

NEW CHALLENGES AND DIRECTIONS FOR HIGH PRESSURE DIE-CAST MAGNESIUM

L. Zaffaina, R. Alain, F. Bonollo, Z. Fan

Being the lightest structural metallic material, Magnesium is widely used by the automotive industry when searching for solutions to address energy consumption, emission reductions and vehicles handling. The need to use light-weight solutions is becoming stronger than it has been so far, as other technologies allowing to reduce emissions have already yield a lot of their potential.

This wider use of Magnesium requires to grow more knowledge on the material properties, corrosion protection techniques and improved production processes. However material R&D cannot be limited to property studies and potentials: directions for innovation implies to understand all the benefits of the material and process for each application and their values to the customer.

In this work, the components' key attributes will be highlighted, together with the efforts to lower costs and the potential use of new technologies.

KEYWORDS: magnesium, optimisation, applications, automotive, CAE led design, innovation, value analysis, HPDC, melt conditioned HPDC

INTRODUCTION

Over the last decades, the demand for magnesium components in the automotive industry kept increasing. The key drivers have been the need to reduce fuel consumption and emissions and the need to improve vehicle handling. However there are other advantages to use cast magnesium solution such as improved tolerances, higher potential to contribute to vehicle stiffness, higher fit and finish, improved noise vibration and harshness performance; but these are difficult to evaluate and not often quantified in assessing the overall product values. In order to plot the directions for innovation in terms of technology and applications, it would be useful to clearly understand the list of benefits of magnesium casting and their value to the customer.

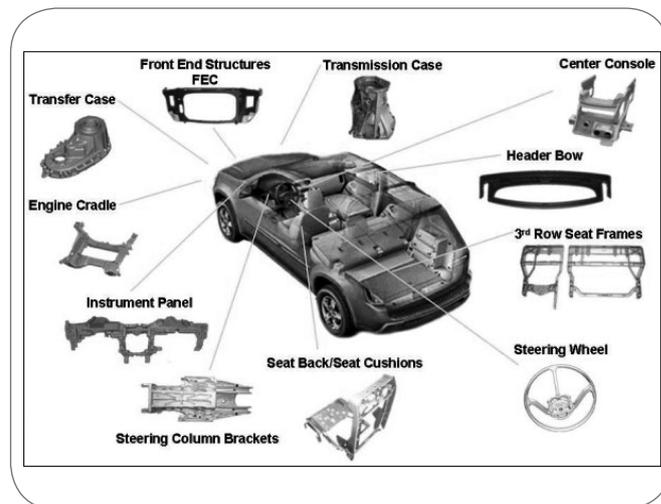
A view of the market from Meridian's point of view is shown here, together with the technologies whose have triggered new applications to appear in the market.

A MARKET VIEW

Fig. 1 shows the main cast magnesium components for automotive industry. Meridian's key products in power-train

applications are transfer cases and transmission housings with more than 2 million cast per year; steering column brackets and instrumentation panels are the main body component produced. (respectively 3 and 2,5 million parts per year).

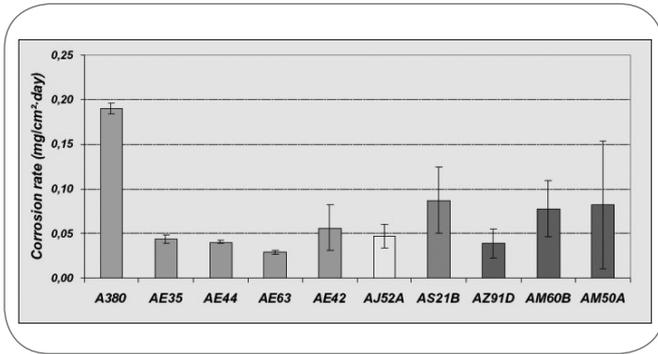
New components are gaining growing interest at car makers, as indicate increased number of request for quotations and ongoing development studies; these applications are Front End Structures, Engine Cradles, Centre Consoles and



▲
Fig. 1

Main automotive diecast magnesium applications.
Principali componenti in magnesio pressocolato nell'auto

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Fig. 2

Various Mg and Al alloys performance after 240 hours ASTM B117 salt spray [2].

