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Design Guidelines for Components Die Cast in Creep-Resistant Magnesium Alloys MRI153M and MRI230D

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ABSTRACT

Magnesium high pressure die casting alloys MRI 153M and MRI 230D offer attractive properties at elevated temperatures up to 150°C and 190°C, respectively.
The presence of specific alloying elements results in different physical and metallurgical properties of new alloys as well as their solidification characteristics during the HPDC process, compared to AZ91D alloy. Hence, process parameters, such as melt and die temperature and injection profile, should be optimized. Furthermore, principles for proper die design, such as gate thickness and runners system, should be considered and addressed.

This paper presents design and process guidelines, in order to optimize the HPDC process of the above alloys and produce high performance components.

INTRODUCTION

Magnesium alloys being the lightest metallic structural materials, offer numerous possibilities for weight reduction. High pressure die casting (HPDC) is the dominant process for production of magnesium alloy parts for different applications [1]. The growing demand for the use of magnesium alloys in the production of powertrain applications has led to the development and implementation of high-creep-resistant die casting alloys, such as MRI 153M and MRI 230D [2-4]. These alloys exhibit high tensile, compressive and fatigue strength (Table 1) combined with improved castability and similar creep behavior in comparison to A380 [4]. These characteristics make MRI alloys a suitable and promising Mg solution for use in powertrain applications.

The most common disadvantage of HPDC process is the formation of porosity, associated with turbulence or atomized filling of the die. Porosity often limits the use of HPDC process in favor of products fabricated by other process technologies.

Table 1: Typical averaged mechanical properties of MRI alloys in comparison to conventional alloys

Properties	AZ91D	MRI153M	MRI230D	A380*
TYS (MPa)				
at 20 °C	160	170	180	165
at 150 °C	105	135	150	150
at 175 °C	90	125	145	135
UTS (MPa)				
at 20 °C	260	250	245	330
at 150 °C	160	190	205	235
at 175 °C	140	172	178	195
Elongation (%)				
at 20 °C	6	6	5	3
at 150 °C	18	17	16	5
at 175 °C	20	22	18	6
CYS (MPa)				
at 20 °C	160	170	180	
at 150 °C	105	135	150	-
at 175 °C	90	110	110	
Fatigue Strength [MPa] (Rotating bending $5*10^7$ cycles)	100	120	110	-

* ASM Metals Handbook

The porosity is generally attributed to two main sources: solidification shrinkage and gas entrapment. The mechanical properties of die castings are affected by the porosity level. However the degree of this effect varies in different alloys [5-7]. It has been reported [5] that the tensile properties of the creep-resistant magnesium alloys MRI 153M and MRI 230D have more uniform patterns and are nearly independent on the porosity level (range of 1-3%).

The main objectives of this paper are:

- To study the influence of die and part design parameters such as runner - gating system and geometry thickness on the porosity level in die castings and their properties.
- To investigate the effect of the distance from the gating system on the grain size and the stability of the mechanical properties represented by impact strength throughout the part.

EXPERIMENTAL PROCEDURE

The experiments were performed at the Magnesium Research Institute (MRI) using an IDRA OL-320 cold chamber die casting machine with locking force of 345 tons. The alloys MRI230D, MRI153M and AZ91D were die cast using a specially designed cavity (Fig. 1), which allows the production of seven impact strength specimens located between the gating system and the overflows. Impact strength specimens were selected due to the fact that this property is highly sensitive to porosity and microstructure variations. Such design provides the simulation of a comparative castabilty study of different alloys and evaluates the properties level as a function of the distance from the gates. All HPDC samples were X-rayed using SIEFERT ERSCO 200 MF constant potential X-ray tube and then subjected to metallographic examination, density measurements and Impact strength testing as per ASTM E 10.

