Flow Modification Properties of Ceramic Foam Filters – A Summary of Recent Work

Abstract

The ability of ceramic foam filters to remove oxides and other inclusions from the molten metal stream as it fills steel castings is widely accepted and has been confirmed repeatedly through post-pouring evaluation of solidified castings. It has also been known that the ceramic foam filter minimizes the formation of reoxidation inclusions through metal flow modification and reduction of turbulence from the metal stream as it enters the casting.

However, until recently, the flow modification capability of filters has only been implied by water modeling and computer simulations of molten metal velocity and turbulence. Through refinements in the use of real-time X-ray techniques to study the ferrous casting process, it has become possible to see and record the effects of various gating and filtration configurations on molten ferrous metal flow and to confirm the validity of computer simulations. This paper summarizes recent work in the field of foam filtration knowledge.

Included in this paper are:

☐ A review of initial work in the use of real-time x-ray procedures to examine the effect of filtration and various gating arrangements on simple plate castings

☐ A summary of recent work showing dynamic computer simulations of fill profile characteristics to determine fill times and optimum methoding

☐ Previously reported examples of real-time X-ray images to confirm the validity of computer simulations and the effect of filters on casting filling characteristics and flow modification

☐ Comparisons of previously documented computer simulation results to real-time X-ray images of the same castings.

Introduction: The problem of inclusions in steel castings

Non-metallic inclusions are a major cause of defects in steel castings. Some, such as furnace slag, ladle slag, flux and alloying residuals, are generated outside the mould and are carried into the mould cavity with the molten metal stream. Others originate inside the running system and mould cavity; these include mould sand, core and core coating materials and reoxidation inclusions generated when the molten metal is exposed to air in the mould during filling.

Non-metallic inclusions compromise the physical properties and surface appearance of the casting, contribute to increased scrap rates or added cleaning room expense and create greater potential for customer returns because of machinability problems.

Both prevention and removal tactics are used to reduce casting inclusions. Melting practices, ladle design and gating system design can all be optimized to minimize the occurrence of non-metallic inclusions in steel castings. One of the most efficient techniques is the use of ceramic foam filters (although filtration is not a substitute for good foundry practices.)

Ceramic Foam Filters

Filtration development history

Early efforts by foundries in the mid 1960's to remove non-metallic impurities from liquid metal included passing molten aluminum through a packed bed of granulated refractory material. Since then, a variety of other filtration media have been tried, including steel wool, wire screens, woven fiberglass fabrics, bonded aggregate, pressed ceramic strainers and ceramic filters.

Ceramic foam filters and extruded ceramic cellular filters were introduced in the late 1970's for aluminum casting and, later, for copper-based castings and iron castings at pouring temperatures up to 1500ºC. Further developments in the mid 1980's led to the first ceramic filters suitable for the filtration of some steel castings. Since the mid 1990's, improved manufacturing methods, the development of lower-weight, higher-strength ceramic materials and improved application practices have made it practical to use ceramic foam filters for many types of steel castings.

These new materials possess the high-temperature strength, creep resistance, thermal shock resistance and low heat capacity to prime effectively and withstand the physical and thermal stresses of flowing molten steel, plus the chemical characteristics necessary for effective filtration.

How ceramic foam filters work:
Ceramic foam filters remove inclusions from the molten metal stream and reduce the formation of non-metallic inclusions in four ways:

- ☐ Coarse inclusions, too large to enter the passageways, are trapped on the face of the filter
- ☐ As pouring continues, inclusions may begin to accumulate on the filter face and form a "cake" of material that filters out even finer particles.
- ☐ Molten metal that flows past the filter cake and into the passageways follows a tortuous path through the body of the filter. The filter walls have a chemical attraction for the remaining inclusions, causing small inclusions to be trapped on the internal filter surfaces. It is estimated that a 100 x 100 mm, 25 mm-thick filter has roughly one square meter of total surface area.
- ☐ The filter prevents the formation of reoxidation inclusions by smoothing the flow of the molten material and reducing turbulence as the mould cavity fills. This minimizes the amount of molten metal surface exposed to oxygen in the mould cavity.

In the past, proof of the filter's ability to entrap non-metallic inclusions was readily available by examination and chemical analysis of the filter portion of solidified gating and the castings themselves. However, the ability of ceramic foam filters to modify the flow of the molten metal to reduce turbulence and prevent reoxidation inclusions could only be presumed.

The Flow Modification Mechanism

Fluid flow through porous material

Fluid mechanics investigations have shown that the steady state flow characteristics of a fluid through a porous material are dependent on the density and viscosity of the fluid, as well as the configuration and porosity of the material itself. Requiring the fluid stream to pass through the porous material (ceramic foam filter) results in a reduction of the average velocity and a drop in pressure as measured at the entry face and again at the exit face of the filter.

These changes in average velocity and pressure occur as energy in the metal stream is dissipated, while the metal follows a tortuous path through the cells of the filter. The drops in pressure and velocity are the result of two factors. One is energy losses in the fluid stream caused by viscous shear as the stream is separated by the cell walls in the filter, and the other is inertial effects that result when the fluid is forced to change directions as it passes through the filter labyrinth (Innocentini, Salvini, et al, 1999).

Evidence of flow modification through physical testing

A variety of physical testing procedures can be used to gather empirical evidence of the ceramic foam filter's effect on liquid metal flow.

Airflow Tests

Air-pressure-drop testing, routinely used during the manufacture of ceramic foam filters to confirm that production requirements are being met, is an indication of the filter's ability to modify the flow of metal during pouring.

