# ALUCAST 2020

Virtual Conference | 11th - 12th December 2020

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## Technical Volume

# Aluminium Casting Technology for the 20s

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Driving
Technology
in the 20s

# ALUCAST 2020

## Virtual Conference

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# ALUMINIUM CASTING TECHNOLOGY FOR THE 20s

These past months have been life changing to say the least – not only for ALUCAST, but for all of us across the country and the globe. But despite setbacks and a sense of some despondency, it gives me immense pleasure to announce that we have decided on **"Aluminium Casting Technology for the Twenties"** as the theme for ALUCAST 2020 – National Conference. Because of the pandemic, ALUCAST 2020, the biennial National Conference on Die Casting Technology will be held virtually this time on 11th and 12th December 2020.

As per a recent study report by World Bank, the global economy, which has severely contracted, is expected to shrink by 5.2 per cent this year due to the massive shock of the Corona Virus pandemic and the shutdown measures to contain the spread. The COVID-19 induced recession is the first since 1870 to be triggered solely by a pandemic.

In the current scenario, the aluminium die-casting industry has to respond by revisiting and reassessing design of key components. In addition, the industry has to strive in the direction of improving quality, aim for zero defects and improve yields. One should not shy away from investing in Research and Development, adopting new technology to improve quality, productivity and safety during these difficult times.

As the Aluminium Die casting industry grapples with these challenges, it would be an opportune moment to take stock of the technological developments in the past year and to deliberate amongst ourselves, the way forward for the Indian Die Casting industry. In this context, I feel that the theme chosen by ALUCAST is extremely relevant.

I look forward to my fellow die casters and associated industries to participate in large numbers in this event, which has already attracted substantial interest. We must use these turbulent times to put pressure on ourselves to see that we build a better future despite adversity.

With best wishes

**PRASAN FIRODIA**

President, Aluminium Casters' Association (ALUCAST)
Managing Director, JayaHind Industries

The die casting industry is facing a multiplicity of challenges today with reduced production demands and an upcoming electrical vehicle scenario that paves the way with uncertainity. We need to be well prepared to face these challenges and focus on the application of the new technologies and their processes.

ALUCAST 2020 Virtual Conference with the theme **"Aluminium Casting Technology for the 20s"** on 11th and 12th December 2020 brings focus on such new technologies and products in die casting industry for sustained growth and new developments in the business. With the pandemic challenge, we need innovative solutions to move forward. For the first time we are hosting our Technical Conference virtually.

The topics selected for technical papers to be presented during the conference are a mix of Die Casting Technology, Management Expertise and related Product Presentations.

Technical papers and presentations made by experts in the field are published in this technical volume to serve as reference reading material for practicing die casters.

The organising committee takes this opportunity to thank for the support extended by all the sponsors and advertisers.

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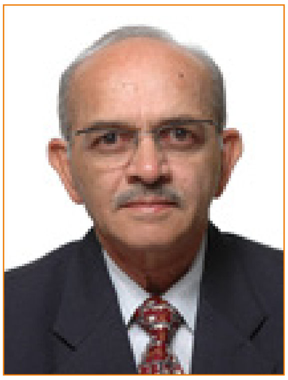

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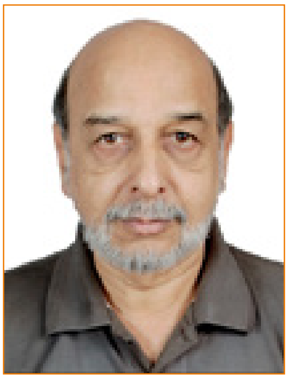

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# ALUMINIUM CASTING TECHNOLOGY FOR THE 20s

# Extending Die Life By Surface Treatment

- Stephen P. Midson,
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Colorado School of Mines, Golden, Colorado, USA

## Abstract

This paper reports on a five year plant trial where an entire die casting die was covered with a Physical Vapor Deposited (PVD) AlCrN coating. The results of the plant trial have shown that coating the entire die allowed a significant reduction in the amount of lubricant to be applied to the die. This has resulted in a number of documented benefits, including a reduction in soldering and erosion problems, an improvement in cycle time as less time is required to spray the die, a reduction in manufacturing costs as lower amounts of conventional lubricants are required and expensive die repairs can be postponed, and most importantly, a significant extension of die life was attained, as the PVD coating makes it possible to apply lower amounts of conventional lubricants, reducing thermal fatigue, and reducing heat checking.

### Introduction

Maximizing die life is one of the goals of most die casters, and so any technology that can significant extend die life is of great interest. The application of Physical Vapor Deposited (PVD) coatings to die casting dies is one such technology, and it is known to significantly reduce both soldering and erosion [1]. However, excessive heat checking is typically the leading reason for having to retire a die and fabricate a replacement, but the impact of PVD coatings on heat checking is less clear.

This paper will report on the results of a plant trial that focused on using PVD coatings to minimize the amount of lubricant applied each shot to a die casting die, which has resulted in a significant reduction the amount of heat checking observed with the die, thereby appreciably extending die life [2-6].

### Background

Before going on to discuss the results of the plant trial, it is worthwhile to briefly discuss the mechanisms that cause die casting die components to be replaced, with the three main ones being heat checking, soldering and erosion [1]. These three die failure mechanisms are briefly described below.

- **Heat checking** – Heat checking occurs due to the thermal fatigue arising from heating and cooling of the surface of the die during the production of each casting. As the liquid metal is injected into the die cavity, the surface of the die cavity immediately heats to a temperature close to that of the liquid metal, and then starts to cool as heat is transferred from the surface into the bulk of the die. This heating places the surface of the die into a state of compressive stress. However, once the casting is ejected and the die surface sprayed with lubricant, the die surface becomes cooler than its interior, placing the die surface into a state of tensile stress. This cyclical heating and cooling, producing cyclical compressive and tensile stresses, fatigues the surface of the die, producing the heat checking familiar to all die casters.

- **Soldering** – Soldering normally occurs when the surface of the die becomes excessively hot, and the solidifying metal sticks, or solders, to the die steel, making ejection difficult. Several authors have suggested mechanism for soldering in aluminum die casting. In 2000, Shankar and Apelian [7] suggested that soldering in aluminum die casting occurs via a six-stage process, which initially involves the molten aluminum causing erosion on the surface of the die steel, followed by a reaction between the molten aluminum and the die steel producing Al-Fe based intermetallics that cause the cast aluminum to solder to the die steel. Two years later, Viswanathan and Han [8] agreed that soldering involves the generation of Al-Fe intermetallic phases, but predicted that soldering will not occur unless a specific high temperature is reached in the die surface (around 500oC for aluminum alloy A380 soldering to H13 steel). Recently however, Monroe and Sanders [9] have questioned the role that the Al-Fe intermetallics play in soldering, and so the mechanism causing soldering for aluminum die casting is still in question.

- **Erosion** - Erosion is the gradual removal of the die steel resulting from the direct impingement of the liquid metal (normally liquid aluminum) during cavity filling. Erosion is affected by a number of processing parameters, including alloy composition, gate velocity, metal pressure, gating design, and die temperature [1].

## Benefits of Using PVD Coatings

Controlled laboratory studies performed at Case Western Reserve University in the USA, and summarized in Reference 10, have shown that the use of PVD coatings can significantly reduce the harmful effects of both soldering and erosion. However, the effect of PVD coatings on reducing heat checking is not so clear from their work, and so it is worthwhile to summarize the results from a plant trial that has been performed over the past five years [2-6].

## Results from PVD Coating Plant Trial in 2016

A series of papers [2-6] has documented a plant trial showing how the use of PVD coatings can significantly extend die life. The plant trial was started in 2016, and was based on research results obtained at the Colorado School of Mines [2-4]. The objective of that research project was to determine whether permanent PVD coatings applied to the surfaces of die casting dies could totally eliminate the need for conventional die lubricants. These studies showed that an AlCrN PVD coating eliminated the adhesion (soldering) of solidifying aluminum A380 to H13 steel during laboratory testing, and therefore this AlCrN coating was chosen for the plant trial.

The casting selected for the plant trial was the balance shaft housing shown in Figure 1. This casting is used in an outboard motor for marine applications, and is about 150 mm by 150 mm, weights around 0.8 kg, and is produced in a single cavity die. For the plant trial, all the surface of the die that are contacted by liquid aluminum were covered with the AlCrN coating, namely the runners, cavity, overflows, vents and vent block, for both the fixed and moving sides of the die (Figure 2). The caster had previous experience running an un-coated version of this die, and found that for the un-coated die it was necessary to spray the die with conventional organic lubricant for 12 seconds.

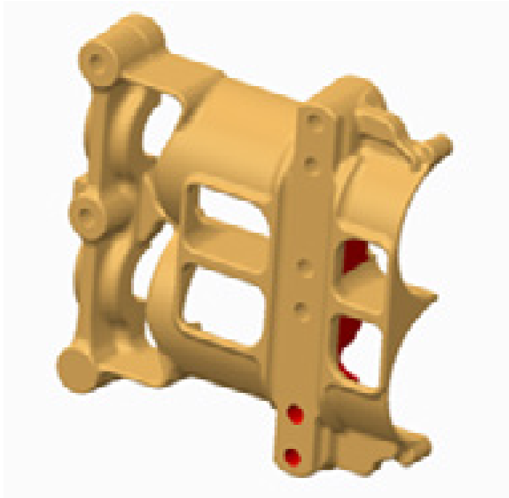

*Figure 1: Model of the balance shaft housing [2,3]*

Initially a 2-day plant trial was performed with the PVD coated die, which is summarized below:

- On the first day of the casting trial using the PVD coated die, the lubricant spray was initially reduced to 2 seconds, and 70 castings were successfully produced without sticking or soldering. This represents an 83% reduction in spray from the 12 seconds used previously with the un-coated version of this die.

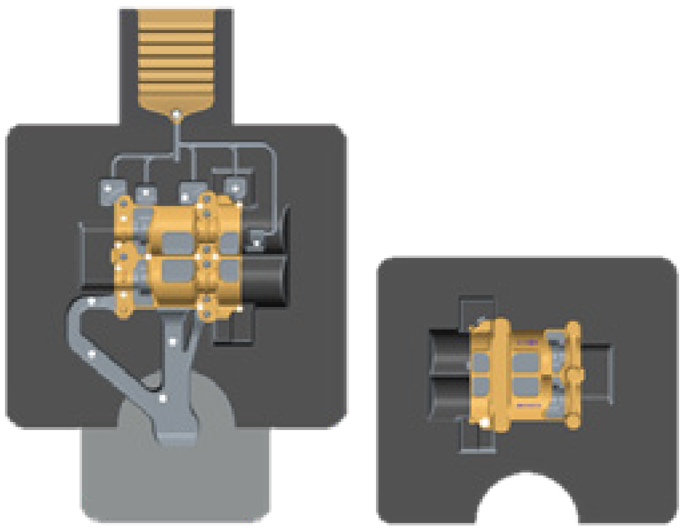

*Figure 2: Models of the die used to produce the balance shaft housing. All die faces contacted by the liquid aluminum were coated [2,3]*

▪ Following this success, the spray time was further reduced to one second, a 92% reduction in spray time over the 12 seconds used previously with the un-coated die, and an additional 30 castings were produced without sticking and soldering.

▪ The lubricant sprayer was then turned off, and an attempt was made to produce castings without conventional lubricant. The first casting stuck, and bent core pins during ejection. The die had to be removed and several core pins replaced with spare coated pins. The die was then replaced on the machine.

▪ Next day, an additional 96 castings were produced using the one second spray, with no evidence of sticking or soldering.

So although it was not possible to produce castings in the lube-free condition, it was possible to significantly reduce the amount of lubricant spray by 92% over that used for a previous un-coated die. The reduction in spray did lead to another benefit – as less time was required to spray the die, the median cycle rate was improved by 12% (see Figure 3). More interesting, an even bigger improvement (18%) was observed for the third quartile cycle rate, most likely as less time was required to periodically stop and remove solder from the PVD coated die.

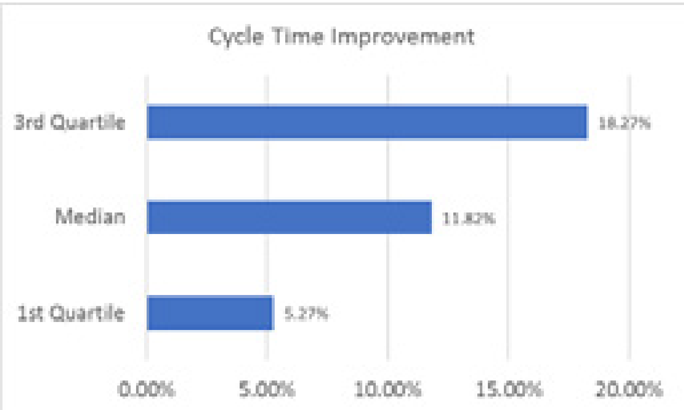


*Figure 3: Data on cycle time improvement [3]*

## Results from PVD Coating Plant in 2019 & 2020

Since the initial trial performed in 2016, the die caster has continued to produce castings in the PVD coated balance shaft housing die using a significantly reduced level of spray. As the caster only produces around 20,000 balance shaft housings per year, the plant trial is still ongoing. Two papers updating the status of the trial have been published, one in 2019 after more than 70,000 castings had been produced in the PVD coated die [5], and one more recently in 2020 after more than 100,000 castings had been produced in the PVD coated die [6]. As a reference, the older un-coated die had to be retired after the production of about 97,000 shots, due to excessive damage (heat checking, and other damage).

Figure 4 shows a photograph of both the fixed and ejector side of the die after more than 100,000 castings had been produced, and both halves of the die appear to be in excellent condition. However, closer inspection (see regions highlighted in Figure 5) shows that minor heat checking has occurred between the shaft-regions on the fixed side of the die, and on the shafts and at ejector pin holes on the ejector side of the die. However, considering that the older un-coated version of the die had to be retired at around 97,000 shots, the PVD coated version of the die shown in Figures 4 and 5 appears to be in excellent condition after the production of more than 100,000 shots. So five years after the start of the plant trial in 2016, the PVD coated die is still running, and clearly will exceed the shot count of the un-coated die by a considerable margin.

*Figure 4: Photographs of both the fixed and moving side of the AlCrN PVD coated balance shaft housing die after 100,000 shots [6]*

a) b)

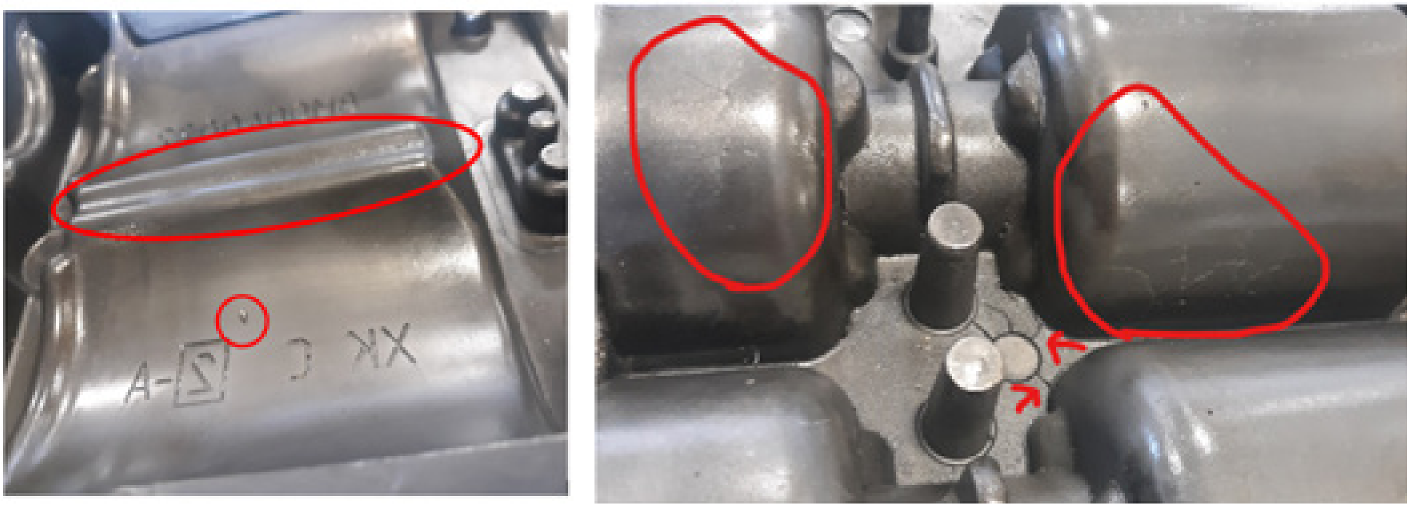

*Figure 5: Minor heat checking present in the PVD coated die after 100,000 shots [6]*
*a) Fixed side of the die b) Ejector side of the die*

Figure 6 shows castings produced in the die after 100,000 shots had been produced, and considering the excellent condition of the die (see Figure 4 and 5), the castings also exhibit very little evidence of heat checking, even after the production of such a large number of castings.

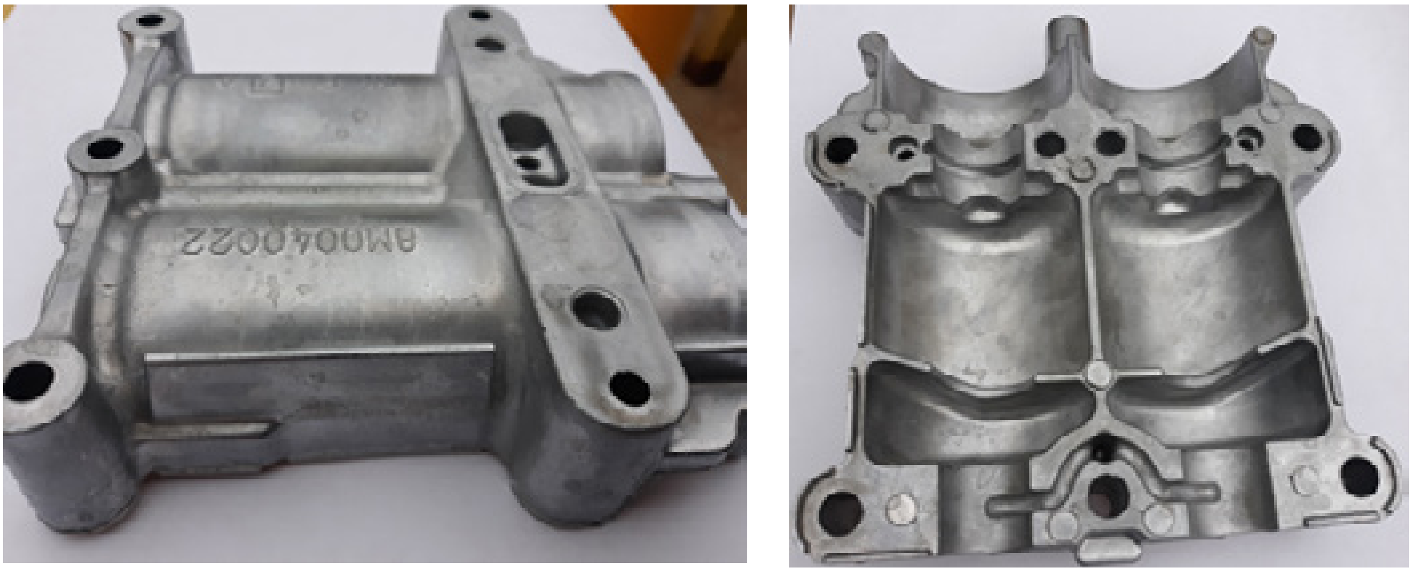

*Figure 6: Photographs of castings made in the PVD coated die after 100,000 shots have been produced [6]*

At this point, it is not clear whether it is the use of the PVD coatings, or the reduced amount of lubricant spray, that is causing the dramatic extension of die life. PVD coatings used in die casting applications are normally very thin (typically 2-8 µm in thickness), and although they are extremely hard (hardness values of between 20-35 GPa), in this author's opinion it is unlikely that these types of thin coatings would have such a significant effect on extending die life. However, it is well known that reducing lubricant spray can have a significant effect on reducing heat checking. For example, the data in Figure 7 shows laboratory data generated at Case Western Reserve University using their accelerated "dunk tester" [10]. Figure 7 shows the effect of spray time on heat checking, measured after 5,000, 10,000 and 15,000 dunks. The data show that considerable heat checking was observed when spraying the dunk test sample for 13 seconds, but the amount of heat checking was reduced significantly when the spray time was reduced to three seconds. When no spray was applied to the dunk test sample (zero spray time), no heat checking was observed in their test.

Based on the data in Figure 7, it is likely that it was the reduction in spray that led to the die life extension of the PVD coated balance shaft housing die. However, without applying the PVD coating to the entire die, it would not have been possible to reduce the lubricant spray, so the use of the PVD coating led indirectly to the die life extension described above.

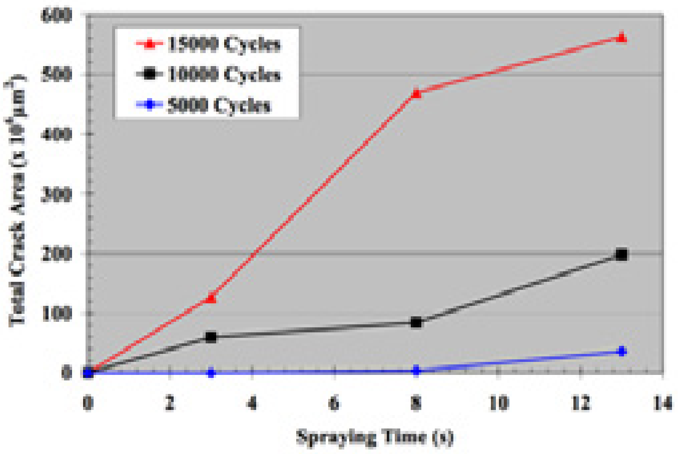


*Figure 7: Impact of spray time on heat checking using the Case Western Reserve University dunk tester [10]*

To better evaluate the benefits of the PVD coating, the die caster producing the balance shaft housing castings performed a cost comparison, comparing manufacturing costs associated with the older un-coated die, and this new die that was covered with the AlCrN PVD coating. The cost comparison was performed in 2019 after around 70,000 shots had been produced in the PVD coated die [5]. Details of the cost comparison are listed below, and the results are summarized in Table 1

- By the time the old un-coated die had reached 70,000 shots, it had been repaired (removing solder and re-welding small piece in critical areas) on three separate occasions, with the first repair occurring after the production of only 37,000 shots. At the 70,000 shot mark the PVD coated had not yet required repair, with its first significant repair occurring at around the 75,000 shot mark. The die caster has estimated that the cost saving associated with avoiding repairs was about 10% of the original cost of the tool.

- Obviously reducing the spray time for the PVD coated die means that less lubricant will need to be purchased. The die caster has estimated that this saving corresponds to about 5% of the original tool cost.

- As noted above, the median cycle rate has been increased by about 12%, due to less time being required to spray the die. Thus more castings can be produced each hour, reducing the magnitude of fixed costs assigned to each casting. The caster has estimated that this cost saving corresponds to 5% of the original cost of the die.

- The biggest cost savings comes from the extension of die life, which is especially important for captive die casters. It is still not clear what the eventual extension of die life will be for the PVD coated die, but in 2019 it was estimated as a 25% cost saving with respect to the original cost of the tool.

- Finally, the cost of coating the entire tool must be subtracted from these costs savings. The cost of PVD coating the entire die corresponded to 20% of the cost of the tool.

By totaling the cost savings together with the additional cost of PVD coating the entire tool, the die caster has estimated that the overall cast savings corresponded to 25% of the original cost of the tool (see Table 1), a considerable cost saving. Note that these calculations were performed in 2019 when the PVD coated die had produced only 70,000 castings, and presumably the cost savings would have been even larger if the calculations had been performed this year when more than 100,000 shots have been produced.

| **Item** | **Saving Over 70,000 Shots (as a percentage of original tool cost)** |
|---|---|
| Reduced die repair | 10% |
| Reduced die lubricant | 5% |
| Faster cycle | 5% |
| Extended Die Life | 25% |
| Cost of Coating | (20%) |
| **TOTAL SAVING** | **+25%** |

*Table 1: Estimated cost savings for a producing castings in a die coated with AlCrN [5]*

### Summary

So, in summary, there are many benefits of applying PVD coatings to die casting dies.  These include:

▪ A reduction in soldering and erosion problems.

▪ Cycle time can be improved, as less time is required to spray the die.

▪ Costs can be reduced, as it is necessary to purchase smaller amounts of lubricants, and expensive die repairs can be postponed to higher shot counts.

▪ Probably most importantly, a significant extension of die life can be attained, as the PVD coating makes it possible to apply lower amounts of conventional lubricants, reducing thermal fatigue, and reducing heat checking

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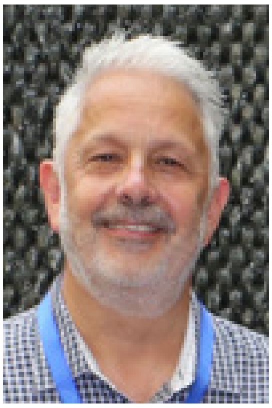
## About Author



Dr. Steve Midson is president of The Midson Group, a Denver-based consulting company specializing in castings and materials.

He has a Ph.D. in metallurgy from the University of Sheffield (UK) and 30 years casting and metallurgical experience, including serving as Chief Operating Officer of a commercial casting company, Director of a development and prototyping company, as well as working in the R & D labs for two Fortune 500 companies.

Midson is an Adjunct Professor at the Colorado School of Mines, where he teaches the undergraduate Foundry Metallurgy class. He is also a Senior Technical Advisor to the general Research Institute for Non-Ferrous Metals in Beijing, China.

Midson is chair of the NADCA Die Materials Committee, a member of the NADCA R&D Committee, and a member of the Semi-Solid International Scientific Committee. He has authored more than 50 technical papers, and has received awards from the North American Die Casting Association, the Society of Automotive Engineers, the American Foundry Society and Sheffield University.

Midson conducted two- & three-day training programs at different Centres (Pune, Delhi, Bangalore & Ludhiana) in 2018 and 2019, on behalf of ALUCAST.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# Changing Customer Requirement – Triggering Technological Transitions

- Jayesh M. Rathode, Sr. General Manager & Head - Diecasting Dies, Godrej Tooling Division

## Abstract

Each Customer industry that uses Die cast Parts are re-inventing themselves to meet bigger challenges of Environmental degradation and Global warming. Newer and tougher norms are being introduced to conserve earth materials and making air cleaner. Today's norms will be challenged tomorrow with more efficient products and processes.

Die casting Industry though upgraded itself quite rapidly in the past two decades but is yet to match the pace with customer industry. Alternate material and processes keep on posing challenges with respect to light weighting and weight to strength ratio. High Tensile sheet metal, Hot forming, Carbon Fibre and Engineering Plastics are examples that keep on appearing in Cost benefit charts and sometimes come out as a winner.

The silver lining is that Die casting offers a variety of options in meeting lower to high production rate, Thick wall to thin wall section requirement, Various porosity levels meeting functional requirements, varied Surface finish from glossy to textured and rugged look. This has helped the industry to survive and thrive when customer industries found it meeting their requirement.

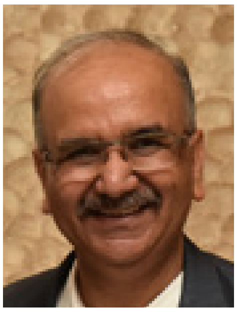
The Problem statement -

Today, we are at cross-roads when customer industry is expecting us to raise our levels to meet their ever-increasing needs without committing business. It requires a major re-setting at our end. Investments in future technologies are non-negotiable and need to be self-financed. It cannot be covered through increase in cost but on the contrary per piece cost is expected to be reduced by using newer technology.

Approach shall be -

- Meeting higher quality norms of customers by investing in new trends and technology
- Upgrading our skills and knowledge in exploiting the newly acquired technology
- Challenge talents to invent and reap benefits
- Automating the processes to eliminate routine and non-value added manual activities
- Applying i4.0 in operations to make it efficient and safer

The paper will provide details of changing needs of customers over the years and possible answers to it through available technologies when applied without questioning it.



## About Author

Jayesh M Rathod

31 years of experience in Design and development of dies for 4-wheeler vehicles and for 2-wheeler parts. Dealt with Dies & Moulds Industries at Japan. Exposure to various Toolrooms in Japan, Korea, Taiwan, Germany, USA & France. Contributed Technical Papers at NADCA, ALUCAST, GDC TECH, ILZDA, AAI and IFC.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# Digitalization application along with Automation in Die Casting and its benefits

- Jagannath V, Business Head, m2nxt Solutions – A BFW subsidiary


## Abstract

BFW/m2nxt IoT device named IRIS which is Conceived, Designed, Developed and Programmed in-house to integrate with any Die casting Equipment on the manufacturing shop floor, not only implements Digitization, but also extends as a smart intelligent device to monitor the Automation. Some of the Automation facilitation IRIS can be used along with Robots are Die Cast Ladling with GDC, Extraction, Spraying and Runner Gate cutting which can yield better Productivity, OEE, Low rejection rates and safety to Human and Equipment. How to implement this in the Brown field OR Green field project as well would be the presentation subject.


### Digitization

Our captive device used named IRIS will be integrated on machines like HPDC, GDC, Gate cutting cell, Ladling cell wherein the critical information like Temperature, Flow, Pressure, No of cavities, Cycle time, etc would be captured to ascertain on Equipment and Cell OEE, Productivity along with MTBF and MTTR to name a few. Further Analytics could be generated to point out Rejections, Rework including Predictive Maintenance on the machines and cell. Further IRIS can also be used on machine tools to monitor the performance of the machine tool like lathe, VMC, HMC, Grinding and so on.

### Ladling Automation

IRIS device would be communicating with Robot, GDC and the Furnace as the Master to coordinate the process with all the parameters being monitored adequately. IRIS would measure the right temperature of Aluminium molten metal in the furnace and command the handling robot with Ladle to skim and scoop the molten metal from Furnace with the right quantity based on the level sensor. Pouring of the molten metal into GDC would be carried within the Process stipulated time(~60Secs) and this shall be dynamically monitored by IRIS through Robot Ladle. Now Pouring into the GDC is accomplished by the servo-controlled Ladle on the Robot to ensure the uniform discharge volume into GDC while overcoming porosity. Overall, the entire cell working can be continuous 24x7 as long as raw material and Power is available. One can get all the reports remotely on their mobile/laptop/tablet from IRIS like the heat batch, OEE, Output and so on based on the customization sought by the user customer.

### HPDC Automation

IRIS device not only monitors the performance of the machine, but can also act as master between HPDC, Extraction and Spraying activity which is executed by Robot or Mechanical device. Here again the IRIS commands the Robot to start extraction once the Injection is complete and later spray on the Mould based on the contour of the mould to overcome the stickiness and increase its life.

### Gate Cutting Automation

Subsequently the gate cutting also can be carried out with either the Robot handling the component or the cutting tool based on the feasibility. Here again the IRIS will be the master to control the Robot to tend the gate cutting activity on to the machine which has the cutting saw/component. IRIS can provide dynamic report on the productivity of the cell with all parameters as desired by the customer.

### Deburring Automation

Robot can be handling the component or Deburring Tool as per the feasibility. IRIS will be monitoring and controlling the cell along with automation logical control.

