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THE INFLUENCE OF GRAIN REFINERS ON THE EFFICIENCY OF CERAMIC FOAM FILTERS

Nicholas Towsey[1], Wolfgang Schneider[1], Hans-Peter Krug[1], Angela Hardman[2], Neil J Keegan[3]

[1] VAW aluminium AG, Research and Development, Bonn, Germany.
[2] London & Scandinavian Metallurgical Co. Limited, Rotherham, South Yorkshire, UK.
[3] Pyrotek Engineering Materials Ltd., Netherton, West Midlands, UK.

Abstract

An extensive program of work has been carried out to evaluate the efficiency of ceramic foam filters under carefully controlled conditions. Work reported at previous TMS meetings showed that in the absence of grain refiners, ceramic foam filters have the capacity for high filtration efficiency and consistent, reliable performance. The current phase of the investigation focuses on the impact grain refiner additions have on filter performance. The high filtration efficiencies obtained using 50 or 80ppi CFF's in the absence of grain refiners diminish when Al-3%Ti-1%B grain refiners are added. This, together with the impact of incoming inclusion loading on filter performance and the level of grain refiner addition are considered in detail. The new generation Al-3%Ti-0.15%C grain refiner has also been included. At typical addition levels (1kg/tonne) the effect on filter efficiency is similar to that for TiB_2 based grain refiners. The work was again conducted on a production scale using AA1050 alloy. Metal quality was determined using LiMCA and PoDFA. Spent filters were also analysed.

Introduction

The performance of ceramic foam filters (CFF's) under simulated production conditions has been reported previously in several international meetings[1-3]. In these studies, grain refiner was deliberately omitted from the process in order that a baseline understanding of filter performance could be established. Under such conditions, LiMCA results showed that ceramic foam filters could give mean filtration efficiencies comparable in range to those of competitive filter systems such as bed filters and rigid media filters. The mechanism of filtration appeared to be associated with the formation of 'bridges' of inclusions across the 'windows' of the ceramic foam pore structure in 50ppi and finer filters.

In the work presented here, the impact of a grain refiner addition (in rod form) on ceramic foam filter performance has been studied for 3/1 TiBAl (Al-3%Ti-1%B) and TiCAl 315 (Al-3%Ti-0.15%C) grain refiners and 50 ppi filters.

Due to concerns over the cleanliness of grain refiner alloys (which could contain salt, oxide, boride based defects or agglomerates of these) such alloys have traditionally been added before filters. However, the effect of the grain refiner on the filtration mechanism has never been clear. Additionally, the filter may remove valuable nucleant particles from the metal stream. If this was the case, post-filter addition might permit lower addition rates.

The objectives of this work then, can be clearly stated:

1. To establish the impact grain refiner rod additions have on metal quality at the point of addition.

2. To evaluate the effect of grain refiner additions on filter performance and resultant metal quality.

Experimental Procedure

The trials in this study were conducted using the specially dedicated, production scale R&D unit at the VAW Rheinwerk plant. AA1050 alloy, batched using reduction line metal and cast into ingots by the direct chill process at a flow rate of 10 tonne/hr, was used throughout. Metal quality measurements were made in the launder using LiMCA and PoDFA techniques. A schematic of the experimental layout is given in Figure 1.

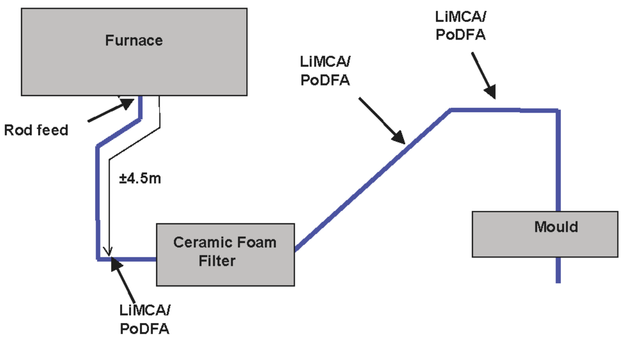

Figure 1: Schematic of the experimental layout for the DC casting trials.

