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Molten Metal Filtration

Molten Metal Filtration – An Engineered Balance.

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1–ABSTRACT
The use of molten metal filters is becoming established practice for an ever growing number of foundries. With this growth in use there is a need for an increased technical understanding of filtering technology in general. It is not enough for a filter to just have good filtration efficiency. It must also have a high and consistent flow rate, good strength, a high capacity and good dimensional accuracy. This must be achieved at the lowest possible cost. Some of these parameters are in conflict with each other; for example if a filter has a very large capacity, the filtration efficiency may be compromised. The most effective filters are therefore ones that have been engineered to give the optimum performance over all of these parameters.

The following paper aims to discuss the relative performance of three of the most popular filtering technologies against each of the above parameters. The filter types considered are pressed filters, extruded filters and foam filters. The results of several technical studies will be presented and discussed. It is hoped that a better understanding of the relative strengths and weaknesses of each filter type can be attained.

2–INTRODUCTION
With the ever increasing quality demands necessary for today’s castings, the filtering of molten metal has become established practice for an ever increasing number of foundries around the world. Traditional methods to remove inclusions such as whirl gates and extensive running systems are now rarely seen. There is a therefore a greater need for increased technical understanding of filtering technology. Experience has shown that characteristics

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...and good filtration efficiency are important properties of filters. The ability to remove inclusions is of course important, but a filter must also have a high and consistent flow rate, good strength, a high capacity, good dimensional accuracy, and a low cost.

Some of the above properties are in conflict with each other. For example, if a filter has a very large capacity, this may be at the expense of filtration efficiency. The most effective foundry filters are engineered to give the optimum performance in all of the important areas.

There are several established filter technologies presently on the market. These include strainer cores, woven cloth or mesh, and ceramic tile filters. Ceramic tile filters are generally considered to be the most effective. The most popular of these are pressed cellular, extruded cellular and foam filters. Pressed cellular are generally characterized by their round cells, extruded filters generally have square cells, whilst foam filters have a random dodecahedron type structure.

The following paper aims to discuss the relative performance of these three filter types against each of the following parameters:

- Filtration Efficiency efficiency is obviously an important property of filters. An effective filter must remove slag and dross from the melt in order to prevent non-metallic inclusions from entering the mold cavity. How effectively a filter does this will depend on several factors.
- Metal Capacity The capacity of a filter should of course be adequate for the casting but it should also be consistent. The capacity should not vary from filter to filter. This may lead to premature blockage in some cases.
- Flow Rate The flow rate should be high and consistent. Wide variations in flow rate may in some cases lead to mold fill problems, or a requirement to use a larger filter thereby increasing cost and decreasing yield.
- Dimensional Accuracy The filters should fit into their print cavity first time and every time. This performance criteria is more closely related to the manufacturer rather than the technology.
- Strength (hot and cold) The strength of a filter is classified in two ways: hot strength and cold strength. The cold strength of a filter is important for shipping and handling purposes. It is important that pieces don't break or loosen as these may well end up in the casting. Hot strength is important so the filter remains intact when molten metal is poured onto it.
- Cost The cost of a filter is obviously an important consideration. Today's modern foundries are highly competitive and ways to reduce costs are always being sought.

In all cases, the studies used filters that are generally recommended for use with ductile iron. All the foam filters tested are 10 ppi (pores per inch). The extruded filters are 100 csi (cells per square inch). The pressed filters have a cell diameter of 0.100 inches (2.5 mm).
3-FILTRATION EFFICIENCY
The ability of a filter to remove inclusions is obviously an important parameter. Ceramic tile filters are generally more efficient at removing micro inclusions than traditional methods such as extensive running systems and whirl gates. The removal of such inclusions will have a positive effect on the machinability of castings, (1), resulting in extended tool life. The fatigue strength will also be improved as a result of improved as cast surface finish.

3.1-FILTRATION MECHANISMS
Filters remove inclusions using a variety of mechanisms (2). Some may be more efficient at one mechanism than others. The following is a brief description of each of the mechanisms, using cellular filters as an example.

3.1.1-SCREENING
Filters will collect dross particles and inclusions that are larger than the filter hole or pore size on their upstream face. These particles are unable to pass through to the casting cavity due to their physical size. Figure 1 shows a diagram describing the screening mechanism. Figure 2 shows a large sand agglomerate retained on the filter surface by screening.

3.1.2-CAKE FILTRATION
The larger dross particles collected on the upstream face during the screening phase will form what is known as a "filter cake". This cake will itself act as an efficient filtration media. This phase is able to collect particles smaller than the cells of the filter. Figure 3 shows a diagram showing the mechanism of cake filtration.

