ENERTEK - a new concept in energy efficient melting and holding crucibles for aluminium

Introduction

Refractory crucibles have been used for many years in the non-ferrous foundry industry. Historically, the principal measure of a crucible's performance has been its lifetime; however, with the ever-increasing cost of energy, the thermal performance of a crucible is becoming more and more important.

ENERTEK is a new family of energy efficient crucibles that have been formulated and manufactured to offer the most thermally efficient crucible for melting and holding of aluminium. Apart from long life, ENERTEK crucibles offer significant saving potential in energy costs and the reduction of the CO_2 footprint of a foundry.

Thermal modelling

Melt rate has been one of the primary thermal performance parameters of a crucible. The rate of melting is obviously dependent on the rate of heat transfer through the crucible wall to the metal charge contained within. For a given wall thickness and uniform heat flux, the rate of heat transfer will depend on the thermal conductivity and density of the crucible. The effect of thermal conductivity and density on melt rate can be relatively easily computer modelled using a finite element analysis (FEA) technique.

To measure these parameters, an axis-symmetric model was set up in ABAQUS to simulate a simple heat up and melt event to compare the heat transfer for different crucible products. The model was set up so that the heat was applied on the external crucible surface using a constant heat flux. The amount of heat flux was first determined to obtain a realistic melt rate of about 50 kg/h based on typical furnace manufacturer specifications (Figures 1 and 2).

By entering into the model the thermal conductivity and density measurements obtained from twelve commercially available crucible products, and by keeping all other parameters constant, the difference in melt rate from the slowest to the fastest was predicted. Using this method, a group of crucible products were rated according to the calculated time taken to melt a 180kg metal charge.

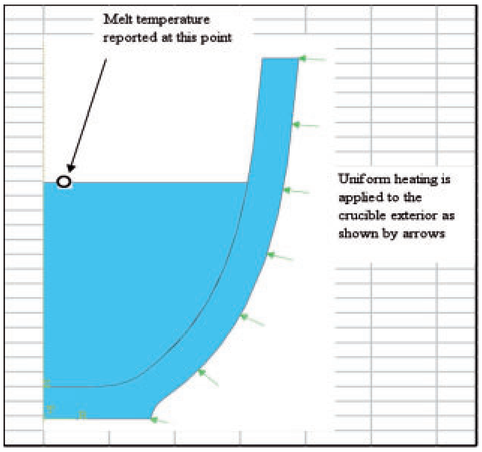


Figure 1. Schematic of FEA model parameters

Test conditions

- charge weight: 180 kg of 356A alloy at ambient temperature
- measure: melt time to achieve 750°C
- gas cost: at 0.012€/ kWh

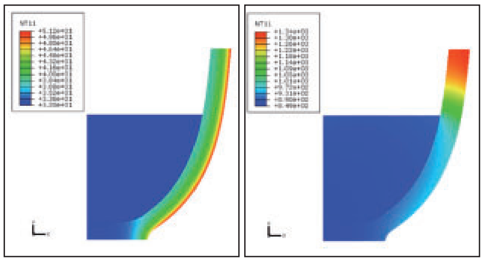


Figure 2. FEA results showing nodal temperatures at the beginning and end of the FEA experiment

This exercise demonstrated a difference of 42 minutes, or just over 20%, from the best to the worst performing crucible (Figure 3).

