AUTONOMOUS ENGINEERING

Redefining the CORE of the Foundry

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Introduction

Core production is an area in the metal casting industry where to this day, experts have to solve problems based on their experience and expertise. This traditional method is a decisive risk factor that could lead to a stable and robust casting production or the complete opposite. This manufacturing process does not allow for the physical observation of the actual production conditions (in detail) due to the nature of the process. With its numerous, and often unknown influencing parameters, it's typically not even possible to measure production variations. In order to overcome such challenges, industry experts teamed up to create an educational, hands-on workshop to address this issue.

A two-day workshop was developed by **MAGMA Foundry Technologies Inc.**, **Laempe Reich Corporation,** and **Anderson Global.** In this interactive workshop, attendees had the opportunity to discuss various technical challenges of core making like; shooting, curing, tool design, vent types/locations, nozzle/blow tube strategies and cavity layout. The enriching environment created between core production and core simulation provided a unique experience for the attendees to assess, in real time, the impact of the most common variables of core making.

Background

The three companies that participated in this workshop provided the necessary technologies to conduct the event. **MAGMA Foundry Technologies Inc.** provided their proprietary software **MAGMA Core & Mold®** and designed a modular core box that was manufactured courtesy of **Anderson Global. Laempe Reich Corporation** supplied their facilities and a LFB-25 automatic core shooter for production in Trussville, Alabama.

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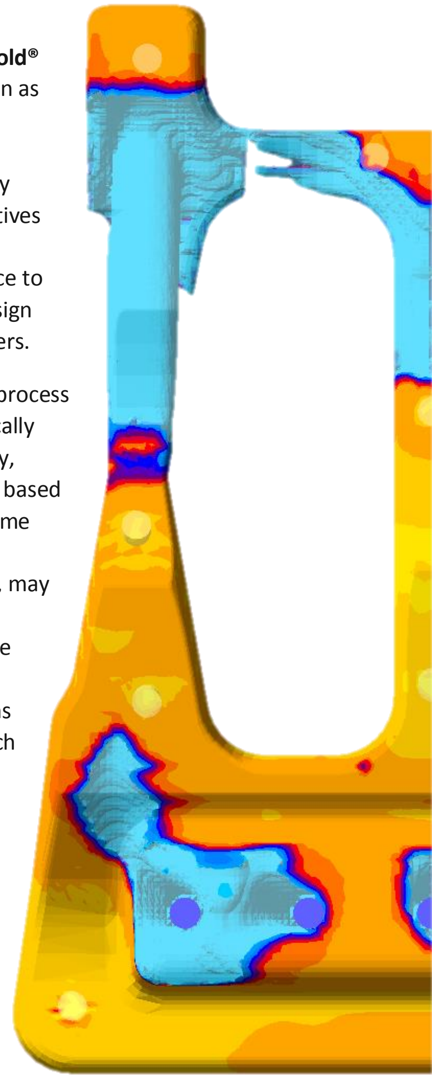

With the use of **MAGMA Core & Mold®** a new concept was employed known as **Autonomous Engineering**; a new methodology that applies to all **MAGMASOFT®** modules. It works by defining sets of variables and objectives to autonomously simulate multiple variations within a large design space to find the optimal combination of design configuration and process parameters.

The variables may be geometric or process based while the objectives are typically related to achieving a certain quality, desired material property or simply based on the engineer's overall goal. In some cases, the full design space, which considers all possible combinations, may span thousands of possibilities. To address such scenarios, the software uses statistical methods combined with genetic optimization algorithms to create a smaller sample size which is analyzed through consecutive generations. In each of these generations the software autonomously changes the variables and analyses each design with respect to the defined objectives. Ultimately, as the optimization progresses the best designs are found without the need to analyze the full design space. Unlike traditional simulation, this methodology requires the engineer to set up only one project while the software makes all of the subsequent iterations covering the entire process window.

Core shooting lab session

The workshop included multiple lab sessions for shooting and curing sand cores. The first lab was focused on shooting sand into the core box. This allowed the group to focus on the challenging task of vent placement and nozzle selection. At the core box design stage, these two variables are the most common in the core shooting process. Traditionally, engineers and designers can only find the best configuration using their experience combined with manually iterative trials on the production floor.

This is commonly referred to as “manual optimization” or “trial-and-error” testing; a process that it is time consuming and does not always lead to the desired results. When defining such configurations, it is imperative for engineers and designers to understand that the main vehicle to transport the sand mixture into the core box cavity is the air. The attendees were given instructions to design the best venting configuration available using one of four possible nozzle configurations. The nozzle configurations provided were: two nozzles, three centered nozzles, three wide-spread nozzles and five nozzles for a particular cavity Fig. [1].

