Trans. Indian Inst. Met.
Vol.57, No. 4, August 2004, pp. 397-408

OVERVIEW

# AUTOMOTIVE APPLICATIONS OF MAGNESIUM AND ITS ALLOYS

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(Received 1 March 2004 ; in revised form 10 May 2004)

## ABSTRACT

Today's interest in magnesium alloys for automotive applications is based on the combination of high strength properties and low density. For this reason magnesium alloys are very attractive as structural materials in all applications where weight savings are of great concern. In automotive applications weight reduction will improve the performance of a vehicle by reducing the rolling resistance and energy of acceleration, thus reducing the fuel consumption and moreover a reduction of the greenhouse gas $CO_2$ can be achieved.

The present paper gives an overview on the actual status of the development of magnesium alloys and technologies for application in the automotive industries. The development of new cast or wrought alloys and the optimisation of existing or new processes for the production of magnesium parts are discussed. Magnesium has a long history in automotive applications. The decrease of magnesium use in automotive applications in the seventies was greatly related to its prize volatility and also to lack of knowledge. Stricter legislative rules (CAFE) and voluntary commitments to reduce the average fuel consumption have nowadays revived the interest in magnesium.

## 1. INTRODUCTION

There is increasing interest in light weight construction since the automobile industry's commitment to achieve a 25% reduction in average fuel consumption for all new cars by the year 2005 (compared to levels in 1990). Magnesium with its good strength to weight ratio is one of the candidate materials to realise light weight construction, but it has to compete with various other materials. So the different light metals have to compete not only with each other, but also with polymers and steels. Materials selection is thereby determined by economical issues as much as by materials and components characteristics or properties.

However magnesium shows high potential to substitute conventional materials. Magnesium alloys should be used in applications where low mass and high specific properties are required. According to the combination of specific Young's modulus and high specific strength magnesium alloys show similar or even better values than aluminium and many commercial steels (Fig. 1).

With the increasing use of magnesium the cost per tonne is coming down, which makes it more competitive from the economic point of view too. The consumption of primary magnesium shows a broad increase in the last 20 years whereas North America is the main consumer followed by the western part of Europe and Japan [1]. Most of the available magnesium (40 %) is still used for alloying aluminium and only about 34% is directly used for magnesium parts, which can be divided into casting applications (33.5%) and wrought materials (0.5%) [2]. It was estimated that the market for magnesium die castings will grow from $10^5$ tons in 2000 to twice this amount in 2006. Approximately 80 % of this market is expected to go towards die casting automotive parts[1]. Normally the price for magnesium

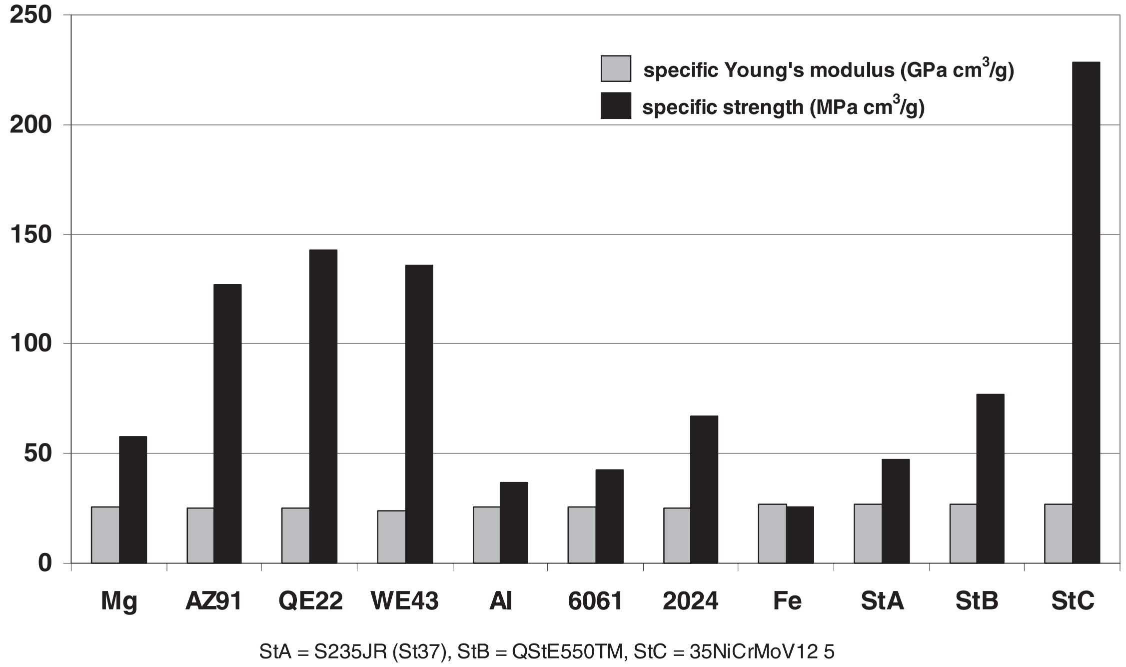


Fig. 1 : Comparison of specific Young's modulus and strength of different materials

is still higher than for aluminium. The pricing forecast is that the magnesium price will decrease from 2300 US $/ton in 2001 down to 1800 US $/ton in 2005 leading to a drop of the magnesium to aluminium price ratio from 1.5 to 1.2 [4]. This decrease in price or at least some price stability is related to a number of long-term agreements between magnesium producers and automotive manufacturers, including Ford's 10 year contract (from 1997) with AMC of Queensland Australia, VW AG's 35% equity interest in Dead Sea Magnesium and GM's long term supply agreements with Russian Solikamsk and Norsk Hydro and to a development of a secondary market (at least in the US, while Europe is still lagging behind) [5].