Confronto tra le prestazioni di alcune leghe di Mg e Al dopo 240 ore in nebbia salina (ASTM B117)[2].

Power train applications (transmission cases, cam covers, oil pan, engine brackets).

The general message perceived from the costumers is that the need to use light-weight solutions is becoming stronger than it has been so far, as other technologies allowing to reduce emissions have already yield a lot of their potential.

CHANGES ON THE MARKET AND THEIR EFFECT

With regards to magnesium applications, the recent changes that have happened are as follow:

a) Availability of chromium-free corrosion prevention solutions helped to introduce exterior components with aesthetic requirements like Front End Carriers, door frames, roof mechanisms or rear window frames.

b) Low creep alloys with high ductility (AE44) led to the introduction of magnesium castings for engine applications, where both crash and high temperatures have to be met. Meridian produces the first example of engine cradle for the General Motors Corvette Z06 and more components are currently under development. In addition to the high temperature mechanical properties, AE44 shows better corrosion resistance than common used ductile alloys (AM60, AM50): the general corrosion resistance is even higher than the AZ91's commonly used for transfer cases (see Fig. 2). As this part is not cosmetic, just like a transfer case, the Engine Cradle is not coated. [1]

c) Over the last two years, the cost of Aluminium alloys increased while magnesium alloys remained stable, hence Magnesium has become more attractive for power train components. This cost evolution and the increased need for weight saving is driving new interest and developments from costumers.

UNDERSTANDING WHAT CUSTOMERS VALUE

The changes mentioned above are not sufficient to understand the growth of specific applications on the market and why for some costumers Magnesium has become core roots for defined applications, while others do not follow the trend.

Above weight saving, costumers see other interesting features in the use of Magnesium on specific applications:

these are not always easy to capture by a tier 1 or tier 2 supplier. For a similar product, the functions to achieve can vary a lot depending on the customers or vehicle and the benefit of using Magnesium will vary. Each product been specific even within a family of products, general rules on reason to use Magnesium are difficult to extract.

More focus has been put to try to understand drivers to chose Magnesium, what influences costs and where the costumer will find more interest in the technology. In other words where will the costumer find values. According to J.C. Anderson and J. A. Naurus "Value is the worth in monetary terms of the technical, economic, service and social benefits a customer company receives in exchange for the price it pays for a marketing offer" [3].

It is important to keep in mind that the customer does not really want materials or services. He wants Use and/or Aesthetic functions to be accomplished. [4]

On products two kind of functions can be individuated: pre-requisites and attributes.

The pre-requisites are the functions for which there is a target to reach and the customer is not willing to see value in an extra-performance.

At the opposite, for attributes, the customer is willing to value an increased performance. By extension the costumer could also review his requirements at the system level and allow a reduction in performance in exchange for a price reduction.

WORK TO LOWER THE COST OF FUNCTIONS

As all automotive suppliers, Meridian works to reduce costs, and different approach are used. The usual one, based on product cost breakdown, is not sufficient to identify actions; it has been found that more ways to reduce cost could be yield by doing the analysis operating on the cost per function. An extension of this approach is the identification of other markets i.e. new applications for which current technology could reach other values at an interesting cost.

In an ideal world, it would be useful to plot for each function, the state of the market, i.e. for each function, what level is reached, at which costs, where Magnesium technologies are present. A successive step should be to assess if different values could be reached, at which costs and with which technology improvements. Unfortunately such approach is not feasible as it would require to grab a high amount of information from the customer.

For a single component, the system is complex, and it is actually sometime not even obvious for the customer to know that he has the information about component/system functions and their value: in fact the data may lay in different functional areas [3].

Considering the complexity of the component and the system, a simple approach has to be developed so that it can be reapplied to other products.

