Calculation of the Die Cast Parameters of the Thin Wall Aluminum Die Cast Part

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Numerical analysis has become an integral part of process development in the die casting industry. With more economical and faster computers, and more efficient and accurate numerical algorithms, engineers can examine more design options and achieve better results in a much shorter time. Efforts to reduce energy consumption and weight, led to die cast parts becoming more complex. Thin wall castings in combination with new materials offer weight reduction with increased strength. These significantly increase the application fit in functional assemblies for pressure die castings.

Secondary operations, including welding, riveting, and heat treatment, have raised quality requirements for these highly engineered castings. In order to achieve the greater structural uniformity, high efficiency vacuum systems are routinely used on die cast dies. We have found that standard vacuum valves provided inadequate venting for the gas in our systems. Rather than adding second and third valves to our die systems, with the associated added operational complexity, we have showed that size of ventilation system could be tripled to meet vacuum requirements of the die cast process in a single valve. Through numerical analysis, utilizing general CFD capabilities of FLOW-3D, a standard vacuum block was modified to achieve a required size of the cross-sectional area of the ventilation channel. Subsequent production runs determined that the numerical calculations were well correlated with the results, generating the predicted improvements.

Introduction

The automotive industry, from its early beginning to our times, starting with the invention of the steam powered engine in the middle 1600's, and then gasoline, electrical, and hydrogen fuel cells in early to a middle 1800's, searched for the most efficient way to power the engine. Power efficiency is a concern regardless of the type of the energy source used. Unable to develop completely new, revolutionary source of energy which would be as efficient and as cheap as existing ones, the automotive industry researchers tried to solve problem of energy conservation by using lighter, stronger materials. Over time many different materials were used with various degrees of success. In the last decade aluminum alloys have become clearly the material of choice for the structural components. Lightweight, relatively high strength, high corrosion resistance, and high thermal conductivity are the major advantages of these alloys. In order to produce thin wall structural die cast parts, much more stringent requirements have to be applied to the high pressure die cast process. Parts have to go though several stages of heat treatment process to obtain required strength and elongation under an applied load. Gas entrained during the process has to be minimized, prompting the use of high efficiency vacuum systems that would allow to lower cavity pressure to about 50 – 60 mbars.

Description of the Problem

In this paper, we describe the process development for a thin wall aluminum die cast part. The part weight is 3.5 kg, with an average wall thickness of 2.5 mm. The manufacturing process includes pressure die casting, heat treatment for 2 hours at 450° C and then an aging treatment at 230° C for 2.25 hours. To enable effective heat treatment, high efficiency vacuum systems are used to aid gas evacuation during the die cast process. There are three sources of trapped gases that contribute to the contaminants that reduce casting properties. Typical atmospheric gases that are displaced by the metal front, hydrogen gas dissolved in the aluminum at the alloy stage that is released at solution temperature during heat treatment, and the lubricant vaporization when the metal front sweeps through the die. All of these gases are required to be at the lowest level to achieve good casting properties. High vacuum in the die during fill accomplishes this goal. Process calculations and subsequent CFD analysis using commercial software FLOW-3D allowed our team to successfully design the process and achieve high quality parts.

Process Parameters Calculations

High efficiency vacuum die cast process calculations have to start with calculation of the size of the vacuum system. Using the analogy of air flow through a nozzle, critical pressure ratio can be calculated [1]:

$$\left(\frac{P_2}{P_1}\right)_{CR} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} = 0.528$$

where, P_1 – air pressure at the nozzle entrance, P_2 – air pressure at the nozzle exit, $\gamma = 1.4$ for air. At the start of the slow shot stage, when the vacuum valve opens, the vacuum tank is connected to the die cavity of the die cast die. The initial pressure in the cavity of the die is atmospheric, while the vacuum tank is at 50 mbars. This pressure differential is much smaller than the critical value. In this case, two equations have to be used to calculate the required cross section area of the vacuum valve.

$$\frac{\dot{m}}{P_1 A}\sqrt{\frac{RT}{\lambda}} = \left(\frac{P_2}{P_1}\right)^{1/\gamma}\sqrt{\left(\frac{2}{\gamma-1}\right)\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

where, m is air mass flow, R is the gas constant, T is temperature, A the cross-sectional area of the vacuum channel.

$$\frac{m}{P_1 A}\sqrt{\frac{RT}{\gamma}} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

Equations 2 and 3 have to be solved independently for A. The maximum value of the two will be accepted as a required ventilation area. For the part presented in this paper the minimum cross sectional area was calculated to be 300 mm^2. Next, the slow shot velocity of the plunger was calculated [2]:

$$X''_{\alpha}(t) = \frac{\left[c_o + \frac{1}{2}X'(t)\right]\left[c_o + \frac{3}{2}X'(t)\right]\tan(\alpha_{max})}{\frac{1}{g}\left[c_o + \frac{1}{2}X'(t)\right]\left[c_o + \frac{3}{2}X'(t)\right] + \tan(\alpha_{max})(L - X(t))}$$

where L is the length of the shot cylinder, t is time, c_0=sqrt(gh), g gravity, h the initial depth of metal in the shot sleeve, α_{max} is the maximum allowed slope of the metal surface during the slow shot stage.

