dissipation, good damping and is readily available. The use of pure magnesium is rare due to its volatility at high temperatures and it is extremely corrosive in wet environments. Therefore the use of magnesium alloys when designing aerospace and automotive parts is critical. Specific alloys are better for certain applications and often also need a coating to provide the longest life of the part. This paper details specific alloys Properties and Their application.

Keywords: **Magnesium alloys, alloying elements, Mechanical properties , physical properties.**

I. INTRODUCTION

Magnesium is an excellent metal as it is readily available commercially and it is the lightest of all the structural metals having a density of 1.7g/cm3; it also has good heat dissipation, good damping and good electro-magnetic shield. It is most commonly found in the earth's ocean. Magnesium has a moderately low melting temperature making it easier to melt for casting. Additionally it is relatively unstable chemically and extremely susceptible to corrosion in a marine environment. It is thought that the corrosion is due more to impurities in the metal versus an inherent characteristic. Finally magnesium powder ignites easily when heated in air and must be handled very carefully in a powder form. The rest of this section will review the advantages and disadvantages to magnesium use in engineering applications. In addition, alloy types and an introduction to coating protections will be discussed.

Magnesium and magnesium alloys are primarily used in aeronautical and automobile industry in wide variety of structural characteristics because of their favorable combination of tensile strength (160–365MPa), elastic modulus (45 GPa), and low density (1740 kg/m3, which is two-thirds that of aluminum). Magnesium alloys have high strength-to-weight ratios (tensile strength/density), comparable to those of other structural metals. Magnesium has relatively good electrical conductivity and thermal conductivity. It also has a very high damping capacity that means, the ability to absorb elastic vibrations. Alloys containing yttrium exhibit good corrosion resistance.

Pure magnesium is rarely used in the manufacturing of aerospace and automotive parts. In order to be used in manufacturing, it is alloyed with other metals. Some of the most common alloyed elements in commercial alloys are: aluminum, zinc, cerium, silver, thorium, yttrium and zirconium. In order to name magnesium alloys, the American Society for Testing Materials developed a method for designating the alloys. The first two letters indicate the principal alloying elements according to the code listed in Table 1. The one or two letters are followed by numbers which represent the elements in weight % rounded to the nearest whole number. For example AZ91 indicates the alloy Mg-9Al-1Zn

Code Letter	Alloying Element
A	Aluminum
B	Bismuth
C	Copper
D	Cadmium
E	Rare Earth
F	Iron
G	Magnesium
H	Thorium
K	Zirconium
L	Lithium
M	Manganese
N	Nickel
P	Lead
Q	Silver
R	Chromium
S	Silicon
T	Tin
W	Yttrium
Y	Antimony
Z	Zinc

II.ROLE OF ALLOYING ELEMENTS IN MG-AL ALLOYS

2.1 Aluminum

Aluminum is the most widely used additive in magnesium alloys. The Mg-Al alloys are considered to have reasonable mechanical properties. The maximum solid solubility of aluminum in magnesium is 12.7wt% at 437°C. Aluminum provides solid solution strengthening, and at greater than 2wt%, precipitation of the β phase occurs which further enhances hardening. Al in this alloy also improves the castabiltiy and fluidity. However, Al also increases the tendency for shrinkage micro porosity up to 9% and then reduces it. The reason for the peak porosity at 9% can be related to the worst combination of mushy zone size, interdendritic feeding, permeability and eutectic volume friction. Aluminum also increases the corrosion behavior of Mg-Al alloys.

2.2 Zinc

Zinc is often said to be added to Mg-Al alloys to impart solid solution strengthening and improved fluidity. But higher amount of Zn in Mg- Al alloys can lead to hot cracking problem. It is further reported that the addition of zinc reduces the ductility of the alloy. Zinc strongly affects solidification pattern of AZ91 alloy thereby forming micro-porosity. It is reported that addition of 2% Zn increases micro porosity in sand-cast magnesium alloys containing 2, 4, 8 and 10% Al. It has also been reported that, zinc widens the two phase α-Mg and β-Mg17Al12 field which may result in a higher degree of precipitation and a corresponding increase in strength in age hardened alloys. Zinc may also have a role to play in accelerating the rate of precipitation in age hardening.

2.3 Manganese

Manganese is added to magnesium alloys in small quantities approximately 0.2wt% to improve the corrosion resistance by removing cathodic impurities such as Fe through the formation of intermetallic compounds which are precipitated out of the melt prior to casting. This leaves the alloys far less sensitive to local galvanic corrosion. The exact amount of Mn addition into Mg-Al alloys is dependent on the chemical compositions and the casting conditions of each alloy. Manganese is predominantly present in the microstructure of Mg-Al alloys in the form of intermetallics such as Al8(Mn,Fe)5 and α-AlMnFe.