In ductile iron, a more probable mechanism for the removal of micro-inclusions, (<1% of the cell size), is through the formation of "inclusion bridges". Small eddy currents, formed when the metal stream splits on the active face of the filter, are generated. These eddy currents will encourage small non metallic particles to make contact with the edges of
As the pour progresses these particles will continue to adhere to each other and will eventually form an "inclusion bridge." Figure 4 shows an inclusion bridge formed from minute sulfide and oxide particles in ductile iron. The phenomenon is regularly observed in both cellular and foam type filters. <1% of the cell size), is through the formation of "inclusion bridges." Small eddy currents, formed when the metal stream splits on the active face of the filter, are generated. These eddy currents will encourage small non-metallic particles to make contact with the edges of the cell. As the pour progresses these particles will continue to adhere to each other and will eventually form an "inclusion bridge." Figure 4 shows an inclusion bridge formed from minute sulfide and oxide particles in ductile iron. The phenomenon is regularly observed in both cellular and foam type filters.

3.1.3—DEEP BED FILTRATION
The internal structure of the filter is able to capture small particles of dross and slag. Small variations in flow will cause particles to touch the ceramic walls of the filter. Once contact is made, the inclusions will have a tendency to adhere to the ceramic material. Figure 5 shows a diagram of the mechanism. Figure 6 shows a sand grain retained by deep bed filtration in a pressed cellular filter.

3.2—RELATIVE FILTRATION EFFICIENCY
Many studies have been undertaken in an attempt to quantify and compare the filtration efficiency of filters. Such a study (3) was implemented to compare the three filter types under discussion. The study was also used to examine the effectiveness of filtration in general. Filtered and unfiltered castings were poured for the study. Quantitative and qualitative examinations were then performed.

For the tests to be valid it was necessary to keep parameters such as composition of the melt, pouring temperature and pouring time as consistent as possible.

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PASSAGES. The melt composition can be kept constant by pouring each casting from the same melt. This, however, will inevitably lead to temperature losses between the first and last pours. To account for this variability, four series of castings were poured and the order of pouring was reversed between the first two heats and the last two. Each series started and ended with an unfiltered casting. The system choke was at the base of the sprue. This was done to ensure that pouring time did not vary with filter type.

A step block casing was designed for the study. A diagram of the complete system can be seen in Figure 7. The casting had a 3 inch, (75 mm), thick section and a 1/4 inch, (75 mm), thick section. The system was gated so that the iron flowed through a drag runner, up through the filter, and into a cope runner.

3.2.1—QUALITATIVE METALLOGRAPHY
The cope surface of each of the castings was examined visually for pit type defects. These defects are normally associated with macroscopic silicate inclusions. The castings were rated as "3" for a good surface finish, "2" for a fair surface finish, and "1" for a bad surface finish. Examples as to what was regarded as good, fair and bad can be seen in figures 8, 9 and 10.

All of the castings poured were scored using the above system. The average scores of each filter type can be seen in the graph in Figure 11.

As can be seen from the average ratings, the choice of filter does not seem to make any difference to the surface quality of the castings. All the filters tested produced good quality castings, and as such can be considered approximately equal in their ability to remove the exogenous silicate inclusions associated with the pitting defects.
3.2.2—QUANTITATIVE METALLOGRAPHY
The castings from one series underwent quantitative metallography. This basically involved counting the number of micro-inclusions present in samples from each of the castings in the series.

Specimens from the three-inch portion of the casting were carefully polished to ensure that inclusions were not torn from the sample. Each specimen was divided up into a 10x10 grid pattern to give 100 fields. Each field measured 300μm x 350μm. Particles with an area greater than 160μm² were eliminated based on the assumption that these were graphite nodules. It is however inevitable that some particles included in the count will be graphite nodules, partially accounting for the relatively low efficiencies observed.

For the purposes of presentation, it is assumed that unfiltered castings have zero filtration efficiency. The number of inclusions found in the unfiltered casting can therefore be assumed to be 100%. The relative efficiencies of each filter type can therefore be calculated. A graph showing this can be seen in figure 12.

It cannot be claimed that this study represents an absolute figure for the relative filtration efficiency of each filter type. The castings are taken from one series only and, as stated earlier, differences from pour to pour will always occur. The study does show, however, that the effects of using filters in general are considerable in their ability to remove micro and macro-inclusions. This is shown in both the qualitative study and the quantitative study.

4—FLOW RATE
Consistency of flow is becoming an increasingly important property. Filters of a particular model should ideally have a high and consistent flow rate. The filter should have as little effect on the pour time as possible. Most ceramic filter manufacturers recommend that the active face of the filter should have a surface area of between 3 and 5 times that of the system choke, but even if these recommendations are followed, high variations in the flow rate can sometimes lead to problems.