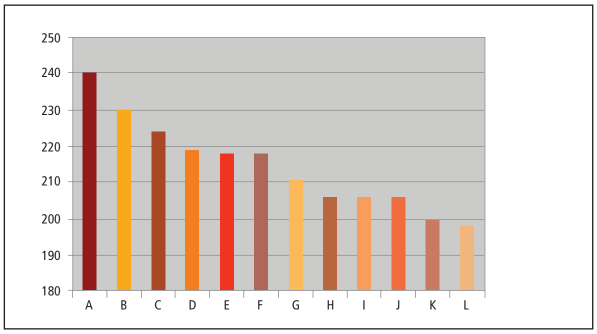


Figure 3. Time taken (minutes) to heat 180kg of metal from ambient to 750⁰C

This calculated time difference would already be significant in terms of the effect on productivity, potentially allowing for an additional heat in a normal working day. However, if the amount of energy required to perform this same operation is then calculated, a difference in cost is also evident. In this study the difference in performance from worst to best product would equate to 0.16€ to melt and heat 180 kg of aluminium. This may seem inconsequential but if this differential is maintained over a typical crucible life of 4 heats per day for 200 working days then the total difference in running costs between the "best" and the "worst" crucible can be over 175€. Perhaps not so significant by itself but multiplied by the number of furnaces, the potential for energy and cost savings will become significant.

Case studies:

Following on from the thermal modelling, foundry trials confirmed the significant potential for energy saving when using ENERTEK crucibles in comparison with conventionally available crucibles in aluminium melting and holding applications.

Case study 1:

An Aluminium Gravity Die Casting foundry using electric resistance heated 400 kg capacity crucibles to hold liquid aluminium.

A conventional crucible was run side by side with an ENERTEK crucible and the electric energy consumption measured over a 6 month period. Both crucibles were used to feed a single casting cell, therefore the amount of metal put through each crucible was identical over the test period.

Test results per furnace:	Conventional	ENERTEK	Saving
Test period (days)	180	180	
Total energy consumption (kW/h)	90,540	86,940	-3,600
= energy consumption (kWh) per day	503	483	-20
= energy consumption (kWh) per year (300 days)	150,900	144,900	-6,000
Total CO_2 emission per crucible (tonnes)	56.1	53.9	-2.2
Total CO_2 emission per year (tonnes)	112.3	107.8	-4.5
Total cost per crucible (0,08 €/kWh)	7,243€	6,955€	-288€
=Total cost per year	14,486€	13,910€	-576€

Table 1. Energy consumption and CO_2 emission comparison from Case study 1

Table 1 shows that the ENERTEK crucible consumed 3,600 kW/h less energy than the conventional crucible over the test period. This reduced energy consumption equates to both a considerable cost saving and reduction in the amount of CO_2 emissions (Figures 4 and 5).

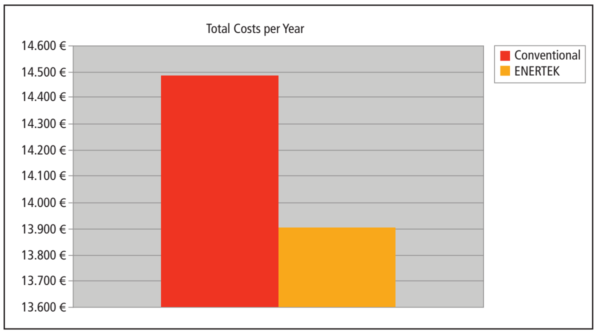


Figure 4. Summary of energy costs ENERTEK v conventional crucible - Case study 1

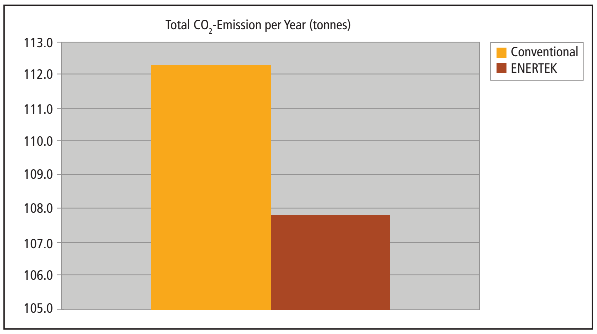


Figure 5. Summary of CO_2 Emissions ENERTEK v Conventional Crucible - Case Study 1

Case study 2:

A High Pressure Die Casting foundry melting aluminium in a tilting gas-fired furnace using a crucible of 800 kg capacity. The total gas consumption over a period of one month was measured for both ENERTEK and a conventional crucible. In addition, the amount of metal melted during each campaign was measured to enable a direct comparison between each crucible to be made.

