OPTIMISATION OF GRAIN REFINEMENT

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Abstract

Considerable progress has been made in recent years with the optimisation of grain refinement practice. In the past this could only be done by trial and error which is time consuming and far from ideal. More recently it has been possible to study and quantify the various factors affecting grain refinement including melt nucleation level, growth restriction, and grain refiner recovery, in line treatments and potency and variation in grain refiners with the help of the Opticast technology which allows data to be generated from sampling the melt in real time. It has been found that whilst it is useful and necessary to quantify the foregoing furnace factors it is equally necessary to control grain refiner variation in order to achieve a fully optimsed result and to support this, a new grain refiner, Optifine, has been developed and introduced in a number casthouses. The results from two casthouse where these techniques have been applied are reviewed.

Introduction

The sole purpose of grain refinement is to obtain a grain size in the final slab or billet that prevents the cast from cracking during casting and subsequent treatment, e.g. rolling and extrusion. This should be done with as small amount of grain refiner as possible. There are two reasons for this: 1) decrease the cost for grain refinement and 2) minimize the amount of impurities added to the melt.

Regarding the second point, it is known that the boride particles added via the grain refiner rod degrade the quality of the final product regarding surface finish. This is especially evident in bright trim alloys and other products where the demand on surface quality is high. Other defects are pinholes in foils and can stock alloys. High addition rates can also have a negative impact on the mechanical properties, since boride particles, not active in the nucleation process, will end up in the grain boundaries of the solidified material.

The Opticast method has been successfully applied as a production tool at AMAG (Austria) since 2002 and at Hulamin (South Africa) since 2005 and is a means to decrease master alloy additions in a controlled way. The technique has been discussed in a number of papers [1-6] and its primary goal is to optimize each cast by adjusting the master alloy addition rate so that a minimum amount of grain refiner is added without risk for cracking.

The experience from Opticast optimization work at 23 cast houses around the world has shown that there are at least three crucial measures that must be taken to reach this goal:

- Control the growth restriction conditions in the melt
- Choose the most efficient grain refiner
- Choose the optimum spot to add the refiner

This paper will focus on how the combination of using the Opticast method to optimize grain refiner addition rates and choice of a potent grain refiner, Optifine, can dramatically reduce the amount of grain refiner needed to obtain an acceptable grain size.

Theory

Growth restriction (Q), which decides how fast nucleated crystals will grow, has a very large impact on the final grain size [7]. This parameter is essentially a function of the melt composition and in principle it can be stated that the higher the concentration of alloying elements, the larger the growth restriction. However, the growth restriction imposed by the alloying elements varies in a large range. GRF or the Q factor is expressed in the following way:

$$\mathbf{GRF = Q = \Sigma(k_i\text{-}1)m_iC_i}$$

Where C_i refers to the concentration of each individual element present in the melt and k_i represents the distribution coefficient for each element in the binary Al-i system and m_i is the slope of the liquidus line. Table 1 shows the growth restriction effect for some common elements in aluminium alloys.

Table 1. Phase diagram data.

Element	k	m	(k-1)m
Ti	9	30.7	245
Si	0.14	-7.1	6.1
Mg	0.51	-6.2	3.0
Fe	0.02	-3	2.9
Cu	0.17	-3.4	2.8
Zn	0.4	-1.6	1.0
Mn	0.94	-1.6	0.1

Ti has a much 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. As a conclusion, the Q-factor can be controlled in an easy way by adding the required amount of Ti in the melt. The necessary Ti level to achieve optimum growth conditions depends on the composition of the actual alloy. AA1000 and AA3000 series require more Ti in solution than AA6000 series alloy, whereas AA2000 and AA7000 series alloys require no extra addition of Ti at all. It is important to notice that the change of growth restriction by adding titanium can be done with concentrations that will have no impact on the properties of the cast; it will only create optimum conditions for the growth of aluminium crystals.

An Al-Ti-B master alloy contains two forms of crystals in an aluminium matrix, Al_3Ti(aluminides) and TiB_2(borides). The relative proportions of these crystals depend on the Ti and B concentrations, which normally vary in the following intervals: Ti:1.5-10% and B:0.2-1%. The by far most common master alloys used in are of the 5/1 and 3/1(%Ti/%B) type.

When added to an aluminium melt, using a standard addition rate of 0.1 to 2 kg/ton, the aluminide crystals are rapidly dissolved and the borides crystals are dispersed into the melt. According to present day theory, as presented by Greer and co-workers [8], there will be thin residues of Al_3Ti left on the borides, actively taking part of the nucleation process when the melt solidifies.

There are a number of factors that determine the efficiency of a master alloy. Two of the most important are the frequency of agglomerates and the boride particle distribution as a whole.