The investigation has then to focus on:

- identify functions
- understand attributes and values
- assess the cost for attributes and values
- reduce cost to achieve attributes and values
- understand costumers sensitivity to different values

In this work, the component's key attributes will be highlighted, together with the efforts to lower costs and the potential use of new technologies.

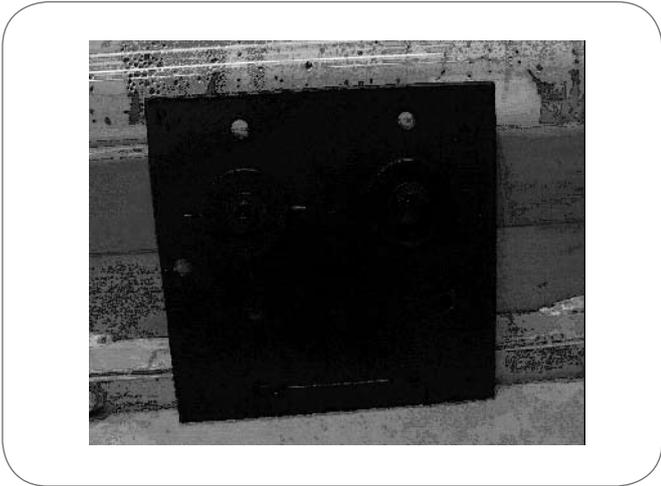


Fig. 3
Sample of AM60B after 1000h of salt spray test - ASTM B117.
 Provino in AM60B dopo 1000 ore di nebbia salina - ASTM B117.

NEW COMPONENTS

a) Front End Carrier (FEC)

- The features that costumers value for front ends are:
- weight saving (40 to 50%), i.e. 3 to 9 kg depending on the type of vehicle [5]
 - induced weight saving: the reduced weight at the front of the vehicle reduces load on the body in white
 - better fit and finish performance compared to steel when requirements increase
 - high stiffness achievable, hence potential to redistribute stiffness target at the system level
 - better air flow management offered by foundry shape
 - higher integration offered by the foundry compared to welded technologies

In the past, the biggest issue facing the use of magnesium for exterior applications has been corrosion prevention and in particular galvanic corrosion. Today galvanic and cosmetic corrosion requirements are achieved by proper design of component and fixings and proper choice of joint materials. Two principles are to respect. The first one is to insure a good drainage in fixing areas to avoid that mud and humidity get trapped. The second is to separate Magnesium from steel by the introduction of an Aluminium spacer, respecting a simple design rule that is to have a minimum distance of 10 mm between Magnesium and steel.

Cosmetic targets have to be achieved, hence parts have to be coated. Current solution consist of an acid etch to remove surface iron particles picked up during casting process, a chemical conversion coating to insure the adhesion of the final top coat that is an epoxy base powder coating. This solution is capable of 1000 hours salt spray tests and of 12 weeks humidity salt spray tests (see Fig. 3).

To reduce cost, new development consider top plastic cover so that the magnesium part is not visible anymore and coating can be removed.

Over last six years, the use of magnesium for FEC extended from light truck to SUV and finally to passenger car where component weight decreased from 5 to 3 kg, whilst increasing crash

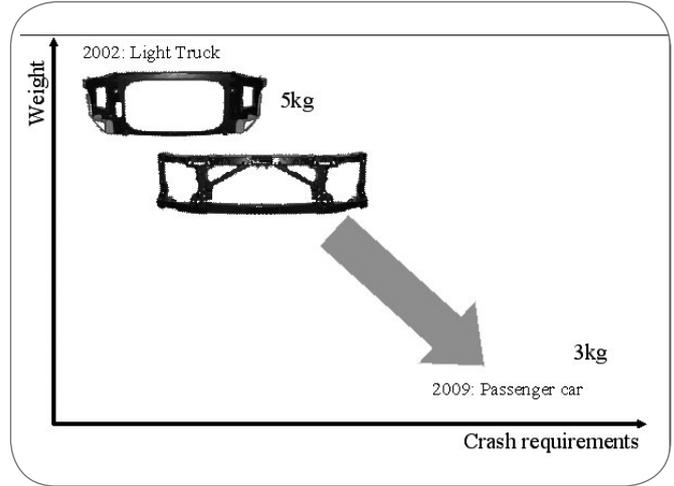


Fig. 4
Evolution of FEC weight and performance.
 Evoluzione del peso e delle prestazioni dei FEC.

