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CUSTOMER CASE STUDY

Understand the Root Causes: Process Analysis Reduces Scrap in Aluminum Wheels

The quality of low-pressure die-cast aluminum wheels is largely defined by the interaction between mold filling, solidification, and gas transport. If defects occur in safety-critical areas, they will often lead to additional inspection efforts and increased scrap. At Lenso Wheel Co., Ltd., Thailand, anomalies detected during X-ray inspection in the hub area during testing in the development of a new wheel model were expected to result in a scrap rate of 25.68 %. The engineering team used MAGMASOFT® to methodically analyze the entire casting process. They realized that the initially suspected porosity could not sufficiently explain the observed quality problems. The actual cause only became apparent through a precise analysis of the casting process. Optimizing the mold inserts allowed the team to ultimately reduce the expected scrap rate to 5.56 %.

High Scrap Rate Expected

Despite many years of experience, simulation-based tool design, modern equipment, and robust process parameters, unexpected quality issues can continue to arise during the development and production of aluminum wheels. During the development of a new wheel model at Lenso Wheel, a high scrap rate was encountered. The defects were not detectable by visual inspection and were only identified during the X-ray inspection, with the defects concentrating in the hub area of the wheel.

As the area affected had a comparatively heavy geometry design, it was reasonable to assume that local porosity or unfavorable solidification conditions could be causing the defects. The goal of the investigation was therefore to identify the mechanisms causing the defects and derive suitable measures for sustainably reducing the scrap rate.

Analyze Defects Systematically

The wheel analyzed was to be produced on a LPDC machine from an AlSi7Mg alloy (Fig. 1).

MAGMASOFT® simulations were performed using the real process parameters used in the first trial during mold development. The goal was to reproduce the actual conditions and systematically analyze the root causes of the defects. For this purpose, the team investigated whether the quality problems occurred primarily during solidification or already during mold filling.

Simulation Identifies the Root Cause of the Defects

Analyzing the solidification behavior did not show any indication of pronounced shrinkage-related defects. Nor did the predicted tendency towards porosity

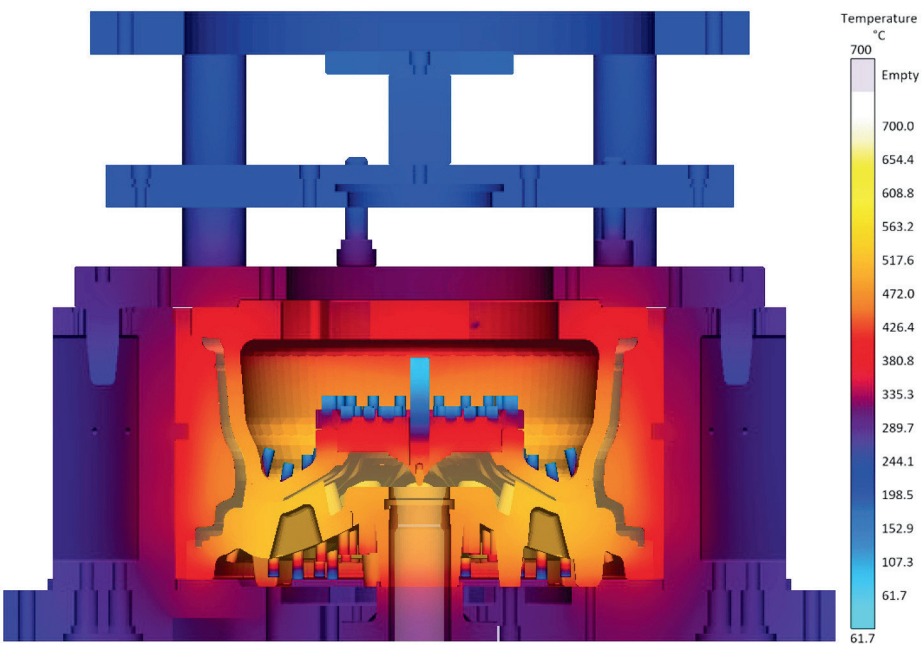

Fig. 1: Model of the low pressure die casting process in MAGMASOFT® after mold filling is complete

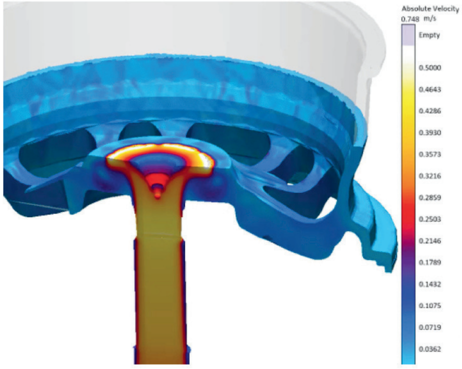

Fig. 2a: The analysis of mold filling revealed increased velocities of the melt in the hub, ...

