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

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ABSTRACT

Numerical analysis has become an integral part of process development in the die cast 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

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. Light weight, 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

The present work started with introduction of a new project, transferred from another manufacturer. During the usual process parameter calculations it became obvious that the vacuum system that came with the die would impose a serious limitation on the process parameters. A high-level vacuum would be necessary in the cavity (100 mbars) to produce an acceptable level of quality in the cast parts. Parts have to be heat treated after die casting, so a small amount of gas porosity could result in blisters on the surface of the part, rendering it unusable.

In order to adjust the process parameters to achieve the vacuum level required in the cavity, a computational model was constructed in which the casting, with overflows and runner system, were combined as a cylinder of the same volume. A moving piston was placed on one end of the cylinder and an open flow area equal to that of the vacuum valve was placed on the other end. A 100 mbar pressure was applied as a boundary condition at the open end. Calculated parameters for both slow and fast shot velocities were prescribed to a piston, modeled as a general moving object. Analysis of the compressible air flow in the cylinder was made to determine the time to lower the pressure in the cavity to the pressure in the vacuum tank, which was necessary before a fast shot velocity can start. It became obvious that limitations of the vacuum system dictate the process parameters. Figure 1 shows air pressure distribution in the cavity of the die. Based on the results of calculations, the slow shot velocity had to be adjusted to allow time for the vacuum system to evacuate air from the cavity. It is also noticeable pressure raise in the cavity on the fast shot stage of the process.

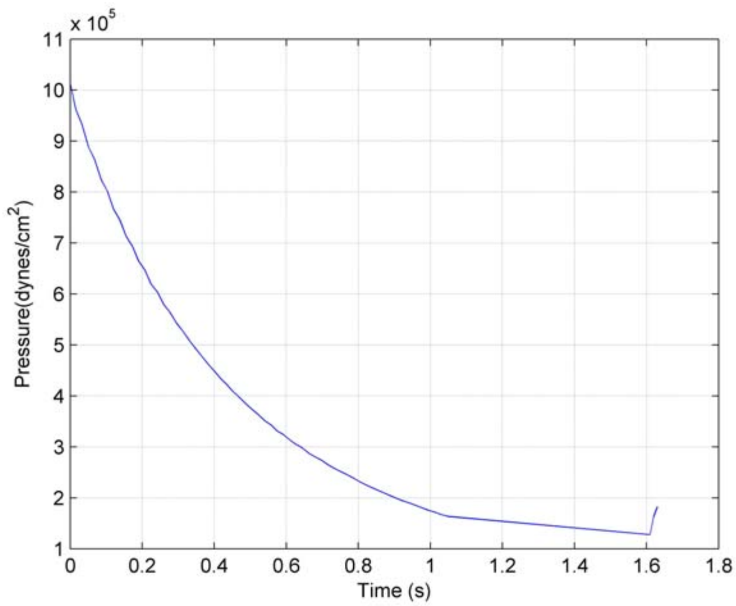


Figure 1. Air pressure distribution in the cavity during die-cast process (initially-calculated velocity profile).

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]:

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

where, P_1 – air pressure at the nozzle entrance, P_2 – air pressure at the nozzle exit, γ=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.

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

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

$$\frac{\dot{m}}{P_1 A}\sqrt{\frac{RT}{\gamma}} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \qquad (3)$$

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]:

$$X''_{\alpha}(t) = \frac{\left[c_o + \frac{1}{2}X'(t)\right]\left[c_o + \frac{3}{2}X'(t)\right]\tan(\alpha_{max})}{\frac{1}{g}\left[c_o + \frac{1}{2}X'(t)\right]\left[c_o + \frac{3}{2}X'(t)\right] + \tan(\alpha_{max})(L - X(t))} \qquad (4)$$

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, $\square_{max}$ 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

