ASK Chemicals L.P., Dublin, Ohio, USA

J. Morris | L. Strom

Reduced Oxide Formation Simply by Reducing the Reynolds Number

Abstract

The effect of foam filters on laminar flow and mold filling was studies by the use of water models. A visual de-monstration will be presented showing a reduction of the air/water interface area. This water model study implies that effective control of the velocities and the Reynolds number reduces the oxide film formation and entrapment. Accepted theories relating to the prevention of oxides in castings will be included.

Introduction

High quality castings whether they come from an investment casting or from a sand foundry, have certain features in common. Experience and research has shown, the best castings come from a mold which filled uniformly and completely with minimum turbulence and minimum potential for air metal interaction. (1) Gating or runner design can play a large roll in reducing potential sources of turbulence, air entrapment, and.or mold erosion sites in ferrous systems. (2-4) Effective gating design can be complex, however, and require a certain amount of trial and error to perfect. Methods to widen the operating window for successful pouring without introducing more complexity or high costs may be beneficial.

Typically, reticulated ceramics are discussed in terms of their filtering effect or removal of existing inclusions from molten metal. (5-7) Discussed less often but of significant importance, is the role of reticulated ceramics as a cost effective component of the gating system which helps prevent the formation of inclusions.

It was observed in the field, that reticulated ceramic filters appear to straighten the flow of the metal and reduce its turbulence before its entrance into the mold cavity. This work lead to subsequent laboratory investigations with water, such as that shown in Fig 1, which visually clearly demonstrate the ability of the reticulated ceramic filter to reduce the turbulence in the flow stream. The unfiltered pour on the left side shows a turbulent flow pattern and high bubble formation down stream of the cup. The filtered pour on the right side shows a smooth flow pattern with little bubble formation.

To understand how reticulated ceramics can be used for flow control devices as well as filters, requires a discussion of Reynolds number. The Reynolds Number, as shown in Equation 1, is the ratio of the inertial force of the fluid to the viscous force of the fluid. It is well known that the transition from laminar to turbulent flow typically occurs for water in smooth pipes at a Reynolds number of 2000 - 3000. „In paractice, however, foundrymen have noticed slag separation and clean castings appear to be possible as long as the Reynolds‘ Numbers are kept below 25,000.“ (4) Therefore, although laminar flow is the ideal condition, any reduction in the

$$R\eta = \frac{(v \cdot d)}{Kv}$$

Where [Rη = Reynolds number; v = fluid velocity; d = diameter [adjusted, and Kv = fluid kinematic

The fluid velocity and the diameter of the „pipe“ are the two main parameters which can be adjusted to reduce the Reynolds Number. The Kinematic Viscosity is a material dependent property as shown in Table I and for all practical purposes is fixed for a given alloy.

ASK CHEMICALS
We advance your casting

Reduced Oxide Formation Simply by Reducing the Reynolds Number with Reticulated Ceramics

Table 1

Liquids	Density (lb/in3)	Viscosity (lb/in/sec)	Kinematic Viscosity (in2/sec)
Water	.0361	.000056	.0016
Aluminium	.0868	.000173	.0020
Magnesium	.0578	.000073	.0013
Copper	.288	.000179	.0006
Iron	.220	.000353	.0016
Steel	.254	.000353	.0014

The velocity of pouring metal is approximated by:

$v = 2gh$ Where: (v = velocity; g = gravitational force; h = heigt)

Typically, the height used to calculate velocity in Equation 2 is the height of the metal in the ladle when the pour is made. When a pool of metal is formed above the filter the velocity can be more accurately calculated by using the top of the pool in the cup. The lowered velocity lowers the Reynolds number.

The most effective way of controlling the Reynolds number is by controlling the diameter the fluid flows through. For the pours shown in Fig. 1, the diameter of the unfiltered system is the cup diamter. For the filtered system, the diameter of the system can be controlled by selecting the pore size of the filter. For example, a 10ppi filter in a two inch diameter sprue will reduce the Reynolds number by a factor of approximately 20. A 30ppi filter in the same system will reduce the Reynolds number by a factor of approximately 60.

Reduction in the Reynolds number and the resultant reduction in turbulence is believed to assist in channeling the flow and reducing the splashing as observed in Fig. 1. The coherent stream and reduced splashing should both minimize the potential for air/metal interaction and therefore minimize the potential for inclusion formation after the

Another factor which has been physically observed and which can play an important role in oxide formation is the separation of large bubbles. Large bubbles which form before a filter due to the turbulence casused by pouring into the cup, are not readily passed through the filter. It is believed that it is energetically more favorable for bubbles to coalesce and rise to the surface rather than separate into smaller bubbles as would be required for passage through a filter. This also assists in minimizing the potential for air/metal interaction after the filter.

