

A CASE STUDY IN EFFECTIVE RESOLUTION

SURFACE POROSITIES IN CAST ALUMINUM GREEN SAND PRODUCTS

BY PAUL SNYDER

Abstract

The green sand-casting process has many benefits over other casting processes, such as low entry cost, minimal waste footprint, and comparatively competitive molding rates when fully automated molding processes are used. As our aluminum foundry adopted these high-speed green sand molding processes, we uncovered a lesser published defect regarding surface porosities that affected areas of significant modulus with extended solidification times. Many foundries that adopted the automated green sand molding process accepted this impediment to producing high-quality products as a by-product of green sand limitation. Many of them tried to mitigate surface porosity through traditional means, such as the use of strategically placed mold chillers, dangerously low pouring temperatures, and costly in-process rework. This settlement, although perhaps justified by popular opinion, did not reflect the opinion of BQC Foundry. Consequently, BQC Foundry decided that the time had come to find a solution to this surface porosity. BQC worked with our supply partner of casting simulation software while we armed ourselves with the work of John Cambell to form an alliance wherein, we could study the development of porosity formation at the mold/metal interface while exploiting our competitive advantage using simulation modeling. The information developed through simulation and functional tests will be reported in this paper.

Introduction

Before traveling through the journey of this case study, we must first establish how green sand becomes “green.” The raw foundry sand is bonded with clay and water before it is hydraulically squeezed around a pattern to create the part geometry. The “Green” in green sand is the water used in this bonding mixture. The fact that the sand turns black in color is due to carbon that is deposited when the clay is burned off after exposure to the heat of the liquid metal. The same interaction that burns the clay and deposits carbon is also the same interaction that creates steam between the mold/metal interface. The permeability of the sand bleeds off steam pressure but reaches a point of neutrality where the permeability of the sand can no longer provide a path of least resistance. This creates an environment where the steam remains present at the mold/metal interface where it can react with the surface of the casting.

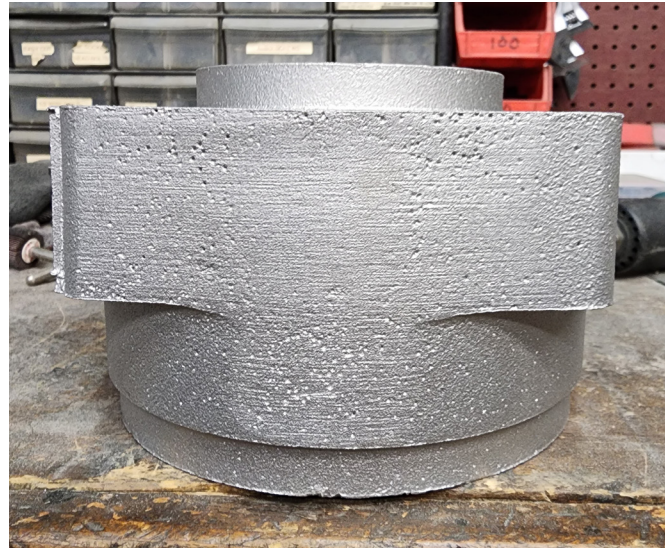


Figure 1.

For the sake of this study, the surface of the casting is defined as the first 1-2mm of metal beneath the as cast surface.

The metallostatic pressure of the metal being poured into the mold helps to maintain a pressure delta of zero between the metal and the steam during solidification, leaving the surface of casting relatively porosity-free. Despite this opposing reaction, BQC’s customers occasionally notify us of surface porosity, particularly with products from other green sand foundries. BQC felt that there should be documented information regarding how we are able to address our customers’ concerns and state that the root cause is much deeper than what was traditionally accepted as the cause of the reaction at the mold/metal interface. The results of the investigation carried out to limit the effect of surface porosities in automated green sand molding processes are reported here. Figure 1 details the cosmetic issues and material quality concerns created by steam build-up at the mold metal interface.

Prior Work

Hetke and Gundlach¹ reported their study of the effects of metal chemistry, particularly the effect of Strontium, on strength and ductility after Sr addition. They found a significant decrease in each with a significant increase in porosity. Byczynski and Cusinato confirmed this finding in 2001 in the Cosworth Process. With the effect of Sr securely linked to increased porosity and enhanced melt reactivity, we can discuss the enhanced effect of Sr on porosity in green sand foundries. The pickup of hydrogen is more serious in green sand foundries because there is a significant influx of hydrogen from the sand binder system introduced to the melt through diffusion, as observed by Chen². In heavier sections, there will be several minutes for the Hydrogen to diffuse into the casting sections. Any cross-section with a solidification time of 100 seconds or longer is susceptible to significant hydrogen diffusion at distances of up to 10mm from the surface. Through this prior work, BQC prioritized metal chemistry and solidification time to expand the investigation onto the production floor.

