

# AM-lite<sup>®</sup>: an Innovative New Alloy Opens Fresh Opportunities for Magnesium Applications

C.Kettler\*, T.Fuest\*\*, G.Stoesser\*\*, T. Abbott\*, M. Murray\* and G.Dunlop\*

\* Advanced Magnesium Technologies, Heidelberg, Germany and Brisbane, Australia

\*\* MacDermid Industrial Solutions, Forst, Germany

## Abstract

The new magnesium alloy, AM-lite<sup>®</sup>, has been specifically developed to satisfy demand for a light weight diecastable alloy that is highly suitable for decorative surface finishing applications. The key technical attributes of AM-lite<sup>®</sup> are its light weight, metallic feel, excellent diecastability, oxidation resistance and suitability for decorative surface finishing operations such as electroplating and painting. Electroplating, using the Bondal<sup>®</sup> Mg pretreatment, results in excellent coating performance. The alloy offers cost savings compared to zinc, aluminium, magnesium alloy AZ91D and also injection moulded plastics, in the manufacture of surface finished articles.

## 1 Introduction

Diecasting provides the biggest market for magnesium alloys. However, at ~170 000 tpa, the current size of this market is very small compared with markets for zinc and aluminium diecasting alloys and also much smaller than that for injection moulded plastics. While markets for magnesium diecasting alloys continue to grow, it is clear that there would be considerably greater opportunities for magnesium if alloys could be developed that have more attractive properties compared with competitor materials.

AM-lite<sup>®</sup> has been specifically developed for a wide range of diecasting applications where diecastability and decorative surface finishes are of prime importance [1,2]. Currently AZ91D is the major magnesium diecasting alloy that competes against zinc, plastics, and to a lesser extent aluminium, for general diecast and moulded parts. This total market is very large and AZ91D only manages to capture a small portion of it. The new alloy, AM-lite<sup>®</sup>, complements AZ91D by addressing some of its deficiencies and is opening up new opportunities in areas where other materials have previously been favoured.

AM-lite<sup>®</sup> and its accompanying surface finishing technology is the product of intensive research and development by AMT, its research partner CAST, and MacDermid. The new alloy has considerable potential to expand markets for magnesium alloys into areas that have previously been the domain of zinc and aluminium diecasting alloys and injection moulded plastics.

The decorative diecasting market requires an alloy that has the light weight attributes of magnesium combined with the diecastability and surface finishing characteristics of zinc. Over the past two decades zinc has lost much of the automotive decorative market, primarily to plastics but also to aluminium and magnesium AZ91D, because of its weight. More recently the rapid rise in zinc prices has made it increasingly favourable to substitute zinc diecastings with other materials that can fulfil the requirements of decorative applications. More than three times as many parts per unit weight of metal can be produced from magnesium alloys compared to zinc. Thus, based on current metal prices, the cost of metal in diecast parts is ~70% cheaper for AM-lite<sup>®</sup> than for zinc.

While magnesium AZ91D has many admirable attributes and has served as a work horse alloy for the magnesium industry for many years, it cannot fulfil all of the requirements required for a wide range of decorative applications. Most importantly, it is difficult and expensive to electroplate AZ91D. Moreover the diecastability and as-cast surface quality of AZ91D is considerably inferior to zinc so that diecast AZ91D generally requires extensive pre-work (polishing, buffing, filling) as part of surface finishing operations. AZ91D also has the typical disadvantages of magnesium alloys relating to melt losses in the foundry, due to dross and sludge formation, and the need for external recycling of casting returns.

Diecast AM-lite<sup>®</sup> has surface characteristics that are very suitable for surface finishing operations and MacDermid has developed specific chemical pre-treatments, Bondal<sup>®</sup> Mg for electroplating and Chemidize Mag Prime for painting and powder coating, that enable high quality durable electroplated and painted surface finishes to be applied.

## **2 General Features of AM-lite<sup>®</sup>**

AM-lite<sup>®</sup> is an Mg-Zn-Al alloy that makes use of its special composition to provide unique properties. It is a highly diecastable light weight alloy that has excellent surface finishing characteristics. The alloy is oxidation resistant in the temperature range of solidification and below. This results in less oxide on the surface of castings and gives them a longer shelf life prior to surface finishing operations. The mechanical strength of AM-lite<sup>®</sup> is somewhat greater than AZ91D and its elevated creep strength is considerably higher.