Water Modeling

Water modeling tests also disclose the flow modification properties of ceramic foam filters. Visual evidence may be seen by holding a filter in the path of a water stream and comparing the appearance of the stream as it enters the filter and as it exits the filter. Figure 1 illustrates the direct impingement of a stream of tap water on a ceramic foam filter. Turbulence is clearly visible in the water entering the filter. The energy absorbing effect of the filter is illustrated by the smooth flow of water exiting the filter.

Figure 1: Ceramic foam filter reduces turbulence from stream of water

Figure 2: Stream of water passing through strainer core shows little reduction of turbulence

For comparison purposes, the same demonstration can be conducted using pressed strainer cores. Considerably less smoothing of the flow is seen. This may be attributed to the "dead zones" on the entry face of the strainer core that lead to splashing of the metal and to the lack of a tortuous pathway within the body of the strainer core to create energy absorbing inertial barriers (figure 2).

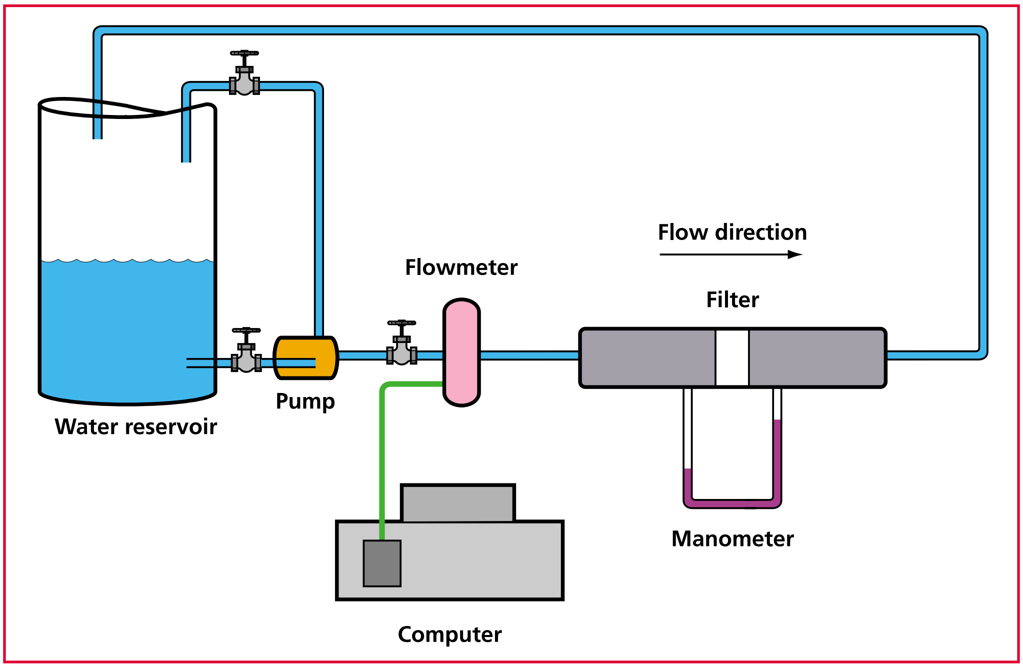

Figure 3: Water modeling test apparatus used to determine permeability coefficients

A more scientific method of water modeling incorporates the test apparatus seen in Figure 3. It consists of a continuous circuit where water is pumped from a reservoir, through the filter mounted in a test chamber, and back to the reservoir. A differential manometer measures the pressure drop between the upstream and downstream sides of the filter. This apparatus has been used to define the flow coefficients necessary to accurately model the flow of molten steel through a filtered gating system and into the casting cavity using computer simulation (Midea, Alquist, Blackburn, 2002; Midea, 2001).

Computer Simulation

The use of computer-aided engineering software to simulate molten metal flow profiles is another tool that has been used to investigate the flow modification capabilities of ceramic foam filters. Computer simulation enables steel foundries to anticipate molten metal behavior as it flows through the filter and into the casting cavity. It has become a basic tool used by many foundries to effect cost reductions and quality improvements in the casting process (McMillin, 1999).

Simulation programs have evolved into powerful tools that solve sophisticated equations, such as the Navier-Stokes equations, to predict fluid flow characteristics. Outputs, such as flow velocity and pressure, can be analyzed to determine the relative levels of turbulence as the metal flows through the gating and into the casting cavity. Figures 4a and 4b illustrate the effect of a filter on metal flow as it enters a valve casting. Figure 4a shows the turbulence that results when no filter is used and the metal impacts directly on the casting wall. Figure 4b shows the calming effect of the filter as the metal passes through it (Outten, 1996).

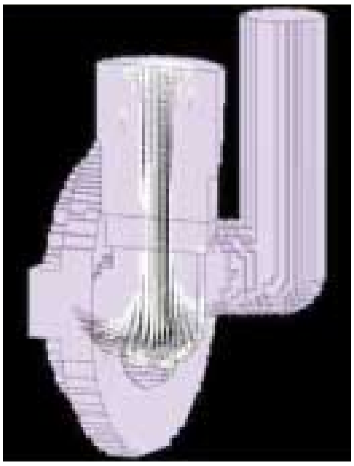

Figure 4a: Turbulence vectors resulting when no filtration is used in a direct pouring application

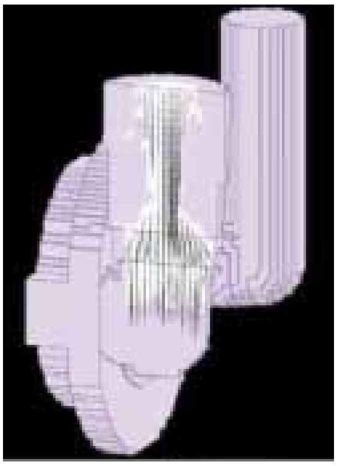

Figure 4b: Reduction of turbulence vectors after metal passes through filter in direct pouring application

