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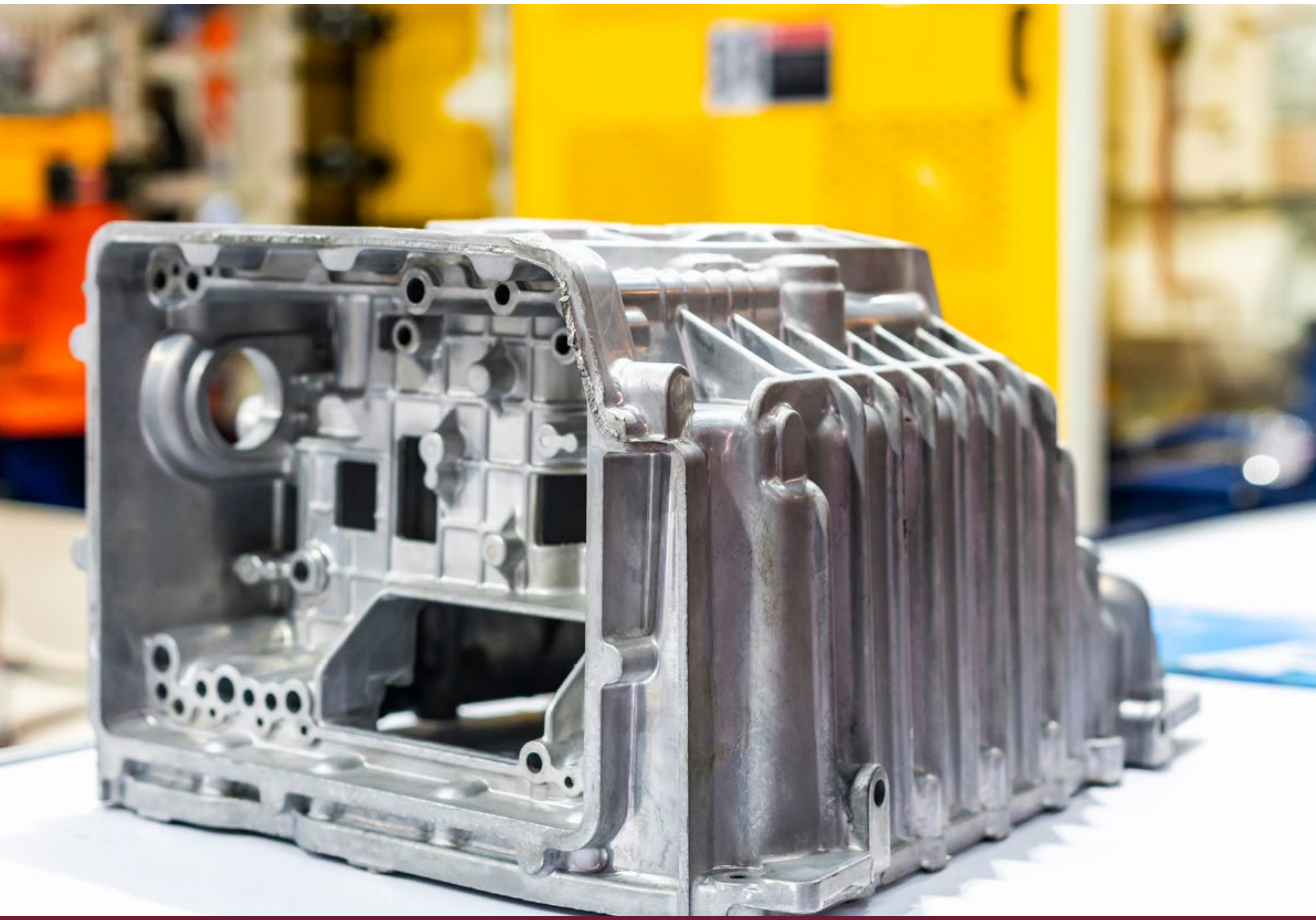


WHITE PAPER

Challenges for high-pressure die casting (HPDC) foundries

01/2024

Non Ferrous Foundries

CONTENT

SYNOPSIS

High-pressure die casting (HPDC) is capable of delivering high volumes of high-quality parts for a wide range of applications. Long used in automotive manufacturing, the process is in greater demand than ever before thanks to lightweighting requirements and the increase in demand of electric vehicles. At the same time, castings are becoming larger and increasingly more complex as auto makers seek to combine multiple parts into single pieces. This is raising a number of challenges for HPDC foundries and as such foundry consumable suppliers have a key role in providing solutions to these challenges and supporting their customers to take the next steps of HPDC evolution.