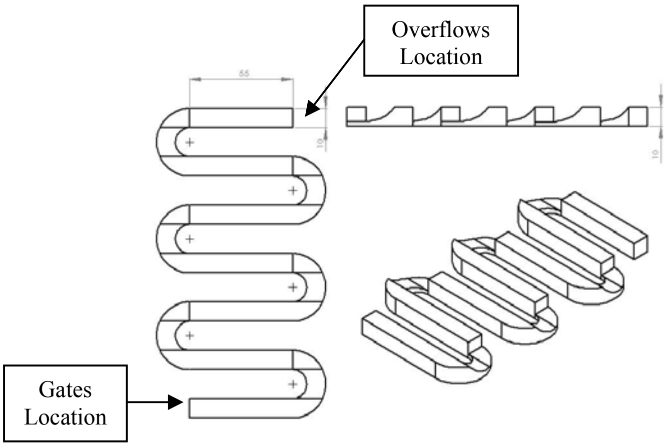


Fig.1. Impact strength specimen's geometry

Prior to experimental casting, the main HPDC process parameters, such as injection profile, melt temperature and die temperature, were optimized for the new die cavity according to the physical properties of each alloy.

RESULTS AND DISCUSSION

PRINCIPLES OF DIE AND PART DESIGN

This section discusses and evaluates the influence of the design parameters on the casting process. Figure 2 presents the effect and relation between different design variables during the production of die cast applications [8-10].

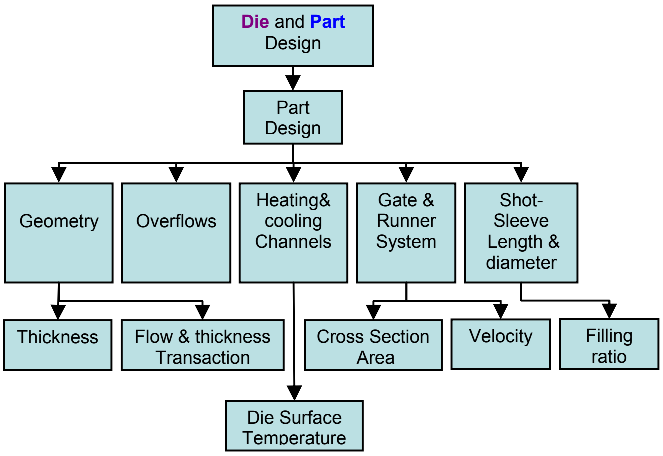


Fig.2. Die and part design scheme

The presented scheme clarifies the complexity of the process optimization phases. During this work the gating system parameters as well as the heat transfer evaluations will be discussed.

<u>Shot Sleeve</u> – During dosing and first phase of the casting process, heat is transferred from the molten metal into the sleeve.

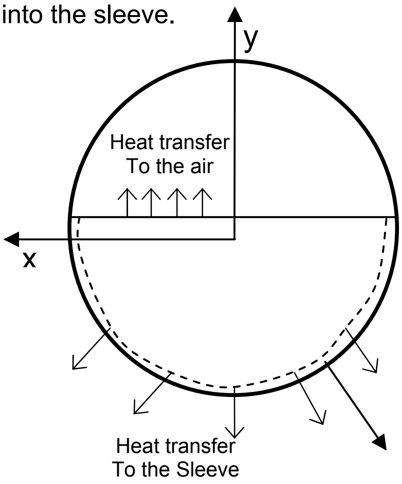


Fig.3. Shot sleeve cross section during injection

Following the pouring of the molten metal into the shot sleeve a solidification layer is formed on the sleeve wall. The overall heat transfer from the molten metal is accomplished by two main mechanisms:

- Conduction (to the sleeve)
- Convection (to the air)

The heat transfer by radiation is neglectable. The dimension of the sleeve (length and diameter) and the filling ratio used during the casting process are the main parameters, which should be considered when calculating the amount of heat lost from the molten metal.

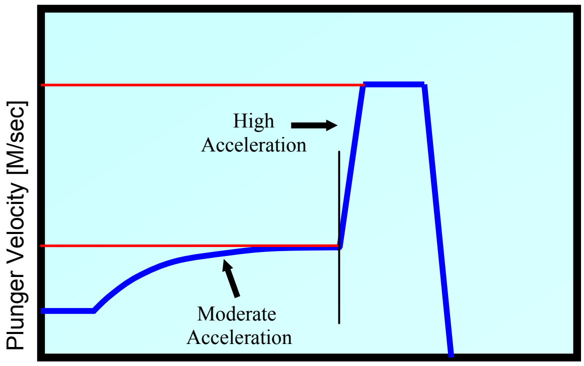
Both low and high filling ratios are associated with certain disadvantages shown in Table 2.