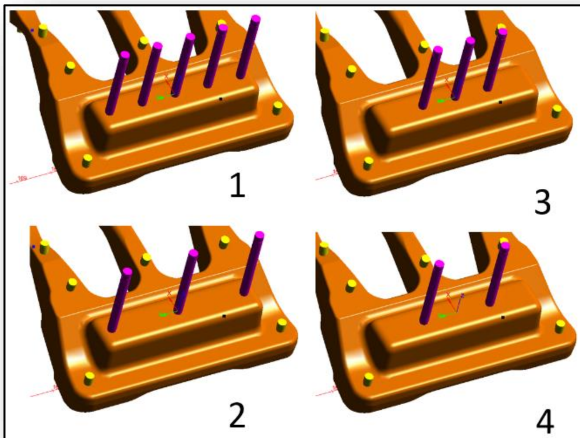

Fig.1 - Nozzle configurations

The geometry of the core had areas of concern with thin-to-thick cross section transitions being located at the most fragile areas and furthest from the nozzles.
These areas would later be analyzed and referred to the “Evaluation Area” Fig. [2].

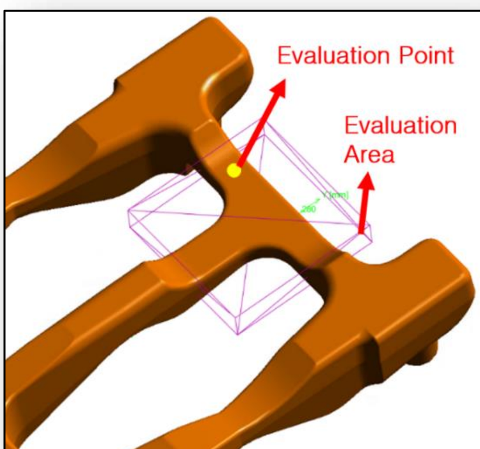

Fig.2 – Evaluation Area & Point

The correct and proper vent placement was the key in obtaining a good core with each nozzle configuration provided to the teams. Each team was challenged to find the correct venting layout from Fig. [3]. The available options for cope and drag were able to be closed or opened to achieve a good result.

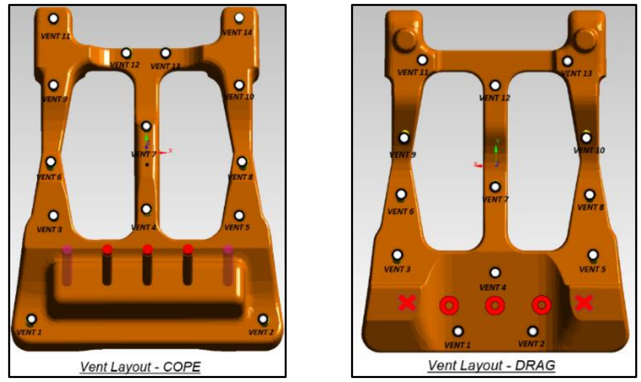

Fig.3 – Venting configurations, Cope & Drag

Upon completion of their venting design layout, they proceeded to shoot the actual cores using one of the LFB-25 **Laempe’s** machines available during the workshop. This was possible due to the modular design of the core box provided by **Anderson Global**, where activating and deactivating of both nozzles and vents was possible. This sophisticated design was built with the intention of selecting, shooting, and comparing the results of each configuration. Each team shared and discussed their ideas based on the final quality of their molded cores. For each layout selected in the core box, a variation in core quality was observed. At the end of their core making trials these same configurations where simulated and evaluated using **MAGMA Core & Mold®**.

Selecting all possible vent and nozzle combinations, a total of 262,144 possible designs exist. Finding the best design using the traditional approach of trial-and-error would be impossible. Even with the use of traditional simulation tools today, simulating this quantity of possible designs in a sequential, iterative manner would be unfeasible. Manually creating 262,144 possible combinations would not only take several years, but would likely contain a significant degree of human error. With the use of **MAGMA Core & Mold®** and the fully integrated **Autonomous Engineering** approach, a total of 160 total designs were autonomously created and simulated. The software uses a semi-random method of selection to evenly select a smaller sample of possible variants. The optimization was completed and the attendees were able to use the software’s comprehensive assessment tools to quickly determine which designs were the best in achieving the defined objective; a core with the highest density. The assessment tools were also used to help the teams understand what design and process parameter combinations had the biggest impact in the production process. More importantly, the simulated designs would then be compared to manufactured cores from each team.