INTRODUCTION

Megacasting has seen the size and complexity of HPDC castings increase.

High-pressure die casting (HPDC) involves the injection and solidification of molten non-ferrous metals into a reusable die under high pressure. It is a high-speed process able to produce high-quality castings in high volumes: features that make it ideal for manufacturing automotive parts. Indeed, vehicle production is the largest market for HPDC foundries and is expected to drive growth in the HPDC market to well over USD100 billion by 2026.[1] Yet the process is not without limitations – notably around coring. Its use has thus traditionally been limited to small- to medium-scale castings or those of relatively low design complexity.

This is now changing. Megacasting has seen the size and complexity of HPDC castings increase. The quantity of aluminium used in cars is also increasing as manufacturers try to bring down vehicle weight. The following white paper takes a look into this brave new HPDC world. It begins with a more detailed look at the trends shaping the HPDC market, before examining some of the challenges facing foundries. It will conclude with a review of the solutions that have been developed to help overcome these problems.

CURRENT TRENDS IN HPDC

LIGHTWEIGHTING AND ELECTRIFICATION

The road transportation sector is responsible for significant greenhouse gas emissions. Decarbonisation of the sector is thus critical for global efforts to mitigate the extent and impact of climate change. Auto manufacturers have generally followed two approaches to achieving this: the adoption of alternative energy sources, notably through electrification, and improving fuel efficiency of vehicles. Both "benefit from the reduction of vehicle weight, which ultimately increases the distance travelled per unit of energy."[2]

The benefits of lightweight can perhaps be best illustrated with a quick look at the electric vehicle (EV) market. EVs raise a number of interesting challenges for auto manufacturers when it comes to vehicle design and construction. Vehicle weight is a notable example. Due to the weight of the battery, EVs are heavier than those with a traditional internal combustion engine (ICE). As a consequence, vehicle makers are switching to lighter-weight aluminium components in order to keep overall vehicle weight down.

According to a 2023 study for industry association, European Aluminium, battery EVs produced in Europe contain 283kg of aluminium on average, compared to an average of 169kg for ICE-only cars.[3] This is expected to rise further to reach 310kg by 2026. The report attributes this growth to the use of aluminium in e-drive housings, battery pack housings, ballistic battery protection, and cooling plates. This has a particular impact for HPDC foundries, which will be responsible for the production of these aluminium castings.

The study's authors also note that "the implementation of large and mega-castings in the body structure of the car will also strongly contribute to a higher aluminium intensity" – which brings us to the second key trend.

RATIONALISING AUTO CONSTRUCTION: THE RISE OF MEGACASTING

Traditional auto construction involves the welding, bonding, and riveting together of many separate parts. It is a proven process that has been streamlined over many decades to the highly-automated and optimised process we see today. However, some auto makers are now breaking with convention and casting increasingly large and complex single pieces ready for series production. These large castings replace tens or even hundreds of smaller parts with just one and thus make the army of process robots used in traditional production lines superfluous. This reduces the space required for production and cuts assembly times with cost savings of up to 40% cited.[4]

Megacasting was pioneered by Tesla in the manufacture of its Model T and has now been taken up by others, including Volvo Cars, which will install two 9000 ton megacasting machines at its new EV production facility in Slovakia,[5] and Toyota, which is also aiming to use the technology for its next generation of electric cars.[6] Yet it is not without issues.

CHALLENGES FOR HPDC FOUNDRIES

These are exciting times to be a HPDC foundry. But to make the most of the opportunities offered by the trends noted above, foundries must address some key challenges:

