

X-ray techniques provide real-time proof of foam filter performance in steel castings

Introduction

The success of zirconia-based ceramic foam filters (Figures 1 & 2) in removing and preventing oxide inclusions in steel castings has been confirmed time and again, through post-pouring evaluation of solidified castings. The mechanisms of inclusion trapment of large particles on the inlet surface of filters, and smaller inclusions within the filter structures are well proven and understood. Now with the use of Real Time X-ray techniques it is possible to view and record the impact of filtration on the flow characteristics of molten steel as the mould cavity is filled.



Figure 1 - STELEX ZR Ceramic Foam Filters



Figure 2 - KALPUR ST Direct Pour Units

Beyond simulation and sectioning

Sectioning of filters in solidified gating systems Figure 3, dye testing, static X-rays, destructive machining and scanning electron microscope (SEM) examination Figure 4, have all been used to confirm the presence or absence of inclusions and thus demonstrate the effectiveness of filtration.

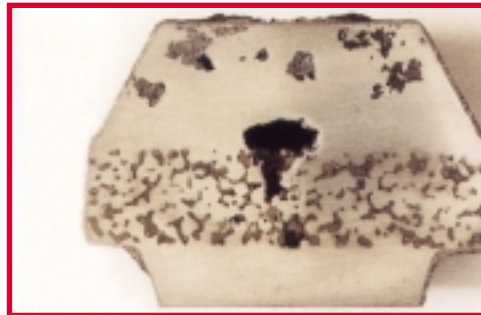


Figure 3 - A section through a used STELEX filter showing large quantities of inclusion debris trapped by the filter



Figure 4 - A Scanning Electron Micrograph of slag adhering to the surface of a used STELEX filter

Computer simulations of molten metal velocity, turbulence and thermal gradients figure 5 during mould filling and simple water modeling studies have strongly suggested that foam filters smooth the flow of molten steel entering the mould. From this, it has been assumed that filters prevent additional entrapment of air in the metal stream, thus minimizing the opportunity for reoxidation inclusions to form from common metal elements in liquid steel, such as iron, aluminum, silicon, chromium and manganese.

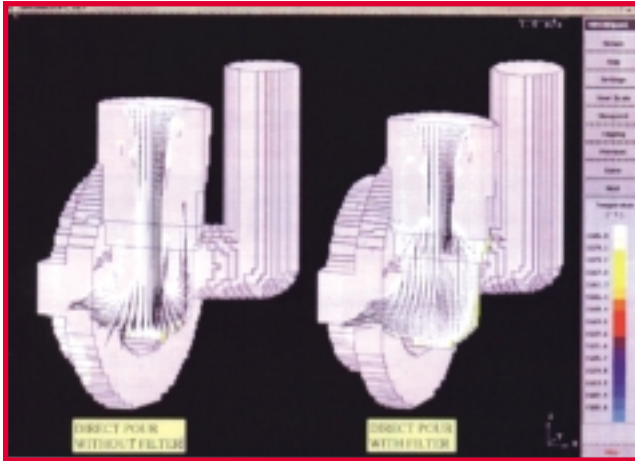


Figure 5 - Velocity vector beneath the KALPUR unit illustrate the effect of the filter on metal flow as it enters the casting. The left image shows the turbulence that results when no filter is used and the metal stream impacts directly on the casting wall. The right image shows the calming effect of the filter as the metal passes through it

But exactly how much influence the use of filters has on flow control and inclusion prevention could only be estimated and debated until a workable procedure for real-time X-ray videography of steel casting was developed.

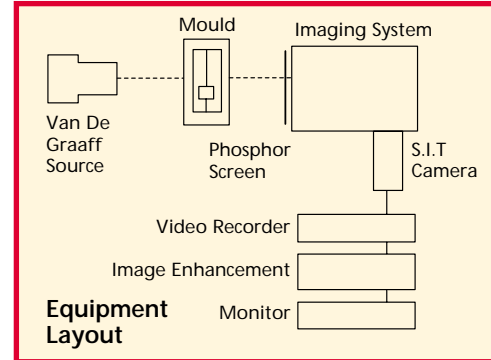


Figure 7 - Experimental layout for the Real Time X-ray investigations

How the tests were conducted

In addition to evaluating the flow control effectiveness of filters in steel casting, the tests were designed to compare the effects of various gating positions and of the direct pouring process using a KALPUR direct pouring unit.

A vertically parted plate casting was designed to accommodate the needs of the X-ray process. Since sand thickness was critical to the process, it was decided to pour the mould within a specially designed steel frame. To facilitate the various in-gate locations and filtration arrangements, a core-assembled mould was developed (Figure 6).