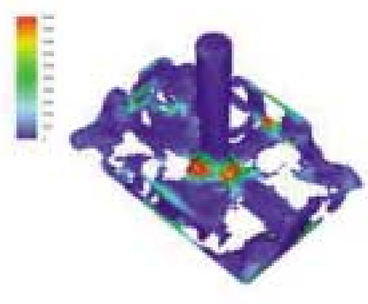

Figure 5: Computer simulation showing unfiltered metal entering plate casting

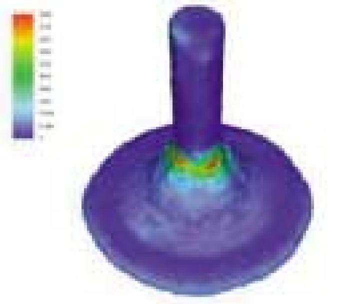

Figure 6: Computer simulation showing filtered metal entering plate casting

Figure 5 shows the flow of metal into a plate casting in a direct pour application without filtration, whereas Figure 6 shows a direct pour application with a ceramic foam filter positioned at the base of the direct pour unit. It can be clearly seen that the metal flows much more evenly and smoothly into the casting after it passes through the filter.

A clear understanding of molten metal flow as it passes through the filter allows steel casters to better anticipate and avoid turbulence and prevent reoxidation inclusions. It allows them to avoid thermal gradients that result in shrinkage and other casting defects. It also allows them to more accurately predict fill times and flow characteristics when selecting specific filters and is an important issue in designing runner systems and maximizing foundry efficiency.

Real-time X-Ray analysis of molten metal flow

X-ray technology is an extremely useful tool to verify filter flow characteristics. It has been widely used in numerous casting research programs. A detailed investigation, using real time x-ray techniques to evaluate the ability of various filter positions and orientations to modify metal flow, was conducted in partnership with the Castings Development Centre of Sheffield, England.

All filters used in the x-ray investigations described in this paper were 10 ppi (pores per linear inch) zirconia ceramic foam filters.

Equipment description

The real-time x-ray equipment incorporates a Van de Graaff x-ray source, a scintillator and a video recorder as shown in Figure 7. The x-ray source generates 2.4 M eV of power, which is directed at the mould cavity positioned between the x-ray source and the imaging system. The images are captured on a phosphor screen and relayed to a camera control using an angled mirror. These images are video recorded for later review. The camera is fitted with a close-up lens. This provides an enhanced image 30.4 cm square. The mould is positioned approximately 1.82 m away from the x-ray source; with the scintillator screen another 45.7 cm away.

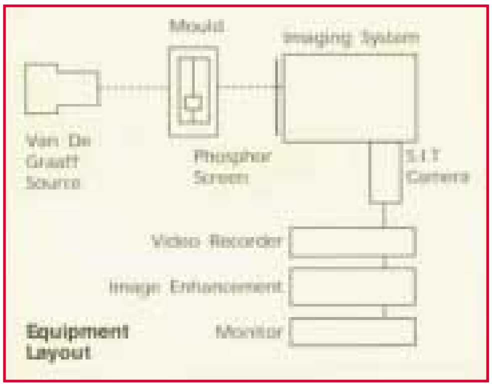

Figure 7: Schematic of real-time x-ray test apparatus

The mould is placed on a specially designed casting tray that rests on a load cell. The load cell records the weight of metal poured as a function of time. With this arrangement, the volume of metal flowing through the filter versus overall pouring time (flow rate) can be determined (figure 8).

Figure 8: Real-time x-ray test setup

Remote controls are used to operate the bottom-pour ladle inside the x-ray bunker. Activity within the bunker is monitored with three remote video cameras.

Initial work – X-Ray analysis of plate castings

Initial work, previously documented, involved the pouring of plate castings - some with filters and some without - to obtain visual confirmation of the flow control effectiveness of filters in steel casting (Wingfield, Delaney, Outten, 1999). In addition to evaluating filter flow control effectiveness, these tests were designed to compare the effects of various gating positions and use of the direct pouring process on flow characteristics as the metal passes through the gating system.

A vertically parted plate casting was designed to accommodate the needs of the X-ray process. Since the thickness of the molding sand was critical to the clarity of the x-ray images, it was decided to support the mould within a specially designed steel frame that reduced the amount of sand required. To facilitate the various in-gate locations and filtration arrangements, a core-assembled mould was developed. Figure 9 shows the mould in the frame.

Figure 9: Plate mould supported in steel frame for x-ray trial

The dimensions of the casting pattern were designed around the typical casting weight produced with a 75 x 75 x 25 mm-thick zirconia ceramic foam filter; this resulted in a plate 600 x 400 x 60 mm thick. The same plate size was used for all tests.

Mould description:

Gating Positions:

Moulds were prepared with both top and side gating. Some of the top-gated moulds were prepared with a nominal 50 mm dia central sprue for direct pouring; others were prepared with a direct pouring unit that incorporated a 75 dia. x 25 mm-thick zirconia ceramic foam filter.

Two side-gating set-ups were tested. One incorporated a nominal 50 mm dia sprue and a filter print sized to support a 75 x 75 x 25 mm-thick zirconia ceramic foam filter for in-line filtration. The other incorporated a direct pouring unit, positioned on a side riser base, which included a 75 dia. x 25 mm-thick zirconia ceramic foam filter.