Today China is dominating the primary magnesium market and due to a strong price competition magnesium is sometimes available for the same price as aluminium. But there is still some uncertainty, with just three primary magnesium producers left in the western world (US Magnesium, Dead Sea Magnesium and Hydro Magnesium, Canada) [3]. As a consequence of the price competition with China, Ford´s contract with AMC was cancelled in 2003 and AMC´s primary magnesium production at Stanwell was taken out of operation [5]. The same happened also to primary magnesium plants of Noranda (Canada) and Norsk Hydro (Norway).

Additionally the widespread use of magnesium and its alloys in transportation industry is limited by some poor property profiles. Low creep resistance, high coefficient of thermal expansion (CTE), low Young's modulus, insufficient ductility and crash energy consumption in car body structures, low fatigue stability, low corrosion and wear resistance are deficits which have to overcome by further alloy and/or process developments.

## 3. HISTORIC REVIEW

In the old literature the term "elektron" is often used for magnesium alloys, where elektron is the historic and advertised name of magnesium alloys given by the German company "Chemische Fabrik Griesheim – Elektron" in the year 1908. Although first successful automotive applications were developed, e.g. an elektron piston (patent no. 386967) in 1921, the real step forward was the introduction of the "Elrasal"-process (patent no. 403802) for melt treatment (refining) in 1923 which resulted in much better metallurgical properties of cast magnesium parts [6]. Since then the number of automotive applications increased steadily. In 1924 a high volume of magnesium cast parts were introduced into trucks by the German company Büssing. Since 1927 the Adlerwerke in Germany were producing an automobile using magnesium cast and pressed parts to the greatest possible extent. 20,000 standard type cars with 6 and 8 cylinders were produced with the following mass production magnesium parts: disk wheels, gear box cases, gear box covers, rear suspension gear box cases, chain locker, chain locker cover, crank cases, fly wheel cases and various bearings, slide guidings and covers. Altogether 73.8 kg of magnesium was used for the 6 cylinder and 86.8 kg for the 8 cylinder car [6,7]. Even in the car body extruded u- and angle profiles were often used to build frames which were then covered with Mg sheets. Examples are German bus trailers [8] and a prototype of Bugatti (Type 57C Atlantic) both build in 1939. The English truck and omnibus company Thornicroft has started a test series of 20 engines equipped with crank cases of cast electron in 1928. Besides the conventional automobile sector magnesium parts were also introduced in motor sport racing cars. Maserati used for their winning racing cars (in the “Monza grand prix” 1930) a great number of elektron parts such as crank, compressor and gear box cases, brake shoes, timing, differential and camshaft cases and various smaller parts [8]. Even in chassis applications magnesium parts have been successfully used. A bus wheel was used for more than 300,000 km without a major corrosion attack [8]. Highly loaded elektron engine parts have also contributed to Autounion’s win of the 1937 Vanderbilt cup in New York. Altogether many magnesium parts have already been used by all major car manufacturers in automotive applications until 1939 (engines, gears, clutch, rear suspension, starter, ignition, steering, breaks, car body, seats, wheels (rims), etc.) and the application was not only restricted to cast parts [6]. After WWII magnesium was further used in some automotive applications. Some racing cars (Mercedes 300SL, Porsche 962) had the frame and skin made from magnesium. The VW beetle was the commercial car with the largest single application of magnesium alloys (crank case and transmission housing with a total weight of 17kg) and with the production stop of the air cooled Mg engine of the beetle a tradition of 50 years of magnesium automotive applications came almost to an end. Since then, there was a steady decrease of magnesium applications until early nineties when the interest and use especially in North America increased again due to new regulations of petrol consumption (CAFE). Though the consumption of magnesium was decreased, various automotive companies continued with magnesium parts in various vehicles (VW Polo, Passat and Golf, Porsche 911 and 928, Daimler Benz, Renault 18 Turbo, Chrysler Jeep and light truck vehicles, Ford light trucks) [9].

Sand casted magnesium wheels were used by Porsche in the sixties for their racing cars 907, 908, 910 and 917 and in 1970 for the first time in standard production for the 914/916 models [10]. This first generation of Mg wheels, although served life-times of more than 150,000 km, were taken out of operation due to lack of understanding of die cast technology, insufficient corrosion properties and the general recession in the seventies. Porsche started the development of the next generation of Mg wheels, produced by low pressure die casting using HPAZ91 [10]. Today most magnesium wheels are forged in 11983 to achieve better strength and fatigue properties.

VW/Audi started with the B80 gearbox housing in 1996 a new era of drive train applications and the available range extended very much since than [11].

## 4. RECENT TRENDS IN MAGNESIUM TECHNOLOGY

### 4.1 Alloy development

Magnesium alloys have two major disadvantages for the use in automotive applications; they exhibit low high temperature strength and a relatively poor corrosion resistance.

The major step for improving the corrosion resistance of magnesium alloys was the introduction of high purity alloys. Alloying can further improve the general corrosion behaviour, but it does not change galvanic corrosion problems if magnesium is in contact with another metal and an electrolyte. The galvanic corrosion problem can only be solved by proper coating systems.