III.COMPOSITION OF ALLOYING ELEMENTS IN MG-AL ALLOYS

	Magnesium Die Casting Alloys Ⓐ Ⓕ						
Commercial:	AZ91D Ⓐ	AZ81 Ⓑ	AM60B Ⓑ	AM50A Ⓑ	AM20 Ⓑ	AE42 Ⓑ	AS41B Ⓑ
Nominal Comp:	Al 9.0 Zn 0.7 Mn 0.2	Al 8.0 Zn 0.7 Mn 0.22	Al 6.0 Mn 0.3	Al 5.0 Mn 0.35	Al 2.0 Mn 0.55	Al 4.0 RE 2.4 Mn 0.3	Al 4.0 Si 1.0 Mn 0.37
Detailed Composition							
Aluminum Al	8.3-9.7	7.0-8.5	5.5-6.5	4.4-5.4	1.7-2.2	3.4-4.6	3.5-5.0
Zinc Zn	0.35-1.0	0.3-1.0	0.22 max	0.22 max	0.1 max	0.22 max	0.12 max
Manganese Mn	0.15-0.50 Ⓒ	0.17 min	0.24-0.6 Ⓒ	0.26-0.6 Ⓒ	0.5 min	0.25 Ⓓ	0.35-0.7 Ⓒ
Silicon Si	0.10 max	0.05 max	0.10 max	0.10 max	0.10 max	–	0.5-1.5
Iron Fe	0.005 Ⓒ	0.004 max	0.005 Ⓒ	0.004 Ⓒ	0.005 max	0.005 Ⓓ	0.0035 Ⓒ
Copper, Max Cu	0.030	0.015	0.010	0.010	0.008	0.05	0.02
Nickel, Max Ni	0.002	0.001	0.002	0.002	0.001	0.005	0.002
Rare Earth, Total RE	–	–	–	–	–	1.8-3.0	–
Others Each Ⓔ	0.02	0.01	0.02	0.02	0.01	0.02	0.02
Magnesium Mg	Balance	Balance	Balance	Balance	Balance	Balance	Balance

IV. MECHANICAL AND PHYSICAL PROPERTIES OF ALLOYING ELEMENTS IN MG-AL ALLOYS

	Magnesium Die Casting Alloys						
Commercial:	AZ91D	AZ81	AM60B	AM50A	AM20	AE42	AS41B
Mechanical Properties							
Ultimate Tensile Strength (B) ksi (MPa)	34 (230)	32 (220)	32 (220)	32 (220)	32 (220)	27 (185)	33 (225)
Yield Strength (E) (B) ksi (MPa)	23 (160)	21 (150)	19 (130)	18 (120)	15 (105)	20 (140)	20 (140)
Compressive Yield Strength (H) ksi (MPa)	24 (165)	N/A	19 (130)	N/A	N/A	N/A	20 (140)
Elongation (B) % in 2 in. (51mm)	3	3	6-8	6-10	8-12	8-10	6
Hardness (F) BHN	75	72	62	57	47	57	75
Shear Strength (B) ksi (MPa)	20 (140)	20 (140)	N/A	N/A	N/A	N/A	N/A
Impact Strength (D) ft-lb (J)	1.6 (2.2)	N/A	4.5 (6.1)	7.0 (9.5)	N/A	4.3 (5.8)	3.0 (4.1)
Fatigue Strength (A) ksi (MPa)	10 (70)	10 (70)	10 (70)	10 (70)	10 (70)	N/A	N/A
Latent Heat of Fusion Btu/lb (kJ/kg)	160 (373)	160 (373)	160 (373)	160 (373)	160 (373)	160 (373)	160 (373)
Young's Modulus (B) psi x 10^6 (GPa)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)
Physical Properties							
Density lb/in^3 (g/cm^3)	0.066 (1.81)	0.065 (1.80)	0.065 (1.79)	0.064 (1.78)	0.063 (1.76)	0.064 (1.78)	0.064 (1.78)
Melting Range °F (°C)	875-1105 (470-595)	915-1130 (490-610)	1005-1140 (540-615)	1010-1150 (543-620)	1145-1190 (618-643)	1050-1150 (565-620)	1050-1150 (565-620)
Specific Heat (B) BTU/lb °F (J/kg °C)	0.25 (1050)	0.25 (1050)	0.25 (1050)	0.25 (1050)	0.24 (1000)	0.24 (1000)	0.24 (1000)
Coefficient of Thermal Expansion (B) μ in/in°F (μ m/m°K)	13.8 (25.0)	13.8 (25.0)	14.2 (25.6)	14.4 (26.0)	14.4 (26.0)	14.5 (G) (26.1)	14.5 (26.1)
Thermal Conductivity BTU/ft hr°F (W/m °K @)	41.8 (C) (72)	30 (B) (51)	36 (B) (62)	36 (B) (62)	35 (B) (60)	40 (B) (G) (68)	40 (B) (68)
Electrical Resistivity (B) μ Ω in. (μ Ω cm.)	35.8 (14.1)	33.0 (13.0)	31.8 (12.5)	31.8 (12.5)	N/A	N/A	N/A
Poisson's Ratio	0.35	0.35	0.35	0.35	0.35	0.35	0.35