Although the laboratory tests to date have correlated well with field observations and given some important insights on the effect of filters on flow behavior, the laboratory tests have been over-simplicications of „real“ flow patterns in castings. Water modeling can be used to study air entrainment and filter effectiveness for steel cas¬tings in greater detail, however, provided a geometrically scaled system is used ensuring similarity of the Reynolds and Froude numbers. The similarity of the Kinematic viscosity for water and steel as shown in Table I is an important parameter for this comparison, particularly in the lower Reynolds number regime encountered with flow through the reticulated ceramic. (9)

This paper will extend the existing water models to geometrically sized systems. Actual investment casting gating systems, filter cups and filters will be used. The results will be documented photographically and by video. This is a preliminary study on geometrically sized systems; A more detailed discussion would require more in-depth experimental and theoretical analysis.

Reduced Oxide Formation Simply by Reducing the Reynolds Number with Reticulated Ceramics

Experimental Procedure

The experimental set-up is shown in Fig. 2. The metal rod with clamps was used for holding the gating system. Standard room temperature tap water with red food coloring was used. (The red coloration assists in bubble and flow pattern detection.) The filters used were partially stabilized zirconia (PSZ(MG)) reticulated ceramics from Hi-Tech Ceramics. The 10 ppo filter was a 2.8“O.D.xl“ thick tapered pour cup UDICEL filter with a 1/8“ ceramic fiber gasket. A plastic tube approximately 5“ long and 5/16“ diameter was used for „venting“ the 30 ppi filters. When using the „vent“ on the filters, the tubve was inserted into a hole drilled in the reticulate and extended approximately 1/16“ out the bottom.

The gating systems used are shown in Figs. 3-5. Fig 3 shows a simple 2 vertical runner bar system with parts attached to one runner. Tests were run with and without filters, and also alternating the fill side from the runner with parts to the runner without parts. A „vented“ 30 ppi filter pour and non-filtered pour, both down the runner side without parts, are shown in Fig, 3.

Fig. 4 shows a more complex runner system with 5 vertical runner bars. This gating system was run with no filter, unvented and vented 10 and 30 ppi filters. Please note that this gating system had no external vents except back through the filter cup.

A gating system incorporating a tapered sprue and a reticulated ceramic disc at the base of the sprue was also evalueated as shown in Fig 5 This gating system had external vents (see Fig. 5) and was run with no filter, un-vented and vented10 and 30 ppi filters.

The water was poured manually as quickly as possible to maintain a full cup without overflow. The results were recorded photographically and by video. The fill times were calculated from analyzing the video. (This allows for repaeat timing of the same event). A synopsis of the photographic results is shown in Figs. 3-5 and these will be used to illustrate the key observations discussed

Experimental Procedure

In a simple 2 runner system, such as that shown in Fig. 3, the addition of a filter reduced the turbulence in the system as evidenced by the decreased amount of foaming observed. (See the relative foam heights indicated by the arrows in Fig. 3a and 3 b).

The reduction in the foaming was independent of which runner was used as the sprue (i.e. the runner with parts or the runner without parts). Careful observation during the run revealed air escaping from the parts during the pour. This was easier to observe when the runner with no parts attached was used as the sprue.

Table 2: Gating system fill time (sec)

Gating System description	No filter	10ppi filter	Vented 10ppi filter	30ppi filter	30ppi filter
2 runner bars with parts	4sec	10 – 20sec	4sec	20 – 30sec	5sec
5 runner bars no external vent	4sec	10 – 20sec	5sec	no fill	6sec
2 runner bars and tapered sprue with external vents	3sec	3sec	3sec	3sec	3sec

An unexpexted result from these hydraulic geometric scaled tests, was the effect of the filter on potential vapor lock problems. With this particular gating design, the majority of the gases in the mold had relatively little resis-tance to escaping out the top of the opposite runner. Even under these venting conditions, however, it was observed that a mold with a vented 30 ppo filter filled faster than a non-vented 30 ppi filter as shown in Table II. This is believed to be the result of the higher pressure drop across a 30 ppi filter hindering the exit of gases trapped between the fluid and the bottom of the filter, back trhough the filter (see the arrows in Fig. 3b). It was also found that is was advantageous to have the vent channel slightly protrude beneath the bottom of the filter. Without this protrusion, it may be that liquid seeping in from other areas of the filter may form a thin liquid barrier across the opening which may also hinder the counterflow of the escaping gases.

