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An Application of Trapped-Air Analysis to Large Complex High-Pressure Magnesium Casting

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AN APPLICATION OF TRAPPED-AIR ANALYSIS
TO LARGE COMPLEX HIGH-PRESSURE
MAGNESIUM CASTING

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INTRODUCTION

The usual method for simulating die-castings consists of a solidification analysis of the casting process - a computer calculation of heat transfer between the casting and the die components. The use of cyclic simulations, coupled with the geometric accuracy of the finite element method, has advanced this procedure to the point where it is routinely used for reliable prediction of shrinkage defects in die-castings. Filling analysis is also routinely used to get a glimpse of cavity filling and ensures that overflows are at their most effective location. When coupled with heat transfer, a filling analysis is also very effective in demonstrating the effects of heat loss in the fluid and how it consequentially can negatively affect filling.

This process is highly effective in dealing with aluminum castings. The solidification analysis alone often gives an accurate representation of where the most egregious defects would occur. A highly accurate filling simulation would not be entirely necessary to give an accurate prediction of shrinkage defects. As such, some software packages with somewhat crude modeling and flow simulation techniques have been able to avoid close scrutiny.

The solidification analysis after the die cavity is filled is dramatically less significant in magnesium die-casting. Magnesium die casting parts are usually very thin and the heat capacity (combining the specific heat and latent heat of fusion) of magnesium is smaller compared with that of aluminum. Meaning, magnesium die-castings are solidifying during the die filling and have completely solidified immediately after the cavity is filled. The amount and location of trapped-gas during filling reflects directly on the casting quality of magnesium casting. Thus, an accurate prediction of the flow pattern as well as the amount and location of trapped-gas are critical in magnesium die casting simulation.

TRAPPED-AIR ALGORITHM

There are a few commercially available casting flow simulation codes. Most of these codes solve the velocities, pressure and fluid fraction only in the liquid phase, with the assumption that the effect of the void (air) is negligible. Such an algorithm, while generally accurate for most casting processes, does not retain any information on the quantity of gas that may be trapped by the incoming liquid metal stream.

The calculated flow pattern itself often gives a good indication of the quality of the cavity fill and is useful for making some judgments about the overall casting quality. However, it is highly subjective process. Knowing the location and amount of trapped-air, could allow for a quantitative and objective analysis.

A trapped-air algorithm has recently been developed [1]. The details of this algorithm have been described in other literature but it is significant to note this method can account for not only the back pressure of the air at remaining empty cavity but also for the trapped air within the liquid metal [1]. Although this algorithm has been successfully demonstrated on aluminum high-pressure die casting, it has not yet been applied or verified on magnesium die-castings.

In this study, it will be demonstrated that this newly developed trapped-air algorithm can be applied to magnesium die-casting and the amount and location of trapped-air can be directly correlated with the quality of the magnesium die-castings. The improvement of the casting quality by applying a vacuum system will also be discussed.

PROCEDURES

The first step in any simulation procedure is to create a mesh for numerical analysis purposes. To do a complete simulation a mesh must be created to represent the casting and the mold. Second, a cyclic thermal analysis was performed using process data supplied by the manufacturer. Generally, 10 production cycles are thermally simulated to achieve a steady state temperature in the die. Temperatures at all phases of the thermal simulation are analyzed to detect unfavorable casting conditions. Third, temperatures that reflect the mold before the shot are imported into the flow simulation. The cavity fill is simulated using shot parameters provided by the manufacturer. Conjugate heat transfer and trapped gas are monitored during this phase of the process simulation. At the completion of the simulation, locations of trapped gas can be identified and final fluid temperatures can be observed.

CASTING

The CAD for this simulation was provided by Gibbs Die-Casting and consisted of the casting, runner, overflows, and 8 mold pieces. The casting itself is a very large complex piece that is approximately 1.5 m long with numerous thin sections (2 mm or less). The integrated CAD model was input into CAPCAST meshing software, a commercially available automatic finite element mesh generator. The entire system was meshed concurrently. The final model consisted of approximately 6,800,000 nodes and 6,900,000 elements. The casting itself consisted of 50,000 nodes and elements. Special care was taken to ensure that at least 2 element layers crossed every surface. This was necessary to ensure proper calculations of viscous shear and fluid velocities, especially in extremely thin sections.