Correlation of **MAGMA Core & Mold®** results matched the behavior and quality of the manufactured cores. A constant cycle time of 1.5 seconds and equal blow pressure of 2bar for all scenarios was considered. The findings indicated that shooting with only two nozzles was more challenging to achieve a fully compacted core than blowing with all five nozzles open.

The average sand velocity for the most compacted cores was 4.5m/s at the point shown in Fig. [2]. The highest recorded velocity at that same location was 5.75m/s. When compared to configurations that did not lead to a compacted core, those designs had average sand velocity of 1.38m/s. Fig. [4].

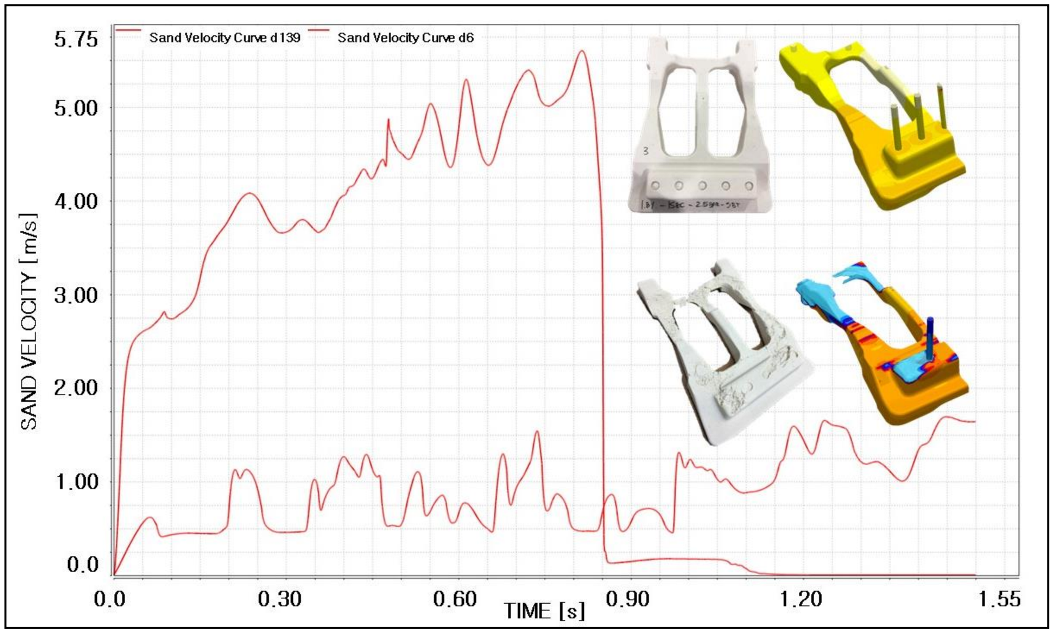

Fig. 4 - Absolute sand velocities measured at evaluation point from best and worst configurations, compared to results from shot cores.

A positive relationship was determined between the shooting area and the quality of the compacted mixture at the end of the shooting process. As the number of nozzles increased, along with the appropriate venting conditions, the core sand fraction increased. This same trend was also seen between the number of nozzles and the Evaluation Area(s). This can be visualized in Fig. [5].

Within the **MAGMA Core & Mold®** comprehensive assessment tools, a Parallel Coordinates plot was created to easily assess the effect of the variables versus the defined objectives. Each line corresponds to one of the 160 total simulated designs. A different color is assigned to each design depending on its performance. Blue lines lead to a poor or low fraction result, where as bright yellow ones lead to the highest fraction results meaning better compaction. This also applies when compared to the sand fraction in the Evaluation Area as seen in Fig[5].