This was discussed in a previous paper [4], where it was stated that a narrow particle distribution was necessary in order to obtain optimum grain refining properties for a grain refiner. The background for this is that the size of a particle decides at what undercooling nucleation will start. When aluminium crystals are formed on the large boride particles, the solidification heat will mask off the possibility for the smaller crystals to nucleate aluminium. Greer et al [9] suggest that a highly efficient grain refiner can be produced, if the borides are confined to a very narrow size range.

The grain refiner can be added at several points in a casting system: before or after a degasser, before or after a filter. In the degasser the recovery will be affected by degassing parameters, e.g. gas composition, bubble size, size of the melt reservoir, melt throughput etc. and the recovery at the filter will primarily be dependent on the pore size, amount of grain refiner added and the melt flow rate. This means that each casting line has to be evaluated regarding these factors in order to find an optimum addition spot. In many places, a favorable place is before the degasser, since the intensive stirring in this promotes a good dispersion of the boride particles. This depends on degasser type and settings. However, there are examples of degassing equipment that enhance the agglomeration of borides thereby increasing the risk of entrapment in the degasser.

The problem associated with filters is the capturing of borides which decrease recovery and also can cause “showers” of boride particles when these particles suddenly break loose from the filter. Particle showers are very detrimental to the final quality of the cast. This may occur if the filter is disturbed mechanically or if the melt flow changes suddenly. There is a close correlation between the problems encountered with filters and the grain refiner addition rates. A high addition rate will lead to a higher degree of captured borides and thus an increased release of particles and thereby a decrease in the quality of the cast.

The ideal situation would be a rapidly dissolving, clean grain refiner which allows a fast dispersion of equally sized boride particles. This could then be added after the filter, which would then eliminate the risks discussed above. However, in practice casthouses are reluctant to do this because there is always some risk. An alternative approach, utilizing a three stage filter with the grain refiner added in an intermediate chamber is described elsewhere [10].

All these considerations have led to the development of a special master alloy, exhibiting a markedly higher potency, Optifine. This master alloy is now used in full scale production at a number of plants.

The process of optimization is described in the following sections starting with a description of the Opticast method followed by a background to the development of Optifine and lastly two case studies are presented, detailing the practical industrial application of the process.

The Opticast method

A detailed description of the different steps in the Opticast method and how it is implemented in the cast house is found in reference [3]. Briefly, it consists of the following steps:

- Calibration
- Sampling in casting furnace

Calibration

The calibration involves establishing how a specific alloy responds to addition of fresh nuclei via the grain refining rod, i.e. finding the equations for the grain refinement curves as shown in figure 1. The figure shows a test with two different grain refiner batches in the same alloy melt. If both grain refiners are used in a cast house, the calibration must be done to handle any variations in the grain refiner efficiencies, i.e. a worst case scenario. In the actual case, this means that the calibration equation must be set up for the upper of the two curves and is used for the other one as well. The practical implication of this is that there is much to gain if the grain refiners used have a constant high efficiency, e.g. Optifine, which will be treated in more detail later in this paper.

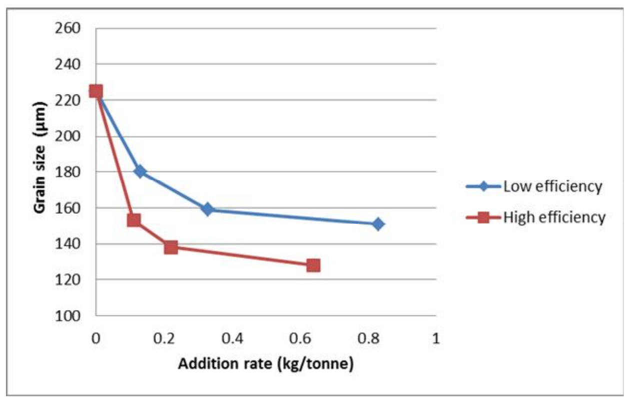

Figure 1. Grain refiner curves for two master alloys with different efficiency.

For the calibration, 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.

Sampling in casting furnace

After calibration the normal sampling commences. This involves taking a sample in the casting furnace and determining the grain size in this. This grain size is then used to establish the rod-feeding rate for the actual charge, by using the equation found from calibration. The total time for treating a sample lies around 10 minutes, depending on the cast house routines and operators experience. This has shown to be more than enough time, since melt conditioning and adjustment of melt compositions always take longer time and the Opticast sample can be taken before this.