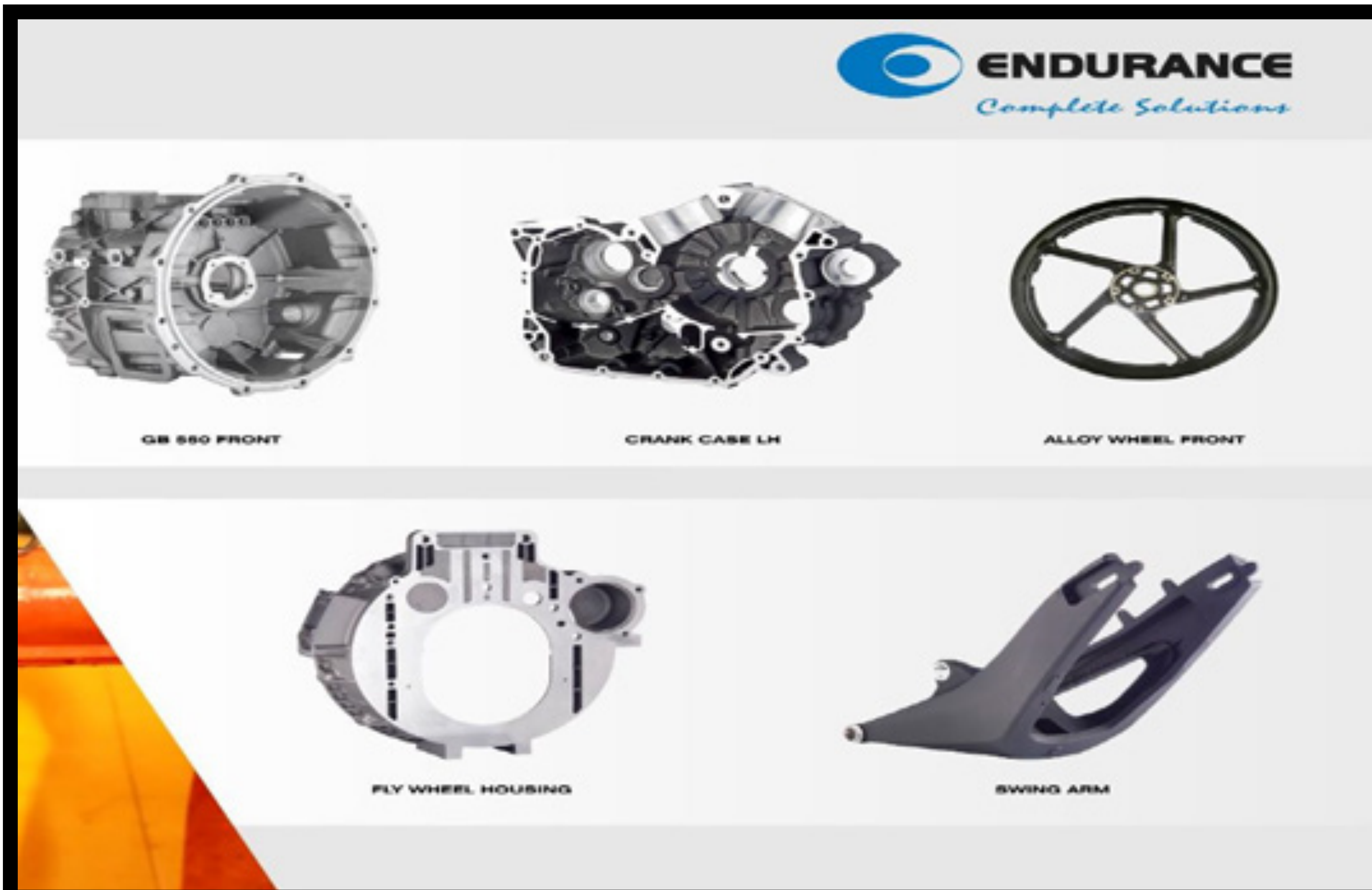
### Machine Tool + Gauging Automation

Robot/CNC Gantry can be used to automate the Loading/Unloading of components into the machine with gauging wherein IRIS will be able to monitor the machines and cells completely.

## About Author

Jagannath Is an Electrical Engineer, five years at a German Grinding Machine Tool specialising in Controls Application., was followed by 23 years at FANUC India, last as Director & SVP Sales and now serving for the past 1.5 years as Business Head & Whole Time Director at m2nxt solutions – A BFW Subsidiary.

Senior management professional with 30 years of experience in catering to Machine Tool Builders, Auto OEMs (2W, 4W & HCV), Auto ancillary Manufacturers (Metal cutting & BIW for 4W), Robot Integrators, VMC turnkey (Fixture & Tooling), Industrial Polymer Manufacturers including Mobile Phones, Medical industry and Tool Rooms with Wire Cut EDMs. Industry 4.0 integrated over 3500 CNC machines in the last 3 years with successful installations up to Enterprise level. Robotic/Gantry Automation Project, AGV (Automatic Guided Vehicle) Design and Development. 3D Printing – Polyjet, FDM and Metal.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FLY WHEEL HOUSING
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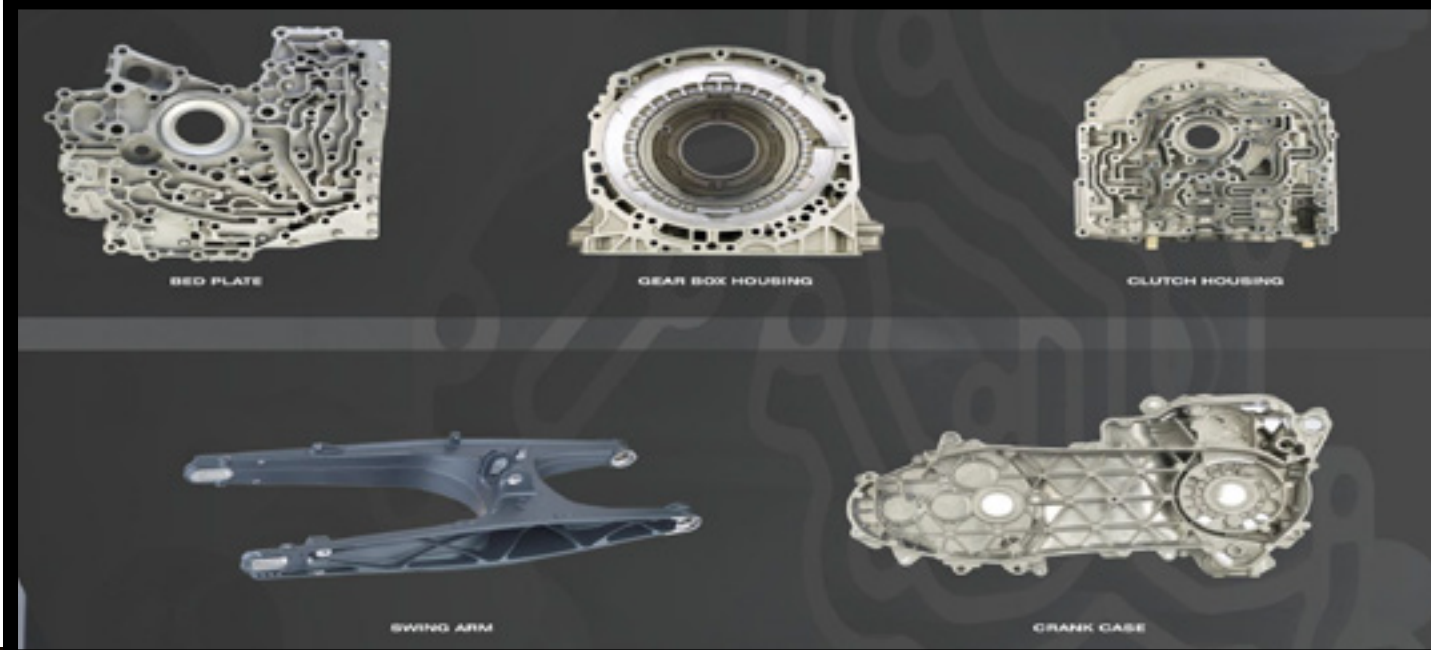
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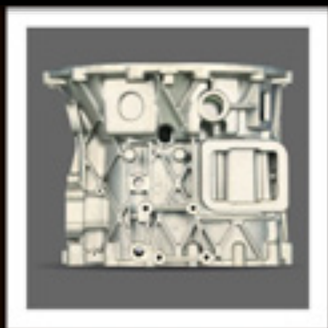


# Advanced Aluminum Refractory Technology for the 21st Century

- Bryan Nelson, Nonferrous Technical Manager, Allied Mineral Products

## Abstract

Refractories for aluminum contact has evolved a lot in the last 50 years. Fifty years ago, an aluminum furnace lining consisted of high fired super duty bricks. A new lining could not produce salable aluminum for days if not a couple weeks until the "silicon bleeding" stopped. The aluminum reduced the silica in the super duty bricks which would "bleed" into the aluminum and the released oxygen would form corundum. Once the reaction went to completion the furnace would last for years. From there the industry evolved to using 85% alumina phos bonded bricks (much less available silica and the phos lowered the porosity of the bricks) and soon afterwards the advent of castables with nonwetting agents. This combination of high alumina phos bonded bricks and nonwetting castables continued for over 30 years before phos bonded two component castables came upon the scene. In the last 10 years refractory companies have developed even lower levels of silica containing refractories and have taken advantage of utilizing calcia in the formulations. Thermodynamically calcia (CaO) is not reduced by aluminum. This paper will highlight two of the latest technologies for containing molten aluminum and resisting the formation of corundum. This paper will discuss the development of a one component phos bonded castable as well as ultra-low silica/calcia based castables.

Fifty years ago aluminum furnaces were bricked from high fired super duty bricks. High firing was done to produce additional glass which lowered the bricks apparent porosity down to 12% which helped stop infiltra- tion by salts and aluminum. The brick was 53% silica and 42% alumina with a Use Limit of 1700ºC, more than enough refractoriness to handle molten aluminum. The problem with this refractory design is best illustrated in **Figure 1**. The $SiO_2$—$Al_2O_3$ brick is reduced to silicon metal and corundum ($Al_2O_3$) as follows: 3($Al_2O3$-$SiO_2$) + 8Al <-> 6Si + 13$Al_2O_3$. The thirteen moles of $Al_2O_3$ is thirteen moles of corundum. As we know corun- dum is a furnace killer. The corundum follows the reduction of silica down into the refractory causing crack- ing which is a result of the significant volume expansion that occurs when molten aluminum takes the re- leased oxygen from the reduced silica and forms corundum.

The liberated silicon metal is absorbed into the aluminum mak- ing its own Al-Si alloy. This phenomenon is referred to as "silicon bleeding". An aluminum producer would have to gen- erate tons of scrap metal until the thermodynamic reaction came to completion. Once industry started demanding newer more custom alloys from everything such as aerospace, trans- portation, extrusions, die cast, etc... aluminum producers couldn't put up with making days or weeks of scrap.

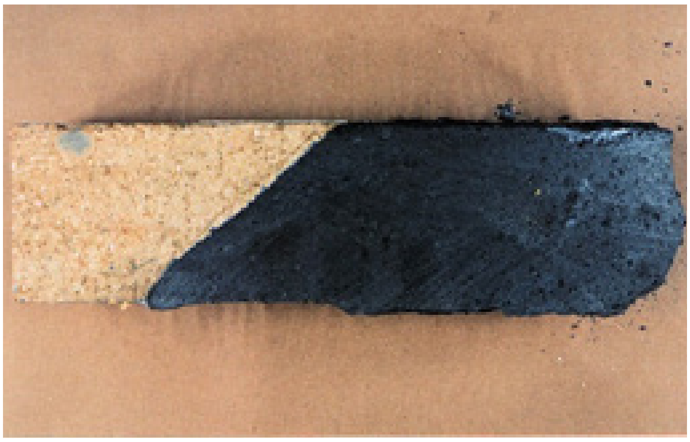


*Figure 1*

Thermodynamically we knew that silica was the culprit so in a matter of a few short years the industry started switching from high fired super duty brick to 80-85% alumina phos bonded brick which lowered the available silica for the reduction reaction from 53 to 11%. **Figure 2** shows the dramatic difference in reducing 11% silica as opposed to 53% silica and thus forming corundum in a high alumina phos bonded burned brick. Around this same time the refractory industry started introducing nonwetting to aluminum castables to speed up installation and reduce the need for skilled brick layers.

*Figure 2*

**Figure 3** shows a standard low cement 65% alumina — 30% silica with non-wetting additive's resistance to attack and infiltration by molten aluminum + salt flux. These type of low cement nonwetting alumina-silica castables have been the industry standard's for over 30 years.

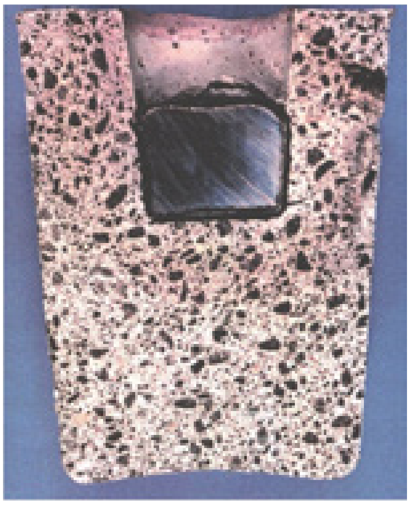


*Figure 3*

In the 1990's the refractory industry introduced phos bonded castables to compete against low cement bonded castables which were the norm since the late 1970's. The phosphate bonded system offered a prod- uct that has superior thermal shock and corundum resistance as well as rapid dryout. The downsize to the phos bonded castables were strength and they required the use of a hazardous chemical phosphoric acid which had transportation issues as well as extra safety via PPE for the installers. The transportation of a haz- ardous chemical requires that the dry material is transported on a different truck than the liquid phos acid thus increasing the cost of an already expensive material. This limitation has resulted in the development of a single component phos bonded castable that requires water for mixing and not phosphoric acid.

**Figure 4** is an 85% alumina - 8.5% silica low cement non-wetting castable that has been run in an Aluminum Alloy + Salt Flux Test at 1000ºC for 72 hours. The aluminum alloy was 1350. As you can see there is significant reaction.

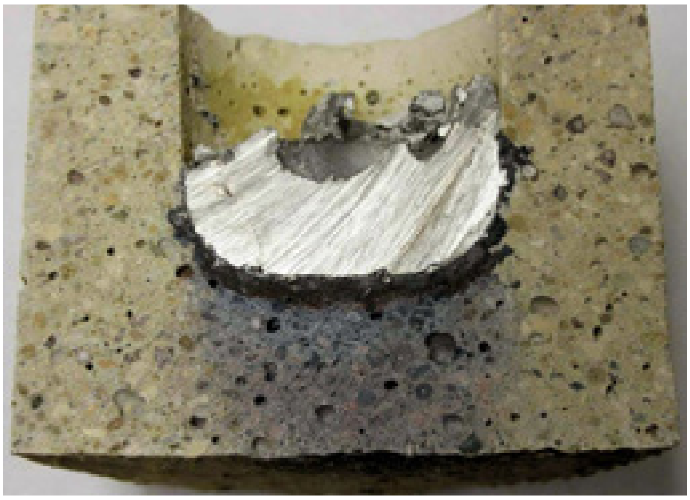


*Figure 4*

Figure 5 is the same Aluminum Alloy + Salt Flux Test but the re- fractory is a two component phos bonded castable. The castable is 88.6% alumina-3.5% silica-3.9% phos. As you can see there is no reduction of silica, no formation of corundum in this phos bonded castable. The Aluminum Alloy + Salt Flux Test is an excellent test to help the researcher differentiate between candidate refractories.

*Figure 5*

**Figure 7** clearly shows that a single component (water activated) phos bonded castable has just as much resistance to infiltration by 7075 alloy as a dual component liquid phos bonded castable, **Figure 6.** The above test is the standard 72-hour 7075 aluminum alloy cup test ran at 815ºC. A major property for the phos bonded castables are their ability to be rapid fired. In the development of the next generation single component phos castable we needed to be at least as permeable as the liquid phos bonded castables or preferably better. Table 1 illustrates the permeability results for both products. Note that the higher the permeability the less tendency for explosive spalling.

**88% Alumina Liquid Phos Bonded Castable**

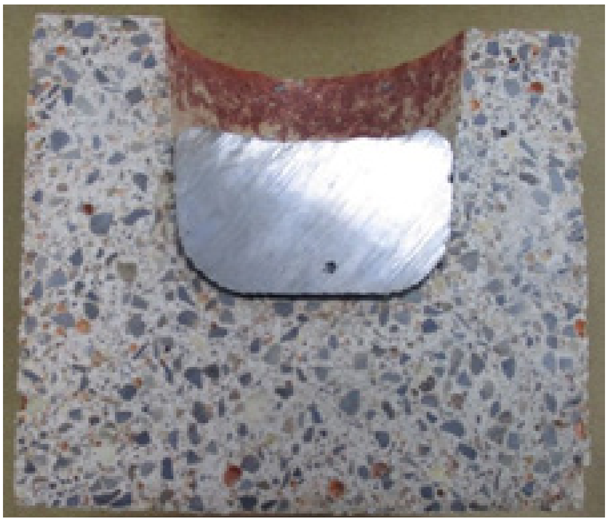


*Figure 6*

**88% Alumina One Component Phos Bonded Castable**

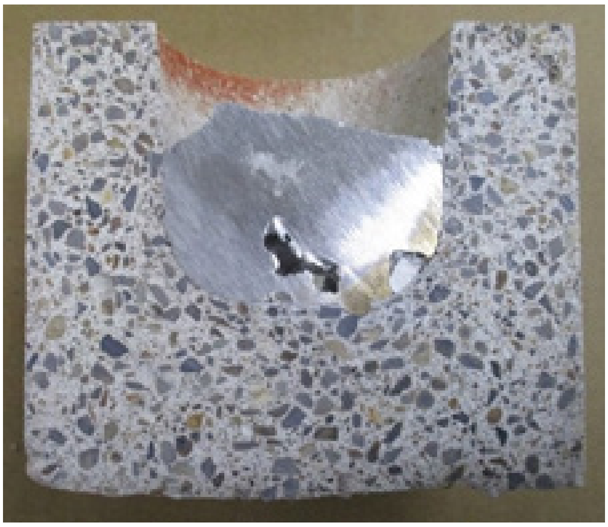


*Figure 7*

| Permeability, cgs | QF88 Liquid Phos Bond | XMT1822 Single Component |
|---|---|---|
| After 110ºC | 10.7 | 17.7 |
| After 200ºC | 12 | 44.6 |

*Table 1*

The ultimate test of a products ability to resist rapid dryout is through An Explosive Spall Test. Test specimens of the QF88 liquid phos bonded castable, XMT1822 single component phos bonded castable as well as a control of an 84% alumina non-wetting low cement castable were cast and then put into a high temperature alloy box and heated at roughly 16ºC/minute to 815ºC.

The box is opened and the samples evaluated for cracking or simply coming apart. The test is a simple pass or fail. On the next page you can see the results of QF88, XMT1822 and a standard 84% alumina nonwetting castable to the Explosive Spall Test. As you can see both of the phos bonded castables are highly resistant to rapid heat up. Low cement castables can't be rap- idly heated due to the cement phases needing time to dehydrate.

**QF88 Liquid Phos Bonded Castable**

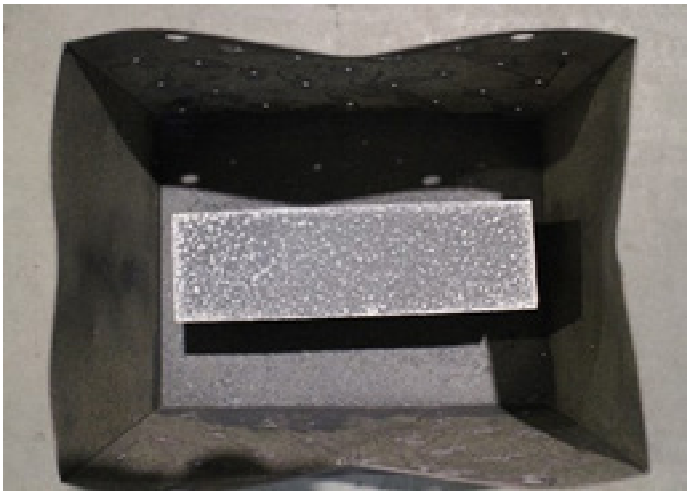


*Figure 8*

**84% Alumina Low Cement Castable**

*Figure 9*

**XMT1822 Single Component Phos Bonded Castable**

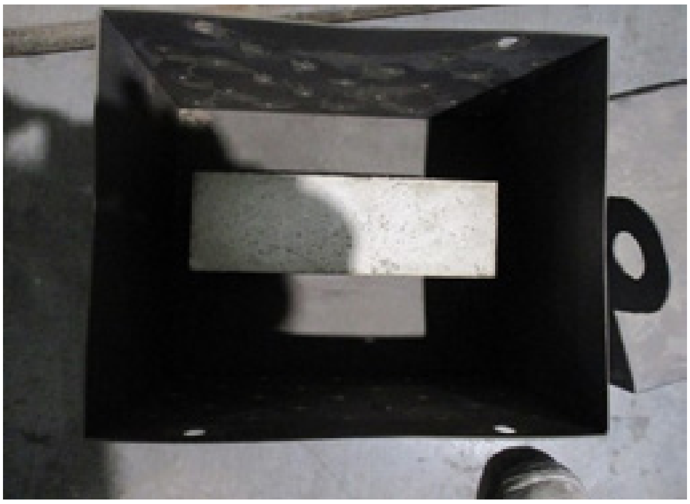


*Figure 10*

Liquid phos bonded castables are known for their ability to bond to other refractories making it an excellent patching or repair refractory. We wanted to make sure we didn't lose that key feature by going to a single component system. Below you see the XMT1822 "bricks" broken after being adhered to a fired high alumina brick, via a 3-point bend test (Modulus of Rupture at Room Temperature). Please note that half of each specimen is a high alumina brick which has the XMT1822 cast against the brick surface to form a 229x114x76mm shape that was subsequently broken in a MOR test.

*Figure 11*

As you can see in **Figure 12** the break did not occur at the adhesion interface thus indicating that the bond or adhesive strength is greater than the surrounding material.

*Figure 12*

**Table 2** shows the adhesive bond strength of the two component liquid phos bonded product QF88 versus the new generation single component phos bonded product XMT1822. Going to a single component system where you only add water does not result in a loss of adhesive strength.

| 110°C | MXQF88 | XMT1822 |
|---|---|---|
| MOR/(MPa) | 3.1 | 4.9 |

*Table 2*

## CASE STUDY 1

A die cast customer with a ZPF Stack Melter has used to some level of success low cement nonwetting castables in their lining. **Figure 13** shows the Stack Melter after 8 years of service. As you can see there is cracking and lining deterioration. **Figure 14** Shows the Stack Melter after a few months service using XMT1822 the single component phos bonded castable. There is no corundum build up on the walls.

*Figure 13*

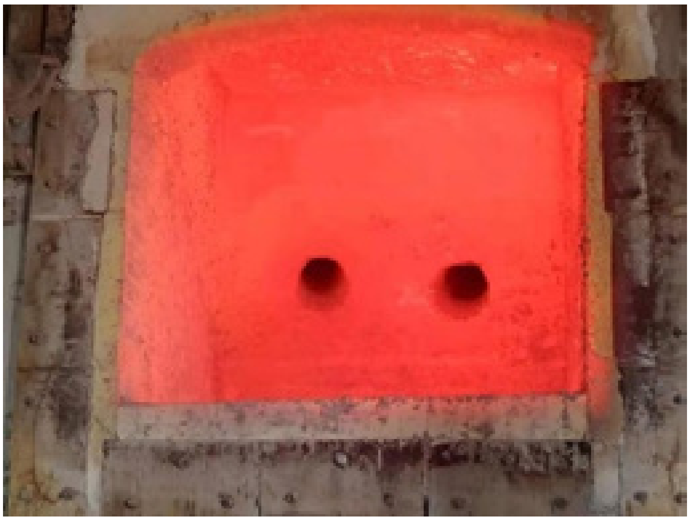


*Figure 14*

The second new generation monolithic for aluminum is a significantly different product built around the use of high calcium materials in the castable formulation. The product is patented due to its unique formulation. The best explanation on why CaO based refractory works so well in the containment of molten aluminum is done through thermodynamics. For a molten metal to reduce an oxide containment refractory the Gibbs Free Energy of the products of reaction have to be negative. The Gibbs Free Energy for the reduction reaction of CaO by liquid aluminum at 700ºC:

$2\ CaO <-> 2\ Ca + O_2\ \Delta G^o = 1075\ kJ$
$4/3\ Al + O_2 <-> 2/3\ Al_2O_3 = \Delta G^o\ -925\ kJ$
$2\ CaO + 4/3\ Al <-> 2\ Ca + 2/3\ Al_2O_3 = \Delta G^o\ 150\ kJ$

Since the Gibbs Free Energy of this reaction is positive it can't proceed at a reaction temperature of 700ºC. The thermodynamics can be verified with an aluminum cup test at 1000ºC as seen in **Figure 15.**

*Figure 15*

**Figure 15** shows the product WAM AL II after being tested with 7075 alloy with salt flux at 1000ºC for 72 hours. The solidified 7075 was easily removed from the cup, no sticking. The coating you see in the photo is not corundum or silicon reduction, it is simply the solidified salt flux .

In **Figure 16** you have WAM AL II after being test- ed with 7075 alloy for 72-hours at 815ºC and as you can see the sample is completely clean of aluminum, no penetration nor adherence of alu- minum. With a silica level of 0.7% the WAM AL II has essentially no silica to be reduced which would liberate oxygen that would readily form corundum and thus destroy the lining of the aluminum containing vessel. Since there are no re- actions between the refractory and molten metal the refractory is clean with no build up.

*Figure 16*

**Table 3**

| Conductivity, W/mK | WAM AL II | WAM AL III | Product A | Product B |
|---|---|---|---|---|
| @ 400ºC | 0.76 | | 1.56 | 2.59 |
| @ 815ºC | 0.69 | 0.7 | 1.69 | 2.66 |
| @1200ºC | 0.76 | 1.2 | 1.83 | 3.1 |
| Density, g/cc | 1.97 | 1.84 | 2.62 | 2.73 |
| Alumina, Wt. % | 61.4 | 75.5 | 60.6 | 72.9 |
| Silica, Wt. % | 0.7 | 0.4 | 34.1 | 15.8 |
| Cao, Wt. % | 26.7 | 22.7 | 1.7 | 2.2 |

Primary Compounds: Alumina-Calcia, Alumina-Calcia, Alumina-Silica, Alumina-Silica

What makes the alumina-calcia products unique 21st century refractories are not just there ability to resist aluminum penetration, sticking and corundum build up but it's low conductivity and low density. **Table 3** illustrates the dramatic difference between conventional nonwetting low cement castables and the new alumina -calcia refractory castables thermal conductivity and density.

**Figure 17** shows the graphical differences between the cold face temperature and heat loss versus a stand- ard 65% alumina-silica nonwetting low cement castable working lining, **Figure 18**. A difference of 52ºC in shell temperature and a difference of heat loss of 1230 W/m2 is significant in safety and lower energy cost.

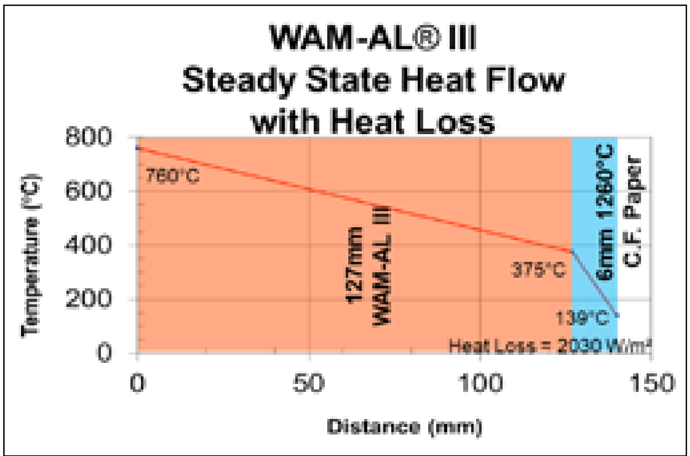



*Figure 17*

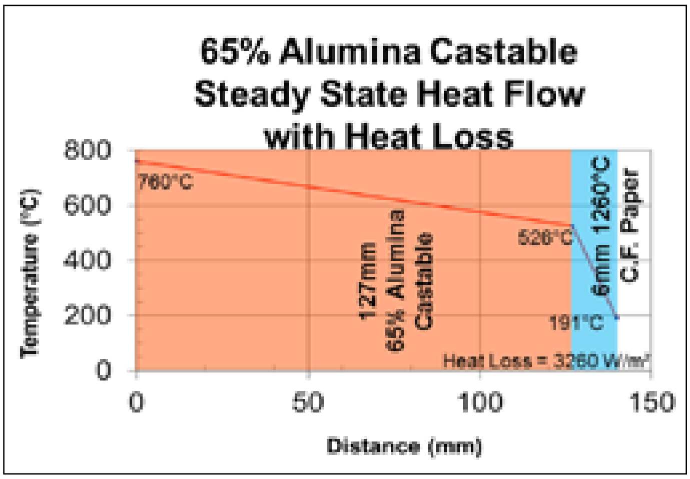



*Figure 18*

## Field Results

**Figure 19** shows WAM-AL II after one year of service, note how easily it cleans and stays clean in operation. The alumina- calcia product line has been in operation as much as 5-8 years in similar applications.

**Figure 20** is showing WAM-AL II in a heated launder. The picture shows the state of cleanliness after 30 days without cleaning.

*Figure 19*

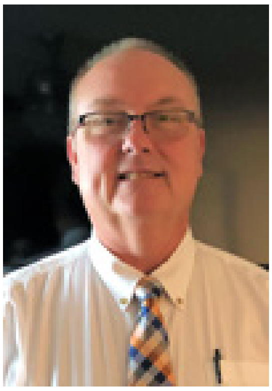
*Figure 20*

## Conclusions

Our purpose is and always has been to advance refractory technology for the aluminum industry. This paper has shown that alumina-phos bonded technology has been advanced such that the aluminum producer can receive the benefits of alumina-liquid phos bonded systems without having to deal with adding phosphoric acid to the dry powder.

The new 21st century alumina-phos bonded system is simply adding water. We have also given the industry new metal contact refractories that incorporate new raw materials that are completely resistant to corundum and have amazing nonwetting characteristics. Besides being nonwetting the patented materials have a high degree of "peelability". There is a distinction between a refractories ability to be nonwetting to aluminum and have a thin layer of aluminum that sticks to the working face and a product that is both nonwetting and aluminum doesn't stick to the working face. One can more than double the life of a launder that has a lining that is both nonwetting and little to no sticking of aluminum/corundum on the working surface.

## About Author



Bryan Nelson is a Ceramic Engineer from Missouri Science & Technology (1977 - 1981).

He has 19 years of working experience for North American Refractories Company doing research, technical services and marketing in the Nonferrous Metals Market. Three years of working experience for National Refractories heading up the Nonferrous Metals Group. Nine years of working experience in sales for Spar, Inc.

Since 2012 he has been working for Allied Mineral Products in sales and is now Technical Manager – Nonferrous Metals.