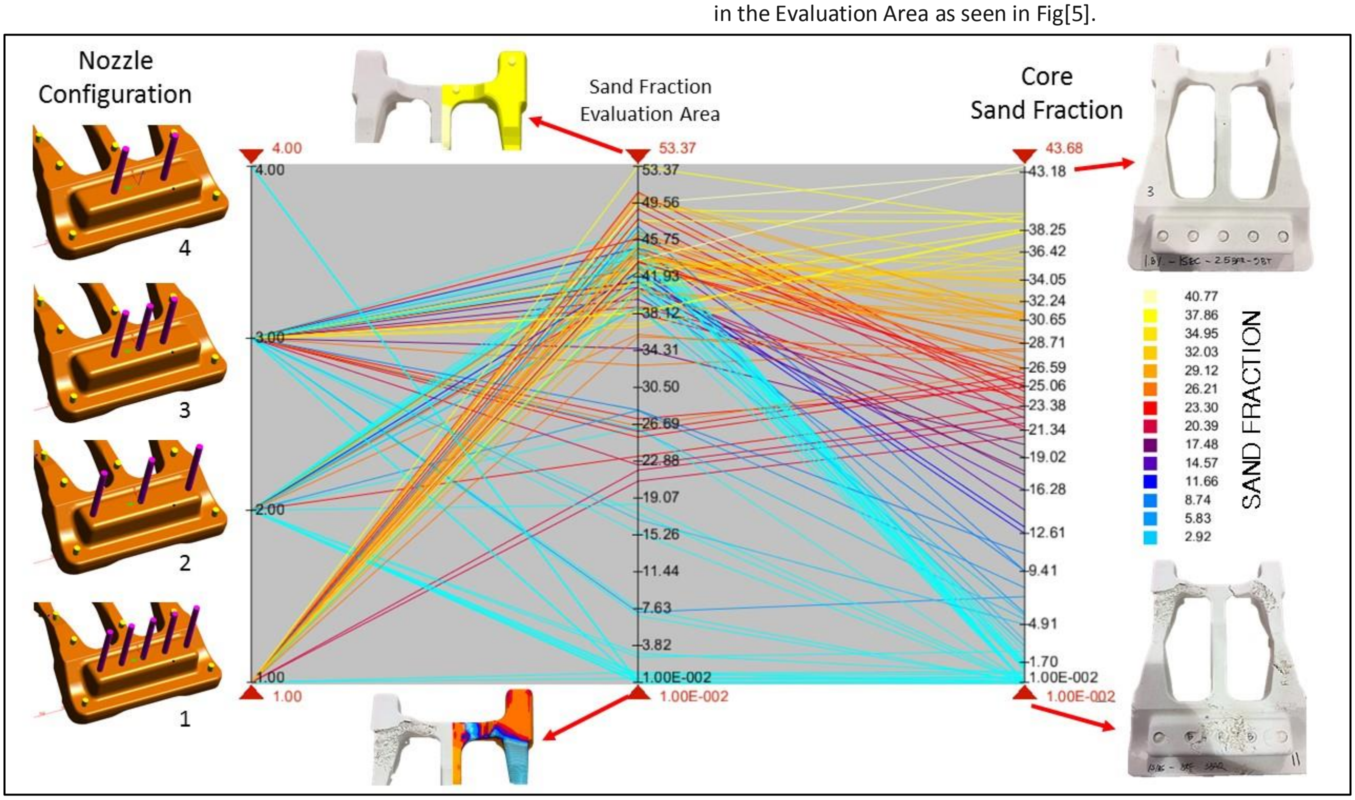

Fig. 5 – The Parallel Coordinates plot shows the impact of the increase or decrease in shooting area, towards the sand mixture compaction at the end of the shooting process.

Through the results and the completion of the first phase of core production, the attendees gained valuable information that helped them understand the principles of physics which influenced why some configurations failed, while others succeeded. With this newly acquired knowledge, the workshop moved on to the gassing phase of the core.

Amine gassing lab session

Shooting a sand-mixture into a cavity and achieving its maximum compaction is half of the battle in obtaining a defect-free core. After this phase, the gassing manifold introduces amine gas into the system which enters the cavity through the nozzles and sometimes the top (cope) vents. The locations of the vents as well as the gassing parameters play a significant role in the outcome of this phase. In common practice, the venting layout is designed with the purpose of filling the core box but it is often ignored for the gassing phase. Therefore, improper vent locations may allow the amine gas to escape the core box before the binder is fully cured. Similarly, improper gassing process parameters may lead to insufficient pressure for the gas to move through the core box and cure the core. These are some of the known potential issues in the gassing phase that were addressed in the workshop.

Typically, in a sand core production environment, the operator will start with an initial amount of amine and increase it until an acceptable core is made. Similarly, the operator may repeat this approach with an extended cycle time to allow more time for the amine to cure the core. This traditional method of finding the proper process parameters can be very time consuming and costly. Through the use of **MAGMA Core & Mold®**, the attendees would replicate this methodology using virtual Design of Experiments (vDoE).