The Opticast samples, for calibration as well as 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 center of a 400 mm thick slab. However, the whole range of various cast sizes, in slabs as in billets, can be covered by

applying correction factors to the grain size in a single Opticast sample.
One of the main advantages of the Opticast method is that it can be implemented at a cast house without necessitating extra personnel and/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, with support and advice from Opticast from time to time. The method can thus be put into full operation within a very short period, which gives a rapid and continuous payback on investment.

Results

The Opticast method is in commercial use at three cast houses and long term tests have been performed at four more. At all places the method has shown to be able to markedly reduce the addition level of grain refiner. This means also that the level of impurities, i.e. boride particles, is decreased and therefore the quality of the casts is raised. An additional benefit is the consistency of grain size in the final casts, which also means a quality improvement, since the properties of the casts are more uniform.
Figure 2 shows typical grain sizes in furnace samples collected from 20 AA5000 alloy charges. These were taken from running production at AMAG, Austria, where the Opticast method is used to continuously monitor each cast.

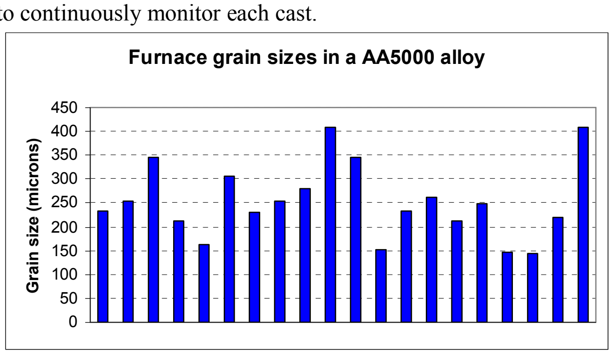

Figure 2. Grain sizes in furnace samples taken from 20 different charges of an AA5000 series alloy.

The furnace grain sizes vary widely, which is observed for all alloys at all remelts. The reason for this is that the charge make-ups will vary widely, from fully scrap based to charges made up from pure aluminium metal and master alloys.
By applying the Opticast algorithm obtained from calibration, the necessary addition of grain refiner was calculated for each charge, see figure 3.

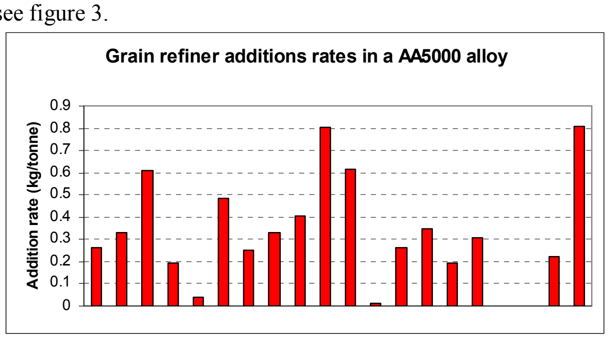

Figure 3. Grain refiner addition rates for the charges in figure 2 in order to obtain a 150 micron grain size.

In the actual cast house the standard addition rate for this alloy was 0.6 kg/ton but the average of the additions shown in figure 3 is only 0.3 kg/ton. Thus a reduction of 50 % was obtained for the 5000 series alloy.
The aim was to obtain a final grain size of 150 microns in each cast, which was confirmed by taking samples in the casting launder after the addition of grain refiner, see figure 4.

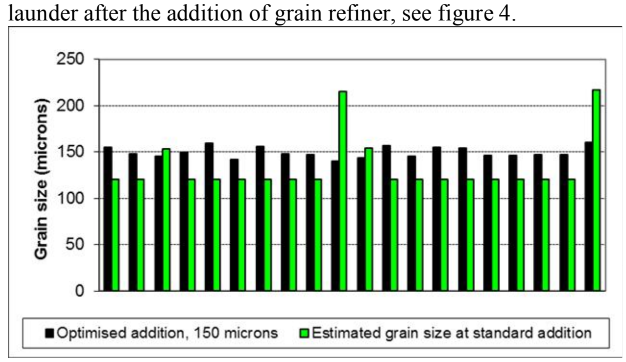

Figure 4. Grain sizes after optimized additions compared with estimated grain sizes, in absence of optimization.

The total spread in grain size values was 150±10 microns after applying the Opticast method. A very important point is that in two of the casts the optimized addition rate was substantially higher than the previous standard rate, around 0.8 kg/ton versus 0.6 kg/ton, which is shown in figure 3. Thus, by applying the standard rate, the grain sizes in these casts would have been substantially larger than the stipulated 150 micron grain size, with a possible risk of ingot cracking.
The foregoing example is typical of the results of optimization work carried out in remelt casthouses. The variation in furnace nucleation level will lead to grain size variations in furnace, in the actual case from less than 150µm up to over 400µm. Of course, this will have a large impact on how much grain refiner is needed, since the 150 µm will require no addition at all, while the large grain sizes will require more than the previous maximum addition. However, in our optimization work we found that there was a similarly large variable factor due to the range of efficiencies encountered in different batches of grain refiners themselves.