Test results per furnace:	Conventional	ENERTEK	Saving
Molten metal in test period (tonnes):	169	212	
Total gas consumption (m^3)	34,956	36,795	
= m^3 gas per tonne aluminium:	207	174	-33
= Total gas consumption/month (m^3)	15,720	13,191	-2,529
Total CO^2 emission/month (tonnes):	39.1	32.8	-6.3
Total CO^2 emission per year (tonnes)	469.7	394.1	-75.6
Total cost per month at gas cost of 0,4€/m^3:	6,288€	5,276€	-1,012€
Total cost per year	75,455€	63,315	-12,140€

Table 2. Energy consumption and CO^2 emission comparison from Case study 2

Table 2 shows that the ENERTEK crucible consumed 33 m^3 less gas per tonne of aluminium melted, compared to the conventional crucible. As in the first case study, this reduction in energy consumption equates to significant savings in both cost and CO$_2$ emissions (Figures 6 and 7).

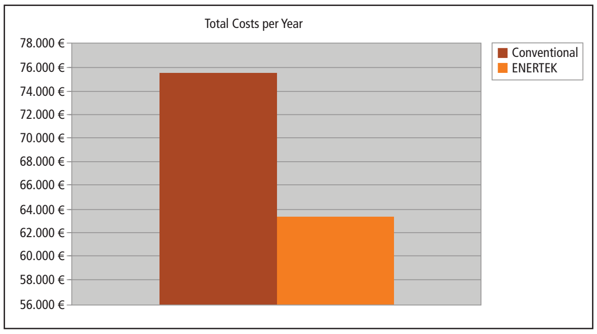


Figure 6. Summary of energy costs ENERTEK v conventional crucible - Case study 2

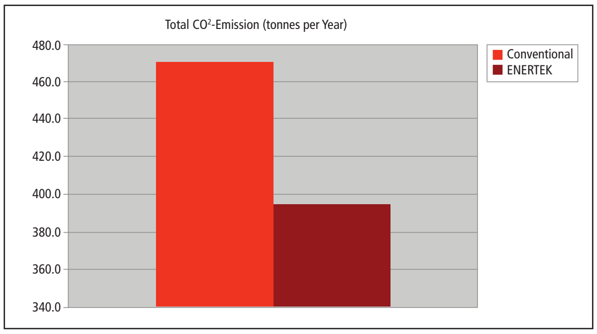


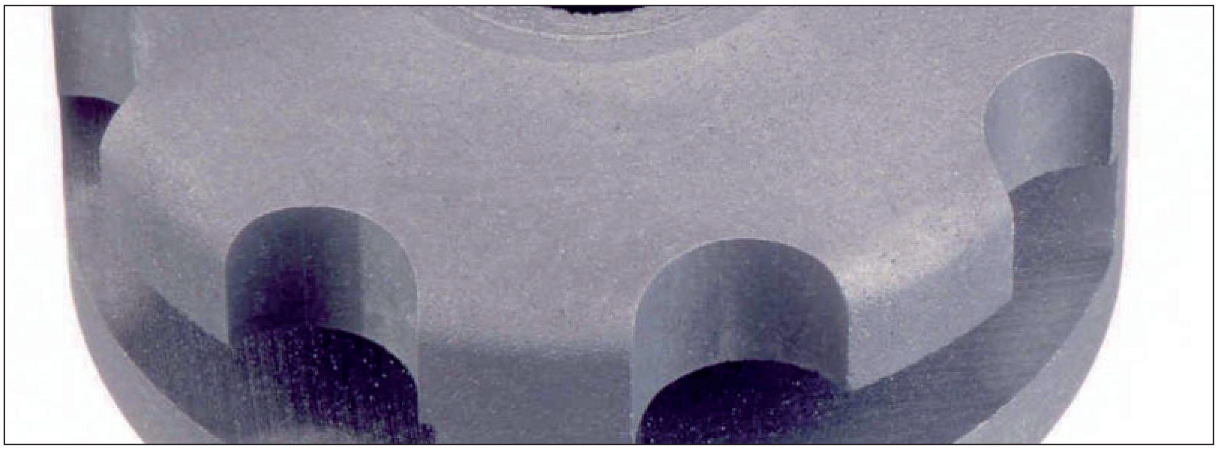
Figure 7. Summary of CO^2 emissions ENERTEK v conventional crucible - Case study 2

Summary

With energy costs continuing to increase, thermal performance is rapidly becoming the most critical operating parameter for crucibles. Computer modelling simulations have been used to demonstrate the large variation in thermal performance that exists in the current range of commercially available crucible products.

