Improving Die Casting Melt Quality and Casting Results with Melt Quality Analysis and Filtration

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ABSTRACT

The use of aluminum castings in automotive applications continues to expand at a significant pace. High volume requirements are served by high pressure, low pressure, permanent mold, and precision sand casting processes. The engineered requirements for these applications demand a high degree of casting integrity, which begins with the aluminum alloy melt conditions.

Information is presented in this paper on several shop floor and laboratory methods of evaluating melt quality cleanliness, especially with respect to inclusions, and the benefits to be derived from sustained-usage, in-furnace filtering systems employing the bonded particle filter.

Substantial gains can be made in reduction of machining defects, improved surface finish, increased elongation, reduced leakers, and overall scrap reduction---all with minimal cost, effort, and risk utilizing bonded particle filtration.

INTRODUCTION

The growth in aluminum casting production and process technology has been very significant over the past decade. Increased automotive usage for engine components, structural components, wheels, and other functional castings is a major component of this growth. The higher property requirements of such castings have demanded excellent metal quality and melt treatment processes to provide more stringent controls on metal cleanliness—control of inclusions and hydrogen content to minimize porosity/microporosity. Melt treatments to produce clean metal include fluxing and/or flux injection, degassing, and filtration. Filtration processes are now employed in virtually every aluminum shape casting operation. Typical benefits that are expected, and achieved, include (1) greater metal fluidity and feeding capability during the casting process; (2) higher casting properties; (3) improved machinability; (4) better surface finish; and (5) overall reduction in scrap and reject castings.

In pressure diecasting, certain gravity diecasting or permanent mold processes, and high volume green or chem-bonded sand casting processes, it is often not practical to provide absolute point-of-pour, in-the-mold filtration. Consequently the remaining option is to employ filters in melting/remelt furnaces and in casting furnaces as close to the point-of-cast as possible. The bonded particle filters have emerged as the preferred filter of choice in such in-furnace applications in most instances (Neff, 1995). This filter is an aggregrate of silicon carbide bonded with a proprietary ceramic binder which resists any degradation in molten aluminum for long periods of time. The silicon carbide material is also very durable and thermally conductive, making it most suitable for extended, continuous usage over long periods of time. The bonded particle filter's lower porosity, tortuosity of internal structure, and affinity of the binder system to capture and retain inclusions enhances the overall inclusion removal efficiency of this filter.

Typical configurations include a Vertical Gate Filter, Figure la, separating the hearth from the dip-out well, in a casting furnace or the 'box filter' (Figure ib). The latter can be confugured to a variety of geometric shapes and sizes to suit furnace geometry and ladle size, and has the advantage of providing greater surface area; metal to be cast is auto-ladled from, or manually dipped from the interior of the filter vessel placed in a holding furnace or crucible furnace.

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Figure 1a: Vertical Gate Filters are placed in the outlet well or dipwell of a casting furnace.

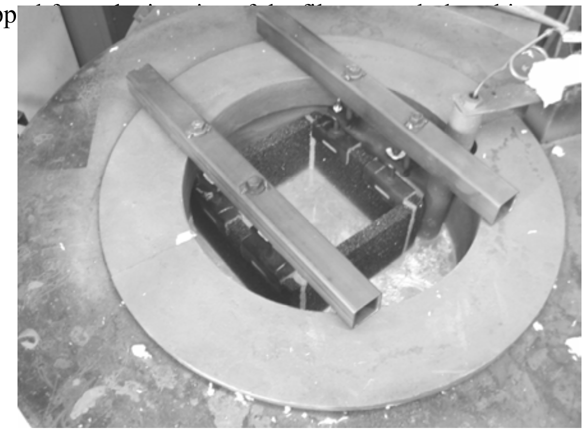

Figure 1b: A box filter is useful in crucible furnaces our dipwells of other furnace types.

To gage filtration effectiveness, it is necessary to have some means to do so, either by some analytical method, or to judge the results by overall casting quality. Diecasters often do not have the capabilities to directly assess filtration efficiency by analytical means, relying on gross process results such as percentage scrap reduction, or antecdotal information such as 'the metal looks cleaner'; 'machines better'; etc. This paper discusses several quantitative measures which have been used to determine melt cleanliness improvements through bonded particle filtration, in both production scale experiments and ongoing production. In addition, several semi-quantitative results regarding improvements in casting machinability and reduction in rejects are presented from several production casting operations.