He is an inventor of porous plug technology for injecting various gases in aluminum and copper. The original brand name was the AL Clean System and also holds a joint patent on New Carbon Bake Brick Technology.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# What vacuum level is needed for a good die casting part?

- Jan Emmenegger, FONDAREX SA

## Abstract

When it comes to pressure die cast good and high-quality die casting parts the use of vacuum automatically comes in mind of many die casters.

Having a look closer into the vacuum pressure die casting production on of the key element is: "Which vacuum level is needed to successful produce a particular part"?

This paper (presentation) will give an overview on recommended vacuum achievement in the die cavity as a guide line with basic explications.

**Overview:**

1. What does the vacuum to the metal structure?

2. Vacuum pressure die casting, what is needed

3. The influences (side effects)

4. Vacuum tank recommendations

5. Structural pressure die casting - sealing of the dies for best vacuum performance

### 1. What does the vacuum to the metal structure?

Looking at the metallurgical aspect of the pressure die casting process, the high injection velocities often entrap air in the metal structure, allowing micro porosity and some larger porosities to arise. Additionally, the fast cooling rates can concentrate porosity and inclusions along the centre and thicker parts of a casting. Both of these factors can reduce the mechanical properties of the casting. Also, the presence of the trapped air often prevents these castings from being heat-treated. Therefore the maximum strength properties to obtain are often much lower in HPDC components compared with other permanent mold and sand-cast processes. The non-uniformity of properties tends to increase with the thickness and size of the HPDC component increases.

In general it is known that the high pressure die casting alloys are rather complex: They are secondary alloys with a higher number of elements therefore some intermetallic phases can show of.

Another point to look at is the humidity. Molten aluminium is hotter than 680 °C then the amount of dissolved hydrogen becomes excessive, the level of magnesium in the melt tends to reduce and the growth rate of dross or oxides accelerates.

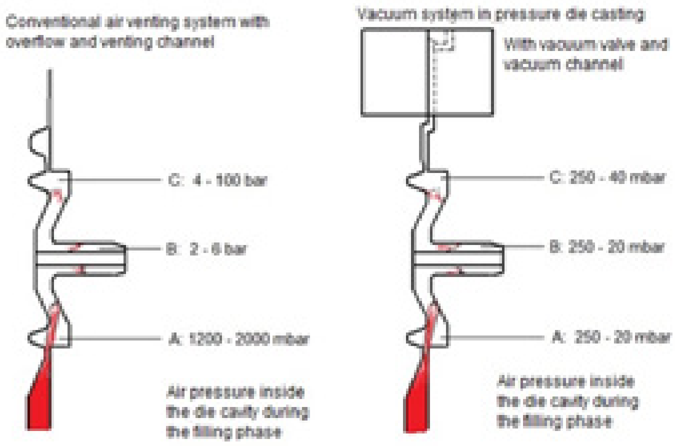
Using the vacuum system correctly, it will not only reduce or eliminate the air (oxygen) volume, it will also reduce the amount of H2O in involved into the filling process.

As a fact the vacuum is taking out Oxygen and H2O during the filling process. That means the HPDC alloy does have much less involved air and gas in the metal when solidification starts. During the solidification under pressure, the alloy gets a much healthier microstructure.

### 2. Vacuum pressure die casting, what is needed

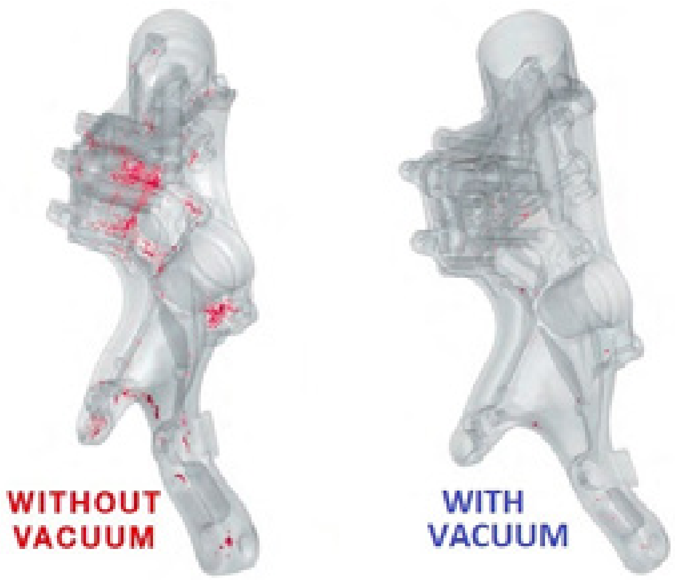
Looking at the standard vacuum pressure die casting process, the vacuum level to achieve is not given by a number in mbar. Of course it is always good to reach a vacuum level below 200 mbar. But the praxis has shown that with only 500 mbar good pressure die casting parts can be produced.

**This is why:** Compared to the standard venting system, the vacuum venting will reduce automatically the air content inside the die (and shot sleeve) cavity. So even if the vacuum level is not that good there is much less air in the process involved




*2.1 Illustration: The difference of cavity pressure without and with vacuum*

On the standard venting system, the air can be compressed inside the die cavity up to 100 bars, during the intensifying phase (solidification) even to 800 bars. This is why some times visible air porosity can be seen at X-ray, tomography and especially after secondary processes such as machining.

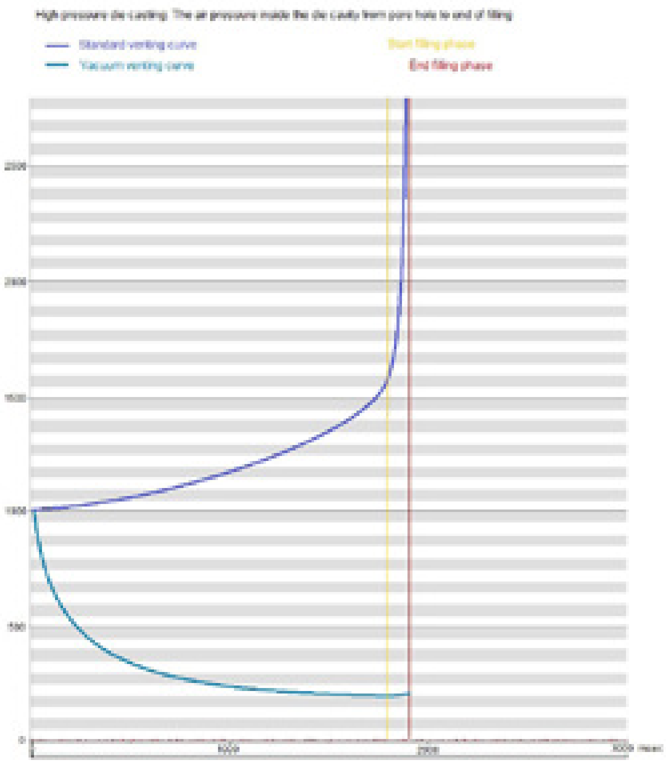



*2.2 Illustration: The difference of the Al basic structure without and with vacuum die casting*

Some metal casting porosity can affect the part's structural integrity, creating a failure point. More commonly, porosity prevents the part from being pressure tight. This will impact performance if the part is designed to hold gases or fluids.

Most porosity in casted aluminium parts are mixed with air/gas and shrinkage. The vacuum technology will mainly handle the air/gas porosity.

It might help to fill some more metal volume into the cavity, but on should never count on solving shrinkage porosity with the use of the vacuum during the cavity fill. Changing the die temperature in this specific part will do much more to reduce the shrinkage. And even better if possible, using a squeeze pin.



*2.3 Illustration: The difference of the pressure curve without and with vacuum*

If the pressure of air in the cavity is reduced during the filling process, automatically less air will be mixed due to turbulences and velocity changes of the alloy.

Note: The better the vacuum, the higher the risk for side effects!

So if the level of vacuum is 400 mbar, 200 mbar or 100 mbar is not that important. What makes the difference is that there are no side effects created by the vacuum.

## 3. The influences (side effects)

The below mentioned points do influence the theoretical effect of using vacuum during the filling process of nonferrous metals:

- Additional air being sucked into the cavity
- Die lubricant (water) being sucked into the cavity
- Air being sucked between plunger and shot sleeve

- The alloy flow being changed too much by the rapid air flow.

### 3.1 Prevention

To overcome the side effects, the precision of the mold is important! The die must be tight at production temperature. It is normal that the mold with an average temperature of 160°C does seal different than with 20°C, At the beginning of the process the die maker must take in consideration that the die inserts in the centre of the die will create more closing force than the die holder and the sections where the alloy mass does not additionally heat the die. 0,02 mm to 0,06 mm have to be taken in consideration. The latest versions of pressure die casting simulation software does show where the die is expending more.

To prevent that air is flowing between pistons and shot sleeve, ring pistons are highly recommended. Especially in structural pressure die casting.

If additional air gets on the surface of the alloy in the shot sleeve, the vacuum level significantly is getting worse. Further the oxidation of the alloy is increasing as well.

With an increased airflow from the shot sleeve into the runner system, the risk that the alloy flow is being changed is proven by cold flow, orange skin, marks and in worst case unfilled cavities. .

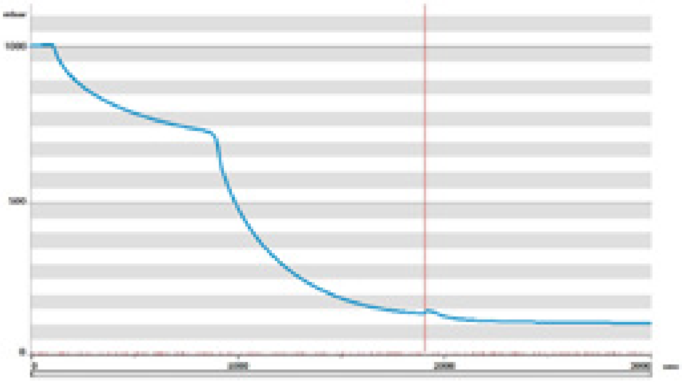
If the alloy does not stay compact, some parts will get to the gate almost solid and stick there. So the gate size is changing and the whole filling.

**Regulation of the airflow created by vacuum:**

In order to control the air moving out of the shot sleeve and runner system, a regulation valve or pneumatic pistons are used to reduce the air flow rate.

The regulation is used mainly in the first third of the evacuation time. The closer the alloy is getting to the gate, the higher the airflow can be without influencing the alloy flow.

*3.3 Illustration: The setting of the throttle valve to reduce the air flow.*



*3.4 Illustration: The regulated vacuum*

In order to qualify the vacuum curve, the advanced vacuum systems do measure how many litres of air has moved into the vacuum tank per shot.

The best vacuum level is not much worth it, if the vacuum is only measured in a good number, but the air still remain in the cavity.

Also the opposite way around: A good vacuum level might be a negative indices if the air volume into the tank shows 35% more than the real volume actually is.

On the high-end MODULAR vacuum unit the airflow on each channel can be measured. This has the advantage to find leaks or limited air flow passages in the die or its connection.


*3.5 Illustration: The setting and measurement of the air volume moved into the vacuum tank*


*3.6 Illustration: The measurement of the air flow moved in each vacuum port*

### 4. Vacuum tank ratio to the application

To create a certain level in a cavity, the vacuum tank needs to have the minimum size. All depending the quality of the die casting part required. The get the right ratio, the volume of the cavity as well as the volume of the vacuum hoses and filters must be known.

The total of the calculated volume gives the 1 in the table. FONDAREX is recommending to use about a ratio 1:50 on standard vacuum applications.

The capacity of the vacuum pump must guarantee an average vacuum level of 20 mbar on standard vacuum die casting applications.

Looking at high quality structural casting parts, the vacuum level should be better than on standard vacuum die casting parts. That does not mean 30 mbar is always needed. But the die caster should have the possibility to get such a resort. This is why the vacuum tank is bigger and the average vacuum level lower.

| | Ratio (cavity hoses to tank) | Average vacuum level tank |
|---|---|---|
| Basic | 1 :35 | 25 mbar |
| Standard vacuum die casting | 1:50 | 20 mbar |
| High tech vacuum die casting | 1:75 | 15 mbar |
| Structural High end | 1:100 | 10 mbar |

### 6. Structural pressure die casting - sealing of the dies for best vacuum performance

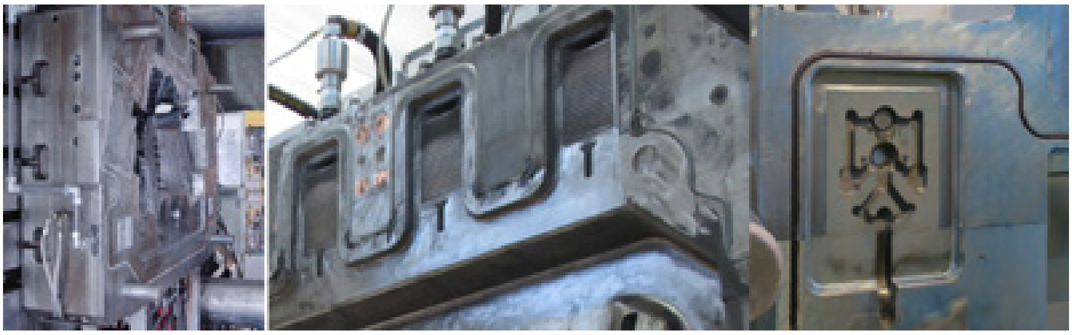
Pressure die casting structural parts is a challenge in our market. Most parts are highly ductile and therefore casted with special alloys Most structural aluminium components are thin walled and do need aging or heat treatment such as T6) to improve the yield strength. Only aluminium alloys with zero porosity, and low iron content, less than 0.15%wt, can be used with such heat treatment.

One of the most popular structural aluminium alloy is Silafont 36 It can reach yield strength, up to 290 MPa, after T6 heat treatment. Silafont is highly profiting with the use of vacuum. The oxidation and hydrogen inclusions can be basically eliminated.

To do so, a high performance vacuum system is needed. The tank must be large in size and the vacuum level lower than 15 mbar in order to have the possibility to reach vacuum levels as low as 30 mbar.
Of course also 100 mbar can give good results if all side effects are eliminated. There is no specific vacuum limit as such to say whether the part is good or out of tolerance. The target is just to get 100 mbar or lower.
The capacity (square section) of the vacuum valves, chill blocs and according channels must be minimum 25 % of the gate. 30 % is better.

To guarantee excellent structural die casting parts the die temperature must be adapted well (often some 20 to 40 °C higher than average molds. Also important is the lubrification of the molds. Precise application with the use of not touch products is important.

A ring piston is a must and die sealing does help to keep the die tight also after 80000 shots.



*6.0 Illustration: Sealing the structural production molds*

If the space is given, the nut for the seal should be placed on a higher level than the parting line of the part. In this case it is more difficult that liquid aluminium gets to the seal. There are different brands on the market. Si Profile 1865 – 19960 M+S Silicon can be recommended by FONDAREX.

It is important that a seal can stand minimum 180 °C. The nut has to be adapted to the seal. If all those points are well maintained a good vacuum die casting part is the result.

***Resume:*** To cast good vacuum parts, some discipline and knowledge is demanded. Other than that, the application should be well done. A good vacuum unit has full automatic functions and can easily be incorporated to the process and the DCM interface. With the vacuum level of 250 mbar, it might be good to get a standard vacuum part. With levels below 100 mbar, structural castings can be successful casted. FONDAREX will support every costumer with its 75 years' experience.

## About Author

Jan Emmenegger is a mechanical engineer and has done a two-year Airplane engineering technician course. He also has a business management degree and a marketing degree. Presently he is the Director-Technical Instructor with FONDAREX Engineering. Working with the pressure die casting industry for 29 years in many specified applications in the high-quality field. Global experience in many points of view.

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# Improved Melt Quality for High Integrity Aluminium Castings

## Critical melt treatment practice and melt quality analysis for Aluminium foundries

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## Abstract

Metal treatment is a critical part of the foundry process, which often has a significant impact on casting quality, reject rates and costs. Existing practice often consists of hand fluxing or rotary degassing, but both have important limitations in terms of costs, efficiency or automation.

Furthermore, the application of fluxes like sodium (Na) modifiers or Ti-B grain refiners, that influence mechanical properties, must be performed in a reliable way otherwise the foundry may experience variations in their process.

Cost efficient grain refining will be discussed in gravity and wheel foundries using newly developed MTS 1500 processes.

As HPDC becomes the preferred method of making aluminium casting, cost savings and inclusion removal can be successfully achieved using MTS 1500 and VMET Melt Quality assessment.

Oxide removal is the most important step in improving melt quality and MTS 1500 together with VMET Melt Quality Assessment has made a significant contribution in Aluminium pistons, wheels and chip re-melting.

### Introduction

Metal treatment is a critical part of the foundry process, which often has a significant impact on casting [1] quality [2], reject rates and costs.

Existing practice often consists of hand fluxing or rotary degassing flux injection, but both have important restrictions or limitations.

Hand fluxing can be unreliable since it is operator dependant. Variations in addition rates, treatment times can cause major differences in efficiency and melt quality when cleaning, grain refining or doing sodium modification. This is especially true in High Pressure Die casting (HPDC) where the number of ladles or furnaces treated can exceed 100 per day.

Rotary degassing flux injection has resolved some of these issues by reducing the variability due to the human operator. It also has increased treatment consistency when performing a larger number of treatments per day. Unfortunately, the injection of flux through a rotating shaft requires a specially formulated and graded flux to prevent blockages. Fine particles smaller than 1 mm can become mushy during injection, whereas those larger than 2 mm can bridge inside the spinning shaft, which in both cases causes the treatment to breakdown. This blockage issue will limit the injection rate of the flux and hence can sometimes increase treatment time.

Furthermore, the application of rotary flux injection is often limited to cleaning fluxes as most other fluxes like sodium (Na) modifiers, Ti-B grain refiners or trace element removal fluxes are more difficult to inject and often lead to shaft blockage which is causing troubles for the users.

As a response to these issues above, Foseco developed the MTS 1500 [3], a robust blockage- free and reliable system to achieve multiple functions in a foundry like:

▪ Faster degassing using more efficient XSR / FDR rotor design
▪ Cheaper cleaning & drossing especially in high-pressure die-casting
▪ Constant and repeatable sodium modification
▪ Cost efficient Ti-B grain refinement in gravity and wheels
▪ Cost saving for drossing in Aluminium HPDC
▪ Oxide removal in Al HPDC, pistons, wheels and chip melting using VMET assessment.

## MTS 1500 principles and technology

MTS 1500 (see Fig.1) is an automated Metal Treatment Station based on Foseco's proven FDU Rotary Degassing technology that was sold to more than 2000 units worldwide.

MTS 1500 [3] is an automated system that can perform most metal treatments.

It is a controlled and automatic addition of fluxes that (see Fig.2):

▪ Performs all metal treatment operations and requirements in a single process.

▪ Increases productivity & reduces costs

▪ Eliminates operator involvement

▪ Reduces risks and emissions

▪ Improves efficiency of the treatment

▪ Is blockage free unlike some rotary flux injectors

▪ can add all grades of fluxes

*Figure 1*

MTS 1500 allows for the successive or simultaneous addition of a range of newly and proprietary developed COVERAL MTS fluxes.

These granulated fluxes are typically ranging between 0 – 5mm in size.

But the equipment can be adapted to accommodate larger particles as well as metal treatment products other than fluxes.

Typical addition rates are 20g/s and as high as 1,2 Kg /min.

Upon request the MTS 1500 can be customised to an addition rate of 40g/s which amounts to 2,4 Kg /min.

*Figure 2*

The MTS 1500 technology comprises 3 major components:

### 1. The Foundry Degassing Unit (FDU): see Fig.3

Our rotary degassing unit is the basis of the system as it provides a stable platform to which all other components can be attached. Any design of FDU unit can be used to build an MTS 1500.

The primary purpose of the degassing unit is to introduce a rotating shaft into the melt through which Nitrogen or Argon gas is injected.

This produces a fine dispersion of gas bubbles inside the melt, which removes hydrogen as well as oxides and makes for better castings without porosities and inclusions.

Furthermore, degassing is always a part of melt treatment and can eliminate excess moisture that fluxes might have introduced.

The MTS 1500 can have up to 2 hoppers to add 2 different fluxes.

Each hopper has a 20 Kg capacity. The hoppers are designed to protect fluxes from the environment and to prevent moisture pick-up.

The screw-dispensing unit is mounted at the hopper outlet and is capable of dispensing accurate and consistent amounts of flux (+/- 3%) into the vortex. Adjusting the length of time the screw operates can control the required flux amount.
The end of the dispensing tube is positioned next to the spinning shaft and directly above the vortex to ensure that all the flux will be added to the metal.

### 2. The movable baffle: see Fig.4

The baffle plate can be moved up and down depending on the cycle phase.

The absence of the baffle helps create the vortex that is needed to efficiently mix the fluxes inside the melt. The presence of the baffle in the melt eliminates the vortex and creates optimum conditions necessary for cleaning and degassing.

The baffle plate is made of INSURAL, an insulating material non-wetted by molten aluminium. It is durable and resistant to thermal shock.

*Figure 3*

*Figure 4*

### 3. The Foseco patented pumping XSR and FDR Rotors:

Foseco developed and patented the XSR (see Fig.5) and FDR rotors (see Fig.6) designed to efficiently mix the flux into the Aluminium melt while remove unwanted gas and inclusions. They are highly efficient pumping rotors, which creates a strong mixing action in the melt.
Thanks to their pumping efficiency, it allows for good reaction between the fluxes and the entire aluminium melt.

Both XSR & FDR Rotors are a key component of the MTS 1500 system and enable:
- Superior degassing efficiency compared to standard designs
- Time savings during treatment and degassing cycles
- High performance at lower RPM, typically 350 – 450 RPM

*Figure 5*

*Figure 6*

**MTS 1500 Degassing performance**

Hydrogen gas porosity is one of the primary concerns of Aluminium foundries. The MTS 1500 when used in conjunction with our patented XSR / FDR Rotors can efficiently remove gas from the melt. Figure 7a and 7b show RPT (reduced pressure test) samples @ 80mb of Al-Si7Mg before and after 4 minutes of degassing with MTS 1500. The measured density before MTS 1500 degassing is 2.34 g/cm3 The measure density after MTS 1500 degassing is 2.68 g/cm3. Average data shows that MTS 1500 is able to degas any foundry alloy within 2-8 minutes at temperatures between 680°C to 780°C.

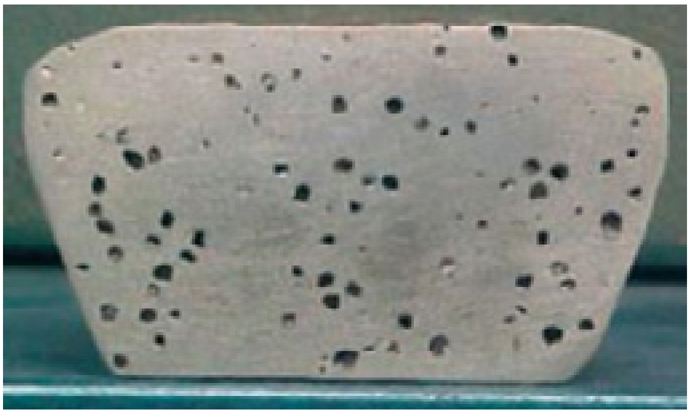


*Fig. 7a before MTS 1500 degassing*

*Fig. 7b after MTS 1500 degassing*

### Laboratory scale degassing experiments:

Foseco undertook some comparative degassing measurements (see Fig.8) performed in a 500Kg crucible (BU 500) of AlSi7%Mg alloy using 18l/min of Nitrogen.

A hydrogen measurement device was used to continuously monitor the hydrogen content in the melt. Within 3 minutes the MTS 1500 + FDR rotor system can reach 0.1 ml/100g of hydrogen thus outperforming standard rotors in this demanding application. This performance is especially valuable in un-heated ladle treatments where a shorter degassing time means less temperature loss and hence energy savings.

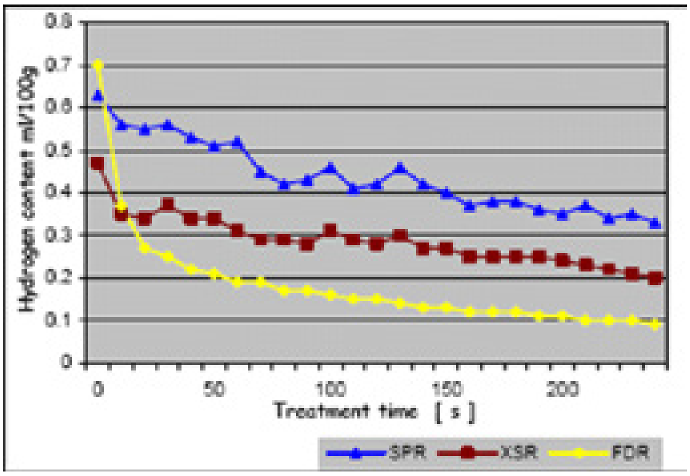



*Figure 8*

### Reliable and consistent Sodium Modification

In the last 10 years, Strontium (Sr) modification has become the most popular modifying agent since it doesn't suffer from the fading issue linked to the use of sodium (Na).

Nonetheless, most people recognise that Sodium is a stronger modifier than Strontium in Aluminium-Silicon alloys. In sand and gravity castings, sodium modification is still used for thicker or difficult castings that are sensitive to shrinkage.

To address this issue, Foseco developed a range of powerful sodium modifiers with a low addition rate (0,1%) that is able to introduce 80 ppm –120 ppm of sodium into Aluminium-Silicon alloys.

Figure 9 presents the benefits of Coveral MTS 1572 in a gravity die foundry making safety critical components for the automotive industry.

The Al-Si12%-Cu-Ni-Mg alloy is held between 740 – 760°C in a 300 Kg (BU 300) gas fired crucible furnace. The former practice consisted of a manual-fluxing treatment followed by a 15- minute degassing cycle.

Unfortunately, this practice is not able to achieve consistent sodium levels after degassing, as there is a +12% variation in sodium content from one treatment to the next.

Using the MTS 1500, the foundry is now able to achieve consistent sodium levels, which result in better consistency of casting properties. Additionally, treatment times and flux addition rates were reduced significantly, which is making an impact on the overall treatment costs.

| **Gravity Foundry** | **Degaser + manual flux addition** | **Automated MTS 1500** |
|---|---|---|
| Flux used | Proprietary flux | COVERAL MTS 1572 |
| Amount of flux used | 890 g + 8% | 270 g + 3% |
| Flux Addition rate | 0.3 % | 0.1 % |
| Treatment time | 15 minutes | 9 minutes |
| Density achieved after degassing | 2.68 g/cm$^3$ | 2.69 g/cm$^3$ |
| Variation in sodium content | + 12.7% | + 5% |
| Sodium (Na) content before treatment | < 18 ppm | < 18 ppm |
| Average sodium (Na) content after treatment | 80 ppm | 78 ppm |

In order to better understand the savings that MTS 1500 can generate in the case of sodium modification, we undertook some extensive lab testing designed to compare sodium uptake (yield) as a function of flux quantity used both in a manual addition and an MTS 1500.

Results in figure 10 shows that MTS 1500 is 2,5 times more efficient at releasing sodium than the Standard degassing units + manual flux addition.

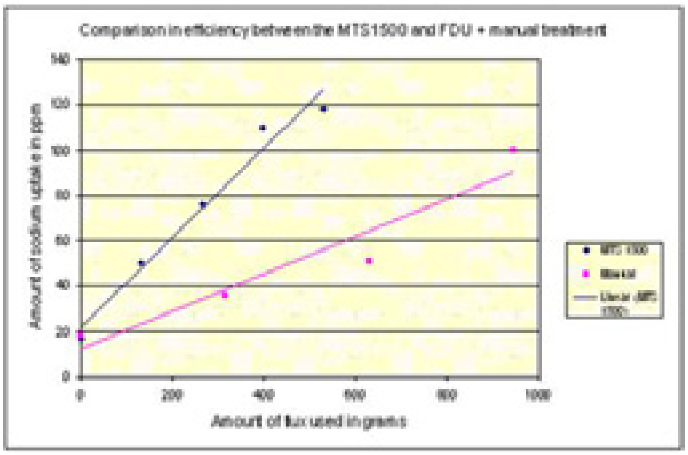



*Figure 10*

## Cost efficient grain refinement in Aluminium Gravity

Aluminium grain refining [4] is one the melt treatment steps that affects most the mechanical properties of castings. It increases elongation [2], resistance to fatigue, improves machinability; reduces hot tear, the size of porosities and the duration of heat treatment. It can also disperse micro-shrinkage in some difficult castings.
Al-Ti5-B master alloys have become the standard practice in foundries around the world, but they are not always the most cost-efficient solution as they contain only 5% Titanium and 1% Boron whereas the remaining 94% Al has no influence on grain refinement.
This Ti-B concentration typically requires a 0,1% addition rate to achieve optimum grain size.

To reduce the addition rate and generate some savings for the foundries, Foseco developed a range of highly concentrated Ti-B grain refining flux [4], which also has an additional cleaning effect on Aluminium melts.

Figure 11a & 11b show the macrographs before and after MTS 1500 treatment of an Al-Si7%- Mg0,3% alloy used to make suspension components for the automotive industry.

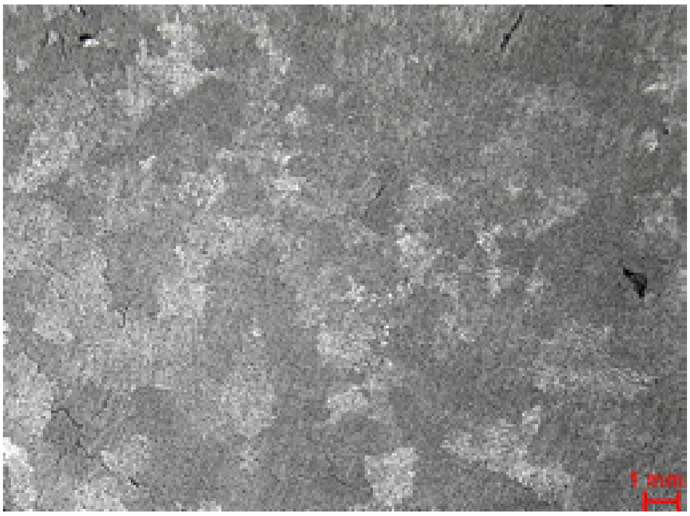



*Figure 11a, as melted*

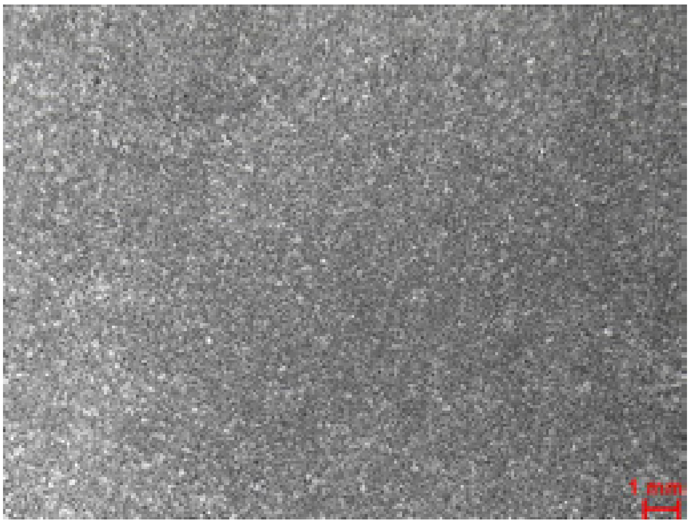



*Figure 11b, after Coveral MTS 1584*

Using only 0,04% addition rate for Coveral MTS 1584, we can match the grain size obtained with 0,1% AT5B1 addition. This represents a 60% reduction in addition for the same grain refining efficiency.