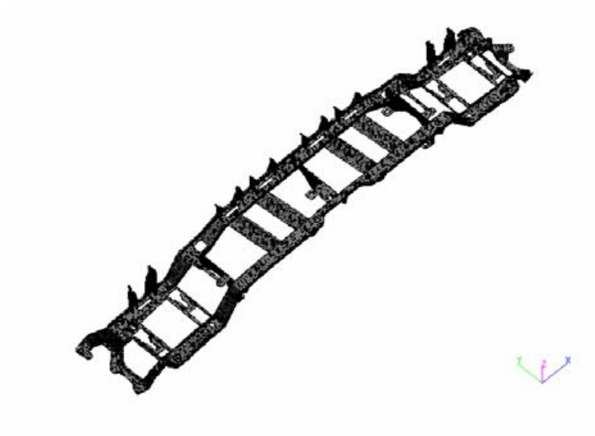


Figure 1. FEM model of casting

CYCLIC THERMAL ANALYSIS

For simulation purposes, the process cycle is divided into 5 distinct phases (dwell, first open, spray, second open and closes phases). The cycle was repeated 10 times, as noted previously.

At the end of the dwell phase the die surface, especially the casting/mold interface, was checked for any regions that might be indicative of 'hot spot' for shrinkage problems. Conversely, the closed phase mold surface was monitored for any regions that were relatively cold. In cases where this occurs, especially far away from the runner, it is likely that the metal will prematurely freeze at those regions and cause mis-run and /or surface defects.

No potential problems were found in the thermal investigation of the process. This was to be expected as this casting has been in successfully produced for some time.

FLOW RESULT/TRAPPED –AIR RESULTS

Using filling parameters provided by Gibbs DC and importing the 10th cycle closed phase temperature, the cavity fill was simulated. The model incorporated vents and was also assigned a back-pressure which in the first simulation was atmospheric pressure. The filling temperatures and the pattern were observed. The pattern was monitored for any obvious blind spots caused by forcing the fluid to turn sharp corners. The simulation was preprogrammed to stop the fluid flow if it went below the solidification temperature. From these temperatures and filling pattern results it is safe to conclude that mis-runs caused by premature freezing or inefficient gate and overflow placement will not be a major concern in this production. Figure 2 shows some of these results.

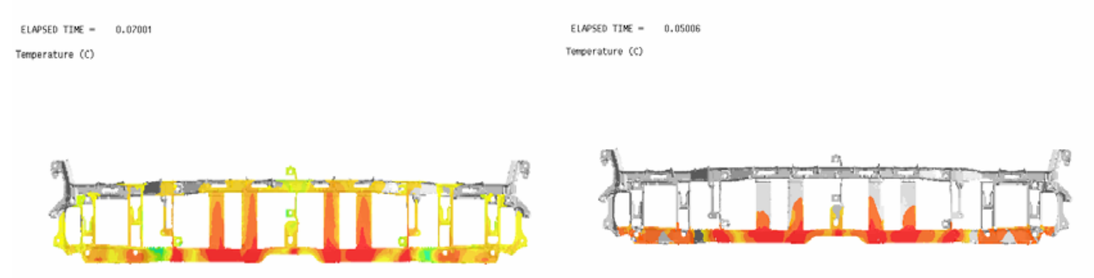


Figure 2. Filling results with conjugate heat transfer

Trapped gas was also analyzed. It is important to note that the simulation does more than track macroscopic voids in the fluid. The simulation can also track gas that has been sublimated into the molten metal. This gas, while not visible, can still play an important role in determining the casting quality.

VERIFICATION

Castings were divided into discrete sections, marked and cut. Each section of the casting was then radiographed and graded for the amount of porosity. The grading was done in accordance with ASTM E505 (American Society of Testing and Materials, Reference Radiographs for Inspection of Aluminum and Magnesium Die Castings). Each section was graded from 1 to 4 with grade 1 having the least and grade 4 having the most porosity. The results of this evaluation are shown in Table 1. Table I groups the casting sections by location and provides the identification of the casting number and the porosity grade for each section. An average grade is also assigned for each casting location.