TECHNIQUES TO EVALUATE MOLTEN METAL CLEANLINESS

There are several means to evaluate molten metal cleanliness that the foundry can employ either in process development or as ongoing production process monitoring. The most common practical and *technical* methodologies are the following: (1) reduced pressure test; (2) actual hydrogen measurement with Alscan, Hyscan, Leco analysis; (3) Qualiflash; (4) Prefil; (5) PodFA or LAIS; (6) mechanical testing; (7) Tatur test; and (8) K-Mold. Several of these are discussed in greater detail in a recent paper (Law, et al, 1999) focusing on diecasting application.

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REDUCED PRESSURE TEST

This is the most common method (Figure 2) which many non-diecasting foundries use today, and it is becoming increasingly prevalent in diecasting as well as a simple means of evaluating metal quality. It provides a semi-quantitative measure of overall melt cleanliness, as well as 'hydrogen gas' content, in the following manner. It is well recognized that inclusions nucleate hydrogen porosity. In the reduced pressure test, the presence of inclusions will assist any hydrogen present to develop an exaggerated visualization of pores, evident when the sample is sectioned after solidification. After the sample has been collected and allowed to solidify under reduced pressure, the specific gravity of the sample can be determined by Archimedes principle to give an apparent density. This can then be compared to theoretical density, and relative to samples prepared *without* reduced pressure, an estimate of hydrogen content can be determined. After the specific gravity or density has been determined, the sample can be sectioned and observed visually to assess the exaggerated porosity induced by the reduced pressure. This can be compared with certain industry rating charts, or a foundry-specific rating system. It must be emphasized, however, that what is assessed is general melt cleanliness rather than absolute hydrogen content.

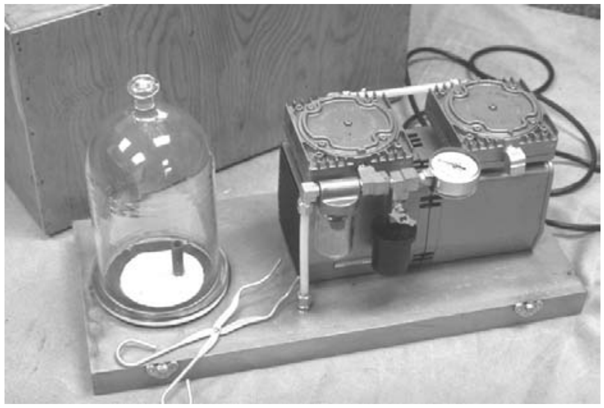


Figure 2: The Reduced Pressure Test is the most common tool used by foundries and diecasters to assess metal quality.

ALSCAN
The Alscan technique measures true hydrogen content in a melt sample in real time (approximately 15 minutes) by means of a carrier gas collecting hydrogen, and thermal conductivity measurement. While not a measurement of molten metal cleanliness per se, this is an excellent tool to gain quantitative information on hydrogen content of the melt. Even in high pressure diecasting with its rapid solidification, porosity nucleation---hydrogen evolution nucleating on inclusion surfaces---can result in problem castings in many applications.

LABORATORY HYDROGEN ANALYSIS
An alternative method to measure hydrogen content is to take a melt sample and cast a permanent mold test bar, for example the Ransley pin mold. This sample is subsequentlyanalyzed in the laboratory by vacuum sub-fusion equipment to capture the hydrogen gas that evolves from the sample during the analysis.

QUALIFLASH
This is a qualitative fluidity test device (Figure 3) which passes a specific volume of metal at a given temperature through a coarse, cellular 'test' filter into a stepped collector pan. The more fluid the metal, the greater the number of 'steps' climbed by the molten metal. A shop-floor result can be achieved in five minutes or less, but the process is sensitive to both temperature and specific alloy as well as melt cleanliness.

Figure 3: The Qualiflash test measures molten metal fluidity semi-quantitatively.