Equation 4 was numerically integrated with respect to time to obtain slow shot velocity profile.

Next step was to verify if the calculated slow shot velocity will allow an adequate time to evacuate air and reduce air pressure to the pressure in the vacuum tank. Transient CFD analyses of the compressible air flow were performed to plot pressure distribution in the cavity during the die cast process. The part, overflows and the runner were modeled as a cylinder of the same combined volume. The plunger was prescribed the velocity equal to the calculated

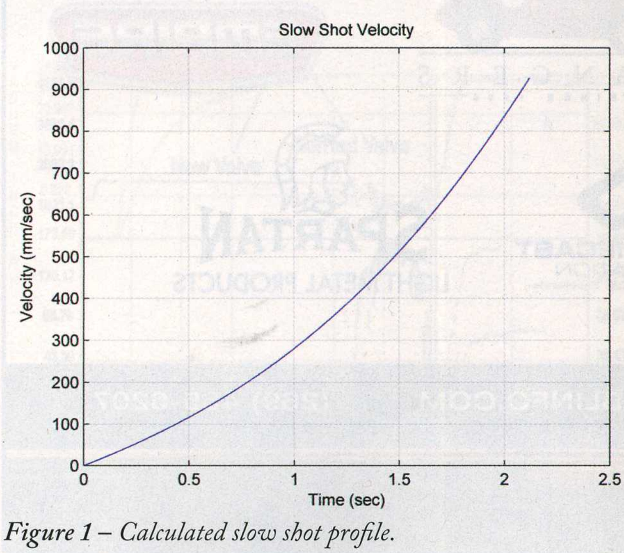

Figure 1 – Calculated slow shot profile.

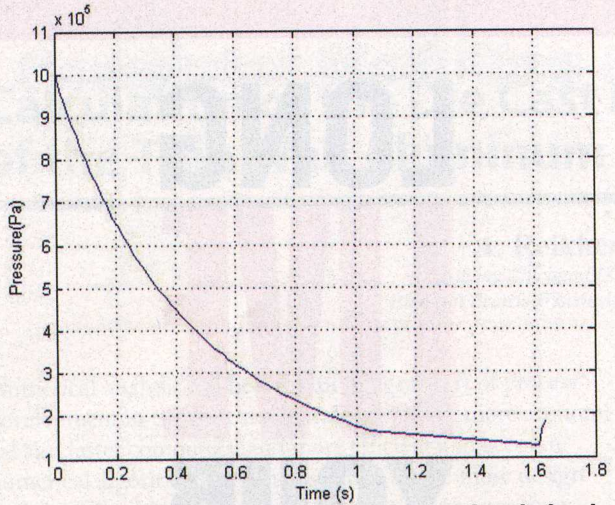

Figure 2 – Air pressure in the die cavity using the calculated slow and fast shot profiles.

fast and slow shot velocities. The opposite end of the shot cylinder had an opening with the diameter equal to the cross section of the vacuum valve ventilation area.

To verify the preliminary calculations, a cross section area of 90 mm^2 (that of a commercial vacuum valve) was used first. The result is shown in Figure 2.

It is obvious that the calculated slow shot profile will not allow enough time to lower air pressure in the cavity to the pressure of the vacuum tank held at 96 kPa. Since variable velocity profile with the speed of the plunger continually increasing will not allow to stabilized air pressure in the cavity before fast shot velocity of the plunger can start, then the constant velocity profile of the plunger must be used [3]:

$$V = 2\left(\sqrt{gH} - \sqrt{gh}\right)$$

where, H is the plunger diameter, and h is the depth of the metal in the sleeve.

The calculated slow shot velocity was 0.38 m/s. To define the optimum slow shot velocity to prevent air entrapment, CFD calculations had to be conducted. Several slow shot velocities in the vicinity of the calculated value have been tried. When the specified plunger velocity was too slow, excessive metal splashing in the shot cylinder resulted. When the specified plunger velocity was too high, wave velocity excited the critical wave form and metal overturned, resulting in air entrainment. Based on several velocities tried, the final slow shot velocity was accepted to be 0.3 m/s (Figure 3).

Next, two CFD analyses of the compressible air flow through the nozzle, using cross sectional area of the commercial vacuum valve and a vacuum valve with the calculated cross section area were performed.