In this lab session, the primary objective was to effectively transport amine throughout the core resulting in a full cure. The venting layout was kept constant as it produced the best sand compaction during the shooting phase. The variables for the vDoE were the concentration of amine and the cycle time. The attendees kept the cycle time constant while changing the concentration of amine to understand the effects it had in the gassing phase. The same procedure was repeated with a constant concentration of amine while changing the cycle time. A total of six possible designs were defined as seen in Table [1].

Design 1 **19cc** Amine 15s Cycle	***Design 2*** **25cc** Amine 15s Cycle	***Design 3*** **30cc** Amine 15s Cycle
Design 4 19cc Amine **20s** Cycle	***Design 5*** 19cc Amine **30s** Cycle	***Design 6*** 19cc Amine **45s** Cycle

Table 1. – Design of Experiments

These six possible designs were then autonomously generated and simulated in **MAGMA Core & Mold®** allowing the attendees to quantitatively evaluate and comprehend the impact each variable had on the defined objective. The simulation results in the workshop allowed for the tracking of the transient behavior of the amine flow as well as the assessment of the local amine amounts within the core during the entire gassing process. The Maximum Adsorbed Curing Gas result was used to see the relationship between the variables and the objective.

Ideally, the best result is one where low values don't exist as they indicate a lack of adsorbed gas resulting in a low degree of cure. At the end of the simulations, the participants had the opportunity to recreate the vDoE in real-life and produce cores using the same combinations of variables. This allowed for a stronger correlation between the virtual Design of Experiments and actual production quality.

As expected, the results showed that as the % amine increased, the defect decreased. These defects are the result of poorly absorbed amine gas resulting in an un-cured core. At the end of the trial, the teams proved that even with a 63% increase in amine content a good core was not possible, leaving un-cured areas in the core. Fig. [6a & 6b].

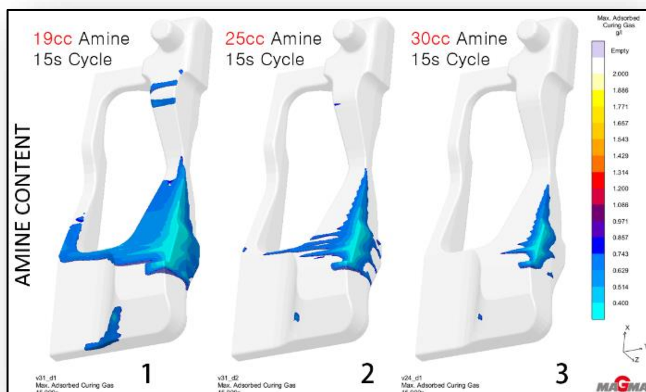

Fig.6a – Simulation results of the increase of amine concentration, maintaining the cycle time constant.

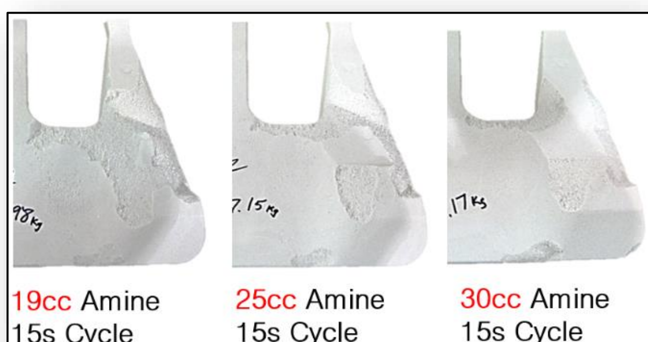

Fig.6b – Production results of the increase of amine concentration, maintaining the cycle time constant.

The second iteration of designs showed how another common practical solution like increasing cycle time can help reduce un-cured areas but does not eliminate them completely. As cycle time increased, the defect shown decreased but was not completely eliminated. These problematic areas of the core showed values lower than 0.5g/l of adsorbed curing gas where fully cured areas adsorbed up to 2.0g/l or more as shown in **MAGMA Core & Mold®** Fig. [7a & 7b].

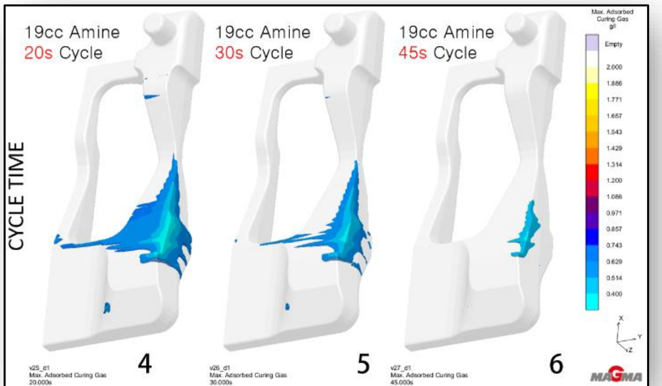

Fig.7a – Simulation results increasing cycle time maintaining amine concentration constant.

