Characterisation of Molten Metal Quality Using the Pressure Filtration Technique

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ABSTRACT

Molten metal quality in terms of consistency, sensitivity to metal disturbance, in-line metal treatment and additions practice has been characterised using the pressure filtration technique called PREFIL-Footprinter. The reproducibility of the data is discussed and compared with the benchmarks for A356.

The pressure filtration instrument resolves small changes due to operator interventions upstream and diagnoses issues related to strontium and grain refiner additions downstream.

INTRODUCTION

THE PREFIL-FOOTPRINTER TECHNOLOGY

PREFIL-Footprinter is the only inclusion instrument that provides a direct result as well as a sample for further metallographic analysis. These two qualities along with its rugged design make the PREFIL-Footprinter a powerful solution for performing inclusion quality control on a day-to-day basis, and/or on a more in-depth audit basis for process optimisation (Simard, 2001; Enright, 1996; Samuel, 1999).

The PREFIL-Footprinter test uses the flow-rate of molten metal through a porous filter disc at constant temperature and pressure to measure the quality of the metal. The operating principle is illustrated in Figure 1.

Throughout the test, the system continuously weighs the metal in the weigh ladle and displays a curve of the accumulated weight versus the elapsed time (Simard, 2000). The cleaner the metal, the higher this curve will be; inclusions in the metal, such as oxide films, quickly build-up on the filter surface during a test, reducing the flow-rate through the filter.
The slope and overall shape of the weight filtered versus time curve indicates the level of inclusions present in the metal. The metal residue above the filter can be saved for supplementary metallographic analysis.

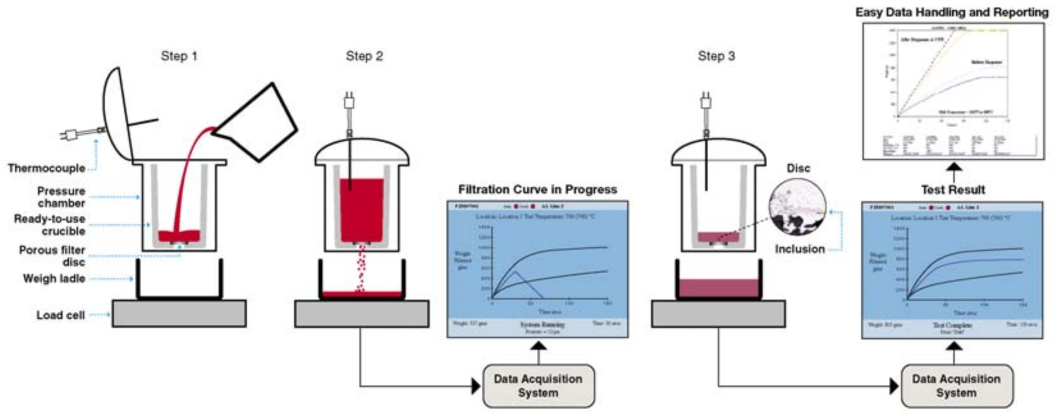


Figure 1: PREFIL-Footprinter Operating Principle

Building a database makes it possible to determine extremes of metal cleanliness found at a specific location. The database is used as a point of comparison or reference thus providing a footprint of a process. The results of a given alloy, obtained at a given filtration temperature and location, can be judged against the footprint database and used for shop floor quality control (Simard, 2001).

There are two other techniques appropriate for the measurement of molten metal quality in this sort of application; the LiMCA II instrument for in-line inclusion counting and sizing (Martin, 1994; Chen, 1996), and a metallographic analysis method based on PoDFA for off-line quantitative and qualitative evaluation of melt cleanliness (Doutre, 1985; Liu, 1997). LiMCA II can measure inclusions from 20 μm up to 300 μm. The density of particles is expressed in thousands of particles per kilogram of melt (K/kg) or also per volume fraction (part per billion, PPB). It can also be plotted as a function of time along a cast.

Because both the PREFIL-Footprinter and PoDFA instruments use a very fine porosity filter, inclusions of the melt are concentrated at the disc surface by a factor of 10 000. These techniques can distinguish inclusions as small as 1 μm, and can also distinguish inclusion types and differentiate between the levels of inclusions that are present within an individual sample. The total inclusion concentration is expressed in area per mass of metal (mm^2/kg).

Recent capability studies have shown that LiMCA II, PREFIL-Footprinter and metallographic analysis show good correlation. Small changes in the inclusion concentration measured by the LiMCA II and the metallographic analysis are associated with observable changes in the PREFIL curves indicating a good sensitivity (Simard, 2001).

CURVE INTERPRETATION

The PREFIL-Footprinter displays a curve of the accumulated weight versus the elapsed time. The cleaner the metal, the higher this curve will be; inclusions in the metal quickly build-up on the filter surface during a test, reducing the flow-rate through the filter.

The slope and overall shape of the weight filtered versus time curve indicates the level of inclusions present in the metal. Oxide films (see Figure 2a) and other coarse particulate, affect the initial slope of the curve (20-30 seconds). They result in straight lines, with a slope that decreases as the number of oxide films increases.

Fine particulate inclusions such as TiB_2, fine Al_2O_3 (see Figure 2b) or carbides cause the curve in the PREFIL test to deviate from a straight line. The loading of fine particles can be inferred from the point at which the curve begins to deviate from the initial slope.