Results shown in Figure 4 indicate that pressure in the cavity using custom made valve can reach the target value 0.5 s sooner than using the commercial valve. Analysis of the pressure rise in the cavity on a fast shot stage of the die cast process demonstrated only 5% pres-

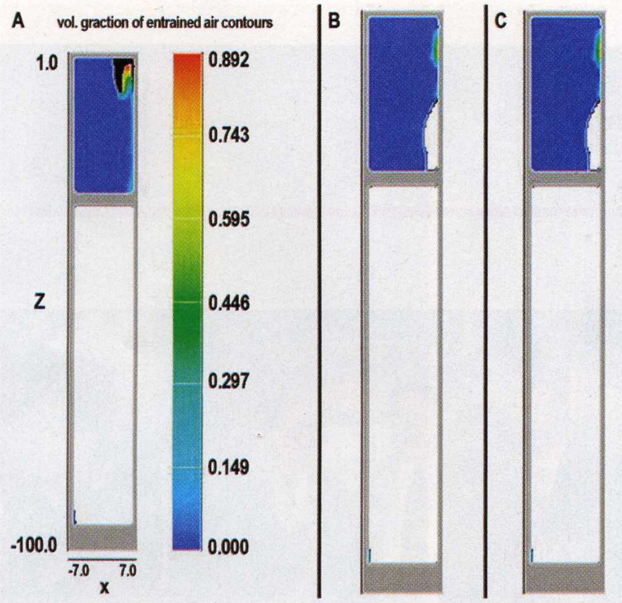

Figure 3 – CFD analysis of the flow inside the shot cylinder during the slow shot stage with the plunger velocity: a. 0.38 m/s, b. 0.3 m/s, c. 0.25 m/s. The plunger is shown in gray and is moving upwards.

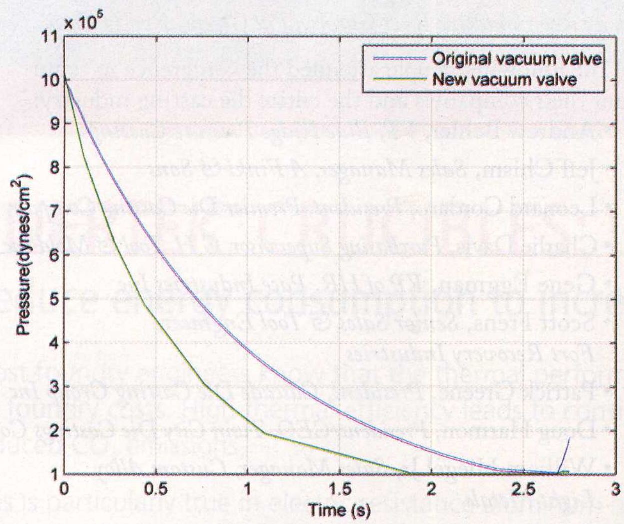

Figure 4 – Results of the pressure distribution in the cavity of the die cast die.

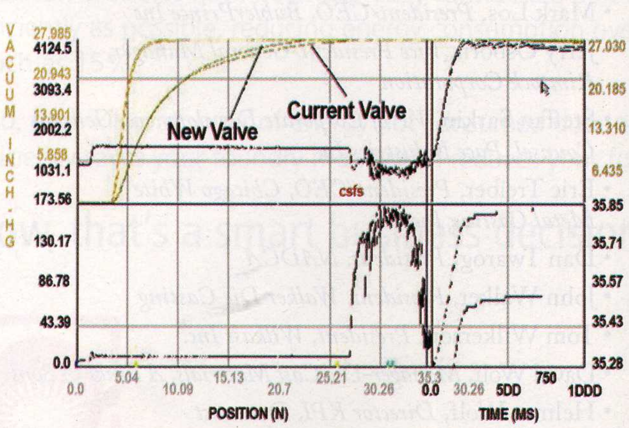

Figure 5 – Comparison of measured the vacuum curves between commercial and custom vacuum valves.

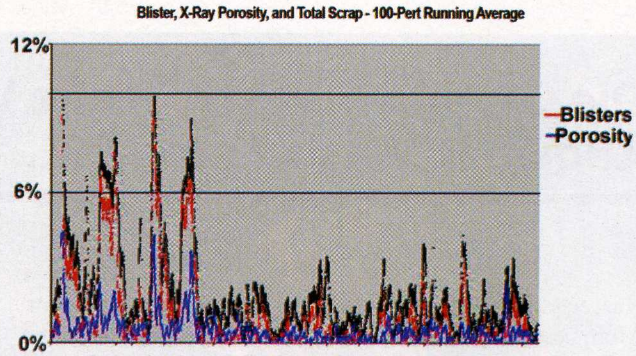

Figure 6 – Rejection rates achieved using the commercial and custom vacuum valves.

sure rise, compared with 50% pressure rise when using the commercial valve. As a result of the analysis, it was decided to use the modified valve to meet the quality requirements of the die cast process.

The next stage was to verify the results of the calculations by comparing the performance of the commercial and modified vacuum valves. Figure 5 shows a comparison between traces of the pressure changes inside the die cavity between commercial and custom made valves. Figure 6 shows the casting rejection rate obtained using the commercial and custom made valves.

Conclusions

Results of the analytical and numerical analyses using commercial software FLOW-3D are in good agreement with results observed in the production process. The calculation of the process parameters for thin die cast parts that has to go through heat treat process has to begin with correctly sizing cross section area of the vacuum channels. The rest of the parameters have to be adjusted to allow for the air to escape from the die cavity.

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