- **Melt quality:** the greater the complexity and size of the casting, the greater the risk of casting defects that impact the mechanical properties or pressure tightness of the finished part. The cost of such defects is also higher. This places additional demands on melt quality to prevent such defects, raising the need for effective and efficient degassing and melt treatment solutions for HPDC processes.
- **Tooling and wear maintenance:** tool integrity plays a key role in preventing defects and ensuring consistent casting quality. But maintaining that integrity is an ongoing battle: HPDC tools are subject to high-pressure and high-temperature operating conditions, which naturally cause wear and tear over time. However, frequent tool maintenance or replacement only adds to the production costs and reduces the efficiency of the process. There is thus a need for solutions that protect against the harsh operating conditions that HPDC tools are exposed to.
- **Casting design complexity:** as noted above, HPDC excels at producing smaller, low-complexity pieces, quickly and consistently. However, as end users place greater demands on HPDC castings, so casting complexity is increasing. For example: a car's rear end can be made up of up to 100 individual parts. Replacing these with just one large piece will require a much more complex casting design, incorporating challenging geometries, thin walls, and intricate shapes. Optimising the design for manufacturability – while also ensuring structural integrity and minimising defects – is a headache that requires careful casting simulation. New sand coring technologies able to tolerate the high pressures, temperatures, and speeds involved in HPDC processes can be beneficial to enable the casting of complex internal cavities.
- **Heat dissipation and cooling:** efficient cooling of the cast parts inside the mould is essential for proper solidification and to prevent defects. Achieving uniform cooling rates across the casting can however be difficult – especially as the size of the casting increases. Uneven cooling can ultimately impact the mechanical properties of the final piece. Overcoming this challenge requires a combination of expert process control, alongside high-performance insulating refractories for metal holding and pouring accessories to maintain optimum melt temperature through the process.
- **Material and process optimization:** Finding appropriate alloy compositions and process parameters to achieve the required mechanical properties, surface finish, and dimensional accuracy – while maintaining competitive production cycle times and costs – is a continuous challenge. Metals producers are responding to this with the development of novel alloys for megacasting applications, such as Alcoa's C611 EZCast™ alloy, which has been

successfully used for die casting a rear floor frame in one part, compared to the previous 87 separate components.[7] However, optimized melt preparation and treatment, even of these new high-performance alloys, will continue to be needed, as will appropriate methods of casting analysis and inspection to ensure quality.

- **HSE impacts:** casting is an inherently energy intensive process. Energy efficiency is thus an ongoing focus for the foundry sector as it works to reduce its carbon footprint amid global efforts to limit climate change. Other environmental challenges facing HPDC foundries are linked to harmful emissions and waste disposal. Solutions that improve the energy efficiency of melting, holding, and pouring operations are needed here, as are technologies that reduce the generation of emissions and hazardous waste streams, and allow recycling of materials such as coring sand.
- **QA and inspection:** HPDC foundries can experience relatively high scrappage rates that undermine competitiveness – a challenge that is only exacerbated when casting larger and more complex pieces. Ensuring consistent high-quality casting thus takes on even greater important. Robust quality control measures throughout the process are needed to assure such quality demands, including effective melt preparation and treatment measures. These should be supported by robust inspection techniques to detect any defects or deviations in casting quality.

There are thus a range of obstacles HPDC foundries need to overcome to be successful in the changing HPDC market. But foundries are not alone on this journey: foundry suppliers, such as Foseco, are stepping into the breach with the development of a range of innovative solutions that help resolve many of these challenges. The remainder of this white paper will be dedicated to a review of some of the technologies currently available.

INSURAL* dosing furnace lining system

Automated and precise dosing of liquid metal is a growing trend at HPDC foundries. It is typically achieved through a dosing furnace comprising a number of refractory components and which facilitates metal transfer from a holding furnace. Diverse dosing furnace designs exist but most are characterised by a refractory-lined rectangular shell that maintains the melt at a consistent temperature and minimises disturbances to prevent dross and gas-related issues.

Several refractory components are typically employed to manage the loading and unloading of liquid metal into and out of the dosing furnace. Cost-effective refractory items have been the standard choice; however, the adoption of high-quality INSURAL dosing furnace linings from Foseco is now proving effective due to their excellent insulation, low-wettability, and strength, as well as the ability to create a wide range of shapes. Benefits of INSURAL lining systems include the following:

Improved energy efficiency: INSURAL lining systems are dry and thus do not requiring sintering or drying-out after installation. Pre-heating can thus take place immediately, without the gradual temperature ramp-up association with wet refractory furnace linings, reducing the energy consumed in this non-productive stage of operation. High thermal insulation also ensures that heat losses are significantly lower throughout the service life of the lining: compared to monolithic lining systems, up to 17% energy savings can be achieved.

