PRACTICAL USE CASE: HIGH-PRESSURE DIE CASTING OF AN ACTUATOR HOUSING

High-pressure die casting (HPDC) is an efficient manufacturing process for producing complex-shaped metallic parts with high dimensional accuracy, excellent surface finish, and superior mechanical properties. In this process, molten metal is injected into a steel mold under high pressure, allowing it to fill the mold cavity and rapidly solidify to form the final product. This process is highly automated and can produce a large volume of parts in a short amount of time.

However, HPDC is susceptible to several casting defects that can affect products' quality and integrity. This requires teams to carefully optimize casting parameters and mold geometry to minimize defects to ensure a high-quality product. Here, a simulation-driven design environment is becoming a key aspect that helps engineers balance design, manufacturability, and performance.

Image: ©Sydow-Druckguss GmbH

This technical paper reports on a collaborative project with Sydow-Druckguss GmbH and two other organizations using simulation methods to assess and optimize process efficiency and enhance product quality early in the design process.

A Collaborative Approach

Altair Engineering, in collaboration with three other businesses, successfully delivered a project to assess the feasibility of HPDC for actuator housing production. Actuator housings are integral to numerous industrial applications, including automotive, aerospace, and hydraulic systems. Designed to protect the actuator mechanism that controls other components' movement, the actuator housing must withstand extreme environmental conditions, high pressure, and heavy loads.

The project aimed to institute a simulation-driven design methodology to enhance product quality and process efficiency – and then utilize that methodology for other parts. The team simulated the HPDC process using Altair® Inspire™ Cast, comparing simulation results with actual experimental data.

The actuator had been cast using permanent gravity die casting, but there are many benefits of HPDC, including fast and automated production and the possibility to achieve smaller thicknesses; as such, a transition to this process was favored.

Initial simulations confirmed that HPDC could yield the required thickness and surface finish but also revealed potential mechanical defects. By understanding these defects and optimizing the mold design, the team successfully mitigated these issues to deliver a successful part.

The close correlation between simulation results and experimental data affirmed Inspire Cast's precision and dependability in HPDC process simulation. Subsequently, Sydow-Druckguss GmbH adopted it as their standard simulation software for casting, inspiring other companies to consider Inspire Cast for their casting design and optimization.

APS Wenden oversaw part design; Sydow-Druckguss GmbH was responsible for HPDC; Böke Engineering was the casting simulation expert; and Altair was the simulation software provider. Let's look at this project in greater detail and analyze its excellent results.

Utilizing Inspire Cast for Comprehensive Simulation

Inspire Cast was used to evaluate typical casting defects in HPDC, such as porosity, air entrapments, misruns due to early solidification, and mold wear. When looking at HPDC casting defects, relying solely on empirical experiments is inadequate because they cannot deliver a comprehensive casting process analysis. The simulations showed that HPDC could produce the desired thickness and surface finish but identified potential defects affecting the part's mechanical properties. The team utilized Inspire Cast to simulate the entire casting process, from the cycling process to acquire mold temperature distribution to the actuator part's filling, solidification, and cooling stages. The software uses advanced algorithms to simulate molten metal's fluid flow, heat transfer, and solidification behavior, allowing engineers to visualize the casting defects and optimize the process parameters to achieve the desired product quality.

The simulations provided a deeper understanding of the filling and solidification processes, which allowed the team to identify and remedy defects such as porosity and air entrapments.

Results: A Successful Transition to HPDC

The simulation results were analyzed in detail and compared with X-ray images from casting experiments. The simulations provided valuable insights into the melt flow, air entrapments, and potential shrinkage-related porosity – all of which were effectively addressed. The project compared simulation results with actual experimental data, and this comparative analysis deepened the team's understanding of the filling and solidification processes, enabling them to identify and mitigate defects. Inspire Cast's advanced algorithms also enabled the team to visualize casting defects and optimize process parameters to achieve the desired product quality. The team successfully optimized the mold design to remove the defects and improve overall efficiency.