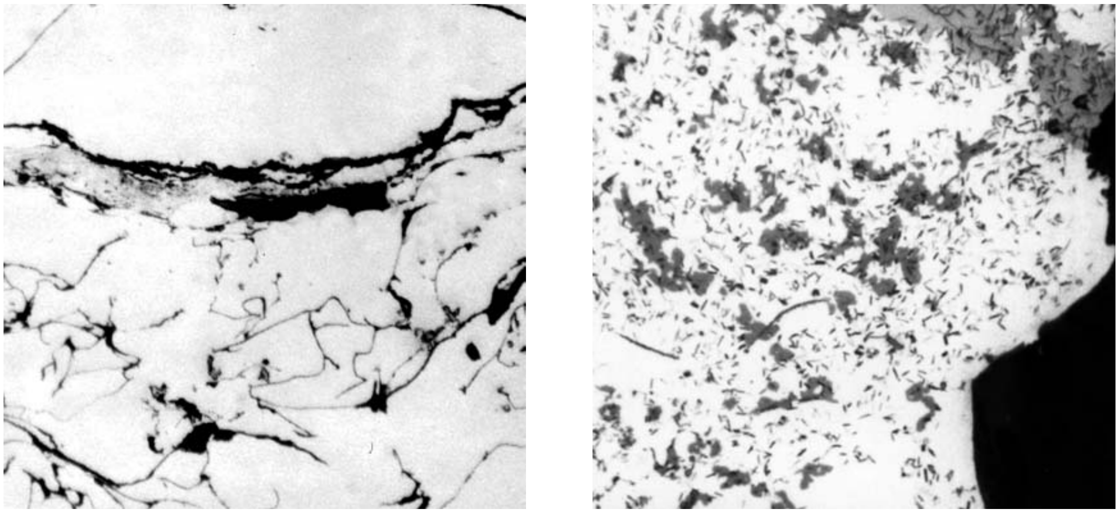


Figure 2: Showing a) oxide films and b) fine alumina needles and carbides concentrated above the filter disc x 420

Metallographic analysis of the residue that is retained after a test can extend the interpretation by allowing identification and quantification of the types of inclusions present.

The build-up of inclusions on the filter, which is known as the inclusion band, gives a quick indication of the level of inclusions within the metal.

An example of an inclusion band is shown in Figure 3.

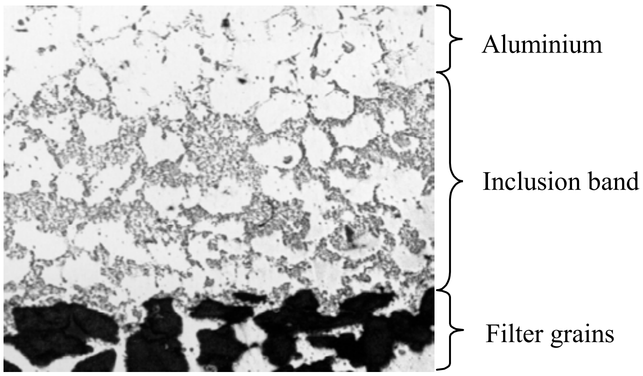


Figure 3: An analysis sample with clearly visible inclusion band (dirty metal)

THE WORLD CLASS BENCHMARKS

The real power of the technique is realized when the curve for a particular sample, obtained on-line, is compared with a pre-established benchmark for premium quality.

Each benchmark is compiled from an upper bound that relates to super clean material and a lower bound that relates to the industrial range of data. This benchmark is referred to as The World Class Benchmark. As soon as new data is compared to the ‘World Class Benchmark’ it is possible to judge the molten metal quality during each casting campaign.

Each curve is compiled in the instrument database and compared with benchmarks. If plant data does not lie inside the benchmark then it is not in the world-class league.

Figure 4 shows the characteristic of A356 alloy in three different foundries superimposed on the World Class Benchmark for this type of alloy.

Different benchmarks exist for different types of alloys. Grain refined materials also have separate benchmarks, since these exhibit a turnover due to the fine TiB_2 particulate, as mentioned earlier (N-Tec, 2002).