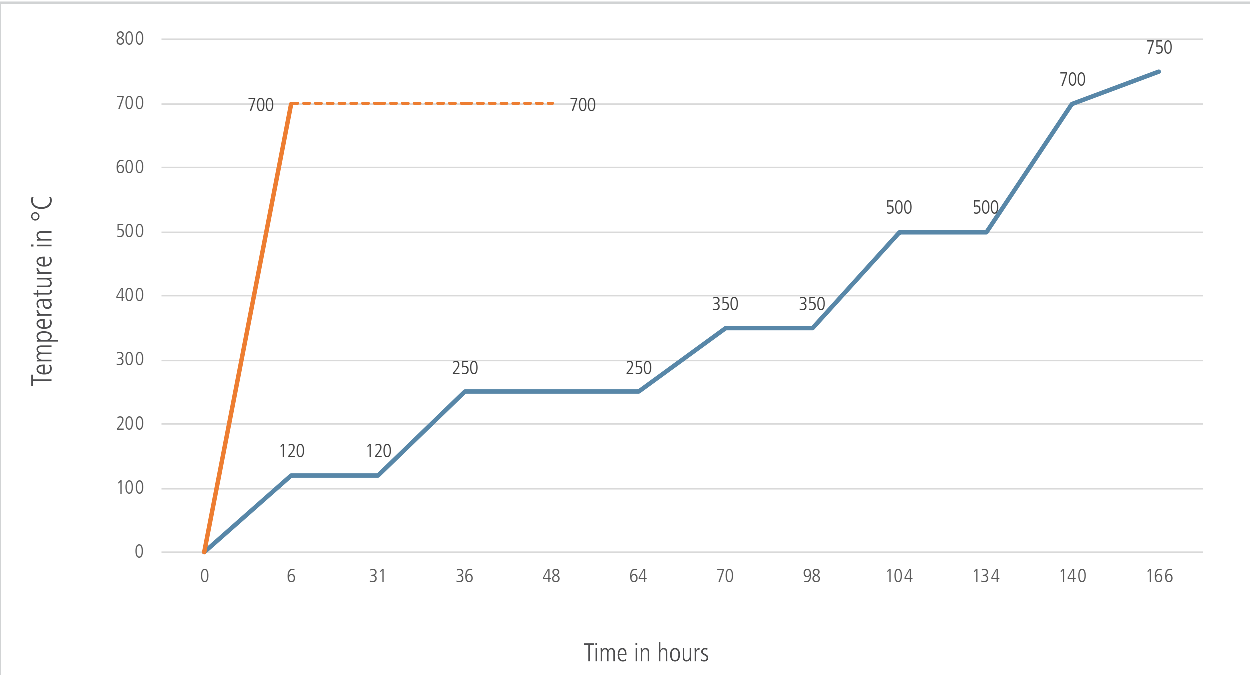


FIGURE 1. Pre-heating programmes for a 650kg furnace lined with a traditional refractory lining (blue) and INSURAL-lined furnace (orange). Note: after heating to normal operating temperature, a 48hr holding time is recommended for the INSURAL-lined furnace before melt charging.

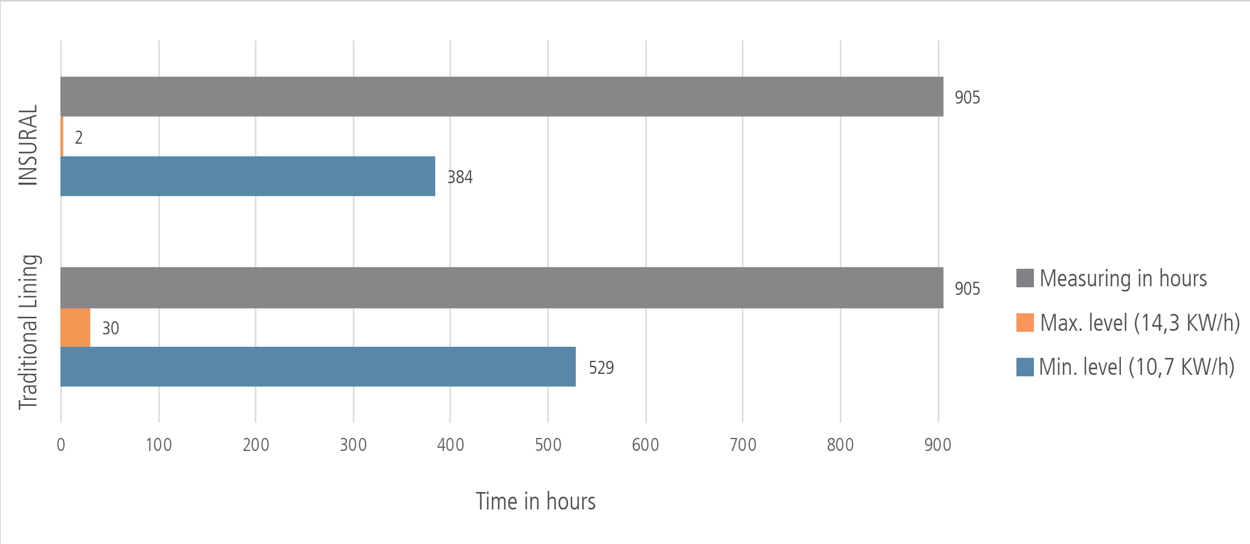


FIGURE 2. Comparing energy consumption of a furnace lined with traditional monolithic lining system and an INSURAL-lined furnace.