Filtration:

Four filtration options were evaluated; no filter, pressed ceramic strainer cores, round ceramic foam filters (direct pour applications) and square ceramic foam filters (in-line applications). Where conventional gating incorporated a filter print, some castings were poured without the filter and some were poured with the filter in place for comparison purposes.

Trial Parameters:

Pouring for the tests was done with a 1-tonne bottom-pour ladle having a 32 mm nozzle diameter. Tests were made with carbon steel and the pour weight was 150 kg. Initial ladle temperatures were between 1600 and 1620°C. By the time the X-ray bunker was evacuated and remote-controlled pouring began, the metal temperature was between 1590 and 1600°C.

In conjunction with these tests, high-speed slow-motion videography was used to record the flow of molten steel as it passed through the nozzle of a bottom-pour ladle. As the metal stream contacts oxygen in the air during pouring, inclusions, indicated by the yellow colouration, can be seen forming on the outer surface of the metal stream (figure 10).

Trial Results:

In tests of the top-gated molding without the filter, the metal was poured through the central sprue directly into the mould cavity, filling the mould in about eight seconds at a rate of 16.8 kg/sec (figure 11). In the slow-motion video of the pour, severe turbulence of the molten metal stream is evident as air is entrained during pouring; large gas bubbles can clearly be seen escaping from the mould as it fills (figure 12). This exposure of large surface areas of molten metal to air produces ideal conditions for the formation of reoxidation inclusions.

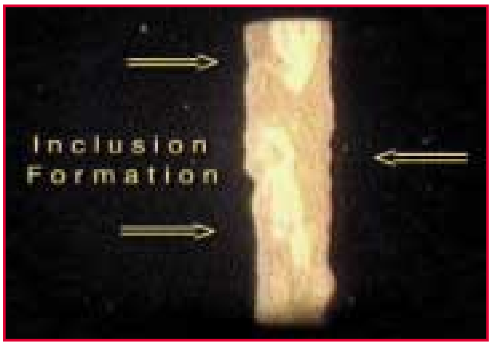

Figure 10: High speed video showing formation of reoxidation inclusions

Figure 11: X-ray view of unfiltered top-gated plate casting early in pouring sequence

Figure 12: X-ray view of unfiltered top-gated plate casting later in pouring sequence

Figure 13: X-ray view of filtered top-gated plate casting during priming of filter

Figure 14: X-ray view of filtered top-gated plate casting showing reduced turbulence as metal enters casting

Figure 15: X-ray view of unfiltered side-gated casting (no filter in filter print) as metal "sprays" into casting

Figure 16: X-ray view of unfiltered side-gated casting showing "rolling" action of metal as casting fills

Figure 17: X-ray view of filtered side-gated casting showing solid stream of metal as it enters casting

In the same test set-up, this time with the direct pouring unit in place, the mould filled in about nine seconds at a rate of 15 kg/sec. The ceramic foam filter was primed with liquid metal in less than 0.25 seconds (figure 13). The filter controlled the metal flow, resulting in a head of metal above the filter in which turbulence and trapped gasses could be seen. The filter dissipated the turbulence, thus helping to prevent entrained gasses from entering the mould cavity.

Slow motion videography of the metal below the filter clearly shows reduced turbulence in the metal stream, and there is an absence of the large gas bubbles seen rising to the surface in the unfiltered test (figure 14).

When castings were poured with side gating that incorporated a filter print to accommodate the in-line ceramic foam filter, equally dramatic results were obtained. When the mould was filled without the filter in place, a wide "spray" of metal could be seen entering the mould cavity (figure 15). As the cavity filled, a "rolling" action was clearly seen as the high-velocity incoming metal continued to scour the walls of the cavity and continued to expose the metal to reoxidation (figure 16).

With a 75 x 75 x 25 mm-thick ceramic foam filter inserted in the filter print, the flow below the filter was no longer a spray, but, rather, a solid stream of metal (figure 17). This quieter flow filled the cavity more smoothly, with very little rolling action and with only the upper surface of the rising metal exposed to reoxidation. This quieter filling sequence allows the easy escape of mould gasses and has a positive effect on the thermal distribution at the mould wall. More uniform mould filling may be expected as a result, with an even distribution of heat throughout the mould cavity providing ideal conditions for directional solidification and sounder castings. Also, because the metal stream remains intact and there is a non-turbulent mould fill, the potential for cold-lapping defects is reduced.

Later work – x-ray analysis to confirm simulation results

While plate castings are ideal for x-ray studies because of their relatively thin, constant cross section, practical application of the results is limited. To gather information that is applicable to typical castings, an x-ray examination of a steel valve production casting was conducted (Midea, Alquist, Blackburn, 2001). As part of the test, the valve was also modelled using computer simulation. Two pouring configurations were prepared: a conventional runner system incorporating a square in-line zirconia ceramic foam filter; and a direct pour application, having a round zirconia ceramic foam filter, that eliminated the need for conventional runner system components.

Figure 18 shows a computer simulation of the conventional running system incorporating a pouring basin, downsprue, an in-line 75 x 75 x 25 mm-thick ceramic foam filter, runner bars and ingates. Figure 19 shows a computer simulation of the direct pour arrangement. In the direct pour application, the unit incorporating an insulating sleeve and 90 mm dia. x 25 mm ceramic foam filter was positioned as a side riser on a suitable riser base. The casting was poured directly through the direct pour unit that also provides feed metal when pouring is completed.

Mould description:

In actual production, the overall sand mould size for the valve casting was 86 x 61 x 46 cm, too large for optimum x-ray visualization. Thus, a specialized proprietary investment casting process* was used to form a highly refractory mould that was exceptionally strong at both room and elevated temperatures. Successive coats of slurry and stucco were applied to a polystyrene pattern until the desired thickness - adequate to safely contain the metal to be poured - was developed. Each coat was air dried at room temperature prior to application of the next coat. The dried ceramic shell was then fired to increase strength and burn away the polystyrene pattern.

