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METAL CLEANLINESS EVALUATION OF REUSABLE CERAMIC FOAM FILTERS

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Abstract

Filtration practices have been developed by the casthouse at Aluminerie de Bécancour that allow ceramic foam filters to be reused for multiple casts. The filter box, which contains two filters in parallel, keeps the filters submerged in molten metal between casts. Rules have been developed dictating the maximum allowable tonnage through the filters based on the alloy and product. Automation and casting practices minimize the possibility of filter releases. A campaign of metal cleanliness measurements using LiMCA and PoDFA was conducted to validate the performance of this process over the allowable filter life for both 3xxx slab and 6xxx billet. The results demonstrate that this practice can reduce filtration costs without adversely impacting metal cleanliness.

Introduction

Ceramic foam filters (CFF) are widely used to remove inclusions from molten aluminum alloys during casting [1]. These filters are produced by impregnating polymeric foam with ceramic slurry, then firing the ceramic and burning away the foam. Ceramic foam filters are almost always in the form of flat plates and are normally used for one cast only. They provide flexibility for alloy changes with inclusion removal efficiencies ranging from 25 to 75% [2]. In order to reduce casting costs by reducing the number of filters used, Aluminerie de Bécancour (ABI) has developed a process to reuse ceramic foam filters. This study was intended to determine whether there is any decline in metal cleanliness as multiple casts are made through the reusable filters.

Experimental Apparatus and Procedure

Testing was done on two similar casting pits, one casting 3xxx slab and the other casting 6xxx billet. Each pit is fed from two tilting holders through an Alpur degasser upstream of the filter. The charge makeup is primarily molten metal from the smelter with less than 25% recycled internal scrap.

The reusable filter box contains two 23” x 23” filters, 30 ppi for billet casting and 40 ppi for slab casting. Metal is held in the filter box between casts so that the filters remain submerged; an electric heating lid maintains metal temperature between casts. The filter box can be drained when alloy changes or filter changes are required. Rules have been developed for the maximum tonnage that can be cast through the filters based on product and end use. In addition, the head loss across the filter box is measured every drop and the filters are replaced if the measurement exceeds a specified value.

Inclusion concentrations were measured by LiMCA [3], a method based on the Coulter counter principle. Metal is cycled in and out of a glass probe through a 300 μm orifice. Non-metallic inclusions passing through the orifice produce a perturbation in the voltage between electrodes situated inside and outside of the glass probe. The inclusion size range covered by LiMCA is 20 to 300 μm. Particles smaller than 20 μm cannot be distinguished from electrical noise.

One LiMCA unit was positioned between the holding furnace and the degasser, while the other unit was located downstream of the filter. The diagram of the casting pit in Figure 1 illustrates the locations of the LiMCA units. Measurements taken between the holding furnace and the degasser are identified as “Taphole” measurements, while those taken between the filter and the casting table are identified as “After Filter” measurements. Regular LiMCA probes were used for measurements at the taphole while extension probes were required downstream of the filter to eliminate interference from micro-bubbles.

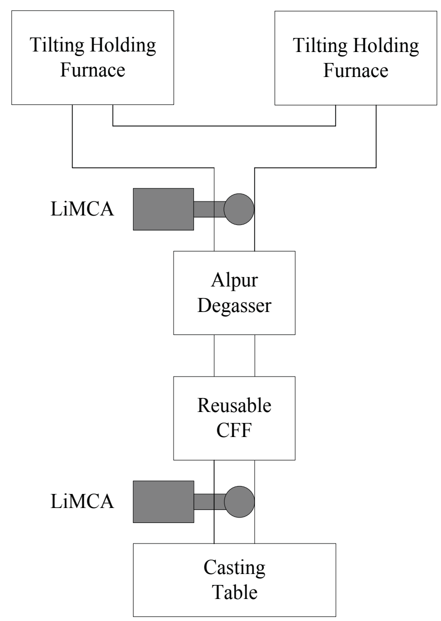

Figure 1. Layout of ABI casting pits with reusable filters.

PoDFA samples were taken between the holding furnace and the degasser (Taphole), between the degasser and the filter (After Degasser), and between the filter and the casting table (After Filter). The PoDFA technique [4] uses vacuum to pull about 1 kg of molten metal through a porous filter disk. This concentrates the inclusions that were present in the metal into a small volume for off-line metallographic analysis. The weight of metal pulled through the filter is measured and recorded so the concentration of inclusions in the sample can be calculated. The PoDFA filter captures all inclusions down to about 1 μm in diameter.

Metallographic analyses of the PoDFA samples were carried out by ABI.