PREFIL FOOTPRINTER

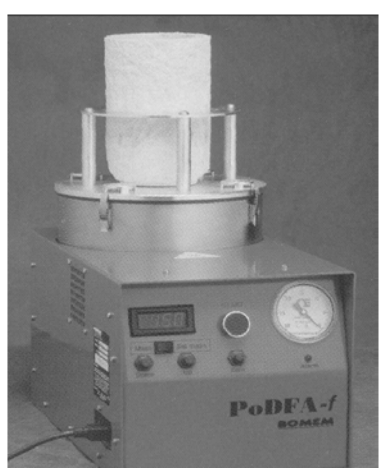
The Prefil Footprinter (N-Tec Ltd) test (Figure 4) uses the flow rate of molten metal under pressure through a fine-pore test filter to measure the quality of the metal. Very clean metal flows quickly giving a steep straight line in the visual output as measured by a load cell recording volume (weight) in the collector mold as a function of time. The electronic package allows a fluidity curve to be generated which can be compared with previously derived data and industry 'standards' developed by the manufacturer (N-Tec). The inclusion content can also be measured by metallographic examination and image analysis of the concentrated inclusions from the test filter.

Figure 4: The Prefil Footprinter provides real-time analysis of metal cleanliness relative to accumulated industry data. (N-Tec)

PODFA

Shown schematically in Figure 5, this test is similar to the second-stage of the Prefil. A small quantity of metal is caused to flow under pressure through a fine-grade test filter. The inclusion content concentrated on the surface of the test filter is then examined metallographically. The LAIS (Liquid Aluminum Inclusion Sampler) is a similar device. All three—Prefil, PodFA, and LAIS—require off-line analysis and therefore their main usefulness is in process development, analyzing benefits of varying process parameters, and they are not useful as real-time production tools. Correlations of results between these three techniques can be difficult.

Figure 5: The PodFA test is a common method to evaluate metal cleanliness using metallography on the collected sample.



MECHANICAL TESTING

Mechanical properties (tensile and yield strength, elongation, fatigue strength) can be determined by casting test bars and comparing results of filtered versus unfiltered metal. Figure 6 displays a useful 5-bar test mold, bottom fed, which affords permanent mold solidification conditions. A single pour provides reasonable ‘significance’ of the validity of the 5-data point average result.

Figure 6: A multiple test bar mold is used to cast specimens for mechanical testing. (N-Tec)

FEEDING AND SHRINKAGE TESTS

A simple spiral fluidity test can be performed by pouring metal at a given temperature into a spiral mold. The distance the metal travels before solidification can then be used as a measure of fluidity, filtered metal vs. unfiltered metal. A more sophisticated test is the Tatur Test (Figure 7), which meausres shrinkage and porosity distribution as a function of (1) hydrogen concentration, (2) alloy/structure/solidification, and (3) metal cleanliness.

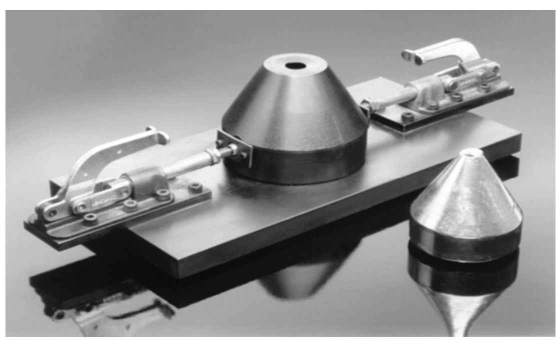


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Figure 7: The Tatur test measures shrinkage and porosity. (N-Tec).

K-MOLD

This is a simple shop-floor, real-time test procedure comprised of casting metal into a notched bar chill mold (Figure 8) and visually examining macro defects (coarser inclusions, gross oxides, and gas bubbles) on the fracture surface in a series of bars. The K-factor is the number of defects seen per number of fracture surfaces examined. This test method originated in Japan and is used extensively there. Many US foundries and and diecasters are now evaluating this test technique both as a process development tool as well as an ongoing production go/no-go step for casting or additional treatment necessary prior to casting.

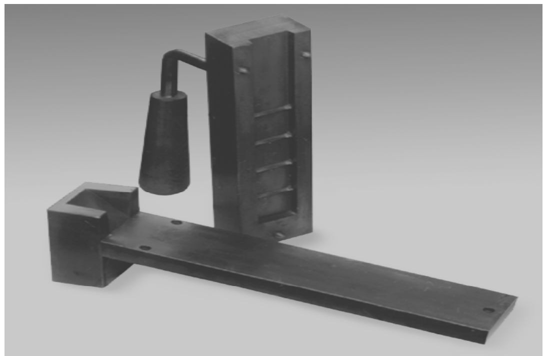


Figure 8: The K-Mold is a simple shop-floor, real-time test which evaluates macro-cleanliness.