The bulk of the trials using grain refiner were carried out using Al-3%Ti-1%B (3/1 TiBAl) or Al-3%Ti-0.15%C (TiCAl 315) rods supplied by LSM. However, a number of additional trials were devised to study the impact of grain refiner on melt cleanliness in more detail:

- The possible mechanical effects of a rod addition, such as vibration and oxide pull-in at the point of entry, were addressed by using a rod of commercial purity Al.
- A binary Al-Ti rod containing 0.7% Ti (approximately the same amount of 'free' Ti as that found in a 3/1 TiBAl grain refiner) was used to study the dissolution of $TiAl_3$ platelets along the length of the launder in the absence of TiB_2 particles.
- Finally, in order to look at the reverse situation, a near-stoichiometric rod (Al-2.3%Ti-1B) was produced (containing the same level of TiB_2 particles as a 3/1 TiBAl) to study the behaviour of TiB_2 particles in the absence of $TiAl_3$ particles.

To minimise melt disturbance the grain refiner rod was fed into the metal via a guide tube. This was done as far upstream of the filter box as possible meaning that the time available for dissolution before the metal entered the filter was approximately 1.5 minutes. All the rod additives used throughout this program were evaluated metallographically.

In most cases the rod alloys were fed at a rate of 1kg/tonne, slightly higher than that used for routine production to deliberately intensify any effects that might occur. For most trials the rod was only entered into the melt partway through the cast after about 20-30 minutes of stable LiMCA readings, to clearly highlight the effect of the rod addition on LiMCA counts. To simulate 'real' casting conditions, additional trials were conducted where the rod was fed from the start of the cast.

The 'loading' on the filter, here specifically defined as the inclusion content of the AA1050 metal flowing from the furnace, was varied by a stirring or settling practice. To markedly raise the inclusion content, the melt was air-stirred for five minutes prior to casting. The impact of sustained high loading throughout casting was also investigated by stirring the furnace during casting.

Finally, trials were conducted without a CFF where LiMCA was used to evaluate the effects of $TiAl_3$ dissolution rate in 3/1 TiBAl. Here three LiMCA units along the length of the launder system were used to monitor the changes in particle concentration with increased distance from the rod insertion point.

Spent filters were removed for evaluation at the end of each cast.

For all trial categories, replicate casts were made to confirm reproducibility of the results.

Results and Discussion

Impact of a 3/1 TiBAl rod on the efficiency of a CFF

Figure 2 shows the impact of a 3/1 TiBAl addition on the performance of a CFF when the incoming inclusion loading is high. It can be seen that before the grain refiner rod was introduced the high level of filter efficiency found in the previous trial series for the 50ppi CFF's was confirmed. The CFF has once again removed the vast majority of the incoming inclusion loading. After the 3/1 TiBAl rod is introduced at 28 minutes a steady rise in the inclusion value can clearly be seen exiting the filter. In order to get a more realistic appraisal of this effect it is necessary to consider the result when the grain refiner was fed from the start of some casts (Figure 3). Figure 4 indicates that the mean efficiency across the inclusion size distribution range for casts run with grain refiner is decreased compared to casts where grain refiner was not used. The filters still give a net benefit, but the overall efficiency is decreased. These efficiency levels are now more consistent with those reported previously under production conditions[4]. More significantly the downstream cleanliness levels for the cast in Figure 3 were around 2–3k/kg as opposed to the 0.2–0.3k/kg level without grain refiner. The effect causing the rise in post-filter values was observed to predominantly occur in the 20–35µm range.