Assuming factors such as melt cleanliness, metal temperature and chemistry are constant the consistency of flow rate through the filter will depend upon the consistency of properties such as

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Studies were undertaken to compare the flow rate characteristics of the three filter types under review. The first study (4) was performed on water flow measuring equipment. The second study (5) used ductile iron.

4.1—WATER FLOW RATE

A water flow testing machine was constructed to compare the flow rate of the different types of filters. The filters studied were all 50 x 50 mm. The foam filters were 10 ppi, the extruded were 100 csi and the pressed had a cell diameter of 0.100 inches. These are generally the filter models recommended for use with ductile iron. The aim was to assess the consistency of flow from one filter to the next. One hundred pieces of each filter type were measured to get an accurate idea of any variation. The filters were the system choke. Figure 13 shows a graph of the first 25 filters to be measured. As can be seen there is a high variation in the flow rates of foam filters, whereas the cellular ceramic filters show negligible variation. This graph depicts the variation that would be expected from one filter to another in normal production. The difference in the filter types can be seen clearly in the distribution plots in figure 14. The distribution curves are normal and this indicates that the test samples are valid. It can be seen that the pressed filters and the extruded filters have almost exactly the same flow rate and consistency.

The reason for the inconsistency in the flow rates of the foam filters is due to their random nature. There will always be variations in their porosity and consequently in the amount of ceramic coating. This variation will occur within the structure of individual filters and from filter to filter. Also, due to the random nature of the foam there will always be "dead spots" were almost no flow occurs — much like the water behind rocks in a fast flowing river. These inconsistencies will compound to give the variation seen on the graph. If a filter type has an inconsistent flow rate, then follows that they will also have an inconsistent capacity. Filters with areas of fine porosity and low percentage open area can lead to premature blockage and consequently short run problems. Conversely, the structure of cellular filters is highly repeatable. As such, due to the filter design, there will almost be no inconsistencies in the flow rate and therefore negligible variation in capacity.

4.2—METAL FLOW RATE

Although water flow rate gives a good indication of the relative consistencies of filter types, it still does not exactly simulate the flow of iron. When iron is flowing through a filter, its rate will not be
metal. It will get less over time, due to the iron metal inclusions progressively blocking more and more of the filter.

Studies performed on the flow rate of iron through filters (5) mirror the results of the water flow study. Cellular filters have a significantly higher flow rate than foam filters. Only one filter of each type was used for the study. If many filters were tested the trend for foam filters observed in the water flow study, would likely be experienced in metal flow also.

5—CAPACITY
The capacity of a filter is closely related to flow rate and filtration efficiency. If a filter has a very high filtration efficiency, it may be at the expense of flow rate and capacity. Foundries would ideally like all of these properties to be high but it is no use having a filter that has an extremely high efficiency if it is prone to premature blockage. Conversely, if the capacity is too high then the filtration efficiency may be compromised.

Studies, (5), have found that at 2462°F, (1350°C), in ductile iron, extruded filters have a marginally higher capacity than pressed filters. Both types had a significantly higher capacity than foam filters. At 2642°F, (1450°C), however, the differences between the filter types are reduced.

In this study only one filter of each type was tested. Given the inconsistency observed in the water flow rate study, it could be expected that the foam filters would also display a similar trend for capacity. Variations in the capacity of filters is often masked by the use of large filter areas relative to the system choke.

6—DIMENSIONAL CAPABILITY
The dimensional tolerance of filters is becoming increasingly important. Filters must fit into their prints first time, every time with minimal danger of leakage around their edges. This is especially true when the filters are set automatically. To compare their dimensional capabilities, one hundred of each filter type were measured. The pressed filters and the foam filters were described as 50 mm x 50 mm x 22 mm. The extruded filters were 55 mm x 55 mm x 13 mm. These were the only filters that were available for analysis at the time. Although there are two different sizes of filter, it is still possible to get a good idea of their capabilities in terms of dimensional stability. The foam filters were the “free formed” type with non-machined edges.

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The results are presented in figures 15, 16 & 17.

The most dimensionally consistent filter type measured are the pressed and extruded filters. The foam filters have almost twice the spread as the pressed and extruded. This is due mainly to their manufacturing processes. Pressed filters of a particular reference are individually made in identical steel dies. This ensures that each filter will have very close tolerances. Extruded filters are made by extruding a large log and then slicing them into individual pieces. Squareness can be a problem due to log twist before or during slicing. The foam filters analyzed are made using individually cut pieces of polyurethane foam. There is therefore a degree of variation from this cutting process before the ceramic is coated on the foam. Whilst being coated with ceramic, the filters will stretch and distort slightly due to the manufacturing process. The edges of the filters also contain a significant build up of ceramic material. This is again due to the forming process. The liquid ceramic slurry will squeeze out the sides of the foam causing the build up. Sharp edges can also be formed on the edges of foam filters. This can cause loose sand to be scraped away from the mold. This could then end up in the casting cavity.

