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The effect of porosity on the microstructure and mechanical properties of die cast Mg alloys

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ABSTRACT

High pressure die casting (HPDC) is the dominant process for the production of magnesium components with complex configuration having typically thin to medium wall thickness.

The growing use of die cast Mg alloys in the automotive industry, particularly for the production of drive-train components, has led to the development of creep resistant alloys, MRI153M and MRI230D, which were launched into the market several years ago.

The present paper aims at exploring the effect of the HPDC process parameters on the porosity and, as a result, on the properties of the two MRI's developed alloys in comparison with common alloys AZ91D and AM50A that are usually considered as benchmark die casting alloys.

The outcome of the research performed includes processing guidelines and recommendations, which allow obtaining high quality sound castings. These recommendations should be implemented in the course of design, optimization and production of high-performance components for various applications.

INTRODUCTION

High-pressure die casting is the leading process for the production of magnesium alloy components, enabling high productivity at a relatively low cost. To date it is worldwide recognized that HPDC is a field with tremendous potential for magnesium alloys, particularly relating to the automotive industry [1-3].

Two common alloys AZ91D and AM50A as well as two high creep resistance alloys MRI 153M and MRI 230D were studied in the present paper. The above alloys were selected as having good potential for applications in the automotive industry due to

- Good combination of mechanical and physical properties.
- Excellent die castability.
- Good corrosion resistance.
- Ease of handling.
- Proven post process operations.
- Recyclability.

The chemical compositions of the alloys as well as their mechanical and physical properties are well known and documented [4-6]. The published properties of the alloys are mostly related to separately die cast specimens. However, the properties of a complex component could be significantly affected by the HPDC process parameters, the component configuration and its solidification characteristics [6-8]. The effect may be different for strength, ductility and energy absorption properties. The most common defect generated during the HPDC process is porosity, which usually originates from two main sources: solidification shrinkage and gas [7, 10]. The effect of the porosity on the high deformation region properties will be mainly investigated using AM50A alloy due to its high intrinsic ductility and superior energy absorption characteristics.

Thus, the main objectives of this paper can be summarized as follows:

- Investigation of the effect of the HPDC process parameters on the porosity level of die cast Mg alloys.
- Assessment of the porosity effect on the microstructure and the tensile (TYS, UTS, Elongation) and impact properties of die cast Mg alloys.
- Establishment of guidelines for HPDC process optimization allowing production of high quality, sound die cast components with improved performance.

EXPERIMENTAL PROCEDURE

The study was carried out on tensile and impact strength specimens that were cast from AZ91D, AM50A, MRI 153M and MRI 230D alloys on an IDRA OL-320 cold chamber die casting machine. Tensile specimens geometry was in accordance with ASTM B557, and un-notched impact strength specimens' configuration was in accordance with ASTM E10. Fifteen tensile specimens and twenty impact strength specimens were tested for each variant.

The quality of specimens was evaluated by X-Ray radiography, using Seifert Eresco 200 MF constant potential X-Ray tube.

In order to produce samples with different porosity levels, three filling ratios of 20%, 30% and 36% were used by changing the amount of the metal poured into the shot sleeve. Furthermore, shot sleeves temperatures of 100°C and 200°C were used as presented in Table 1.

Table 1. Tested injection parameters

Variant	Shot sleeve temp. °C	Filling ratio (%)	Fill time [msec]	2nd phase starting position [mm]
1	200	20	6.0	332
2		30	7.5	300
3		36	9.2	270
4	100	20	6.0	332
5		30	7.5	300
6		36	9.2	270

The fill time and the pressure intensification phase were optimized in order to obtain proper injection profile for each of the above six variants of process parameters. The percentage of porosity was measured by Archimedes method.

Table 2 presents the main HPDC process parameters used for the production of different specimens.

Table 2. HPDC process parameters for magnesium alloys investigated

Mg Alloy	Temperature data		Spraying & Lubrication		Dwell time (%)
	Melt (°C)	Die (°C)	Spraying time (%)	Mixing ratio	
AZ91D	650-670	150-200	100	1/40-1/80	100
AM50A	680-695	150-200	100	1/40-1/80	100
MRI153M	660-670	200-250	120-150	1/25-1/40	70-80
MRI230D	680-690	200-250	150-170	1/15-1/40	50-75

RESULT AND DISCUSSION

THE EFFECT OF HPDC PROCESS PARAMETERS ON ORIGINATION OF POROSITY IN CASTINGS

The effect of the shot sleeve filling ratio and shot sleeve temperature on the porosity level in the castings is presented in Table 3. The term porosity refers to the total porosity including micro- porosity, gas porosity and shrinkage porosity. The variants numbers are consistent with the parameters presented in Table 1. (The levels of porosity are the mean porosity measurements).

