

Opticast for optimised aluminium grain refinement

Opticast has proven to be capable of achieving significant reductions in the level of grain refiner additions in cast houses without the risk of ingot cracking by assessing the potential nucleation content in the furnace melt and using this to calculate the additional grain refiner needed to produce the required grain size of the cast.

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The Opticast system is a unique technology and methodology for the in line control and optimisation of grain refinement in aluminium alloys. It was originally developed from research carried out at Stockholm University, by Lennart Backerud and his co workers.

Over the past few years the system has been extensively further developed and tested in production trials, instigated and monitored by Opticast Aluminium AB and MQP, and also successfully adopted into routine production at cast houses.

The aim of this article is to provide an insight into the basic theory and technology behind the system, how it is implemented in the cast house and provides detailed results and implications from an industrial cathouse where today it is routinely used to monitor each cast.

It is also shown how the Opticast system can be used to provide valuable comparative data on the performance of commercially available master alloy grain refiners.

BACKGROUND

Grain size is one of the most important properties of an aluminium ingot. Apart from its impact on further treatment of the ingot, it is also critical that the grain size is fine enough to avoid ingot cracking during casting.

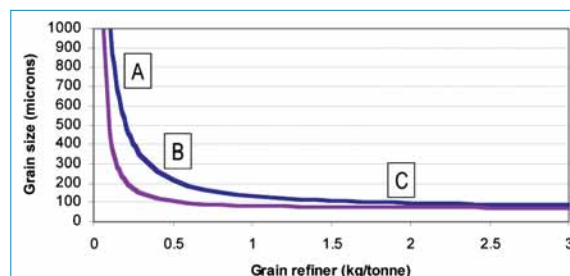
Often when problems with hot tears and cracking arise, the most common remedy is to add more grain refiner. However, the real cause of the problem may not be related to the grain size. There are several other factors that may be involved, such as incorrect temperature of the cooling water or melt, or high level of gas or inclusions, but these are much more difficult parameters to deal with from cast to cast.

The real problem with 'temporary' increases of grain refiner additions is therefore that they tend to remain permanent. During the period of an enhanced grain refiner addition level, the real cause of the cracks may at the same time be eliminated and a false impression is created that the increased grain refiner addition was the answer to the problem.

The only way to deal with the problem of cracks in relation to the grain size of

the cast is to control the grain size from cast to cast. This is what the Opticast system offers. Each melt is sampled in order to control the inherent grain refinement effect of nucleating particles already present. It is then possible to calculate the amount of grain refiner needed to obtain a desired grain size in the final product.

The Opticast system has been developed for the optimisation of grain refiner additions to all casts of wrought aluminium alloys and is particularly valuable where charges containing some aluminium scrap, with variable amounts of potentially nucleating borides, are involved.



1 Grain refinement curves for two alloys. Regions A, B and C are explained in the text

THEORY

Grain refinement is the combined effect of:

- nucleation and,
- growth.

Based on an understanding of the basic mechanisms of grain refinement^(1,2) the inherent grain refining ability of a given melt can be enhanced by:

- Determining and adjusting the factors controlling the growth rate of the nucleated aluminium crystals;
- Adding sufficient nucleating particles to obtain the desired grain size.

The growth rate of crystals is controlled by the 'Growth Restriction Factor' (GRF), which is related to the solute diffusion layer that builds up ahead of the growing crystal front.

The element titanium (Ti) has a higher growth restriction effect than any other element. Most grain refining agents

therefore contain an excess of Ti, which goes into solution in the melt. Thus, the GRF can be controlled in an easy way by increasing the amount of Ti in the melt with a master alloy or a titanium briquette.

Each aluminium alloy responds differently to additions of fresh nucleants but the basic shape of the grain refining curve remains the same. This is shown in grain refinement curves for two alloys (Fig 1), where the change in grain size is plotted versus the amount of grain refiner added.