The HPDC process involved a shot weight of 6.8 kilograms, Casting alloy AlSi10Mg, casting temperature of 680°C, mold material 1.2343, and an initial mold temperature of 210°C. The first phase's velocity is 0.2 meters/s, and the second phase is 4.7 meters/s. For this case, cyclic simulations were performed to obtain an appropriate temperature distribution in the mold, followed by filling and then solidification simulations. The simulation model consisted of around 1.98 million tetrahedral elements, and an Intel® Core™ i9-9900K CPU @ 3.60GHz with 16 cores was deployed for the simulation.

However, the number of CPU cores used was around eight. The filling analysis took around 27 hours, 8 minutes, and 55 seconds, and the solidification analysis took 2:06:03. Later, following the simulation, the calculation was also performed using an MPI version of Inspire Cast on a Linux cluster machine with 32 cores, and considerable computing time could be reduced. Filling and solidification results from the simulation were analyzed in detail and compared against the X-Ray images available from the casting experiments.

Figure 1 shows the filling sequences. Initially, the melt flow from the ingates is less chaotic and has an almost planar front. However, as the melt flows into the upper region of the housing, it becomes chaotic, and the possibility of air entrapments can be observed.

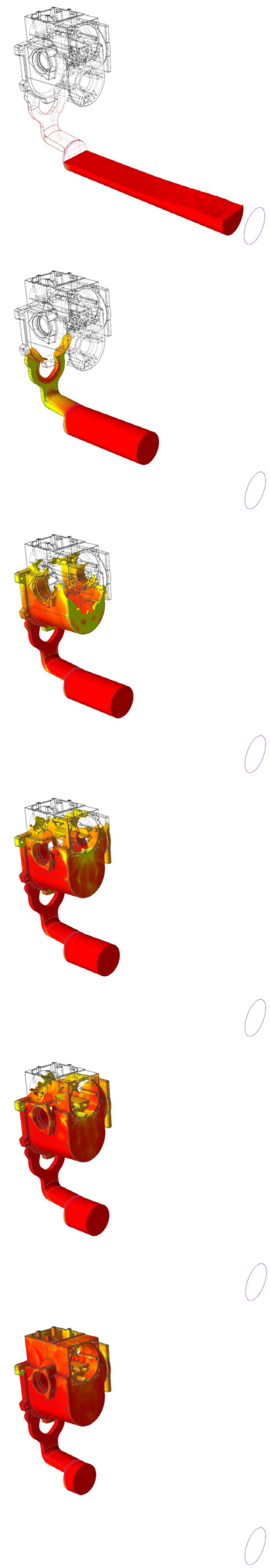

Figure 1: Filling Sequences.

Fig. 2 explains this chaotic nature of flow and the reasons for air entrapment.

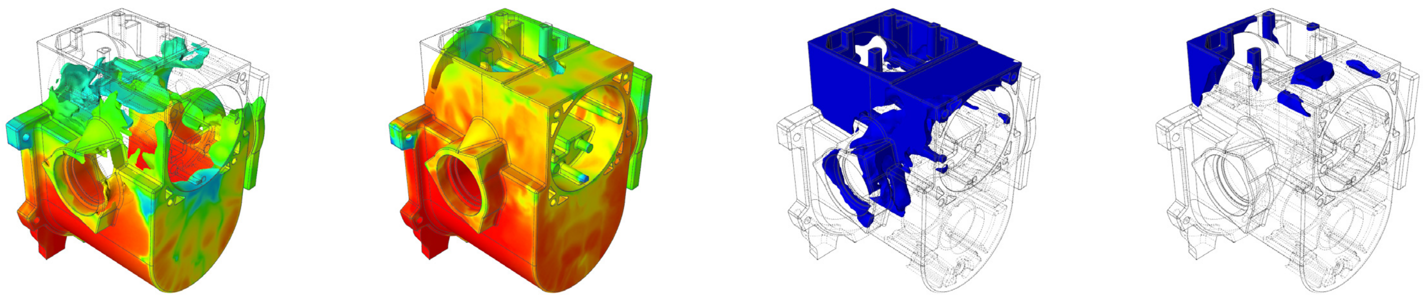

Figure 2: The chaotic nature of filling towards the top of the housing at two different times. The images on the left are melt flow and corresponding airflow movements at that time.

The comparison of porosity and X-rays can be seen in Fig. 3B, near the dome area and in the inner area in Fig. 3C. However, air entrapments can also be seen near the gating system.