The development of Optifine

A large number of grain refiners from all major producers have been tested and two different test methods have been used. By taking Opticast samples during production casting, before and after the rod addition point, the efficiency of a grain refiner can be evaluated. The other method utilizes the crucible method, described in detail in reference [5], where melt samples are taken in Opticast crucibles containing 100 g of melt and master alloy pieces are added to these, in concentrations simulating the normal addition rates for the alloys in question. The two tests are often performed on the same production cast. The results have shown that the grain refinement efficiency varies markedly between master alloys, even if they are of the same nominal composition and from the same producer. These differences are mainly consequences of variations in base materials used and the production route.
During Opticast optimization work in laboratory scale and numerous tests at cast houses around the world a small number of very potent grain refiners have been identified. Seen on a relative

scale, the efficiency is at least twice, sometimes up to thirty times higher than the standard refiners normally used.
These master alloys have been used as reference materials in all tests and so far no grain refiner has been found that could match their efficiency. They are produced via a special production route, which optimizes their nucleation efficiency and are currently marketed under the name Optifine.
The Opticast sampling technique has been designed to give a slow solidification rate, in order to exaggerate grain size differences, i.e. as compared to rapidly cooled samples. Before sampling, the crucible is preheated to the same temperature as the melt. After the melt is collected, the crucible is placed on an insulating refractory material. The melt is allowed to solidify and the crucible must not be disturbed during this time period.
Regarding ordinary slab casting, the grain size in Opticast samples corresponds well to the grain sizes obtained close to the centre of 400 mm thick slabs. Thus, for the AA1050 tests discussed below the grain sizes will correlate fairly well to those found in the slabs. For billet casting there will be a large difference in grain size between the billet and the Opticast sample. The grain size in the latter will typically be 80 to 100 µm larger compared to the grain size in the corresponding billet. However, the cooling rate of the Opticast sample can be accelerated in order to get a closer correspondence in grain size, or a factor may be applied in order to adjust the grain size reading.
When the Opticast method is implemented in a cast house, the method is calibrated against the actual casting conditions. In the work presented in this paper, all samples have been cooled similarly, since it is the difference between the grain refiners that is in focus for this paper. The relative efficiencies of the grain refiners will, however, be the same regardless of casting operation and cooling.
All grain size measurements reported in this report have been performed using the line intercept method and at least 150 grain boundaries are measured for each sample.

Results and Discussion

Three sets of results are presented here:

- Grain refiner comparisons in anAA1050 alloy
- Case study 1: Hulamin, a remelt cast house
- Case study 2: Eti Aluminium, a smelter casthouse

<u>Grain refinement tests in AA1050</u>

A number of Ti/B=5/1 master alloys from two producers were obtained from the stores of a cast house and compared with two Optifine grain refiners. The latter are of the Ti/B=3/1 type and the results are shown in figure 5.To clarify it must be stated that Optifine master alloys are available also as 5/1, which have very similar nucleation characteristics as the 3/1 alloys used in experiments presented in this paper.
In figure 5, alloy number 1 is from one producer while master alloys number 2 to 8 are from another producer. It is evident that the efficiency of the two Optifine grain refiners is markedly higher compared to the others.

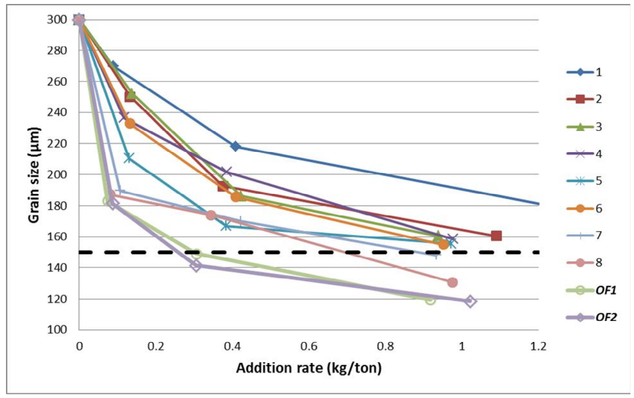

Figure 5. Opticast crucible tests during production cast of alloy AA1050, master alloys 1 to 8 are Ti/B=5/1 master alloys. OF1 and OF2 are two Optifine master alloys, Ti/B=3/1.

If it is assumed that the required grain size in the final ingots corresponds to a 150 µm grain size in the Opticast samples, as shown by the horizontal hatched line in figure 1, then it is possible to calculate how much is needed of each master alloy. The point where the horizontal line hits the grain refinement curve gives the amount of grain refiner necessary, which is shown in figure 6.