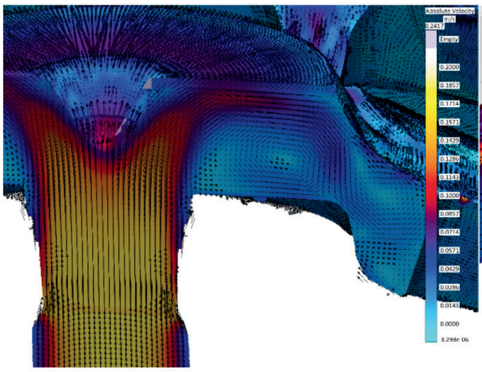

Fig. 2b: ... indicating vortex conditions that contribute to gas porosity and oxide defects.

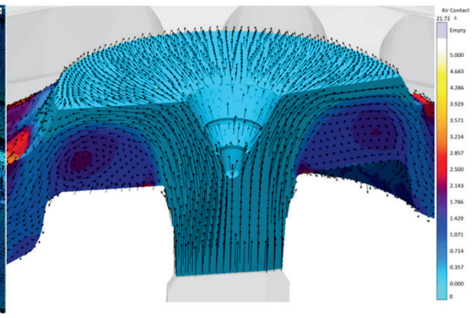

Fig. 2c: 'Air Contact' results showing vortex and higher air contact with the melt

formation in the critical area provide a sufficient explanation for the high scrap rate.

The analysis showed that the cause of the quality problems could not be explained by individual defect criteria. Therefore, the engineers analyzed the casting process as a whole, investigating the interactions between mold filling, solidification, and air entrapment.

The simulation results identified several critical influencing parameters in the hub area. Locally increased velocities of the melt (Fig. 2a) resulted in turbulent mold filling, increased melt-air interaction, and localized entrapped air, indicating vortex conditions that contribute to gas-related defects and oxide inclusions (Fig. 2b, 2c).

These areas closely matched the defect locations identified by X-ray inspection and cross-section examination of a prototype (Fig. 3), further corroborating this assumption. The results confirmed that the quality problems observed were not primarily caused by local shrinkage effects but were closely related to the conditions during mold filling.

Use Autonomous Engineering to Evaluate Virtual Variants

After the analysis of the complete system indicated that the geometry of the upper mold insert had a significant influence on the local filling conditions in the hub area, the engineering team developed eight design variants of this mold insert (Fig. 4).

The goal was to improve the local filling conditions and reduce the contact between melt and air while maintaining stable thermal boundary conditions at the same time.

With the Autonomous Engineering tools in MAGMASOFT®, the design variants were evaluated as a virtual design of experiments. The automated calculation allowed different mold insert designs to be compared systematically under identical process conditions based on several quality criteria.

The evaluation in the parallel coordinate diagram (Fig. 5) revealed the relationships between geometry, mold filling, and quality criteria. The engineers were able

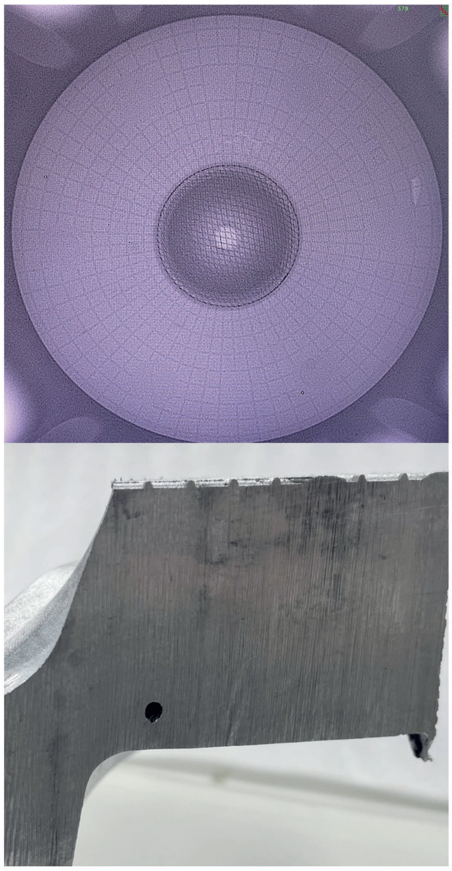

Fig. 3: The areas coincided with the defect locations identified by CT scanning, as well as cross-section examination, providing additional clues to the causes of the defects.