FILTRATION EVALUATION RESULTS

In order to demonstrate the effectiveness of bonded particle filtration, many of the above techniques have been employed in several studies. The first of these was a 'laboratory' evaluation conducted on a production-size melt. Other studies involved similar production-sized melts in a laboratory setting, and still others were conducted directly in production pressure and gravity diecast foundries.

LABORATORY EVALUATION OF PRODUCTION SIZED MELT

In one 'laboratory' evaluation conducted at N-Tec, a 1000 pound, 50-50 scrap/ingot mix of LM24 (A380) alloy was melted in a gas-fired bale-out furnace. An 8 grit Metaullics Box Filter was placed in the melt, as in Figure 1b, and the temperature allowed to equilibrate to approximately 1340 degF (720 degC). No melt treatment such as fluxing or degassing was performed. To simulate a typical diecasting cycle, approximately 2 lbs were ladled from the vessel repeatedly until the metal depth was lowered approximately 4 inches, then the furnace was re-charged with 100% molten scrap metal from a second furnace. Alscan and Prefil measurements were taken, as were tensile bars, K-mold, and Tatur shrinkage test specimens from time to time.

Prefil Results

Figure 9(a) depicts the Prefil curves obtained outside/inside the box filter, versus the typical industry standard over many different evaluations for this alloy. Clearly the test with the bonded particle filter shows a metal cleanliness result comparing well with the comparable best 'clean metal' industry standard. A production diecaster Prefil result is shown in Figure 9(b), again demonstrating significant improvement over unfiltered metal.

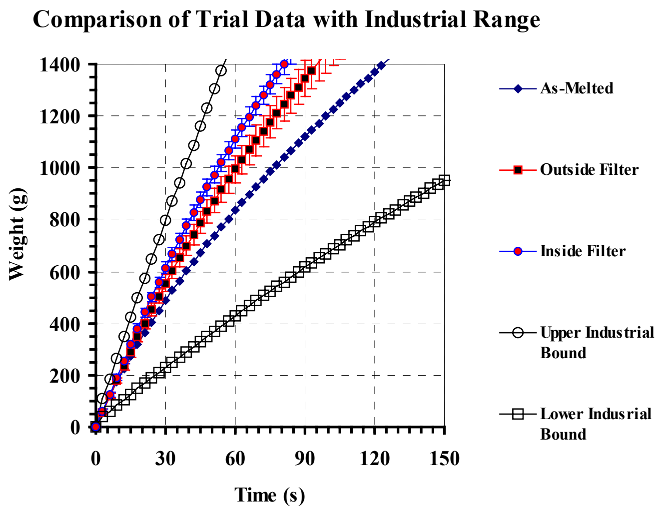
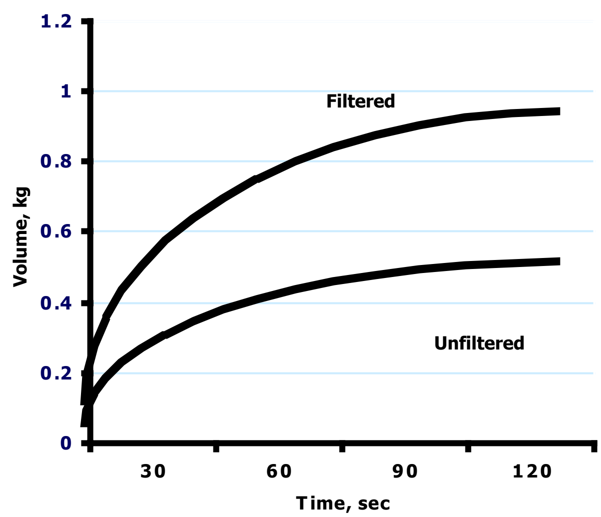


Figure 9a:The Prefil curve demonstrates improved fluidity with the filter compared with



normal industry data.

Figure 9b: Production foundry Prefil results verify benefits of filtration.