This process produced a relatively thin shell mould of the valve, leading to clear images of the metal fronts as they passed through the filter and flowed into the mould cavity (figure 20).

Trial Parameters:

The valve was cast from ASTM A351.A351M-91a Grade CF8M stainless steel, deoxidized with CaSi. Castings were poured from a 907 kg bottom pour ladle, with 408 kg of steel in the ladle. The pouring temperature range was 1582-1593°C.

Observations:

The predicted fill time for the direct poured casting (total pour weight of 113 kg) using filter flow data developed in the water modeling described previously, is 12.3 seconds; the actual fill time from foundry practice is known to be 12 seconds. There is no foundry experience for the configuration of this casting using a conventional runner system, but the simulation for this arrangement (total pour weight of 125 kg) predicted a fill time of 15 seconds, which was confirmed when the castings were poured during the x-ray trials.

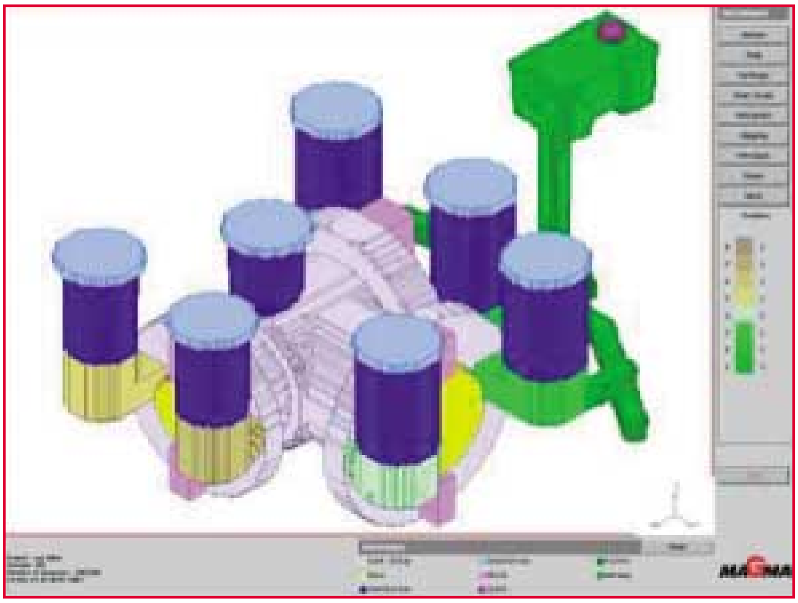

Figure 18: Computer simulation of valve casting rigged with in-line filter and conventional gating system

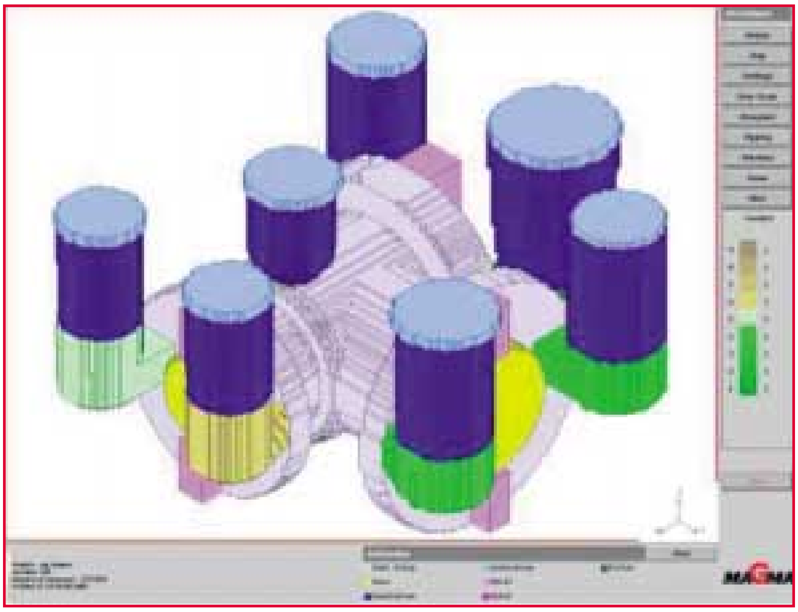

Figure 19: Computer simulation of valve casting rigged with direct pouring unit (including filter) on a side riser base

Figure 20: Specialized shell mould used to facilitate x-ray visualization of valve casting during pouring

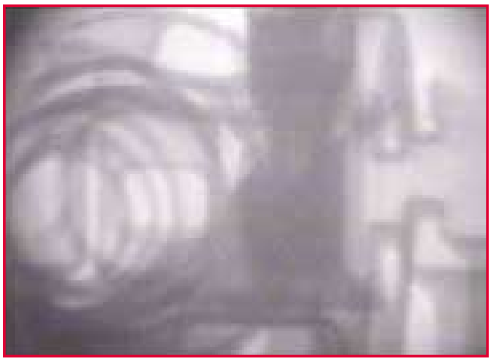

Figure 21: Computer simulation of direct-poured valve casting at 1.5 seconds into filling

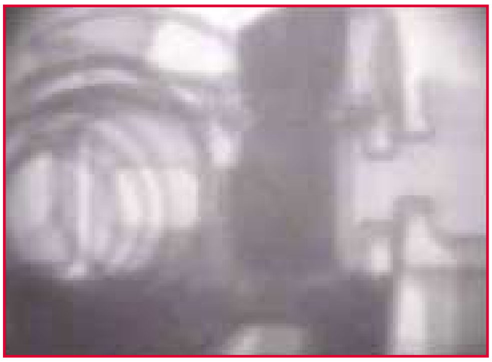

Figure 22: Computer simulation of direct-poured valve casting at 2.0 seconds into filling