Table 3. The effect of the filling ratio and shot sleeve temperature on the die cast Mg alloys porosity

	AZ91D		AM50A		MRI 153M		MRI 230D	
Specimens Porosity (%) Variant	Tensile	Impact	Tensile	Impact	Tensile	Impact	Tensile	Impact
1	1.8	2.6	3.2	3.4	2.0	2.7	2.0	2.0
2	1.6	3.0	1.2	2.2	1.7	2.6	0.7	2.6
3	1.2	2.4	1.3	1.7	2.0	2.9	3.0	2.3
4	2.2	3.0	3.3	3.4	2.7	2.9	2.9	2.8
5	2.1	2.3	2.3	2.8	1.4	2.3	2.3	2.5
6	1.2	2.8	2.0	2.2	1.9	2.8	1.4	2.2

Fig. 1 illustrates the effect of the shot sleeve temperature and the filling ratio on the formation of porosity in AM50A die cast specimens. The results obtained indicate that the shot sleeve temperature is the dominant factor only for higher filling ratios (30% and 36%).

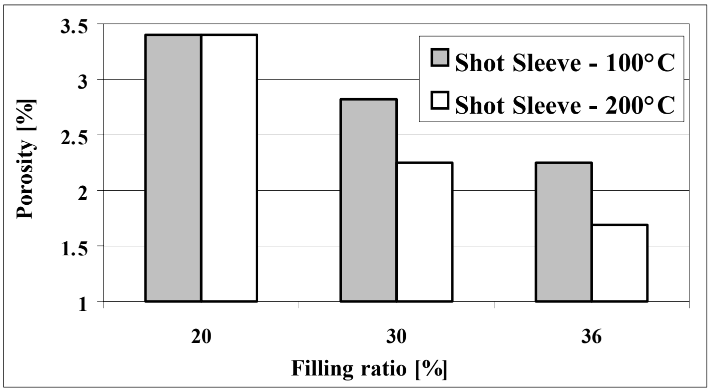

Fig. 1. The effect of the filling ratio and shot sleeve temperature on the porosity (AM50A-Impact strength samples)

The values of average percentage of porosity found in the tested alloys for the shot sleeve temperature of 200°C are presented in Fig. 2.

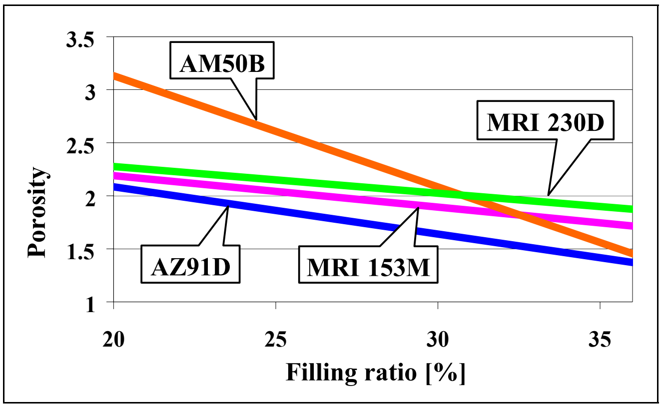

Fig. 2. The effect of the filling ratio on the porosity of die cast Mg alloys(The shot sleeve temperature of 200°C)

It is evident that in MRI153M and MRI 230D the percentage of porosity is practically not dependent on the filing ratio. On the other hand, AM50A, which has high ductility, exhibits a very sharp increase in porosity when decreasing the filling ratio from 36% to 20%.

The effect of the distance from the gating system on the porosity level was also studied. This effect demonstrates the influence of the intensification pressure on the porosity distribution along the specimen. It is believed that the percentage of porosity at areas located near the gating system should be reduced. Proper die design and optimized process parameters, particularly injection profile and melt and die temperatures should reduce origination of porosity in the casting. Faster filling time allows retaining an increased portion of the liquid metal (end of the second phase, cavity fill). This enables the applying of the intensification pressure by the end of the second phase. The porosity of the impact strength specimens was measured from its gating system to its overflows as presented in Fig. 3.