We did a cost comparison between Ti-B rod and MTS 1584 summarised below.

MTS 1500 can reduce the (grain refining + melt cleaning) cost from 1,60 € down to 0,70 € / Tonne of Aluminium, i.e. a 56% saving for the foundry.

| | Addition Rates | Addition rate / 1000 Kg Al | Grain Refining Cost / 1000 Kg Al | Other Savings | Treatment Cost / 1000 Kg Al |
|---|---|---|---|---|---|
| Al-Ti5%B1% | 0,10 % | 1,0 Kg | 3,00 € | 1,40 € * | 1,60 € / Tonne |
| MTS 1584 | 0,04 % | 0,4 kg | 1,20 € | 0,50 € ** | 0,70 € / Tonne |

* AT5B1 contains 94% Aluminium which is recovered by the foundry and valued at 1500 €/T

** Coveral MTS 1584 doesn't require any additional cleaning flux, which is a savings of 0,50 €.

### Superior grain refining in LPDC wheels using MTS 1582 - Grain refiner

Aluminium wheels are one of the most important automotive castings made mostly using the Low-pressure diecasting process. As OEM wheels are considered safety components, it is critical for these castings:

- To be exempt of gas and shrinkage porosity
- To be free of oxides and inclusions
- To have a very fine microstructure which will ensure adequate mechanical properties

Grain refining [4] is one of the critical steps which most foundries achieve by adding Ti-B rod master alloy. The typical addition rate is usually 0.1%.

Fig.12 is showing the key parameters used in an Asian LPDC wheel foundry where A356 alloy is being treated in 700 Kg transfer ladle prior to transfer into the low-pressure furnaces.

| Alloy A356.2 | Ti-B traditional process | Coveral MTS 1582 |
|---|---|---|
| Ladle Size | 700 Kg | 700 Kg |
| Ti-B Flux Quantity | - | 310 g |
| Master alloy Ti-B rod | 500 g | - |
| Degassing Time | 9 min | 9 min |

*Figure 12*

This wheel foundry was using 500 g of Ti-B rod master alloy in their traditional process in order to achieve the required mechanical properties. The newly introduced MTS 1582 process [4] was able to achieve similar quality levels with only 310 g of flux addition. Fig. 13 compares the degassing efficiency and Titanium levels without & without any Ti-B master alloy addition.

| Alloy A356.2 | Ti-B traditional process | Coveral MTS 1582 | Remarks |
|---|---|---|---|
| RPT Density @80mbar | 2.65 | 2.65 | Identical |
| Chemical Analysis | Ti : 0.114% | Ti : 0.114% | Same level |
| DAS in spoke section | 45.88µm | 47.21µm | Spoke Section (Hot Area) |
| DAS in rim section | 26.09µm | 27.26µm | Rim Section (Cold Area) |

*Table 13*

Furthermore, in order to compare both grain refining processes, the foundry took samples from several wheels to measure UTS and Elongation. From Table 14, we can see a clear improvement of the mechanical properties despite addition of a smaller amount of MTS 1582 grain refiner.

| Properties in Wheel Hub | Ti-B traditional process | Coveral MTS 1582 |
|---|---|---|
| Yield Strength (N/mm²) | 208.1 | 213.5 |
| Tensile Strength (N/mm²) | 276.0 | 286.7 |
| Elongation (%) | 6.8 | 8.0 |

*Table 14*

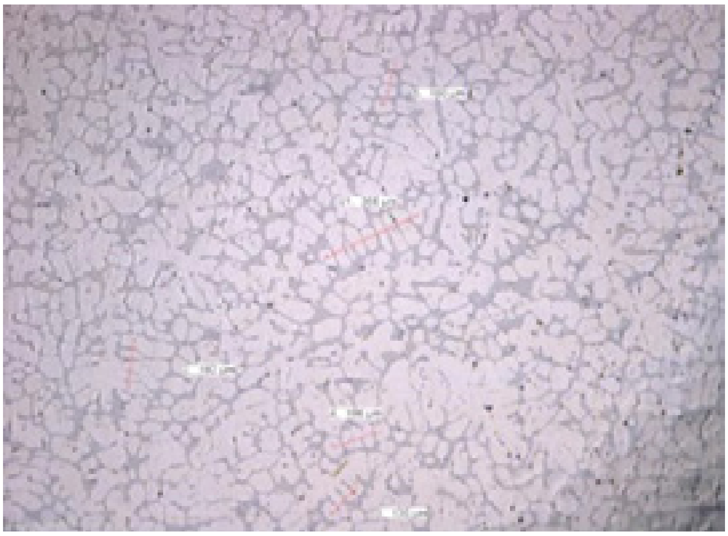


*Figure 15*

Fig.15 shows some micrography pictures taken from the wheel spoke which was treated with MTS 1582 Grain refiner. We can see the structure is very fine and homogeneous. DAS measurements gave a value of 47 µm which is fitting the requirements of modern OEM wheels.

### Cost saving in HPDC drossing with MTS 1500

Drossing is a key part of ladle treatment in Aluminium foundries. Globally, more than 50% of all Aluminium castings are now made using the High-Pressure diecasting process. Metal treatment is usually carried out in transfer ladles using simple degasers for 3 – 5 min. The purpose is not to degas the melt but to remove unwanted oxides and inclusions which will float up into the dross. These oxide films can lead to defects and casting failures. HPDC creates huge amounts of Aluminium dross which can be very rich in metallic Al droplets trapped within the dross.


*Figure 16*

Fig.16 shows the dross that was collected and sampled in a very large HPDC foundry making automotive castings. The standard dross is wet and heavy with Aluminium. While the dross collected after MTS 1500 is much lighter and poor in Aluminium.

Dross samples were sent to a specialized laboratory which analysed residual Al metal in the dross using a salt melting technique which is common in the industry.

Table 17 below shows the process comparisons between a Standard HPDC process and MTS 1500. We can see this foundry is able to save 136 Tonnes of Aluminium / year which leads to a saving of more than USD 250 K for the foundry.

| Automotive HPDC foundry | Standard HPDC process | New MTS 1500 process |
|---|---|---|
| Ladle capacity (Kg) | 1400 | 1400 |
| Collected dross quantity (Kg) | 4.7 | 3.5 |
| Aluminium content (%) | 86.4% | 43.6% |
| Aluminium lost in dross (Kg) | 4.06 | 1.53 |
| Aluminium saved / ladle (Kg) | - | **2.53** |
| Number ladles / day | 180 | 180 |
| Number ladles / year | 54 000 | 54000 |
| Aluminium saved / year (Kg) | - | **136879** |
| Flux cost / year (USD) | - | $ 47250 |
| Foundry savings @ LME price | - | **$ 253884** |

*Table 17*

This saving led the foundry to invest into 2 MTS 1500 units Type Rotostativ in 2019.

## VMET Principles [5] for Melt Quality Assessment in Al foundry

Vesuvius has developed a new technique [5] in order to evaluate metal quality in Al foundries. Upon collecting them, VMET samples need to be polished to a mirror finish and free of scratches as shown in Fig.18 below. Received samples are cut to fit in a 32 mm diameter sample cup. They are mounted in a heat set epoxy resin and polished using a polisher. Dust or fingerprints on the surface should be avoided as they will show up as contamination.

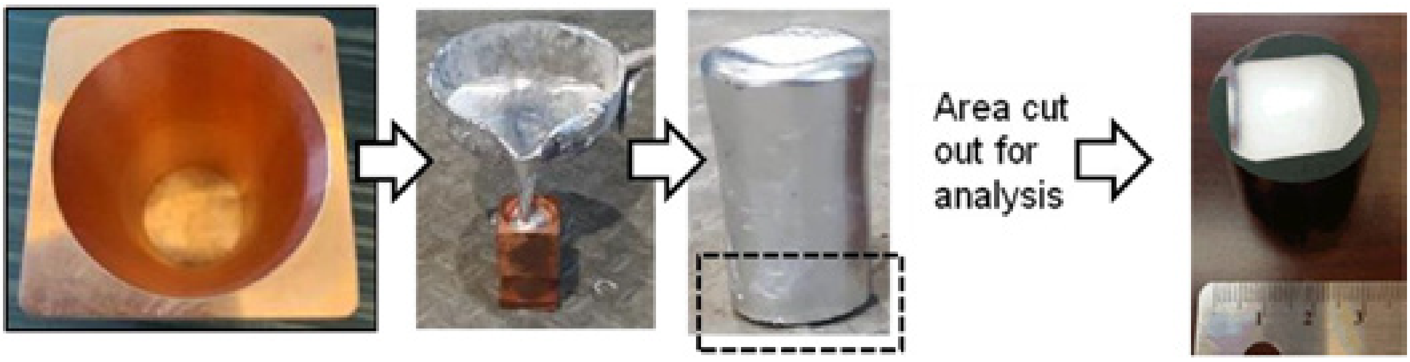
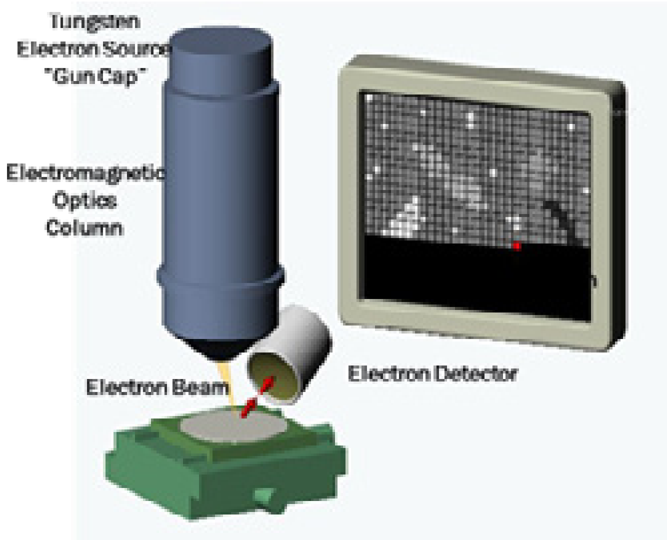



*Figure 18*

Micrograph images of polished samples are acquired using a Scanning electron microscope (SEM) - see Figure on the right.




Images are taken to provide a qualitative indication of the metal microstructure and porosity. Vmet analysis makes use of an automated SEM accompanied with an energy dispersive X-ray spectrometer (EDS) and also an attached software that is capable of classifying found features based on size, shape, chemistry and multiple other metrics as defined by the user.

The Aluminium sample will be scanned using SEM as shown on Fig.19 and an image analysis software will identify all Features > 0.5 µm in the sample. These features will be counted, measured and their chemical nature identified so that they can be classified as:

- Pores (gas or shrinkage)

- Oxide films

- Other non-metallic inclusions

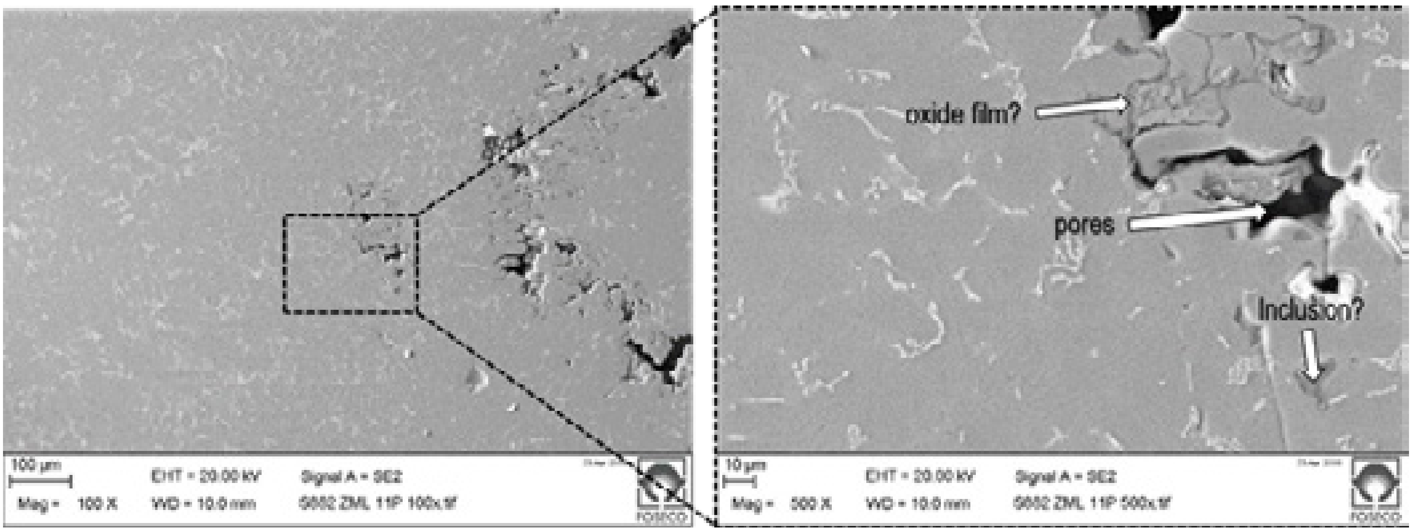



*Figure 19*

VMET will then generate a report where these features will be displayed by chemical nature and size in order to make interpretation easier. Depending on their respective sizes, these features can lead to defects in castings. Table 20 shows the example of Melt #1 which VMET finds to be a clean melt due to:

- All oxides and inclusions found are < 15 µm which is not a concern in foundry castings

- No oxides or inclusions were found > 15 µm which is a good indicator of melt quality

- 15 µm < Features < 75 µm is a concern for safety components and thin wall casting

- Features > 75 µm are indicative of very poor melt quality.

| Feature size | Melt # 1 | Explanation of Features | Comment |
|---|---|---|---|
| Area Analyzed (mm²) | 100 | Area of sample analyzed | |
| ***Total Aluminum Oxides*** | **18** | ***Sum of Aluminium & Mg Oxides*** | |
| 0.5 – 15 µm | 18 | Too small to give defects in castings | **No concern** |
| **15 – 30 µm** | 0 | Can reduce mechanical properties | **Concern +** |
| **30 – 75 µm** | 0 | A risk for all castings | **Concern ++** |
| **> 75 µm** | 0 | **Very bad metal quality** | **Concern +++** |
| ***Total Other Inclusions*** | **48** | ***Sum of Other inclusions*** | |
| 0.5 – 15 µm | 48 | Too small to give defects in castings | **No concern** |
| **15 – 30 µm** | 0 | Can reduce mechanical properties | **Concern +** |
| **30 – 75 µm** | 0 | A risk for all castings | **Concern ++** |
| **> 75 µm** | 0 | **Very bad metal quality** | **Concern +++** |

*Table 20*

### VMET [5] assessment in European Wheel foundry

In the Last 20 years, Aluminium wheels have become the standard for OEMs around the world. The preferred manufacturing route for OEM wheels is Low Pressure Diecasting (LPDC) using A356 alloy which can meet the required OEM mechanical specifications after T6 heat treatment. But adequate melt quality is a key requirement which can often be tarnished by the excessive presence of porosity, shrinkage or oxides.

Some European wheel foundry asked us to conduct a melt quality audit using VMET to assess the quality of their ladle melt as melted and after various treatment processes.

Fig.21 summarizes the VMET findings and clearly shows significant improvements as:

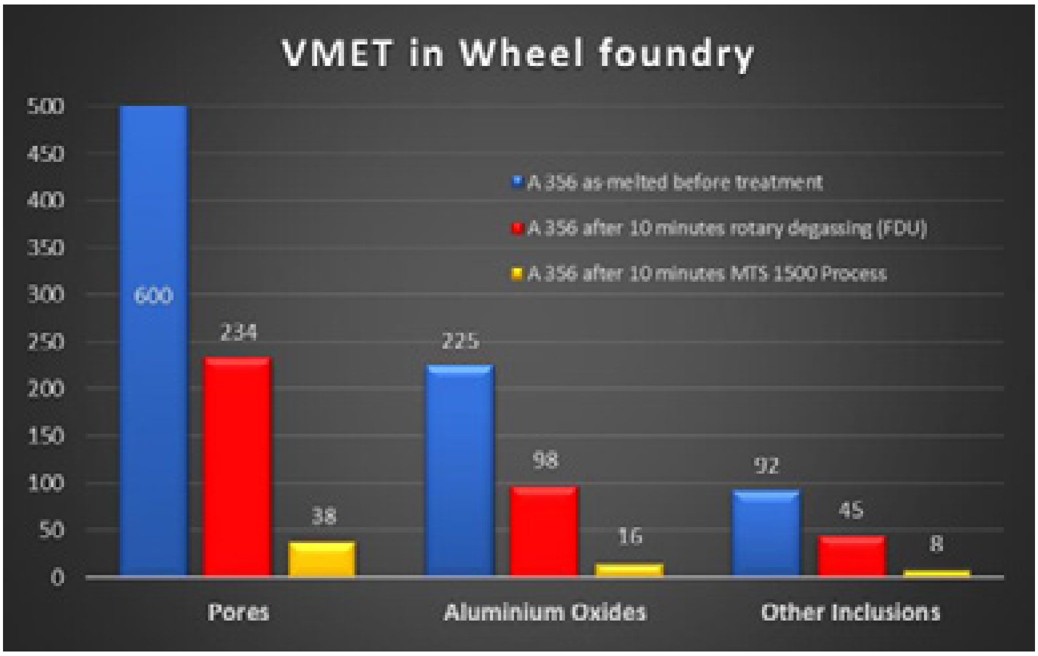
- The total number of features is reduced from 917 to 377 with FDU and to 62 after MTS
- Total Aluminium oxides reduce from 225 to 98 with FDU and to 16 after MTS
- Total Other inclusions also reduce from 92 to 45 with FDU and to 8 after MTS
- Σ of features > 15 µm are greatly reduced from 137 (as melted) down to 3 after MTS.

| **Foundry** | **VMET Features explanation** | **European Aluminium Wheel foundry** | | |
|---|---|---|---|---|
| **Alloy** | | **Al-Si7%-Mg0,3% (A356)** | | |
| **Sample Description** | | **A356 alloy as melted** | **After 10 min Rotary degassing (FDU)** | **After 10 min MTS 1500 treatment with MTS 1524** |
| Total Features | Total # of defects porosity & inclusions | 917 | 377 | 62 |
| Features by Nature & Chemistry | | | | |
| Pore | Gas and shrinkage porosity | 600 | 234 | 38 |
| Aluminium Oxides (Al2O3) | Aluminium Oxide & Mg Spinels | 225 | 98 | 16 |

| | | | | |
|---|---|---|---|---|
| Other inclusions | Other inclusions (carbides, refractory...) | 92 | **45** | **8** |
| Features and inclusions By Size | | | | |
| 0.50 – 15.0 µm | Defects size – little significance in castings | 780 | 368 | 59 |
| Σ all features > 15.0 µm | Defects size – concern in castings | 137 | **9** | **3** |

*Table 21*

VMET analysis is showing that MTS 1500 has a significant impact on melt quality in wheel foundries by reducing unwanted defects like porosity, oxides and other non-metallic Inclusions as shown in Graph 22. This trend has led to a strong development of MTS 1500 use in wheel foundries around the world.




*Graph 22*

## VMET assessment of intermetallic inclusions in HPDC foundry

More than 50% of all Aluminium castings are now made using the High-Pressure diecasting process in the world.

Metal is usually transferred from the melting to the casting furnaces using transfer ladles with capacities ranging from 300 Kg up to 1500 Kg. During this melt transfer, some metal basic metal treatment is performed using rotary degassers for 3 – 6 min.

The purpose is not to remove hydrogen but unwanted oxide films and inclusions that can lead to defects and casting failures.

Fig.23 shows a typical transfer ladle undergoing metal treatment using MTS 1500 Rotostativ with following attributes:

- Casting: Automotive transmission

*Figure 23*

- Alloy: ADC12 secondary ingot
- Flux addition: 0.03% Coveral MTS 1565
- Rotor XSR 220.70 + DSK 75/800.70
- Ladle capacity: 1400 Kg
- Treatment time: 3 min only

This automotive foundry asked to evaluate their Melt Treatment practice using VMET on several transfer ladles prior to filling the casting furnace. Fig.24 shows the VMET results before and after MTS 1500 treatment in the transfer ladle.

| Ladle | Ladle # 1 | | Ladle # 2 | | Comments / Explanation |
|---|---|---|---|---|---|
| Sample from ladle | Before | After | Before | After | |
| RPT density (g/cc) | 2.27 | 2.62 | 2.25 | 2.61 | Fit for purpose degassing improvement |
| Total Features | 1973 | 296 | 243 | 70 | Overall reduction of Total Features ↘ |
| *Total Aluminum Oxides* | 1683 | 253 | 205 | 63 | Overall reduction of Oxide presence ↘ |
| 0.5 – 15 µm | 1682 | 253 | 205 | 63 | Little significance in casting |
| > 15 µm | 1 | 0 | 0 | 0 | Reduction of oxides ↘ |
| *Total Other Inclusions* | 290 | 43 | 184 | 7 | Overall reduction of inclusions ↘ |
| 0.5 – 15 µm | 285 | 43 | 183 | 7 | Little significance in castings |
| > 15 µm | 5 | 0 | 1 | 0 | Reduction of inclusions ↘ ↘ |

*Figure 24*

In the case of both ladles, the VMET Analysis found:
- an overall reduction of total # Features, Oxides and Inclusions.
- the oxides and inclusions larger than 15 µm were completely eliminated
- the Fe-linked intermetallic components that can be present in HPDC alloys were reduced significantly.

VMET shows a clear impact of MTS 1500 process on melt quality in HPDC.

## VMET assessment of Magnesium oxides in an Automotive piston Foundry

Aluminium Pistons have become the norm in the automotive industry due to their relative strength vs light weight. But to achieve such performance, pistons must be free of porosity, oxides & inclusions as well as unwanted alkali elements like Na or Ca which at levels > 5 ppm will affect mechanical properties.

One additional issue are the Magnesium oxides forming in the melt due to the high Mg content of eutectic piston alloys like ACA8-336-LM13.

Hence, particular care is given to metal treatment which includes the use of rotary degassers with injection or addition of various fluxes or gases designed to remove such impurities. Chlorine gas ($Cl_2$) or chlorine releasing fluxes ($C_2Cl_6$) are still used in some parts of the world, but they are no longer perceived as the most environmentally friendly technology. As can be seen


*Figure 25*

below, there are often strong chlorine emission linked with the use of such toxic additives.
- C2Cl6 + [Na] =>NaCl + Cl2 gas ↗
- C2Cl6 + [Ca] => CaCl2 + Cl2 gas ↗

Due to environmental pressure, a new MTS 1500 technology (Fig.25) has emerged in pistons which combines the use of Rotary degassing using inert gases (Ar, N2) and several types of fluxes which have multiple functions like to:
1. remove oxides and especially MgO (spinels) which are detrimental to piston quality
2. reduce all alkali elements like Na & Ca below 5 ppm

Coveral MTS 1565 has been proven to effectively remove oxides and particularly MgO spinel inclusions in an environmentally acceptable manner.

While Coveral MTS 1591 can effectively remove unwanted Alkalis according to the following mechanism: Coveral MTS 1591 + [Na] + [Ca] => NaCl + $CaCl_2$ (which will float into the dross)

A market leading automotive piston foundry has asked us to use VMET to investigate their melt quality following a customer complaint linked to MgO inclusions.

Table 26 below shows the VMET report and findings Before and After metal treatment. This VMET analysis was able to identify the presence of:
- excessive amounts of Na & Ca in the melt before treatment
- many small oxides and inclusions in the melt prior to rotary degassing treatment
- 26 MgO spinel inclusions in the sample, smaller than 15 µm
- 3 MgO spinel were found to be larger than 15 µm - a real problem for pistons

VMET also showed that MTS 1500 process together with Coveral MTS 1565 cleaning flux was able to significantly improve melt quality by removing all oxides and MgO inclusions > 15 µm.

This VMET work led to the sales of several MTS 1500 units in this piston foundry.

| **Piston Foundry** | **MTS 1500 Process with Coveral MTS 1591/1565** | | |
|---|---|---|---|
| **Trial** | **500 Kg Crucible** | | |
| **Sample location** | **Before** | **After** | **Explanation** |
| Na (ppm) | 4 | 0.1 | Excellent Alkali removal |
| Ca (ppm) | 7.9 | 2.6 | Excellent Alkali removal |
| Density Index (%) | 7.5 | 0.1 | Fantastic degassing perfomance |
| **Total Aluminum Oxides** | 64 | 200 | |
| 0.5 – 15 µm | 64 | 200 | Breaking up of clusters - not a concern |
| Σ all oxides > 15 µm | 0 | 0 | No oxides found |
| **Total Other Inclusions** | 69 | 74 | |
| 0.5 – 15 µm | 66 | 74 | Breaking up of clusters - not a concern |
| Σ all inclusions > 15 µm | **3** | 0 | **Reduction of inclusions ↘↘** |
| **Total MgO & Spinels** | 29 | 5 | |
| 0.5 – 15 µm | 26 | 5 | Reduction of spinels |
| Σ all MgO > 15 µm | **3** | 0 | **Reduction of spinels ↘↘** |

*Figure 26*

## VMET Assessment of Chip melting operation for Foundry ingot production

In recent years, many operations have looked at remelting machining chips in order to produce secondary ingots suitable for Aluminium casting production. This is particularly true in Asia for very large amounts of A356 chips coming from LPDC wheel machining.

But many such operations encounter quality issues as they underestimate the level of oxides created during the remelting of such finely divided chips which have large specific surfaces. Hence extreme oxidation will create millions of very fine oxide films as shown in Fig.27 where VMET found extremely high levels of oxide between 0.5 µm – 15 µm.

Such high levels of oxides will create excessive dross during melting but also aggregate to form larger oxide clusters & films which are the cause of reject castings.

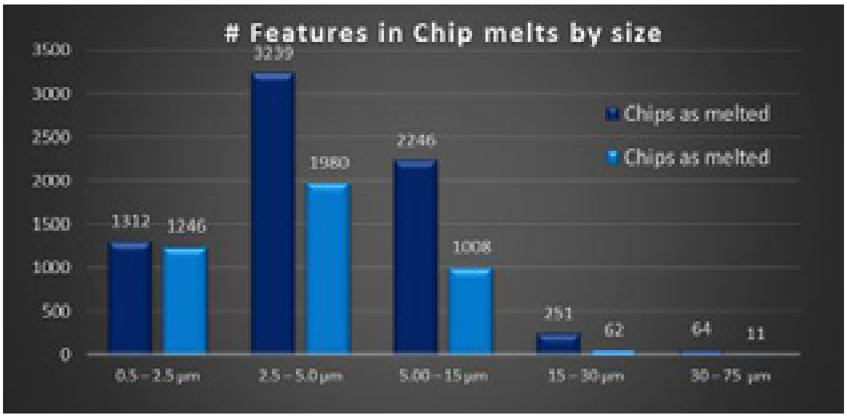


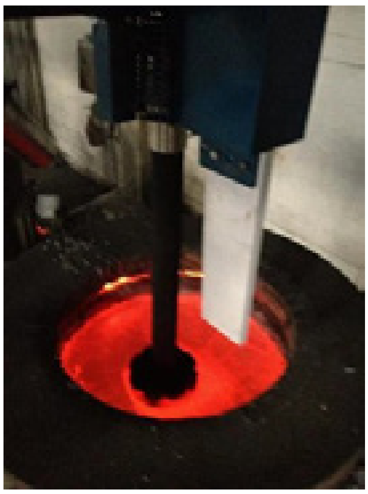

*Figure 27*

Such chip generated melts must undergo intense metal treatment in order to reduce the level of oxides significantly. Strong cleaning fluxes should be applied to de-wet the oxide films and make sure they can be floated into the dross.

One secondary ingot maker asked us to implement such a metal treatment and use VMET to quantify the level of oxides and the improvement observed.

Fig.28 shows the fuel fired crucible furnaces that are used to remelt 100% charges of A356 chips. The melting temperature exceeds 780°C. The crucible capacities are 1 Tonne of chips. Foseco implement our MTS 1500 type Mark 10 mobile device able to treat up to 5 furnaces.

*Figure 28*



VMET Samples were taken from one chip melting furnace before and after a 10 min MTS 1500 treatment. The SEM pictures with 100x magnification are shown in Fig.29.

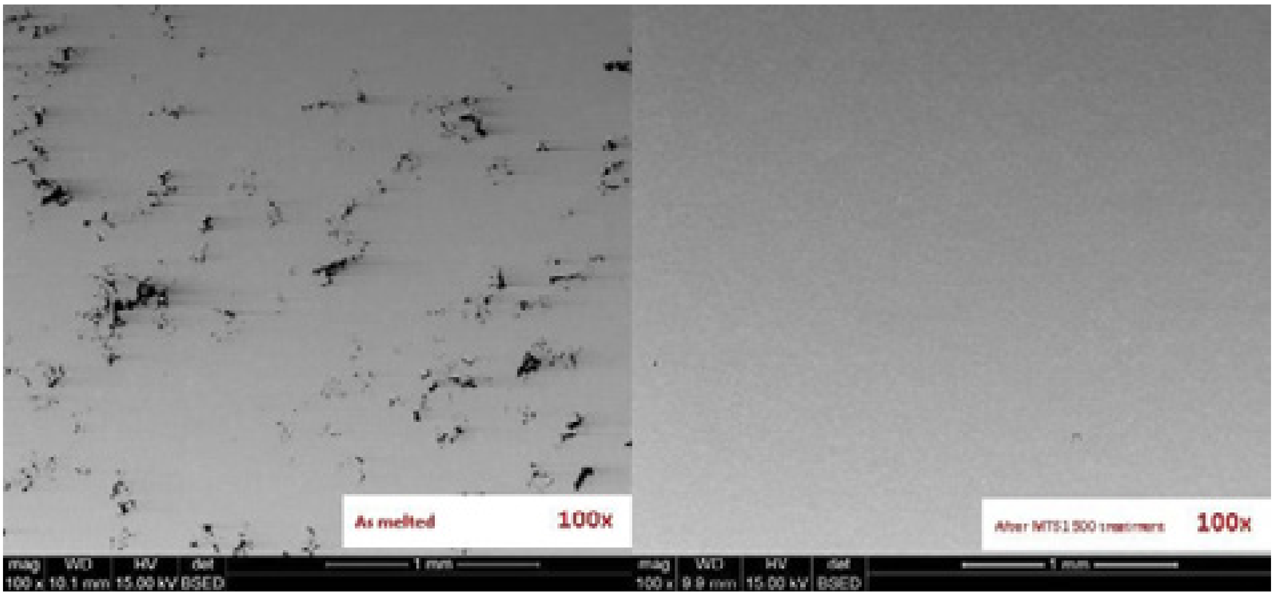



*Figure 29*

We can see the melt "as melted" shows many defects which are a mixtures of porosity and oxide films. Whereas after the 10 min MTS 1500 treatment, the sample is clean without any visible traces of oxides. This is a visual confirmation that MTS 1500 process is able to achieve good melt quality even with 100 pure chips.