Table 2: Disadvantages attributed to Low and High filling ratio

Low filling ratio	**High filling ratio**
Missruns	Entrapped air in the shot sleeve
High Fraction of Solid	Shorter effective stroke
Cold shuts	Low velocity
Intensification pressure is not effective	-

In order to produce sound, high quality components, optimization of the filling ratio is necessary. Low filling ratio might cause pre-solidification of the molten metal in the shot sleeve resulting in defects such as missruns, cold shuts, etc. Due to the rapid heat loss, the intensification pressure is not effective and might cause formation of excessive porosity.

Figure 4 presents the typical recommended injection profile. The acceleration during first phase has a major effect on the porosity level in the die cast component. It is recommended to use moderate acceleration profile in order to minimize the porosity level. Hence, the injection profile, the filling ratio and the selection of suitable shot sleeve dimension should be optimized in order to minimize the formation of porosity.



Plunger Stroke [mm]
Fig.4. Typical injection profile

<u>Gating and Runner system</u> – The gating and runner system determines the flow pattern during injection. Laminar, turbulent or atomized flows may take place during the filling of the cavity. In order to fill the cavity properly and achieve optimized flow pattern it is necessary to set correctly several design and process parameters such as gate area, runner design (length and cross section) and second phase velocity. In addition, possible soldering phenomena when casting performed with high gate velocity should also be taken into consideration. Figure 5 presents the recommended gate area for a given component volume. These curves are the outcome of several successful casting trials and different applications that were cast using MRI230D and AZ91D alloys.

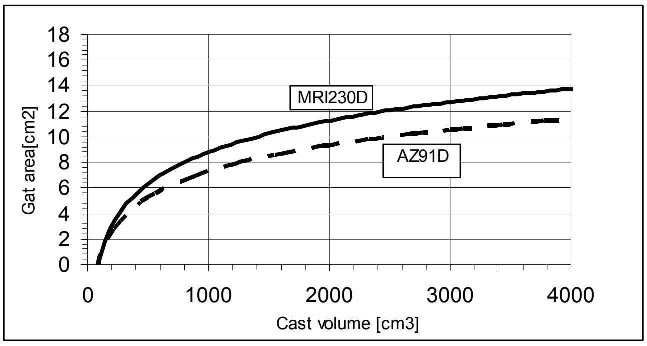


Fig.5. Recommended gate area for a given cast volume

If the ratio of the gate's area to the cast volume is higher than outlined by the plot in Figure 5 curve flow marks and missruns may occur. On the other hand, if the above ratio is lower than that indicated by the plot, the soldering phenomena may be expected.

Figure 6 presents the recommended optimal gate velocities for a given cavity volume, gate area and die surface temperatures of 80, 120 and 160°C for casting different components in MR230D [11]. It is evident that reduction of die temperature leads to higher gate velocity (for a specific cavity volume and gate area). Optimization of the gates velocity is required in order to avoid soldering. Low gate velocity with relatively low die temperature would result in formation of cold shuts and missruns due to rapid solidification of the molten metal before the die cavity is properly filled. It is recommended to reduce the gate velocity when the ratio between the cavity volume and gate area is relatively high. The intensive heat transfer (convective heat transfer with relatively small gate area) in the case of casting large components (high volume of metal) might cause soldering in the gating area. Hence, proper lubrication and cooling is necessary in these areas.