The gating system shown in Fig. 4 was not as well vented as that in Fig. 3, to the point where a non-vented 30 ppi filter caused enough of a vapor lock to prevent the mold from filling completely. For efficient filling of this mold, (see Table II), it was found that venting of both the 10 ppi and the 30 ppi filters was beneficial. Providing a vent for the escaping gases reduced the fill times to less than 10s as shown in Table II and reduced the amount of bubbling back up through the filter.

Reduced Oxide Formation Simply by Reducing the Reynolds Number with Reticulated Ceramics

The effect of filters on channeling flow is clearly shown in Fig. 4. In the gating system without a filter in place (Fig. 4a), even the runners farthest from the venter showed signs of „deflected flow“. In other words, the size of the flu¬id steam entering the entral runner bar is larger than the runner bar and this excess volume of liquidis deflected or splashes over into the neighboring runner bars, causing those bars to fill from the top of the runner as well as the bottom. The introduction of a 10 ppi filter channels the flow and limits the „deflected flow“ to the middle 3 runner (Fig. 4b). A 30 ppi filter reduces the „deflected flow“ further (Fig. 4c) but there is still some present in the 2 runner surrounding the central runner bar or sprue.

The more uniform and quieter filling of the mold by reducing the amount of splashing and „deflected flow“ with reticulated ceramic filters would be expected to decrease the amount of air/metal interaction and therefore reduce potential inclusion formation. The reduction in overall turbulence can be seen from the transition of a large amount of gray swirled and buble rich regions in Fig. 4a to more well defined quiescent boundaries between air and liquid in Fig 4c.

A gating system incorporating several positive design components, such as a tapered sprue and external vents, is shown in Fig. 5. Comparing the depth of the interaction region in a straight sprue (Fig. 4b - It extends almost to the bottom of the central runner) to the interaction region in a tapered sprue under similar run conditions (Fig. 5b), indicates that the tapered sprue may be contributing to a reduction in the air/metal interface.

The external venting is believed to have significantly reduced the potential for vapor lock and slow fill or incomplete fill problems. The run times for all the tests on the externally vented gating system was not significantly affectedby the presence of a filter, vented or unvented, as shown in Table II.

The reticulated ceramic foam filters do significantly impact the overall turbulence in the system. The air/metal interface is significantly reduced by using the filters and the 30 ppi appears to be more effetive than the 10 ppi as shown in Fig. 5a-5c. Not only is this apparent at the main transition at the top of the fill region, but also at the bot¬tom of the sprue at the top of the „bubble separator“ (bottom) filter. Although it is difficult to detect in the black and white photographs, the region directly above the bottom 10 ppi filter contains a large number of large bubbles in the unfiltered pour (Fig. 5a), smaller bubbles but still turbulent region in the 10 ppi filter pour (Fig. 5b), and a quiet, relatively bubble free region in the 30 ppi filter pour. The feeders on either side of the bottom filter leading to the side runner bars in all cases is relatively bubble free.

Summary

Reynolds number calculations for reticulated ceramic filters predicted a reduction in the turbulence of the system due to decreased metal flow velocity (i.e. decreased metal head height) and decreased flow diameter due to the size of the pours relative to the overall size of the sprue. In this study, the use of reticulated ceramic foam filters has been shown to dramatically reduce turbulence in geometrically sized hydraulic models of investment casting gating systems. In addition, it has been found that the filters channel the flow into the sprue or central runner and reduce „deflected flow“ and splashing in other runners. These observations would be expected to hold true for metals of similar kinematic viscosity to water, such as steel and other ferrous alloys.

In the hydraulic models, it was also found that proper venting of the gating system was important to ensure fast mold filling and complete fill. With proper venting, even 30 ppi filters did not negatively impact fill times. Although the difference in wetting behavior of water vs. steel and the solidification issue will not allow us to make a direct analogy, it is believed that the differences observed between vented and unvented were large enough to make venting an important factor to consider when designing gating systems, particularly those which will be use with filters.

Reticulated ceramics may also potentially be used as „Bubble Separators“ within the gating system as demonstrated in this study. The secondary use of a filter at the base of the sprue was found in the hydraulic system to prevent bubbles from readitly passing out into the runners. Surface tension effects may also impact the ability to draw a direct analogy to steel systems in this case, but the effect was dramatic enough to warrant further investigation.