<u>PodFA and Metallographic examination</u>

In general metallographic examination of solidified melt samples, searching for inclusions, and characterizing them, much less providing quantifiable data, can often be characterized as 'searching for a needle in a haystack'. Further, a grab sample of perhaps just one kg from a melt is just that—a very small sample indeed, and often not truly representative. A large number of such samples would need to be collected and analyzed to achieve a meaningful conclusion. The PodFA test, on the other hand, does *concentrate* the inclusions present, albeit still from a rather small sample, but still gives a reliable, industry-

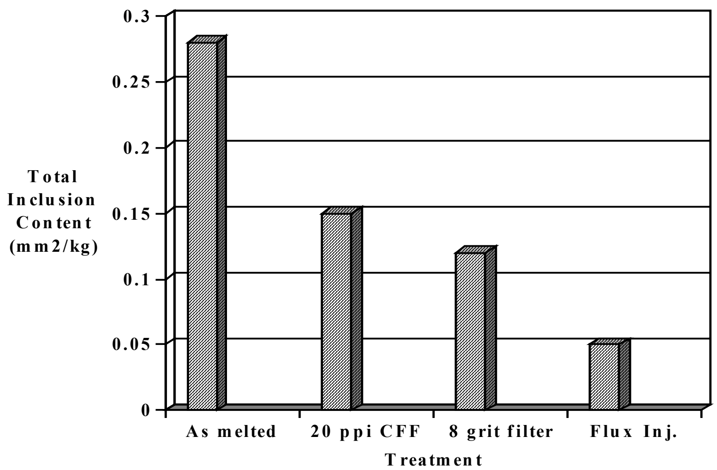
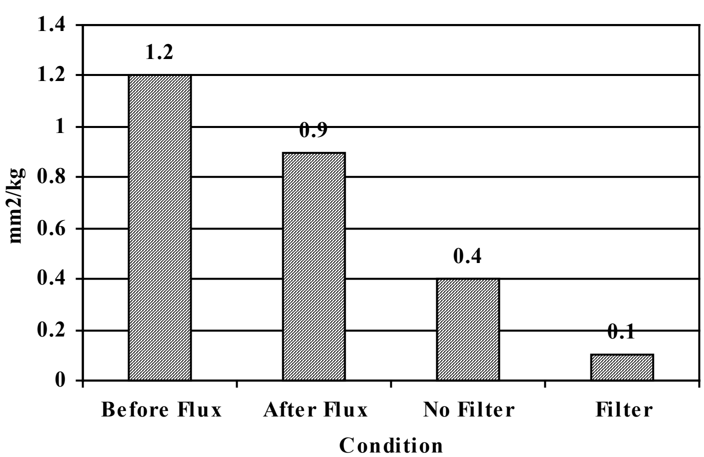


Figure 10: PodFA results show improvement of 8 grit bonded particle filter over 20 ppi ceramic foam filter.

recognized-technique result. Figure 10 shows improvement of the 8 grit bonded particle filter over results obtained from a 20 ppi ceramic foam filter. Note that corresponding results with rotary flux injection

would seem to be even better. However, this result was obtained just after flux treatment. In practice, the metal is then delivered into the casting furnace with subsequent re-oxidation through pouring. Figure 11

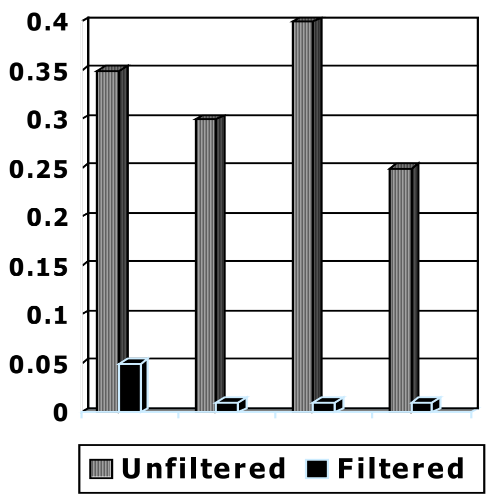
demonstrates the result when samples are taken in a production foundry from the pour-in well, and then in the dipwell downstream of the filter. In this case, the bonded particle filter clearly shows an improved



quality result over the previously fluxed metal.

Figure 11: PodFA results show further improvement by filtration after flux injection.

<u>K-Mold</u>
From the aforementioned 'laboratory' test, K-mold values were obtained on five random samples taken outside/inside the box filter. Results are shown in Figure 12(a).
There is a clear distinction provided by filtration. Note the 'steady' result inside the box filter versus the more erratic 'upstream' or before-filtering data. The result compares favorably with production K-mold testing, Figure 12(b).



