Quiescent Filling Applied to Investment Castings

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Inside This Story:

- The effect of controlled and uncontrolled bottom-filled gating systems on casting quality are compared with a typical top-filled system used as a benchmark for poor practice.
- The results indicate that controlled filling can substantially increase the quality of both alloys considered in this research.

Despite the strong market for investment castings, there is little doubt that end-users are concerned about the quality and reliability of safety-critical components. While the choice of gating systems for investment castings is influenced by a number of factors—including ease of processing and cost of cleaning machining—the effect of the gating system design on casting quality and reliability is usually ignored. This may be because information on the effect of different designs is lacking.

In this article, the effect of controlled and uncontrolled bottom-filled gating systems on casting reliability for aluminum alloy A356 and low alloy chrome-molybdenum steel are compared with a typical top-filled system used as a benchmark for poor practice. Controlled systems are those in which metal flow is constrained for most of the filling time by the gating system, which remains completely full for a very high proportion of the filling time. In addition, these systems promote minimal formation of free surfaces.

The controlled system was based on a wide runner 5 mm thick with and without a filter, with no concessions made for ease or economy of manufacture. The uncontrolled system was a conventional bottom-filled design based on a 25 mm square runner with design compromises made for ease and economy of manufacture.

The runner systems were used to cast bars for 4-pt bend tests. The scatter in the breaking stress of these bars was analyzed using the Weibull statistical technique that has been established as a useful method of quantifying the effect of turbulent filling conditions and the consequential entrainment of oxide films on the reliability of castings.

Runner System Design

The objective of the runner system is to carry metal into the mold cavity with minimal surface turbulence. This means that the metal must remain in contact with the mold walls to prevent free surfaces from forming on the metal. In this situation, the metal flows inside an oxide film formed on the outside surfaces in contact with the mold, and it is unlikely that this film will become entrained in the metal flowing inside.

The top systems evaluated were:

Top-Filled—A standard conical pouring cup was placed onto a 25 x 25 mm square section top runner bar from which six test bars were suspended (Fig. 1a).

Uncontrolled Bottom-Filled—A standard conical pouring cup was connected to a tapered sprue and a 25 x 25 mm square section runner bar (Fig. 1b). This was connected to a cross bar to which the bend test bars were directly attached. The cross bar served as a riser during solidification. A central vertical bar between the test bars maintained metallostatic pressure in the cross bar. No filter was use.

Controlled Bottom-Filled—A rectangular offset pouring basin with a weir (dam or slag skimmer) was used on top of the downsprue (Fig. 1c). The feeding system was identical to that described above but the aspect ratio of the runner was increased to 10:1 (5 mm deep x 50 mm wide). This ran over the top of a 20-ppi ceramic foam filter to a bubble trap. After flowing through the filter into the runner below, there were two bends to reduce velocity. The runner continued from the bottom of the filter to a dross trap. A 25 x 25 mm square cross-section cross bar/riser was connected on top of the runner onto which the test bars were mounted.

Controlled Bottom-Filled Without a Filter—Similar to the controlled bottom-filled, except that the runner was a straight rectangular plate 50 mm wide x 5 mm thick.

Bottom-Filled Systems Design

The pouring basin for the controlled bottom-filled design was formed during shell molding and included a weir to contain the first metal to be poured into the basin. The rectangular shape minimized the possibility of forming a vortex. When the weir was full, metal overflowed into the remainder of the basin to which the sprue was attached. The size of the basin allowed it to be kept full throughout filling and to maintain a reasonably constant metal head.

Both bottom-filled systems used a tapered sprue of 15 mm exit diameter, 30 mm entrance diameter and 235 mm metallostatic head. The sprue constrained metal during its fall from the highest to the lowest point in the mold and controlled the filling time. The sprue exit had a generous fillet radius of 20 mm to minimize air entrapment.