Improved productivity due to deduced furnace downtime: the majority of an INSURAL lining system comprises pre-cast shapes for easy and fast installation in about three days.[8] Hydrogen pick-up from a new lining system is also negligible due to the fact it is a dry system: the melt density index goal can thus be achieved within a very short period after installation. Add to this to the lack of sintering required, and furnace downtime for lining installation is significantly reduced.

INSURAL linings are also inherently non-wetting and thus minimise corundum build-up, resulting in much simpler furnace cleaning and longer service life, again reducing downtime.

INSURAL lining systems are available for a range of dosing furnaces and with a full-range of consumable ceramic products including filling funnels, dosing tubes, launders, and thermocouple and heating element sheaths.

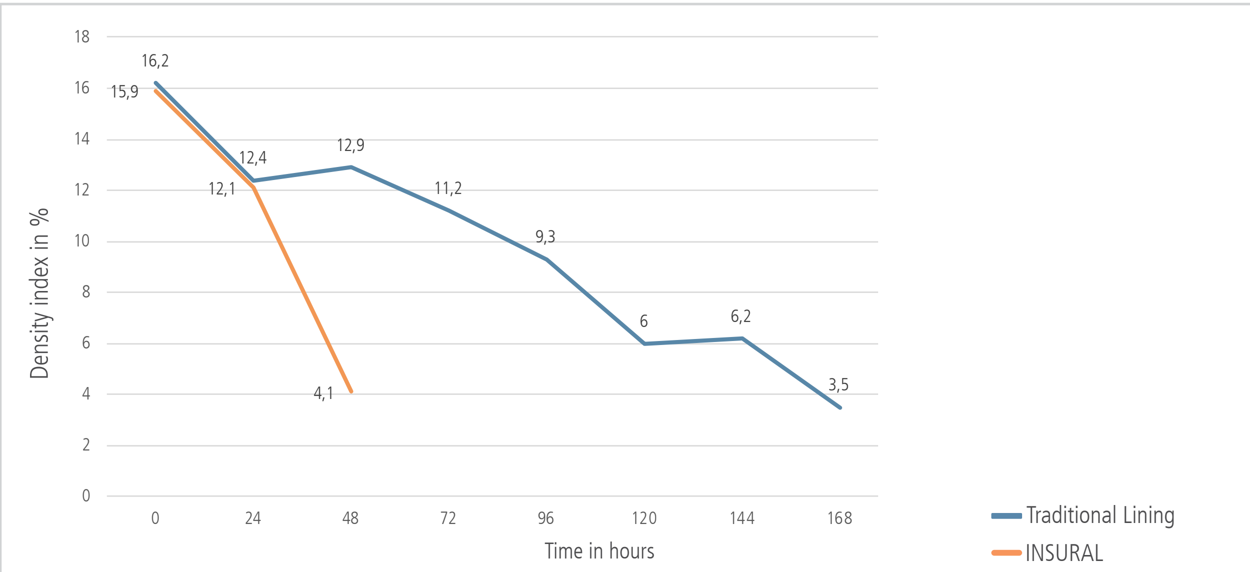


FIGURE 3. INSURAL linings allow the desired density index to be achieved must sooner for faster integration of the furnace into the production process.

DURATEK* Supermelt and ENERTEK* ATL crucibles

Foseco offers a wide range of crucibles suitable for all casting process and designed to offer good thermal efficiency to reduce energy consumption needed to melt and hold the liquid metal; long service life to reduce installation and maintenance downtime and raise productivity; and fast melting to improve cycle times, again improving productivity. However, for HPDC processes, the company's DURATEK Supermelt and ENERTEK ATL crucibles have particular relevance.

DURATEK Supermelt crucibles aim to solve challenges related premature and unpredictable failure of crucibles in fuel-fired aluminium melting application such as HPDC ingot melting. These crucibles are isopressed and clay bonded for superior strength, toughness, and oxidation resistance, resulting in longer service and reliability.

Meanwhile, ENERTEK ATL crucibles – part of the ENERTEK range of energy efficient crucibles for melting and holding applications – are the latest innovation to help reduce heat

loss during melt transport. This reduces the need to overheat the melt to compensate for such losses, while still maintaining the required melt temperature at pouring for high-quality casting and to mitigate the risk of temperature-related defects.

