ENHANCING CRUCIBLE PERFORMANCE IN NON-FERROUS APPLICATIONS

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Crucibles have an important role to play in improving the energy efficiency and environmental performance of non-ferrous casting operations. Recent technological advances have seen crucibles developed that increase thermal performance and improve the consistency and length of their operating life. Installation and operating practices are also critical to achieving consistent crucible performance however, and therefore careful attention to recommended procedures should be followed to ensure foundries get the most from their crucibles.

Figure 1: Foseco crucibles

INTRODUCTION

Crucibles have three overlapping functions within the non-ferrous foundry:

- Melting.
- Holding the melt at a specified temperature.
- Transferring the melt to the casting area.

These applications – and especially the first two – are particularly energy intensive functions. According to one estimate, melting and holding molten metal accounts for 60% of a typical foundry's energy consumption and 40% of its energy costs.[1] Improving the energy efficiency of these two processes thus carries significant advantages in terms of the cost and environmental footprint of casting production.

The job of improving a crucible's energy efficiency is not however an easy one, due in part to the competing demands posed by its role in melting and then in holding the molten metal at temperature. The first requires the crucible melt a defined quantity of alloy within a certain timeframe; any delay or decrease in performance can decrease the output and slow casting. Good heat conductivity through the crucible to the metal within is the major factor here. However, when holding that metal in molten form, the opposite is true.[2] Proper consideration of the thermo-mechanical properties of crucible design is thus essential.

In addition, crucibles should perform consistently, without excessive deterioration over time. This requires consideration of the materials and process used to manufacture the crucible, as well as the way in which they are handled. As one expert has noted, "customer practice across the industry is so variable that even correlating a furnace's efficiency to its own crucible becomes extremely difficult".[3] This reveals the importance of both proper training of operators and the application of best practices in the installation and handling of the crucible when it comes to achieving best performance.

Complicating the picture further still, crucibles are not a standard product, but are variable in size and capacity – including very large crucible sizes of more than 3 tonnes – as well as the metal being cast. This article will consider several technical innovations within the crucible space that have improved energy efficiency and operating life. It will conclude with a consideration of best practices in crucible care.

TECHNICAL IMPROVEMENTS

Most crucibles for the non-ferrous casting sector are jiggered, rotationally moulded, or isostatically pressed from clay-bonded graphite or resin-bonded silicon carbide. These materials are suitable due to their refractoriness and their compatibility with non-ferrous alloys.

Technical improvements in the production of crucibles can however gain important benefits – e.g., improved energy efficiency, increased operating life, or improved resistance to oxidation. This includes:

- Adjusting the manufacturing process to improve physical properties such as density consistency and porosity .
- Adjusting the mix chemistry and material specifications to improve the mechanical strength, fracture toughness, thermal properties, or the electrical properties of the crucible, among others.
- Optimizing the external glaze or additional protective coating according to the needs of the foundry or application.

IMPROVING ENERGY CONSUMPTION: ENERTEK* CRUCIBLES[4]

ENERTEK crucibles are a family of crucibles that are designed and manufactured to offer high thermal efficiency in both melting and holding furnace operations. The technology was originally developed for aluminium melting and holding applications, with a solution for zinc oxide production introduced in 2017 (ENERTEK ZnO, Fig 2) and more recently, a novel approach for aluminium transfer ladle applications (ENERTEK ATL).

Key benefits of the ENERTEK product line include:

- Reduced energy consumption during melting and holding due to:
  - The use of high-quality refractory materials, which are formulated to maximize thermal conductivity in any given casting application
  - Isostatic pressing in manufacture to maximize the density profile of the crucible.
- Minimal reduction in thermal conductivity over time due to refractories that are designed to withstand the effects of continuous use and aging.
- Maximized operating life and energy savings due to the proper balance in baseline thermal conductivity in conjunction with good refractory stability over time.
- Reduced carbon footprint due to improved energy efficiency and the resulting drop in energy consumption.

Figure 2: ENERTEK ZnO crucibles

In aluminium casting applications, standard ENERTEK crucibles can be applied to all standard designs of melting and holding furnaces; they are, however, particularly effective in electric resistance furnaces. Typical performance improvements over other crucible types include a 5 %-15 % energy saving and a significantly reduced temperature variation within the melt. In one example a foundry operating an electric resistance holding furnace with a target aluminium holding temperature of 677 °C observed a temperature delta of just 26 °C in the liquid metal with the ENERTEK crucible compared to a 42 deg° C variation with a conventional crucible over the same production period.