Location	Test Group	Cast #	Location	Grade	Avg.
1	"G-4"	5	1	2	2.0
	"G-4"	7	1	2	
	"G-4"	6	1	2	
	"G-4"	8	1	2	
	"G-5"	9	1	2	
	"G-5"	10	1	2	
2	"G-3"	1	2	1	1.0
	"G-3"	11	2	1	
	"G-3"	3	2	1	
4	"G-6"	5	4	1	1.0
	"G-6"	6	4	1	
	"G-6"	7	4	1	
5	"G-6"	5	5	Other	Other
	"G-6"	10	5	Other	
	"G-6"	7	5	Other	
6	"G-1"	5	6	1	1.1
	"G-1"	6	6	1	
	"G-1"	7	6	1	
	"G-1"	8	6	1	
	"G-1"	13	6	2	
	"G-1"	14	6	1	
	"G-2"	9	6	1	
	"G-2"	10	6	1	
	"G-2"	11	6	1	
	"G-2"	12	6	1	
8	"G-4"	7	8	2	2.2
	"G-4"	8	8	2	
	"G-4"	9	8	2	
	"G-4"	10	8	2	
	"G-5"	5	8	3	*
	"G-5"	6	8	2	
9	"G-3"	1	9	2	1.3
	"G-3"	11	9	1	
	"G-3"	3	9	1	

Location	Test Group	Cast #	Location	Grade	Avg.
10	"G-4"	9	10	2	2.2
	"G-4"	10	10	2	
	"G-5"	5	10	2	
	"G-5"	6	10	3	*
	"G-5"	7	10	2	
	"G-5"	8	10	2	
11	"G-4"	5	11	2	2.8
	"G-4"	6	11	2	
	"G-5"	7	11	4	*
	"G-5"	8	11	4	*
	"G-5"	9	11	3	*
	"G-5"	10	11	2	
12	"G-1"	5	12	2	1.7
	"G-1"	6	12	1	
	"G-1"	11	12	1	
	"G-1"	12	12	2	
	"G-1"	13	12	2	
	"G-1"	14	12	1	
	"G-2"	7	12	2	
	"G-2"	8	12	2	
	"G-2"	9	12	2	
	"G-2"	10	12	1	
18	"G-1"	9	18	1	1.4
	"G-1"	10	18	2	
	"G-1"	11	18	1	
	"G-2"	5	18	1	
	"G-2"	6	18	2	
	"G-2"	7	18	1	
	"G-2"	8	18	1	
	"G-2"	12	18	2	
	"G-2"	13	18	2	
	"G-2"	14	18	1	
19	"G-4"	5	19	3	3.0
	"G-4"	6	19	3	*
	"G-4"	11	19	3	*
	"G-5"	8	19	4	*
	"G-5"	9	19	2	
	"G-5"	10	19	3	*

Table 1. Results of x-ray examination of casting

A condensed list from Table 1 is provided in Table 2.

Porosity Grade (avg.)	Location	Comment
1	2, 4, 6	Minimum Porosity
1.5	9, 12, 18	
2	1, 8, 10	
3	11, 19	Significant Porosity

Table 2. Summarized (condensed) listing of porosity grade verses casting locations.

Figure 3 points to regions in a test casting that were found in the laboratory to have significantly high levels of porosity.

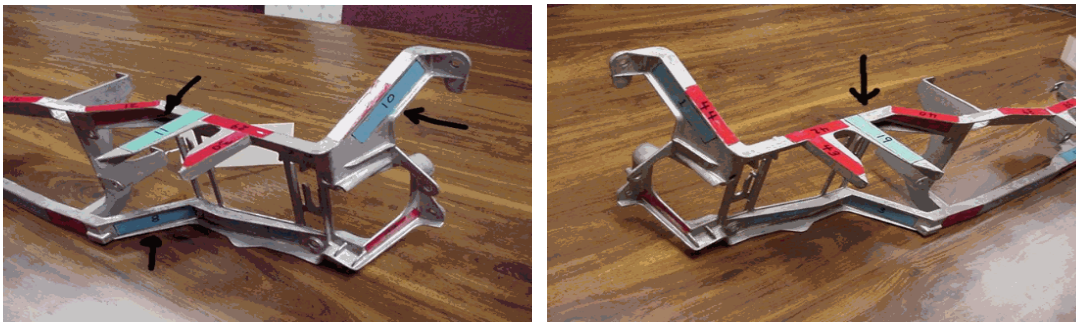


Figure 3. Regions of high gas porosity identified by x-ray

In Figure 4, the arrows are pointing to the corresponding regions in the simulation results model. The simulation had predicted those regions to contain a high concentration of gas.