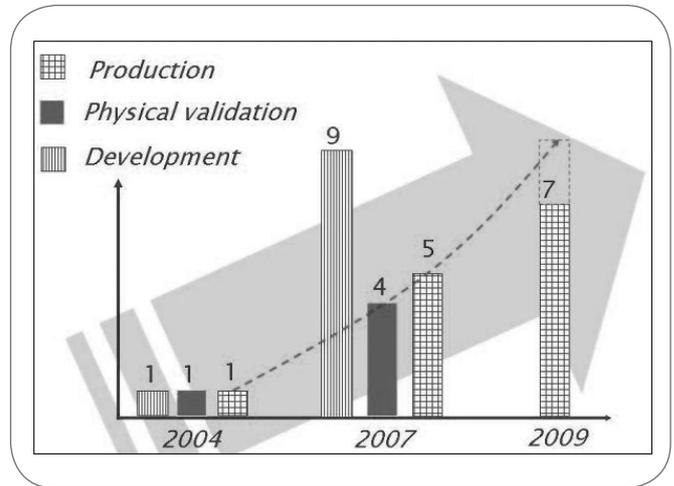


Fig. 5
FECs developments and production trend.
 Nuovi FEC in sviluppo e in produzione.

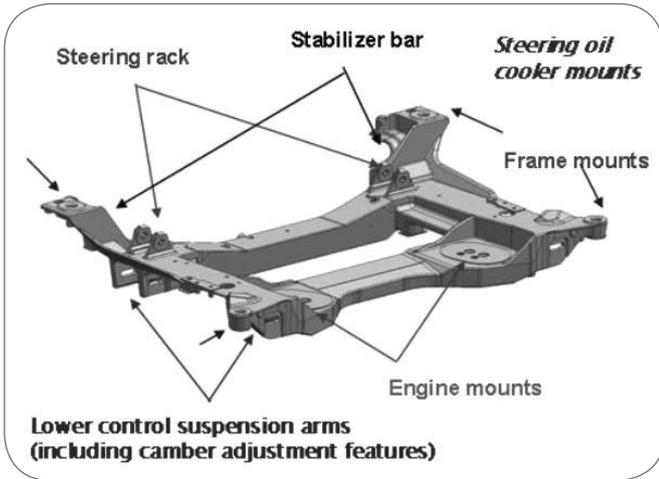
requirements were met. (Fig. 4)

The potential of Front End Structure is strongly dependant from the type of Front End and the functions it has to achieve.

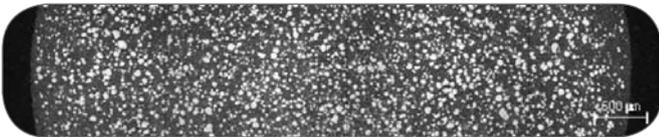
The number of part in production in Europe has increased from 1 to 4 from 2004 to 2007 and 7 will be in production in 2009. Components under development and physical validation increase coincidentally, as shown in Fig. 5.

The first development was carried out in North America and led to development and production of the Corvette Z06 Engine Cradle (Fig. 6). The project's aim was to achieve significant weight savings and it led to the development of a new alloy capable of high to moderate strength, ductile behaviour to function in cyclic loading, elevated temperature and corrosive environment resistance.