ENERTEK ZnO crucibles have been designed for use in the indirect or French process for zinc oxide manufacture, as well as the production of zinc dust. Temperatures here are significantly higher than in aluminium casting applications, reaching about 1000 °C in order to achieve vaporization of the zinc melt and consequently the energy demand in the process is significant and a major cost factor for the operation. ENERTEK ZnO crucibles are designed with high thermal conductivity and durability to ensure optimum thermal efficiency which in turn delivers energy savings by reducing the energy usage per tonne of zinc oxide output. Zinc oxide operations have also reported a higher zinc oxide output per shift due to the superior heat transfer of the ENERTEK ZnO crucibles.

ENERTEK ZnO crucibles are available in most standard shapes and capacities and can be fitted to the majority of crucible furnaces without any change to current practice.

In addition to the standard aluminium and zinc oxide ENERTEK solutions, the product line was updated in 2019 with the introduction of ENERTEK ISO crucibles for induction melting and continuous casting, and ENERTEK ATL for aluminium transfer.

ENERTEK ISO crucibles are insulating "duplex" crucibles that combine optimum physical properties, strength, and toughness with a highly insulating proprietary Vesuvius coating technology. A relatively thin layer (typically 12 mm) of this proprietary coating significantly reduces thermal conductivity of a standard crucible from 25-30 W/mK to about < 2 W /mK.

The highly insulating nature of ENERTEK ISO crucibles delivers substantial performance benefits in induction furnace operations used for melting precious metals and in continuous copper production lines. Customers testing ENERTEK ISO crucibles in continuous copper wire production were able to reduce the furnace operating temperature "set point" by over 60 °deg C, with consequent benefits for crucible life due to reduced thermal stress. An increase in casting rates and reduced scrap levels have also been observed.

ENERTEK ATL crucibles offer an alternative technology for foundries using castable lined ladles or over-road hot charger transfer ladles for melt transfer. These crucibles also use the same proprietary Vesuvius insulating coating as ENERTEK ISO crucibles (Fig. 3) and provide several benefits in the transfer ladle application - notably reduced ladle preheat requirements – both on commissioning and daily use – as well as lowering melt temperature loss to 1.5 ° C per minute, compared to 2-3 °C per minute with standard refractory ladles. They also require very little maintenance or repair when in service, and deliver improved melt quality, lower oxide build-up, and no 'off-gas' during initial aluminium transfer cycles after installation.

Figure 3: ENERTEK ISO continuous casting crucible

IMPROVING OPERATING LIFE: DURATEK* CRUCIBLES

Manufactured via a high-pressure isostatic pressing process, DURATEK crucibles are formulated to deliver longer operating life in harsh operating conditions. The range includes DURATEK PM and the recently developed DURATEK Supermelt crucibles.

DURATEK PM crucibles are resin-bonded silicon carbide crucibles, suitable for use with a wide range of alloys, including aluminium, copper, and precious metals. Benefits include:

- High density and strength.
- High thermal conductivity.
- Low porosity.
- Excellent resistance to chemical attack (e.g., from fluxing practices).
- Excellent oxidation resistance leading to long service life.

With chemical attack and erosion a particular feature of the aggressive conditions found in induction furnace applications and precious metal reclamation, refining and casting processes, DURATEK PM crucibles offer consistent performance over a longer period, for fewer planned changeovers and reduced downtime.

For example, in Miller gold refining process, extremely challenging conditions are created by the passing of chlorine gas through the melt to remove impurities. Both chorine gas and the chlorides created its reaction with impurities in the liquid metal are reactive at high temperatures with most crucible materials. However, this is not the case with DURATEK PM, which is formulated and processed to resist this harsh chemistry.

Meanwhile, in the Wohlwill process for gold refining, where high-purity gold cathodes are melted in an induction furnace to produce very pure ingots, the stability of DURATEK PM crucibles at very high temperatures – as well as their resistance to erosion and corrosion – means they do not require the usual wash-melts to achieve the finest quality gold.