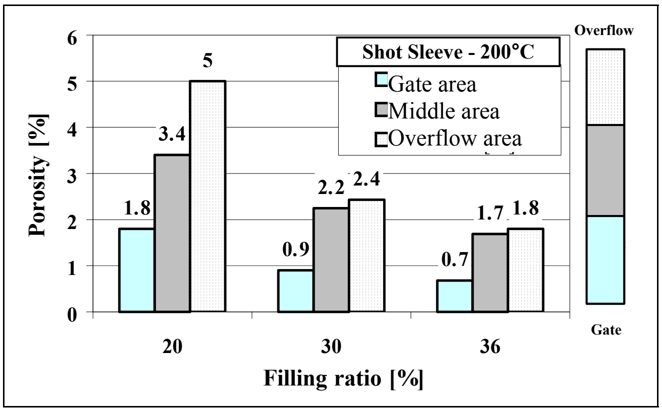

Fig. 3. Porosity distribution along the AM50A impact strength specimen

It is evident that higher filling ratios and die design that allows placing of critical component sections near the gate system can significantly reduce the casting porosity level.

METALLOGRAPHY EXAMINATION

Radiography inspection and metallography examination were performed on cylindrical specimens with a 10 mm diameter and a 100 mm length. Fig.4 illustrates X-ray radiography pictures for AM50A.

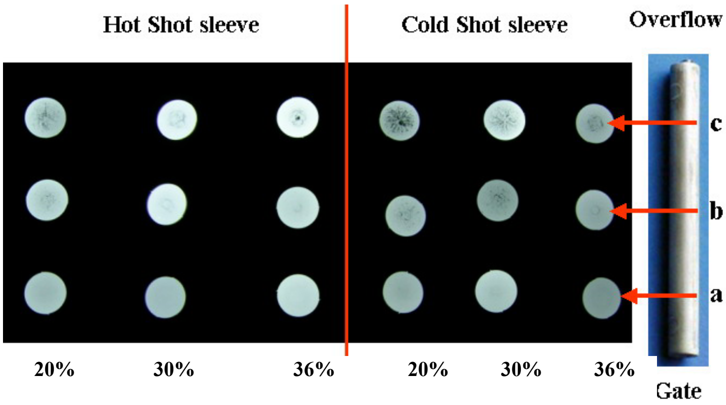

Fig.4. X-Ray Radiography image

The microstructure was evaluated at three cross sections along the specimen's length:

- -Close to the gating area.
- -Mid-length section.
- -Close to the specimen overflow

The typical microstructures are shown in Figs.5 and 6. Both figures present the mid-length (gage area) section microstructure. Similar analysis was performed for all three sections and for all tested parameters.

The results obtained distinctly illustrate that higher filling ratio and shot sleeve temperature result in finer microstructure. The "skin" near the casting surface (a) exhibits finer grains with more homogeneous distribution and lower porosity. As can be seen in Fig.6, the volume fraction of large α-Mg grains, which have been formed during the solidification in the shot sleeve is significantly lower in the skin area. It is also evident that the average grain size at the surface area (a) is smaller than at 0.5 radius (b) and largest grains are present at the specimen's center (c). Molten alloy introduced into the shot sleeve of a cold chamber die casting system looses heat and cools during its residence there. If the residence time is sufficiently long, then solid forms on the alloy-shot sleeve and plunger interfaces prior to the injection of the alloy into the die cavity. This solid, which is subsequently injected into the die cavity, has larger microstructural features compared to an alloy, which solidifies in the die cavity [10].

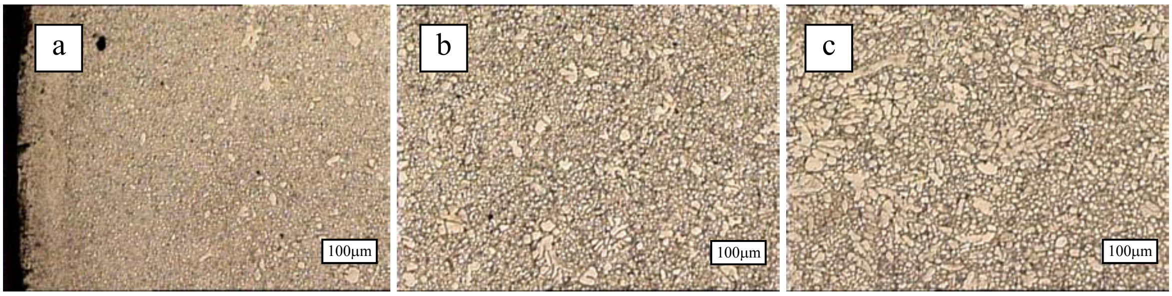

Fig. 5. Microstructure at mid-length cross –section of AM50A specimen produced in accordance with variant 3 (200°C shot sleeve, 36% filling ratio) a-near the surface; b-0.5 radius from the surface, c-center of the specimen