Metal Cleanliness Measurements - Slab

Metal cleanliness was measured for seven consecutive casts of 3xxx slab ingot. The LiMCA inclusion concentrations are shown in Table I as normalized R values. These values were calculated by setting the highest cast-average N20 value equal to 100 and multiplying all other inclusion concentrations by the ratio (100/maximum taphole N20). R20, R30, R50, and R100 represent the relative concentrations of particles larger than 20, 30, 50, and 100 μm, respectively.

Table I. Relative LiMCA Inclusion Concentrations – Slab

Number of casts through filter	Tons cast through filter	Taphole LiMCA				After Filter LiMCA			
		R20	R30	R50	R100	R20	R30	R50	R100
1	0	24.0	4.4	0.29	0.000	56.8	4.87	0.19	0.000
2	42	84.8	19.8	1.40	0.019	39.3	2.64	0.16	0.018
3	84	61.5	13.3	1.07	0.000	49.7	3.79	0.19	0.000
4	126	85.4	16.4	0.63	0.014	61.5	4.78	0.18	0.000
5	168	100.0	20.0	1.06	0.000	40.8	3.43	0.12	0.000
6	210	92.6	22.0	1.65	0.019	25.5	1.81	0.08	0.000
7	252	75.9	12.6	0.57	0.009	46.5	3.15	0.12	0.009

LiMCA values measured after the filter are plotted against tons cast through the filter in Figure 2. The trendlines shown for R20 and R30 demonstrate that there is no increase in inclusion concentrations as the filter is reused; the trends indicate a slight improvement in metal cleanliness as the filter ages. This trend also applies for R50. Only a few particles larger than 100 μm were detected downstream of the filter; these occurred in casts 2 and 7.

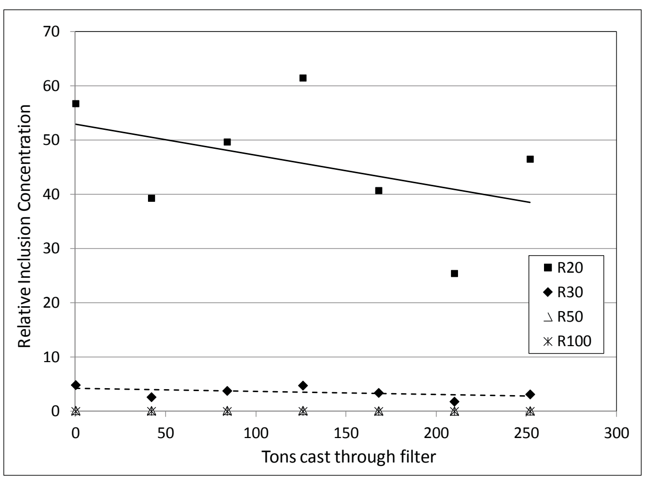

Figure 2. LiMCA values after the filter vs. tons cast through the filter for 3xxx slab.

One explanation for the decrease in inclusion concentrations as the filter ages would be that particles caught in the filter from previous casts act to reduce the effective pore size of the filter, enhancing its ability to capture additional inclusions. This raises the concern, however, that particles accumulating in the filter from one cast may be released during a later cast. Figure 3 shows the individual R20 values measured during each of the casts. Only three filter releases were observed, two during cast 3 and one near the end of cast 7.

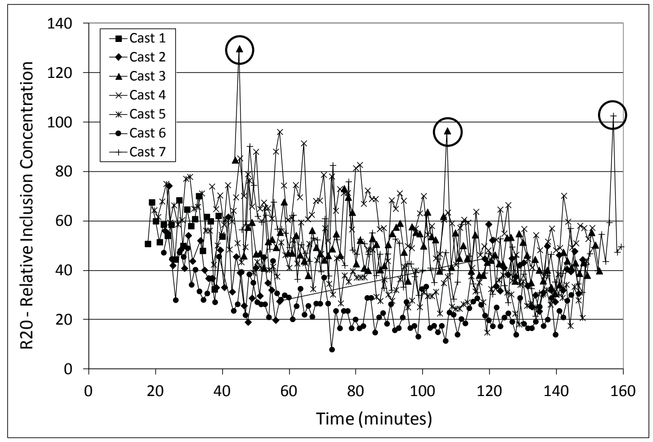

Figure 3. LiMCA R20 values after the filter vs. time for slab casts

PoDFA inclusion concentrations from the slab casts are shown in Table II. These values have been normalized in a manner similar to the LiMCA measurements, multiplying the inclusion concentrations by the ratio (100/maximum taphole total PoDFA inclusion concentration). Both the total inclusion concentration and the total concentration without grain refiner are reported.