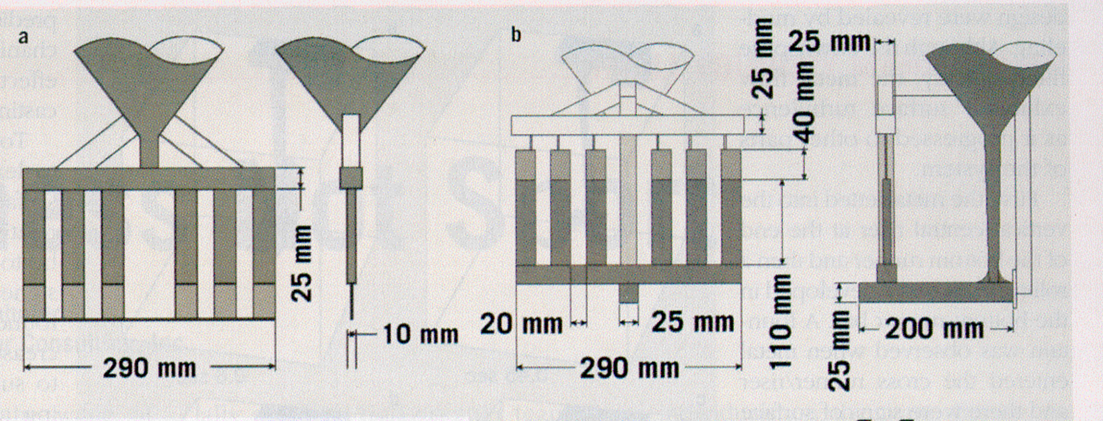
The most damaging surface turbulence occurs at the beginning of filling when metal speeds are highest and the gating system is not full. A characteristic feature is a rolling back wave in which the initial stream of metal running along the bottom of the runner is reflected back from the far end of the runner, rolling back over the top of the incoming metal.

To prevent a back wave from forming, the runner thickness should be reduced to that of the initial metal stream flowing along the runner. The "glissile height" of an unconstrained stream of flowing molten aluminum was measured to be approximately 6 mm and tests confirmed that thin runners did prevent the back-wave from forming.

However, a further function of the gating system is to reduce the metal speed from that at the sprue exit, which is always excessive and usually above 1.5 m/s, to an acceptable value at the ingate of less than the critical velocity of 0.5 m/s for aluminum alloys.

The effect of runner width on metal speed and stream separation in 5-mm thick runners has been studied by modeling runners with widths in the range of 25-95 mm. This showed that a 50-mm wide runner provided a satisfactory compromise between a low ingate velocity and minimal stream separation.

When designing gating systems to maintain a metal velocity below 0.5 m/sec, it is important to include generous allowances to ensure that the average value is well below the critical ingate velocity of 0.5 m/sec. If the cross-sectional area of the ingate is inadequate, the metal speed will be excessive. But even if the cross sectional area is adequate, the metal speed may still be excessive depending on the flow conditions created by the runner design.



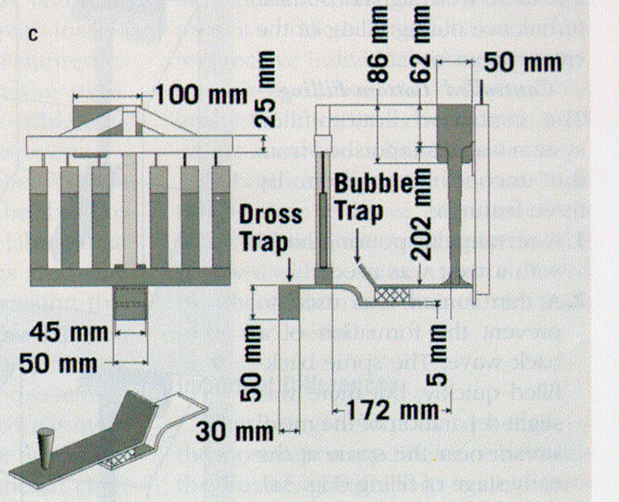


Fig. 1. Schematics of the three running systems used include top-filled (a), uncontrolled bottom-filled (b) and controlled bottom-filled (c).

Aluminum Results

Top-Filling—Although top-filling is the most cost-efficient system to implement, it represents the furthest departure from the ideal of containing the metal inside a full gating system since metal falls freely without significant control throughout the filling process. The flow characteristics include drop formation, ricochets off mold walls, waves and surging flows.

Frames from a simulation of top-filling are shown in Fig. 2a-d. Figure 2a shows the start of a rolling back-wave in the top runner and this develops as the filling progresses. Random splashing in the test bars can be seen in Figures 2c and d. The two central bars are the last to fill.