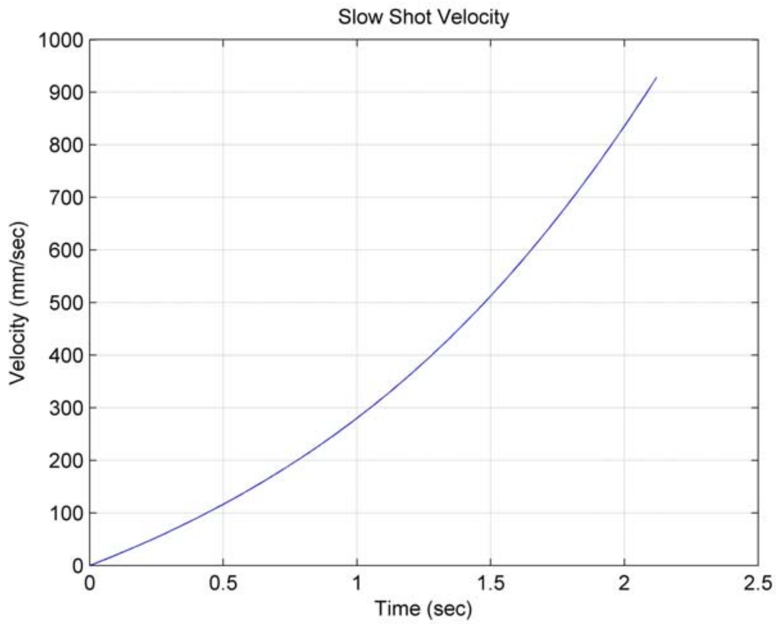


Figure 1. Calculated slow shot profile

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 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 Fig. 2.

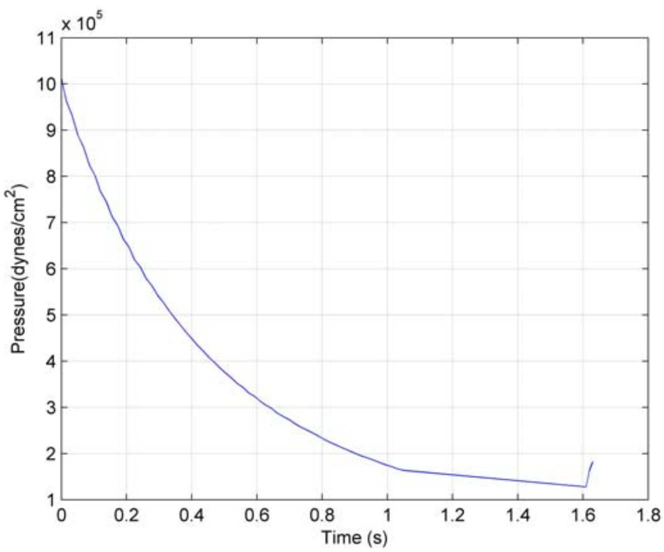
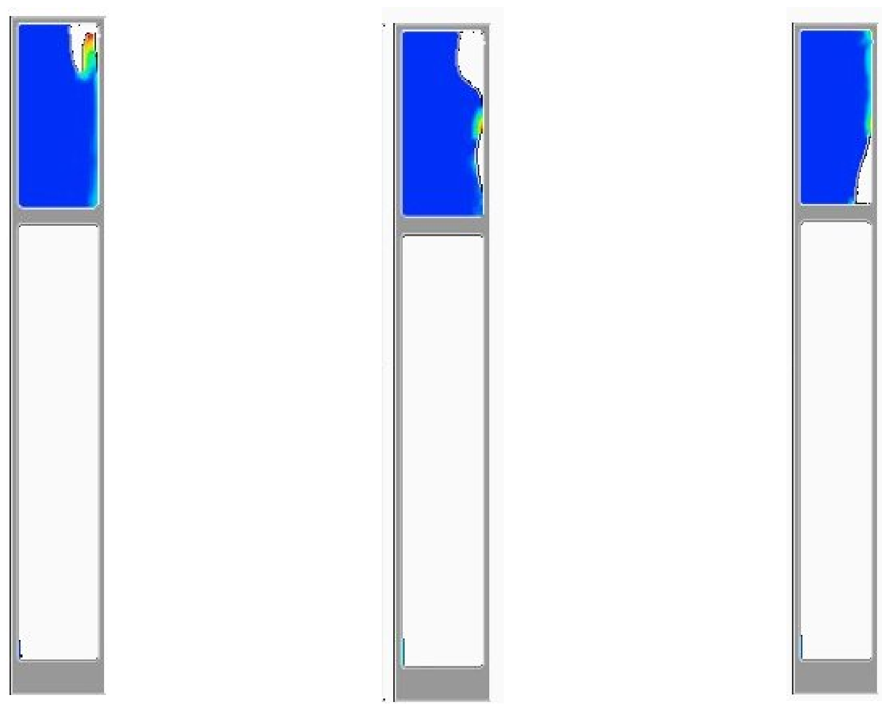