Beside the galvanic corrosion problems related with magnesium the low temperature strength is another serious problem, limiting the use of magnesium especially for power train applications. Typical creep strength/performance requirements and operating temperatures for such applications are shown in Fig. 2. The use for transmission cases and engine blocks requires temperature stability up to 175°C

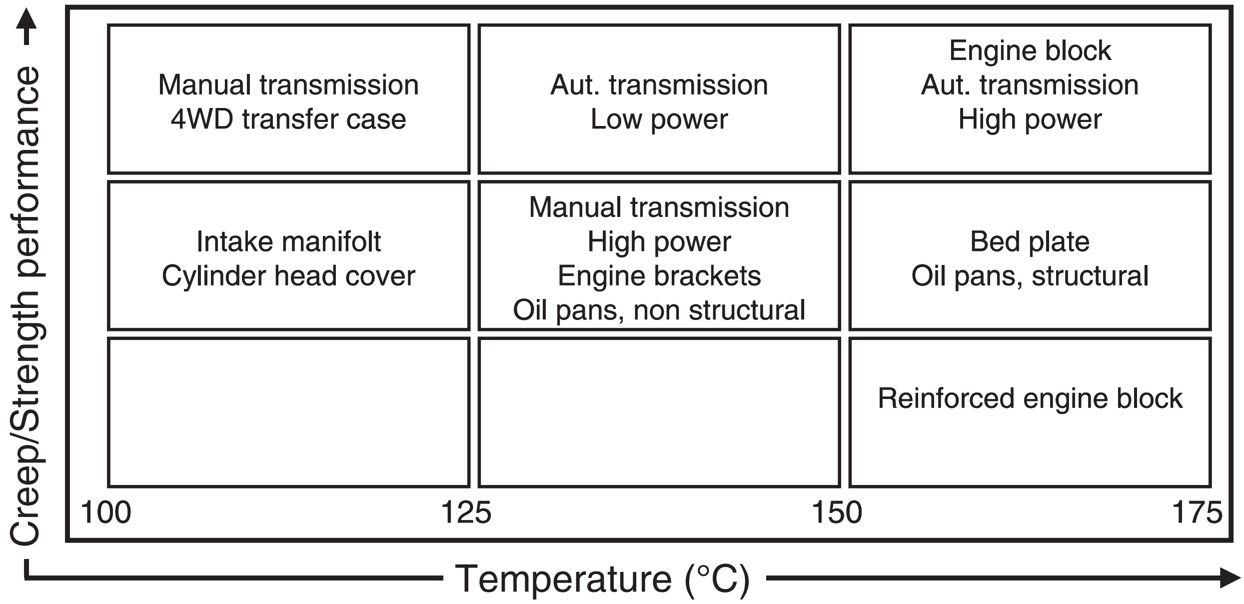


Fig. 2 : Creep/strength performance versus temperature requirements for some automotive drivetrain applications [12]

and in some cases even 200°C for engine blocks. The new high temperature resistant alloys are under further development and testing. Few alloys are already available in the market (e.g. MRI, modified AE and AJ alloy systems) [12,13]. These alloys contain mostly aluminium for good castability and strontium, calcium and/or rare earth elements for better high temperature stability. For automotive applications it is important that the development of new casting alloys addresses creep resistance and cost effectiveness [13]. Under this aspect Mg-Al-Si, Mg-Al-RE, Mg-Al-Ca, Mg-Al-Sr and quaternary combinations of them are very promising new systems for high pressure die casting and Ca, Sr and RE additions are also studied for gravity or low pressure castings [14]. These new alloys have already high temperature properties comparable to common aluminium alloys. A comparison of the performance of an oil pan made from the new magnesium MRI153M alloy and from aluminium A380 alloy revealed that the magnesium alloy performed similar and had the better damping properties [15].

Automotive applications require also good ductility for many components, especially energy absorbed in the case of an accident is a very crucial issue. One direction in the alloy and process development for wrought alloys is to optimise the energy absorption of the material [11]. Nevertheless other components require preferentially higher strength than ductility. Thus alloy development follows various requirements and certain alloy groups can be identified to provide certain properties (Fig. 3).

### 4.2 Processing

#### 4.2.1 *Casting*

Magnesium alloys, especially those with aluminium as a major alloying element show a very good castability. This lead to the use of magnesium alloys in pressure assisted casting processes like warm and cold chamber high pressure die casting. By using the alloy AZ91 thin walled castings with wall thicknesses less than 1 mm can be obtained easily. Other alloy systems like the WE series show a lowered castability but they are well suitable for permanent mold casting or for sand casting. Even these casting operations can be supported by pressure to achieve thin walled structures.

Thus magnesium has excellent die-filling properties and large, thin-walled and complex components can be produced by casting rather than by joining smaller parts together. Low heat capacity, lower latent heat of solidification and less affinity to iron are further advantages of magnesium castings resulting in shorter casting cycles and longer die life times. Magnesium alloys furthermore show thixotropic properties and there are several processes (Thixomolding, Thixocasting, New Rheocasting) under development