Two furnaces # 1 & #2 with similar capacity were loaded with the same amount of chips. After a melting time of around 1 hour, the MTS 1500 unit was applied respectively to furnace 1 for 15 min and furnace 2 for 10 min.

All other working parameters were kept identical including:

- Furnace capacity: 750 Kg chips
- Rotor Size: XSR Φ 220 mm
- Gas flow: 20 l/min
- Shaft length: 900 mm
- Flux addition: 1.2 kg (0.16%)
- Treatment temperature: 720°C

| **Chip melting** | **Furnace 1** | | **Furnace 2** | |
|---|---|---|---|---|
| Sample location | Chips as melted | After 15 min MTS | Chips as melted | After 10 mn MTS |
| Total Features | 7116 | **73** | 4307 | **53** |
| Total Pores | 3804 | **63** | 3791 | **29** |
| **Aluminium Oxides** | **2958** | 3 | **329** | 19 |
| **Other Inclusions** | **354** | 7 | **187** | 5 |
| 0.5 – 2.5 µm | 1312 | **9** | 1246 | **17** |
| 2.5 – 5.0 µm | 3239 | **21** | 1980 | **18** |
| 5.00 – 15 µm | 2246 | **21** | 1008 | **11** |
| 15 – 30 µm | 251 | **19** | 62 | **3** |
| 30 – 75 µm | 64 | **2** | 11 | **4** |
| > 75 µm | 4 | **1** | 0 | **0** |

*Figure 30*

The VMET results in Fig.30, clearly show that MTS 1500 treatment was able to reduce:
1. Total # features from 7116 & 4307 down to 73 & 53 respectively.
2. Total # pores from 3804 & 3791 down to 63 & 29 respectively.
3. Total # oxides from 2958 & 329 down to 3 & 19 respectively.
4. Total # other inclusions from 354 & 187 down to 7 & 5 respectively.

From this chip melting case, we can conclude that the MTS 1500 process is able to remove more than 98% of all defects in Aluminium castings.

## Conclusions:

Metal treatment is one of the critical parts of the foundry process, which often has a significant impact on casting quality, reject rates and costs. Existing practice may have limitations in terms of quality, efficiency or automation.

MTS 1500 process clearly demonstrated a higher efficiency of Na modification in sand and gravity as well as better grain refining both in gravity and LPDC wheels.

In High Pressure Die Casting, MTS 1500 showed significant cost savings in terms of less dross generation.

Finally, MTS 1500 together with VMET Melt Quality Assessment has clearly proven that it can significantly improve melt quality in Aluminium pistons, wheels and chip melting, by removing detrimental oxides and inclusions.

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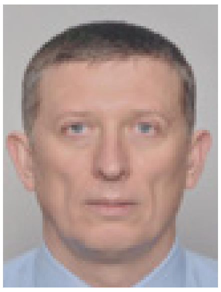
## About Author



Dr. Philippe Kientzler, MS in Metallurgy, Mineral Processing & Powder Metallurgy, is associated with the FOSECO, Nonferrous Group for over 16 years with postings at Shanghai, (China), Kobe (Japan), Tamworth (UK), and Lognes (France).

He has contributed in upgrading of the Rotary Metal Treatment Station to eliminate the drawbacks and provide consistent metal quality, with improved productivity. In this paper, the author explains some of the salient points.

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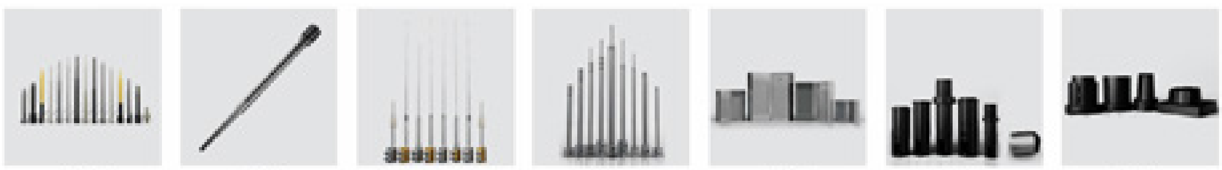

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# Developing High Quality Castings And Optimising Casting Processes Through Casting Simulation

- Kaushik B, Sendil Kumar K, Dr. Ravindran B. Kaushiks International, Bangalore

## Abstract

Today, the market demands for shorter design and manufacturing lead-times, good dimensional accuracy, overall product quality. A rapid change of product design and process configuration are becoming increasingly significant. Producing such high-quality components at reduced cost and with shorter development time is now possible. Even though casting process simulation technology has been available for almost four decades, many casters still use the conventional trial-and-error approach for process development. Unfortunately, a traditional approach rarely allows the operators to participate in the design and engineering phases prior to the costly production stage.

In this paper we shall discuss a few examples of simulation software technology for the High Pressure Die Casting (HPDC) process, which is believed to be one of the most complex of the casting processes.

**1. Plunger Speed or shot profile optimisation.** Here we will discuss how the optimisation of the shot sleeve plunger velocity using FLOW-3D CAST's accurate free surface capabilities to push the air out of the cavity first before filling it instead of the standard shot profile used by the customer that was resulting in gas porosities. Importance of shot sleeve simulation is more often ignored.

**2. Improving Product quality through gating design.** Impact of different design alterations such as traditional versus centre gating system can be easily observed through the aid of simulation technology to achieve quality parts.

**3. Balancing and optimisation of runner system.** Many a times, it is required to design the die with multiple cavities. In such cases, it is essential to accurately orient the cavity and the runner so as to accommodate the part on the desired size of machine. An incorrect runner design or orientation of the cast part can lead to many issues and losses including time and money. Here is one such case where FLOW-3D CAST has helped to overcome the problems by saving time and money, and also convince the customer by justifying the results.

**4. Understanding benefits of using the right plunger tip.** While our major focus remains in the design of the casting part itself, another important aspect lies in the correct selection of plunger tip and its importance in the overall achieving high quality sound castings and cycle time. Here we shall see through simulating effect of plunger material, proper cooling inside a plunger tip and how it helps in reducing the cycle time.

**5. Process Improvement and Quality Improvement.** In this study, we shall see the cause and mechanism of the defect in the casting part and try different design solutions, through simulation to achieve a quick turnaround to improve quality of the casting and also yield

**6. Economic benefits through casting design optimisation.** A major cause of defects include leakage & non-fill in the castings leading to reduction in the yield and higher operational costs. Here we will see how FLOW-3D CAST validates the optimised design of runner system to achieve benefits many folds.

**7. Economic benefit for cost optimisation.** There are several instances where an existing design or process can be modified and improved. But to check the viability of that proposed change and to implement it with confidence would require skilled craftsmanship and the assurance of experienced casters. With the availability of casting simulation software, this work can be made a lot easier and simpler like this present case.

Today, the market demands for shorter lead-time in design and manufacturing, good dimensional accuracy, overall product quality. A rapid change of product design and process configuration are becoming increasingly significant. Producing such high-quality components at reduced cost and with shorter development time is now possible. Even though casting process simulation technology has been available for almost four decades, many casters still use the conventional trial-and-error approach for process development.

In the manufacturing industry or foundry, designers, manufacturers, and process engineers all play a crucial role, collaborating together, in the overall development. In many foundries, new components are often put together by different departments working independently of each other. Inevitably, the manufacturers are under pressure to produce high quality castings within a tight schedule and budget. Thanks to advanced computer-aided technologies and casting process modelling, the traditional approach is becoming a thing of the past. Casting simulation helps quick visualisation of castings to be developed in a computer and provides valuable information. This facilitates participation by the foundry engineer early in the product development stage, which reduces the time between the concept stage and production stage of a new component without defects and saves costs. Also, casting simulation is an effective educational tool in the foundry industry to understand what happens inside the black-box of the die. The simulation software models all of the underlying physics of the process accurately, so that important process variables may be identified and effectively controlled. By visualizing the entire casting process in a virtual environment, problems associated with liquid metal flow, solidification and part distortion become apparent to the designer and foundry engineer to eliminate problems in the process and defects in the castings.

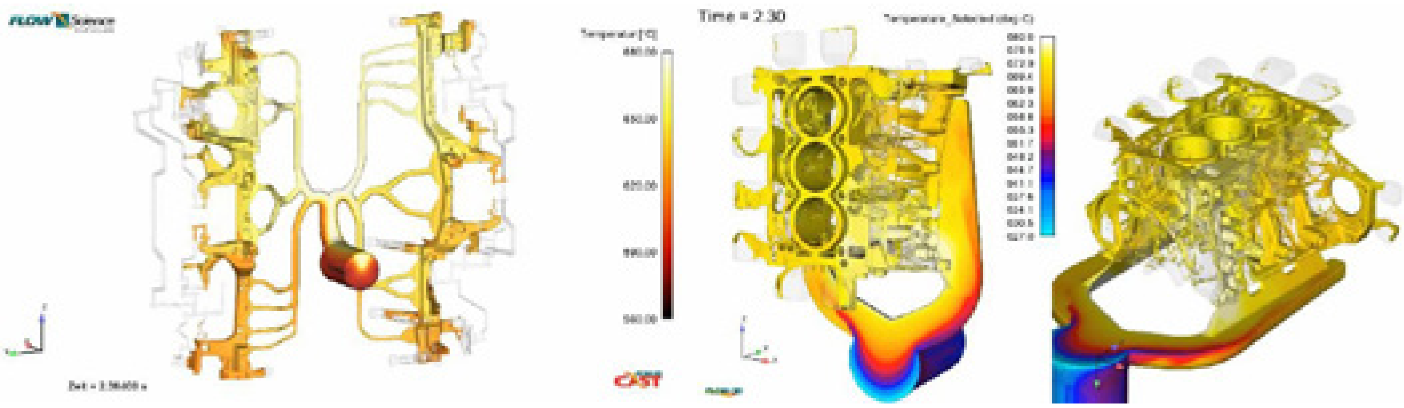


Fig 1a, b: Large, complex castings modeled with complete process simulation in FLOW-3D CAST

Let us now look at a few examples on how simulation has been beneficial in the study of High Pressure Die Casting (HPDC) process, which is believed to be one of the most complex of the casting processes, as seen in figures 1a and b.

### 1. PLUNGER SPEED OR SHOT PROFILE OPTIMISATION

Determining proper casting configuration (parameter) during production is a relatively complex process and the results are not always known beforehand. Every casting has specific geometry, material and process. It is estimated that majority of the errors in casting usually occur due to design errors and that only a very low percentage are actually attributed to production problems. Many design errors can be observed on time using simulation software, following which, the design or the process parameters can be adapted.

Many casting defects are introduced into the final part at the time of fill. A correct temperature distribution in the metal at the end of fill is the foundation for correct solidification analysis. Short-shot / early freeze defects analysis is tightly coupled to accurate fill and heat transfer. Therefore, details of molten metal flow play a critical role in preventing many fill-related defects.

Casting processes are complex due to the wide range of physical processes typically present. Every casting process is closely coupled with each other and taking the decision regarding the best method, layout or process can be challenging. Modifying any one process parameter, can have a multi-fold impact on the other parameters and final quality of the casting. By simulation of casting process, a high degree of process certainty can be observed by preventing technical problems, ensuring that projects do not encounter delays, and most importantly produce First-Time-Right, high QUALITY parts.

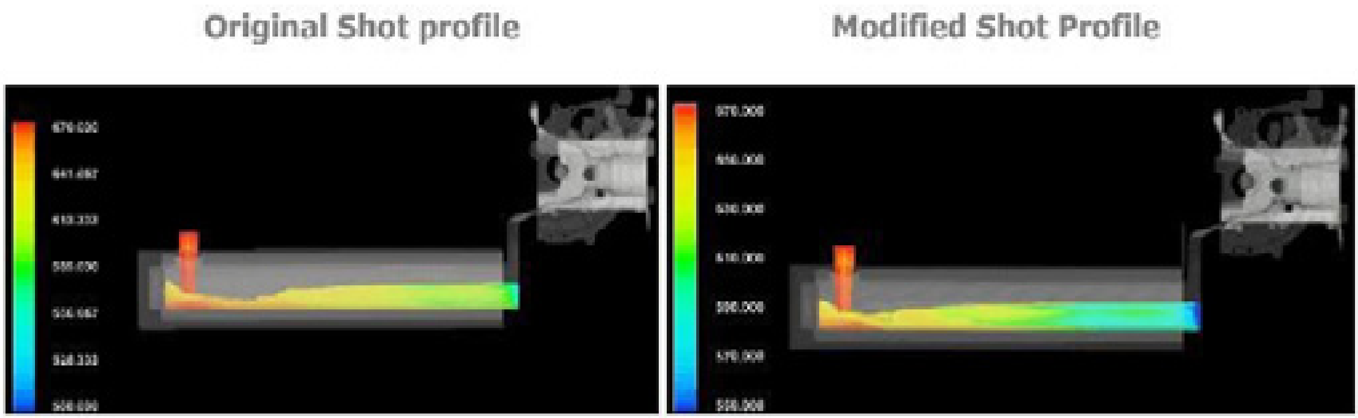



*Fig 2a: Shot sleeve filling with liquid metal*

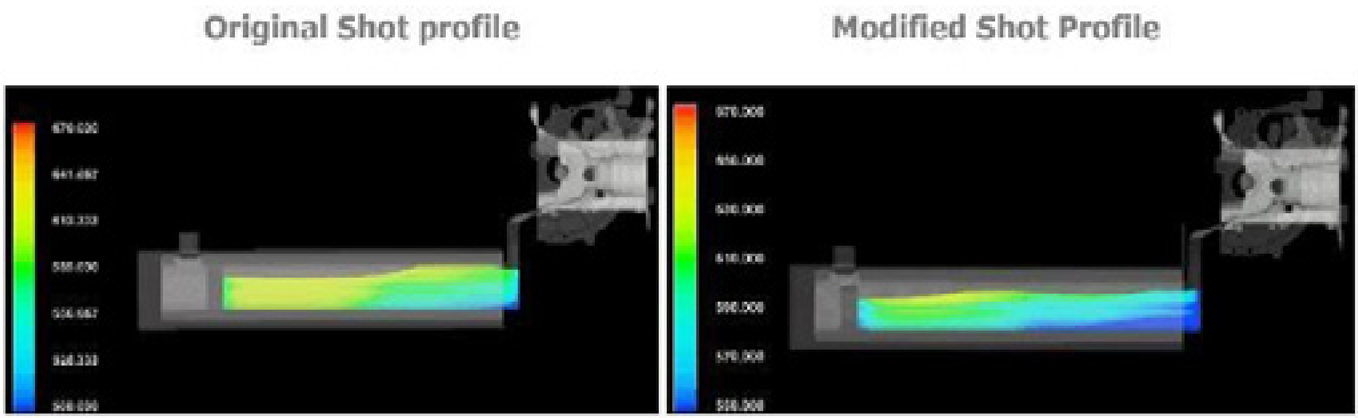



*Fig 2b: Start of First Phase velocity and metal wave motion*

Importance of shot sleeve simulation is more often ignored. Simulation allows testing of novel component designs and process modelling techniques, along with re-engineering designs in the early stages of development. By the traditional approach this would be undesirable due to the high cost associated with trial and error on the production floor. In order for computer-aided modelling to be implemented successfully into the design stage, it should perform a wide variety of tasks. An example shown in Figs 2a to 2d (Courtesy Buhler) shows the optimisation of the shot sleeve plunger velocity using FLOW-3D CAST's accurate free surface capabilities to push the air out of the cavity first before filling it instead of the standard shot profile used by the customer that was resulting in gas porosities.

In each of the four images, the left image shows the original shot profile for the plunger movement speed, while the right image shows the modified plunger movement. As seen, there is a large void or pocket of air entrapped in the original shot profile, in comparison to the modified shot, where the air in the shot sleeve is pushed out ahead of the liquid metal. This ensures the casting is well packed with the liquid metal instead of air porosities, giving a good, sound casting.

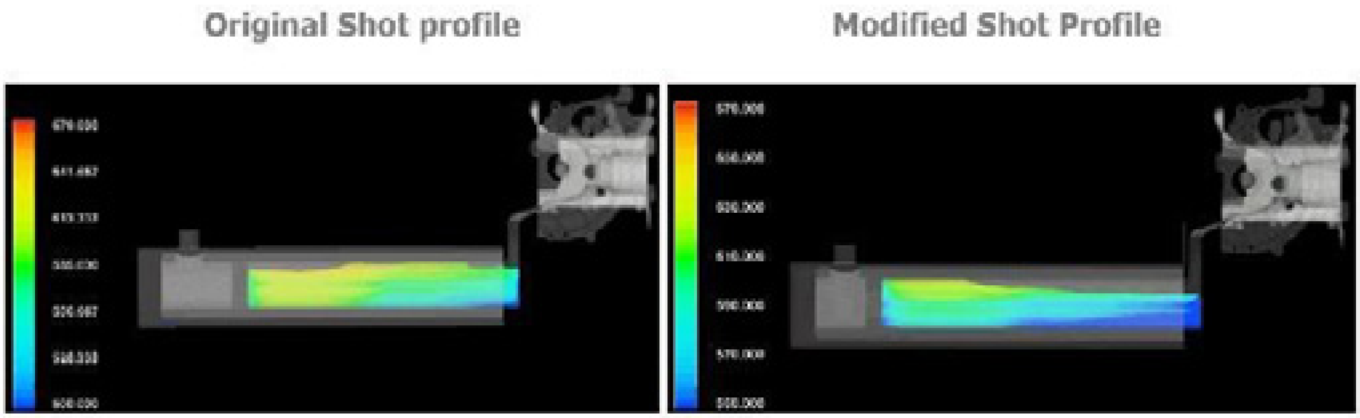



*Fig 2c: Comparing movement of air in shot sleeve; original model traps air between plunger and metal while modified shot profile pushes air ahead of the liquid metal*

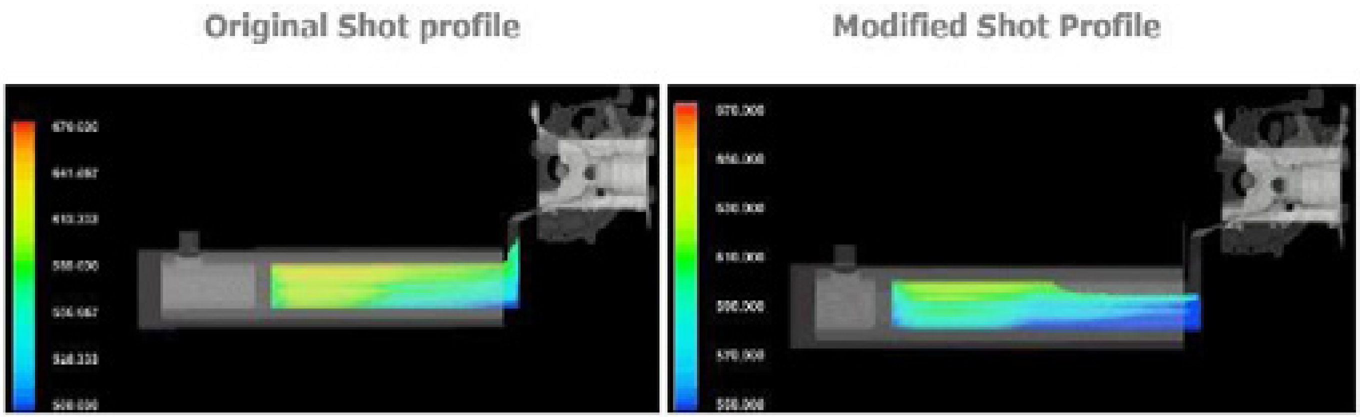



*Fig 2d: Original shot profile: Air entrained in metal, casting rejected; Modified shot profile: air is pushed out by metal front, good casting*

*Courtesy: Buhler*

**2. IMPROVING PRODUCT QUALITY THROUGH GATING DESIGN**

Most often we prefer to go with the tried and tested methods when designing a gating system for a HPDC casting. But there may be instances when we would like to try a new and unconventional method which may be a potential game changer with many unknown benefits. Obviously, it is highly unlikely anyone would venture manufacturing in an unconventional method without a sound working proof. The only logical way to assess is by means of a virtual tool to verify the correctness and feasibility of any new design.

Figures 3a and 3b, show two types of gating systems. Compared to the regular fan-gate type of system, a centre gating model throws a lot of challenges while also offering a lot advantages. The biggest disadvantage could lie in the removal of the runner and gate system itself, but several advantage overshadow this, such as (i) saving in metal and mould material due to shorter runner, (ii) a more uniform filling of the cavity and therefore consistent metal temperature after filling, (iii) a more solid mould structure and a good, effective venting system.

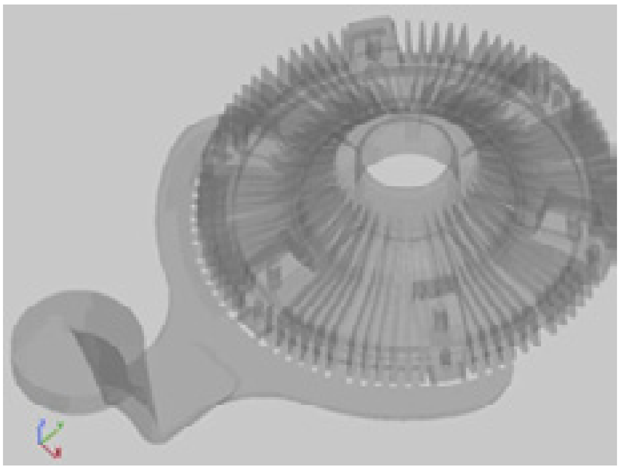


*Fig 3a: A traditional design*

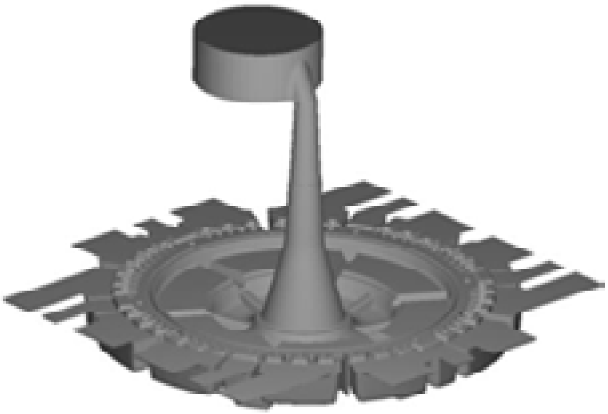


*Fig 3b: New design: Centre gating*

Figures 3c and 3d compare the air bubble particles in the cavity as the metal fills in and shows the distribution of these mass particles at the end of the fill. As clearly seen, the particles are distributed entirely in the casting part and fins in the traditional design, while in the new design, a majority of the mass particles are pushed into the overflows, thereby reducing the pinhole defects seen in the casting.

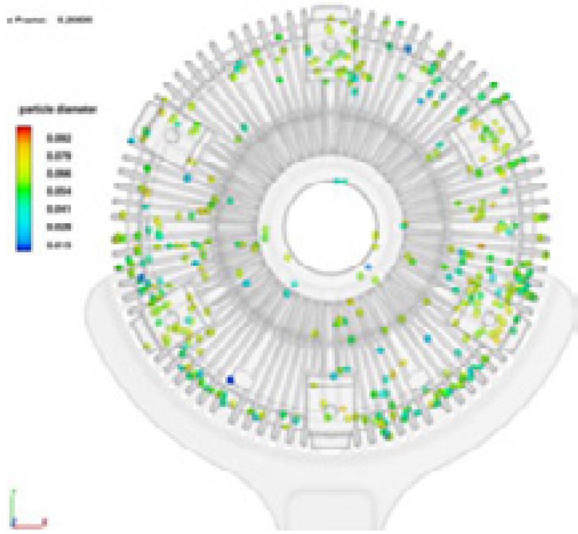


*Fig 3c: Traditional: Air particle distribution throughout the casting in fins*

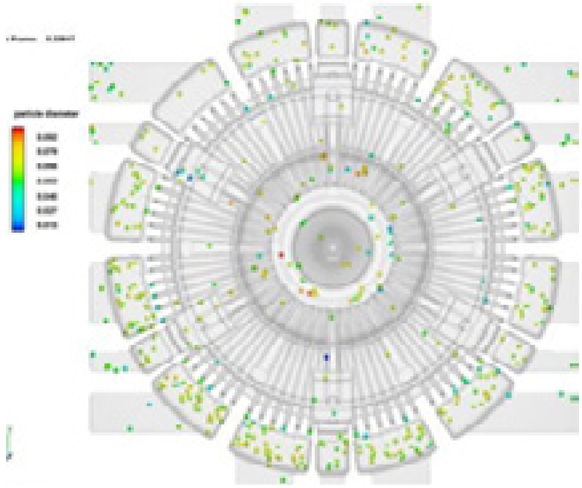


*Fig 3d: New: Air particle distribution mostly majority in the overflows and not fins*

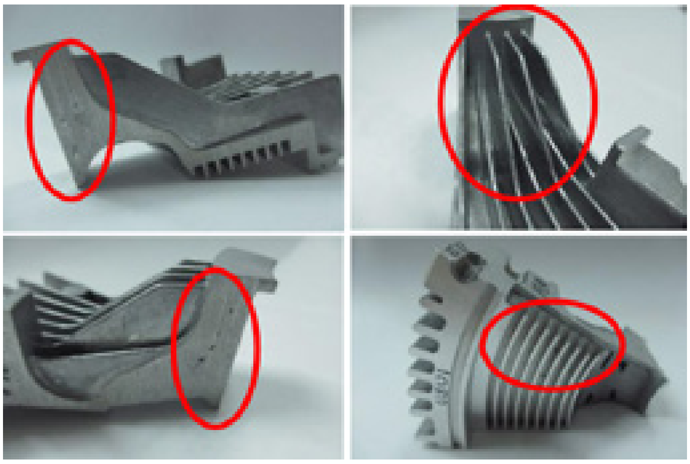


*Fig 3e: Traditional design showing the pinhole and air porosity defects in the casting*

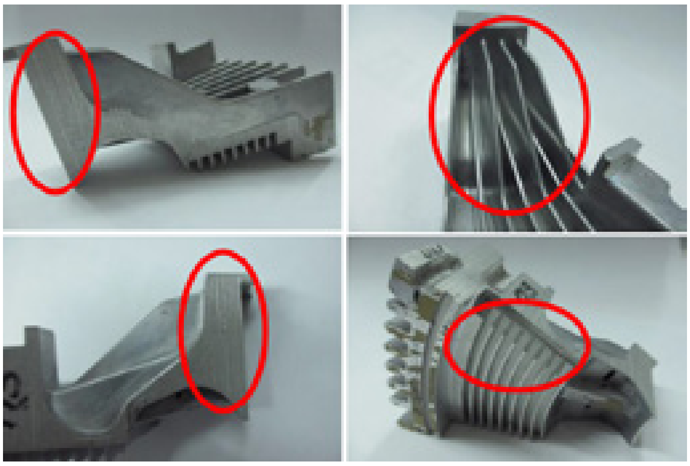


*Fig 3f: New design showing reduction or elimination of pinhole and air porosities for a defect-free casting*

*Courtesy: Jonshin Mould Industrial Studio*

As predicted in the simulation, the original design of casting with fan gate shows the pinhole and air porosity defects in different locations, Fig 3e. With the new gating design, pin hole and air porosities are eliminated, Fig 3f, which matches well with the simulation. This provides good validation and confidence to the design engineers and manufactures to try and test new designs.

### 3. BALANCING AND OPTIMISATION OF RUNNER SYSTEM

Many a times, it is required to design the die with multiple cavities. In such cases, it is essential to accurately orient the cavity and the runner so as to accommodate the part on the desired size of machine. An incorrect runner design or orientation of the cast part can lead to many issues and losses including time and money. Here is another such case where FLOW-3D CAST has helped to overcome the problems by saving time and money, and also convince the customer by justifying the results.

The design challenges posed were:

1. Need of a 4 cavity die

2. One moving slide per cavity

3. Flow to be balanced

4. And an optimized layout

The initial version of the design, Fig 4a showed satisfactory results in simulation, but the tool layout was large for the die casting machine selected. Also, the moving slides for each cavity was on the top side of machine making it difficult to accommodate.

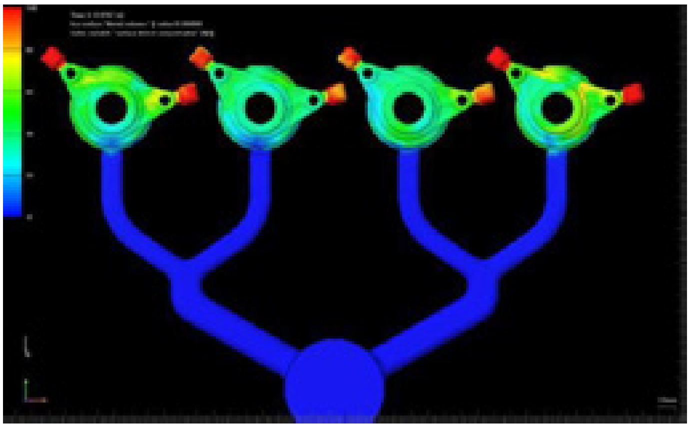


*Fig 4a: Version 1: Original layout simulation result*

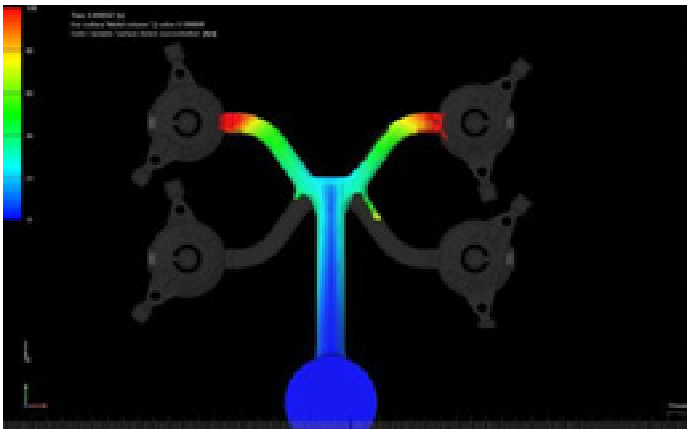


*Fig 4b: Version 2 layout, unbalanced runner*

The second version, Fig 4b, placed two cavities on each side, left and right, and so were the moving slides oriented two on each side. This enabled the tool layout to be accommodated in the specific DC machine. However, when the flow simulation was observed, it was found that the metal in the runner at the gate entry were unbalanced. After many more revisions and modifications of the runner system, an optimum layout was obtained in version 10, Fig 4c, which fulfilled the needs of the customer and the design criteria. Most importantly, the cast was made FIRST TIME RIGHT (Fig 4d).