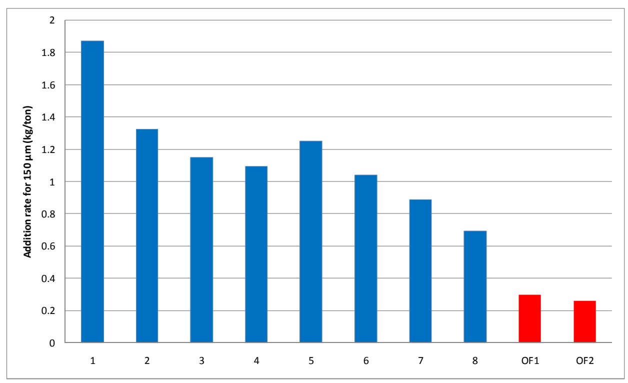

Figure 6. Necessary addition rates to obtain 150 µm grain size. Based on grain refinement curves in figure 1.

Thus this evaluation method has shown that the variation in grain refiner efficiency leads to the fact that only 0.3 kg/t is needed when using the best alloy, while up to 1.8kg/t of the less efficient master alloys is required to produce a grain size of 150µ; or referring to figure 5 a 0.3kg/t addition of a range of grain refiners with varying efficiencies will result in a final grain sizes between 150µ and 240µ.
However the highest degree of optimization can be achieved by applying the Opticast method together with Optifine thereby eliminating variations due to both melt nucleation level and grain refiner efficiency. Referring back to the theory section it is also necessary to consider the effect of growth restriction factor. Growth restriction factor in remelt casthouses is typically quite adequate because of the presence of higher titanium levels in the scrap charge; this will of course vary with the make-up of the charge and will be significantly less where a high proportion of prime metal is included. On the other hand, in smelters the titanium level present from the plotlines is usually in the range of 10-20ppm which is rather low for adequate growth restriction; and

as a result some casthouses make an addition of titanium waffle or tables to bring the titanium level up to 40-50ppm as a minimum.
To look at the effect of the above factors in practice two case studies are presented: one from a remelt casthouse, Hulamin, and the second from a smelter: Etui Aluminium.

Case study 1 A remelt casthouse – Hulamin

The details for the tests performed and the implementation of Optifine is found in reference 6. The campaign showed that adequate grain refinement could be achieved in all of the alloy groups with additions in the range 0.1kg/t up to 0.24kg/t compared to the 0.34 kg/t up to 0.78 kg/t previously used, see table 2. Expressed in percentages this means reductions in addition rate as noted in table 2 from 56 % up to 81 %. Optifine usage has been implemented in full production since 2010 resulting in overall grain refiner usage being reduced to 45tonnes/year.

Table 2. Reductions in master alloy addition for the alloys tested in the full scale casts at Hulamin.

	Additions in kg/ton		
Alloy	**Standard addition**	**Optifine addition**	**Reduction (%)**
AA1050	0.67	0.20	70
AA3003	0.68	0.24	65
AA3004	0.35	0.10	71
AA3105	0.43	0.15	65
AA5042	0.78	0.15	81
AA5052	0.34	0.15	56
AA5083	0.62	0.15	76
AA5182	0.77	0.15	81
AA5754	0.60	0.15	75
AA6061	0.66	0.24	64
AA6082	0.70	0.15	79

The full scale production usage clearly shows that Optifine is a very potent grain refiner which allows reduction of addition rates to extremely low levels. Since the master alloy has a constant high potency, and the grain refinement process can be closely monitored with the Opticast method, there is no risk for cracking of ingots and billets. Furthermore improvements in cast ingot quality can be expected due consistent grain size, lower levels of borides, boride agglomerates and oxides introduced as a result of the >55 % reduction in grain refiner addition.

Case study 2 A smelter casthouse – Eti Aluminium

Eti Aluminium is producing approximately 65,000tpa of 6063 billet and currently add 2.2kg/t of a standard 5/1 grain refiner. Casting equipment comprises 2x45 t holders, an Alpur inline degasser, filter box with 40ppi ceramic foam filters and a Wagstaff billet casting table. Pure metal is obtained from a neighboring smelter and a substantial fraction of the charges contains a large proportion of this.
The objective of the Optifine trial was to demonstrate the ability to achieve a minimum of a 50% reduction in grain refiner addition with a second target to reduce consumption by 70%. This would mean initially reducing addition rates from 2.2kg/t down to 1.1kg/t and then to 0.65kg/t.