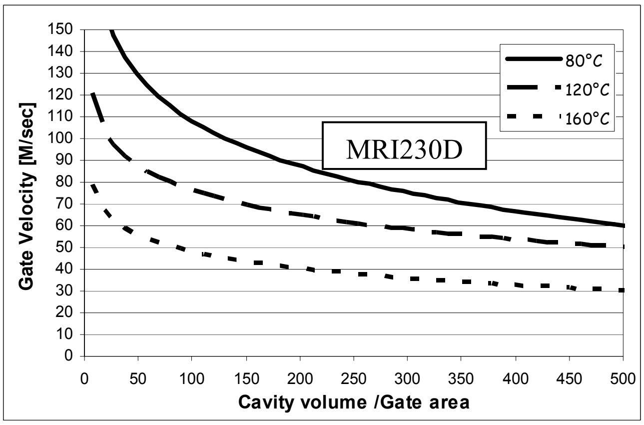


Fig.6. Recommended gate velocity for a given part volume and gate area

The runners should have optimal cross section area in order to provide the required metal flow rate. All changes in cross sections and directions within the runners should be made smoothly, in order to reduce turbulence flow in the molten metal. This will minimize the amount of entrapped air. In addition, the runner structure and length must allow short and smooth flow arrival of metal to the gates [8]. By proper location of the vents and overflows, gas entrapments should be minimized significantly resulting in high quality improved parts. The above processing and design guidelines should be implemented in order to produce sound high quality components. Special attention should be devoted to the component's critical cross section (in terms of external loads of stresses), proper die design and process parameters optimization. This will be carried out in accordance with the presented principles, in order to achieve the required properties and performance.

THE EFFECT OF DISTANCE FROM THE GATE ON THE MECHANICAL PROPERTIES

The aim of this section is to investigate the effect of the distance from the gating system on the mechanical properties of the component. The die used for this study is presented in Fig.1 and contains seven impact strength specimens. Specimen 1 is located near the gate while specimen 7 is the most distant.

Figure 7 presents the porosity level in specimens located at different distances from the gate for all alloys investigated. In general, specimen 7 has the highest porosity level while specimens 2 and 3 have the lowest one. In addition, shrinkage porosity was observed over X-Ray evaluation in specimen 1-2 due to the slow solidification rate at these locations (Fig 8).
As can be seen from Fig.7, porosity increases with distance from the gate. Compared with the other inspected alloys, MRI230D alloy exhibit no increase in porosity until specimen 6. This result further substantiates conclusions drawn [5]. On the other hand, in AZ91D and MRI153M alloys the porosity level is more sensitive to the distance from the gating system.

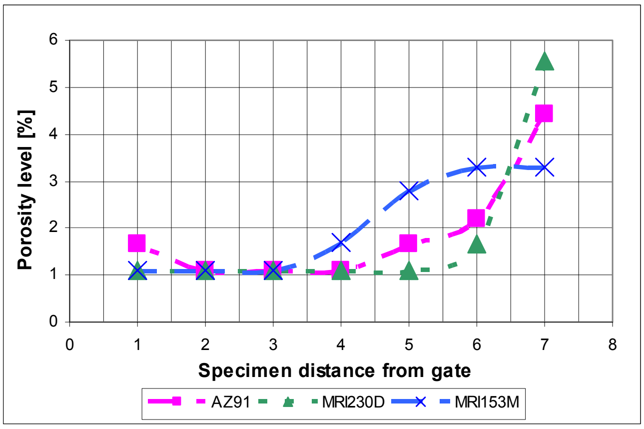


Fig.7. Porosity as function of distance from the gate

Figure 9 presents the average grain size for specimens 1, 3 and 7 of alloys MRI 153M, MRI 230D and AZ91D. Specimen 1 has the largest grain size of the three alloys investigated due to slower solidification rate near the gates. Specimen 7 exhibits finest grains, as a consequence of fast solidification.

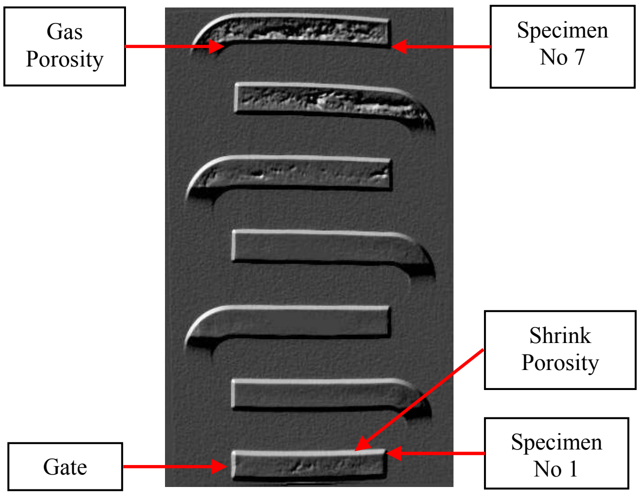


Fig.8. X-Ray images of the inspected specimens

The effect of the distance from the gating system on the microstructure is shown in Figure 10. It is evident that the grain size increases towards the sample cross-section centre. In addition, due to the slow solidification of the specimens near the gate, there is a decrease in the average grain size from specimen 1 towards specimen number 7. Specimen number 7 exhibits high porosity level due to filling problems and fast solidification.