DURATEK Supermelt has been designed specifically for aluminium melting applications in gas or other fuel-fired crucible furnaces. It offers longer lifetime in aggressive melting conditions enabling the foundry melting department to melt continuously over a longer lifetime. This improves melting output compared to conventional crucibles.

For example, at Mahle, a Polish piston manufacturer, the foundry melts aluminium piston scrap on an almost-continuous basis. Before the introduction of DURATEK Supermelt, standard crucibles achieved 740 cycles on average. Following implementation, the DURATEK Supermelt crucible achieved 1284 cycles – an increase of more than 70%. During the period of crucible operation the crucible experienced noticeably lower oxidation (Fig. 5) , thereby reducing the risk of oxidation inclusions.

Figure 4: Mahle and Foseco Teams after the unloading of the trial crucible.

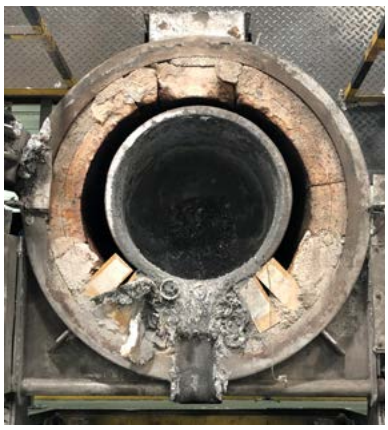

Figure 5: The DURATEK Supermelt after 1284 melt charges.

CRUCIBLE CARE: BEST PRACTICES TO IMPROVE SAFETY AND SERVICE LIFE

In addition to the technical improvements discussed above, how the crucible is installed and operated all influence the operating life of a crucible. Best practices include:

- Inspection of the crucible upon receipt.
- Storage in a dry location.
- Proper handling of the crucible using a hand cart. Crucibles should not be rolled or shimmied.
- Using the correct pedestal, which should be made of the same material and be of the right size.
- Never wedging a crucible: let is expand and contract.
- Avoiding top smothering:
  - The furnace cover or lid should not rest on the crucible wall.
  - In electric resistance furnaces, the fibre blanket should not be compressed on top of the crucible.

- Maintenance of the furnace lining to keep it in good condition and in as concentric a position as possible. This prevents flame deflection or impingement in flame-fired furnaces, and will ensure proper melting in induction furnaces.
- Careful charging of the crucible to optimize capacity and avoid damage to the crucible.
- Using a slightly oxidizing flame, which should not directly contact the crucible. To ensure this, the centre line of the burner should be at the juncture of the crucible and the base block.
- Using properly fitting shanks that support the crucible bottom at all times.
- Correct use of fluxes as per the manufacturer's instructions, which should be added to molten metal when possible.
- Keeping the crucible clean by removing the dross carefully when the crucible is hot.

CONCLUSION

Solutions to improve the energy efficiency of the metal casting process are a win-win for foundries, as they simultaneously reduce costs and carbon emissions: two of the most pressing challenges currently facing the industry. Foundries that use less energy through lower operating temperatures and enhanced heat retention also experience fewer temperature fluctuations in the process, which ultimately results in fewer casting defects – another major win.

Crucibles have a crucial role to play in tackling these challenges. Recently technical improvements are enhancing both thermal behaviour and physical endurance. However, operating practices are also a significant factor. It is thus beneficial to work with a partner who understands not only the technology but can also guide foundries in the best practices of installation, operation, and maintenance.

REFERENCES

[1] K. Salonitis, B. Zeng, H.A. Mehrabi, M. Jolly, 'The challenges of energy efficiency casting processes', Procedia CIRP 40 (2016), pp. 24-29 (p.28).
[2] B. Pinto and W. Shi, 'Thermally-efficiency crucible technology: fundamentals, modelling, and applications for energy savings', Foundry Practice Issue 266, pp. 03-12 (p. 2).
[3] Ibid, p. 2.
[4] For more on ENERTEK crucibles see: Energy efficiency considerations for aluminium and zinc crucibles, Foseco whitepaper (2021), p. 5.

ANIMATION

Experience energy-efficient performance with ENERTEK ISO and unmatched durability with DURATEK Supermelt.
Watch the animated videos to learn more!

ENERTEK ISO

DURATEK Supermelt

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