Figure 23: Computer simulation of in-line-filtered valve casting at 2.0 seconds into filling

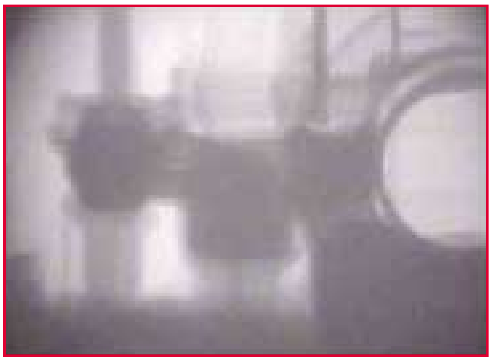

Figure 24: Computer simulation of in-line-filtered valve casting at 4.0 seconds into filling

Direct Poured Configuration

At 1.5 seconds, the metal has begun to enter the casting cavity with minimum turbulence (figure 21).

At 2.0 seconds, the metal is beginning to back up in the direct pouring unit. The level of the metal predicted in the simulation generally matches the x-ray results (figure 22).

In-line Configuration

At 2 seconds into the filling cycle, the computer simulation does not perfectly predict the actual filling profile, but there is close agreement with the x-ray footage (figure 23).

At 4 seconds into the filling cycle, there is general agreement between the simulation prediction and the x-ray footage. This is important because one of the most powerful applications of computer simulation is the ability to predict the effect of the filter on flow and thus, porosity/shrinkage (figure 24).

Poured weight vs. time comparisons

A comparison of the information obtained from the load cell supporting the mould in the x-ray bunker with the computer-predicted flow rate further validates the simulation results. Both the measured and predicted flow rates for the in-line configuration were 7.7 kg/sec. (figure 25) and 9.1 kg/sec. for the direct pour configuration (figure 26).

Clearly, these results show that computer simulations, when using accurate filter flow coefficients, can closely predict flow rates and thus, fill times.

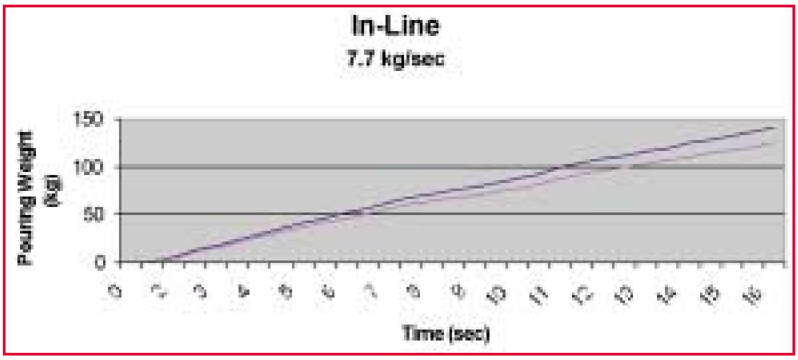

Figure 25: Poured Weight vs. Time comparison graph, in-line filtration with conventional running system

Figure 26: Poured Weight vs. Time comparison graph, direct-pour unit (including filter)

Summary/conclusion

There is ample evidence that filtration is a valuable tool in the removal of slag inclusions and the prevention of reoxidation inclusions in steel castings. Recent work in computerised simulation and real-time x-ray examination of the flow modification properties of ceramic foam filters will make it possible to refine the selection and application of ceramic foam filters.

Benefits to foundries include more precise filter size selections, more accurate fill time predictions and greater overall foundry efficiency through the elimination of trial-and-error methoding.

Acknowledgements

The authors wish to thank Tony Midea for his work in directing the water modeling, the simulations and x-ray trials that are the basis for much of the original work reviewed here and for his guidance in preparing this paper.

References

Innocentini, M.D.M.; Salvini, V.R.; Macedo, A.; Pandolfelli, V.C.; "Prediction of Ceramic Foams Permeability Using Ergun's Equation," Materials Research, vol 21, No. 4, pp 283-289 (1999)

Innocentini, M.D.M.; Salvini, V.R.; Pandolfelli, V.C.; Courey, J.R.; "Assessment of Forchheimer's Equation to Predict the Permeability of Ceramic Foams;" American Ceramic Society Journal, vol 82, No. 7, pp 1945-1948 (1999)

Innocentini, M.D.M.; Salvini, V.R.; Pandolfelli, V.C.; Courey, J.R.; "The Permeability of Ceramic Foams," The American Ceramic Society Bulletin (Sept., 1999)

Innocentini, M.D.M.; Pardo, A.R.F.; Salvini, V.R.; Pandolfelli, V.C.; "How Accurate is Darcy's Law for Refractories?," The American Ceramic Society Bulletin (Nov., 1999)

McMillin, T., "Optimize Casting Design and Quality with Process Simulation," Engineered Casting solutions (Winter, 1999)

Midea, A.C., "Pressure Drop Characteristics of Iron Filters, " AFS Transactions, 01-042 (2001)

Midea, A.C; Alquist, B.R.; Blackburn, C.; "Increasing the Accuracy of Metal Flow Results in Steel Castings," SFSA Transactions, (Oct., 2001)

Outten, J., "KALPUR for steel Direct Pouring System Improves Yield, Productivity and Quality," Foundry Practice, No. 227 (1996)

Wingfield, B.; Delaney, I.; Outten, J.;"A Unique Look at the Benefits of Foam Filtration using X-ray Technology;" Presented at the Australian Foundry 31st National Convention (1999)

* The REPLICAST process is a patented process exclusive to the Casting Development Centre, UK.