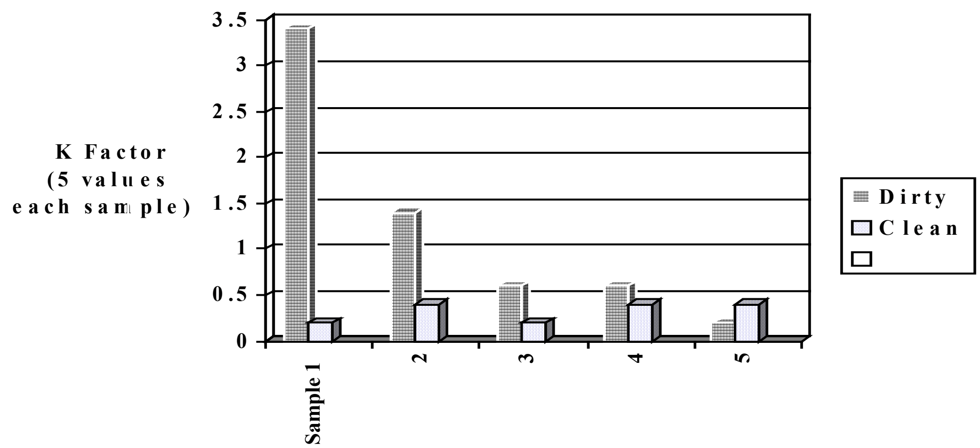


Figure 12a: Laboratory K-mold results after continuous re-use of the same metal.

Figure 12b: Production diecaster K-Mold results show exellent results on 380 alloy.

<u>Tatur Test</u>
Tatur test results in the 'laboratory' study are shown in Table 1. Information can be gained on shrinkage and feeding with this test. Analysis of the the pipe volumes shows a 3% difference between filtered and unfiltered material. While many factors can be responsible for shrinkage/pipe volume, as filtering is the only variable in this particular trial, the result can be considered to be significant in relation to pipe volumes obtained by varying factors in other tests (ie grain refinement, modification, etc). Analysis of the feeding characteristic suggests that the filtered material has a 10% higher feeding distance.

Table 1. Tatur Test Results, Laboratory Melt

Sample	Pipe depth (cm)	Weight of Casting (g)	Weight of Casting with H20 (g)	Volume of Pipe (cm3) Shrinkage	Height of Pipe above chill (cm) Feeding
TO1 (outside)	7.6	1136.5	1150.5	14.0	28.0
TO2	7.1	1135.0	1151.9	16.9	29.0
TO3	6.6	1139.5	1153.0	13.5	35.0
TO5	6.7	1153.7	1167.8	14.1	32.5
TI1 (inside)	6.8	1140.3	1155.6	15.3	32.5
TI2	6.8	1139.5	1155.0	15.5	32.0
TI3	6.2	1136.3	1149.8	13.5	37.0
TI4	6.7	1141.6	1156.7	15.1	33.5
TI5	6.0	1137.7	1149.8	12.1	37.0

Mechanical Properties

In general, inclusions are usually detrimental to mechanical properties. Tensile and yield strength results may be relatively insensitive if the inclusion concentration and sizes are small. In all but the dirtiest metal, it can be expected that tensile and yield strength properties may not be greatly affected filtered vs. unfiltered. Elongation, however, is a much more sensitive parameter to filtration. Table 2 indicates a significant improvement in elongation of filtered samples versus non-filtered material in the 'laboratory' study, whereas the tensile and yield results are not greatly affected which is to be expected.

Table 2. Mechanical Property Determination, Laboratory Melt

Sample No.	0.2%Proof Stress (N/mm2)	UTS N/mm2)	Elongation %	Comments
TBIN-1	125	213	3	
TBIN-2	129	217	3	
TBIN-3	122	205	2.5	
TBOUT-1	123	202	2	
TBOUT-2	127	218	2	
TBOUT-3	118	209	2	
TBSCRAP-1	126	222	0.5	Slight flaw
TBSCRAP-2	128	199	2.5	
TBSCRAP-3	126	209	2.5	

The average elongation values show that with the scrap additon, the result is less than 2.5%, and in the Pot outside the filter the result is 2%, whereas inside the box filter the result is 2.83%.

Qualiflash

In a separate study, the Qualiflash device was used to ascertain molten metal cleanliness in a variety of circumstances (3). The results are presented in Figure 13(a) laboratory study, and in (b), a production foundry. Clearly there is a strong advantage shown in metal fluidity in this test with filtered metal. In production, as settling occurs in the holding furnace, the metal quality can show 'improvement', as noted in (b). However, subsequent pouring in can deteriorate this result. In addition, 'fade' of filtered quality can be caused by the accumulation of oxide skins from repeated ladling. This differential is restored by periodic surface skimming as shown in the second chart in (b). The frequency of skimming should be determined by specific operating conditions such as cycle times, ladle geometry, etc, and always must be recommended for all casting operations.