### **2.1 Diecastability and as-cast surface quality**

AM-lite<sup>®</sup> exhibits considerably improved fluidity and diecastability which in many ways is similar to that of zinc diecasting alloys. The usual difficulties experienced with diecasting of AZ91D, such as cracking along flow lines, cold cracks and hot cracks, are significantly reduced with AM-lite<sup>®</sup>. Because of the higher alloy fluidity the dimensions of runners and volume of overflows can usually be reduced.

As might be expected, the optimum diecasting conditions for AM-lite<sup>®</sup> are different from those for AZ91D. In fact AM-lite<sup>®</sup>'s operating window, for the production of good quality castings, is wider and therefore the alloy provides greater stability of operation in mass production situations and allows for easier automation. This is especially true as AM-lite<sup>®</sup> does

not adhere to, or react with, the die (soldering) as does AZ91D. Hence, die maintenance is significantly reduced with AM-lite<sup>®</sup>, thus reducing down-time and improving automation. Very thin sections are more easily achieved with AM-lite<sup>®</sup> than for AZ91D and the alloy will reproduce very fine detail from the die.

In general terms, AM-lite<sup>®</sup> can be cast into thin sections that are 10-20% thinner than can be cast with AZ91D. This is of particular value for intricate thin walled parts for portable electronics such as mobile phones and laptop computer housings.

The excellent diecastability of AM-lite<sup>®</sup> stretches to an ability to produce an as-cast mirror surface finish. Production of such a finish requires a polished die surface, minimization of the amount of die lubricant used and appropriate adjustment of diecasting parameters. An example of a mirror as-cast surface is shown in Fig. 1. As-cast surfaces such as this provide considerable advantages in surface finishing.



**Figure 1:** Reflected image in the as-cast surface of an AM-lite<sup>®</sup> diecasting produced under conditions that provide a mirror finish.

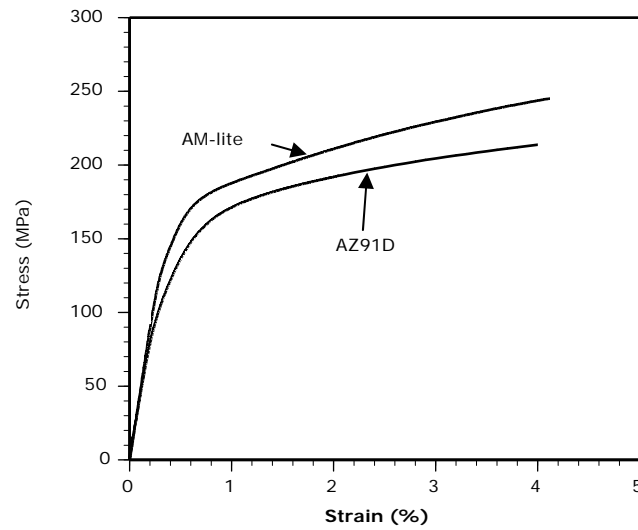
## 2.2 Mechanical properties of AM-lite diecastings

The mechanical properties of AM-lite<sup>®</sup> diecastings are summarised and compared with AZ91D in Table 1. The tensile properties in this table were obtained on 2mm thick diecast plates. Both the yield strength (0.2% offset proof stress) and ultimate tensile strength of AM-lite are higher than for AZ91D. The most important difference in mechanical properties can be seen with reference to Fig 2. AM-lite<sup>®</sup> maintains its linear elastic behaviour to higher stresses than AZ91D. The limit of linear elastic behaviour for AZ91D is ~ 40 MPa while for AM-lite<sup>®</sup> this limit is ~100 MPa. This means that, for stiffness critical parts, the design strength of AM-lite<sup>®</sup> is considerably higher than that for AZ91D.

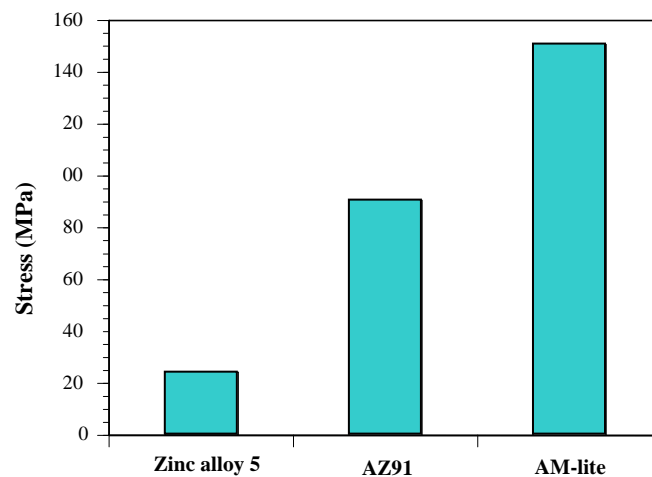
AM-lite<sup>®</sup> also has better creep strength than AZ91D and zinc alloys. Zinc alloys creep significantly even at room temperature under relatively low loads. As shown in Fig 3, the creep strength of diecast AM-lite<sup>®</sup> at temperatures around 100°C is about 65% greater than AZ91D and 600% greater than a typical zinc diecasting alloy.