7—COLD STRENGTH

The cold strength of filters is important for handling and shipping purposes. It is important that pieces of the filters don't loosen and break off, as these may well end up in the casting. The filter must also have adequate strength to survive the closing of the mold.

The cold strength of filters can be measured by subjecting them to a three point loading test. In this test, filters are supported on two horizontal pins. A load is applied from a third pin from above. The load is increased until the filter breaks and peak load is recorded. Twenty of each filter type were measured in this way. The results are reported in the graph in figure 18.

In terms of cold strength, pressed cellular filters are by far the strongest. This is due to the inherent advantages of processing ceramics by pressing. The extruded filters are less than half the strength of the pressed. The foam filters are less than one third of their strength. The foam filters are also friable in nature, (small pieces of the strands tend to break away). There is a danger that these small pieces may get washed right through into the casting cavity. This can be especially dangerous during mold closing especially if the filters are not dimensionally accurate.

8—HOT STRENGTH

A filter must obviously have sufficient strength at molten metal temperatures. To http://www.aucue.org/issue1_1999/molten.html
compare the hot strengths of the filter types in question, a small furnace was heated to 2732°F (1500°C). Inside the furnace is a refractory tube measuring 1.60 inches in diameter. The filters are introduced into the hot furnace through a small opening at the front, and placed on top of the tube, simulating the thermal shock experienced in the mold. The furnace is then allowed to equilibrate for one minute back up to 2732°F, (1500°C), after which load is then applied to the center of the filter with a refractory rod, 0.705 inches in diameter. The load is increased until the filter breaks. The peak load is then recorded. Ten samples of each filter type were measured in this way. The results are illustrated in figure 19.

As can be seen the pressed cellular filters are far stronger than both the extruded cellular and the foam filters. The hot strength of pressed cellular filters measured are on average over twice the strength of both extruded and foam. This is again due to the inherent strength advantages of pressed ceramics.

The test described above is only a static test designed to compare strengths at elevated temperatures. It is accepted that there are other factors to consider when iron is poured onto the filters.

9—COST
The actual cost of each filter type is impossible to give. Different manufacturers will have different costs and each foundry will purchase different volumes. However, it is generally accepted that at present foam filters are the most expensive type followed by extruded. Pressed cellular filters are generally regarded as the least expensive option of the three in types under review.

The price difference is due to processing costs. Foam filters go through a relatively complicated manufacturing cycle that involves coating a polyurethane precursor with a ceramic slurry. The filter then usually has to go through several spraying and drying stages before it is eventually fired in a kiln. Extruded filters are formed as a continuous log and individual filters are sliced from this. Pressed filters are less complicated to manufacture in that the filter is formed in one pressing operation after which it is dried and fired.

10—GENERAL DISCUSSION
The filtration efficiency study showed that all of the ceramic filters were effective in their ability to remove non metallic inclusions and to improve the surface quality of castings. The main differences between the filter types were found to be in the areas of strength, consistency of flow rate, dimensional stability, capacity and cost.

The water flow study was really aimed at comparing the consistency of filters rather than attempting to simulate the flow of iron. The flow rate of a filter will have an effect on its capacity and also its filtration efficiency. The higher the flow rate, the higher the capacity and the lower the filtration efficiency. This is, of course, also true in the opposite sense. Therefore, if a filter type has a highly inconsistent flow rate, it follows that its filtration efficiency and its capacity will also be variable. The gradual decrease in the flow rate marks the progressive blockage of the filter. Kahn et al.

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(1) studied the fatigue strength of castings produced from cellular filters and foam filters. It was found that cellular filters gave more consistently improved casting quality. Foam filters gave a more unpredictable casting quality ranging from the best quality castings to the worst.

All foundries are different and some may not be so sensitive to some parameters than others, however in terms of an engineered balance, it is clear that the more consistent filter solutions are the cellular types. Foam filters offer good filtration efficiency but they lack consistency, strength and are generally more expensive. The extruded filters offer good consistency in terms of flow rate and dimensional accuracy, but they tend to lack some strength. The pressed cellular filters give good filtration efficiency, good consistency in terms of flow rate and consequently capacity, have good hot and cold strength, have good dimensional stability and are generally the least expensive option. As such it is reasonable to conclude that in ductile iron, pressed cellular filters offer the best engineered balance of the performance parameters discussed.

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