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High Performance HPDC Alloys as Replacements for A380 Aluminum Alloy

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Abstract

One of the most direct methods of improving fuel economy and reducing CO2 emissions is automotive light weighting. Currently the automotive industry is searching for lightweight materials for powertrain parts which are subjected to both high temperature and dynamic loads. However until recently, the utilization of magnesium alloys in powertrain parts is very limited due to some reasons mainly associated with increased magnesium cost compared to aluminum and to great extent with, with lack of suitable HPDC magnesium alloys with properties which match closely those of HPDC aluminum alloys like A380. The present paper addresses high-pressure die cast magnesium alloys MRI 153M and MRI 230D that combine numerous advantages of standard magnesium alloys over aluminum alloys with enhanced general corrosion resistance and creep performance at competitive cost. Specific benefits and weight reduction associated with the use of MRI alloys are discussed and disclosed.

Introduction

Currently the automotive industry is searching for lightweight materials for powertrain parts, which are subjected to both high temperatures and dynamic loads. Magnesium high-pressure die casting (HPDC) alloys are finding increasing applications in the automotive industry due to the range of their attractive properties such as high strength/stiffness to weight ratio, diecastability, damping capacity, the possibility of integrated design, etc [1,2]. Magnesium alloys are widely being used in safety related parts such as steering wheels, instrumental panels, seats and doors. For automotive powertrain applications, the alloy selection is dictated by number of requirements that include creep and corrosion performance, tensile, compressive and fatigue properties, castability and production cost. Until recently, the utilization of magnesium alloys in powertrain parts was not realized due to reasons mainly associated with increased magnesium cost compared with aluminum and, to great extent, with lack of suitable HPDC magnesium alloys that have characteristics that match closely those of HPDC aluminum alloys like A380.

The situation is now changing due to the emergence of several creep-resistant HPDC alloys during the last 5 years [3-9]. With the increasing pressure towards fuel efficiency and reduction of CO_2 emissions, major automotive manufacturers have initiated component development programs particularly in the area of powertrain applications where significant weight reduction can be obtained by replacement of existing aluminum or steel components with creep-resistant high performance magnesium alloys.

The present paper addresses the possibility of using DSM's proprietary alloys MRI 153M and MRI 230D as direct substitutes for widely used HPDC aluminum alloy A380.

Overview of HPDC MRI alloys

Creep-resistant alloy MRI 153M alloy [5,7] was developed to provide an inexpensive solution for powertrain parts being used at temperatures up to 150^0C under loads up to 80 MPa. This alloy has excellent castability due to increased Al content, around 8 wt.%. The relatively high Al concentration does not lead to a formation of undesirable ß-$Mg_{17}Al_{12}$ phase (which would degrade creep resistance), since the excessive aluminum is bounded to other alloying elements such as calcium and strontium to produce thermally stable compounds Al_2(Ca,Sr) and also modify the ß-phase with Ca thereby increasing its thermal stability[5-7].

Fig.1a shows a typical network of such compounds along α-matrix dendrites in the microstructure of die cast MRI 153M alloy. The high Al concentration in MRI 153M actually results in increased room temperature tensile, compressive and fatigue strength as well as improved corrosion resistance.

The microstructure of MRI 230D [8] is shown in Fig. 1b. Due to the higher Ca content compared to MRI 153M alloy, intermetallic compounds in MRI 230D make up a continuous network with lower secondary dendrite arm spacings (SDAS). The microstructure of MRI 230D alloy is very stable and it is capable to serve up to 190^0C, under stresses of 70-100 MPa. The alloy also has adequate castability and the highest tensile and compressive yield strengths among all new and commercial magnesium alloys [3-9]. The general corrosion resistance of MRI 230D also surpasses that of aluminum alloy A380 [3, 6].

Mechanical properties of MRI alloys are listed in Table 1 in comparison with properties of AE44 magnesium alloy and A380 aluminum alloy. AE44 is a creep-resistant magnesium alloy that was developed by Dow Magnesium at the beginning 70's [10] and then restored and explored in detail by Hydro Magnesium over last 4 years [11, 12]. As outcome of these activities AE44 alloy is being used in for use for the Z06 engine cradle.

As can be distinctly seen from Table1 MRI alloys and A380 alloy have similar TYS and CYS values in the temperature range 20-175°C. On the other hand, all the three alloys significantly outperform AE44 alloy in strength properties. The combination of strength and ductility for different alloying systems is shown in Fig. 2. The points related to MRI 153M, MRI 230D and AE series of alloys lie on the same curve while AJ magnesium alloys and aluminum alloy A380 exhibit inferior combination of TYS and ductility.