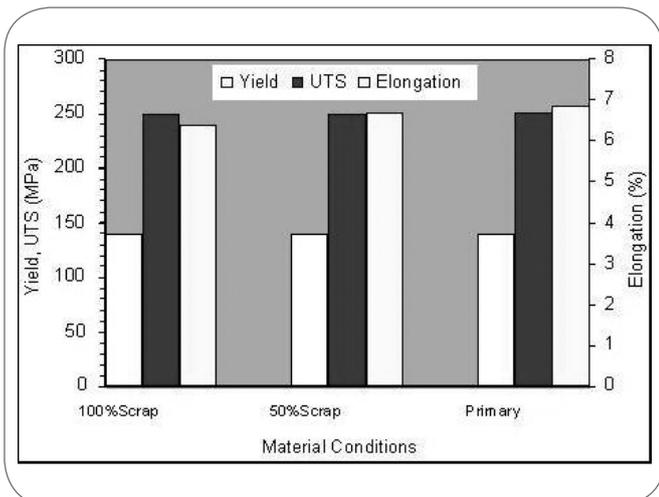
The magnesium solution led to a 32% weight saving in comparison with aluminium which means 4,8kg. The new alloy is capable of working at 125°C, has improved elongation (9-10% with 7mm-thick walls) and good corrosion resistance. Proper alloy properties together with an accurate fixings design allowed to avoid any surface treatment. For this sport car the key attribute



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Fig. 6
Corvette Z06 Engine Cradle.
Supporto motore della Corvette Z06.



▲
Fig. 7
Microstructure of AZ91 alloy bar (6mm diameter) produced by the MC-HPDC process showing fine and uniform microstructures and close to zero porosity (<0.2%).
Microstruttura di una barra di AZ91 (diametro 6mm) prodotta con il processo MC-HPDC. Si notano la microstruttura fine e uniforme e la porosità prossima a zero (<0,2%).



▲
Fig. 8
Comparison of mechanical properties of AZ91D alloy with different levels of scrap addition produced by the MC-HPDC process.
Confronto delle caratteristiche meccaniche della lega AZ91D prodotta con il processo MC-HPDC utilizzando differenti percentuali di materiale di scarto.

is an important weight saving associated with the size of the part in an area where Magnesium had not been used before. Alloys development has allowed new chassis and power train application to be considered: productions processes in conjunction with material properties and Meridian design approach [6] will lead to more engine cradles, engine brackets, power train components.

c) Centre Console Structure (CCS)

The Centre Console Structure is one of these products for which requirement can differ strongly for one application to another. Key attributes are:

- weight saving of 50% compared to steel
- high integration in a small mass of Magnesium, hence very cost efficient
- increased potential to offer storage volume offered by casting potential
- improved assembly precision due to one-piece solutions, which improves visible perception of quality
- can be structural and transfer load in lateral impact in specific vehicle configurations
- can be cosmetic with a coating: an example of that is the ford GT40 console

Customers show more and more interest in Centre Console Structure, and the amount of development is growing significantly.

INCOMING APPLICATIONS AND TECHNOLOGIES

Some interesting opportunities and projects under development are briefly mentioned here.

a) Increased use of optimisers

CAE-led design approach [7] gives interesting advantages such a significant reduction of time to deliver the concept, possibility to provide to customer the CAE model in advance to verify structural performance and a mid-surface model to check the package.

In addition to that, the use of optimisers since the early concept-design stage makes that geometry can be design to maximise the value to customer by using optimisers to lower the cost for functions or to minimise the weight-saving premium price.

Ongoing and future developments will extend this approach with increased use of optimisers on process and design.

b) MC-HPDC process

Melt conditioned high pressure diecasting (MC-HPDC) process, previously named rheo-diecasting (RDC) process, is a combination of a MCAST (melt conditioning by advanced shear Technology) machine for melt conditioning with a standard high pressure diecasting (HPDC) machine for component shaping [8].

Laboratory trials show that the MC-HPDC process is capable of producing close to zero porosity samples with a fine and uniform microstructure throughout the entire component (Fig. 7). MC-HPDC process provides samples with improved strength and ductility in the as-cast condition, compared with HPDC or other available semisolid processing techniques. Initial tensile test have shown elongations up to 20% on AM50 test sample [9].