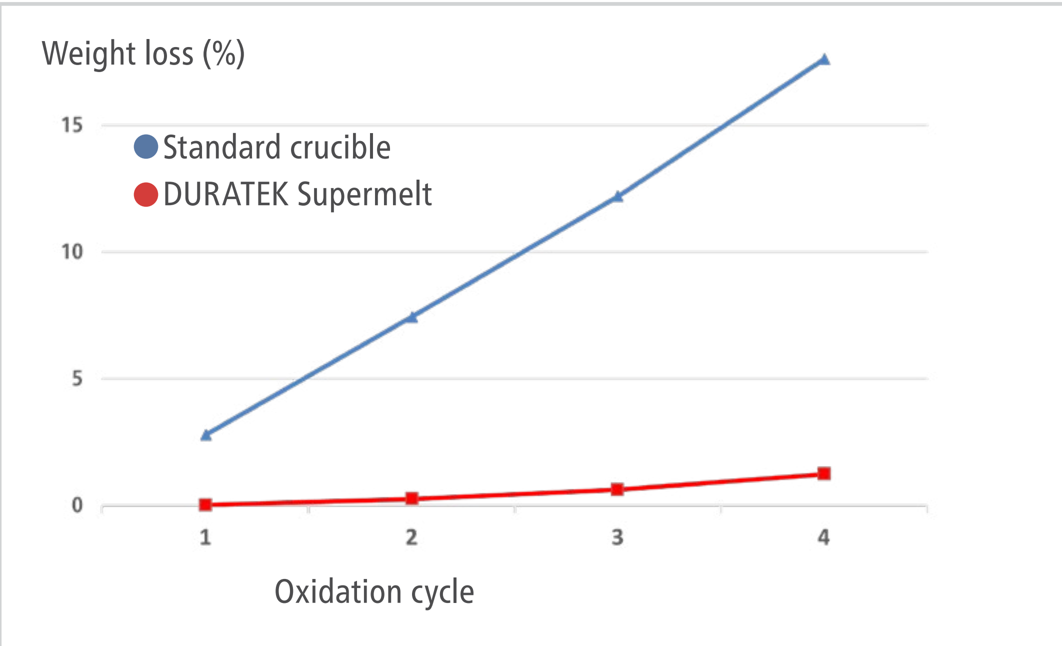


FIGURE 4. Drastically reduced oxidation

MELT TREATMENT

Melt treatment plays a critical role in enabling high-quality casting, enabling the melt shop to supply molten aluminium at a defined composition and temperature and at the right purity and hydrogen level. Moreover, as the "window for melt properties to fulfil [quality] requirements [is becoming] smaller and smaller […] a more effective and technically sound melt treatment is essential".[8] When considering melt treatment for HPDC, any process should also be highly reproducible and consistent. However, melt treatment is not a single process: it is rather a combination of different solutions that range from chemical treatments to degassing and process control, all of which must be manager correctly to produce the required result.