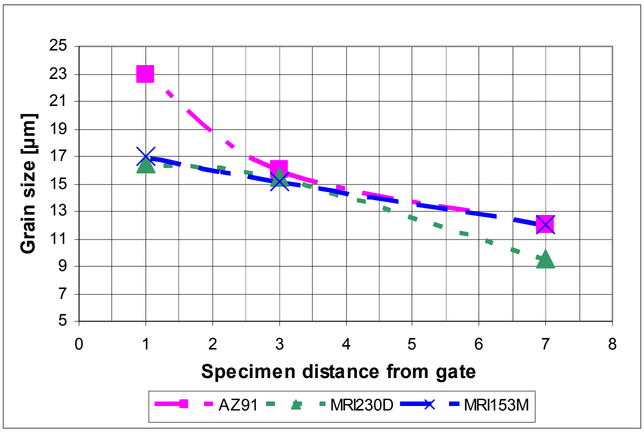


Fig.9. Grain size as function of distance from the gate

The effect of the specimen location on the relative impact strength values for all alloys investigated is shown in Fig.11. The selected alloys have different TYS and consequently different absolute impact strength values. Fig.11 represents impact strength distribution as percentage from maximum value observed for each tested alloy. It is evident that impact strength of MRI 230D is practically independent on the specimen location. This behavior can be attributed to more uniform

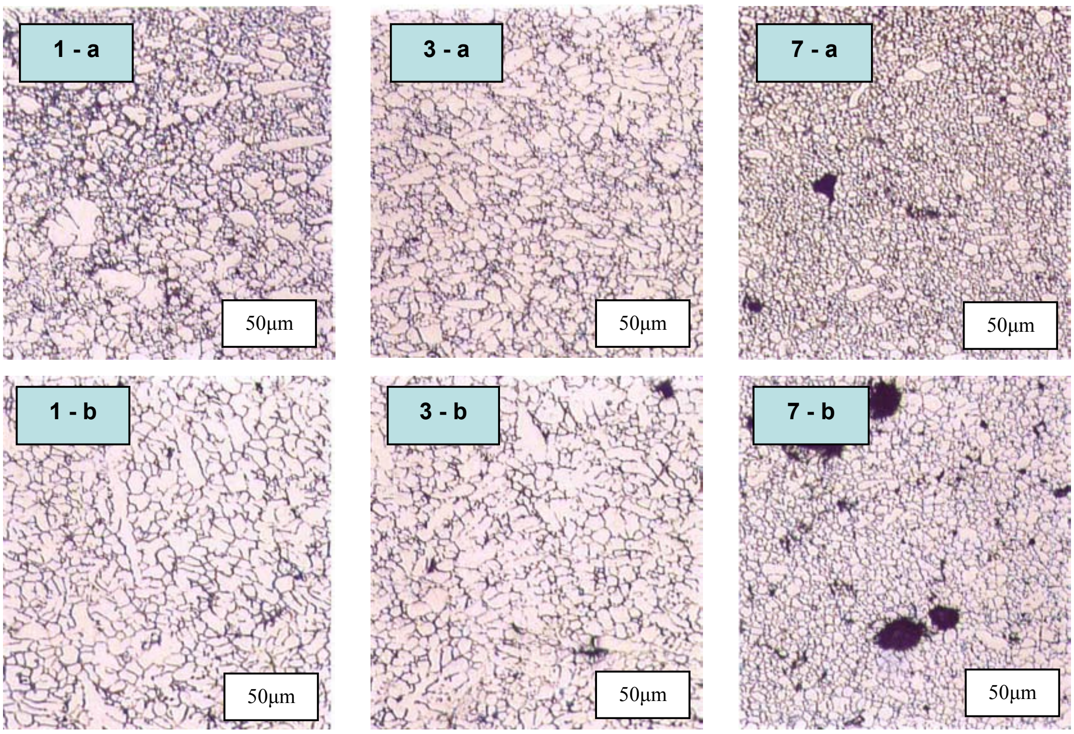


Fig.10. Microstructure at mid-length cross –section of MRI230D specimens 1, 3 and 7
a – Near the surface; b – Center of the specimen