Table II. Relative PoDFA Inclusion Concentrations – Slab

Number of casts through filter	Tons cast through filter	R PoDFA Total			R PoDFA Total without Grain Refiner		
		Taphole	After Degasser	After Filter	Taphole	After Degasser	After Filter
1	0	28.2	78.7	32.1	18.7	16.2	3.7
2	42	57.6	49.6	31.7	13.3	2.5	2.4
3	84	66.6	47.6	13.4	21.0	8.0	4.8
4	126	100.0	57.1	22.3	17.8	4.6	0.7
5	168		37.4			5.5	
6	210	99.8	94.0	29.8	72.1	16.5	2.9
7	252		174.0	57.7		5.0	1.4

PoDFA values measured after the filter are plotted against tons cast through the filter in Figure 4. While the trendline for total inclusion concentration increases with increasing tonnage, this effect is driven entirely by the sample from the final cast. When the amount of grain refiner in the sample is subtracted out, the trend shows a slight decrease in inclusion concentrations as the filter ages as was seen in the LiMCA data. The PoDFA value without grain refiner is a better indication of metal cleanliness since grain refiner represents particulate that is purposely added to the metal.

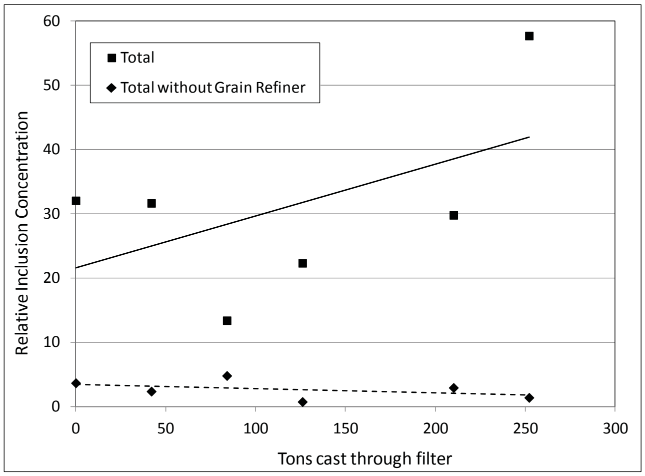

Figure 4. PoDFA values after the filter vs. tons cast through the filter for 3xxx slab.

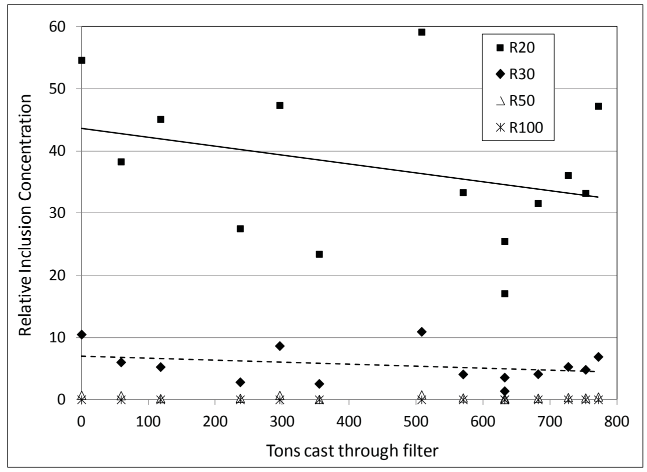

Figure 5. LiMCA values after the filter vs. tons cast through the filter for 6xxx billet.

Metal Cleanliness Measurements - Billet

Inclusion concentrations were measured for 14 casts of 6xxx billet at another ABI casting pit. The pit layout is similar to that of the slab pit shown in Figure 1. LiMCA inclusion concentrations, again reported as normalized R values, are shown in Table III. For billet products, the rules governing filter change frequency allow for more casts and more tonnage between changes.