The creep performance of HPDC alloys MRI 153M and MRI 230D is demonstrated in Figs 3-5. It is evident that MRI 230D and A380 have similar creep resistance at 100-180°C under stresses of 70-110 MPa. On the other hand, AE44 alloy has inferior to other alloys creep performance under 110 MPa at 100°C (Fig .3).

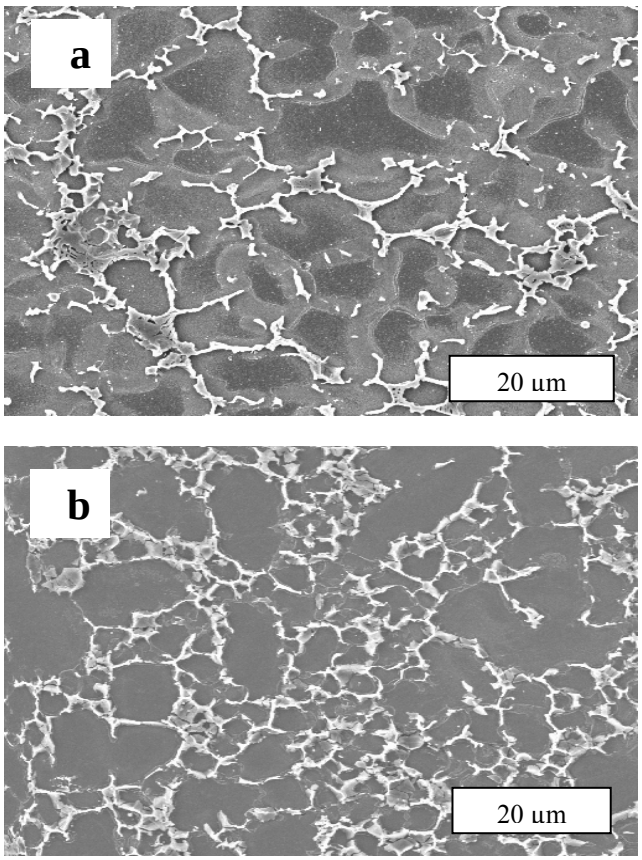


Fig. 1.The microstructure of die cast MRI 153M (a) and MRI 230D (b) alloys

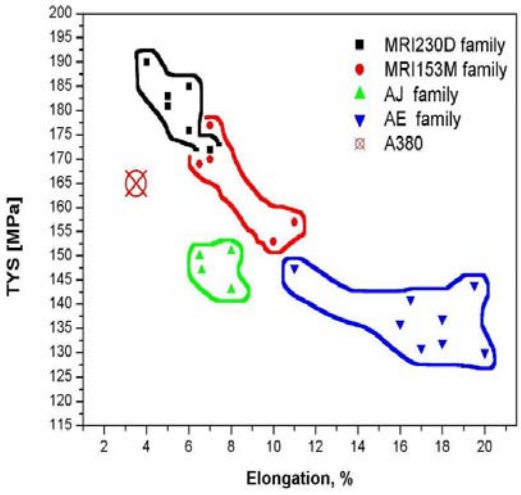


Fig.2. Correlation between TYS and elongation for different creep resistant magnesium alloys and aluminum alloy A380 [3, 5-8, 11-12]

Table 1. Mechanical properties of MRI alloys compared to AE44 magnesium alloy and A380 aluminum alloy

Properties	MRI 230D	MRI 153M	AE44	A380
TYS (MPa)				
20 °C	180	170	136	165
150 °C	150	135	115	150
175 °C	145	125	110	135
UTS (MPa)				
20 °C	245	250	240	330
150 °C	205	190	162	235
175 °C	178	172	150	195
Elongation (%)				
20 °C	5	6	11	3
150 °C	16	17	19	5
175 °C	18	22	25	6
CYS (MPa)				
20 °C	175	165	130	-
150 °C	145	130	110	
175 °C	140	120	105	

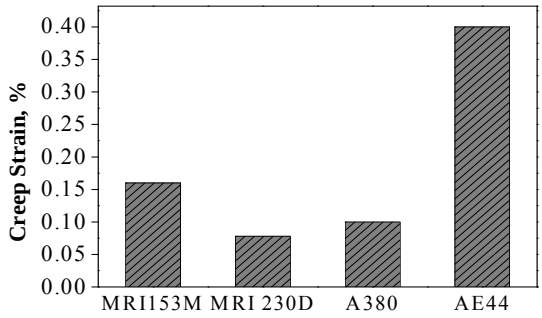


Fig. 3. Creep strain achieved in different alloys at 100 °C / 110 MPa for 500 hours