Trial procedure

1. Samples of un-grain refined metal from the furnace spout were taken and crucible tests carried out with standard 5/1 grain refiner and Optifine added at 0.5kg/t,1.0kg/t and 2kg/t respectively to establish the current acceptable launder grain size and confirm that it was safe to reduce current grain refiner addition rate to 1.1kg/t with Optifine.
2. 5 casts were produced with Optifine added at 1.1kg/t and launder samples and billet slices taken to confirm launder grain size and correlation between Opticast sample grain size and actual billet grain size.
3. Further crucible tests were carried out on un-grain refined metal to check optimum addition rate. Samples were prepared with additions from 0.56kg/t up to 0.86kg/t
4. Further production casts were made with the final optimum Optifine addition according to the test results

The results from the initial test, according to point one above, are shown in figure 7. The results reveal a large difference in efficiency between the actual standard grain refiner mounted at the casting line and Optifine. Before discussing any further it is important to point out that the standard grain refiners at Eti are bought from several suppliers and, as discussed earlier, these suppliers deliver batches with differing efficiency. Some of these grain refiner batches may be of quite high efficiency, but some could have very poor nucleation properties. The blue curve in figure 7 may thus shift upwards or downwards and a preferred practice would be to sample the batches of grain refiners in storage and construct a number of grain refinement curves, similar to the tests shown in figure 5. However, due to time limitation only one of the master alloys was tested at this stage, i.e. the one mounted at the casting line, and it was found to be substantially less efficient than Optifine. If it is taken into consideration that there may be less efficient grain refiners in storage, the savings potential will be even larger than presented below.

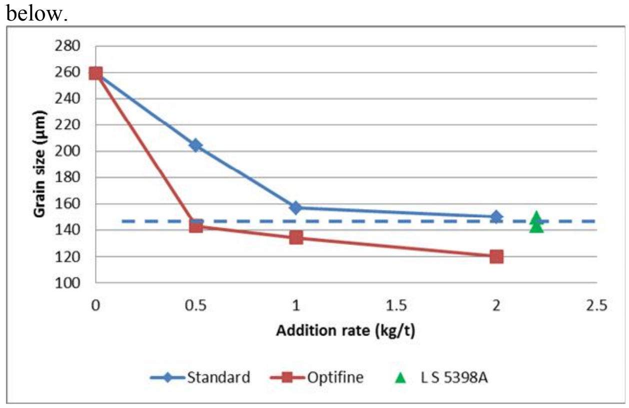

Figure 7. Grain refinement curves obtained by crucible tests in charge 5398A. Launder samples (L S) were collected at casting table.

The horizontal, hatched line demarks the grain size that is obtained in the Opticast samples taken in the launder at an addition rate of 2.2 kg/t, when the standard grain refiner is used. Two samples were taken at the casting table and the average grain size in these was 146 µm. The blue curve is the result from the crucible tests with this grain refiner. To horizontal line indicates that the same grain size may be achieved with an addition of only 0.5 kg/t of Optifine.
Based on these results it was decided to mount an Optifine coil and run a test charge with an addition rate of 1.1 kg/t and the result from this is shown in figure 8, where the two launder samples from this cast, charge 5398B, are shown.

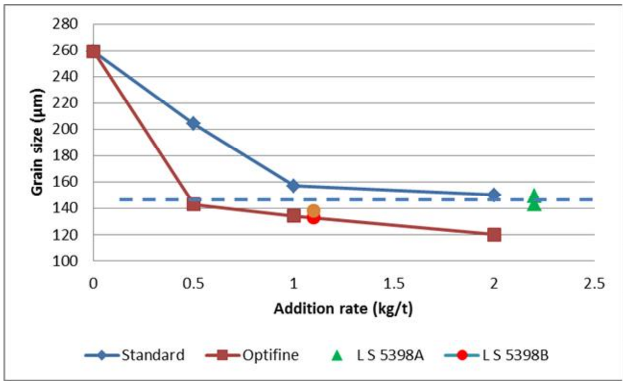

Figure 8. Launder samples, collected at casting table in charge 5398B.

It is evident that the prediction made in the first charge was good, since the grain sizes in the launder samples fell almost on the grain refinement curve obtained in the first test charge. The measured average grain size was measured to 135 µm.
After homogenization, a billet slice was obtained and the grain structure is shown in figure 9.