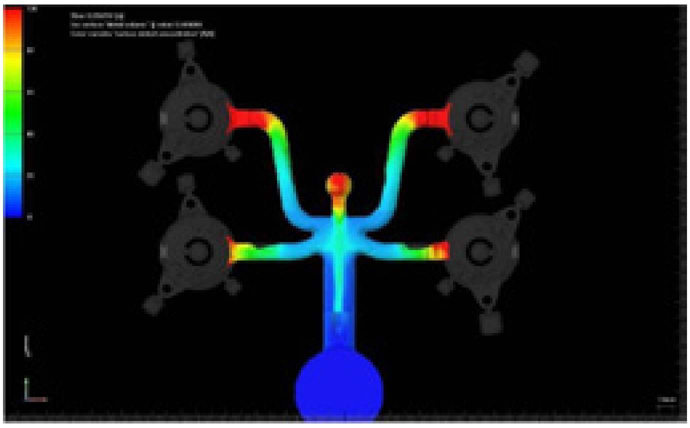


*Fig 4c: Final design, V10 showing balanced runners*

*Fig 4d: Casting shot model obtained First-Time Right*

*Courtesy: CRP India Pvt Ltd., Chennai*

**4. UNDERSTANDING BENEFITS OF USING THE RIGHT PLUNGER TIP MATERIAL**

Many a times, there are parameters which are overlooked for improving productivity in HPDC, in addition to quality and overall cycle time. Plunger tip choice is vital in this analysis as we shall see here. Commonly used plunger tip material are Cast Iron and Steel. Another plunger tip material widely used is of Beryllium Copper (Be. Cu.) alloy. Beryllium Copper alloys are also widely used for other purposes in HPDC such as chill vents.

The factors influencing use of Be. Cu. alloy are:

▪ **Excellent thermal dissipation property:**

Beryllium Copper has a high thermal conductivity capacity, about 4 to 5 times that of steel. This allows the Be. Cu. plunger tips to run with a tighter clearance than steel plunger tips. Since the plunger tips dissipates heat quickly, thermal expansion is reduced greatly while at the same time solidifying the biscuit quickly. This allows for a reduced cycle time thus increasing the number of shots per hour.

▪ **Increased sleeve life:**

In an H-13 steel sleeve, copper-on-steel versus steel-on-steel, dissimilar metals abrasion is lesser, leading to longer sleeve life. Though Be. Cu. plunger tips can be made to tool steel hardness, the copper based material sliding back and forth inside the shot sleeve, causes less wear and damage to the shot sleeve. It is well known the sleeves are very expensive. Lower thermal expansion of Be. Cu alloy also prevents abrasion on the sleeve.

▪ Another important point to be mentioned is the time lost due to tip change after wear out. Every time, the machine is stopped and started again, there would be need for additional time spent to get the die temperature to regular production temperatures resulting in loss of production time. Due to a longer tip life of the Be. Cu. alloy, the number of times a machine has to be stopped for tip change can be drastically reduced, thereby allowing for continuous production and more number of shots.

We shall look at just one of the aspects, the thermal dissipation property to see how one can gain through reduced cycle time and more number of shots in a shift. This study has been undertaken at Kaushiks International with inputs given by customers.

The images in Figures 5a, b, c d, e and f depict the shot sleeve filling and metal injection using the three solid plunger tip materials, namely Cast Iron, Steel and Beryllium Copper alloy, and their temperature profiles in various stages.

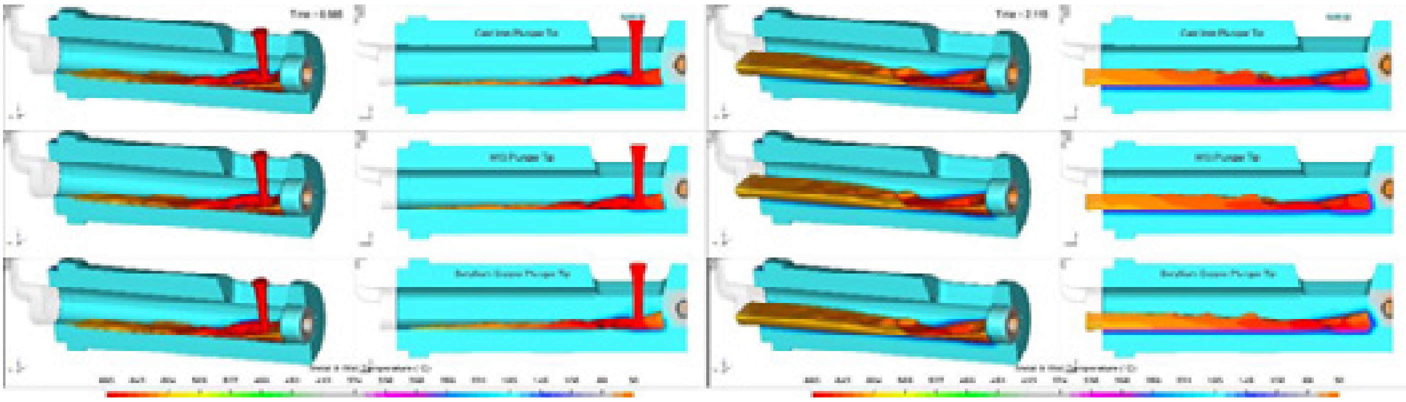


*Fig 5 a & b: Metal pouring in shot sleeve*

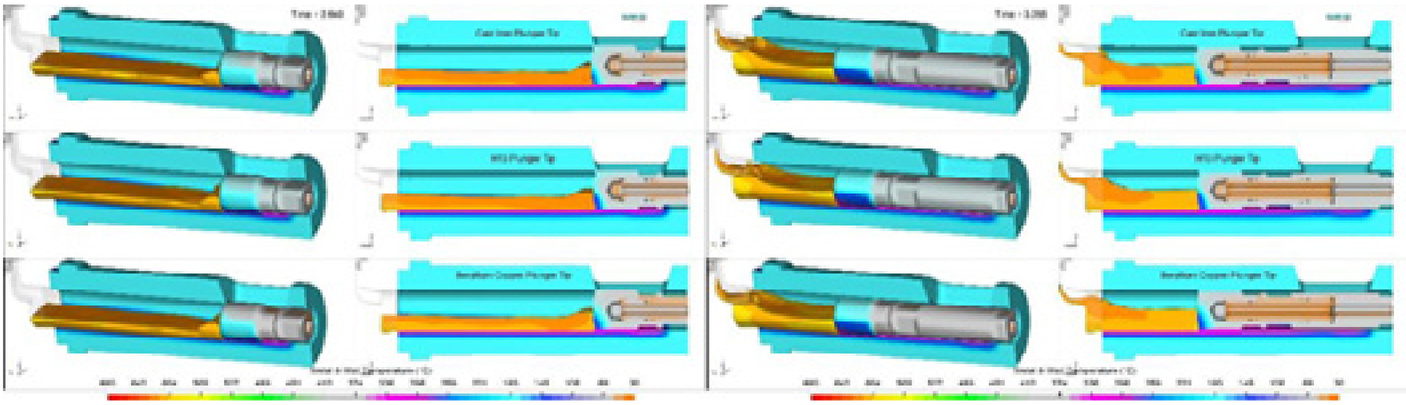


*Fig 5 c & d: Plunger movement, slow shot/first phase velocity*

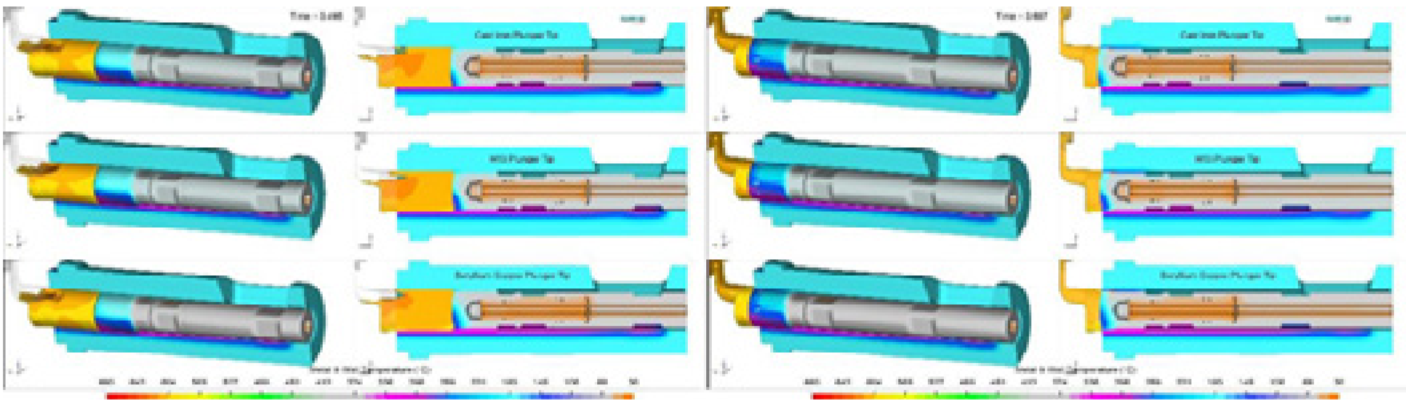


*Fig 5 e & f: Plunger movement, slow shot/first phase to fast shot velocity and end of fill*

As we can see, the temperature of the tips gradually increase from the time of its contact with liquid aluminium metal. However, it is very clearly visible that the temperature absorption and distribution in the three plunger tip material is very different. At the end of fill, which is less than 4 seconds from the start, we can clearly see the temperature distribution in the Be. Cu. tip is higher and more uniformly distributed on its front surface which is in contact with the hot metal, compared to either Cast Iron or H13 steel tip.

After filling of cavity with liquid metal, the intensification stage tries to squeeze the molten aluminium further to pack the casting well. During this solidification stage, the biscuit is the last to solidify. As seen in figures 5g, h and i, the heat extracted from the metal (biscuit) in contact with the plunger tip surface is extracted highest and fastest in the Be. Cu. alloy, compared to Cast Iron and

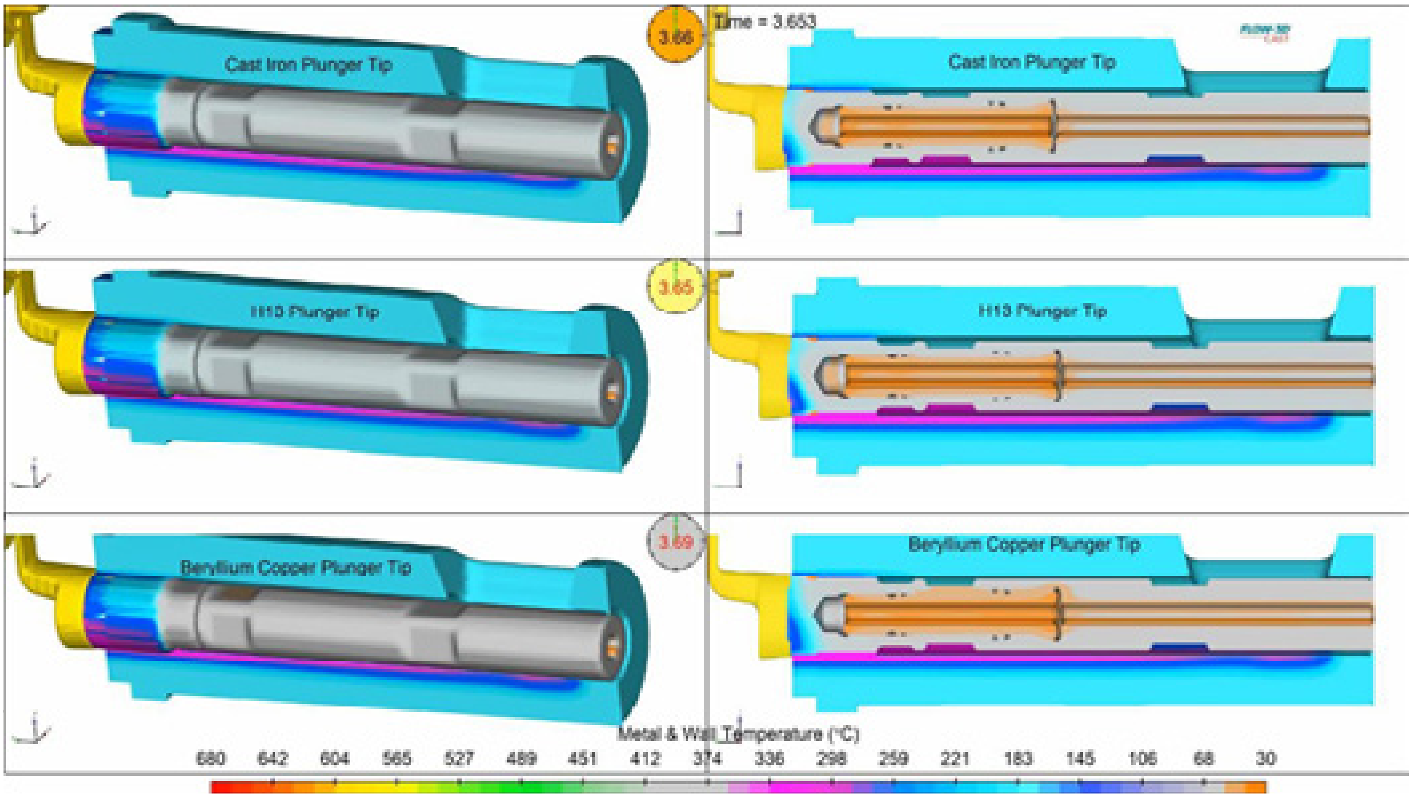



*Fig 5g: End of Fill and start of solidification*

It is evident that with the Be. Cu. tip, the final solidification is improved by at least 2.64s compared to Cast Iron tip and by 1.69s compared to H13 steel tip, in each cycle. Over a period hours, shifts, and weeks, there would be a significant gain in the number of shots produced.

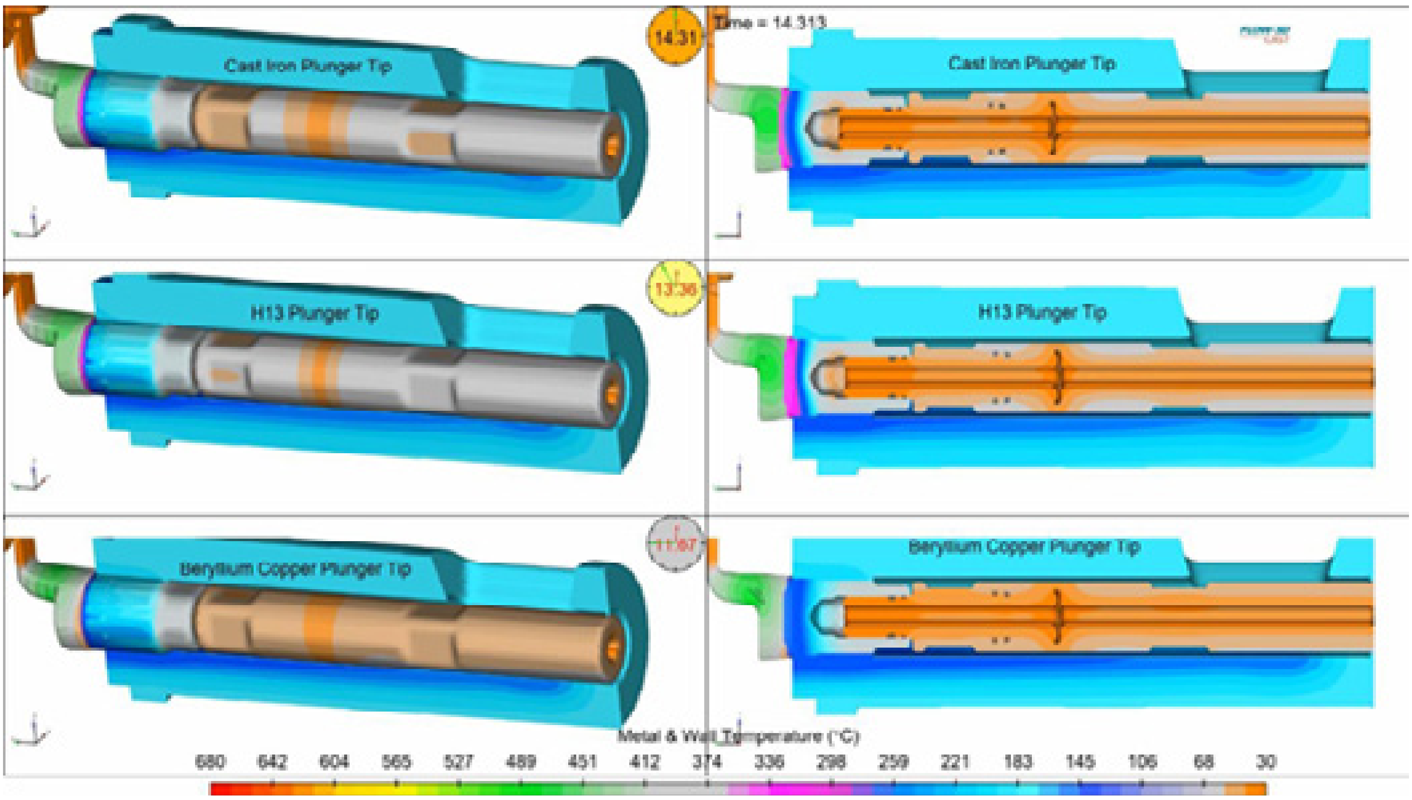



*Fig 5h: End of solidification, a complete thermal profile seen in the tips and more importantly the time for solidification in Be. Cu tip is faster by 2.64s for Cast Iron and by 1.69s for H13 steel*

In Fig 5i, we can observe two graphs, one is the average tip temperature and the other is maximum temperature reached in the tip. The first graphs indicates how quickly the average temperature of the tip rises during the intensification and solidification stage, while the second graph depicts the maximum temperature achieved in the plunger tip during the same stage.

We can understand that heat in the Be. Cu. plunger tip is being uniformly distributed in the Be. Cu. tip rather having a high temperature at the surface of its contact with the metal compared to the other two material. This allows heat extraction from the hot the hot metal at the biscuit thereby cooling it faster and also reduces thermal expansions. In turn, this increases tip life and also protects the sleeve from abrasions as it retracts for the next shot, thereby increasing the life of the shot sleeve as well. A multi- fold benefit is achievable when good analysis is made using the tools available.

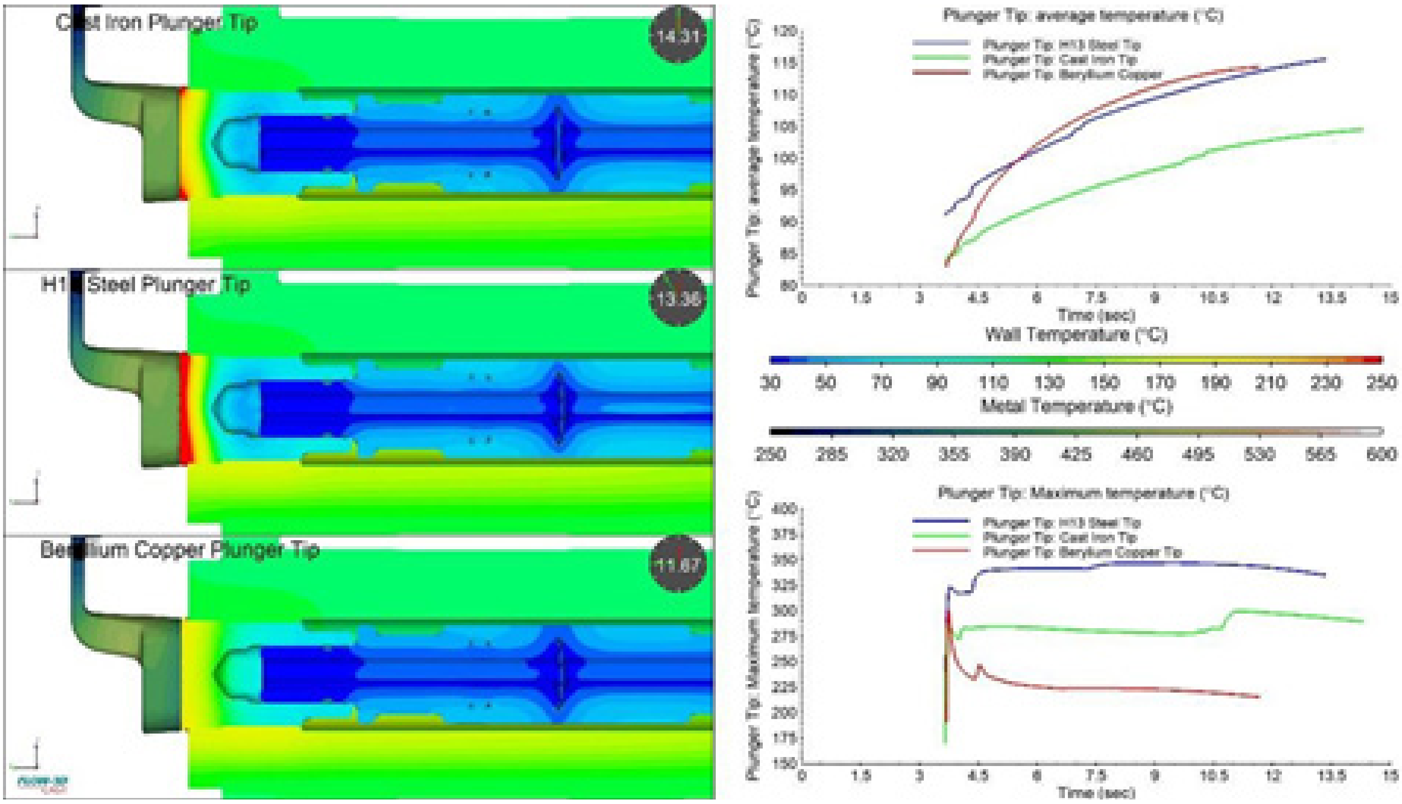



*Fig 5i: End of solidification, a complete thermal profile seen in the tips and more importantly the time for solidification in Be. Cu tip is faster by 2.64s for Cast Iron and by 1.69s for H13 steel*

## 5. PROCESS IMPROVEMENT AND QUALITY IMPROVEMENT

As we know, the cause of defects can be through any source and unless one understands this cause and its mechanism correctly, any effort to overcome the issue will remain unresolved. The type of defect after correct assessment can be reduced or eliminated through modifying the process parameter or change of runner/gate design or a combination of both.

High pressure die casting is known for its turbulent flow patterns and these can cause vortices which can lead to loss of metal temperature and cold shuts resulting in poor surface finish quality and leakages in the casting.

*Fig 6a: Loss in temperature, cold shut, and air entrainment defect in the casting*

After a detailed analysis of the existing design and layout shown in the figure above, it is observed that this design is very likely to produce defects in the casting. The gate velocities observed were high, 50 m/s or more, the position of entrained air is determined, and also locations of metal temperature loss and cold shut formation can be observed.

Now that it is clear (Fig 6a) as to why the vortex or circulation zones of the metal being formed, we can now alter the design or orientation of the casting part eliminate this vortex formation. So the idea is to fill metal from the larger end to the smaller end to ensure the filling speed of aluminium metal. After reorienting the model and upon further analysis it was observed that though the large temperature drop due to vorticity and porosities were eliminated, there was still some considerable temperature drop in the sides as seen in Fig. 6b, which was validated in the casting.

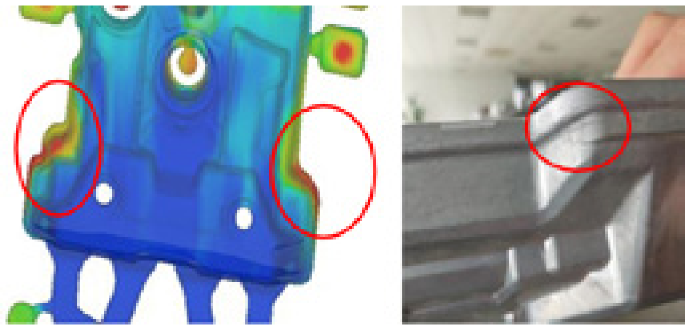


*Fig 6b: Optimised model 1: Improved casting, yet some loss in temperature seen in the casting*

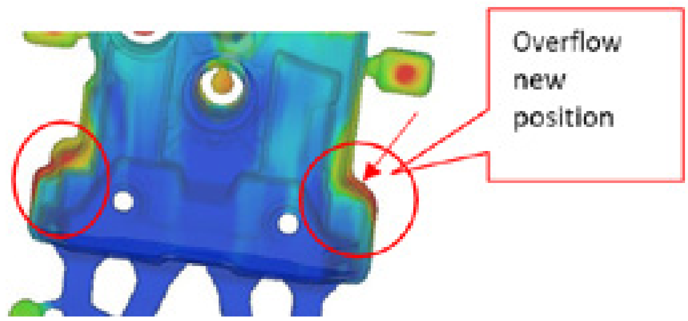
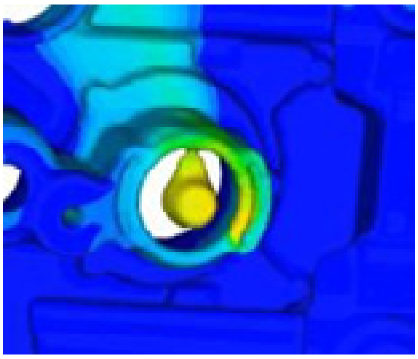



*Fig 6c: Optimised model 2: Change in location of the overflow pads to account for the loss in temperature and push the colder metal into these overflows*

*Courtesy: Asimco Technologies*

With more information available from the analysis which yielded a marked improvement from the first design, a further modification was made in the design by relocating the overflow positions as depicted in Fig 6c.

With this optimised model 2, the previously obtained defects have been overcome and also a significant improvement in the quality of casting is observed. A reduction in gate velocity from 50m/s to 35 m/s ensures the die erosion is minimised giving a longer die life; a more uniform temperature filling in the die cavity; and most importantly no trapped air is found in the casting ensuring a leak- tight high quality casting Fig 6d.



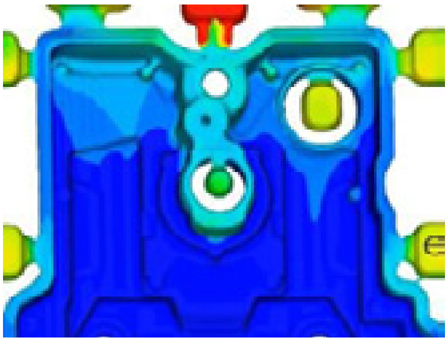
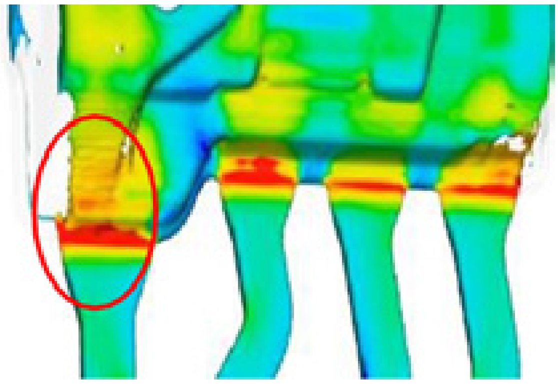
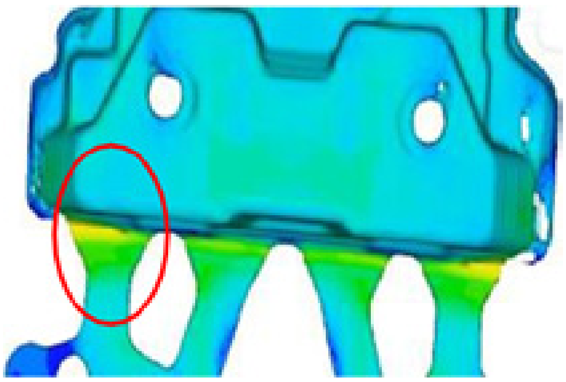


*Fig 6d above and 6e below: Comparison of Original model with final model to produce defect-free casting*





Through simulation, it is evident that one can use this tool well to understand the cause and mechanism of the defect formation in the casting parts and try different design solutions to achieve a quick turnaround to improve quality of the casting and also yield.

**6. ECONOMIC BENEFITS THROUGH CASTING DESIGN OPTIMISATION**

A major cause of defects include leakage and non-fill in the castings leading to reduction in the yield and higher operational costs. Again, to overcome these issues, a good knowledge of design and process parameters is essential. In any given market situation, economic factors play a vital role in sustaining the company and its future. Here we will look into the benefits obtained by the optimization of a runner system using FLOW-3D CAST to modify the flow direction to offer a less turbulent fill, thereby reducing the oxides and air entrained in the casting.

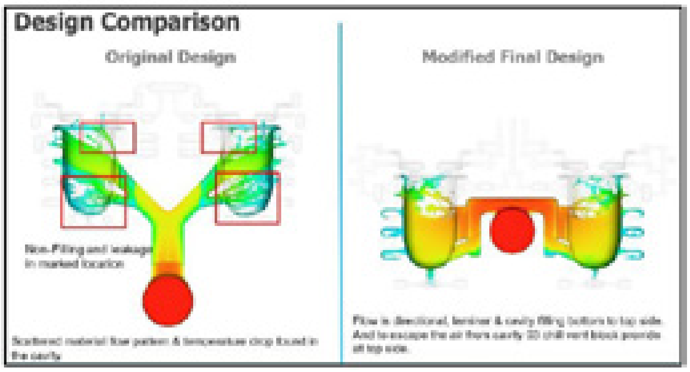
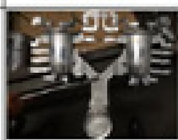
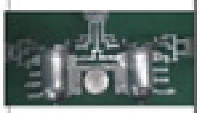



*Fig 7a: Casting design before and after*

| | Before | After | |
|---|---|---|---|
| Shot Image |  |  | Benefit |
| Shot Weight | 2130 gram | 1732 gram | 398g /shot |
| Yield % | 33% | 41% | 8% |
| Leakage & N/F | 6% | 2% | 4% |

**Yield Improvement**
Weight reduced per shot: 398gram
Shot produced per month: 30,000 shots
Melting reduced in a year: 11.94x12=143Ton
**Rejection Reduction**
Leakage & Non-filling reduced from 6% to 2%
Rejection reduced in a Year : 28,800 Parts

*Fig 7b: Economic benefits calculated*

Courtesy: ASK Automotive Pvt Ltd., Manesar

With FLOW-3D CAST, it was possible to optimize the design. We can see straight away the benefits achieved in terms of the material saved of about 398g per shot, yield improvement by 8%, reduction in the rejections by

4% and above all, a Happy customer for timely delivery and Happy company for increasing the profit margins.

### 7. ECONOMIC BENEFIT OR COST OPTIMISATION THROUGH DIE DESIGN

There are several instances where an existing design or process can be modified and improved. But to check the viability of that proposed change and to implement it with confidence would require skilled craftsmanship and the assurance of experienced casters. With the availability of casting simulation software, this work can be made a lot easier and simpler like this in present case.