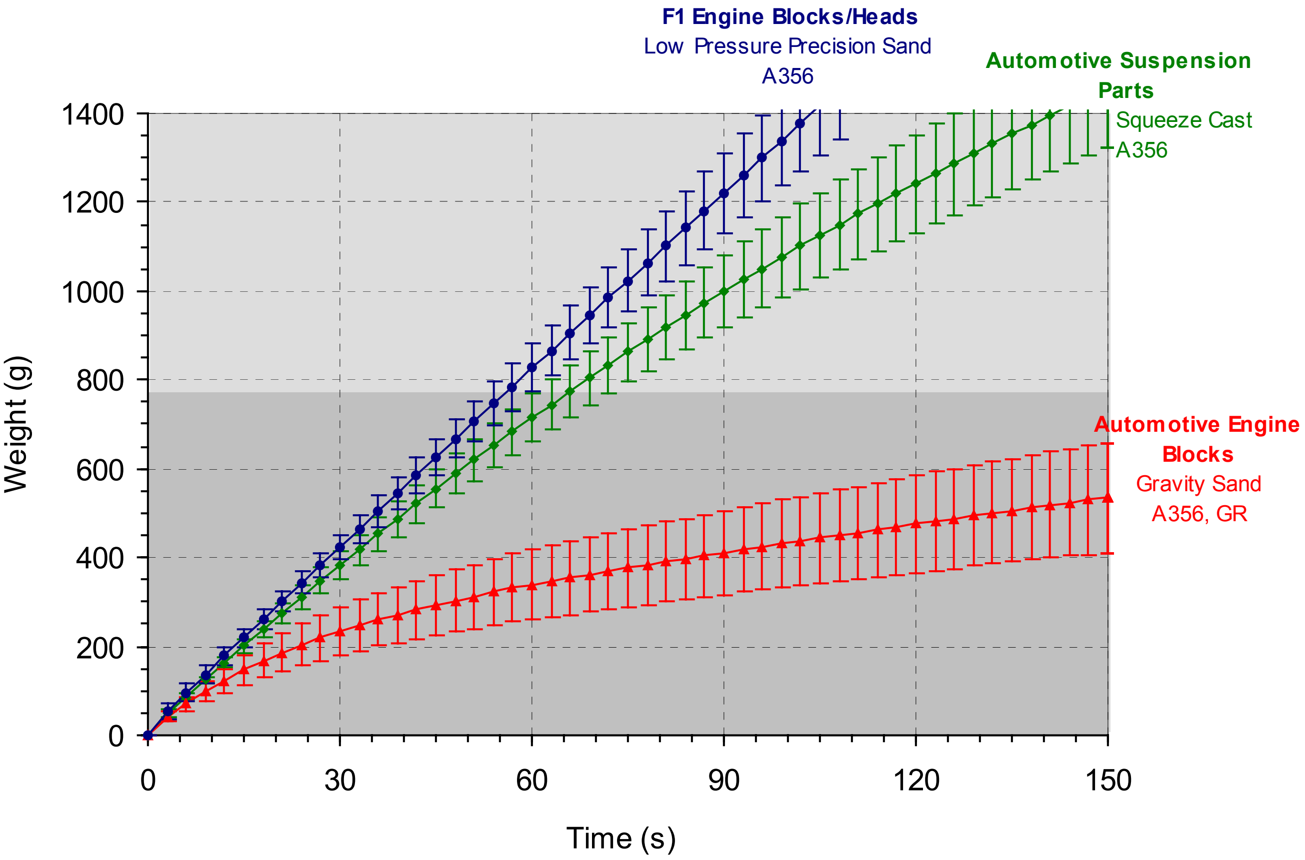


Figure 4: The World Class Production Benchmarks for A356

The data shown in Figure 4 is based on work with over 120 customers, and over 2600 individual tests.

RESULTS

TEST LOCATION

Measurements took place in the aluminum foundry of an automotive plant. The foundry line starts with a melter and a degasser at the exit of the melter. Metal flows in a launder system to holders/melters and then reaches an in-line melt treatment, consisting of a degasser and a filter box using Bonded Particule Filter. The line ends at the casting station having three distinct fingers. Tests were performed in the following positions.

PREFIL Sampling Positions	1	Launder after melter and degassing well
	2	Before in-line degasser
	3	After in-line degasser
	4	After Filter Box
	5a, b, c	At each casting fingers

The audit of the melting system shows the following important features of the pressure filtration measuring technique.

REPRODUCIBILITY OF DATA AND MOLTEN METAL CONSISTENCY

Metal was repeatedly sampled from launder position 1 using a sampling ladle and the recommended sampling practice of preheating the ladle, back skimming the metal surface to avoid picking up surface oxide layers, quiescent filling of the ladle and immediate transfer to a preheated PREFIL crucible. The instrument was pre-programmed to run the tests at 680ºC.

Slight differences in the metal carry over temperature lead to different residence times in the crucible before the test triggers. In order to ensure thermal equilibrium at the filter surface prior to the test, a minimum residence time of thirty seconds is in the test protocol.

The results of the first 14 metal samples are shown in Figure 5. The data is presented as the average of all 14 curves superimposed on the world-class benchmark for A356. The error bars represent +/- one standard deviation about the mean. The scatter in the data is ± 14 % at 95% (2 sigma), which compares to the machine repeatability of ± 9 % at 95% (2 sigma) indicating a high degree of molten metal consistency at this sampling point (Simard, 2001).