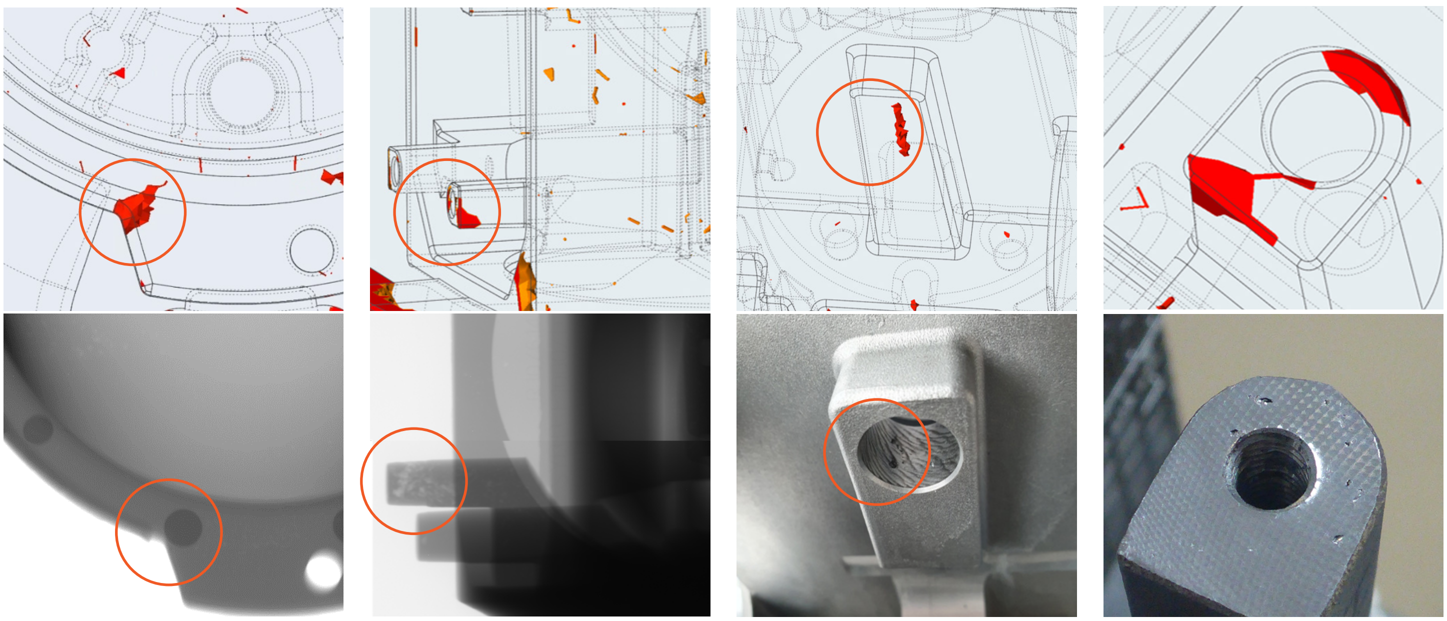

Figure 3: Comparisons of air entrapments in simulations and experiments (X-rays) during the filling phase.

The next steps involved analyzing solidification simulation results; here, the isolated melt pool formation was considered an indication of a volume deficit that could lead to the formation of shrinkage-related porosity.