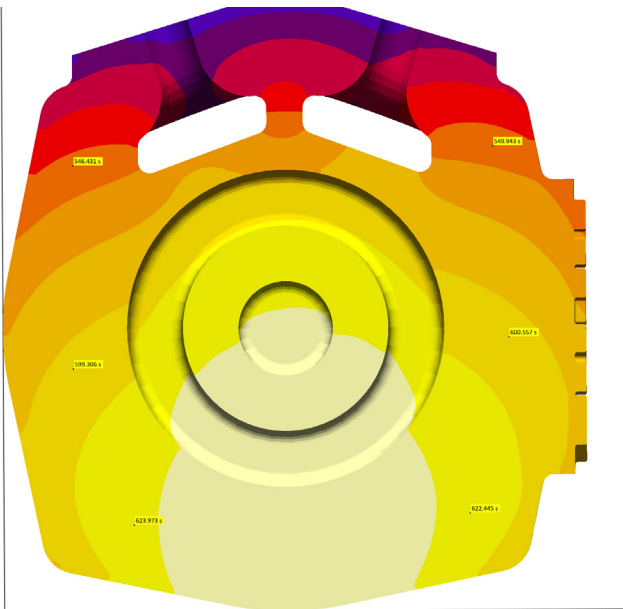


Figure 3. Baseline Solidification Time result – Solidification times are as high as 680 seconds before the aluminum reaches its coherency point.

Functional Testing

To validate the effectiveness of the simulation results and their interpretation, real-time process testing was performed on a sample casting. Acceptance standard SAE AMS 2175 Edition A Table 4, Grade C was used to qualify the material. There were no failures and zero areas of concern.

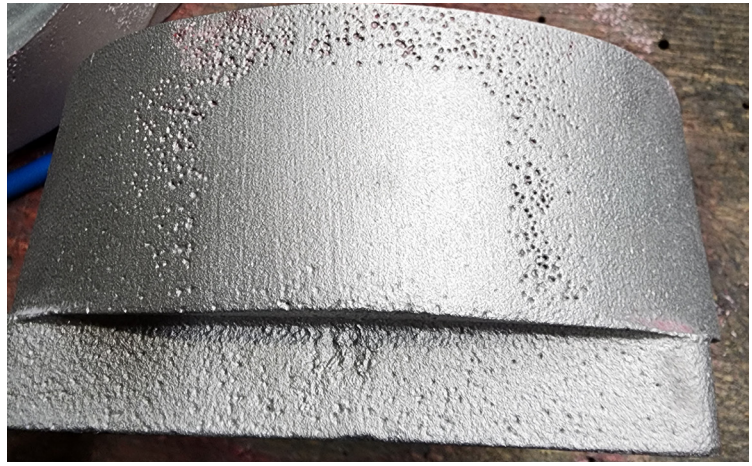


Figure 2. Extreme Case of Surface Porosity

EXPERIMENT DETAILS

Alloy Examined

A356 – 7% Si

Metal Chemistry & Solidification Time

The metal chemistry was altered between Sr levels of 100PPM through 500+ PPM to determine the functional effect of Sr as a weighted percentage of the overall heat. The final chemistry was established through a methodical sampling progression. The solidification rate of the casting was also manipulated using iron mold chillers. The mold chillers increased the solidification rate and lowered the overall solidification time. The final chill pattern was again established through a methodical sampling plan and casting simulation.

Simulation Tests

The simulation setup started with the baseline gating system used during production. The casting was poured with a standard down sprue and fed with a traditional feeder approach around the OD. The results of the baseline gating system are shown in Figure 2.

The solidification time result (Figure 3.) of the baseline simulation revealed that the solidification time of the baseline process exceeded the 100s threshold where hydrogen diffusion begins to occur. In fact, the baseline process had a maximum solidification time of 680s. As expected, the peak values were predicted to be where the gate contact and casting connect. Figure 2. Shows a strong correlation between the surface porosity and the longest solidification times.