*Fig 8a: Original die design*


*Fig 8b: New die design*

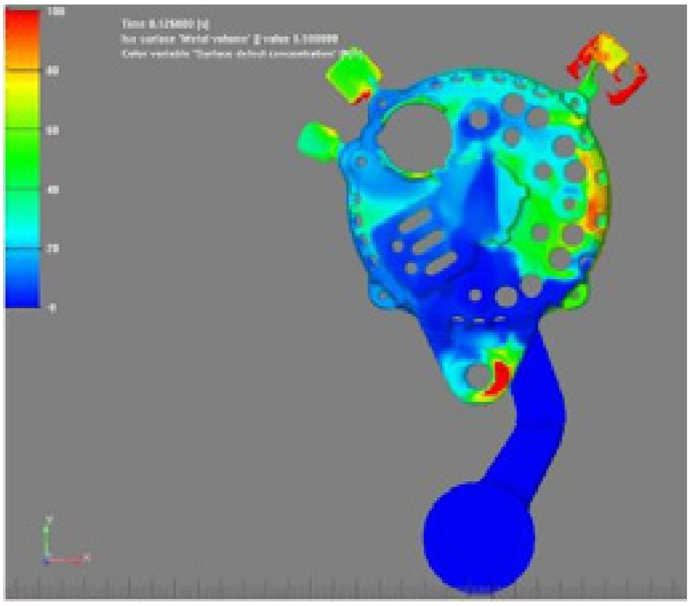


*Fig 8c: Validation of new design*

While the original design did not pose any problems, since the die life was nearing, a new design was suggested to optimize the manufacturing cost. A satisfactory design backed by FLOW-3D CAST yielded the benefits in material savings of 26% and reduction in the machine size used thereby adding to the savings in terms of energy consumed by the machine during production, as shown in Table 1.

| | Casting Projected Area (cm$^2$) | Shot weight (Grams) | HPDC Machine tonnage |
|---|---|---|---|
| Existing Design | 240 | 767 | 250T |
| New Design | 130 | 570 | 150T |
| SAVINGS | 46% | 26% | |

*Table 1: Cost Optimisation*

*Courtesy: CRP India Pvt Ltd., Chennai*

### SUMMARY AND CONCLUSION

There is a gradual shift in the manufacturing sector from the trial-and-error system of casting production and process to adopting a more scientific approach which is more reliable. As seen in just a handful of examples, a multitude of benefits, both tangible and intangible, are achieved by use of high-fidelity casting simulation software such as FLOW-3D CAST. It offers a robust and an efficient methodology for casting prototyping and production processes, even before metal is first poured. Casting simulation is a powerful tool for predicting and understanding the cause defects in casting, and also for overcoming the problems.

**A few benefits that foundries can achieve including casting simulation in their regular operations are:**

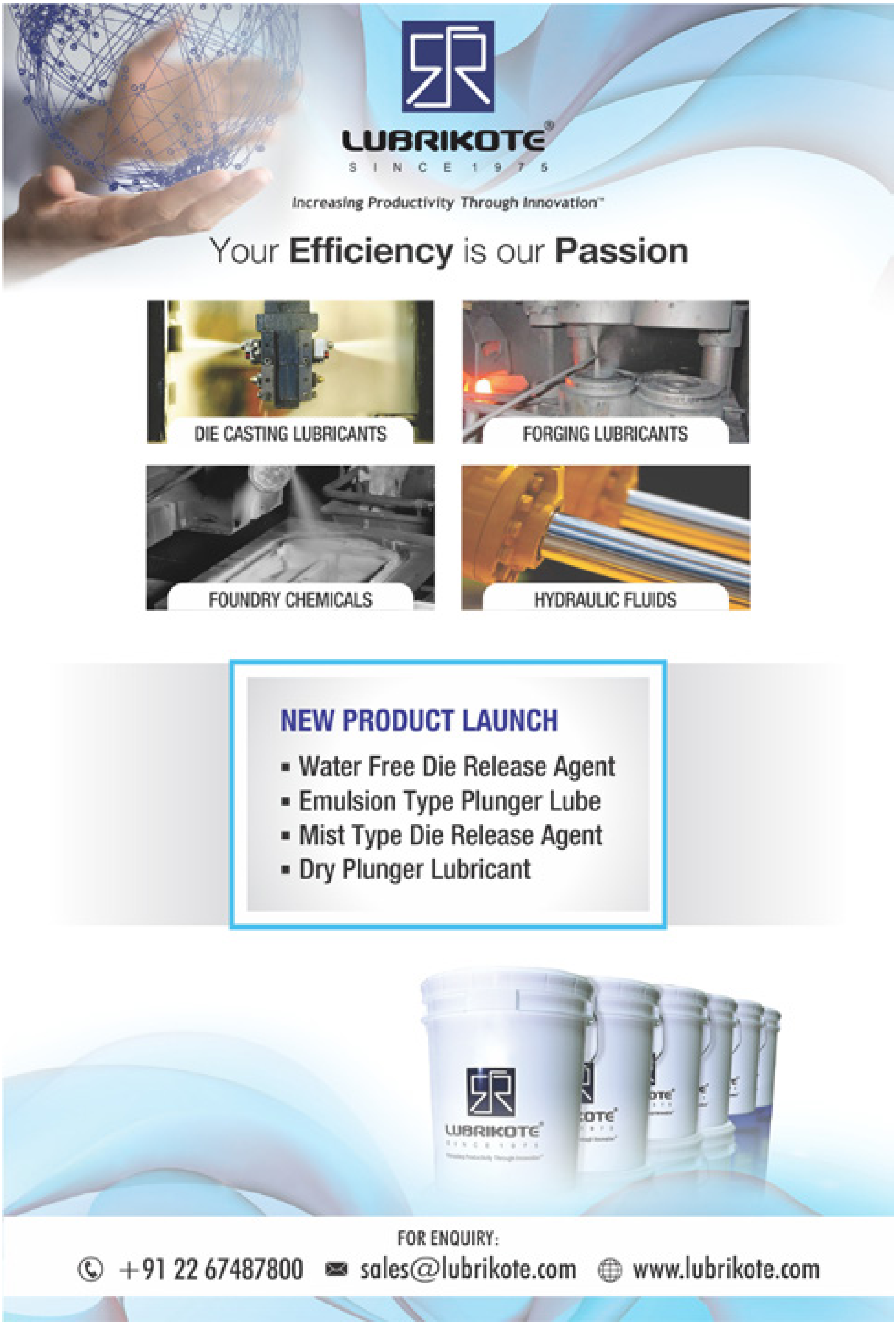
- Reduced Sample Castings, Production Runs & thereby reduced lead time
- Analysis of Design Alternatives
- Design Optimization
- Reduce cycle time
- Increased productivity
- Reduced Cost Overruns
- Eliminate Rework
- Scrap Reduction
- Overall Cost-Savings
- Production of the Highest Quality Castings

Use of casting simulation software is highly recommended to be adopted in the casting industry. The collaborative efforts of product engineers, design engineers, manufacturing process engineers and the casting engineers, with the aid of a casting simulation software that provide scientific data, ensures there is no compromise in the quality of the casting while delivering it on time and of the highest quality in a shortest time.

## About Author

Mr. Kaushik has completed Masters in Aerospace Engineering from University of Southern California, Los Angeles. He has worked extensively on FLOW-3D® CFD simulation software, a state-of-the-art software for several engineering applications including Metal casting processes, water hydraulics, aerospace, microfluidics, Additive Manufacturing and Welding etc. Has participated in various National and International conferences and seminars, and made numerous technical presentations at various forums.

He has performed numerous simulations in various casting processes as well as other CFD applications such as Water Hydraulics, Automotive, Coating, Aerospace, etc. Has provided extensive training to engineers and academicians on use of FLOW-3D simulation software. He has published technical paper in an International journal on shock waves for Treatment of kidney stones using CFD Software, as well as in other forums.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# "Digital is the (New) Normal – 10 Misconceptions When it comes to Digitalisation of Metal Casting Operations"

- Christian Kleeberg, Managing Partner, RGU Asia Pte Ltd

## Abstract

"Foundry 4.0" in digital transformation and the 10 most common misconceptions that lead to the failure of digitalization projects especially in foundry.

- Digitalisation and digital transformation lead to fundamental changes in the business world.

- It has an impact not only on technology, but on the entire organisation. This counts especially for metal casting operations!!

- The Covid-19 pandemic is putting external pressure on these operations as many aren't prepared to work with 50% (or less) of their workforce from home.

- Christian Kleeberg, Managing Partner @ RGU Asia Pte Ltd, the leading provider of digitalisation and digital transformation solutions in the metal casting industry, explains the challenges associated with digitalization and digital transformation as well as the thought patterns that can cause a project to fail, especially in these dire times.

- There are many reasons why digital transformation fails!

- IT IS a hot topic, but nobody seems to know exactly how to tackle it. Simply putting a team on the job – without a budget and without a clear goal – is by no means digitalisation and / or digital transformation.

- Many hope to remain competitive by making small changes to their processes. Usually, however, the approach is just too narrow. Contrary to popular misconception, digitalization or digital transformation is NOT an IT project – it is an organisational transformation in which structures have to be changed in order to achieve strategic goals. Some companies are mastering it with bravura and some fail miserably and fall into the trap of continued business decline.

- This is all too often underestimated and the cultural aspects of structural change are not sufficiently considered.

- Understanding the challenges means understanding the way how to succeed. Understanding what doesn't work and what is also outright wrong in digitalisation and digital transformation of metal casting operations will lead to immediate improvements and ultimate success even under most difficult business climates prevailing.

### Misconception no. 1: It is sufficient for the management team to initiate the process

Digitalization or digital transformation is a feat of strength and requires profound change. Therefore, the management team must also be prepared to fundamentally change their attitude.

When a project affects several areas of the organisation, directly impacting staff and practices, the role of the Management Board is not just to initiate the process, approve budgets and sign a contract. In practice, however, this is often how leaders see their own role.

For the full duration of the project, the management team must be a point of contact for staff, trust those responsible for the project and equip them with the necessary decision-making authority to ensure that the project runs smoothly. Only then will the change be successful throughout the entire organisation.

### Misconception no. 2: Everyone loves modern solutions

During a change process, employees can become demotivated if they lose faith or fail to understand the ultimate goal. For many the first reaction is to resist change. Some employees fear for their jobs. Others are afraid of losing influence because they no longer have a monopoly on information, and for others it is the fear that their work will now be more closely controlled. For everyone involved such projects mean more work. The data transparency involved will result in a higher employee transparency. Certain business are used to that, others are not and in metal casting many even say the foundry is "a black hole", where somethings comes out after putting something in but nobody really knows why and how this happens and how much it precisely cost.

Corporate management must recognise these fears and from the word go provide targeted information: Why the new system is necessary? Why working methods need to be changed? How the individual staff members can benefit from it? Only then can a common vision, acceptance and understanding emerge. Communication is therefore an essential component on the way to a successful digitalization and digital transformation project.

### Misconception no. 3: Digitalization – the IT guys can take care if it

The topic of digitalization is often placed in the hands of the "IT guys". But as said before, digitalization is not an IT project. When choosing a suitable project manager, it is not only IT skills that are required. On the contrary, soft skills such as communication, empathy and credibility are more important than technical skills, when it comes to extensive digitalization and the selection of the right change agents.

In contrast to the project manager, the key users should have the necessary specialist and cross-departmental knowledge. Because they are the ones who formulate the requirements for a digitalized and more efficient infrastructure and are ultimately best equipped to evaluate the results.

▪ As for us – being the experts in this digital transformation – we start ALWAYS at the core and that is production planning and controlling using a dedicated digital twin approach (resource plan solution) that allows to describe the process in its entirety. Once that core area is covered and mastered almost all other departments fall in place – one by one and one after the other.

### Misconception no. 4: THINK BIG – let's optimise everything in one shot!

An efficient and productive workflow only emerges when cross-departmental processes are well coordinated. That is why a digitalization and digital transformation strategy should be implemented across the board.

However, this does not mean that you have to digitalize everything all at once and cannot initially concentrate on specific areas. On the contrary, it makes more sense to focus on key processes than to simply start in all departments.

In order to minimise risks, manageable and achievable goals should be set from the beginning and by the management. The key is to take small steps, rather than a "one hat fits all approach"! The MoSCoW method (Must, Should, Could, Won't), where requirements are prioritised according to their importance and impact, is a proven tool for this.

### Misconception no. 5: Trial and error is the way to go!

Digitalization and digital transformation in metal casting operations is not an end in itself but means far-reaching investments that generate concrete added value – whether through higher sales and profits or through new customers.

The failure of the transformation, and the resulting impact on employees as well as customers and partners, must not be an option. In practice, there are countless examples of digitalization projects that were pursued over many years and in the end had to be scrapped. Certainly, a setback that not many companies could survive unscathed.

### Misconception no. 6: The shop-floor does not need it!

In metal casting operations transparency is the key to success. Digital solutions and digital transformation concepts contribute for this. Now, in order to achieve any type of transparency you must collect data. This data must come – among others – from the predominant source where the data is created and that is the shop-floor.

Many metal casting operations however neglect the shop-floor data source thinking they do not need it in terms of feedback and in return cutting off vital information for operational excellence.

The shop-floor is the "treasure box" of metal casting operations data and the more precise this data is collected and used in integrated systems the more benefits will result from it. The motto should always be: In digitalisation projects involve your data source from day one, the operation and company results will be positively affected.

### Misconception no. 7: BIG DATA is only for big companies

When it comes to the concept of harvesting a company's biggest asset – its manufacturing data - and especially SME's or even M-SME's when they are moving into this direction a very important misconception has been seen in the past. The perception is that big data involves big companies.

The reality however is quite different, and the actual contrary is the true reality. Any metal casting operation of any size – be it the 20 man "mom & pop" hand moulding show or be it the 3500 employee / 1500T a day automotive mass-producing casting operation – both produce "big data". May be the latter one slightly more than the other but in quality and quantity of what you need to harvest the same there is no difference.

Digitalisation in metal casting operations means always big data and this big data represents big money too. So, a management team should define here the type of data they require in what format and whether it's in real time or not, then you will see very quickly what it means when "big data" is involved

### Misconception no. 8: We have ERP means we are digital

That's a classic one! It requires almost no further comments. Still many metal casting operations haven't understood that having an ERP system means you merely administrate your data flow, many times only in finance. So, what about operations, planning, controlling, WIP-reporting, rolling shop-floor inventory, consumables, etc. the list endless. If MS-Excel prevails in any of these – and in many companies that's the case unfortunately – then you are NOT digital at all.

The digitalisation / digital transformation team must point out the areas where MS-Excel prevails and where it is destined to be eliminated via integrated system, real-time or on-time date collections and steady visualisation using dashboards and other means.

### Misconception no. 9: Foundry is dirty – dangerous and difficult, let's outsource

Image of the industry! Legacy issues galore! Lack of adequate work-place design!

Do we need to say more? Foundry is indeed 3D = "dirty-dangerous-difficult" but foundry can also be D3 = "digital – dynamic – different".

Remember, we can't change the process as such as metal has to be molten into a liquid and poured under various process conditions into a mould of any kind. The shaping process itself is maybe sometimes "3D" but the planning – controlling and data collection / visualisation process can be very much "D3".
Here digitalisation must be monitored especially in order to lift up the image of the industry. And digital transformation means automatically productivity and image improvements. Some companies will then rather outsource than doing it yourself, as such that's an opportunity with those who are committed to the process and to the full understanding of benefits this process brings along.

### Finally, misconception no. 10: Digitalisation and digital transformation is not for me

Another Classic One! How many times have we heard this? Probably way too often. Despite "Industry 4.0" movements and many other initiatives the metal casting industry has yet to discover the great potential digitalisation and digital transformation entails.

**It's all about your mind-set, your digital mind-set.**

Once that is available the rest comes by itself. And by the way it is NOT, repeat NOT expensive to digitalise and it also not merely an IT project as stated earlier too. You start small and continue over time. Companies in Europe in the early / mid – 90's started on that journey and are today where many want to be, but they are ahead, no doubt about that.

Here we want to present here a small story from OHM & HAEHNER in Germany. A classical German SME with around 600 employees. The aluminium sand-casting foundry is the company's backbone, however operated at a level where in one plant roughly 800 metric tons / month are produced (from 20 gram to 2 ton single piece) however only involving around 35 staff in this plant. A very high grade of automation combined with digitalisation solutions from core making monitoring all the way to melting control, automatic pouring, automatic shake-out, fettling using minimal manual action and raw cast shipment are deployed. Information is available in real time and although 60% of castings are still of a "jobbing" nature and 40% are automotive, the delivery reliability stands at 99% throughout with strong tracking and tracing in place on 24/7 level. Productivity is in comparison even to other German / European foundries at its peak, with proven track record over many years.

**SEE: Ohm and Haehner customer solution FRP**

## SUMMARY

PLEASE REMEMBER!

- Digitalization and digital transformation is going far beyond the use of modern technologies in companies. It is a process that fundamentally changes structures and people's familiar working practices.

- In order for a FOUNDRY to start digital transformation and to be successful within an organisation and for resistance to be effectively overcome, it is important to implement professional change management.

- This starts with the right selection of project managers, but also implies a change in the attitude of the management board and continuous communication of the necessity and objectives of the transformation.

- If this is successful, the process is not necessarily easier for those involved, but in the end the results will prove to be of benefit to all parties and worth the effort.
- Today, various foundries in India have now started this process and are slowly but steadily moving into the digitalisation and digital transformation journey. They will be the front-runners when it comes to national and international competitiveness.

- Last but not least, many foundries still do not have a concept but there is a solution for them too: SFRI – Smart Foundry Readiness Index, a simple audit to check whether you are ready for digitalisation and digital transformation.

## About Author


Christian Kleeberg – Managing Partner and founder of RGU ASIA PTE LTD (www.rgu-asia.com) in Singapore, an APAC joint venture with the RGU GmbH company in Dortmund / Germany – the leading provider of digital transformation solutions for metal casting foundries in central Europe with more than 320+ installations under its belt.

Christian brings along more than 20 years' experience in digital software applications for metal casting operations and has profound knowledge in digital transformation applications including IoT for foundries.

He holds a dual M.Sc. degree in mechanical- and economics - engineering from the University of Applied Science in Munich / Germany. Christian is married and has 2 teenage children and living in Singapore since 1995.

# Prex India Automation Pvt. Ltd.

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**Die Closed Loop Cooling**

**Trimming Press**

**Die Loop Checking Device**

**Jet Cooling Device**

**Plunger Oil Supply Device**

**Die Lube Mixing & Pumping Unit**

# Design and process-specific optimization of complex 3D temperature control systems in order to increase the effectiveness of a combination with a high-speed casting cell

- W. Sokolowski, R. Aspacher, N. Clauss, G. Hartmann, H. Rockmann, H. Bramann
Presented by: Ms. Kanaka Laxmi, Manager – Non Ferrous Applications,
MAGMA Engineering India Private Limited

Every optimization measure in die casting has the goal of positively influencing availability, process speed and component quality. The subject of temperature control of die casting molds is as old as die casting itself. The cycle time, tool durability, microstructure and distortion of the parts as well as other technical and economic aspects are strongly dependent on the temperatures in the tool. The layout and process-specific optimization of die temperature control should therefore be a focus for the entire die and process design.

In fact, complex three-dimensional, contour-adapted temperature control systems, such as those that can be produced using generic AM processes, represent the state of the art in polymer injection molding. They are also attracting attention in die-casting: the approach of temperature control systems to the component drastically increases the controllability of the casting processes and makes them more robust, sustainable and cost-effective. To achieve a robust, reliable casting process, the design of close contour temperature control systems must be considered in the context of the overall system consisting of die casting cell, tool and production parameters.

This article deals with the virtual layout of complex three-dimensional, contour-adapted temperature control systems and the determination of optimally adapted process settings. The methodology and examples of a frontloading approach, where the design of the die temperature control system is developed and verified in parallel to the part design, are demonstrated. This approach is based on virtual molding supported by automated virtual DOEs and optimization algorithms - all applicable in the die casting component development environment. The evaluation of the virtual process variants is based on the real production key figure OEE.

## 3D temperature control systems in casting tools

The design of casting tools or die-casting dies is usually carried out according to the following aspects (in the order of their weighting): adaptation to the machine including determination of the number of die cavities, part removal, die layout with minimum slide effort and,-ejector. Casting or process-technical interests such as the flow-favourable course of the casting runs or the entire thermal design are only taken into account afterwards. The definition of the thermal process control includes the determination of the cooling and heating temperatures, the corresponding heating/cooling devices with the required capacities, the cycle time, etc. This is done during the patterning and running-in of the mold, i.e. completely decoupled from the definition of the heating/cooling channels and other temperature control devices and measures in the die.

On the other hand, the thermal design of a die-casting tool must ultimately support an optimum result from the casting process, i.e. variables such as casting quality, process stability, cycle time or tool service life. However, if these parameters are to be influenced, all equipment and measures for the temperature control of tools must be relevant to the casting result and must also be easily reproducible, adjustable and controllable. From this, two essential boundary conditions for the design of a mold temperature control system can be derived:

**1. Design of die segments:** In the thermally relevant die segments, the temperature control must be individually and efficiently controllable and, if possible, variable in time. For this purpose, the corresponding mold segment must be thermally agile. This is made possible by powerful heating/cooling units with the option of variothermal control and by temperature control ranges that are close to the contour and adapted to the contour, which can also be represented by generic (AM) processes.

**2. Development methodology:** The effect of temperature control measures and parameters on casting quality, process stability, cycle time or tool life must be known and documented at the time of tool design. This is possible by early virtual assessment and optimization of the casting process with full consideration of the temperature control measures to be tested.

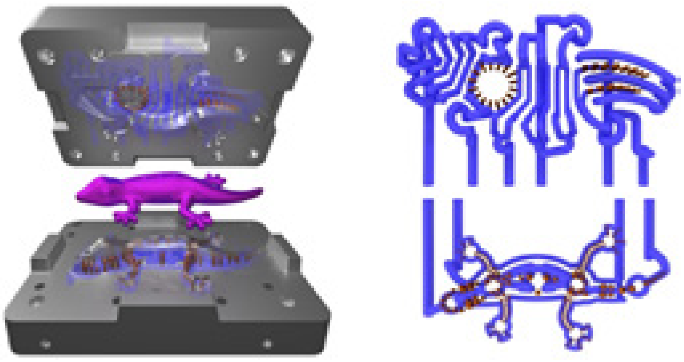


*Fig. 1: "Thermally nimble" die with close contour and contour-following temperature control, consisting of temperature control channel meanders and copper pins for the connection between temperature control medium and cavity (Contura MTC: Plastics + Processing 40/2019 Kuhn Fachverlag, page 65 Citation of Contour article)*

Thermally agile die segments with variothermal temperature control (Fig. 1) have been under discussion in the field of plastic injection molding for about 20 years, but even today they still tend to mark the "high end" of die technology.

Reiner Westhoff, Contura MTC: "Tools with near-contour temperature control are able to reduce the unit costs of molded or cast parts significantly, in some cases well over 15%, like hardly any other technological development in mold making.

The reported advantages in plastic injection molding are almost always in the area of shorter cycle times and improved component quality. This also results in a well calculable ROI of the additional costs in tool making and operation.

In the field of die casting tools, near-contour temperature control, at least as core cooling, has also been used for a long time. There may be several reasons why this narrow field of application has hardly been exceeded: First of all, in conventional die-casting tool making it is still true that cooling holes should not be closer than approx. 10-15 mm to the engraving. This is certainly understandable and correct if you consider the likewise classic casting process with two violent thermal shocks during shooting (high compressive stresses) and during spraying of the release agents (high tensile stresses).

Furthermore, the significantly higher costs of die segments with three-dimensional temperature control ranges that follow the contours and are close to the contours play a role. In general, no detailed information is available on the actual heating and cooling requirements during operation at the time of the decision on mold temperature control. But this is the exact information needed to identify and qualify the risks and potentials hidden in the heat balance of the casting tool and thus justify additional costs in tool making.

This is where the virtual design of the casting process comes into play. Parallel to the design of the casting, it is already necessary - and possible - to qualify the temperature control expenditure for a safe and economical production process. As soon as 3D CAD data of a casting is available, the first simulation calculations for the casting process provide a clear picture of the locally necessary temperature control measures around the cavity of the tool.

Later, when casting runs and venting areas are designed in the die, further, more detailed simulation calculations for the casting process provide the flow-optimized design of the casting run and the gates as well as the optimum thermal design of the temperature control in the casting chamber and anvil area and in the area of the casting run.

The methodology described here is not new, exotic or difficult to implement. It is based on approaches of collaborative engineering, whose positive effect on the economic efficiency of development processes prior to SOP has been extensively documented for 40 or more years. From a technical point of view, this methodology is supported by "state-of-the-art" CAE tools from 3D CAD to FE simulations to virtual assessment and automatic process optimization.

Collaborative engineering across this entire development process chain is even supported today by interdisciplinary media, which represent a common information platform between departments and companies with their interlinked tasks (Giesserei 106, 11/2019, p. 81).

**Virtual assessment and optimization of temperature control systems in die casting**

Using the example of the new product range presented at GIFA 2019 by Oskar Frech GmbH & Co. KG presented at GIFA 2019, the technical possibilities in combination with a methodology of virtual process planning according to the principle of Collaborative Engineering are explained.

The motivation for this project was a significant increase in productivity of an aluminum die cast component by reducing the total cycle time by at least 35%.The real challenge, however, was to determine an "optimal process" - i.e. the best compromise between product quality, economy and robustness of production. Starting from the existing series process, a benchmark was to be created using state-of-the-art plant technology combined with innovative tool design and supported by a methodical virtual process analysis.

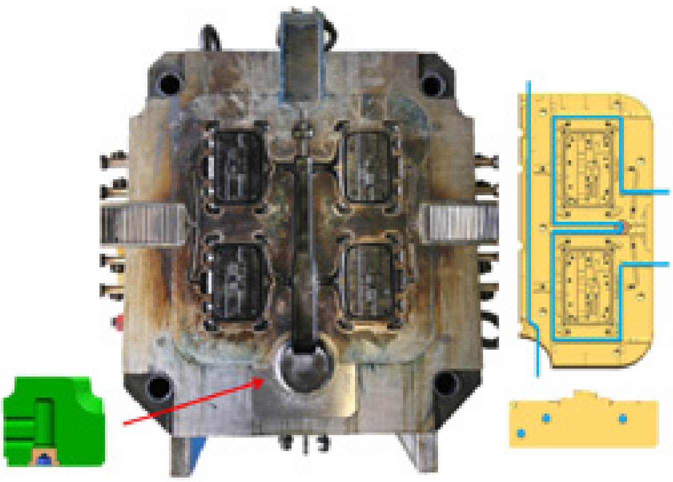


*Figure 2: 4-fold series tool for the die-cast aluminum heat sink; the tool inserts and anvil have conventional cooling channels and stab cooling*

The starting point for the "High Speed Casting Cell" project was a series production concept for an aluminum heat sink. The die casting cell consisted of a DGM of the type Frech DAK580 with a conventional dosing device as well as spraying and handling technology. The tooling used in 4-fold design is based on a classic casting run design with vertical arrangement of the nests (fir tree) as well as a tempering system with conventional cooling holes at a distance of 10-15 mm from the die engraving (Fig. 2).

The component is a thin-walled cover with cooling fins made of the aluminum alloy EN AC-Al Si12 (Fe) used for an electronic application in the automotive sector (Figure 3).

*Figure 3: Schematic thin-walled die-cast component "heat sink" made of the aluminum alloy EN AC-Al Si12 (Fe)*

The essential requirements for the component are a high surface quality and dimensional accuracy as well as optimum heat dissipation from the heating banks via the cooling fins. The corresponding technical casting objectives are:
- Avoidance of flow errors (flow lines, cold running, oxides)
- Avoidance of surface defects due to shape erosion and adhesives
- Avoidance of large filling time differences between the 4 cavities of the mold
- Avoidance of internal defects due to trapped air or shrinkage porosity

In order to increase productivity by reducing the total cycle time, the first step was to investigate the optimization potential by using state-of-the-art networked plant technologies. For this purpose, a "High Speed Casting Cell" consisting of the following components was set up at MONEVA GmbH + Co KG Leichtmetallguss:
- Frech die casting machine K640
- Meltec vacuum dosing furnace with integrated system for fast weighing of the dosing quantity (dosing accuracy and repeatability) as well as a fast servo-controlled transport device
- Robamat high-performance multi-zone temperature control units for mold inserts, in particular with close contour temperature control
- Spesima handling and removal system

By consistently linking modern plant technologies, valuable seconds can be saved during dosing, die -opening and removal (see Table 1 for a comparison of the proportional cycle times). With the high-speed casting cell, the total cycle time can be reduced from 38 (series process) to 33.4 seconds. This corresponds to an increase in productivity of approx. 12%.

| **Production Status DAK580** | | **High Speed Casting Cell K640** | |
|---|---|---|---|
| | [sec.] | [sec.] | |
| Closing | 2,8 | 2,7 | |
| Metering | 5,5 | 2,1 | Start dosage with "mold protection end" for K640. Use of special dosing containers from Meltec |
| Casting | | | |
| 1. Phase | 1 | 1,2 | |
| 2. Phase | 0,1 | 0,1 | |
| Cooling Period | 6 | 6 | |
| Opening | 2,5 | 2 | |
| Ejector before | 0,5 | 0,4 | |
| Withdrawal | 5,6 | 4,9 | Optimized process |
| Spraying | 11,5 | 11,5 | |
| Ejector back 0,5 sec | | | During spraying |
| Casting plunger 1,5 sec | | | During spraying |
| Waiting time for removal until spraying starts | 2,5 | 2,5 | Optimized process |
| Total cycle time | 38 | 33,4 | Reduction of the cycle time by 12% |

*Table 1: Comparison of process times for series production and for the innovative high-speed casting cell; cycle time reduction from 38 to 33.4 seconds*

Based on the newly installed high-speed casting cell, the potential of tool optimization in combination with further process improvements in temperature control and spray technology was investigated in a second step.

The aim was to find the best compromise between maximum reduction of the cycle time while maintaining the same component quality, minimum use of resources (aluminum/return component) and maximum tool service life. The focus of the tool optimization was on a targeted design of the casting run with regard to minimum energy input and rapid solidification, as well as an innovative design of an effective, local temperature control through near-contour cooling in the die casting mold.

The specified surface quality of the components requires a fast and homogeneous mold filling of all 4 cavities of the tool. In view of the thin-walled component geometry of the heat sink and the relatively uniform wall thickness distribution, the risk of significant shrinkage-related porosity in the component is low. The runner system does not have to ensure effective replenishment of the component and can be optimized for resource efficiency and short solidification time. A corresponding runner system with reduced mass and increased specific surface area was developed by the tool development department of Oskar Frech GmbH & Co. KG and designed in CAD.

The near-net-shape design of the heat sink with minimal draft angles requires a robust release agent application for the shake out process. The conventional application of water-based release agents by spraying is characterized by two second-intensive process phases:
- Local cooling of the die surface into the effectively usable temperature range
- Blowing out residual moisture before the next casting cycle

A significant reduction of the cycle time for the spraying process (conventionally 11.5 seconds) can be achieved by modern water-free micro-spraying processes. In the second optimization step, the WOLLIN Micro Spraying Technology was therefore integrated into the high-speed casting cell with a mask spray tool that is individually adapted to the mold. In contrast to a conventional spraying process, the WOLLIN Micro Spraying Technology withdraws almost no energy from the tool surface. The energy balance has to be maintained by an adapted internal die temperature control. Innovative, near-contour temperature control offers a targeted and efficient way of influencing the local temperature balance of the mold.

Starting from the conventional temperature control of the die casting tool, the relevant areas (partial inserts of the cavity and anvil) were reconstructed to highly efficient near-contour cooling using Frech Laser Melting (FLM®) technology (Fig. 4).