**Table 2:** Mechanical properties of AM-lite<sup>®</sup> diecastings compared to AZ91D

Property	AM-lite	AZ91D
Yield stress (0.2% proof), MPa	160-170	120-150
Ultimate tensile strength, MPa	230-250	180-205
Young's modulus, GPa	45	44
Elastic limit, MPa	~100	~40
Tensile elongation, %	3-4	3-4



**Figure 2:** Tensile curves for AM-lite<sup>®</sup> and AZ91D. 2mm thick diecast plates



**Figure 3:** Comparison of creep strength of AM-lite<sup>®</sup>, AZ91D and zinc Alloy 5. Stress required for 0.5% strain after 100h at 93°C (200°F).

### 2.3 Oxidation resistance

The strong resistance of AM-lite<sup>®</sup> to oxidation during solidification is illustrated in Fig 4 which shows samples of AZ91D and AM-lite that have been allowed to solidify in air in open muffin-cup moulds. Under such circumstances AZ91D oxidises extensively and eventually burns but AM-lite freezes with a shiny surface.

The oxidation behaviour of AM-lite<sup>®</sup> in the molten state and during solidification is responsible for many of the alloy's surface properties. For example, during diecasting, the surface film on a liquid metal influences its flow characteristics and in particular the ability for opposing flows to bond metallurgically during filling of the cavity. The high resistance to oxidation of AM-lite<sup>®</sup> enables such opposing flows to bond effectively during solidification contributing to a much lower defect density in these regions. It also allows molten metal to flow smoothly under pressure to fill small interstices created through shrinkage and, in particular, contributes to the smooth shiny as-cast surface of AM-lite<sup>®</sup> die castings whose oxidation resistance persists after casting.



**Figure 4:** Comparison of oxidation of AZ91D (left) and AM-lite<sup>®</sup> (right) solidified in air.

The oxidation resistance of AM-lite<sup>®</sup> has other important effects. While use of a cover gas is still required in melt handling, the amount of dross formed is significantly reduced. This may be helped by a furnace temperature that is typically 20°C lower than that for AZ91D. Experience from industrial trials has shown that melt losses due to dross formation are ~75% less for AM-lite<sup>®</sup> than those usually experienced for AZ91D under similar circumstances. Sludge formation is virtually negligible. Reduced melt losses are an important cost saving for diecasters. Another virtue is that there is a significant reduction of the amount of burning of magnesium adhering to tools when they are removed from the furnace, or when removing dross, leading to less fuming and a cleaner foundry environment.

### 3 Surface Finishing of AM-lite<sup>®</sup>

AM-lite<sup>®</sup> is suitable for surface finishing by a wide range of surface finishing processes. The high quality as-cast surfaces that can be achieved during diecasting reduce the need for polishing, buffing and filling. The alloy can be surface finished by a wide range of processes including:

- electroplating
- powder coating
- painting
- electrophoretic coating
- anodising
- physical vapour deposition.

### 3.1 Electroplating

The as-cast surface of AM-lite<sup>®</sup> provides an improved substrate for electroplating because of two main reasons. Firstly, the high as-cast surface definition reduces the amount of buffing, or polishing, that is necessary to produce a prepared polished surface for coating. Secondly, the surface chemistry of AM-lite<sup>®</sup> is such that good adhesion of deposited layers is obtained.

Key differences in procedures for electroplating of different materials arise in the pretreatment sequences prior to electrodeposition of subsequent layers of copper, nickel and chrome (or what ever top coat is desired). For electroplating of zinc, pretreatment only involves cleaning and activation of the surface. However for aluminium and magnesium AZ91D steps of etching, deoxidation and zincating must be added. Even then the quality of adhesion of electroplated layers on aluminium and AZ91D is significantly lower than for zinc.