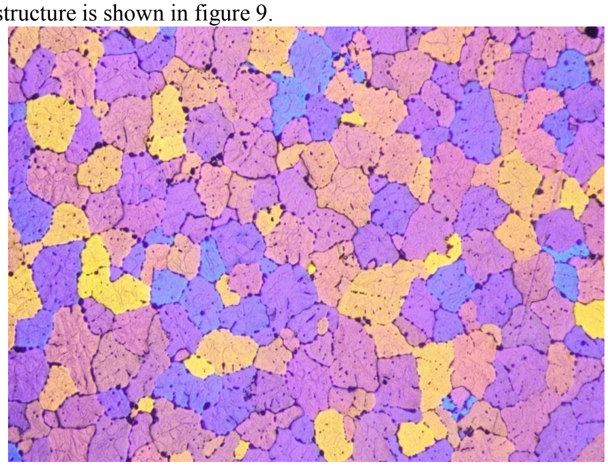
Figure 9. Billet micrograph of heat 5398B. Optifine was added at 1.1kg/t. After homogenization. Grain size 65 µm.

The grain size was measured to 65 µm which should be compared to the 135 µm measured in the Opticast samples.
It was now decided to proceed to cast 5 production casts with a 50% reduction in the addition rate down to 1.1kg/t. These were produced during the night and Opticast samples were collected at the casting table. Before discussing the results, the growth restriction imposed by the level of Ti in the furnace need to be addressed. Normally, the practice at Eti is to assure a titanium level of 50 ppm in the furnace before the cast is started in order to assure a high enough growth restriction. The Ti concentrations in the charges may vary from as low as 5 ppm to 100 ppm in the furnace, depending on the ratio between pure metal and scrap. This means that if the analysis shows less than 50 ppm, Ti waffles are added to increase the concentration to 50 ppm. In the first two casts, the Ti concentrations were adjusted to this concentration level.
Since the time was short for the trials and there was need of as much information as possible, it was decided not to add any Ti during the 5 production casts, in order to evaluate if Optifine could perform acceptably even if the growth restriction conditions were not optimized. The results from the tests are shown in figure 10.

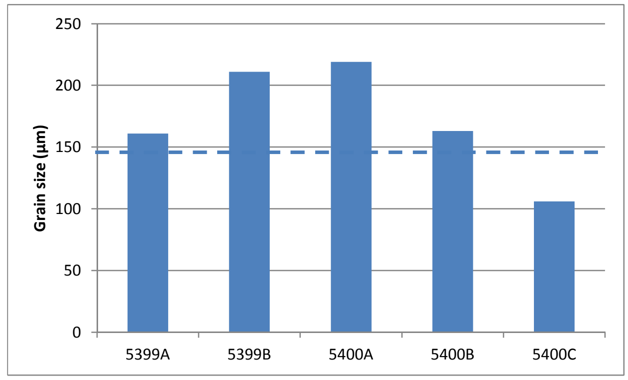

Figure 10. Grain sizes in Opticast samples collected at casting table for 5 charges cast with an addition rate of 1.1 kg/t. The horizontal line indicates the predicted grain size for charges with a level of Ti adjusted to 50 ppm in the casting furnace.

The results indicate clearly that the compensation of Ti level is essential in order to obtain conditions to ensure a small grain size. Two of the five casts had extraordinary low Ti levels, about 2 ppm, which results in grain sizes around 210 µm. Two other casts had Ti levels around 20-30 ppm and the grain sizes were then just above160 µm, while the Ti concentration in the fifth cast was well above 50 ppm. The reason for this was that a large proportion of scrap was used.
It should be noted that no billet cracked in the five charges, pointing at a robustness of the casting system, especially in combination with Optifine.
From these seven first test charges it was concluded that it would be safe to proceed with the next charge being cast with an Optifine addition rate of 0.85kg/t.
During this charge more crucible tests were conducted with the addition range of 0.56kg/t up to 0.86/kg/t to check if a further optimization was possible. The base Ti concentration in this charge was adjusted to 50 ppm and the result from the cast is shown in figure 11.

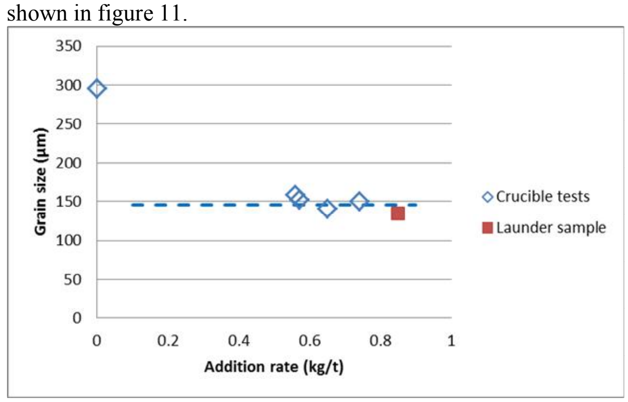

Figure 11. Grain sizes in crucible test samples and launder sample at an addition rate of 0.85 kg/t, charge 5404B. The horizontal line indicates the predicted grain size for charges with a level of Ti adjusted to 50 ppm in the casting furnace.