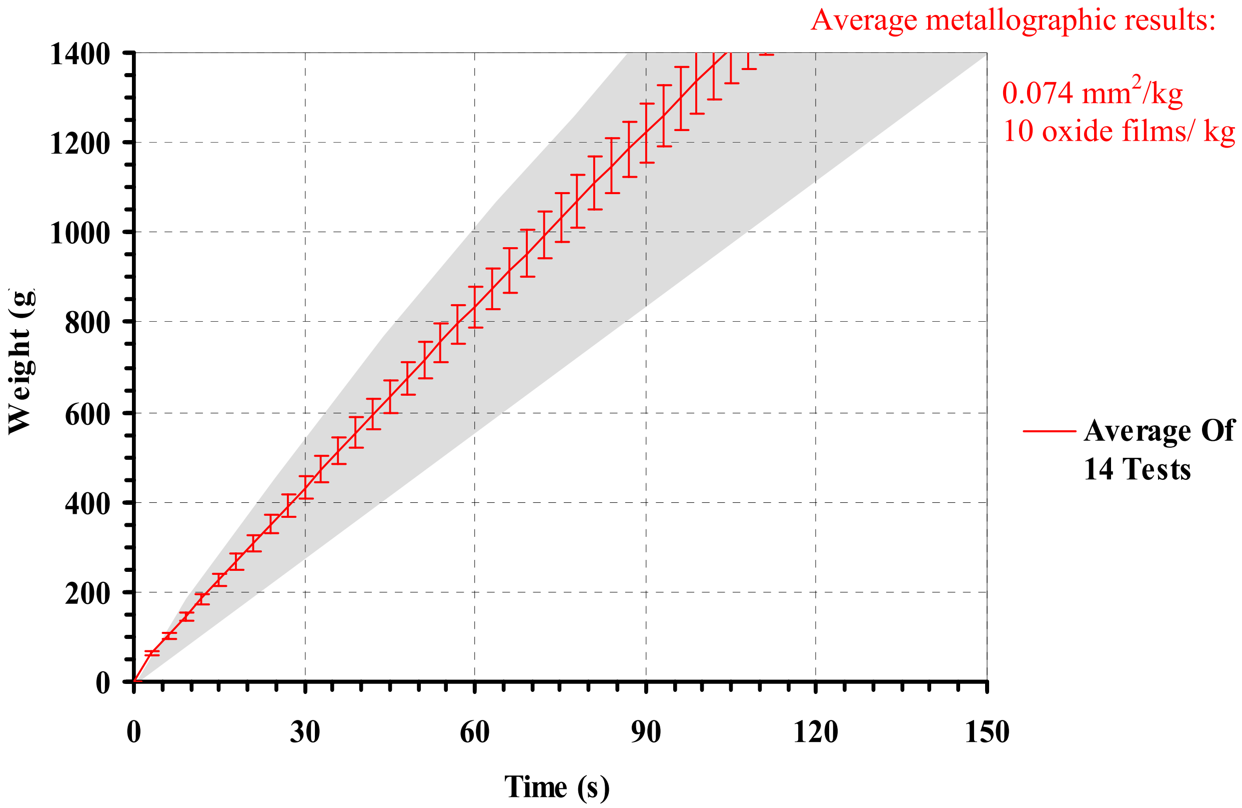


Figure 5: Tests from Launder after Melter (superimposed on the Word Class Benchmark for A356)

SENSITIVITY TO TURBULENCE AND MOLTEN METAL DISTURBANCE

Turbulence and molten metal disturbance is well known to introduce oxides or other inclusions into molten aluminum alloys. It is important that any monitoring system is capable of resolving small inclusion releases due to transients to molten metal flow, or operator intervention (Campbell, 1991).

Figure 6 shows the effect of scraping the sidewall of the launder prior to taking the sample. This was done intentionally, in order to show instrument's sensitivity.

It clearly illustrates how important it is to sample consistently and from a position that does not compromise the molten metal quality. If the instrument sees inclusions after wall scraping then there will be a significant downstream transient in the launder that might affect product quality.

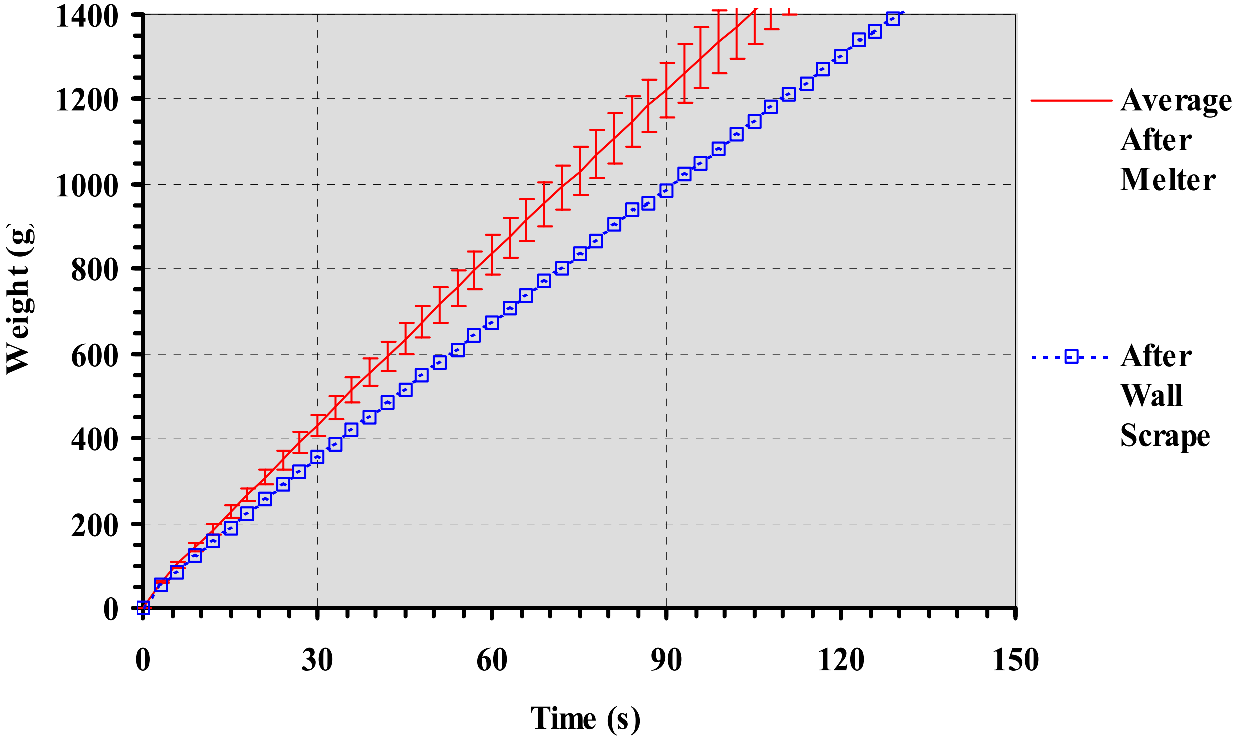


Figure 6: The Effect of Scraping the Launder Sidewall (superimposed on the Word Class Benchmark for A356)