V. RECENT TRENDS IN MG ALLOYS AND APPLICATION

5.1 Automotive Applications

The magnesium industry has made great efforts to educate the automotive industry on the benefits of utilizing magnesium to reduce vehicle weight, cost, and/or complexity. Applications of magnesium in automobiles using the die casting approach has been in components such as instrument panels, steering wheels, steering columns and seat risers which take advantage of magnesium's high strength-to density ratio & excellent ductility combined with attractive energy absorbing characteristics. Magnesium parts in production include: accessory drive brackets (AZ91D), automatic transmission clutch piston and stator (AS41B), clutch housing (AZ91D), door mirror brackets (AZ91D), headlamp retainers (AZ91D), upper and lower inlet manifolds (AM60B, AZ91D), oil filter adapter housing (AZ91D), power window regulator housings (AZ91D), seat frames

(AM60B), steering wheel armatures (AM50 [Mg-5Al-0.3Mn], AM60B) and valve and cam covers (AZ91D). Fig.1 shows some of the automotive components made from magnesium alloys.

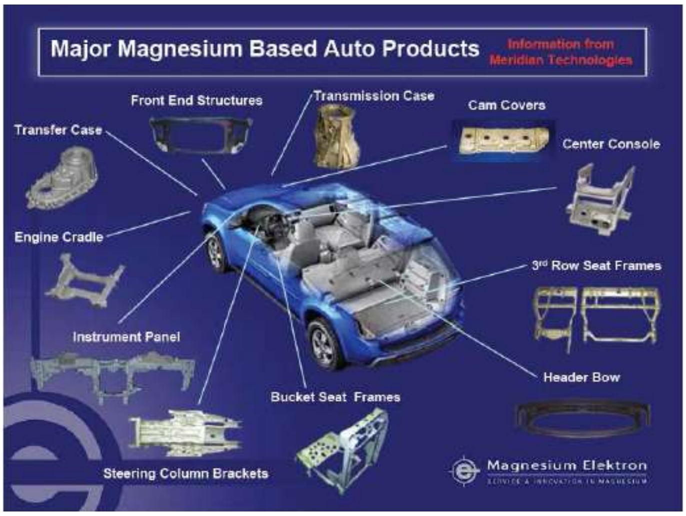

Fig.1: Some of the Major Magnesium Based Automotive Components

5.2 Aerospace Applications

Magnesium has seen quite extensive use in both civil and military aircrafts. Some applications include the thrust reverser (for Boeing 737, 747, 757, 767), gearbox (Rolls-Royce), engines, and helicopter transmission casings, etc. Military aircraft, such as the Euro fighter Typhoon, Tornado, and F16, also benefit from the lightweight characteristics of magnesium alloys for transmission casings. There is also widespread use of magnesium in spacecraft and missiles due to the requirement for lightweight materials to reduce the lift-off weight. This is coupled with its high specific mechanical properties, ease of fabrication, and other attractive features such as its capability to withstand (i) elevated temperatures, (ii) exposure to ozone, and (iii) bombardment of high-energy particles and small meteorites. Alloys such as ZE41 (Mg-4.2% Zn-0.7% Zr-1.3% MM), QE22 (Mg-0.7% Zr-2.5% Nd-2.5% Ag) and particularly WE43 (Mg-4% Y-3.25% Nd-0.5% Zr) are commonly used for aircraft applications due to their improved corrosion and creep resistance. Fig.2 gives some of the aerospace components made from magnesium alloys.