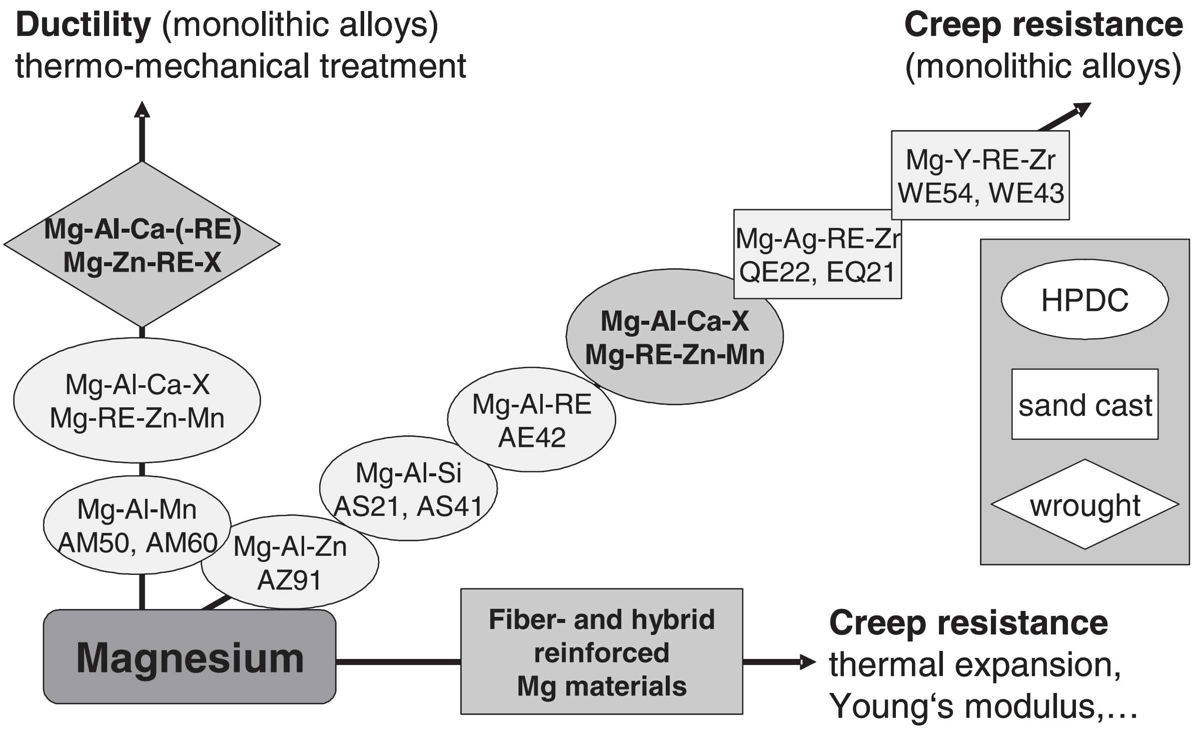


Fig. 3: Directions of alloy development to improve the performance of magnesium components

and optimisation to use semi-solid processing. Better properties and a greater choice of castable alloys (e.g. rare earth containing alloys) are expected. Today protective gases are used in magnesium casting operations rather than covering salts. This greatly improves the quality of the castings. Research is performed to substitute $SF_6$ by more environmental friendly protective gas mixtures.

4.2.2 *Forming*

Wrought alloys generally have higher strength and ductility in comparison with cast alloys. Thus exploitation of the whole potential of light weight construction requires the increased use of rolled, extruded or forged magnesium components. Unfortunately the hexagonal structure of magnesium requires elevated forming temperatures to activate more slip systems and to allow better formability, causing higher energy consumption during processing and causes also a poorer surface appearance. Surface quality and corrosion requirements of the present magnesium sheet alloys are not sufficient for outer panel applications [11]. Therefore alloy and process development especially for sheet material is from major interest to solve these problems. So far mainly AZ31 sheet products are available on the world market in a thickness of 0.8 – 30 mm and widths of up to 1850 mm [16]. Twin roll casting for the production of continuous Mg strips has reached a prototype stage and promises reduced costs due to a reduced number of passes to achieve the fine sheet thickness.

The deep drawing potential of AZ31 sheet was successfully demonstrated [11] as magnesium has similar hot deep-drawing characteristics as steel and aluminium sheet [5]. At 225°C the limiting draw ratio of AZ31 is 2.6, and is thus higher than that of deep drawing Al and deep drawing steels in common use which have a ratio of 2.5 and 2.2 respectively [16]. Further research is performed for processes like bending and hydroforming. A typical automotive applications are extruded and bent profiles for car bumpers [17].

Realisation of mass reduction for extruded magnesium components with comparable strength and stiffness to steel and aluminium requires use of hollow sections with reduced wall thickness and increased cross-section area. Minimal wall thicknesses of approx. 1.5 mm are possible, depending on the section's geometry [18]. To use the forming temperature of the extrusion processes, extrusion can be successfully combined with a subsequent bending step to produce bended extrusion profiles [19].

Nevertheless, potential application of magnesium profiles will strongly depend on the question whether established forming processes for aluminium and steel can be easily adapted to magnesium [11].

### 4.2.3 *Joining*

Joining of magnesium is not very difficult and all conventional joining technologies can be used, although it might be required to adopt the process parameters and to consider some special material properties of magnesium.

Screw joints causes no problems if the property profile of the magnesium alloys is considered for dimensioning and designing of the joint. Different coefficient of thermal expansion can cause loss of pre-stress due to creep of the Mg parts at temperatures above 100 °C if steel bolts are used. For use at elevated temperatures it is better to replace the steel by aluminium bolts. Problems with contact corrosion can be minimized on the one hand by constructive measures and on the other hand by an appropriate choice of the material couple or the use of protective coatings (see also chapter below). Joints can be realised using metric ISO-bolts or self-forming screws. An overview of the various aspects of screw joints is given by Weissert [20].

Adhesive technology has a high potential especially for joints of mixed materials as there are almost no restrictions regarding the material combinations. The selection of the adhesive should consider especially for magnesium a low thermal load, good sealing and electrical isolating properties for corrosion protection, sufficient aging resistance and a suitable coefficient of thermal expansion. Epoxid and polyurethane adhesives fulfil these requirements and are commonly used [21]. To obtain good adhesive strength the magnesium surface requires a suitable pre-treatment, which can range from mechanical roughening for interiors to conversion coatings for corrosive environments. A sub-surface migration of any electrolyte should be prevented by the pre-treatment. Chromating pre-treatments generally show the best results regarding strength and durability, while chrome-free alternatives require further optimisation [22].