Bibliography

In the 21 years since the introduction of foam filters to the foundry industry, FOSECO has not only been responsible for major innovations in filtration technology but has led the field in the development of application expertise. Typical examples are the many technical papers on this subject which we have written and presented at conferences and congresses worldwide.

Review iron gating design, filter use to optimize benefits; Adams A; Modern Casting (USA), vol. 91, no. 3, pp. 34-36, Mar. 2001 Adams A;

Increasing the accuracy of metal flow results. Pressure drop studies define new flow coefficients for ceramic foam filters; Midea T; Foundry Management and Technology (USA), vol. 129, no. 8, pp. 50-51,56-58, Aug. 2001 Midea T;

Industrial experience in the filtration of cast iron at the Peugeot Citroen foundries; Sadon P, Hurdebourcq D, Besville J-C, Taylor KC; Hommes et Fonderie (France), vol. 314, pp. 24-30, 33-42, May 2001 Sadon P, Hurdebourcq D, Besville J-C, Taylor KC;

X-ray techniques provide real-time proof of foam filter performance in steel castings; Child N; Foundry Practice, vol. 233, pp. 12-16, 2000 Child N;

How STELEX filters and the KALPUR system reduce your steel casting manufacturing costs; Child N; Foundry Practice, vol. 229, pp. 18-20, 1999 Child N;

In praise of ceramic foam filters; Clark H; Foundry Trade Journal (UK), vol. 173, no. 3560, pp. 21-22, Nov. 1999 Clark H;

Dross inclusions in double poured castings made of nodular iron - example of joint problem solving by foundry and supplier; Dieterle U, Bleck J; Giesserei (Germany), vol. 86, no. 2, pp. 44-47, 15 Feb. 1999 Dieterle U, Bleck J;

SIVEX FC foam filters - more than just a filter; Kendrick R, Wahl HP; Foundry Practice, vol. 229, pp. 13-17, 1999 Kendrick R, Wahl HP;

Optimizing casting yield using computer simulation; Midea AC, Christensen D, Outten JF, Baker P; American Foundrymen's Society, Inc., Transactions of the American Foundrymen's Society, Vol. 107 (USA), pp. 299-305, 1999 Midea AC, Christensen D, Outten JF, Baker P;

KALPUR direct pour systems for mass production iron castings; Sovakar A; Foundry Practice, vol. 231, pp. 1-8, 1999 Sovakar A;

SIVEX FC - A 'Filter' with a ceramic foam structure especially for aluminium repetition castings; Wahl HP; Foundry Practice, vol. 232, pp. 6-11,1999 Wahl HP;

A unique look at the benefits of foam filtration using X-ray technology; Wingfield B; Australian Foundry Institute, Casting the New Millenium: 31st National Convention of the Australian Foundry Institute Proceedings (Australia), pp. 18, Oct. 1999 Wingfield B;

Gray Iron Filtering; Besville JC; Hommes et Fonderie, no. 186, pp. 7-17, June-July 1988 Besville JC;

Production experiences with improved filtration of ductile iron castings; Mani PH, Fite S, Rajan C, Rush L; American Foundrymen's Society, Inc., Ductile Iron Society's 1998 Keith D. Millis World Symposium on Ductile Iron Proceedings (USA), pp. 252-271, Oct. 1998 Mani PH, Fite S, Rajan C, Rush L;

STELEX ZR filters and KALPUR ST direct pour units; Child N; Foundry Practice, vol. 228, pp. 1-2, Sept. 1996 Child N;

Energy savings using SIVEX FC filters; Kendrick R; Foundry Practice, vol. 228, pp. 13-14, Sept. 1996 Kendrick R;

Waupaca breaks out of the mold with new gating approach; Mathems R; Modern Casting (USA), vol. 86, no. 10, pp. 47-48, Oct. 1996 Mathems R;

Reduce defects with direct pour technology; Outten J; Foundry Management and Technology (USA), vol. 124, no. 8, pp. 108-110, Aug. 1996 Outten J;

Optimization of Al casting productivity using foam filter technology and application; Sandford P, Sibley SR; Transactions of the American Foundrymen's Society, Vol. 104, American Foundrymen's Society, Inc., 1063-1068, 1996 Sandford P, Sibley SR;

Filtration of aluminium-a Weibull statistical approach to the analysis of mechanical properties; George RD, Keegan NJ; Foundry Practice, vol. 226, pp. 14-17, July 1995 George RD, Keegan NJ;

Aluminium casting productivity increases with predictive techniques; Jeffs P; Foundry Practice, vol. 226, pp. 1-2, July 1995 Jeffs P;

Optimising yield for iron castings through direct pouring technique; Sovakar A; Foundryman, vol. 88, no. 1, pp. 16-19, Jan. 1995 Sovakar A;

The Effect of Filtration of the Pressure Tightness of Thin Walled Castings; Powell C; Foundry Practice, vol. 225, pp. 15-16, June 1994 Powell C;

Advances in Production of High-Yield Aluminum Castings Using Direct-Pour Technology; Sandford P; American Foundrymen's Society, Inc. (United States), pp. 817-824, 1994 Sandford P;

Quality- and Cost Optimisation of a Safety Critical Component Produced in Aluminium; Wahl HP; Foundry Practice, vol. 225, pp. 7-8, June 1994 Wahl HP;