CHEMICAL MELT TREATMENT

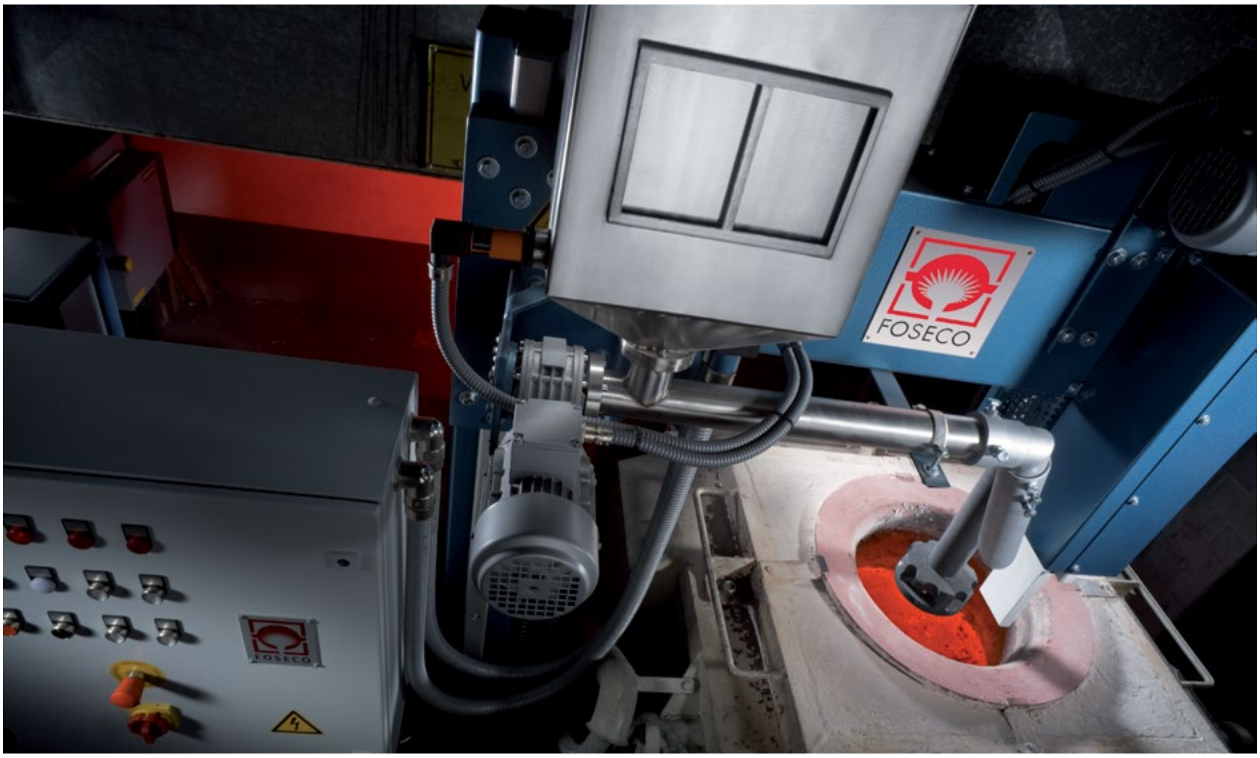
The use of chemical products – fluxes – has been accepted practice in most casting processes for decades; however, their use in HPDC applications poses a challenge. Fluxes are traditionally added manually but this relatively uncontrolled approach increases the risk of chemical inclusions in the melt that would result in quality problems during welding (pore formation) and heat treatment (blister formation) of HPDC parts. HPDC foundries have thus been reluctant to use fluxes: yet growing demand for larger and more complex castings may well demand it.

The MTS 1500 process from Foseco provides a solution to this conundrum: an upgrade to the company's FDU rotary degassing system, the MTS 1500 allows the simultaneous addition of different melt treatment products through a controlled vortex that provides effective application and mixing of the chemicals and the melt. The result is a melt with consistent mechanical and physical properties, homogeneous microstructure and composition, low oxide content, and controlled gas porosity.

In addition to these melt quality advantages, the MTS 1500 also reduces the cost of treatment as the use of chemical products is more carefully controlled (and ultimately lower) compared to manual additions. is the additional benefit of dryer dross with less retained Aluminium content further improves the cost advantage through Aluminium savings, increased productivity and reduced heat loss (higher energy efficiency).

The MTS 1500 process has been successfully demonstrated with COVERAL* granulate fluxes from Foseco, which offer a number of advantages over traditional powdered fluxes. Granulates are easier to apply and are free of fines and dust. Together with the fast vortex-induced introduction of the flux into the melt, this means less product loss and it also mitigates health and safety risks. Additional benefits include greater product consistency as granular fluxes exhibit grain chemistry entirely consistent with the flux recipe. The combination of MTS 1500 and COVERAL* granulate fluxes was proven in testing at Magna Cosma, where a significantly lower density index value after treatment demonstrated improved oxide removal confirmed through VMet analysis showing casting defects were reduced by sixfold from 460 to just 75. The project also demonstrated the melt treatment resulted in no negative impact on casting quality, weldability, or corrosion resistance.[10]

DEGASSING



Degassing forms another key element in melt treatment. SMARTT – or self-monitoring adaptive recalculation treatment – is an innovative process control method from Foseco that analyses incoming parameters (humidity, air temperature, ingot quality, melt temperature, casting requirements) and automatically calculates the appropriate parameters (rotor speed, inert gas flow rate, treatment time) to achieve target hydrogen content. Treatment can also be optimised to achieve various targets including treatment time, gas consumption, rotary speed, or standard degassing. SMARTT degassing can also be combined with MTS 1500 automated granulate flux addition.

A final element in melt treatment is the rotary degassing consumables themselves. DIAMANT* degassing rotors from Foseco are produced using an isopressed ceramic that significantly extends service life compared to graphite in demanding, high-production melt treatment applications, such as HPDC. The most recent development in the DIAMANT range are the Turbo and NINJA rotors for HPDC applications, which through their innovative designs deliver the most efficient mixing and degassing.