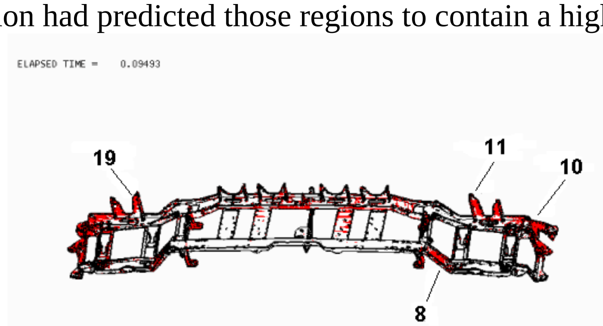


Figure 4. High porosity regions predicted by the simulation model

Conversely, the simulation and the test casting were compared for prediction of relatively high quality regions. Figure 5 points to the regions in the test casting that were of relatively high quality.

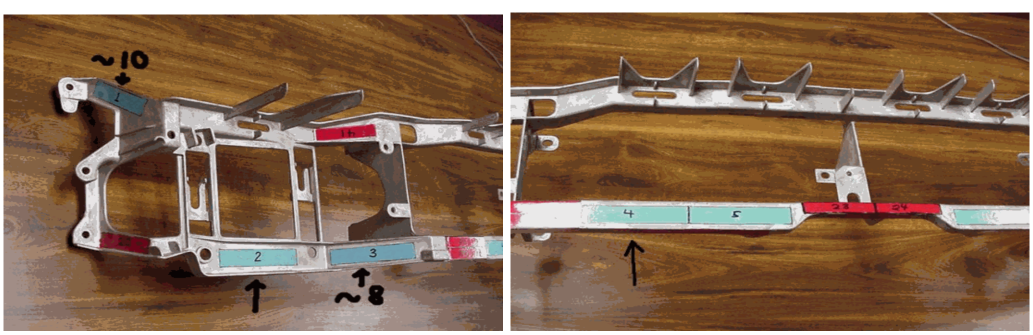


Figure 5. Regions of relatively low concentrations of gas porosity, confirmed by x-ray

The following figures 6 show the corresponding regions in the simulation results model. Note that the regions are clear, indicating that those regions were predicted to be relatively free of gas upon cavity fill.

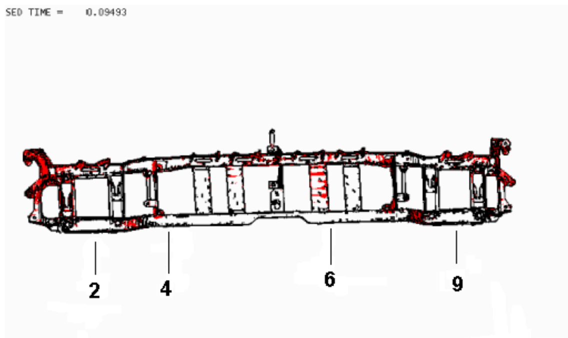
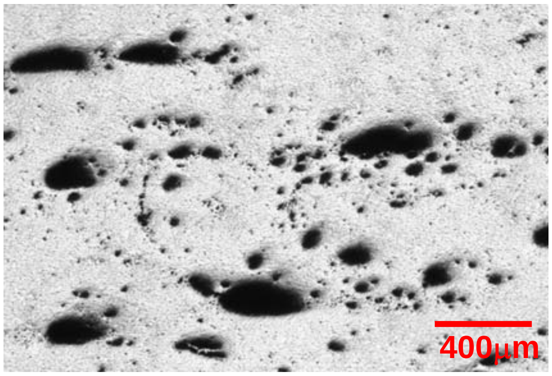
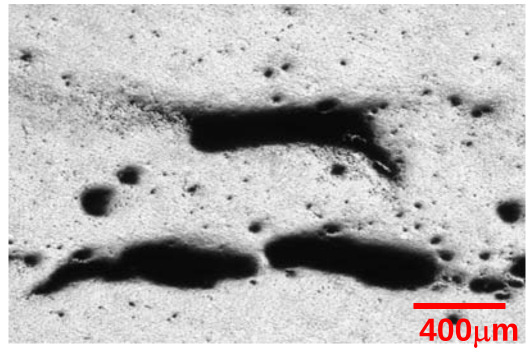