In this graph there are three distinct regions:

- A - The very steep slope leading from large grain sizes to a transition region which is where the effect of new nuclei is predominant.
- B - In this region the GRF becomes more dominating and there are differences between alloys depending on their composition, ie influence of the GRF factor.
- C - Very little happens to the grain size in this region, since the melt has in principle been saturated with nucleants.

In the background calculations used to apply the Opticast system the three regions of the curves are dealt with by the use of either linear approximations or by applying the general equation for the grain refinement curve.

OPTICAST METHODOLOGY

Implementing the Opticast system in the cast house comprises the following steps:

- Calibration;
- Sampling in the casting furnace.

Calibration: The calibration involves establishing how a specific alloy responds to addition of fresh nuclei via the grain refining rod that means finding the equation for the grain refinement curve of the type shown in Fig 1. Furthermore, it is also important to consider the layout of the casting line and how it influences the recovery of the grain refiner used. The calibration routine in the Opticast method is designed to take care of these parameters.

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Sampling in the casting furnace: After calibration the normal sampling commences. This involves taking a sample from the casting furnace, solidifying it and assessing its grain size using an image analysis system. The Opticast samples for calibration and the furnace samples, are taken with specially designed stainless steel crucibles. The solidification characteristics in these will result in a final grain size which is comparable to that encountered close to the centre of the standard slab in the actual cast house. However, the whole range of various cast sizes, in slabs as well as billets, can be covered by applying correction factors to the grain size in a single Opticast sample.

The grain size measured is then used to establish the rod-feeding rate of the grain refiner for the actual charge by using the equation derived from the calibration stage. The total time for treating a sample is around 10 minutes, depending on the cast house routines and operator's experience. This has been shown to be more than enough time, since melt conditioning and adjustment of melt composition normally takes longer than this.

One of the main advantages of the Opticast system is that it can be implemented at a cast house without necessitating extra personnel or large capital expenses. After a short introductory period, normally less than two weeks, workers at the casting line or technical staff, are able to perform the sample preparation and grain size analyses on a routine basis. The method can thus be put into full operation within a very short period, which gives a rapid and ongoing payback on investment.

OPERATING RESULTS

The system is presently in commercial use at three cast houses and long term tests have been performed at ten other cast houses. At all places the method has shown to be able to markedly reduce the average amount of grain refiner added. This means also that the level of boride particles is decreased which can be a significant quality advantage in terms of melt cleanliness.

An additional benefit is the consistency of grain size in the final casts, which also means a quality improvement, since the properties of the cast product are more uniform.

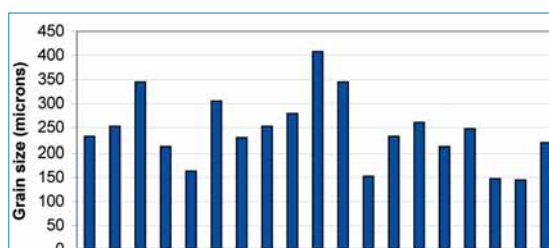
Fig 2 shows typical grain sizes in furnace samples collected from twenty AA5000 alloy charges. These are taken from production runs at AMAG, Austria, prior to the Opticast treatment being implemented. As can be seen the grain sizes vary widely, which is common to all alloys produced at remelters.

By applying the Opticast algorithm obtained from calibration, the necessary addition of grain refiner is calculated for each charge as shown in **Fig 3**.