In summary, reticulated ceramic foam filters ware not only useful for removing inclusions already present in the metal, but also as a cost effective flow control device in the gating system to prevent

Reduced Oxide Formation Simply by Reducing the Reynolds Number with Reticulated Ceramics

Fig. 1 Simplified laboratory demonstration of turbulence reduction through the use of reticulated ceramic filters.

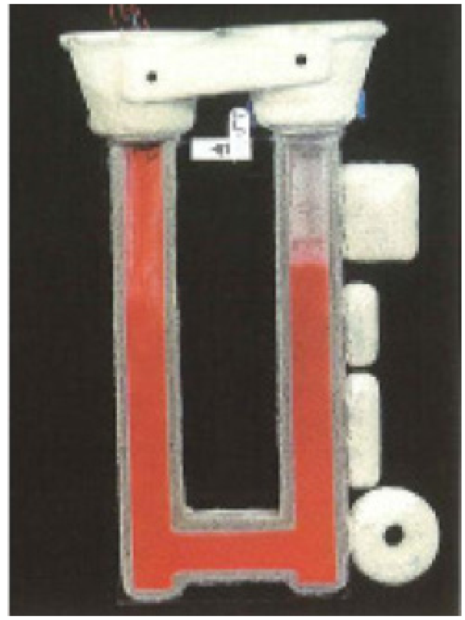
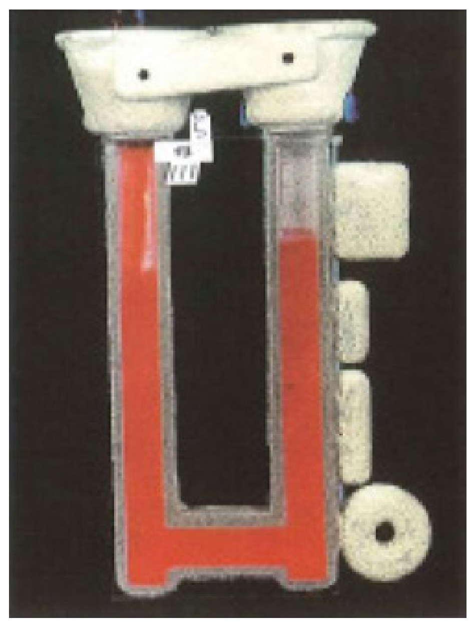


Fig. 3 Simple two vertical runner bar gating system with parts attached to one runner. A) No filter, poured down the runner without parts attached

Fig. 2 Experimental set-up (see text).



B) 30 ppi vented filter, poured down the runner.

Reduced Oxide Formation Simply by Reducing the Reynolds Number with Reticulated Ceramics

References

1. N.R. Green and J. Cambell, The Influence of Oxide Film Filling Defects on the Strength of Al-7Si-Mg Alloy Castings, submitted to AFS, 1994.
2. M.C. Ashton, Gating System Design and Bottom-Pour Ladle Practice - Their Interactive Effect on As-Cast Qua¬lity, SFSA Exchange paper from SCRATA.
3. X. Xue, S.F. Hansen, and P.N. Hansen, Water Analog Study of Effects of Gating Designs on Inclusion Separati¬on and Mold Filling Control, AFS transactions 93-69, pp 199-209.
4. T.S. Piwonka and N.H. El-Kaddah, Gating of Steel Castings - The Foundryman's Dilemma: Lessons from Tun-dish Flows, AFS transactions 90-109, pp295-300.
5. J.R. Morris, H. Eck, Advanced Reticulated Ceramic Metal Filters and Performance Results, I.C.I. 36th Annual Meeting (1988).
6. J.M. Morris, S. Sahu, and U. Sievers, Advanced Reticulated Ceramic Metal Filters and Performance Results from Select Steel Foundries, ???
7. J.M. Morris, P. LeTarte, and S. Oswald, Taguchi Analysis of Quality Improvement by Filtration, ???
8. J.M. Morris, The Effect of Reticulated Ceramic Filters on Reducing Turbulence, Incast, pp20, May 1995.
9. C. Beckerman, Analysis of Water Modeling as a Means of Studying Air Entrainment and Filter Effectiveness as Steel Castings are Poured, Special Report No. 26, Steel Founders Society of America, March 1993.

ASK Chemicals L. P.
495 Metro Place South | Suite 250 | Dublin, OH 43017
Phone: +1 800 848 7485 | Fax: +1 614 761 1741
info.usa@ask-chemicals.com | www.ask-chemicals.com

ASK CHEMICALS
We advance your casting