Metal filtration: an easy way to produce quality castings economically; Karkhanis SR, Gadagkar VH; 41st Indian Foundry Congress Transactions, Institute of Indian Foundrymen, 535-546, 1993 Karkhanis SR, Gadagkar VH;

Direct Pouring of Aluminum Improves Yields and Quality; Pischel RP; Foundry Management and Technology (USA), 121, (6), 40-42, 44, June 1993 Pischel RP;

Filtration of Liquid Metals; Clark H; Foundryman (UK), vol. 84, no. 9, pp. 366-368, Oct. 1991 Clark H;

The Use of Ceramic Foam Filters for Automotive Castings; Clark H, Kallisch W, Matsuo H; IBF Publications (UK), pp. 34, 1991 Clark H, Kallisch W, Matsuo H;

Replacement of Conventional Runner Systems for Steel Castings by Direct Pour, Filtration-Feeder Units; Ecob CM, Moffat GL; Foundry Practice, vol. 222, pp. 7-11, Sept. 1991 Ecob CM, Moffat GL;

Ceramic Foam Filtration: a Cleaner Way to Cast Aluminium; Karkhanis SR; Aluminium: Strategies for the Nineties and Beyond. Vol. I, Aluminium Association of India, 269-272, 1991 Karkhanis SR;

The Elimination of Conventional Running Systems in Aluminium Sand and Gravity Die-Casting Foundries; Sandford R, Kendrick R; Foundryman, vol. 83, no. 6, pp. 262-267, June 1990 Sandford R, Kendrick R;

Gating: the Foundryman's Dilemma, or Fifty Years of Data and Still Asking "How?"; Wukovich N, Metevelis G; American Foundrymen's Society, Inc., pp. 285-302, 1990 Wukovich N, Metevelis G;

FOSECO - the Innovating Developer; Foundry Trade Journal, vol. 164, no. 3411, pp. 296-297, 4 May 1990;

New Ways to Meet Foundries' Needs; Foundry Focus, pp. 27, 29, Spring 1990;

New Procedure for the Inoculation of a Mold With a Filter; Besville J-C; Hommes et Fonderie, no. 198, pp. 13-21, Oct. 1989 Besville J-C;

Assessing the Efficiency of Ceramic Filters for Ductile Iron Castings by the Use of Radio-Active Isotopes; Boyce IS, Knights CF, Plowman AM, Simmons W; Fonderie Fondeur Aujourd'hui, no. 82, pp. 24-28, Feb. 1989 Boyce IS, Knights CF, Plowman AM, Simmons W;

STELEX - an Efficient Filter for the Steel Casting Industry; Foundry Practice, no. 217, pp. 11-14, Apr. 1989;

Metals Filtration and Its Effect on the Properties of Cast Material; Farre S; Gjuteriet, vol. 78, no. 4, pp. 32, 34-35, 37-39, 42-44, 1988 Farre S;

Simplified Running Systems and Improved Quality in Sand and Gravity Diecasting Foundries; Sandford P; Foundryman, 81, (3), 110, 112, 114, 116, 118, Mar. 1988 Sandford P;

Gating design; Suschil AL, Plutshack LA; ASM International, ASM Handbook. Vol. 15. Casting (USA), 1988, pp. 589-597, 1988 Suschil AL, Plutshack LA;

Influence of Metal Filtration on the Production of High Integrity Cast Products; Simmons W, Broome AJ; South East Asia Iron & Steel Institute, pp. 20, 1987 Simmons W, Broome AJ;

Aluminum Alloy Filtering; Journal of Metals, vol. 39, no. 9, pp. 47, Sept. 1987;

Castings Clean-Up, Filter Applications in Aerospace; Foundry Trade Journal, vol. 161, no. 3360, pp. 954, 19 Nov. 1987;

Inclusions in Cast Iron; Briggs J, Simmons W; Foundry Practice., no. 212, pp. 11-15, Mar. 1986 Briggs J, Simmons W;

Metal Filtration; Mehrotra AK; 35th Annual Convention of the Institute of Indian Foundrymen, The Institute of Indian Foundrymen, 133-144, 1986 Mehrotra AK;

Machinability and Properties of Irons Filtered With SEDEX (Ceramic Foam Filters); Menk W, Simmons W, Wise MLH; Foundry Practice, vol. 212, pp. 2-4, Mar. 1986 Menk W, Simmons W, Wise MLH;

Optimising Filter Performance; Plowman AM; Foundry Practice, vol. 212, pp. 8-10, Mar. 1986 Plowman AM;

Filtering Liquid Metals for Enhanced Quality and Productivity; Sibley S, Simmons W; Non Ferrous Metals World, (1), 88-94, 1986 Sibley S, Simmons W;

The Filtering of Molten Metal to Improve Productivity, Yield, Quality and Properties; Simmons W; Indian Foundry Journal, vol. 32, no. 8, pp. 21-28, Aug. 1986 Simmons W;

The Removal of Non-Metallic Inclusions From Molten Metal by Filtering; Simmons W; South African Institute of Foundrymen, pp. 35, 1985 Simmons W;

Inclusion Control of Die-Casting Alloys; Miller SK; Die Cast. Engineer, 28, (5), 54, 56, 58, Sept.-Oct. 1984 Miller SK;

Effect of Filtration on the Castability of Brake Discs Made With Lamellar Graphite; Delaney IN, Aspinwall DK, Wise MLH; Giesserei, vol. 80, no. 19, pp. 663-668, Oct. 1993 Delaney IN, Aspinwall DK, Wise MLH;

SIVEX -- a New Cost-Effective Technique for Cleaning Molten Aluminum; Sibley S; Foundry Practice, vol. 20, pp. 5-6, Dec. 1980 Sibley S;