Uncontrolled Bottom-Filling—The simplest design of bottom-filled system used a square section runner that was attached onto the cross-bar/riser below the test-bars. The disadvantages of this

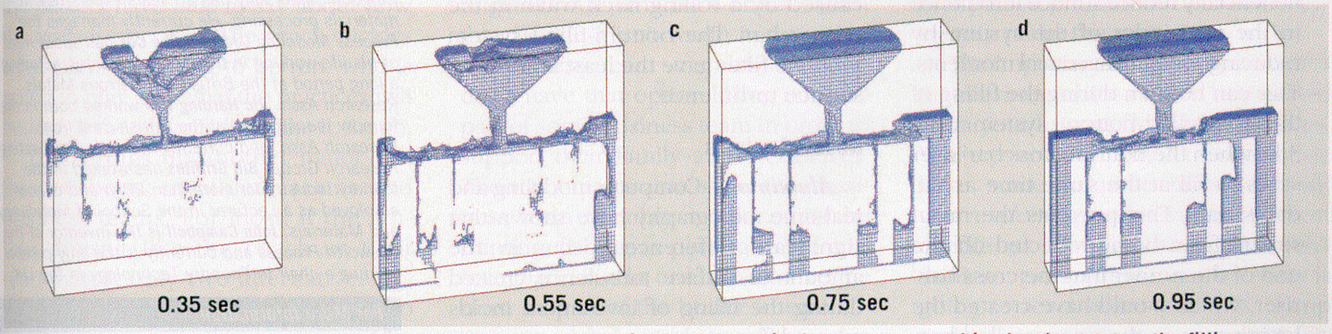


Fig. 2. Frames from a simulation of top-filling show the start of a rolling back-wave in the top runner and its development as the filling progresses. Random splashing in the test bars can also be seen.

design were revealed by modeling. Although the downsprue filled quickly, the metal flow exhibited surface turbulence as it progressed to other parts of the system.

First, the metal jetted into the vertical central riser at the end of the bottom runner and then a rolling back-wave developed in the bottom runner bar. A fountain was observed when metal entered the cross runner/riser and there were signs of surface turbulence during filling of the cross runner/riser.

Controlled Bottom-Filling—The controlled bottom-filled system was distinguished from the uncontrolled system by three features:

1. A rectangular pouring basin with a weir was used.
2. A thin runner was used to prevent the formation of a back wave. The sprue backfilled quickly, but there was slight separation of the metal stream near the sprue at the early stage of filling (Fig. 3a). This disappeared when the filter started to fill. Flow after the filter appeared to be controlled, although a little jetting into the vertical up-runner could be observed in the simulation as metal entered the dross trap at the end of the runner. There was some evidence of back-waves in the simulation as metal filled the cross bar/riser, but these were little more than undulations on the surface. Flow after this point was quiescent and the test bars filled evenly.
3. A dross trap at the end of the runner was used to collect the first metal—which is both damaged and cooled—entering the mold. This reservoir can beneficially reduce surface turbulence in the remainder of the system by reducing pressure at critical moments. This can be seen during the filling of the controlled-bottom system (Fig. 3d), when the bottom cross bar/riser starts to fill at the same time as the dross trap. This prevents the metal stream from being reflected off the end of the runner into the cross bar/riser, which would have created the jetting seen in the uncontrolled bottom-filled system.