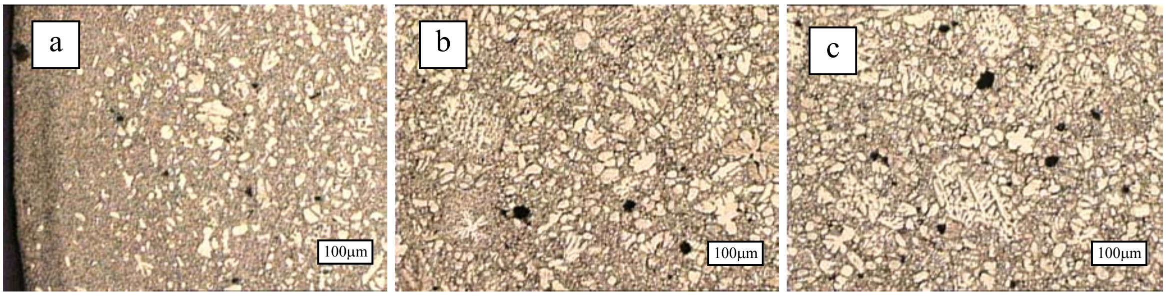

Fig. 6. Microstructure at mid-length cross –section of AM50A specimen produced in accordance with variant 4 (100°C shot sleeve, 20% filling ratio) a-near the surface; b-0.5 radius from the surface, c-center of the specimen)

THE EFFECT OF POROSITY ON PROPERTIES

Tables 4-7 summarize mechanical properties obtained on specimens produced by all the variants.

Table 4. Mechanical properties of AZ91D obtained for the different process parameters

Variant	TYS [MPa]	UTS [MPa]	E %	Impact strength [J]
1	166 ± 4	256 ± 13	5 ± 1	8 ± 1
2	170 ± 3	262 ± 14	6 ± 1	9 ± 1
3	173 ± 2	277 ± 10	7 ± 1	10± 1
4	170 ± 3	246 ± 15	4 ± 1	8 ± 1
5	162 ± 8	266 ± 17	7 ± 2	9 ± 1
6	168 ± 3	255 ± 11	6 ± 1	9 ± 1

Table 5. Mechanical properties of AM50A obtained for the different process parameters

Variant	TYS [MPa]	UTS [MPa]	E %	Impact strength [J]
1	115 ± 3	190 ± 5	7 ± 1	13 ± 1
2	123 ± 2	259 ± 4	20 ± 2	31 ± 2
3	124 ± 1	267 ± 2	23 ± 2	30 ± 2
4	111 ± 3	180 ± 7	5 ± 1	13 ± 1
5	121 ± 2	212 ± 2	8 ± 1	18 ± 1
6	120 ± 1	253 ± 3	17 ± 2	26 ± 2

Table 6. Mechanical properties of MRI 153M obtained for the different process parameters

Variant	TYS [MPa]	UTS [MPa]	E %	Impact strength [J]
1	168 ± 8	262 ±18	8 ± 2	11 ± 1
2	171 ± 2	272 ± 9	9 ± 1	11 ± 2
3	170 ± 3	265 ± 14	9 ± 2	10 ± 1
4	167 ± 3	263 ±12	6 ± 1	8 ± 1
5	166 ± 3	260 ±10	8 ± 1	9 ± 2
6	163 ± 2	256 ±14	6 ± 1	10 ± 1

Table 7. Mechanical properties of MRI 230D obtained for the different process parameters

Variant	TYS [MPa]	UTS [MPa]	E %	Impact strength [J]
1	186 ± 3	237 ± 3	4 ± 1	6 ± 1
2	184 ± 2	237± 10	4 ± 1	5 ± 1
3	185 ± 5	250 ± 7	5 ± 1	5 ± 1
4	180 ± 2	235 ± 8	4 ± 1	6 ± 1
5	183 ± 3	261 ± 8	4 ± 1	4 ± 1
6	181 ± 6	252 ± 9	5 ± 1	5 ± 1