Clinching is another suitable joining technology for magnesium, but it requires good formability and therefore elevated temperatures. Experimental tests producing tempered clinchings at 250-300°C were successful [23]. Punch riveting needs also temperatures above 200°C. The rivets are made either from aluminium or steel, while latter are coated with a composite coating (trade name Almac-Zinc) to minimise contact corrosion problems [21]. Blind rivets using a prefabricated hole can be used without or less preheating. Hybrid joints combining adhesive bonding and riveting offer further possibilities to increase the strength of the joint.

Most alloys are readily fusion welded. All well-established welding processes in automotive production (automated MIG/TIG welding and Nd:YAG laser welding) can be used for magnesium, although processing parameters and equipment used for aluminium welding have to be modified [11]. The low heat capacity and low heat of fusion of magnesium requires low power inputs and allows high welding speed. In the Mg-Al-Zn alloys aluminium content up to about 10 wt.-% aids weldability by helping to refine the grain structure, while zinc content of more than 1 wt.-% increases hot shortness which may cause weld cracking [2]. The most promising method for welding thin Mg sheets is laser or electron beam welding and they are also suitable for manufacturing tailored blanks from Mg sheets [16]. Fusion welding of cast parts, especially of high pressure die castings, can cause problems due to entraped gases during the casting process. Friction stir welding (Fig. 4) is a more recent development suitable for joining materials that are more difficult to weld or even for joining dissimilar materials like magnesium or aluminium alloys. Reproducible weldings can be carried out on similar and dissimilar magnesium alloys [24] and also for magnesium/aluminium combinations.

### 4.2.4 *Machining*

Magnesium and its alloys are the most machinable of all structural materials: greater amounts of metal can be removed per unit of time or per unit of power, surface finish is smoother for any given set of conditions, deeper holes can be drilled, and tools retain their sharpness for longer times [25]. But due to its high affinity to oxygen special care needs to be taken if very fine chips occur during machining operations. Especially grinding creates fine dusts or powders that may react easily with water or oxygen. Therefore dry machining or the use of water free coolants is advised.

4.2.5 *Surface protection*

To improve the corrosion and wear resistance of magnesium and to fulfil decorative requirements coating systems are generally used in automotive applications, especially for view parts which are in contact with the environment. Combinations of conversion coatings as a primer and sealing top coats (paint, laquer, e-coat etc.) are state-of-the-art for corrosion protection of magnesium.

Chemical conversion coatings are just a few micrometer thick and thus they are only offering a limited protection. However they are an excellent primer for a subsequent organic coating [26,27]. Best results were obtained by chromating, but because of the health risk involved with chromating the use is strictly limited since 2003 in Europe. Alternatives for chromating are conversion coatings based on phosphate-permangenate or fluoro-zirconate [27]. Depending on the application and the aggressiveness of the environment multilayer systems are used. A typical coating on Mg wheels consists of the conversion coating, a primer, a filler (wet paint or EPS), base coat and clear coat (Norsk Hydro). Sufficient corrosion resistance is also required for the tailgate of the 3-l VW-Lupo, which is a Mg-Al hybrid construction [28]. The inner lining is made of AM50 (HPDC), which is joint to an outer aluminium sheet by adhesive bonding and seaming. A similar multilayer system (pickling treatment, chromating, wet paint (KTL 20 $\mu$m) + EPS (> 80 $\mu$m) is also suitable to prevent contact corrosion on the magnesium part. A two layer system can be sufficient, if a part is less exposed to the surrounding. An example is the inlet pipe of the Audi W 12 cylinder engine which is made of AZ91 and coated with MAGPASS-COAT® and a 200 $\mu$m polyester powder coating [29].

Better wear resistance and also good primer properties are obtained with anodized coatings instead of conversion coatings. However the use for automotive applications is limited due to much higher costs [30], especially for the new high voltage electrolytic plasma anodizing treatments (AHC, Keronite, etc...). Keronite is addressing the problem by reducing the coating time and has reached a deposition rate of 5 $\mu$m/min by optimising the process (introduction of acoustic vibrations and air micro-bubbles). A two minute treatment offers now sufficient corrosion resistance to replace multi layer systems by a single layer of Keronite and moreover the coating is able to withstand a conventional steel body automotive paint line [31].

Electroplating of magnesium is also used in the automotive industry for decorative applications, especially for parts inside the car. For higher corrosion resistance electroplating is deposited as a top layer on a conversion coating/special e-coat layer system. Such a system provides with a chromium top layer a corrosion resistance of 500 h salt spray [32].

In many cases it is sufficient to simply coat the counterpart and leave the magnesium uncoated (if it is no view part), as a defect in a coating on magnesium would result in an enhanced localised corrosion attack of the magnesium component [33]. No contact corrosion of magnesium is caused by anodised AlMg3 alloy [34]. Conventionally galvanised steel bolts can be attached to magnesium by using a silicate sealing. The silicate sealing of galvanised steel bolts was successfully applied by Audi and VW at the B80 magnesium gear housing [35]. A good protection can also be obtained by multi-layer coatings on the critical counterpart, e.g. a zinc coating in combination with a cathodic dip-coating (KTL, 15 $\mu$m) [36]. Another possibility is the use of Sn/Zn-coatings instead of conventional zinc galvanising [37]. Additionally new electrolytic deposited Al-Mg coatings for steel bolts are under development and testing [38]. Already used are also insulating polymer coatings (nylon) or plastic caps for screw heads [33,37]. In addition often washers made of aluminium (6XXX series, sometimes anodised) or polymers are used with steel bolts to minimise the contact corrosion on magnesium [39]. Fibre reinforced PEEK based polymer screws with carbon- or polyamide fibres are also available, with the advantage that polymers are inert against contact corrosion [37].