Pretreatment of AM-lite with the Bondal Mg process developed by MacDermid reduces the separate etching and activation steps that are necessary for aluminium and AZ91D to a single step and utilizes a newly developed zincating process. The process is simple and provides better adhesion than is possible on AZ91D. The quality of electroplating should be similar to that expected of electroplated zinc diecastings.

The Bondal<sup>®</sup> Mg pretreatment process for AM-lite<sup>®</sup> allows the full range of possibilities for deposition of decorative electroplated layers and top coats that are available to other materials. Electroplated AM-lite<sup>®</sup> displays excellent coating performance in standard testing regimes. For example, no chipping or adhesion loss is experienced in standard saw cut tests. Accelerated CASS corrosion tests in accordance with ASTM and DIN standards have shown the absence of corrosion for up to 72 hours which is equivalent to more than 500 hours in standard neutral salt spray testing.



**Figure 5:** Diecast AM-lite<sup>®</sup> automobile parts electroplated using the Bondal<sup>®</sup> Mg process.

### 3.1 Conversion coating for painting and powder coating

Because the surface chemistry of AM-lite<sup>®</sup> is very different to conventional magnesium alloys, such as AZ91D, AM50 and AM-60, the passivating conversion coatings that are commonly used for painted and powder coated surfaces of these alloys are generally not suitable for AM-lite. MacDermid has developed a conversion coating process, Chemidize Mag Prime, that provides excellent corrosion protection to AM-lite<sup>®</sup> while at the same time providing a highly suitable undercoat for paint and powder coat finishes. Chemidize Mag Prime is very environmentally friendly as it does not utilise any Cr compounds.

Powder coated and painted samples, that had been pretreated with Chemidize Mag Prime, have been shown to survive 240h neutral salt spray testing in accordance with DIN 50021 SS and DIN EN ISO 6270-2 CH.

## 4 Comparison with other materials

Table 2 is a score card that has been drawn up to show the relative attributes of competing materials for diecast or moulded parts. The scores are in the range 1-5 with 5 being best and 1 being worst. While such a quick comparison does not allow a detailed comparison of the nuances of each material, it can be easily understood that, when considered over a range of properties, AM-lite<sup>®</sup> is consistently better than its competitors for many applications.

**Table 2:** Score card for attributes of competing materials for diecast and moulded parts

Attribute	AM-lite <sup>®</sup>	Zn	Al	AZ91D	Plastics
Diecastability / mouldability	4	5	2	3	5
As-cast surface quality	4	5	2	3	5
Electroplating	4	5	2	1	2
Painting/Powder coating	4	3	5	3	3
Melt loss	4	4	4	1	5
Recycling	4	5	5	3	1
Productivity	4	4	3	2	5
Mechanical properties	4	3	5	4	1
Conductivity (metallic feel)	4	4	5	4	1
Density (lightness)	5	1	4	5	5
Cost of finished product (5 is cheapest)	5	3	4	3	3

### 4.1 Comparison with zinc

Zn diecasting alloys are highly diecastable and their electroplating characteristics are excellent. The main disadvantages of zinc are its high density and the high current cost of the base metal. The density of AM-lite<sup>®</sup> is less than 1/3 of the density of Zn and therefore more than

3 times as many parts can be made with AM-lite<sup>®</sup> for the same weight of material. Based on current metal prices, this results in the cost of metal per AM-lite<sup>®</sup> part being only about 1/4 of the cost of zinc alloy for castings of the same volume.

The electroplating characteristics of AM-lite<sup>®</sup> using MacDermid's Bondal<sup>®</sup> Mg technology allow the same standard of electroplated surfaces to be produced as can be formed on Zn die-castings with only a small increase in the cost of electroplating.

The high density of zinc makes zinc diecastings unfavourable in applications, such as automotive and personal electronics, where light weight is important. Painted and powder coated zinc parts are also vulnerable to the formation of surface blisters during baking due to the expansion of gases trapped in the metal during diecasting. AM-lite<sup>®</sup> is resistant to the formation of blister defects during baking because the alloy has an inherent creep resistance that stops the growth of gas bubbles. This much improved creep resistance of AM-lite<sup>®</sup> also enables the design of thinner bosses for bolted joints compared to what is necessary for zinc.