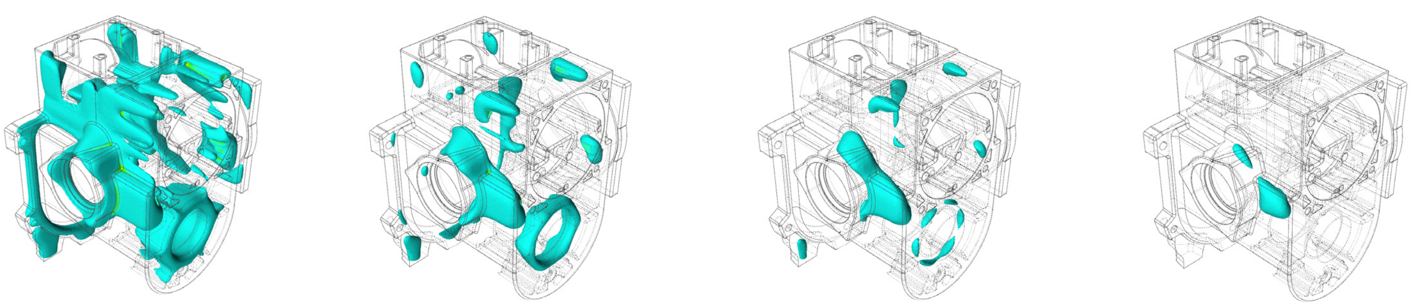

Figure 4: Isolated melt pools during the solidification process

Fig. 4 shows isolated melt pools, and Fig. 5 shows the shrinkage porosity placed in the entire housing.

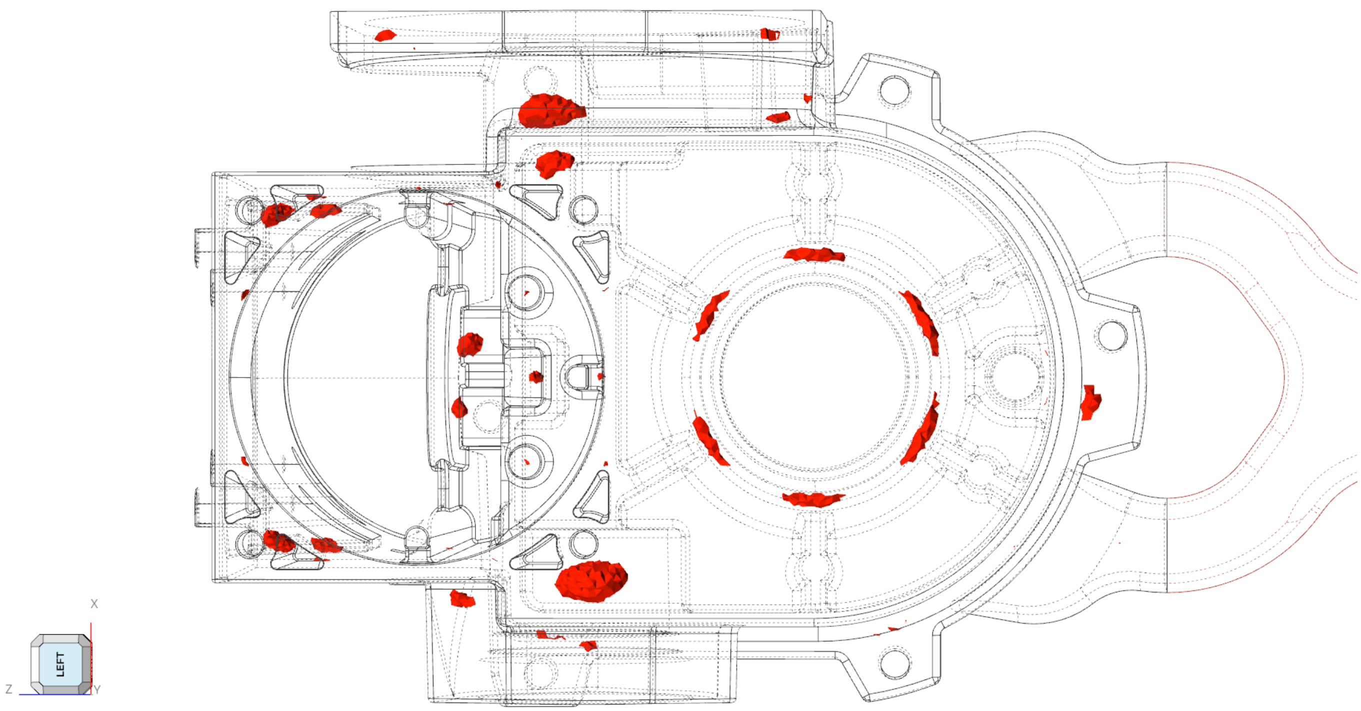

Figure 5: Predictions of porosity after HPDC simulation

These shrinkage porosity predictions were compared successfully at various places against X-rays in the inner area, near the thread and the flange (see Fig. 6).