Figure 7 shows the effect on the curve of manually stirring and drossing off the melter rotary degassing well 2 meters upstream of the sampling position 1. Note that the samples were taken at the same position as the previous samples and that the transient lasts for about 20 minutes. After things have settled down the molten metal returns to the average levels measured previously. The characteristic of metal sampled directly from the degassing well is also shown.

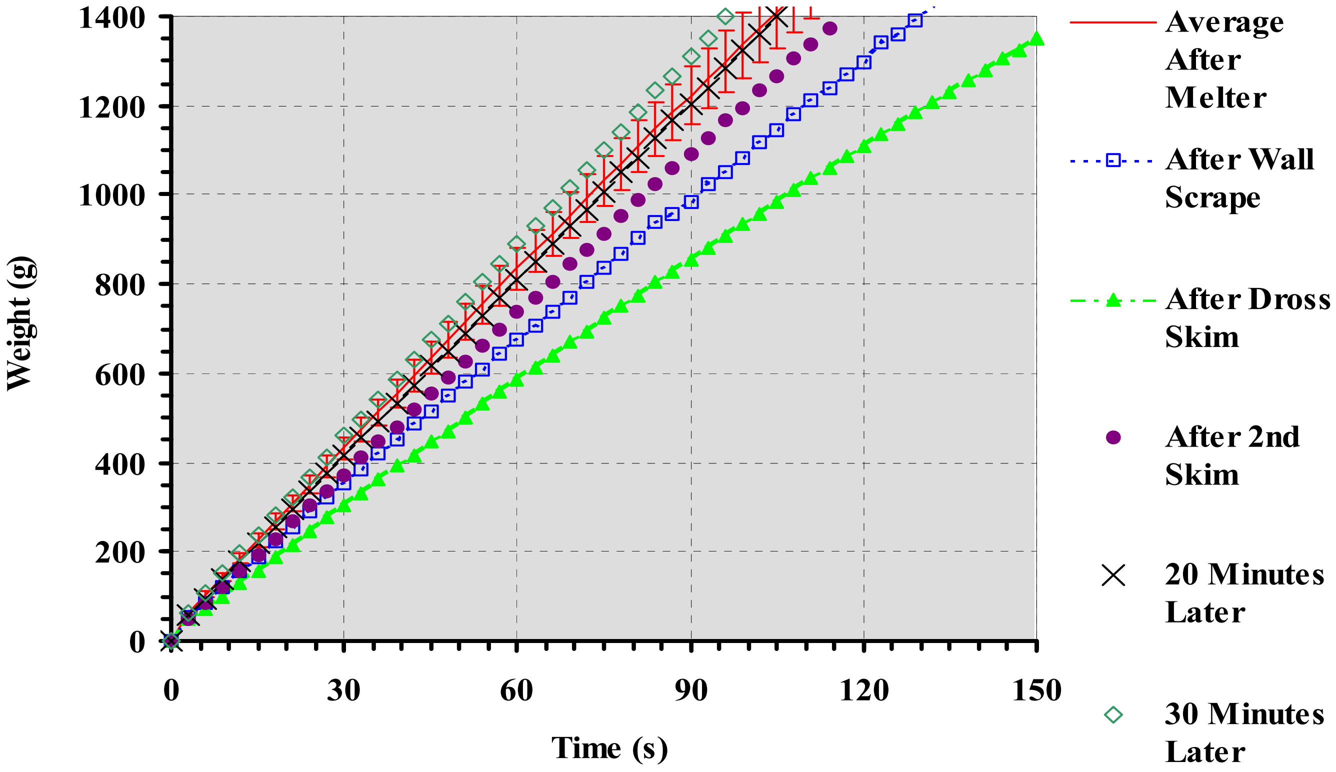


Figure 7: The Effect of Disturbance in the Degassing Well (superimposed on the Word Class Benchmark for A356)

CHARACTERISATION OF IN-LINE METAL TREATMENT SYSTEM (DEGASSING AND FILTRATION)

Degasser

The degasser is a two-stage in-line Revrot system with argon injection. Strontium rod is injected into the first (upstream) chamber at a rate of 3 meters of 10% rod every casting cycle. The addition rate of strontium varies between 200-600 ppm.

When strontium is added to molten aluminum it increases the oxidation potential of the metal considerably, especially if it is added continuously to the surface of a turbulent bath. Wherever possible the strontium should be added below the surface but mixed in quickly.