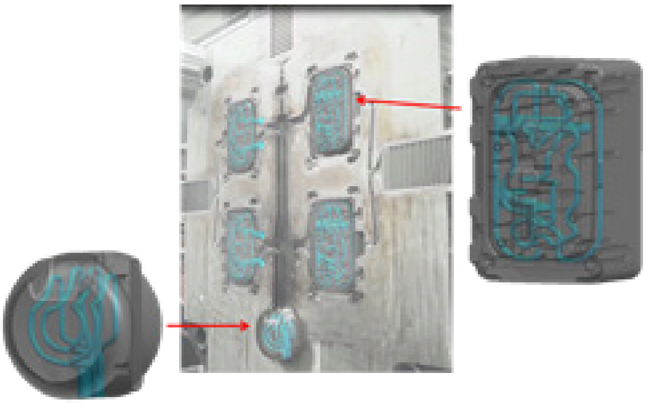


*Figure 4: 4-cavity mold with schematic view of the near-contour temperature control in the area of the anvil and the cavity inserts*

In parallel to the design and implementation, a comprehensive virtual process analysis of all relevant geometry and process parameters was performed with MAGMASOFT® according to the principle of collaborative engineering. Methodical, virtual experimentation with MAGMASOFT® is a forward-looking way of working in order to design component geometry, tool and manufacturing processes in an optimal and robust way through transparent and quantitative process understanding.

The goal of the virtual process analysis was to identify a concrete manufacturing solution, the best compromise between quality and efficiency.

A systematic approach to the use of casting process simulation can be divided into the following steps:
- Definition of the goals
- Definition of the relevant variables: These can be process parameters as well as geometry variations of the component or tool.
- Selection of resilient quality or measurement criteria: Which simulation results describe the objectives or document a desired change.
- Definition of the start sequence: Number of simulations that provide statistically validated findings.
- Target-oriented evaluation of the statistical simulation data.

For the virtual assessment of the Frech high-speed casting cell, all relevant geometric modifications of the casting system, the mold temperature control as well as critical process parameters were considered as variables. Specifically, the original state and the tool and process modifications planned for the second optimization step were integrated into the simulation model. For example, the resource-efficient redesign of the casting run with regard to a reduced return flow portion, reduced energy input and accelerated solidification (Fig. 5 a./b.) as well as a geometric variation of the gate section to the component with regard to a fast and uniform filling of all four cavities with the lowest possible filling time differences (Fig. 5 c./d.).

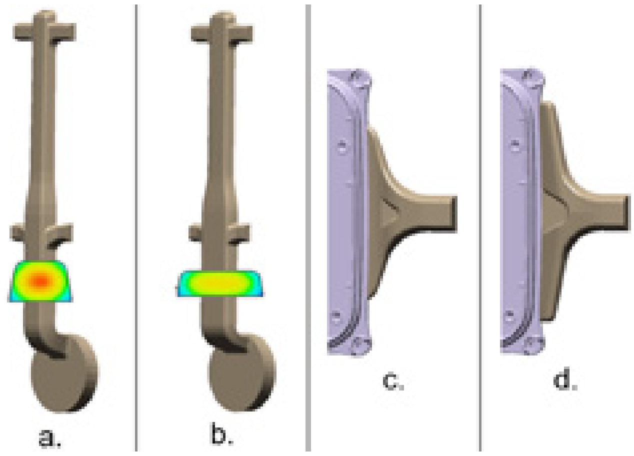



*Figure 5: Geometric variants of the casting run (a. conventional / b. modified) and the gate design (c. original design / d. modified design)*

In order to achieve a balanced energy balance in connection with the planned Micro Spray Technology, the conversion of the internal tool cooling (from conventional cooling channels to complex near-contour cooling structures) was also integrated into the virtual process model.

To evaluate the effectiveness and sensitivity of the different cooling variants, the following process parameters for the temperature control channels were also varied:
- Flow rate between 8 and 15 l/min
- Temperature of the cooling medium between 80 and 150 °C

Particularly in the case of complex cooling channel geometries, such as the near-contour cooling systems shown above, knowledge of the cooling or temperature control performance that can be achieved locally in the mold is of decisive importance. In MAGMASOFT® the

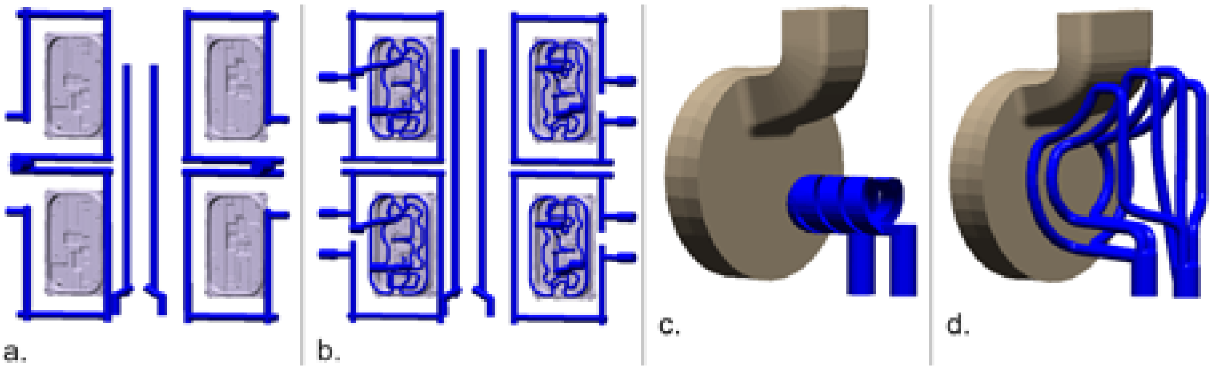



*Figure 6: Geometric variants of insert temperature control (a. conventional / b. close contour) and anvil cooling (c. conventional / close contour)*

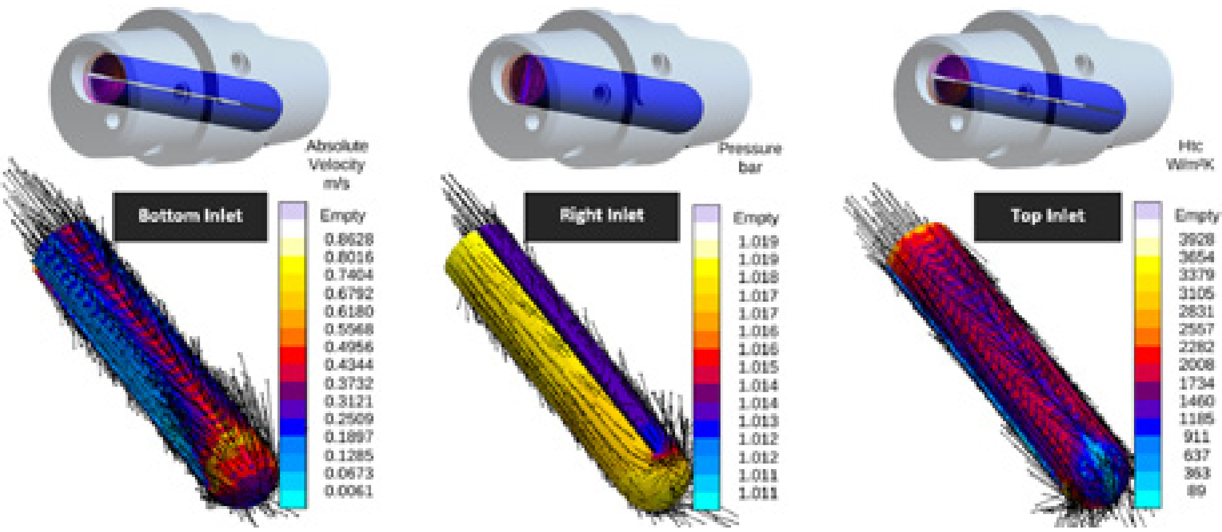



*Figure 7: Exemplary presentation of the results of a flow calculation in a tower cooling system with different inflow conditions*

flow conditions in the cooling channel can be calculated in parallel to the classical mold filling and solidification simulation of the cavity. Using a simple tower cooling as an example, some results of a flow calculation in the cooling channel are shown. Besides the absolute flow velocity with vectors (Figure 7 left) or pressure curves in the temperature control circuit (Figure 7 middle), the local heat transfer coefficients (Figure 7 right) of each activated cooling channel can be calculated, visualized and evaluated.

The conventional, water-based application of release agent or the innovative WOLLIN Micro Spray Technology is taken into account in the simulation model in a simplified way by means of defined spray areas with different intensities of heat extraction from the tool surface.

In order to better evaluate the robustness of the technical casting design, the switchover time was integrated into the virtual investigation as a further process variable - from the slow first to the fast second phase with the states early, medium, late (Fig. 8)

The most important step in the systematic and goal-oriented use of casting process simulation is the definition of meaningful quality criteria and measurement variables for the evaluation of the virtually examined process variants. For the heat sink, the selection of the relevant MAGMASOFT® results is based on the defined requirements of the component:

- Flow error - Minimum fill temperature (cold run risk) in the 4 cavities
- Surface defects – MoldErosion (washout) and DieSoldering (adhesion/sticking)
- Fill time differences - FillTime as maximum difference between all cavities
- Internal defects - Entrapped AirMass (gas porosity) and Porosity (shrinkage porosity)

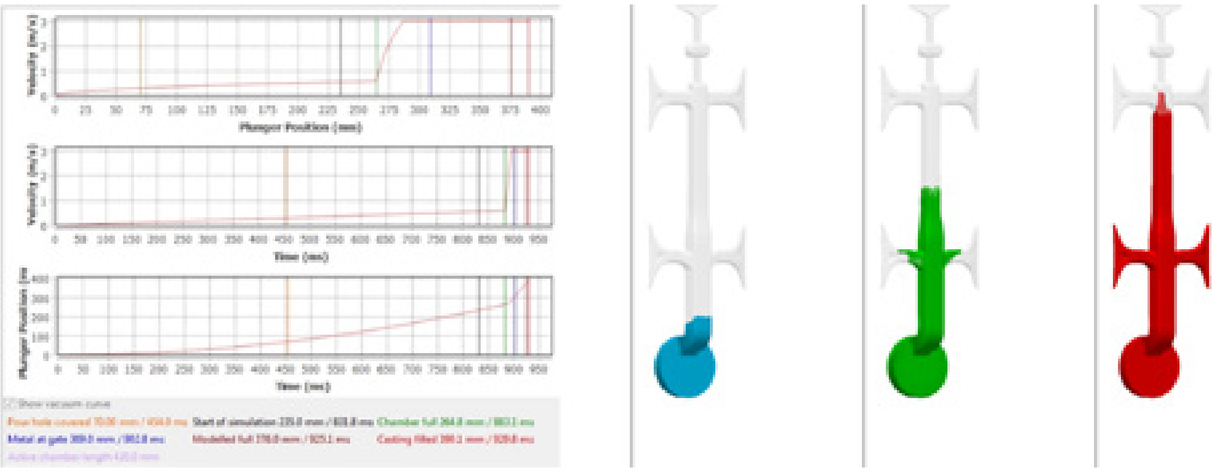



*Figure 8: schematic shot profile and visualization of the varied switchover point (early/medium/late)*

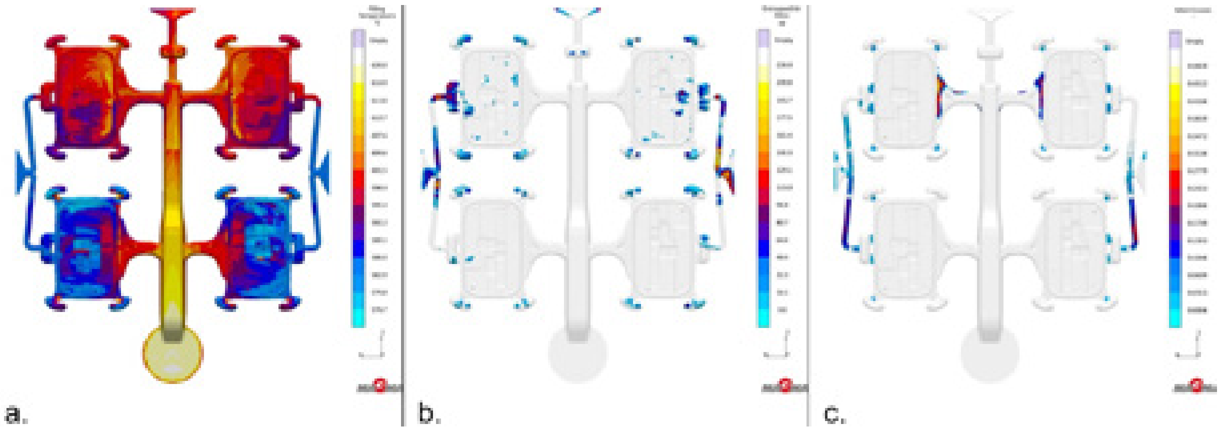



*Figure 9: classic 3D MAGMASOFT® results for the evaluation of flow defects (FillTemperature), imperfections in the part or porosity (EntrappedAirMass) or surface defects on the part and tool (MoldErosion)*

In the following, some corresponding 3D results from casting process simulation with MAGMASOFT® are shown as examples for the above-mentioned quality criteria (Figure 9).

The number of defined variables and their degrees of freedom determine the experimental space for the virtual experiments:
- Casting run design conventional / optimized (2)
- Gate geometry narrow / wide (2)
- Anvil cooling conventional / close contour (2)
- Insert cooling conventional / close contour (2)
- Flow rate 8 / 15 l/min (2)
- Medium temperature 80 / 150 °C (2)
- Spraying process conventional / micro spraying (2)
- Changeover point early / medium / late (3)

In order to reduce the calculation effort, MAGMASOFT® allows using different statistical design strategies (e.g. Sobol) to generate the so-called start sequence. Usually, the approach is "statistically validated findings with a minimum number of experiments". Within the benchmark project "High Speed Casting Cell" a full factorial DoE (Design of Experiments) was used, i.e. all 384 theoretically possible parameter combinations were simulated. The virtual experiment No. 108 corresponds to the initial process after the conversion of the original series process to the "High Speed Casting Cell".

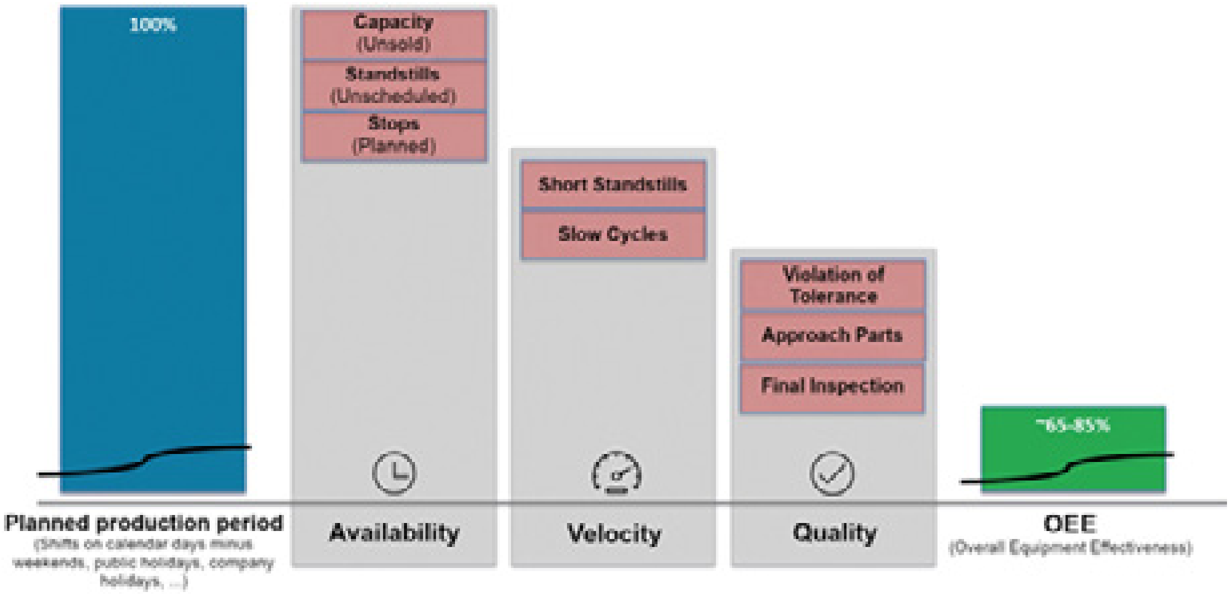



*Figure 10: Composition of the production key figure OEE (Overall Equipment Effectiveness) from machine availability, process speed and the resulting component quality*

Since a conventional evaluation of the virtual experiments using 3D results is not feasible, the simulation results in MAGMASOFT® are additionally automatically converted into quantitative numerical values according to defined criteria. With the integrated statistical analysis tools, all investigated experiments can be evaluated comfortably, clearly and quickly.

The selected quantitative criteria for casting quality, die loading or the efficiency and robustness of the manufacturing process were summarized into easy-to-understand key performance indicators (KPI's) via so-called UserResults. The KPI's are based on the real production-related KPI OEE, which is also gradually being adopted in die casting. As a measure of the increase in effectiveness, OEE combines the categories availability (e.g. tool life, ...), speed (e.g. cycle time, ...) and quality (or scrap), Figure 10.

The formation of the key figures for the description of an "optimal process" - i.e. the best compromise between product quality, economic efficiency and robustness of the manufacturing process - is achieved by mathematically linking the MAGMASOFT® results. The virtual key figures do not necessarily correspond to physical relationships and were standardized to reference experiment no. 108 for a simplified evaluation of the complex virtual test field. Values greater than 1 correspond to an improvement over the initial state of the "high-speed casting cell". The reduction of the cycle time is given as a percentage in reference to the original series process.

| | |
|---|---|
| Cycle time: | Filling time + time to die opening (solidification time during the run) + defined idle times, e.g. for spraying/blowing |
| Casting quality | Minimum filling temperature (cold run risk) / trapped air mass in the components * Porosity risk |
| Productivity | Ratio component / shot weight * difference in filling time between the upper and lower nests |
| Tool load | Risk of shape erosion + risk of sticking |

In MAGMASOFT®, a ranking of the virtual experiments is generated on the basis of the normalized ratios (Figure 11), which, with uniform weighting of the ratios, allows an immediate determination of an optimal solution.

In order to take the real process conditions into account, the virtual experimental design was evaluated in detail

| Rank | Design | Cycle Time | Cycle Time Reduction | Casting Quality | Productivity / Robustness | Tool Life |
|---|---|---|---|---|---|---|
| Rank 1 | Design 316 | 24.7 | 0.65 | 1.09 | 2.14 | 3.59 |
| Rank 2 | Design 315 | 24.91 | 0.656 | 1.08 | 2.14 | 3.56 |
| Rank 3 | Design 314 | 25.69 | 0.676 | 1.08 | 2.14 | 3.47 |
| Rank 4 | Design 313 | 26.05 | 0.685 | 1.08 | 2.14 | 3.45 |
| Rank 5 | Design 220 | 24.68 | 0.65 | 1.25 | 2.13 | 2.33 |

*Figure 11: Top 5 virtual experiments from the MAGMASOFT® ranking with uniform weighting of key figures*

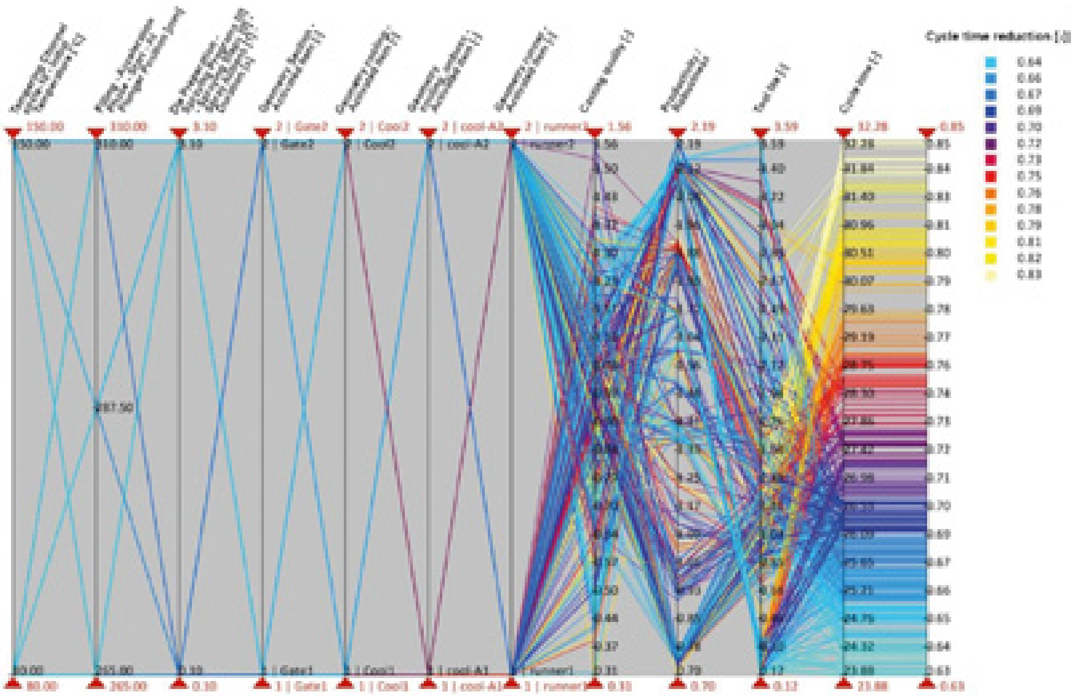



*Figure 12: Interactive analysis and evaluation of the virtual test space using the parallel coordinate diagram; each line describes a simulation with the corresponding combination of variables and the resulting quantitative results or key figures*

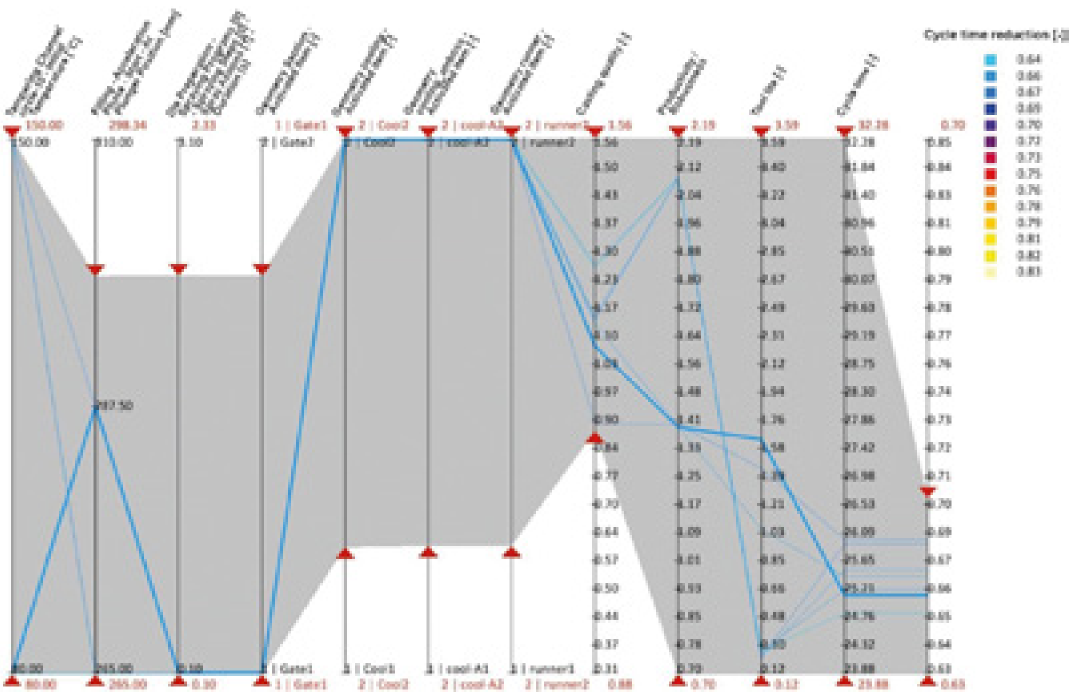
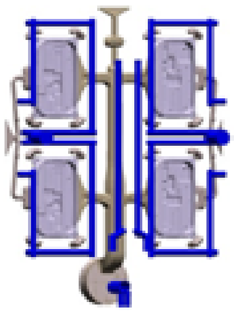
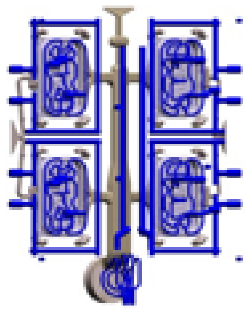



*Fig. 13: Individual selection of the "optimum process" taking into account the specific plants and process conditions; experiment no. 274*

| Rank | Design | Cycle Time | Cycle Time Reduction | Casting Quality | Productivity / Robustness | Tool Life |
|---|---|---|---|---|---|---|
| Rank 67 | Design 228 | 24.95 | 0.657 | 1.01 | 1.53 | 1.48 |
| Rank 68 | Design 88 | 24.56 | 0.646 | 0.974 | 1.36 | 1.64 |
| Rank 69 | Design 299 | 27.73 | 0.73 | 1.31 | 1.89 | 2.1 |
| Rank 70 | Design 276 | 23.99 | 0.631 | 0.972 | 1.39 | 1.1 |
| Rank 71 | Design 300 | 27.5 | 0.724 | 1.37 | 1.88 | 1.74 |
| Rank 72 | Design 270 | 25.5 | 0.671 | 1.15 | 2.09 | 0.219 |
| Rank 73 | Design 103 | 28.36 | 0.746 | 0.9 | 2.13 | 3.16 |
| Rank 74 | Design 39 | 25.78 | 0.678 | 1.08 | 1.84 | 1.2 |
| Rank 75 | Design 3 | 27.66 | 0.728 | 0.885 | 2.11 | 2.64 |
| Rank 76 | Design 274 | 25.11 | 0.661 | 1.08 | 1.39 | 1.64 |
| Rank 77 | Design 324 | 24.98 | 0.657 | 0.638 | 1.88 | 1.61 |
| Rank 78 | Design 179 | 24.33 | 0.64 | 0.49 | 1.63 | 2.01 |
| Rank 79 | Design 104 | 28.46 | 0.749 | 0.897 | 2.13 | 3.15 |
| Rank 80 | Design 80 | 24.33 | 0.64 | 0.76 | 2.08 | 0.215 |

*Figure 14: The virtual experiment no. 274 determined from the individual evaluation is on position 76 in the MAGMASOFT® ranking with uniform weighting of the key figures*

| | | | |
|---|---|---|---|
|  | Cooling: conventional<br>Anvil: conventional<br>Pouring run: conventional<br>Bleed: narrow<br>Flow rate: 15l/min<br>Temp. medium: 150 °C<br>Spraying: conventional<br>Switchover point: late |  | Cooling: close contour<br>Anvil: close contour<br>Casting run: optimized<br>Bleed: wide<br>Flow rate: 15l/min<br>Temp. medium: 80 °C<br>Spraying: Micro Spray<br>Switchover point: medium |
| Virtual Design 118 | | Virtual Design 274 | |

| High Speed Casting Cell K640 | | K640 including tool modification | |
|---|---|---|---|
| | [sec.] | [sec.] | |
| Closing | 2,7 | 2,7 | |
| Metering | 2,1 | 2,1 | |
| Casting | | | |
| 1. Phase | 1,2 | 1,2 | |
| 2. Phase | 0,1 | 0,1 | |
| Cooling Period | 6 | 5,1 | Reduction through WZ – temperature control |
| Opening | 2 | 2 | |
| Ejector before | 0,4 | 0,4 | |
| Withdrawal | 4,9 | 4,9 | |
| Spraying | 11,5 | 4,5 | Micro spraying in combination with WZ - temperature control |
| Ejector back 0,5 sec | | | During spraying |
| Casting plunger 1,5 sec | | | During spraying |
| Waiting time for removal until spraying starts | 2,5 | 2,5 | Optimized process |
| Total cycle time | 33,4 | **23** | **Reduction of the cycle time by a further 31%** |

*Table 3: Comparison of the process times for the high-speed casting cell with series tool and with the modified tool and use of Micro Spray Technology; cycle time reduction by almost 40% to 23 seconds*

and interactively with the aid of the parallel coordinate diagram (Fig. 12). The columns (from right to left) show the variables with the respective states and the defined key figures. The scaling is based on the cycle time reduction. Each line in the diagram corresponds to a virtual experiment. The sliders allow a quick adjustment of the desired boundary conditions and objectives. Figure 13 shows an individual selection based on the primary optimization goals for the "High Speed Casting Cell". The virtual experiment no. 274 is the chosen compromise between product quality, economic efficiency and robustness of production while reducing the cycle time by almost 35% compared to the original series production. In the standardized MAGMASOFT® ranking, virtual experiment no. 274 is ranked 76th (Figure 14).

After the modification of the die casting tool at Oskar Frech GmbH & Co. KG, the process was implemented using the virtually determined parameter combination in the "high-speed casting cell". In combination with the use of Micro Spray Technology, the close contour temperature control integrated into the tool allows a reduction of the total cycle time to approx. 23 seconds (Table 3). This corresponds to a capacity increase of almost 40% compared to the original series process. Intelligent temperature control of die casting tools to increase OEE

"The temperature control of die-casting tools comes last" - This is the principle according to which the positions and dimensions of temperature control channels are generally designed today. If no information is available at this time about the heat balance of the die during operation, there is no other way. However, this approach is by no means up to date. The potentials of front loading, which has been known in mechanical engineering for 140 years, the possibilities of computer-aided optimized design of casting processes, which have been available for 30 years, and the modern, partly generative manufacturing technologies for contour-near and contour-adapted temperature-controlled tool segments are not used. The above-mentioned potentials are known and quantifiable - in individual cases, the only thing that is required is a decision for a different approach.

The approach proposed in this paper allows not only the identification of the concrete manufacturing technology solution for the tool and the casting process, but also the determination of the best compromise that the caster strives for in terms of quality and economy. Almost free of economic or productive risks, any scenarios can be examined for their contribution to increasing the efficiency (OEE) of a die casting cell. The methodical approach allows correlations between production parameters and quality features of the casting to be generated systematically and early in the development process, even for complex issues.

Decisions are backed up on the basis of a CAE development process in which the component and process are simultaneously optimized by the designer and the foundryman, thus supporting the product developer, the toolmaker and the foundry expert in designing robust, cost and resource-efficient products and processes.

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Ms. Kanaka Laxmi, Diploma in Tool & Die Making from NTTF, Bangalore, has a total of 12 years' experience in Tool and Die Design, working for reputed Companies like Geometric, Bangalore, Tool Mak, Hyderabad and Endurance Technologies, Pune.

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## Celebrating 25 years of Innovation and Excellence

"Companies are built up by the people, organisations are built by teams but an institution is built by teams who own it"

Raga Group is a renowned name in the die casting sector supplying over 350+ die casters in more than 10 countries worldwide since the last 25 years now.

Like any other company, Raga have had its share of struggles and downfalls during these last 25 years. What made it stand again was the will to create value and a positive learning attitude to the mistakes it made and improve.

Since its inception in 1995, the focus is to create value to the die casting process. Raga could develop innovative technologies like Jet Cooling and Vacuum systems which are world class products accepted in countries like South Korea, Spain, USA and Taiwan. Raga is also known for high quality consumables like core pins, jet coolers and injection parts like shot sleeves and plunger tips.

On this occasion of our 25th year anniversary, we attribute and dedicate the growth and success to the team who stood by it, the suppliers who continue to believe and the customers who kept unparalleled faith.

# THANK YOU!

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