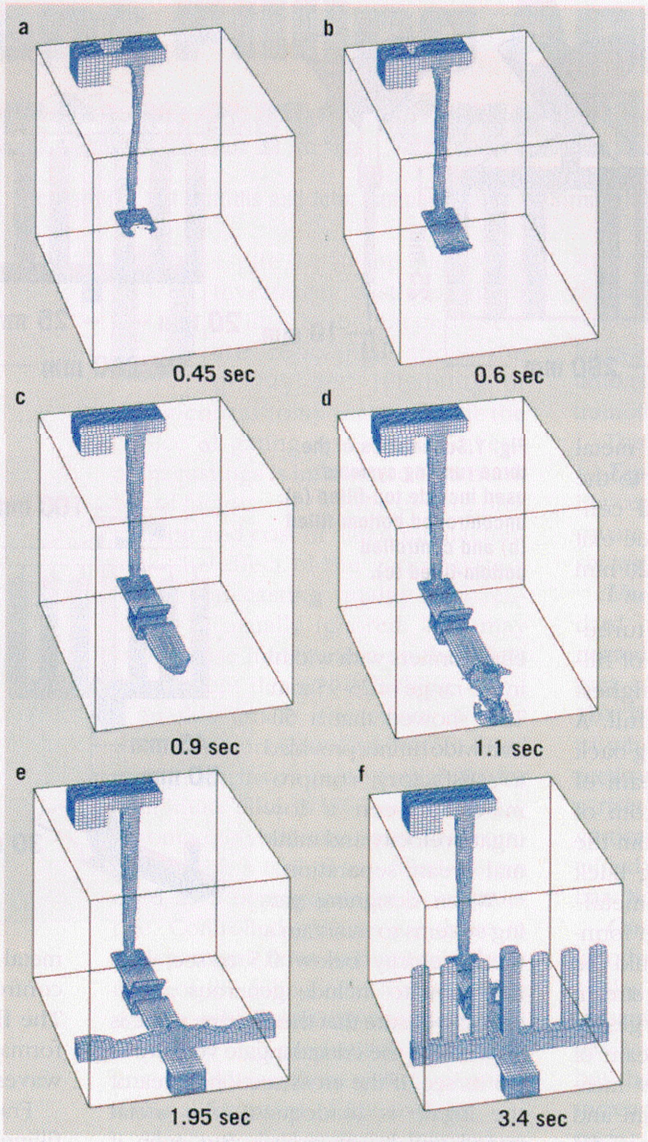


Fig. 3. The computer simulation for the controlled bottom-filled system showed controlled metal flow following the filter, filling the test bars evenly.

Steel Results

The greatest amount of surface turbulence occurred in the top-filled molds. The bottom-filled molds without the filter represented an intermediate case in which the test-bars filled more quiescently than the top-filled molds, although some entrainment was caused by a rolling back wave in the runner bar. The bottom-filled system with the filter gave the least amount of surface turbulence.

Result Analysis

Aluminum—Computer modeling and real-time radiography have shown that significant differences occur in the amount of surface turbulence created during the filling of investment molds when different designs of running systems are used. While it is impossible to predict the exact effects, the mechanical testing showed a clear effect on the reliability of the castings produced.

Top filling has been shown to lead to a large amount of surface turbulence (Fig. 2). The relatively simple uncontrolled bottom-filled system was designed for ease of use in a foundry and its low-cost increase. However, this also led to surface turbulence, including a rolling back wave and jetting of the metal. The results obtained for the controlled bottom-filled systems confirmed the advantages of using thin runners to prevent a rolling back wave.

The surprising result that the uncontrolled bottom-filled system offered no advantage over top-filling indicates that the reduction in surface turbulence brought about by a tapered sprue at the front end of a bottom-filled system must be coupled with another element such as a pouring basin with a weir, a dross trap or a filter to obtain maximum benefit.

Steel—The similarity between the top- and unfiltered bottom-filled running systems agrees with the results obtained for the aluminum alloy test-bars. These results confirm that bottom-filling of castings may not necessarily result in greater reliability. **MC**

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All the authors work at the Interdisciplinary Research Centre in Materials Processing at the University of Birmingham, Edgbaston, United Kingdom. ***Mark Jolly*** *has 20 years experience in materials processing. He currently manages the Process Modeling Group.* ***Mike Cox*** *has spent most of his life working in the metals industry including a long period at the British Non-ferrous Metals Research Assn.* ***Ric Harding*** *has worked both in the foundry industry and at the British Cast Iron Research Assn. and currently manages the Casting Research Group.* ***Bill Griffiths*** *has worked in the foundry industry for more than 20 yr and is now employed as a Lecturer in the School of Metallurgy and Materials.* ***John Campbell*** *is the inventor of the Cosworth Process and currently is the only person holding a chair in Foundry Technology in the UK.*

For More Information

"Gating and Feeding of Investment Castings," *CMI Course, June 4-5, 2003, AFS.*