Extended work on this process has shown that the MCAST machine is actually mostly acting as a grain refining device and that it could be used with 100% liquid, meaning that all process parameters can remain unchanged compared to conventional HPDC process. The addition of this single

piece equipment to an existing HPDC machine would limit investment and permits new applications. Potential applications could be in the suspension area, together with AE44 showing high temperature resistance, very good corrosion performance and increased ductility.

Another interesting characteristic of the MCAST machine is the fact that it breaks up oxides in small round-shaped particles well dispersed through the entire components. This characteristic opens another potential that is the possibility to use scrap parts and runners systems for specific internal applications, leading to interesting cost savings [10]. Fig. 8 compares the mechanical properties of AZ91 alloy produced by the MC-HPDC process using different amount of scraps.

c) New trend on approaching cosmetic corrosion

As market grows, cost for coating has significantly decreased; another consideration is the fact that the coating is acting just to respect visual requirements, while the structural-galvanic corrosion resistance is obtained through spacers and proper design of components. Hence in some cases where part would not be visible coating could be removed: it could be the case on FEC by masking the top surface with a plastic cover.

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ABSTRACT

NUOVE SFIDE E DIREZIONI DI SVILUPPO PER IL MAGNESIO PRESSOCOLATO

Parole chiave: magnesio e leghe, corrosione, pressocolata, tixoforatura, impieghi alta/bassa temperatura, processi, produzione, proprietà

È noto come il magnesio sia il più leggero tra i materiali strutturali: è questo il principale motivo per cui è utilizzato in maniera estensiva nell'industria automobilistica (fig. 1) al fine di minimizzare i consumi energetici e le emissioni inquinanti e nel caso in cui si voglia migliorare la maneggevolezza dei veicoli.

La spinta verso l'alleggerimento ha visto un'accelerazione negli ultimi anni dovuta probabilmente al fatto che altre tecnologie tese a ridurre le emissioni hanno già raggiunto gran parte del loro potenziale.

Un utilizzo più ampio del Magnesio comporta la necessità di aumentare la conoscenza delle proprietà del materiale, delle tecniche di protezione dalla corrosione (figg. 2, 3) e di processi produttivi migliorati.

Tuttavia le attività di R&S non possono essere limitate allo studio delle proprietà e dei potenziali del materiale: indirizzare l'innovazione in termini di tecnologie e applicazioni implica comprendere tutti i benefici

del materiale e del processo per ogni applicazione e il loro valore per il cliente.

Oltre alla riduzione di peso ci sono infatti altri vantaggi nell'uso di soluzioni in magnesio pressocolato quali: riduzione delle tolleranze, potenzialità di contribuire alla rigidità del veicolo, miglioramento dell'assorbimento delle vibrazioni; purtroppo questi benefici sono difficili da valutare e spesso non quantificati nella stima del valore complessivo del prodotto da parte del cliente.

In questo lavoro sono analizzati alcuni dei cambiamenti tecnologici e di mercato che hanno permesso l'estensione del magnesio pressocolato a nuove applicazioni (fig. 6) e il loro impatto su specifici componenti.

Si è evidenziato come i cambiamenti citati non siano sufficienti a spiegare la crescita di specifiche applicazioni (fig. 5) e come sia difficile estrarre regole generali che spieghino le ragioni per cui si scelga di utilizzare o meno soluzioni in magnesio pressocolato.

Diventa quindi importante lavorare al fine di comprendere quali siano le funzioni del componente e i loro costi e cercare di indirizzare le attività di R&S alla riduzione del costo delle specifiche funzioni.

A titolo esemplificativo sono sottolineati in questo lavoro gli attributi chiave per alcuni componenti (fig. 4), gli sforzi tesi a ridurre il costo e il potenziale d'uso di alcune nuove tecnologie (figg. 7, 8).