Examining technical know-how

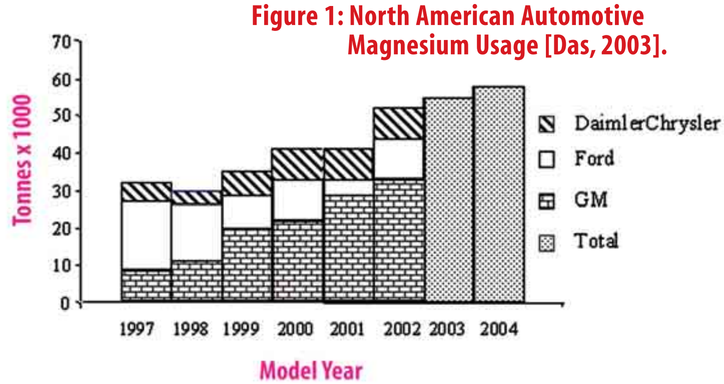
Mamoun Medraj and Anwar Parvez analyse the importance of Magnesium-Aluminium-Strontium alloys for more fuel-efficient automobiles

Magnesium is 36 per cent lighter per unit volume than aluminium and 78 per cent lighter than iron, which indicates that significant automobile weight reduction can be achieved through replacing aluminium and some steel components by those made using magnesium alloys. Reducing the automobile weights by certain amount will result in similar percentage of improvement in fuel economy. For a typical vehicle, this represents a fuel saving of about 0.5 liters per 100 kilometers for every 100 kilograms of weight reduction. Reduction in weight is best accomplished through a combination of innovative structural design and increased use of lightweight materials. Magnesium alloys are very attractive materials for weight reduction in automobile applications. Currently, the average vehicle in North America uses only 0.25 per cent magnesium (3.8 kg) compared to eight per cent aluminium (120 kg). Magnesium and its alloys are important for structural application and demand for them will increase considerably in the coming years. However, significant research is still needed on magnesium processing, alloy development, joining, surface treatment, corrosion resistance, as well as, mechanical properties improvement. Since high cost is a major obstacle to greatly increased magnesium use in autos, developing new alloys, which have better formability could enable major cost reduction. New magnesium alloys are also needed to meet the automobile and aerospace requirements for elevated-temperature strength and creep resistance. This research area is presently one of the most active areas in light metals technology. Industrial demand for highly qualified personnel in magnesium alloys area is a fact for years to come.

Magnesium and its current use

Magnesium is the eight most abundant metal on the earth surface at approximately 2.5 per cent of its composition. It is an alkaline earth element that crystallises in a hexagonal structure. Magnesium is the lightest metallic material used for structural applications with a density of 1.738 g/cm^3 in comparison with the densities of Al (2.70 g/cm^3) and Fe (7.86 g/cm^3). Magnesium also has a very good strength to weight ratio of common structural metals and has the exceptional die-casting characteristics [Gradinger and Stolfig, 2003; Pekguleryuz et al., 2003]. In addition, on a per-pound basis, magnesium costs more than aluminium, whereas on a volume basis the price of both becomes approximately the same. This makes magnesium alloys one of the most promising lightweight materials for automotive applications. Emerging goals for reduced emission and fuel economy in passenger vehicles is exerting a driving force for expanding the use of magnesium [Mordike, 2002]. The current use of magnesium in automotive application includes cross-car instrument panel beams, steering wheel armatures, cam covers and valve covers. The market for automotive magnesium parts has grown rapidly, nearly 15 per cent per year during the 1990s. The average magnesium content in the 2002 model cars was 4 kg. Figure 1 shows the North American automotive magnesium usage for different car manufacturers [Das, 2003]. Die-casting is one of the

Figure 1: North American Automotive Magnesium Usage [Das, 2003].



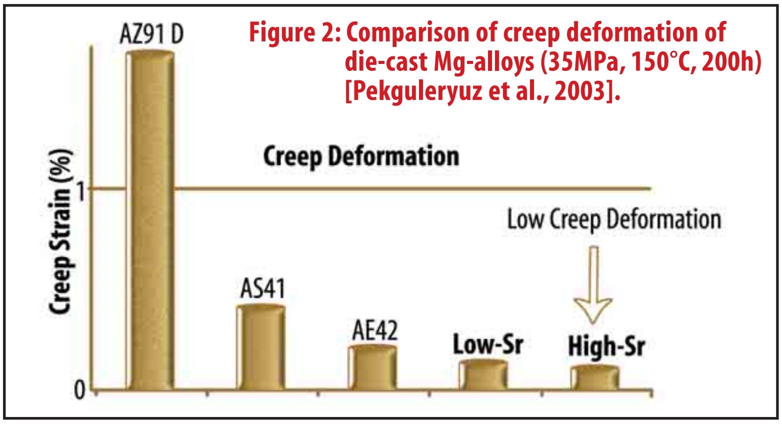


Figure 2: Comparison of creep deformation of die-cast Mg-alloys (35MPa, 150°C, 200h) [Pekguleryuz et al., 2003].

most effective fabrication methods to produce magnesium components in automotive industry. However, the number of available Mg-based alloys for die-casting is very limited. AZ91 (Mg-9 wt. per cent Al-1wt. per cent Zn) is the principal alloy, which represents 80 per cent of the magnesium casting components [Zhang and Couture, 1998]. These alloys are not suitable for applications over 95°C such as powertrain components in automobile applications because of their restricted creep properties which limited the current application of magnesium to non-critical parts such as valve covers and instrument panels. In contrast to steels and many Al-alloys, the conventional Mg-alloys have a relatively low resistance to creep [Blum et al. 2001].