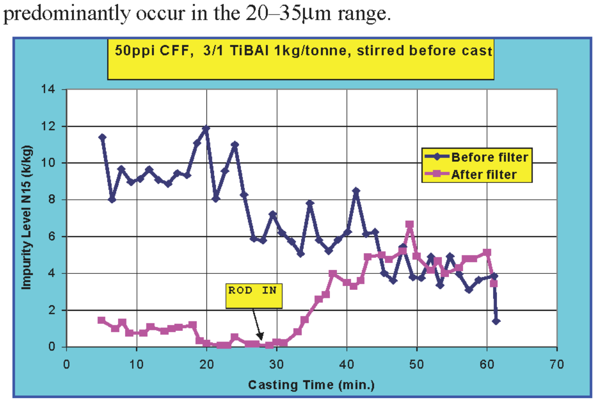

Figure 2: 3/1 TiBAl rod fed partway through cast – 'high' inclusion load.

To appreciate the magnitude and implication of this post-filter effect, it is necessary to first consider the pre-filter effect of adding grain refiner rod. This is best seen on a well-settled melt (Figure 5) where the effect of adding the rod results in a relatively mild increase in the LiMCA N15 count (the number of defects >15µm) of 0.5–1.5 k/kg (the possible causes of this effect will be dealt with later).

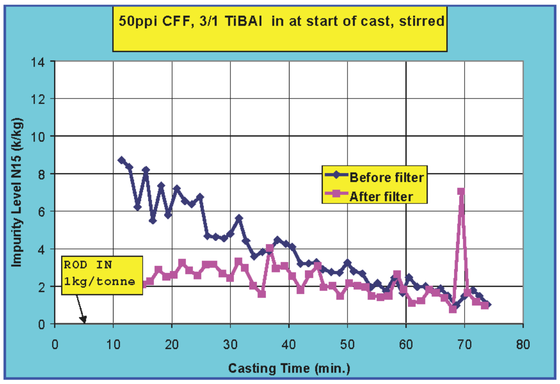

Figure 3: 3/1 TiBAl rod – fed from start of casting – 'high' inclusion load

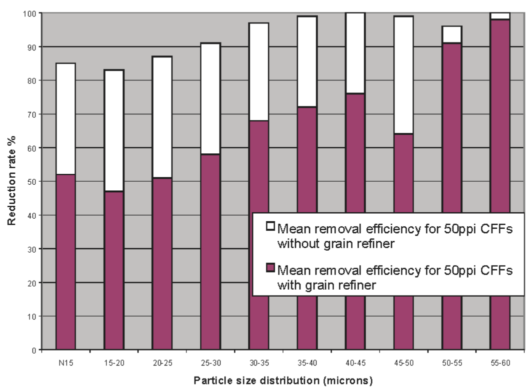

Figure 4: Inclusion Removal Efficiency 50ppi filters with and without 3/1 TiBAl rod.

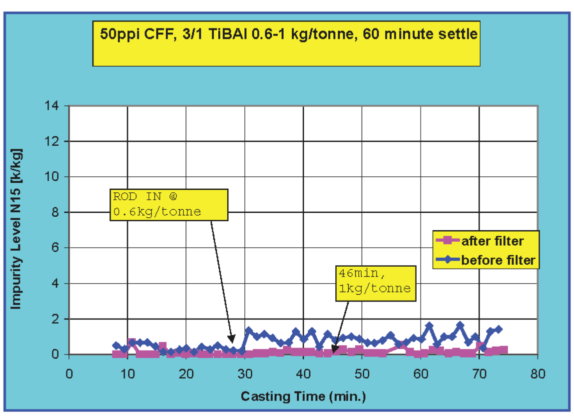

Figure 5: 3/1 TiBAl rod - fed partway through cast – 'low' inclusion load.

The corresponding post-filter effect is negligible for the low loading situation. However, when the loading is high (Figure 2) the post-filter effect is clearly much greater. In all the trials carried out the pre-filter effect appeared similar to that seen in Figure 5. It is therefore clear that the post-filter effect in Figure 2 is much too large to be attributable to the introduction of grain refiner alone and must have a secondary contribution from another source.

Table I summarises the effect of 3/1 TiBAl rod on the N15 inclusion levels for all the 50ppi CFF's under investigation.