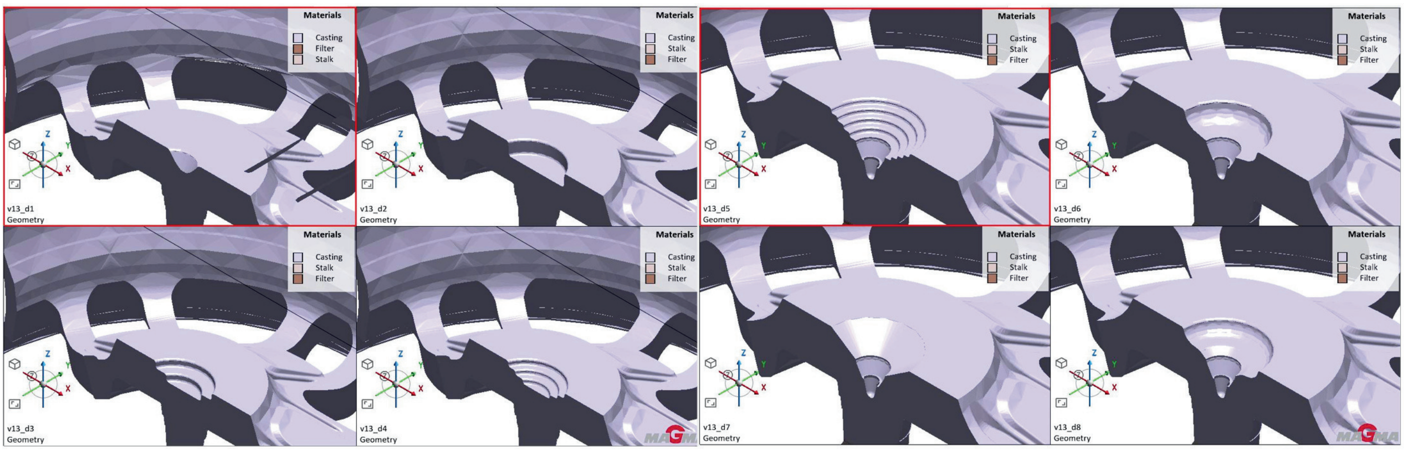

Fig. 4: The engineering team virtually analyzed eight variants of the upper mold insert to improve mold filling in the hub area.

to identify which design changes reduced the critical air pressure values without negatively affecting the thermal boundary conditions.

When comparing the designs, design D5 displayed the best combination of improved filling conditions, lower maximum air pressures due to reduced air entrapments, and stable thermal conditions (Fig. 6). The virtual design of experiments thus not only provided an optimized mold insert geometry but also a better understanding of which design changes had the greatest effect on the local filling conditions and, thus, on defect formation.

Validation on the Shop Floor

After implementing the optimized design, Lenso Wheel conducted test runs under unchanged process conditions. The temperatures measured in the mold thermocouples showed a good agreement with the simulated values. This confirmed that the improved filling conditions were not achieved at the expense of the thermal process stability.

CT scans and X-ray inspections confirmed the effectiveness of the optimization measures. The first production trials already revealed a significant improvement in quality. The scrap rate dropped from an initial 25.68 % to just 5.56 %.

Understand Root Causes to Sustainably Reduce Scrap

The example of Lenso Wheel illustrates that quality problems cannot always be explained by the causes that initially seem most obvious. Although the defects detected by X-ray would suggest local shrinkage porosity in the heavy hub area, the analysis showed that neither solidification nor the predicted tendency towards porosity formation could sufficiently explain the high scrap rate.

Adjusting the upper mold insert significantly improved the filling conditions in the critical hub area. The scrap rate dropped from 25.68 % to 5.56 % while the robustness of the series production process was increased at the same time.