Table III. Relative LiMCA Inclusion Concentrations – Billet

Number of casts through filter	Tons cast through filter	Taphole LiMCA				After Filter LiMCA			
		R20	R30	R50	R100	R20	R30	R50	R100
14	682	17.5	2.7	0.21	0.000	31.6	4.12	0.26	0.000
15	727	17.3	4.4	0.58	0.000	36.1	5.29	0.36	0.000
16	772	34.8	8.6	1.40	0.051	47.2	6.90	0.45	0.000
1	0	38.6	15.6	4.11	0.352	54.6	10.50	0.73	0.015
2	59	31.6	5.6	0.45	0.021	38.3	6.02	0.67	0.000
3	118	55.0	11.3	1.36	0.048	45.1	5.27	0.20	0.000
4	237	28.7	6.1	0.77	0.020	27.5	2.82	0.24	0.000
5	296	61.1	22.7	4.71	0.063	47.3	8.65	0.71	0.000
6	355	29.8	5.6	0.52	0.000	23.4	2.56	0.06	0.000
9	508	100.0	43.5	11.77	0.902	59.2	10.94	0.79	0.000
10	632	17.4	2.9	0.18	0.036	25.5	3.58	0.24	0.000
11	570	65.6	21.4	5.50	0.380	33.3	4.09	0.30	0.000
12	632	17.7	2.9	0.36	0.000	17.1	1.39	0.05	0.000
13	753	34.6	13.8	3.61	0.243	33.2	4.83	0.29	0.000

LiMCA values measured after the filter during the billet casts are plotted against tons cast through the filter in Figure 5. Trendlines for R20, R30, and R50 again show that there is a slight improvement in metal cleanliness as the filter ages. Particles larger than 100 µm were detected downstream of the filter in only one of the casts, the first cast after a filter change. No significant filter releases were observed in any of the 14 casts.

PoDFA inclusion concentrations for the billet casts, again reported as normalized R values, are shown in Table IV.

Table IV. Relative PoDFA Inclusion Concentrations – Billet

Number of casts through filter	Tons cast through filter	R PoDFA Total			R PoDFA Total without Grain Refiner		
		Taphole	After Degasser	After Filter	Taphole	After Degasser	After Filter
14	682	45.2	91.8	24.8	22.7	19.1	4.3
15	727	10.2	10.5	14.3	10.2	4.6	4.7
16	772	20.3	26.5	14.5	17.0	17.7	10.7
1	0	9.1	7.2	6.4	9.1	2.7	2.2
2	59	35.3	7.4	12.2	33.9	4.1	3.6
3	118	34.2	33.7	10.6	33.2	10.2	4.7
4	237	30.9	11.7	8.0	30.1	7.8	3.0
5	296	30.2	20.4	10.6	22.4	11.2	2.1
6	355	100.0	52.7	24.5	90.5	22.1	9.4
9	508	8.8	6.7	3.4	7.8	2.7	1.9
10	632	55.3	83.4	45.6	55.3	37.6	18.8
11	570	11.5	92.7	11.2	11.5	41.2	4.8
12	632	34.1	18.7	21.8	33.8	11.5	6.5
13	753	14.6	17.6	7.6	14.0	7.2	2.4

PoDFA values measured after the filter are plotted against tons cast through the filter in Figure 6. In this case, the trendlines show a slight increase in PoDFA inclusion concentrations with increasing tonnage through the filter. The absolute PoDFA inclusion concentrations remained below ABI's internal rejection criteria for all of the casts.

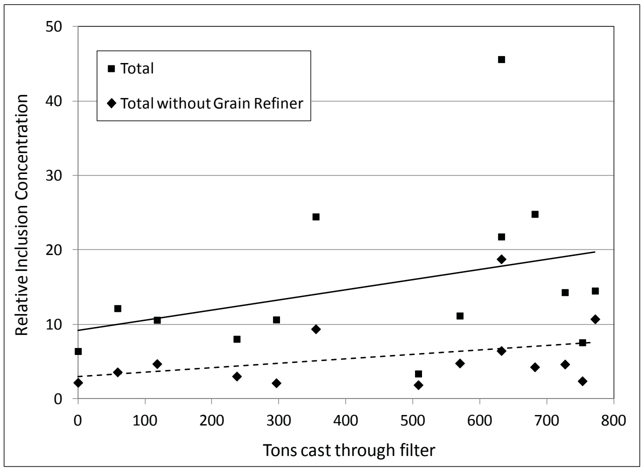

Figure 6. PoDFA values after the filter vs. tons cast through the filter for 6xxx billet.

Conclusions

Metal cleanliness measurements by both LiMCA and PoDFA demonstrate that ABI's process to reuse ceramic foam filters does not increase the inclusion concentrations in the final product. Measurements generally show a slight improvement in metal cleanliness as additional tonnage is cast through the filters. There was also no increase in the likelihood or severity of filter releases with additional tonnage. The absence of filter releases demonstrates ABI's attention to detail in their charging, alloying, skimming, settling, and casting practices. Critical casting parameters, including metal level, are carefully controlled and monitored to produce consistently high quality slab and billet.

While there are clearly potential operating cost savings in reusing ceramic foam filters, the costs incurred in flushing or draining the filter box for alloy changes must also be considered. The overall economic analysis has been positive for ABI, generating substantial cost savings compared to the typical single use of ceramic foam filters.

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