Figure 6. Regions of low gas porosity predicted by the simulation model

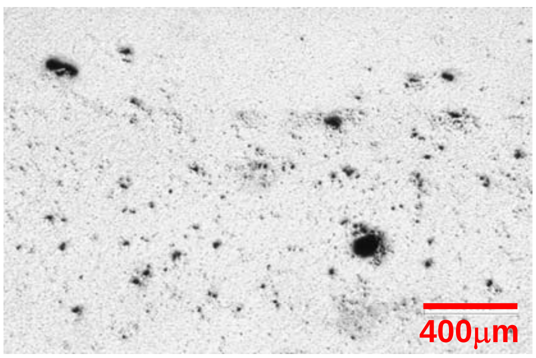
Specimens from selected locations of the casting were sectioned and prepared for metallographic observations. Figure 7 shows typical unetched microstructures depicting porosity at three locations in the casting. The amount of total porosity that includes trapped air (gas) porosity and shrinkage porosity was quantitatively characterized using digital image analysis techniques. Figure 8 compares the percentage of the porosity measured using the combination of metallography and digital image analysis, with the X-ray grading, and the predictions of the simulations for the high-porosity regions, and Figure 9 depicts similar comparison for low porosity regions. Observe that there is a good agreement between the experimentally measured values and the porosity distribution trends predicted by the computer simulations in both high and low porosity locations.



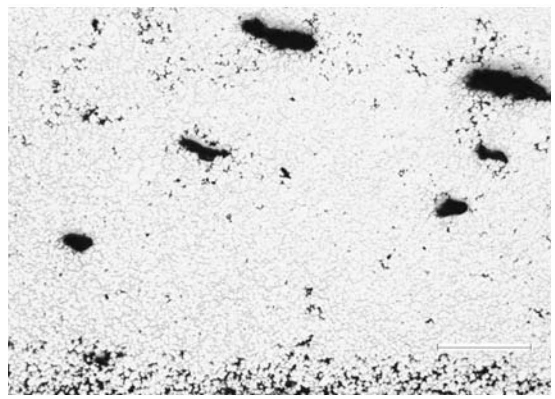
(a)



(b)



(c)



(d)

Figure 7: Porosity present at different locations in the casting: (a) and (b) at location 19, (c) at location 16, and (d) at location 3.

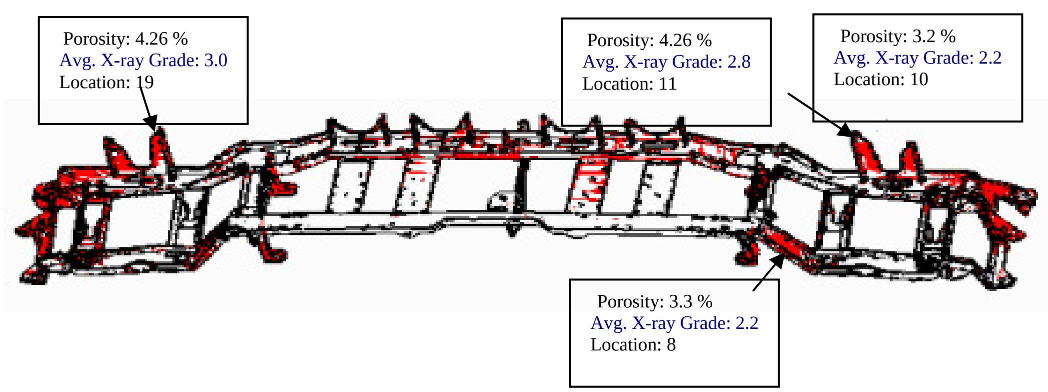


Figure 8: Comparison of experimental measured % porosity using metallography and image analysis, X-ray grading of porosity levels, and the high porosity region locations predicted by simulations.