Based on these results, correlations between mechanical properties and percentage of porosity were developed (Figs.7-10)

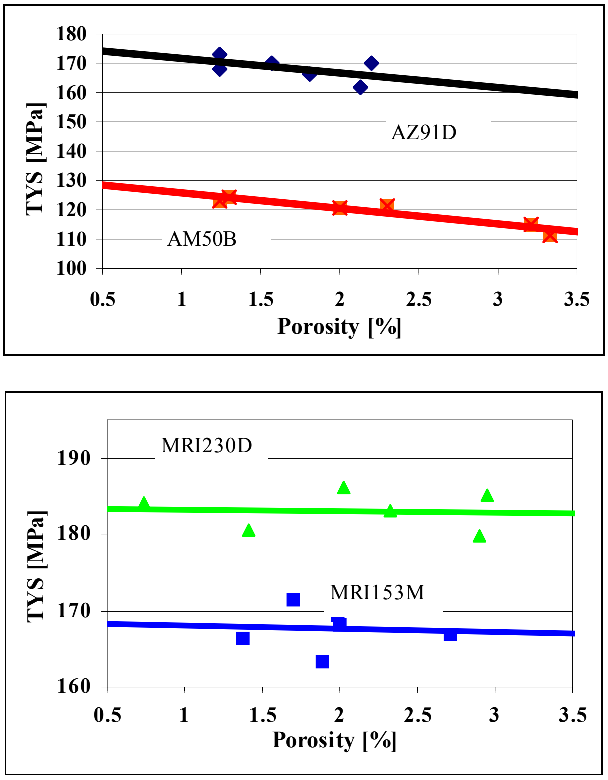

Fig. 7. The effect of porosity on TYS.

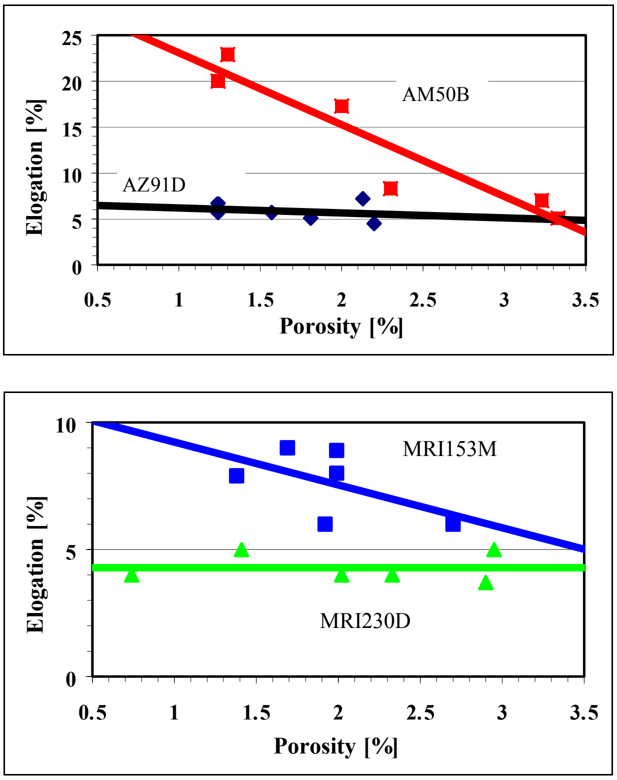

Fig. 9. The effect of porosity on Elongation.