In the normal cast house practice at

Alloy type	Standard additions (kg/t)	Optimised additions (kg/t)
AA1000	0.6 - 2.0	0.2 - 0.5
AA2000	1.0 - 2.0	0.3 - 0.5
AA3000	0.6 - 1.5	0.4 - 0.6
AA5000	0.5 - 3.5	0.1 - 0.4
AA6000	0.6 - 1.7	0.4 - 0.6
AA7000	0.6 - 2.8	0.3 - 0.7
AA8000	0.6 - 1.2	0.3 - 0.5

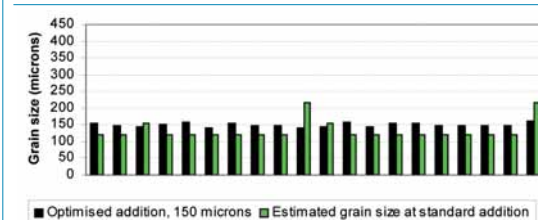
Table 1 Standard vs optimised grain refiner addition rates



2 Grain sizes in furnace samples taken from 20 different charges of an AA5000 series alloy prior to implementation of Opticast



3 Grain refiner addition rates for the charges in fig 2 in order to obtain a 150µm grain size



4 Grain sizes after optimised additions compared with estimated grain sizes, in absence of optimisation

AMAG, the standard addition rate for this alloy was 0.6kg/t but the average of the calculated additions shown in **Fig 3** is only 0.3kg/t. This indicates that theoretically a reduction of 50% in grain refiner additions is possible for the 5000 series alloy when aiming at a final grain size of 150 microns in each cast. This was confirmed by making the predicted additions and taking samples in the casting launder after the addition of grain refiner (**Fig 4**).

As can be seen, the desired final grain size of 150µm has been achieved in all cases with a total spread of $\pm 10\mu\text{m}$ after applying the Opticast system.

A very important point is that in two of the casts the optimised addition from the Opticast system was actually higher than the previous standard rate, (around 0.8kg/t versus 0.6kg/t) (**Fig 3**). It follows that by applying grain refiner at the standard rate, the grain sizes in these casts would have been substantially larger than the specified 150µm grain size, with a

considerable risk of ingot cracking.

Since the addition of grain refiner is individually adjusted for each cast when the Opticast system is used, it means that in most cases significant reductions in grain refiner addition levels can be obtained. The amount of savings depends on how much scrap is used in production and the quantity of potent nuclei left in the scrap and of course the existing practice at the cast house prior to adopting the Opticast system.

At the remelters investigated the average scrap ratio was over 50% and various standard practices had evolved at each cast house. The standard addition rates varied within wide limits. This is shown in **Table 1**, together with the proposed additions after optimisation with the Opticast system.

The range given for the standard additions, illustrates the large variation in the grain refinement practice from cast house to cast house.

On the other hand the range shown for the additions optimised according to the Opticast system are due to

variations in scrap ratio in the charge make up and variations in the level of active nuclei in the scrap.

It should be pointed out that a general decrease of the addition levels to the low levels in the right hand column of **Table 1** could increase the risk for cracking in charges with a low level of potent nuclei and the only way to avoid this is to monitor each charge using the Opticast system.

PERFORMANCE OF MASTER ALLOY GRAIN REFINERS

As explained above, in an industrial cast house the Opticast system can be used to determine the precise addition of master alloy grain refiner rod required to achieve the target level of grain size in aluminium alloys. It is obviously essential therefore that the grain refiner used has a consistent level of performance in terms of grain refining effectiveness.

Using the Opticast system, work has been carried out to check and compare the grain refining effectiveness of

CASTHOUSE

Titanium-Boron (5/1) rod from different manufacturers.

This involved adding small pieces of master alloy rod to 100g of molten aluminium alloy, of known furnace grain size, in an Opticast crucible at addition levels from 0.1kg/t to 1.0kg/t. The melts were stirred and a standard contact time of one minute observed.

A total of 24 samples of 5/1 Titanium-Boron rod from four different manufacturers were considered. Additions were made to seven different alloys, of various compositions, to give final boron levels from 1ppm to 10ppm. Grain sizes were plotted against boron additions as shown for the alloy containing 2.4% zinc (Fig 5).