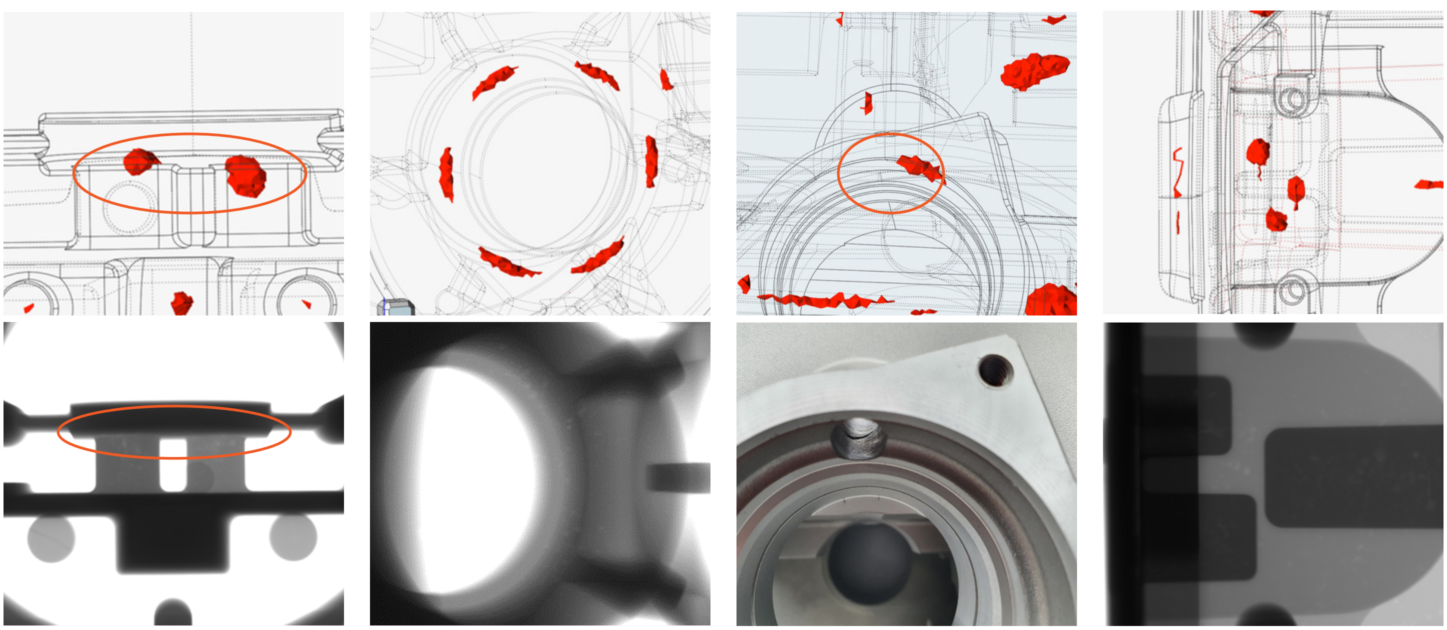

Figure 6: Comparison of shrinkage porosities predictions (left) and X-rays (right)

Conclusion: Validating Inspire Cast for HPDC

The foundry industry faces many challenges, including rising customer demands, the escalating complexity of cast components due to lightweighting initiatives, increasing energy costs, and raw material shortages. Foundry engineers must guarantee efficient, cost-effective processes and align their operations with sustainability targets. Digital methodologies are coming to the fore in response to these complex challenges, and a simulation-driven design environment is becoming crucial, facilitating a balance between design, manufacturability, and performance.

Altair® Inspire™ is a pioneering simulation-driven design environment that fosters collaborative engineering among various stakeholders such as designers, manufacturing engineers, CAE experts, suppliers, and supply chain professionals.

In this project, the Inspire Cast simulations successfully demonstrated the feasibility of using HPDC for actuator housing production. The comparison between the simulations and X-ray results from casting trials showed a high level of agreement, confirming the accuracy and reliability of Inspire Cast. This successful endeavor validates Inspire Cast as a high-precision casting simulation tool for the HPDC process.

As a result of this successful project, Inspire Cast is now the standard casting simulation software within Sydow-Druckguss GmbH for developing other high-quality HPDC parts. The work should encourage other companies to use Inspire Cast for casting design and optimization.

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