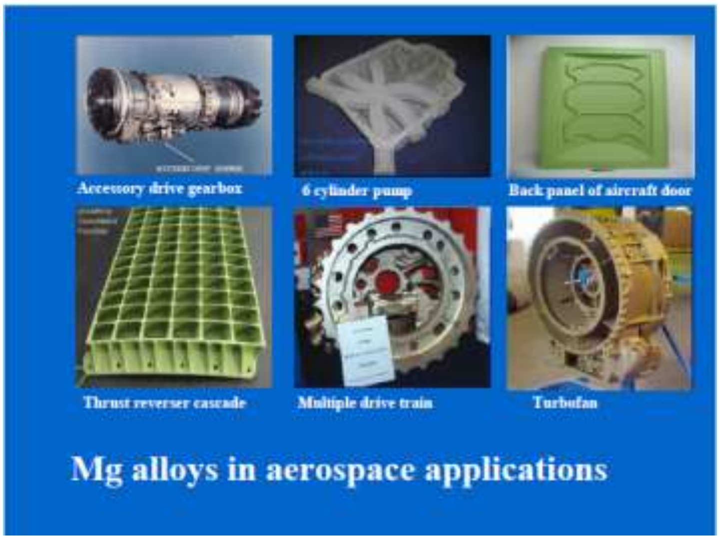

Fig.2: Some of the Aerospace Components Made up of Mg Alloys

5.3 Nuclear Industry

With natural uranium as a fuel, it is essential to conserve neutrons by only using materials in the reactor which will not absorb them readily. Natural uranium plants with operating temperatures suitable for power production essentially determine the general reactor design and limit the canning material to magnesium and the coolant gas to magnesium dioxide. The advantages of magnesium over competing materials are: (a) low tendency to absorb neutrons, (b) does not alloy with uranium, (c) adequate resistance to carbon dioxide up to the highest service temperatures envisioned, and (d) good thermal conductivity.

5.4 Sports Applications

The excellent specific strength and ability of magnesium alloys and magnesium composites to form intricate shapes resulted in many applications in sports-related equipment. For example, magnesium-based materials are used in the handles of archery bows, tennis rackets, and golf club heads. The lightweight and excellent damping characteristics of magnesium-based materials have also made them a popular material choice in bicycle frames and the chassis of in-line skates.Fig.3 gives some of the sports components made from magnesium alloys.

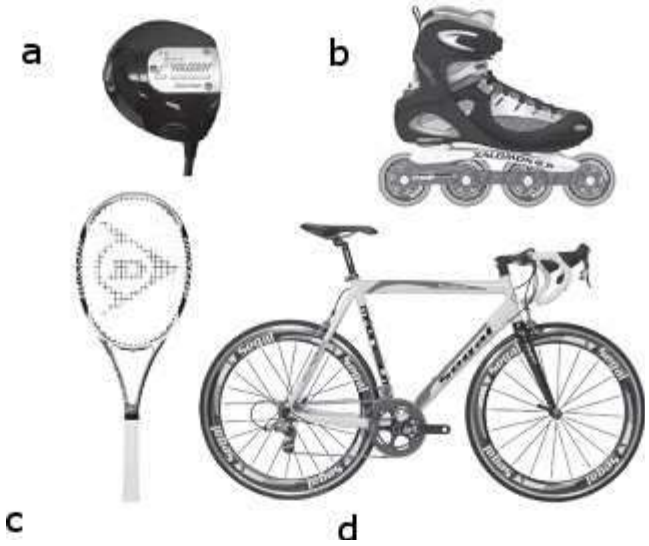

Fig.3: Magnesium sports equipments: (a) golf club head, (b) in-line skates with magnesium chassis, (c) tennis racquet with magnesium head and (d) bicycle with magnesium frame

5.5 Electronic Applications

In spite of automobile and aerospace components, magnesium also finds application in electronics items. Magnesium-based materials are used in housings of cell phones, computers, laptops, and portable media players. The ability to form magnesium alloys into complex shapes and the good heat dissipation and heat transfer characteristics of magnesium alloys also result in the use of magnesium alloys in heat sinks and the arms of the hard-drive reader. Other examples of the use of magnesium include the housings of cameras and digital image projection systems.

5.6 Medical Applications

Magnesium alloys were first introduced as orthopedic biomaterials in the first half of the last century. However, due to its low corrosion resistance, a large amount of hydrogen accumulates around the implant during the *in-vivo* corrosion process, confining the widespread use of magnesium-based materials as biomaterials. Despite, magnesium still possesses many attractive characteristics that make magnesium based materials potential candidates to serve as implants for load-bearing applications in the medical industry. Magnesium is also present as a natural ion in the human body, whereby approximately 1 mol of magnesium is stored in a 70 kg adult human body and an estimated amount of half of the total physical magnesium is present in the bone tissue. It also assists in many human metabolic reactions and is nontoxic to the human body. Magnesium has good biocompatibility and it is biodegradable in human body fluid by corrosion, thus eliminating the need for another operation to remove the implant. All these desirable features make magnesium-based material a promising implant material.

VI. CONCLUSION

Magnesium is a critically important metal in design of aerospace and automotive parts because of its desirable mechanical properties. The low density, good heat dissipation, good damping and good electro-magnetic shield all make it a top choice for design of aerospace and automotive parts. However, the varying operational environments require a material that is more corrosion resistant. Therefore, magnesium is alloyed with other materials (metals and rare earth elements) to provide the best material for aerospace and automotive parts.

This paper provided the selection of an alloy type depends on how the part will be made (cast or wrought), the strength required, and the operational environment. There are other considerations made in designing each specific part to help select between several very similar alloys. This paper documents a number of different alloys that can be used for aerospace and automotive applications.

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