Figure 2. Air pressure in the die cavity using the calculated slow and fast shot profiles

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]:

$$V = 2\left(\sqrt{gH} - \sqrt{gh}\right) \tag{5}$$

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 (Fig. 3).



a b c

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.

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.

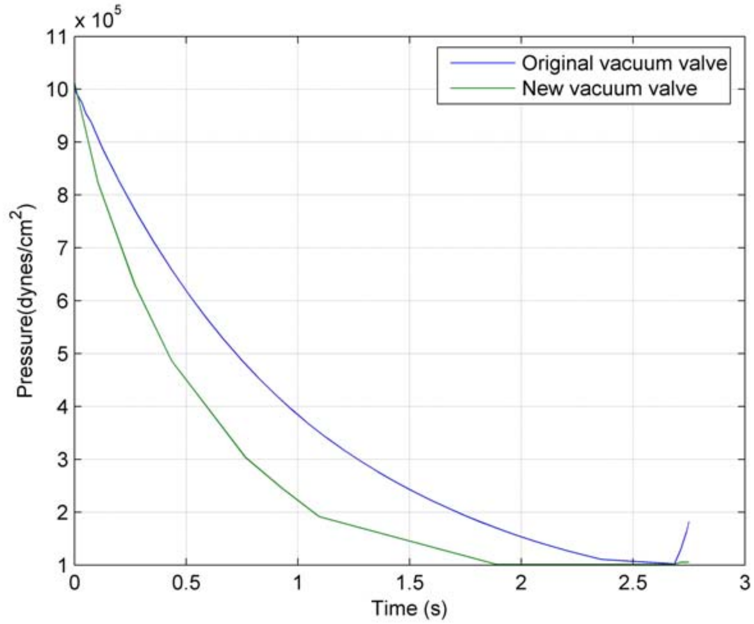


Figure 4. Results of the pressure distribution in the cavity of the die cast die

Results shown in Fig. 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% pressure 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.

After several iterations, a slow shot velocity was chosen. It allowed time to reach pressure in the cavity of the die equal to a pressure in the vacuum tank. The next step was to open up the air flow area of the vacuum valve to eliminate restrictions imposed by the current design. Initial calculations showed that the minimum size of the air passage has to be 300 mm^2. The original valve had only a 90 mm^2 cross section area for ventilation.

It wasn't possible to just open up channels in the vacuum valve to a calculated size. Restriction of the metal flow is necessary to build pressure in the vacuum channel to close the valve. It was decided to adapt a proprietary, previously-developed system used for plunger deceleration. Instead of restricting metal flow by reducing the cross sectional area of the channel, a flow loss was generated at turns in the channel. Metal flowing through the channel requires progressively more pressure to maintain the same velocity. As resistance to the metal flow increases, the pressure of the metal in the cavity also increases.

After several design iterations, the final model was chosen based on the space restriction of the current die and the metal pressure necessary to close the vacuum valve. Metal flow analyses were conducted using the final vacuum channel design. Pressure generated by metal at the mechanical valve button is compared to the analysis result of the current system.