High temperature behaviour of magnesium and its alloys

Grain boundary sliding has been observed to be the main creep mechanism in magnesium alloys in the stress-temperature ranges of interest for automotive application. Magnesium seems to creep even at low temperature by a stress-recovery mechanism.

The creep mechanisms at low temperature are basal slip within the grains and sub-grains formation while at the higher temperatures diffusion-dependent mechanisms become predominant [Blum et al. 2001].

Mg-Al alloys are one major group among the magnesium-based alloys. The strength of these alloys is improved by forming a solid solution where 11.5 atomic per cent Al are soluble in the Mg-matrix at 437°C. The microstructure of these alloys is characterised by the Mg-g (Mg17Al12) eutectic at the grain boundaries.

The non-stoichiometric phase g is incoherent with the a-Mg matrix. In addition to this poor coherency, if Mg-Al alloys are exposed to elevated temperatures (>150°C) for longer time, the supersaturated Mg solid solution transforms to Mg-matrix with coarsely dispersed g precipitates and contributes to grain boundary migration and creep deformation. g is also prone to aging and has poor metallurgical stability, which limited the application at higher temperature [Aghion et al. 2003; Pekguleryuz and Renaud, 2000].

Development of creep resistant magnesium alloys

Early developments in improving the creep properties of magnesium were made in the 1960's by Volkswagen. It was based on the Mg-Al-Si system. These alloys exhibit marginally improved creep resistance but are quite difficult to die-cast. The 90's have seen renewed activity in the development of elevated temperature magnesium die casting alloys. Developments in recent years have led to the discovery of certain alloys containing rare earth elements and calcium. The AE42 (Mg-4 atomic per cent Al-2 atomic per cent rare earths) has improved creep resistance over the other alloys.

For example, magnesium-thorium alloys displays excellent creep properties (350°C) and used in the aircraft engines. However, these alloys have cost disadvantages due to expensive rare-earth additions [Pekguleryuz, and Renaud, 2000].

Also, thorium is a radioactive element. Magnesium alloys, which are used commercially, contain Al and Zn. Some attempts were made in the last decades to replace the rare earths metals by Ca. But these alloys suffer from inferior diecastability (e.g. Mg-Al-Ca) or have disadvantages in terms of marginal performance improvements (e.g. Mg-Al-Ca-RE and Mg-Al-Ca-Sr-RE). Die-sticking and hot-cracking behavior also caused problems.

This alloy system has been considered subsequently for semi-solid forming applications. Later, Mg-Al-Zn-Ca showed much improved castability but the alloy seems to work only in an extremely narrow composition range and the properties of the alloy vary due to macro segregation of the heavier Zn. Newly developed Mg-Al-Ca-based alloys with micro-alloying additions of Si and Sr showed better creep properties and die-castability [Pekguleryuz, and Renaud, 2000; Gröbner et al. 2003].

It is very important to have magnesium alloys with acceptable creep resistance and affordable cost to automotive industry. The intermetallics in these alloys should be thermally and

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metallurgically stable and would be expected to yield effective grain boundary strengthening and resistance to flow during creep loading. In addition, it should have adequate corrosion resistance, castability and strength.

Strontium, alkaline earth elements, is one of those metals, which play a very positive role as an agent modifying or improving the casting and mechanical or structural properties of commercial Mg-based alloys. The microporosity of Mg-based alloys by low-pressure castings can also be overcome by an addition of Sr [Zakulski, 2004].

Magnesium-Aluminium-Strontium system

The Mg-Al-Sr system has emerged in recent years as promising material system for the heat resistant lightweight Mg alloys.

Recently, Noranda developed alloys based on Mg-Al-Sr system, which are used by BMW for the manufacturing of die-cast engine blocks. It exhibits excellent mechanical properties, good corrosion resistance and excellent castability. Timminco Ltd., which produces Al-Sr master alloys, has also patented master Al-Sr-Mg compositions with an increased Sr content. Figure 2 shows a comparison of creep deformation of different diecast Mg-alloys. It can be seen from this figure that Mg alloys with Sr addition outperformed the other alloy systems in terms of creep resistance.

Tensile and yield strength of the alloys at 150°C was found to be superior to AE42. Corrosion resistance of the Mg-Al-Sr alloys is similar to AZ91D and better than the AE42, which indicates that strontium does not have adverse effect on corrosion properties.

The microstructure of this alloy is characterized by highly stable compound Al4Sr and (Mg) lamellar phase, which improved the creep resistance [Pekguleryuz et al., 2003]. Within the ternary Mg-Al-Sr system, there is a huge amount of possibilities to select alloy compositions.

The importance of phase diagram is enormous in all parts of material development because the diagram can illustrate the phase relations and phase stability under given conditions. It also assists in selecting promising alloys. To date little effort has been made to construct the phase relationships of Mg-Al-Sr system.

The published experimental works on the phase equilibria of Mg-Al-Sr system are self-contradictory. The calculated phase diagram exhibited substantial disagreement with the experimental data. The ternary system was modeled without using ternary phases or ternary interaction parameters.

A considerable discrepancy among the published results and very few experimental data demands new experimental investigation for the verification and reassessment of this highly potential system.

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