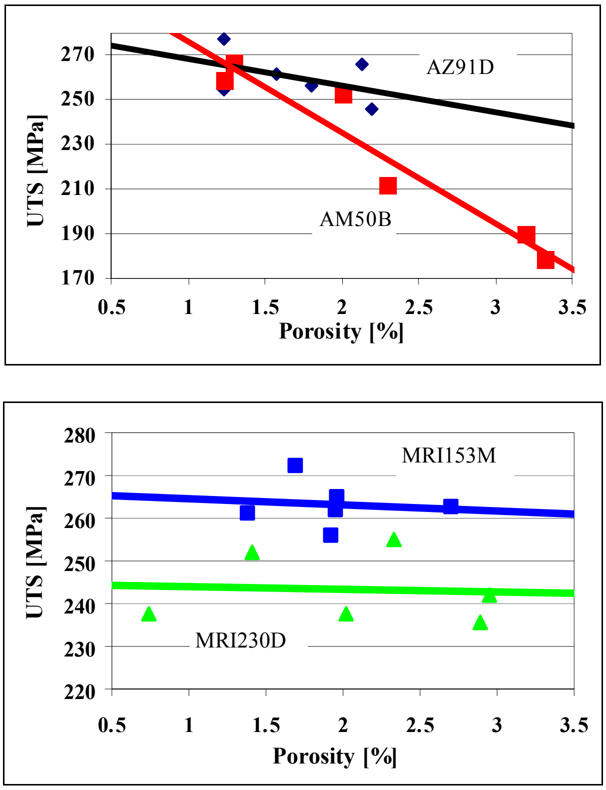

Fig. 8. The effect of porosity on UTS.

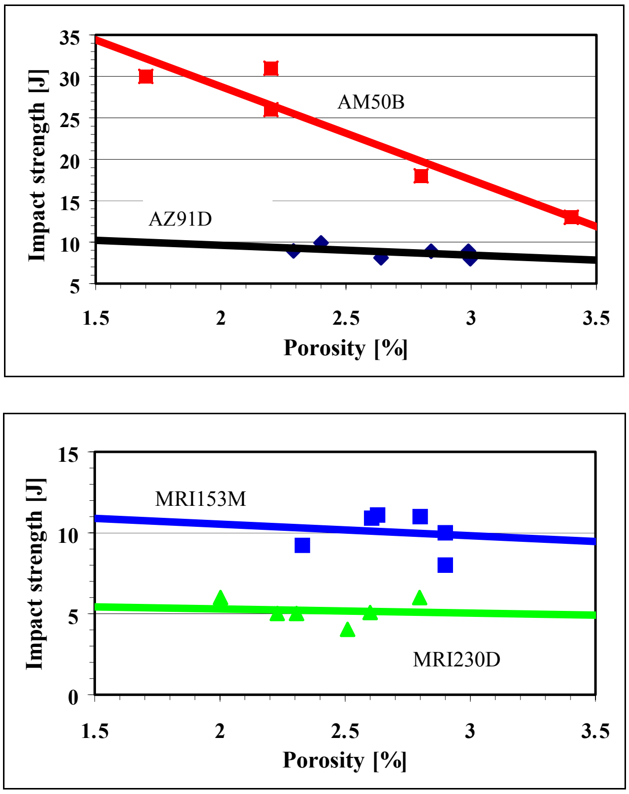

Fig. 10. The effect of porosity on impact strength

The obtained correlations demonstrate that the percentage of porosity significantly affects the properties associated with the developed deformation such as room temperature impact strength, elongation and UTS. For example, for AM50A two-fold increase in the porosity level leads to four-fold decrease in the elongation. On the other hand, the above increase in porosity results by only 15% reduction of TYS.

Comparison of the data presented in Figs.7-10 with minimum acceptable values allowed by ASTM B94 standard for AM50A alloy (TYS = 110 MPa, UTS = 200 MPa and E = 10%) shows that 3.5-4% porosity provide acceptable TYS values. For mechanical properties associated with high-developed deformation, 1.5-2% porosity lead to unacceptable values of the elongation, impact strength and UTS.

AZ91D alloy exhibits similar behavior to that of AM50A. The properties vary more gradually with increasing percentage of porosity. However, creep resistant alloys MRI 153M and MRI 230D exhibit relatively constant properties for all the variants investigated,

These findings may play a very important role in the adjustment of HPDC parameters. The process operational window may be expanded by using the guidelines presented within this work frame of activities. This will allow wider specter of process parameters during the HPDC process and will result in production of sound, high quality Mg die castings.

CONCLUSIONS

1. The porosity level is reduced near the die gating system due to the pressure intensification and fine evenly distributed grains are formed with increasing filling ratio and shot sleeve temperature. Hence, proper design and optimized HPDC parameters are essential for the production of high-performance components.
2. The mechanical properties of AZ91D and AM50A alloys, which are associated with high degree of plastic deformation (UTS, Elongation and Impact Strength) are more sensitive to porosity level compared to tensile yield strength (TYS).
3. Tensile and impact strength properties of MRI 153M and MRI 230D are practically not dependent on porosity level. Thus, wider specter of HPDC process variables can be used at manufacturing high-performance components of the above alloys.

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