Complex strontium spinels and aluminates can form if strontium is allowed to build up locally and react via ion exchange with furnace refractories or binders in launder wash. Because of the effect of strontium on surface tension it also has a tendency to promote gas and shrinkage related porosities in cast product; it is therefore very important to have good control over the strontium addition practice and not to over-modify. Gas, in addition to inclusion content, should be simultaneously measured either side of a degasser to properly characterise the degasser performance. (Tenekedjiev, 1995)

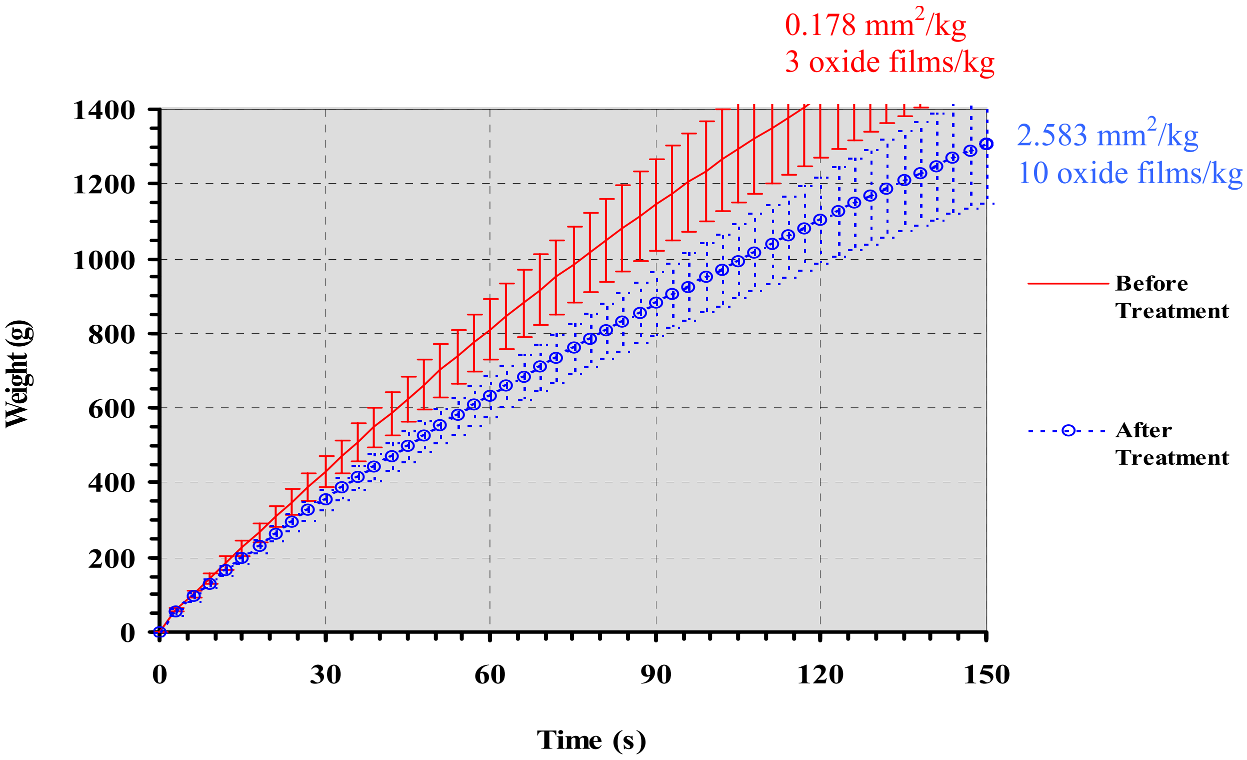


Figure 8: Before and After Degasser (superimposed on the Word Class Benchmark for A356)

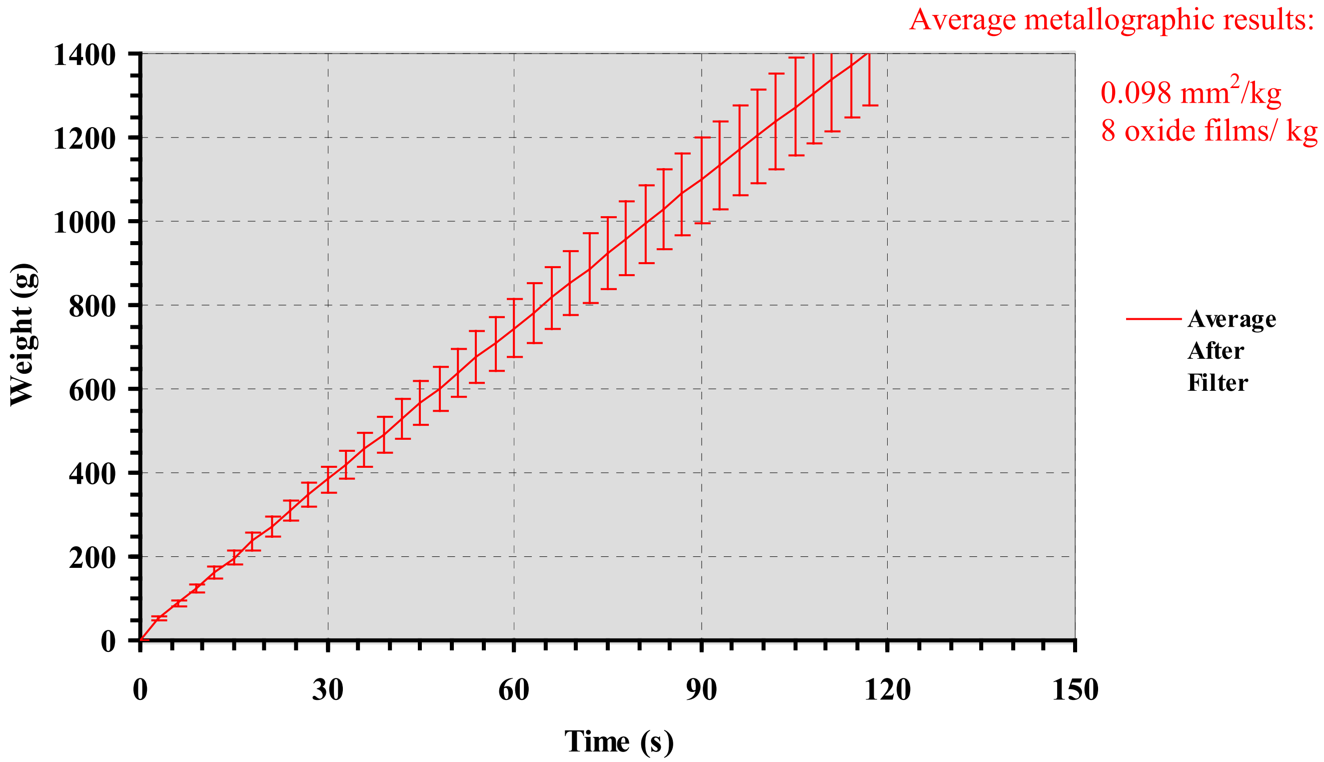
Figure 8 shows the average curve before (position 2) and after (position 3) the degasser. The results show that on average the metal quality before the degasser is slightly lower than the metal quality at launder position 1 and that there is a significant increase in inclusions after the degasser. Since both the average curve slope and the rate of change of curvature of the PREFIL characteristic have altered this suggests that there has been an increase in both film type defects and fine particulate.