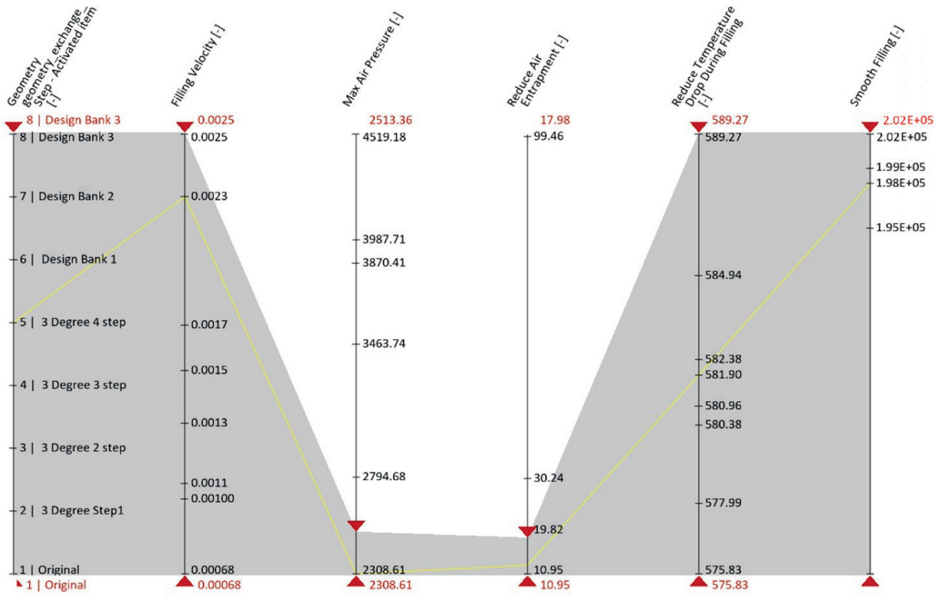

Fig. 5: The parallel coordinate plot supports the systematic evaluation of different solution approaches and visualizes the interactions between geometry and quality criteria.

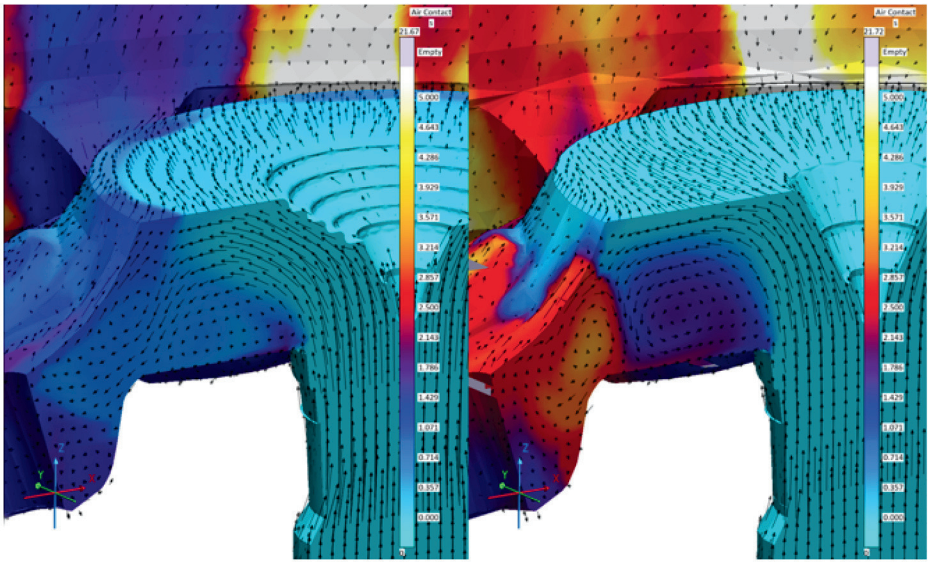

Fig. 6: Comparing mold filling using the example of the 'Air Contact' result for the initial geometry (on the right) and design D5 (on the left). The optimized design reduces the contact between melt and air while improving the filling conditions in the hub area.

Moreover, virtual design of experiments with Autonomous Engineering enabled the methodical evaluation of several design variants under identical boundary conditions. The automated calculation and direct comparison of different quality criteria not only helped to identify the most effective solution but also to better understand the relationships between design, mold filling, and defect formation. This enabled the engineers to evaluate cause and effect systematically and make reliable decisions already in the virtual experimentation stage during development of new products.

The project illustrates how simulation-based decision-making helps engineers understand complex cause-and-effect relationships and develop robust solutions even before implementation on the shop floor.

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