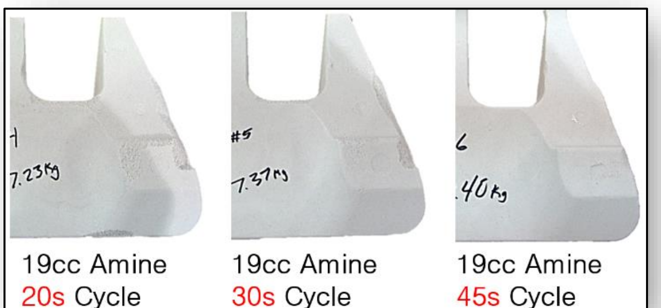

Fig.7b – Production results increasing cycle time maintaining amine concentration constant.

One of the most expensive core making elements is time and in this particular case, after 45 seconds of curing time, the core still shows un-cured areas. Increasing the cycle time further may lead to a reduction of the defect but it slows the core making process which can also delay the casting process. The traditional approach leads to lower profits and can result in financial losses.

After both vDoE and manufactured cores were compared, it was evident that both of the common practices shown did not completely eliminate all the un-cured areas in the cores. Even though the trends showed an improvement, testing in this manner is expensive and time consuming in a production environment. To provide the attendees with further understanding of defect resolution for an un-cured core, an alternative venting layout was presented to them.

For this new layout, the cycle time was set to 15 seconds with 19cc of amine (the original starting conditions). Next this combination was simulated and produced during the final session of the workshop. Fig. [8].

The findings indicated that all previous un-cured areas were now fully cured and the core had achieved all objectives for shooting and gassing. The venting layout was a key element as it significantly impacted both shooting and gassing phases of the core making process. Moreover, with the use of **MAGMA Core & Mold®** it was highlighted how optimization tools can assist the early stages of tooling design to avoid production issues.

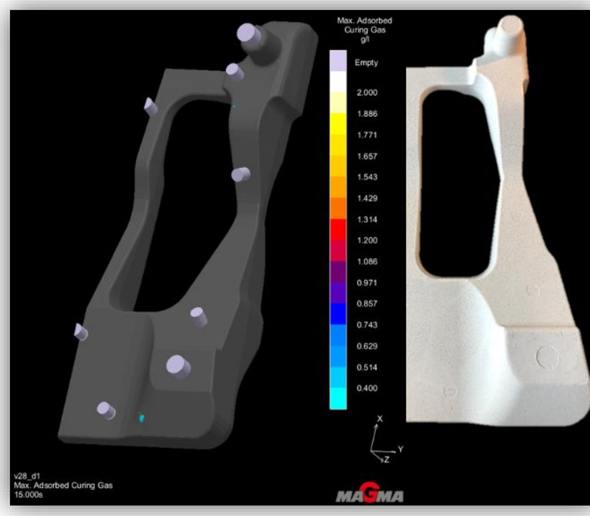

Fig. 8 – End result of the gassing simulation and the produced core using the initial values of 15s cycle time and 19cc of amine.

Conclusion

The teams concluded that using **MAGMA Core & Mold®** dramatically reduced the time spent finding the best vent locations. The attendees gained significant tooling and core making knowledge during this workshop. Although we can optimize shooting and gassing independently, it was realized in this workshop, that these processes should be designed concurrently to reduce the cost of producing cores.

This newly introduced optimization and assessment tool enabled the attendees to not only find the best design for a given core, but it also enabled them to quickly see dependencies between quality criteria and process/design variables.

This technology significantly reduces the total time designers and process engineers need to find the best possible solutions to core making challenges. Today, this technology can already provide 160 different design scenarios in less time than it would take to make 2 real live trials. It also maximizes the time the computer is working for them without the need for human interaction. The combination of significantly more data and powerful evaluation tools allow engineers and designers to efficiently find optimal solutions for maximum profitability. The utilization of statistical methods and optimization algorithms by the software helps to quickly minimize the required number of simulated iterations to expedite the process.

Images (right) of attendees inside the classroom and at the core shop floor.

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