## 5. RECENT AUTOMOTIVE APPLICATIONS

Although there is increasing interest in using

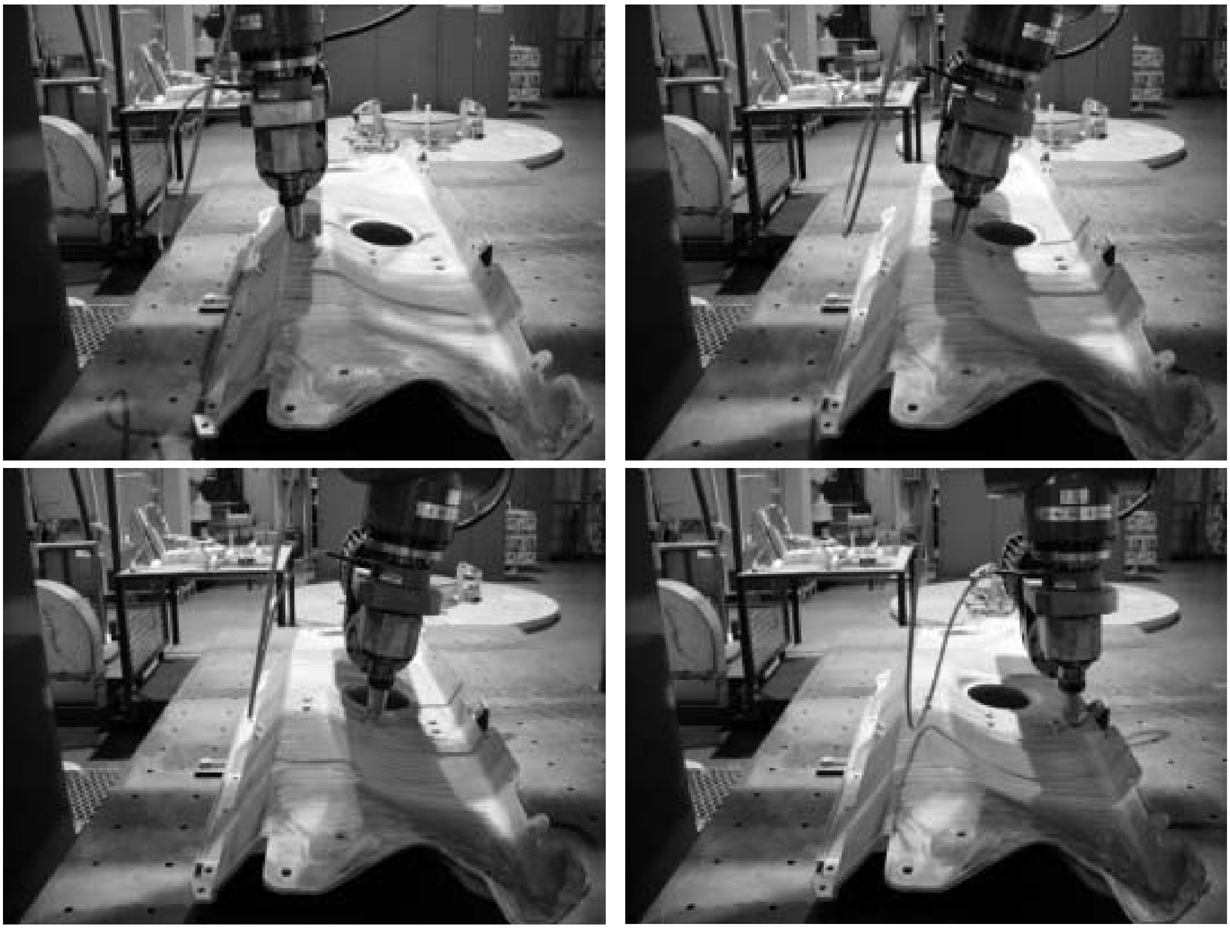

Fig. 4 : Robotic friction stir welding of an AM60 component

magnesium the actual applications are still limited in comparison to their major competitors steel, aluminium and plastics. For example, in a average GM vehicle, the consumption of aluminium is 123 kg against 4 kg magnesium [40]. In some of the vehicles the amount of magnesium used was higher e.g. 12 kg used for instrument panel, transfer cases, steering wheel and side mirror brackets of a GMT800 full-size pickup truck [41], but generally in total it is far less than 1% of the total vehicles weight. The average weight of magnesium in European cars is about 2.5 kg and it is predicted that the 300 different magnesium parts used in European cars today will have doubled within the next ten years [3].

The majority of magnesium applications can be found in interior applications since galvanic corrosion is a less severe problem. The major fields are instrument panels, steering and seat structures. Instrument panels and parts of the steering structure can be found in various mainstream models (e.g. Cadillac models CTS, SRX, STS, Seville, Opel Vectra, BMW Mini, 5 and 7 Series, Rolls-Royce Phantom (Fig. 5) and seat structures in the SL Roadster from Daimler-Chrysler, the Jaguar X-type or the Alpha Romeo 156 [41-43]. VW's 3l Lupo has a magnesium steering wheel core [18] similar to many other cars (e.g. models from Toyota, BMW etc.). Actually the highest part penetration in Europe is in steering wheels, nearly 85% of which are made of magnesium alloys [3].