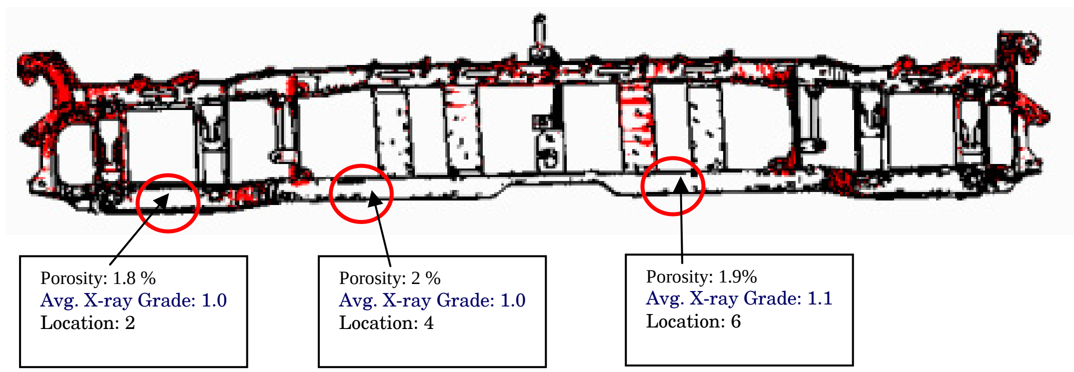


Figure 9: Comparison of experimental measured % porosity using metallography and image analysis, X-ray grading of porosity levels, and the low porosity region locations predicted by simulations.

VACUUM EFFECTS

It was decided to run further simulations assigning a vacuum with a pressure differential of 0.8 atm and 0.2 atm. This was accomplished by reassigning the backpressure value discussed earlier to those vacuum values. Both vacuum settings yielded less trapped gas in the cavity than did the original analysis. The vacuum power of 0.2 atm yielded the least amount of trapped gas in the cavity. Figures 10 and 11 illustrate the results.

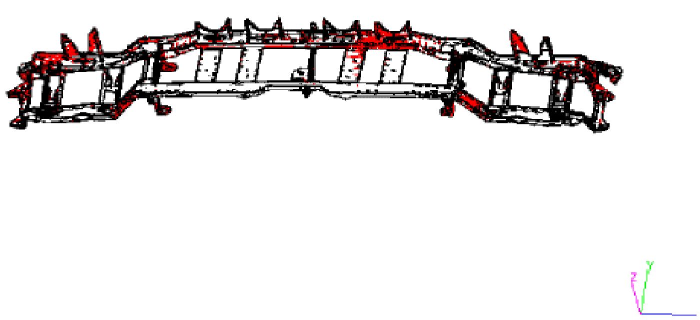


Figure 10. Trapped gas results from 0.8 atm vacuum power

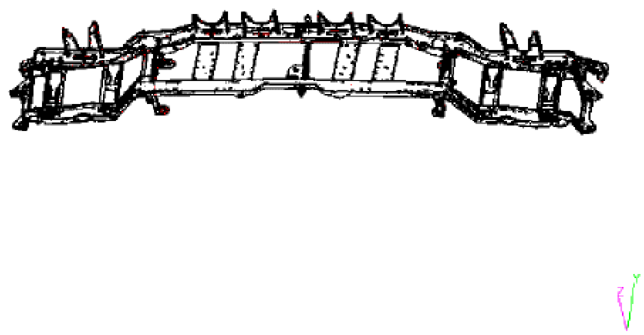


Figure 11. Trapped gas results from 0.2 atm vacuum power

CONCLUSIONS

The newly developed trapped-air algorithm can be applicable to large complex thin-wall high-pressure magnesium die casting. Since the magnesium high-pressure die castings are thin and its heat capacities are low, the amount and location of the trapped-air has a direct impact upon the quality of the casting. This study also showed that the amount of the trapped-air can be reduced with increasing vacuum strength.

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