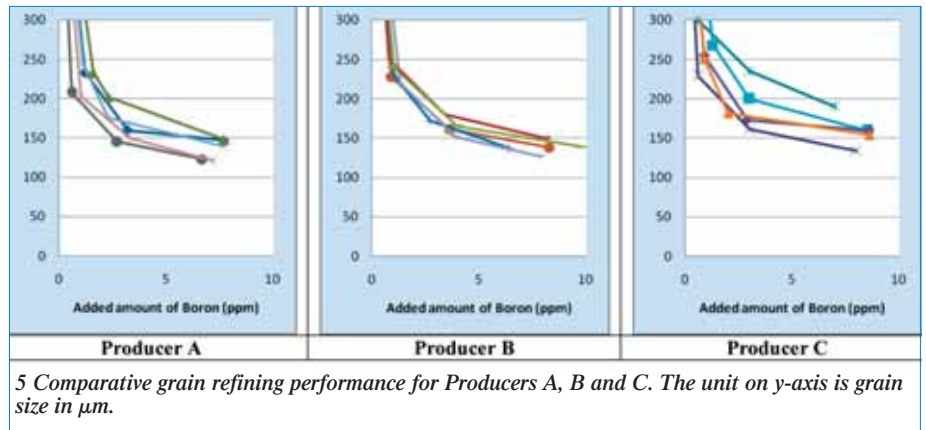
Clearly in this series of plots the consistency of grain refining efficiency is superior for master alloys from Producer B. However, the grain refiner efficiency varies markedly and this is better illustrated by plotting the added amount of boron against the number of efficient nuclei added ie how many of these actually nucleate an aluminium crystal (Fig 6).

It is evident from Fig 6 that even though the grain size consistency is excellent for Producer B the efficiency is not the best. Producer A has a larger spread of efficiencies but also two of the most efficient grain refiners.

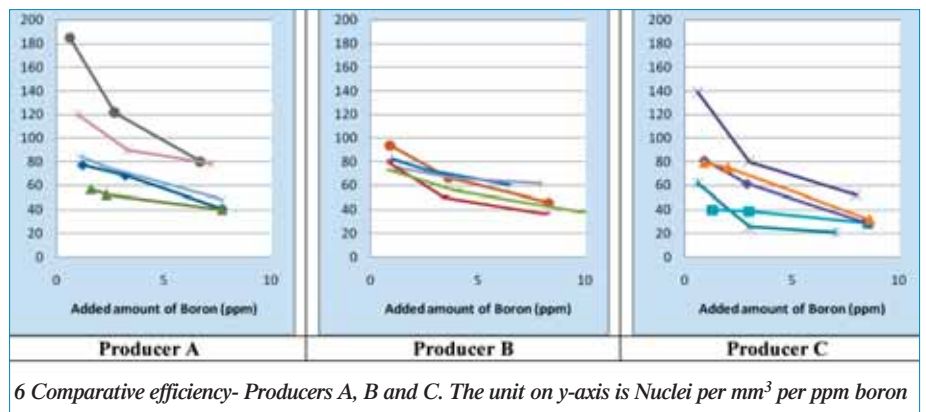
Thus, the Opticast system can also be used to generate valuable data on the comparative performance of commercial grain refiners.

In conclusion, Opticast has proven to be capable of achieving significant reductions in the level of grain refiner additions in cast houses without the risk of ingot cracking. The direct consequences of this are:

- Cost reductions-which can be substantial and ongoing.
- Quality increases- due to decreased titanium boride additions
- Quality increases- due to reproducible



5 Comparative grain refining performance for Producers A, B and C. The unit on y-axis is grain size in μm .



6 Comparative efficiency- Producers A, B and C. The unit on y-axis is Nuclei per mm^3 per ppm boron

- grain sizes in casts
- Since the grain refiner addition is tailored for each charge, ingot cracking due to large grain sizes in the final casts, is eliminated.
- The Opticast system can be implemented at a cast house without requiring extra personnel to be employed and provides a quick return on the initial investment cost.
- Opticast can also be used to generate valuable data on the comparative performance of commercial grain refiners.

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