#### **4.2 Comparison with aluminium**

Aluminium alloys are not as diecastable as zinc or magnesium alloys. Therefore they are not used for thin walled or intricate diecastings. Aluminium is more favoured for thick walled robust parts such as automotive transmission housings and other structural parts. Aluminium also has a 50% higher density than magnesium alloys so the latter have a distinct advantage when weight is at a premium. Current high prices for aluminium combined with the larger number of parts that can be made from the same weight of AM-lite<sup>®</sup> mean that there is a cost saving of about 14% on the input metal for AM-lite<sup>®</sup> castings of the same volume. In die casting, aluminium is significantly more aggressive on dies than AM-lite<sup>®</sup> and therefore the cost per part due to die replacement is much more expensive for aluminium.

For these reasons, AM-lite<sup>®</sup> is being considered by a number of manufacturers for current aluminium applications where the advantages of light weight, improved diecastability, longer die life, ease of electroplating and lower cost make compelling arguments.

#### **4.3 Comparison with magnesium alloy AZ91D**

As can be seen in Table 2, AM-lite<sup>®</sup> is superior to AZ91D in many respects. Most importantly, AM-lite<sup>®</sup> is more diecastable, can be electroplated and saves substantial costs for surface finished components. The improved diecastability enables sections that are 10% thinner to be readily diecast and also allows casting yields to be improved through the use of thinner runners and smaller overflows. The as-cast surface is improved and the oxidation resistance of AM-lite<sup>®</sup> provides a longer shelf life for unfinished castings.

In melt handling, costly melt losses due to dross and sludge are reduced, from an industry average of 4% for AZ91D to about 1% for AM-lite<sup>®</sup>, through a virtual elimination of sludge and significantly less dross formation.

AM-lite<sup>®</sup> has a higher design strength than AZ91D and this allows for the incorporation of even thinner sections and thinner bosses in bolted sections. The greater creep resistance of AM-lite<sup>®</sup> also makes it an option for components, such as valve covers, that experience raised temperatures and require maintenance of tight bolted joints over long periods.

The most important advantage of AM-lite<sup>®</sup> over AZ91D is however its excellent surface finishing characteristics and, in particular, its ability to be electroplated.

#### **4.4 Comparison with plastics**

Electroplated plastics might look like metals but, because the underlying plastic substrate is thermally non-conductive, they do not feel like metals. This simple matter of aesthetics often disappoints consumers when it is realized, when touched, that an outwardly metallic looking item clearly isn't what it was thought to be. Because it is a conductive metal, AM-lite<sup>®</sup> does have a "metallic feel" and so is more attractive to customers.

AM-lite<sup>®</sup> has a much higher stiffness, yield strength and creep strength than unreinforced plastics thus allowing improved thin section light weight designs. The alloy's electrical and thermal conductivity, and EMS shielding, is also important for the design of consumer electronics such as mobile phones and laptop computers.

### **5 Applications of AM-lite<sup>®</sup>**

From the above it can be understood that AM-lite<sup>®</sup> is highly suitable for a wide range of products that previously may have used zinc, aluminium, magnesium AZ91D and plastics. Thus applications are being uncovered in many areas where these materials have been or are currently being used. These include:

- building and furniture hardware, such as handles, knobs and cover plates
- light fittings
- sanitary ware, such as tap handles, kitchen and bathroom fittings
- hand tool housings
- enclosures for portable electronics such as mobile phones and laptop computers
- motor cycle parts such as cover plates, badges and filler caps
- automotive decorative components and trim such as door handles, console panels and gear shift paddles.

### **6 Conclusions**

1. AM-lite<sup>®</sup> is a new general purpose magnesium diecasting alloy especially suited for decorative applications.
2. AM-lite<sup>®</sup> is highly competitive with zinc, aluminium, magnesium AZ91D and plastics for most decorative applications.
3. Key attributes for AM-lite<sup>®</sup> include:
  - light weight
  - high diecastability
  - improved as-cast surface for all surface finishing operations
  - can be readily electroplated

- resistant to oxidation
  - potential for in-cell recycling
  - higher design strength than zinc, magnesium AZ91D and plastics
  - cost savings in both diecasting and surface finishing
4. AM-lite<sup>®</sup> can be readily electroplated using the Bondal<sup>®</sup> Mg electroplating technology.
  5. Conversion coating with Chemidize Mag Prime provides an excellent passivating base for painted and powder coated surfaces
  6. Cost savings in both diecasting and surface finishing

## 4 References

- [1] Abbott, T.; Murray, M.; Dunlop G., in *Magnesium Technology 2006*, San Antonio, TMS 2006, p. 481 - 485
- [2] Dunlop, G.; Abbott, T.; Murray, M.; Bettles, C.; Gibson, M.; in *Proceedings International Magnesium Association World Conference*, Beijing, IMA 2006, p. 24 - 33