Applications for the car body are very limited. GM has been using a one-piece die casting roof frame in its C-5 Corvette and BMW roof compartment lid on the BMW 3 Series Convertible [41,43]. Daimler-Chrysler and VW have been experimenting with magnesium door inners (Fig. 6) or tail gates in the SL Roadster, CL Coupé model and the three-liter Lupo respectively. All these applications have been die castings and no sheet/wrought applications. However the 1-Liter-Auto demonstrator from VW shows that there is potential for more wrought magnesium

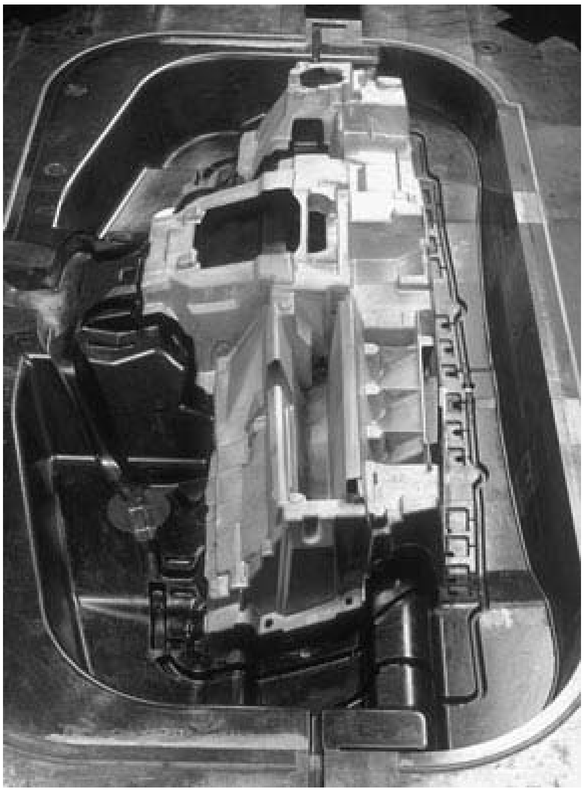

Fig. 5 : Magnesium instrument panel for the Rolls-Royce Phantom: casting in the die [43]

products in the car body. The whole space frame is made from magnesium cast and wrought products.

In the field of chassis applications Porsche has quite a long experience with magnesium wheels and also GM has been offering cast magnesium wheels for Corvette since 1998 [41]. However magnesium wheels didn't succeed to spread from these special sport car applications to the high-volume vehicle market due to much higher costs and potential corrosion problems.

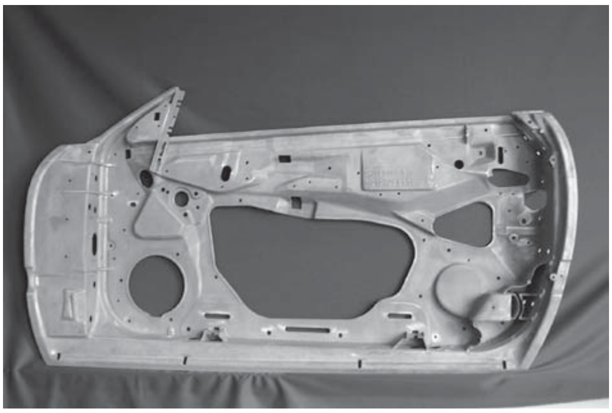

Fig. 6 : Inner door frame of the Daimler-Chrysler SL Roadster [Courtsey Jo Wilkens, HydroMagnesium Marketing GmbH, Brussels, Belgium]

Powertrain applications are so far restricted to lower temperature applications. GM uses magnesium transfer cases in their GMT800-based trucks and sport utility vehicles, VW uses manual transmission cases in the Passat and the Chinese Santana model and Audi in the A4/A6 model. Cam covers are made from magnesium on vehicles ranging from the Dodge Viper to the new Ford F-150, utilising the good sound dampening characteristics [42]. Audi has some more magnesium applications in the power train, such as the air intake module on its W12 engine, cylinder head covers on its V8 and the company's multitronic CVT and five speed manual transmission both have magnesium housings [42]. BMW uses a magnesium housing for the fully variable intake manifold featured on BMW's 8-cylinder power units [43] and also VW's W12 engine for the Phaeton has a magnesium inlet manifold [44]. Engine blocks (after the end of VW's beetle air cooled engine) are just used in racing cars, as with more conventional engine applications corrosion is a problem, because the coolant tends to react with the magnesium [42]. Nevertheless BMW has recently introduced a magnesium engine block, which is the first major high temperature engine application for magnesium [3]. Actually it is the world's first composite magnesium/aluminium crankcase for a water-cooled engine [43]. The composite crankcase incorporates an aluminium insert surrounded by magnesium in the upper section of the cylinder liners and water cooling jacket providing sufficient thermal strength for the bolts and connections for the crankshaft bearings and cylinder head (Fig. 7). The magnesium housing serves primarily for the oil ducts and the connection of ancillary units. This crankcase for a straight-six power unit is a series-based development and is scheduled to enter regular production in BMW power units in the next two years.