A 600 ppm strontium is a high addition rate for this alloy and taken together with the absence of any continuous chlorine or flux addition in the degasser, oxide generation is to be expected.
This type of in-line degasser is particularly good at maintaining inclusions in suspension. This means that inclusions do not build up locally in the system, or become attached to the walls of the unit. Provided that adequate down-stream filtration is in place, inclusions (and oxides) can be properly managed.
Visually there was a deep layer of wet oxide and dross on the surface of the exit launder from the degasser.

Bonded Particle Filter

After degassing the metal is filtered through a bonded particle 6 grit vertical plate filter in a preheated filter box with a hold up to approximately 600 kg.

The average curve measured immediately after the filter is shown in Figure *9*. It is clear that the filter has removed most of the inclusions generated by the degasser and the metal quality has returned to within the World Class Benchmark for this alloy.



Average metallographic results:

0.098 mm^2/kg
8 oxide films/ kg

Figure 9: After Filter (superimposed on the Word Class Benchmark for A356)

GRAIN REFINEMENT AND THE DIAGNOSIS OF A PROBLEM

After the filter the material is grain refined by the addition of 5:1 rod. The rod is injected at the rate of 30 cm every casting cycle i.e. 30 cm of rod per 100 kg of metal (boron addition of 6 ppm).

Figure 10 shows the average curve of material sampled close to the casting head from the three casting fingers. The strong rate of change of curvature (plateau) is a clear indication that the material contains fine particulate (grain refiner particles). By reference to Figure 11, which shows the footprint for different grain refiner additions, this level of plateau would be expected for this boron level.

Note: Grain refiner particles tend to settle quickly (about 1mm per minute) in quiescent liquid aluminum (Enright, 1987). It is also well known that grain refiner particles tend to agglomerate, especially with oxide films, when allowed to settle. These agglomerates are very ineffective grain refining nuclei and become deleterious inclusions in a cast product. There is also the risk of loss of grain refinement potential in the casting.