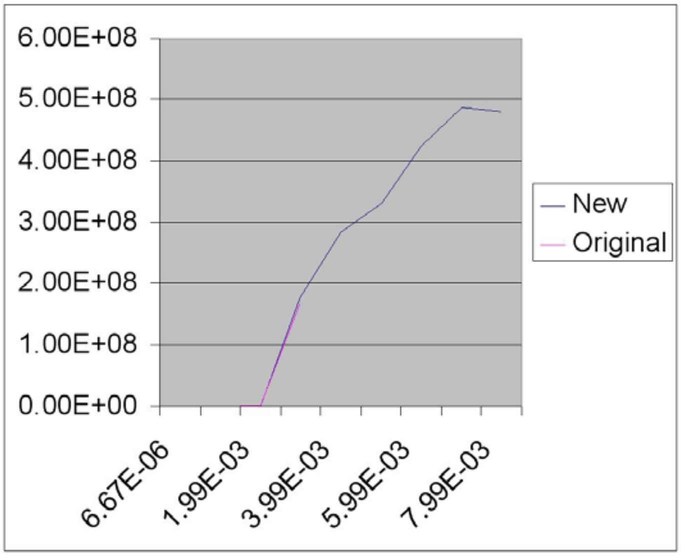


Figure 5. Pressure generated in original and new vacuum system (dyne/cm2).

Analysis Results: Comparing the Old and New Systems

Comparison analysis of the air pressure in the cavity between the original and the new vacuum system confirmed previous calculations (Fig. 5). A newly-sized ventilation block will allow adequate time to reach the specified pressure in the cavity. Analysis has also shown that the new vacuum block will allow an adequate air flow from the cavity of the die into the vacuum tank during the fast shot velocity stage as well. Visi-Trak plots shown in Fig. 6 compare the pressure curve in the cavity of the die between the old and new vacuum blocks. Subsequent production runs have demonstrated that the new vacuum block achieves the specified pressure before the start of the fast shot stage. A 50 percent reduction in defects attributed to the new vacuum system (see Fig. 7) confirms the results of the simulations that the new vacuum system would be able to maintain air pressure in the cavity within process requirements.

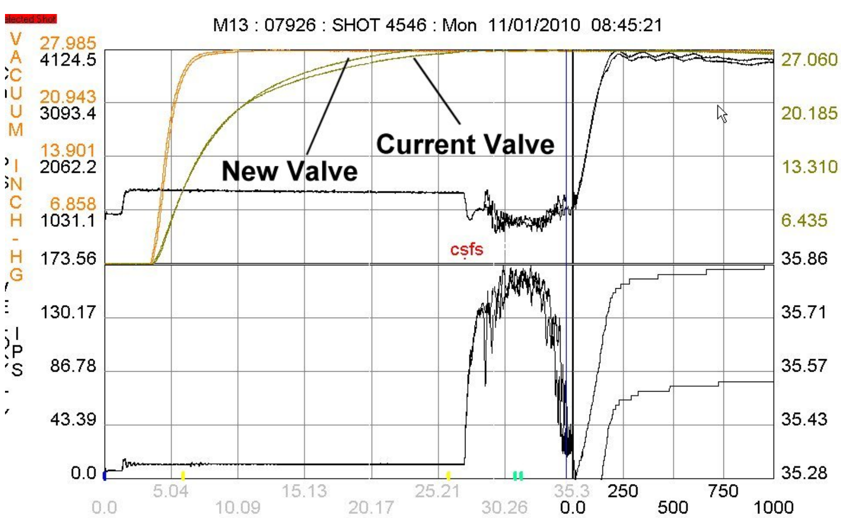


Figure 6. Visi-Track plot of the pressure measured in the vacuum valve.

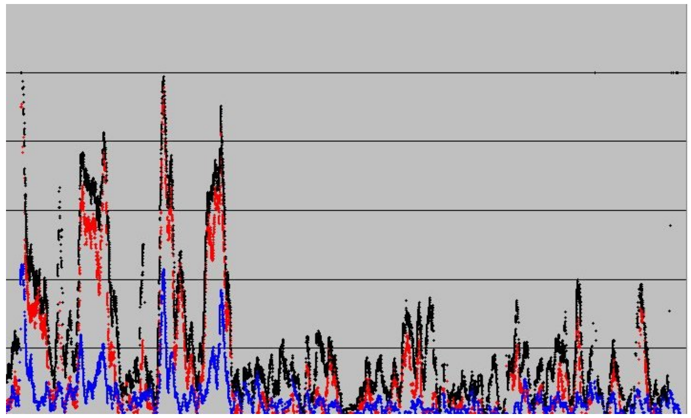


Figure 7. Scrap reduction after implementation of the new vacuum system.

Excellent agreement of the numerical results and physically measured parameters confirm the design of the new vacuum valve without the need for any subsequent modifications.

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 without restriction.

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