The potential for energy and cost savings suggested by the modelling work has been confirmed in foundry trials and show that ENERTEK crucibles offer significant savings and reductions in CO$_2$ emissions compared to conventional crucibles.

The technology of batch degassing for hydrogen removal from aluminium melts utilising different rotor designs



Introduction

Rotary degassing of liquid aluminium alloys is a widely used commercial process to control levels of hydrogen, alkali metals and inclusions in the melt prior to casting. A comprehensive theoretical understanding of the kinetics of aluminium degassing has been established in the past twenty years. Whilst there have been some published experimental tests of degassing theory in molten aluminium, in many cases key pieces of information are not reported or determined, such that a critical assessment of the underlying theory is compromised. Similarly, practical implementation of such understanding in usable shop-floor process models has met with difficulties owing to lack of knowledge concerning some key parameters. These include the stirring intensity dissipated in the melt, and its relationship to the average gas bubble size, and the mass transfer coefficient at the free surface of the melt.

A selection of different Foseco degassing rotors have been characterised in a comprehensive experimental program. The study resulted in an Internet based simulation software for the degassing processes in foundries; the elements of this simulation are presented in this paper.

Gas porosity and inclusions

The key attribute for early aluminium applications was primarily aesthetic, as surface porosity was unacceptable for ornamental applications. The development of the electrolytic production route and dramatic cost reductions led to an increasing range of engineering applications. Slowly, an empirical understanding emerged that certain practices applied to molten alloys could harm performances. Slow cooling of large castings could also be detrimental, or different alloys varied in their ability to fill the mould.

In foundries today we recognise two major issues of molten metal quality; gas content and inclusions. The presence of porosity became even more problematic when age hardening alloys were developed, because near surface porosity invariably blistered on the surface. Additionally, a significant loss of mechanical properties, such as tensile strength was found with increasing porosity levels.

Figure 1. Surface porosity visible on a casting

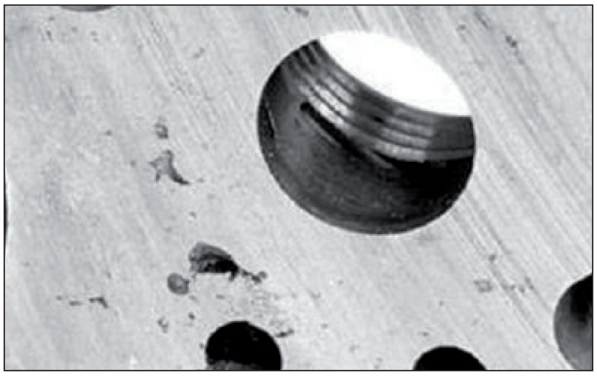


Figure 2. Internal porosity visible on a machined face

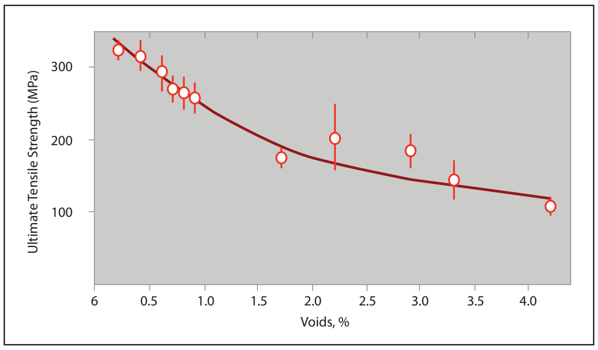


Figure 3. Tensile strength vs. porosity level [1]