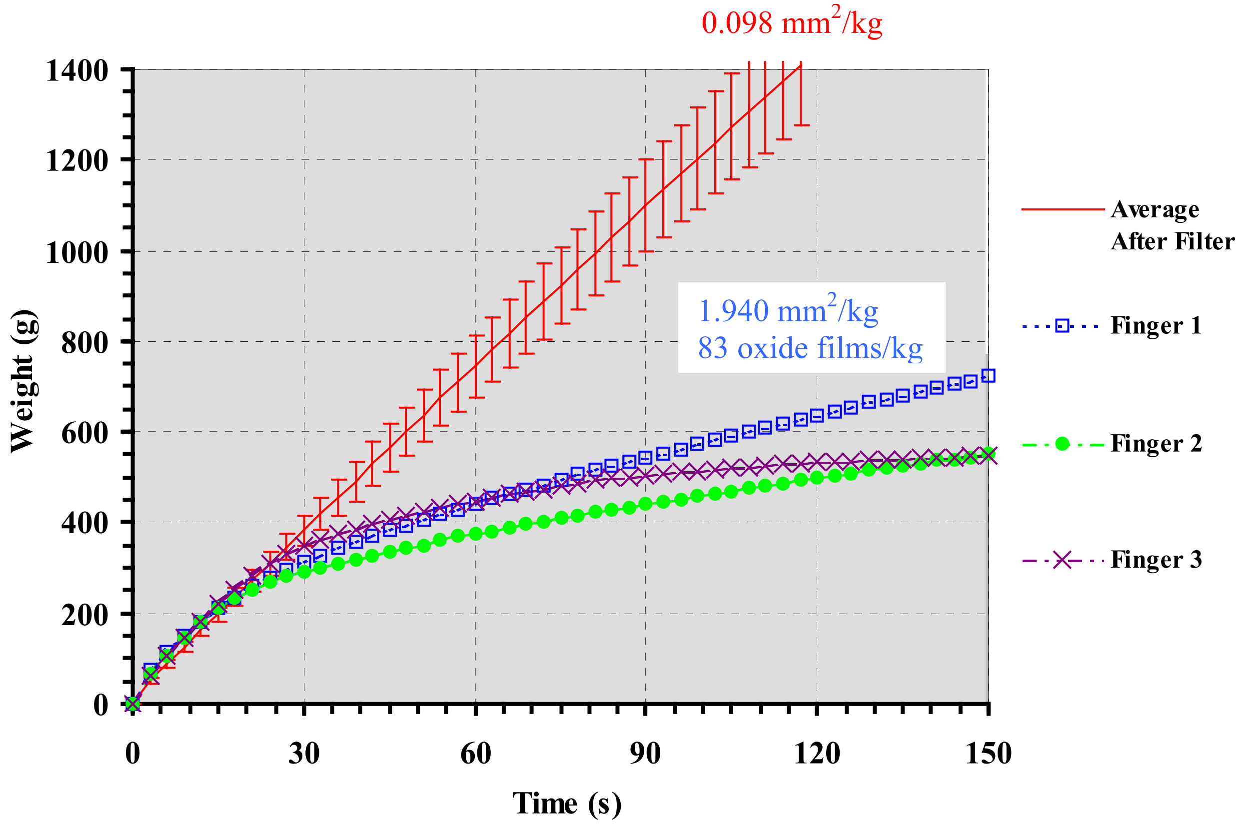


Figure 10: Average after Filter and Casting Fingers (superimposed on the Word Class Benchmark for A356)

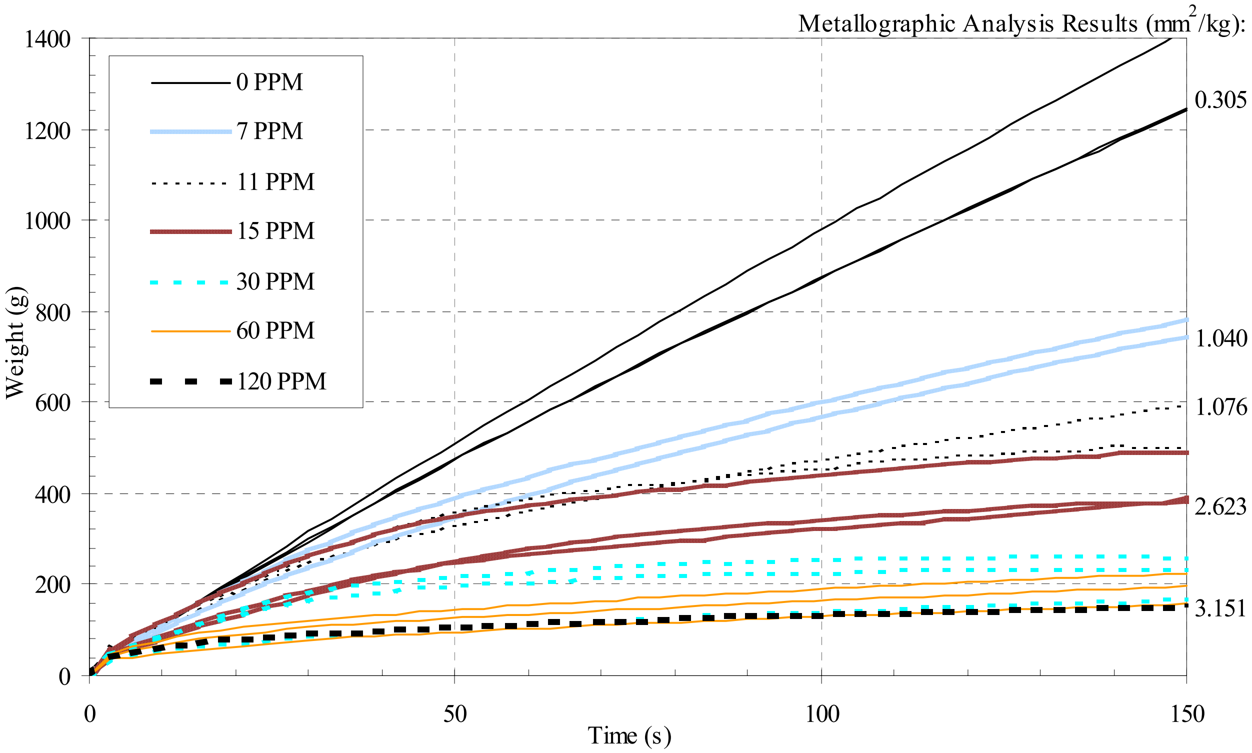


Figure 11: Effect of Grain Refiner Additions on Curves (Simard, 2001)

CONCLUSIONS

The pressure filtration technique called PREFIL-Footprinter has been used to carry out an audit of an automotive foundry.

The results show that the plant produces consistently clean metal, but that there are issues related to the addition of strontium.

Under steady state casting conditions, the instrument has excellent reproducibility and measures consistently clean metal.

The instrument is sensitive to small changes in metal sampling practice and can resolve time dependent metal quality fluctuations, such as the drossing off a degassing well.

Issues related to strontium and grain refiner additions have been characterised and the effectiveness of the filter has been demonstrated.

All data has been compared to the World Class Benchmark for A356 and clearly shows that this automotive foundry meets the criteria for World Class Production.

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