Solidification time can help with understanding the thermal conditions within the casting and analyzing defects related to extended solidification time. The highest values should appear in the feeders and gradually become shorter within the casting. In comparison to the solidification rate, solidification time applies a singular time delta after taking the effects of sand heat transfer coefficients and chillers into account, which leads to a decrease or increase in the effective solidification time. Therefore, a more aggressive solidification time is possible with mold chillers than with non-chilled mold. The benefits of the chilled solidification time were further supported by the solidification time results shown in Figure 4.

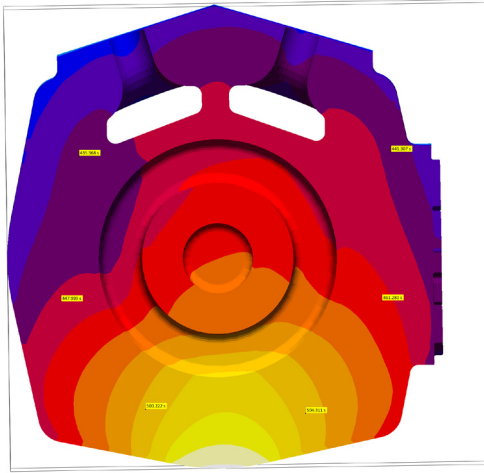


Figure 4. Optimized Solidification Time – Mold chillers reduced the solidification time by over 100s. Peak times were around 500s.

The optimized geometry used 4 large iron mold chillers in the bottom half of the mold and focused on optimizing the solidification rate and time. The chillers replaced the molding sand that was in their place during the baseline simulation, as shown in figure 3.

RESULTS & DISCUSSION

Solidification Time

Solidification Time

The solidification time of the non-chilled casting versus the solidification time of the chilled approach is shown above in figures 3 and 4. A linear relationship exists between the solidification time and the solidification rate when chilled.

Figure 3 shows that the non-chilled casting solidified in ≈ 680 seconds, whereas the chilled casting took ≈ 500 seconds to solidify, as shown in Figure 4.

Hydrogen diffusion risk increases around 100 seconds into the solidification phase, which makes decreasing solidification time by over 25% a massive process change. The faster solidifying material has less time for hydrogen to diffuse into the casting, creating a cleaner casting surface.

Strontium PPM

The Strontium PPM was reduced by 50 % to ≈ 150 PPM from ≈ 300 PPM between the baseline and optimized processes. The reduced Sr PPM resulted in a less reactive melt that limited the amount of hydrogen diffusion into the solidifying aluminum.

References

1. Ramachandran. AFS Transactions 75-57.
2. Chen, X.G., Engler, S., 1994.TAFS

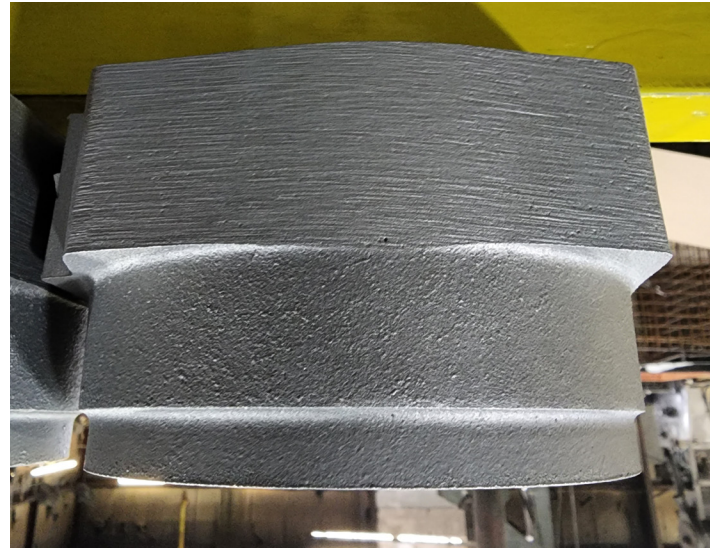


Figure 5. shows the improved final casting finish after the Sr PPM was lowered and mold chillers were applied.

Summary/Conclusions

The results of the analysis of reduced Sr PPM and applied mold chillers indicated the following:

1. There is a linear relationship between the solidification time and the amount of hydrogen diffused into the surface of the casting.
2. In both the chilled and non-chilled processes, the amount of hydrogen diffusion can be limited by reducing the reactivity of the melt through the reduction of Strontium PPM.
3. The chilled casting process promotes a more aggressive solidification rate when compared to the non-chilled process.
4. Mold chilling was more effective in reducing surface porosity when paired with lower Sr PPM.

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Definitions/Abbreviations

BQC Boose Quality Castings
Sr Strontium