Table I The Effect of a 1kg/tonne Addition of 3/1 TiBAl Rod made Before the Filter on LiMCA N15 Level

Melt Condition	Increase in Pre-Filter N15 Inclusion Level (k/kg)	Increase in Post-Filter N15 Inclusion Level (k/kg)
Settled (clean)	0.5 - 1.5	0.25 - 0.5
Stirred (dirty)	0.5 - 1.5	2 - 6

In order to better understand the observed effects of the 3/1 TiBAl rod addition on the before and after LiMCA curves the next phase of the work investigated whether these results could be attributed to some or all of the following:

- The possible 'mechanical' effects of rod addition introducing inclusions into the melt by disturbing its surface.
- Slower than expected aluminide dissolution.
- CFF inclusion loading, as defined previously.
- Boride agglomeration in the launder along with other inclusions present in the melt.

Impact of mechanical disturbance on metal quality

Trials conducted using commercial purity aluminium rod clearly showed that the impact of mechanical disturbance or oxide pull-in at the point of feed was negligible and could thus be discounted.

Impact of partially dissolved $TiAl_3$ particles from the 3/1 TiBAl rod on filter performance

This was investigated by conducting trials using a specially produced 0.7% TiAl rod (i.e. no TiB_2 phase, similar free Ti ($TiAl_3$) to the 3/1 TiBAl rod). Note that it was assumed that the absence of borides had no effect on the $TiAl_3$ dissolution rate.

Figure 6 shows the LiMCA curves for a 50ppi CFF with dirty metal (stirred melt) where the 0.7% TiAl rod has been introduced after 30 minutes of casting. No effect of the addition is evident before or after the filter suggesting that partially dissolved $TiAl_3$ does not contribute to the pre or post-filter counts. A similar effect was observed for trials conducted with settled melts.

Further trials feeding 3/1 TiBAl into the system without a CFF showed that the dissolution of $TiAl_3$ did not have a significant influence on the results. During these trials 3 LiMCA units were situated along the launder covering over 10m of its length (see Figure 1). The N15 value could be seen to have lifted slightly after the rod was added (after 20 minutes) but a constant value was recorded for all three LiMCA units.

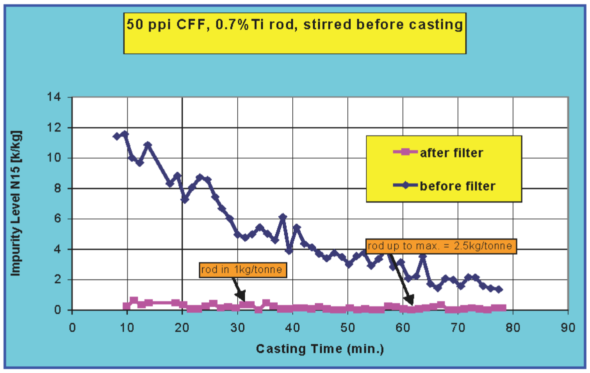

Figure 6: 0.7%TiAl rod fed partway through cast – 'high' inclusion load.

Impact of inclusion loading on the efficiency of a CFF

Figure 7 shows the LiMCA traces for a trial where the loading on the CFF was kept at a high level throughout by stirring continuously during the cast. Grain refiner was omitted from this trial to check if loading alone resulted in release effects. It can be seen that despite a very high incoming inclusion loading (>16k/kg) no release effects at all are evident. In fact, despite there being severe metal level disturbances due to the vigor of the stirring, the 50ppi CFF displayed a very high efficiency and a stable and consistently low post-filter LiMCA value (0.25k/kg). It could be concluded therefore, that inclusion loading alone at the levels investigated did not reduce the filter efficiency. This is accepting that at even higher loading levels filter saturation and diminished efficiency may occur.