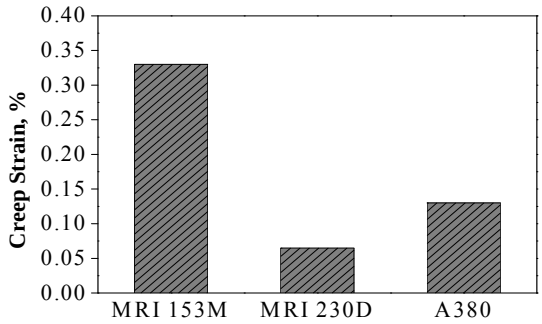


Fig. 4. Creep strain achieved in different alloys at 150 °C / 70 MPa for 500 hours

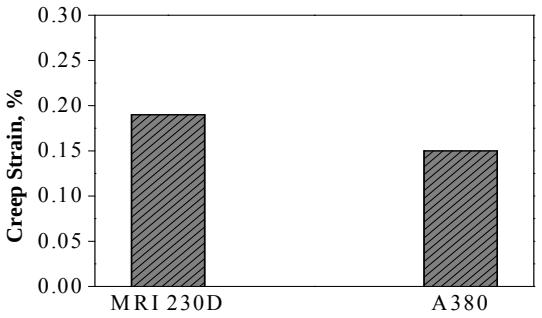


Fig. 5. Creep strain achieved in different alloys at 180°C / 70 MPa for 500 hours

Another very important characteristic of high-temperature behavior is bolt load retention capability that associated with resisting the metal to stress relaxation under the bolts. The stress relaxation may lead to loss of clamp load and oil leakage. The results of bolt load retention tests performed at 150 and 175 °C for 200h on samples excised from actual components are given in Table 2. Comparison of the results obtained show that under compression test magnesium alloys are still inferior to A380 alloy. However MRI alloys significantly outperform AZ91D alloy. The retained stress at room temperature in the range of 50-75 % that was determined for MRI alloys is sufficient for reliable service of these alloys at the temperature range of 150-175°C.

In addition to superior tensile compression and creep properties, MRI 153M and MRI 230D alloys exhibit excellent corrosion performance. Table 3 demonstrate the corrosion rates of four alloys obtained on the HPDC plates with dimensions of 140x100x3 mm under salt spray testing as per ASTM B 117 and two widely used cyclic corrosion tests GM 9540P and SAEJ2334. It is evident that at all the above tests corrosion behavior of MRI alloys is similar to that of benchmark alloy AZ91D and superior to corrosion resistance of A380.

Table 2. Bolt load retention properties of MRI alloys compared to AZ91D and A380 alloys

Alloy	Percentage of retained stress at room temperature after 200 h testing at elevated temperatures		
	150°C / 50 MPa	150°C / 70 MPa	175°C / 70 MPa
AZ91D	25	19	-
MRI 153M	51	48	-
MRI 230D	76	73	67
A380	95	92	79

Table 3. Corrosion performance of MRI alloys compared to AZ91D alloys and A380 alloy

Test	Mils/year			
	MRI 153M	MRI 230D	AZ91	A380
ASTM B117 (240 h)	7.2	7.9	7.2	15.6
GM 9540P (40 days)	1.01	1.25	1.1	4.59
SAEJ2334 (80 days)*	0.72	0.72	0.56	-

equivalent to 5 years of real world test

These findings were also supported by testing actual automotive parts cast in MRI 153M and A380 alloys (Fig.6). It is seen that the A380 oil pan experienced serious corrosion attack resulting in remarkable accumulation of corrosion products while the oil pan cast in MRI 153M alloy retained a relatively clean surface after salt spray testing for 96 h.