CORES FOR HPDC APPLICATIONS: THE WASCO WATER-BASED BINDER AND COATING SYSTEMS

One of the major limitations of HPDC casting has been the inability to produce complex internal geometries due to challenges in the production of disposable sand cores. Traditional binders either cannot cope with the extreme conditions involved in HPDC processes, or are too strong and thus difficult to remove. Salt cores are sometimes used but suffer from technical and commercial limitations.

WASCO* water-soluble binders and coatings from Foseco are designed to solve this challenge, enabling cost-effective core production for HPDC applications using standard sand core production equipment. An example of collaboration between Foseco and its foundry customers – in this case, Limatherm S.A., a Polish manufacturer of die-cast aluminium components – the WASCO sand binder system provides both sufficient strength to withstand high casting pressures, as well as fast and simple de-coring. Castings need only be flushed with water to remove the core and ensure a smooth finish. The need for mechanical force to remove sand – with the consequent risk of damage to the casting – is thus eliminated. Meanwhile, a protective coating minimises the risk of penetration defects (another risk when using sand cores in HPDC).

The development of WASCO water-soluble binders has enabled HPDC foundries to pursue ever more complex geometries, creating new opportunities for lightweighting and megacasting of large structural components. Moreover, WASCO products do not contain any hazardous materials, while the sand and water used can easily be recycled.

CASTING ANALYSIS AND PROCESS CONTROL

The casting engineering skills needed to bring high-quality and complex castings to market involve an evolving blend of technical knowledge, practical experience, and problem-solving skills, alongside advanced digital solutions. Within this latter category, simulation engineering is "a key technical element behind efforts to gain competitive advantage [...] For either new or existing castings, computer modelling with simulation tools such as MAGMASOFT™ provide invaluable insights to help manage [production] factors before committing to making pattern or process changes".[11]

When considering the design of large HPDC castings, where patternmaking changes may cost upwards of hundreds of thousands of dollars and the casting process is particularly intricate, simulation takes on a particularly acute value. Indeed, in the case of large dies, simulation may be the only cost-effective way to optimise the design and casting process. Foseco and casting simulation software provider, MAGMA, have a decades-long history of collaboration when it comes to creating value for foundries through advanced simulation, helping to improve product quality by minimising defects, increasing casting efficiency and reducing costs.

CHALLENGES FACING HPDC FOUNDRIES AND POTENTIAL SOLUTIONS

CHALLENGE	SOLUTIONS
MELT QUALITY	MTS 1500 MELT TREATMENT SYSTEM, SMARTT DEGASSING, COVERAL GRANULATE FLUXES, DIAMANT DEGASSING CONSUMABLES, INCLUDING DIAMANT TURBO AND NINJA ROTORS
CASTING DESIGN COMPLEXITY	WASCO WATER-SOLUBLE BINDERS, CASTING SIMULATION
HEAT DISSIPATION AND COOLING	INSURAL INSULATING REFRACTORIES. ENERTEK ATL
MATERIAL AND PROCESS OPTIMIZATION	CASTING SIMULATION, VMET ANALYSIS, SMARTT DEGASSING, DIAMANT TURBO AND NINJA ROTORS
HSE IMPACTS	INSURAL FURNACE LININGS, DURATEK AND ENERTEK CRUCIBLES, WASCO WATER-SOLUBLE LININGS, COVERAL GRANULATE FLUXES
QA AND INSPECTION	MTS 1500 MELT TREATMENT SYSTEM, SMARTT DEGASSING, VMET ANALYSIS

THE CONCLUSION

HPDC foundries play a critical role in manufacturing supply chains, particularly within the automotive industry, thanks to their ability to provide high volumes of high-quality castings in very short periods of time. These benefits are now prompting auto makers to push the boundaries of what is possible with the development of larger-scale and more complex HPDC castings. At the same time, the quantity of cast aluminium parts in cars is increasing – and will continue to do so – as components are lightweighted to offset the added weight of the battery in EVs, driving additional demand for high-quality HPDC castings.

With its range of solutions for HPDC foundries and tradition of innovation, Foseco is supporting foundries in their quest to take advantage of these new opportunities and deliver castings that meet the growing demands of end users. This white paper had provided a brief outline of these solutions: interested readers are encouraged to contact the Foseco team for more information and to discuss their specific challenges and needs or take a look at our brochure dedicated to our high pressure die casting portfolio.

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