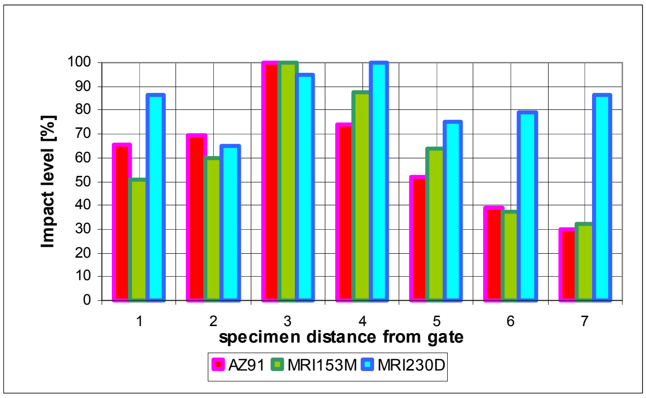


Fig.11. Relative dependence of impact strength on the specimens location (percentage from maximum value for each alloy)

grain size and porosity distribution throughout samples 1 to 7. This pattern should be considered as an advantage during the design phase of HPDC components. On the other hand, in MRI153M and particularly AZ91D alloys, specimens 3 and 4 exhibit significantly higher relative impact strength values compared to other positions.

CONCLUSIONS

1. Injection profile and gating system parameters significantly affect the die cast component quality. Design guidelines for the HPDC of MRI alloys, particularly MRI230D were introduced in terms of the correlations between the cast volume, gate area cross section, gate velocity and die surface temperature.
2. Based on the casting trials, performed on specially designed die, the correlations between the porosity, geometry (distance from the gate) and properties represented by impact strength were studied. The finding obtained can be implemented in order to minimize the porosity level and achieve improved properties throughout the die cast component, particularly in its critical cross-sections.
3. The location of the component critical cross section is one of the most important parameters that should be taken into consideration during the design phase of the die cast part. The distance from the gating system has a major affect on the properties variation over the component. The optimal location for the part's critical cross section should be about 1/3 from the distance between the gating area and the overflows.
4. The more homogeneous grain size and porosity distribution observed in samples cast in MRI 230D should be considered during the design phase of a die cast component. It was shown that the above microstructural features result in uniform properties (demonstrated by the dependence of impact strength on the sample location) and offer significant advantage for the design of parts to be cast in MRI 230D alloy.

REFERENCES

1. S. Schumann, “Future Use of Magnesium in Cars – Potential and Prerequisite”, 12th Magnesium Automotive and User Seminar, Aalen, 13-14 September, 2004
2. B.Bronfin et al, EP Patent1,308,530, May 11, 2006
3. B.Bronfin et al, EP Patent 1,308,531, April 26, 2006
4. B.Bronfin et al, “Development of Magnesium Alloys for Advanced Applications”, Magnesium alloys and their applications”, 2003, 55-61.
5. N. Moscovitch. et al ,"The Effect of Porosity on the Microstructure and Mechanical Properties of Die Cast Mg Alloys", SAE paper 2006-01-0524
6. Moscovitch N. et al.,” The Effect of High Pressure Die Casting Process Characteristics on The Properties and Performance of Advanced Mg Alloys”, pp.357-363, TMS 2005.
7. N. Moscovitch et al.,” The effect of HPDC process parameters on the performance of high creep resistant alloys MRI153M & MRI 230D", Aalen seminar 2006, 39-49
8. “Die casting”, Metals Handbook, 10th Edition, ASM, OH, 1995, Vol.1z5, pp. 286-295.
9. The Essentials of Magnesium Die Casting, International Magnesium Association, 1991, 10 p.
10. M. Avedisian and H.Baker, Magnesium and Magnesium Alloys, ASM Specialty Handbook, 1999
11. G.Gertsberg et al., “Effect of HPDC Parameters on the Performance of Creep Resistant Alloys MRI153M and MRI230D”, SAE paper 2005-01-0334, Detroit, MI, 2005.

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