From figure 11 it is evident that the grain size prediction works very well, when the Ti level is adjusted to 50 ppm in the furnace. It also indicates that it definitely would be possible to cast this alloy with the aimed 0.65 kg/t or maybe even as low as 0.55 kg/t, i.e. an decrease with 75 % from the original level of 2.2 kg/t.

A micrograph of a billet slice from this cast is shown in figure 12.

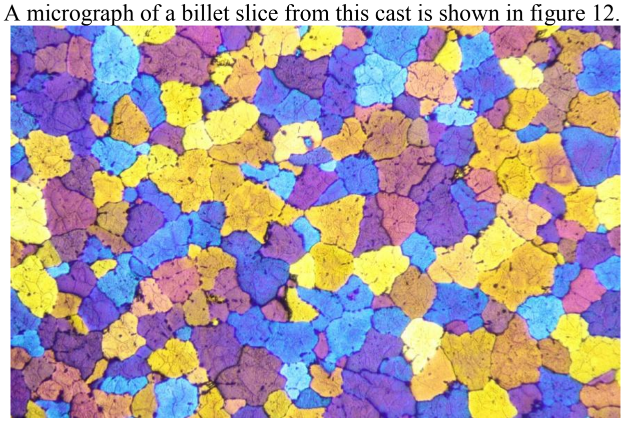

Figure 12. Billet micrograph of heat 5404B. Optifine was added at 0.85 kg/t. After homogenization. Grain size 63 µm.

The grain size is 63 µm in the billet, which is very small, as in the first cast in this trial series.

An additional cast was made with Optifine and the applied addition rate was 0.65 kg/t. In this charge no crucible tests were made but a billet sample was prepared after homogenization, see figure 13.

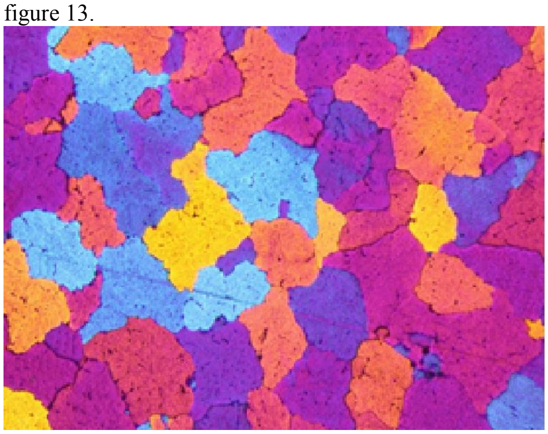

Figure 13. Billet micrograph of heat 5407B. Optifine was added at 0.65 kg/t. Titanium 0.005%. Grain size 110 µm.

When casting billets a correlation factor has to be established between the Opticast sample grain size and grain size observed in a billet slice. Generally the billet slice grain size will be considerably finer than that seen in the Opticast launder sample.

The normal range that Eti is aiming for is between 2.0 – 3.0 as measured on the ASTM scale, see table 3. This means that the maximum grain size can be as large as 176 µm in the billet, the maximum in grade 2. The billet grain size examples for the charges reported here are between 63 to 110 µm, i.e. well in range for the accepted size range.

Table 3. Conversion chart grain size in µm to ASTM grade

Grain size, µm	ASTM grade
75-88	4
89-103	3.5
104-122	3.0
123-167	2.5
168-176	2.0
177-203	1.5
204-246	1.0
>246	0.5

It is very likely that the billet grain sizes even for the very large grain sizes measured in the Opticast samples will lie in the accepted range. As said before, the Opticast sample will result in a grain size that is about 80-100 µm larger than what is measured in the corresponding billet. Thus, the very large grain sizes measured in the Opticast samples taken in the low Ti charges, as shown in figure 10, may very well show to be in the acceptable range, when referred to the ASTM scale. The investigation is going on and will be reported in coming papers.

Conclusions

The Opticast technology and method have proven to be invaluable tools in carrying out optimization and control of grain refinement practice in casthouses.The method allows rapid and reliable results to be generated so that accurate conclusions can be drawn allowing implementation of Optifine, a high efficiency grain refiner, at very low addition rates.

Optimization programs carried out at a remelt casthouse and a smelter cast house both resulted in reductions in the grain refiner addition rate of 70% or higher to be safely achieved. In the one case, Hulamin, the Optifine has been used for the whole production since 2010.

The results at Eti Aluminium confirmed that although in the case of smelter metal the growth restriction factor is substantially less than in a remelt, this can be successfully managed by controlling titanium levels to 0.005%. Optifine was successfully applied for casting of 6063 billets on a trial basis with the addition rate being reduced by 70% compared to standard practice.

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