The dimensions of the casting pattern were designed around the typical casting weight produced with a STELEX ZR 75 dia by 25 mm/10 ppi ceramic foam filter; this resulted in a plate 600 x 400 x 60mm thick. The same plate size was used for all tests. When direct pouring was employed, a KALPUR ST 75 x 150mm. Direct Pour Unit incorporating a 75 dia. by 25 mm/10 ppi filter was used at the base of the central pouring sprue.

The real-time X-ray equipment incorporates a Van de Graaff X-ray source, scintillator and video recorder (Figure 7). The video screen has an area of 1100 x 800 mm, representing 1.5mm per pixel. The X-ray beam is able to cover the complete pattern or focus on a smaller portion for a close-up view. The mould and X-ray equipment are housed in an X-ray bunker, necessitating the use of remote-controlled pouring equipment (Figure 8).



Figure 6 - A mould being fabricated showing a filter print in the running system



Figure 8 - The ladle over the mould in the X-ray bunker

Pouring for the tests was done with a 1-tonne bottom-pour ladle having a 32mm nozzle diameter. The material was carbon steel and the pour weight was 150kg. 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 passes 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 9).



Figure 9 - Slow Motion Videography of the metal stream exiting a bottom pour ladle. Inclusions can be seen forming on the surface of the metal stream

More influence than was ever imagined

The pouring tests were conducted using identical gating arrangements, with and without filters; dramatic differences in flow patterns and turbulence were clearly evident.

In tests of the top-gated moulding without the filter, the metal was poured through the central sprue of the mould cavity, filling the mould in about eight seconds at a rate of 16.8 kg/sec. Figure 10. In the slow-motion video of the pour, severe turbulence of the molten metal stream is evident as air is entrapped during pouring; large gas bubbles can clearly be seen escaping from the mould as it fills (Figure 11). This exposure of large surface areas of molten metal to air produces ideal conditions for the formation of reoxidation inclusions.



Figure 10 - A top gated mould without a filter. Note the turbulent molten metal stream and air being drawn beneath the molten metal surface



Figure 11 - A top gated mould without a filter showing air bubbles rising through the casting cavity at the end of pour



Figure 12 - The STELEX filter incorporated in the KALPUR system primed in less than 0.25 seconds

In the same test set-up, this time with the KALPUR unit in place, the mould filled in about nine seconds at a rate of 15 kg/sec. The STELEX filter was primed with liquid metal in less than .25 seconds (Figure 12). 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 high surface area of the filter absorbs the turbulence and helps to prevent trapped gasses from entering the mould cavity. Also, solid inclusions float to the top of the metal head and do not enter the casting cavity. Slow motion videography of the metal below the filter clearly shows reduced turbulence in the metal stream and absence of the large gas bubbles that are seen rising to the surface in the unfiltered test (Figure 13).



Figure 13 - With the KALPUR applied to the top gated mould a controlled metal stream exited the filter resulting in a non turbulent fill of the casting cavity

Side-gated set-up results

When castings were poured using side gating techniques, 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 14). As the cavity filled, a “rolling” action was clearly evident as the high-velocity incoming metal continued to scour the walls of the cavity and continued to expose the metal to reoxidation.



Figure 14 - When the side gated mould was poured without a filter a wide spray of metal entered the casting cavity and a rolling wave could be seen as the casting cavity filled

With a KALPUR ST Direct Pour Unit applied which incorporates a STELEX 75 mm diameter the flow below the filter was no longer a spray, but, rather, a solid stream of metal (Figure 15). 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 within the mould. 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.



Figure 15 - Application of a filter system to the side gated mould resulted in a Non turbulent mould fill

While these still images extracted from the video footage give clear indication of the flow modifying capabilities of filters, the continuous video is even more convincing, especially when filtered and non-filtered sequences are viewed side-by-side.

Conclusions

The use of real-time X-ray techniques has confirmed the ability of filters to control the flow of molten steel as it enters the mould cavity.

Tests to date have been conducted on simple plates, Figure 16 and the evaluation and results have been primarily subjective. Further X-ray testing, coordinated with objective evaluations of casting inclusion counts and inclusion chemistry, will enable the benefits of filtration to be quantified in terms of reduced inspection, grinding, welding and heat treating to repair surface defects. Potential exists for the application of X-ray techniques to evaluate production castings.



Figure 16 - The resultant casting from one of the tests

Confirmation that the use of KALPUR direct-pouring techniques produces quality castings enables steel foundries to reduce casting engineering costs and simplify patterns; and it allows them to improve yield through better metal-to-sand ratios, improved pattern plate utilization and elimination of runner systems.

References

“A unique look at the benefits of foam filtration using X-ray technology” presented at the Australian Foundry Institute 31st National Convention.