## 6. SUMMARY AND CONCLUSIONS

There are various problems to be solved but there is a much bigger potential for magnesium alloys in automotive application than currently used. Figure 8 shows an estimation from VW revealing the amount of magnesium in potential future use in the major four groups of car components - power train, interior,

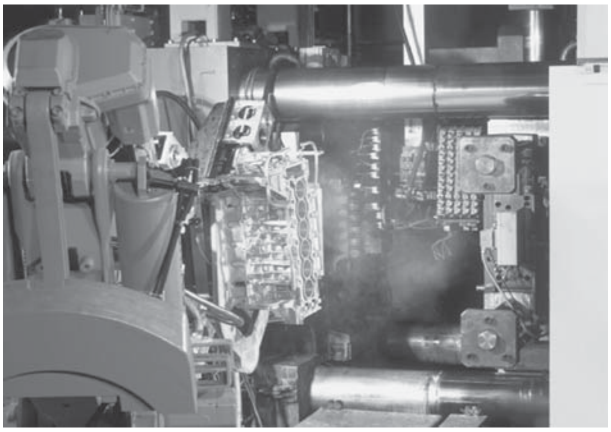

Fig. 7 : World's first composite magnesium/aluminium crankcase for a water-cooled engine developed by BMW - automated removal of the crankcase from the die casting maschine [43]

body and chassis. This means that an increase from less than 2% to about 15% of the total weight, assuming a weight of 1200 kg for an average modern car, can be expected in the long term. This increase of magnesium in automotive applications is considered as possible by VW if further basic conditions are achieved, which are[11]:

- increased inhouse-recycling to reduce costs
- secondary material flow
- adaptation of existing and development of new cast and forming technologies
- development of new Mg alloys with improved properties
- construction appropriate to magnesium
- integration into a multi-material-design concept
- enlargement of the know how data base

Similar numbers are known from other major car manufacturers. Ford uses an average of around 2.3kg of magnesium in each vehicle and its annual usage of around 16,000 tonnes per year now is forecast to rise to about 45,000 tonnes by 2005. By 2020 Ford would like to be using 113kg per vehicle, or around 870,000 tonnes at today's volumes [5].

The ongoing developments should be able to generate alloys with sufficient properties and also a suitable coating technology for corrosion protection to fulfil all automotive requirements. Developing new and perfecting old casting and manufacturing technologies will help to minimize the costs for components and help to increase the area of applications. BMW's new magnesium/aluminium composite crankcase is a good example how innovative casting technology in

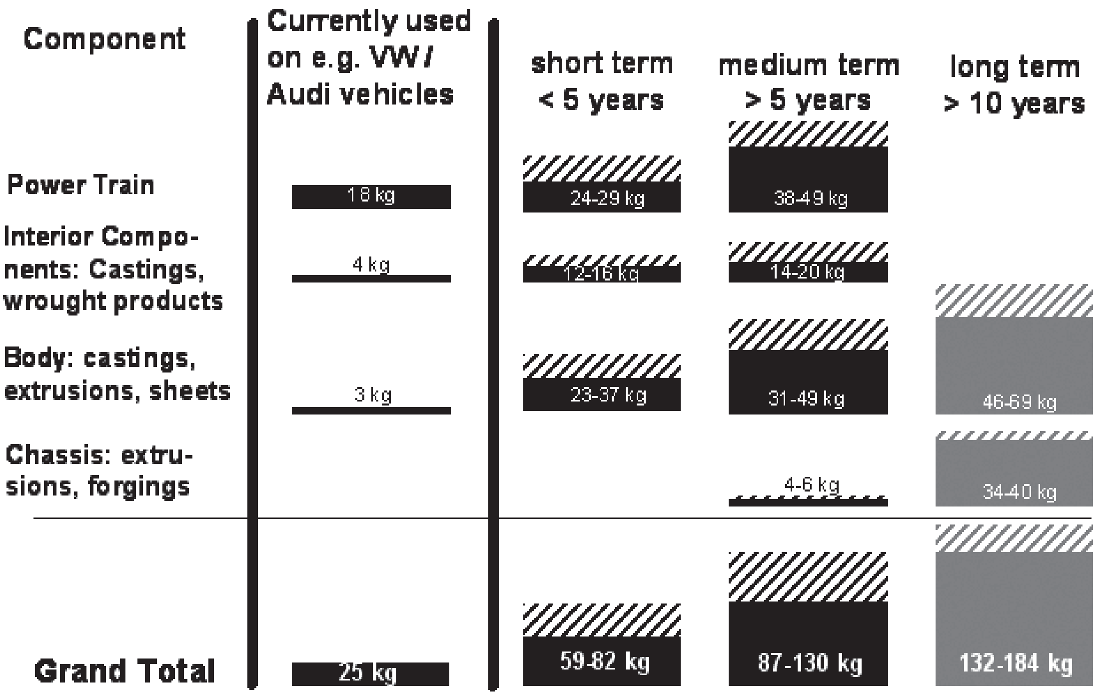


Fig. 8 : Currently used magnesium and prediction of potential use of magnesium in VW/Audi vehicles [11]

combination with material development can develop a new field of application. But however the future use of magnesium will still depend on the development of the raw material price and the availability. The cheaper it will become the more likely is a replacement of aluminium, steel and plastics by magnesium, but especially the automotive industry requires also a secure supply of high quality alloys. The role of China as the dominating producer of primary magnesium has a positive effect on the price, but with more and more western producers forced to close down their establishments comes as concern of being to depended on one supply source. To address a part of the problem Hydro Magnesium is already the first western magnesium alloy producer who set up facilities in China. The other point regarding costs is the development of a sufficient recycling concept for magnesium including the development of suitable secondary alloys to guarantee the recycling of all magnesium components at the end of a vehicles life time. A final crucial point is how easily shaping and forming techniques and equipment used so far for steel or aluminium can be modified to the requirements of magnesium processing. It becomes clear from the above that the further promotion of magnesium use requires a joint effort of the suppliers and the automotive manufacturers together.

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