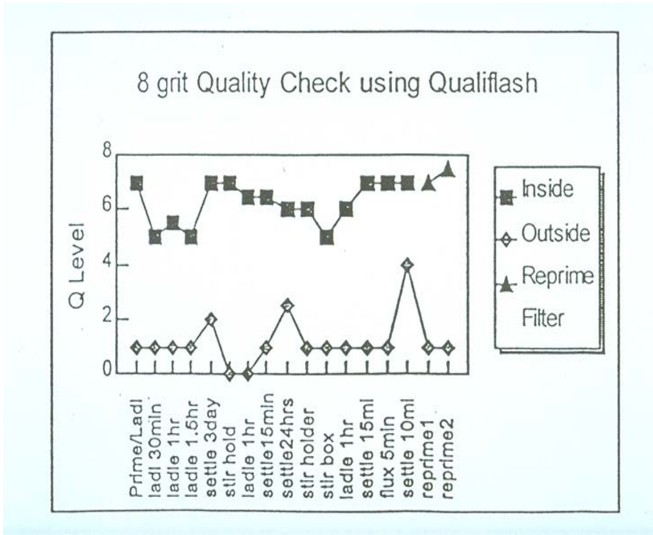


Figure 13a: Laboratory results with Qualiflash show significant improvement with the box filter.

Machinability, Scrap Reduction

The value of the foregoing analytical techniques is especially useful in process development and ‘proving analytically’ that filtering is ‘doing something good’. However, the ultimate objective of the foundry is to reduce metallurgical or inclusion-related scrap, and achieve greater productivity and profitability. By establishing the correct protocol in melt treatment, and incorporating filtration properly into the process, it is possible to reach the objective. In many production diecast foundries it is often very difficult to track filtration versus non-filtration results on specific casting production. However, if the effort is undertaken, significant improvements can be verified in machinability and scrap reduction.. Table 3 presents a collection of typical results from a number of foundries which clearly demonstrate *direct casting production benefits* of filtration. These results are representative of many foundries who have achieved significant reductions in machining defects using filtration to virtually eliminate hardspots caused by sludge, corundum particles, oxides, and refractory erosion with point-of-cast bonded particle filters in the dipwells.

Table 3. Typical Benefits achieved with In-Furnace Bonded Particle Filtration

Foundry	**Alloy**	**Filter Result**
A	**380**	**Hardspots eliminated**
B	**319**	**Leakers reduced 75%**
C	**380**	**Tool life extended 600%**
D	**319**	**Scrap reduced 95%**
E	**380**	**Tool breakage reduced 95%**
F	**518**	**Scrap eliminated**

CONCLUSIONS

A variety of techniques have been used to demonstrate the beneficial effects of filtering die casting metal with the bonded particle filter media. The use of the Prefil Footprinter, PodFA, K-Mold, Qualiflash, Tatur test, and mechanical property testing may be used successfully to evaluate filtration results during process development or during actual production. While specific results will vary from foundry to foundry, it is clear that filtration has a beneficial effect on

(1) metal fluidity
(2) elongation
(3) overall metal cleanliness

when analytical, quantitative or even semi-quantitative evaluation methods are used. The ultimate realization of these technical improvements has significant impact on aluminum foundry casting quality:

- Improved metal fluidity results in better die fill and fewer feeding defects.
- Higher elongation is often a critical quality for structural or engineered aluminum castings.
- Increased metal cleanliness results in fewer problems with microporosity.

While laboratory or analytical techniques are useful in process development studies, they are not always available. Further justification for filtration can be obtained on an even broader basis by the foundry through monitoring results of the casting process—in downstream processing such as improved machinability (reduced tool wear, longer tool life), and reduced levels of scrap. Internal scrap in the diecasting foundry, and customer returns/rejects can be significantly reduced with filtration, with obvious financial and casting marketability realizations.

The bonded particle filter which is the prime staple of in-furnace filtration technology has been shown to provide measurable benefits in filtering effectiveness through these evaluation methods. This filter technology is uniquely suitable to the pressure diecasting process.

ACKNOWLEDGEMENTS

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