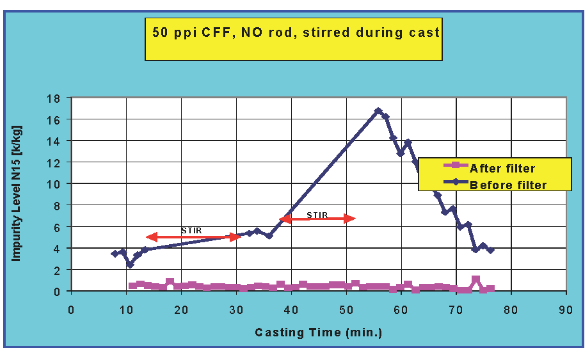

Figure 7: No grain refiner, stirred throughout cast – 'high' inclusion load.

Figure 8 looks at the problem in another way, with the rod entered at the beginning, as per normal practice, but this time with stirring occurring later in the cast. Here, the same response as before can be noted. When a higher loading is introduced from the furnace in the presence of the grain refiner, a sharp rise in the post filter values occurs.

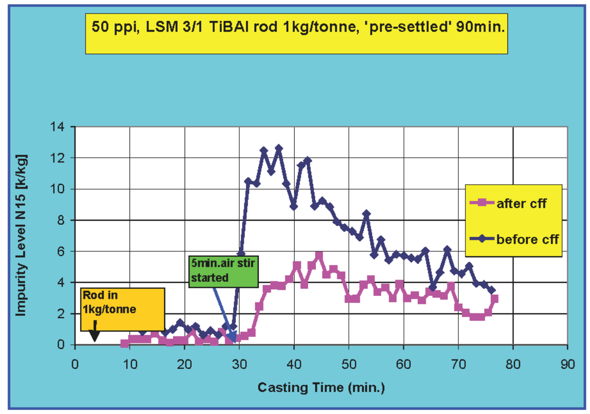

Figure 8: 3/1 TiBAl fed from the start of casting plus stirred partway through cast

Impact of TiB_2 particles or agglomerates from the TiBAl rod

This was investigated by producing a near-stoichiometric TiBAl rod, i.e., one containing TiB_2 without $TiAl_3$ particles. The composition of the rod was deliberately targeted at the titanium rich side of stoichiometry for two reasons. To inhibit the formation of coarse aluminium borides during the manufacturing process and, more importantly, to ensure there is sufficient free Ti for a $TiAl_3$ layer to be formed around individual TiB_2 particles. In this way it can be assumed that the TiB_2 particles in this rod are comparable to those in the 3/1 TiBAl rod used in the original trials.

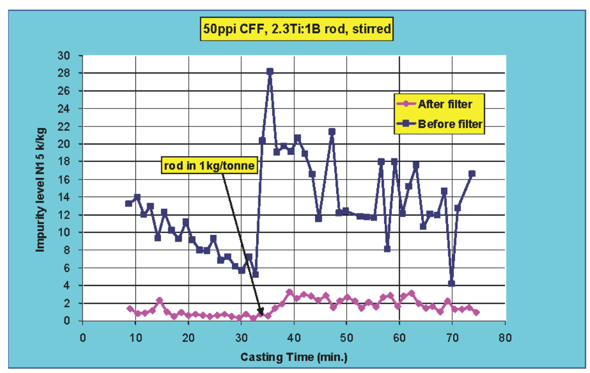

Figure 9: Near-stoichiometric TiBAl rod fed partway through cast – 'high' inclusion load.

Metallographic assessment of this rod showed that it contained a high number of TiB_2 agglomerates. This was expected as TiB_2 is more prone to agglomeration at the stoichiometric composition. In this case the agglomerates were compact, and in the worst cases fused, so are unlikely to break down during subsequent processing.

Figure 9 shows the LiMCA curves for a stirred melt where this rod was fed in after 35 minutes of casting.

It can be seen that:

1. The introduction of the near-stoichiometric rod has led to a massive increase in the N15 level for the pre-filter curve (> 12 k/kg). This may be attributed to the presence of TiB_2 agglomerates in the rod (as observed metallographically), the agglomeration of individual TiB_2 particles from the rod with other inclusions in the launder or a combination of the two effects.