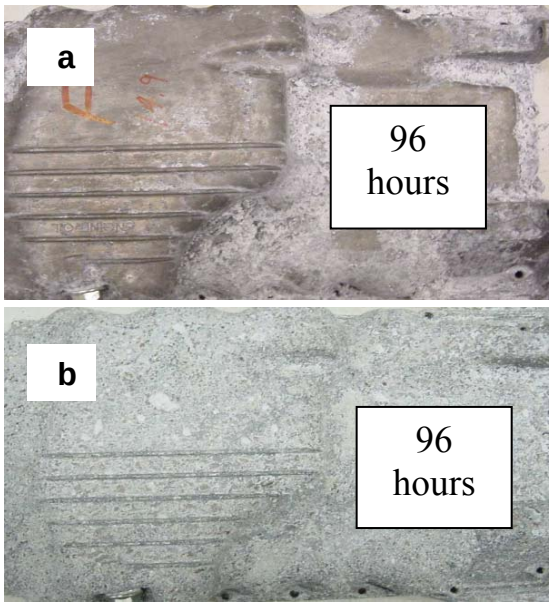
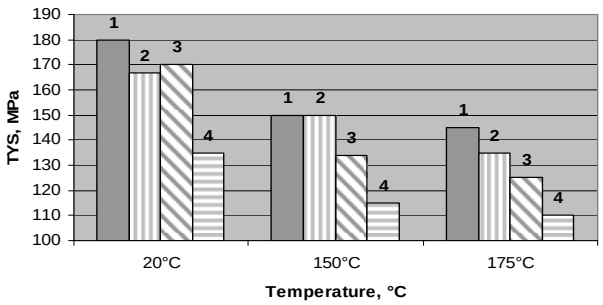


Fig. 6. Visual appearance of the oil pans after ASTM B117 salt spray for 96 hours
a- MRI 153M, b- A380

Weight Reduction using MRI alloys

Reducing vehicle weight can play a significant role in decreasing fuel consumption while simultaneously improving performance and handling. High tensile and compressive ambient and short-term elevated-temperature yield strengths of high-pressure die cast MRI alloys (Fig.7) suggest considering them as direct replacements of A380 alloy in powertrain components to achieve significant weight reduction.



1-MRI 230D, 2-A380, 3- MRI 153M, 4- AE44

Fig.7. TYS temperature dependence for different alloys

Let's consider the service temperature of 150°C. As can be seen from Table 1 and Fig 7, both MRI 230D and A380 have the same TYS (150 MPa). Taking into account that yield strength, multiplied by cross-section area, gives a load which should be a constant value, and assuming that for selected fragment cast in A380 the cross-section area is 1 cm^2, one can obtain automatically the same cross-section area for the same fragment to be cast in MRI 230D.

Assuming that the height of both fragments is 1 cm the percentage of weight reduction can be obtained from the following expression:

$$\frac{weight(A380) - weight(MRI230D)}{weight(A380)} \times 100 \qquad (1)$$

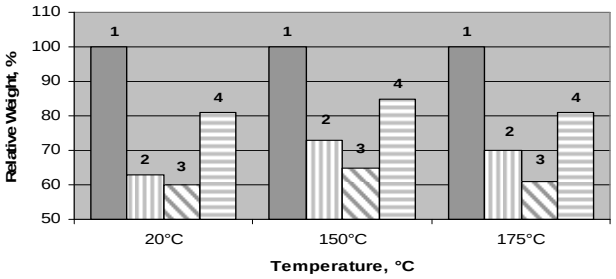
Where weight = volume density (ρ) · cross-section area (A) · height (1 cm).

Taking into consideration that the densities of MRI 230D and A380 are 1.8 g/cm^3 and 2.76g/cm^3, respectively, the weight reduction will be 35%.
In the case of two other magnesium alloys the weight reductions for service temperature of 150°C will be lower (Table 4).

Table 4. Percent of the weight reduction to be achieved for components operating at 150°C

Alloy	A380	MRI 230D	MRI 153M	AE44
Relative cross-section area	1.0	1.0	1.1	1.3
Relative weight	1.53	1.0	1.1	1.31
Weight Saving [%]	-	35	27	15

Similarly, the percentage of weight reduction can be easily obtained for other service temperatures as it is shown in Fig.8. It can be seen that MRI 230D offers the best solution within the entire range of temperatures. MRI 153M showed a less satisfying reduction at 175°C, since it was designed to serve up to 150^{0}C. AE44 alloy, having the lowest tensile yield strength of all the tested alloys, provides as expected the lowest weight reduction.



1-A380, 2- MRI 153M, 3- MRI 230D, 4- AE44

Fig.8. Weight reduction to be achieved by replacement of A380 alloy with creep resistant magnesium alloys at different service temperatures

Summary

DSM's creep-resistant, high-pressure die casting alloys MRI 153M and MRI 230D exhibit high strength, outstanding creep and corrosion resistance combined with excellent castability. These alloys particularly MRI 230D provide weight and cost savings

over A380 aluminum alloy and can be considered as its direct replacement for different automotive powertrain components and non-automotive applications such as power hand tools, lawn and garden equipment. Excellent corrosion performance of MRI 153M combined with adequate creep strength makes this alloy the best candidate for oil pan applications.

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