2. The filter has removed the vast majority of incoming inclusions.

3. The post-filter N15 levels showed an increase similar to that observed for the good quality 3/1 TiBAl rod (see Figure 3).

When this trial was repeated for a settled melt the introduction of the rod caused a pre-filter effect of similar magnitude. The effect on the post-filter cleanliness level was marginal and similar to that when a 3/1 TiBAl rod was used.

The results from this phase of the work suggest that the increases observed in pre–filter curves when a grain refiner is introduced are due to agglomerations of TiB_2, either from the rod or with inclusions in the launder, rather than oxide pull-in at the point of entry or undissolved aluminide particles. The post-filter effects appear to be due to an interaction of the TiB_2 particles with inclusion species arising from the furnace metal.

Spent filter evaluation

Metallographic assessment of spent filters suggested that the 'bridges' of inclusions across the filter cell junctions seen in the absence of grain refiner[1-3], do not appear when grain refiner is employed. 'Bridges' across the 'window' regions (at least for the particle types in the study) may be a form of cake filtration and appear to be associated with high filtration efficiencies.

It is believed that the above mechanism of filtration is altered by the interaction of TiB_2 particles from the rod with other inclusions and is responsible for the significant increase in inclusion counts at the filter outlet when the grain refiner was introduced. The presence of the grain refiner from the start of casting appears to prevent the formation of bridges within the filter structure. Whereas, the introduction of grain refiner partway through the cast results in the destruction of any previously formed bridges.

Impact of TiCAl 315 rod on the efficiency of a CFF.

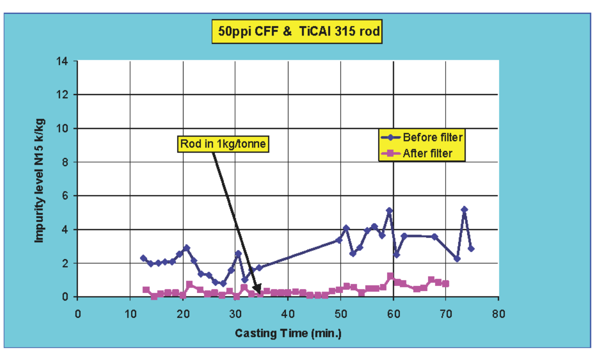

Figure 10: TiCAl 315 fed partway through cast.

Figure 10 shows the impact of a TiCAl 315 (Al-3%Ti-0.15%C) rod addition on the performance of a CFF. Again, before the rod is introduced the filtration efficiency is good. On addition of the TiCAl 315 rod the pre-filter LiMCA N15 inclusion level shows a significant increase (at the upper end of the range seen for a 3/1 TiBAl grain refiner under similar conditions). As before, this is assumed to be due to the agglomeration of TiC particles with or without inclusions in the launder. The N15 inclusion levels downstream of the filter show a slight increase 20 minutes after the rod was added. At these addition levels (1kg/tonne) the effect on the filter efficiency is similar to that for TiB_2 based grain refiners.

Summary

In summary, it is postulated that the introduction of TiBAl or TiCAl based grain refiner alters the behavior of the ceramic foam filter in trapping and/or retaining particles thus causing them to have a diminished efficiency compared to those found in the absence of grain refiner. This was only found to be significant when the incoming inclusion loading is high. If good furnace practices are followed and the inclusion loading is low (settled melts) there appears to only be a minimal impact of the grain refiner on the filter's performance.

Conclusions

1. Ceramic foam filters have the capacity for high efficiencies in the absence of grain refiner, even under severe disturbance conditions and with sustained high loading throughout the cast.

2. The introduction of 3/1 TiBAl and TiCAl 315 leads to a reduced filtration efficiency. This is only significant at high inclusion loadings.

3. It appears that the introduction of grain refiner leads to a change in the filtration mode of ceramic foam filters. 'Bridges' across the 'window' regions (at least for the particle types in the study) may be a form of cake filtration and appear to be associated with high filtration efficiencies. The presence of the grain refiner would seem to prevent the occurrence of bridges within the filter structure.

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