Many variations of the permanent mold process are well-suited for mass production of high-integrity light metal castings for automotive components. This article is based on “High Integrity Permanent Mold Casting Processes: Current and Future,” a presentation at the American Foundry Society’s 6th International Conference on Permanent Mold Casting of Aluminum and Magnesium.

J. L. Jorstad*
JLJ Technologies Inc.
Richmond, Virginia

Permane mold casting consists of several basic processes. In this article, key characteristics of each will be considered in terms of their impact on high-integrity products.

**GRAVITY FILLING PROCESSES**

Gravity pouring, whether manual, via auto-ladles, or robotic pouring, can be susceptible to turbulence, which has a negative effect on high-integrity castings. It is nearly impossible to have molten aluminum free fall more than a few centimeters without initially exceeding a safe flow velocity of about 0.5 to 1 m/s. Note that a free fall of less than 0.1 m will accelerate to more than 1 m/s flow velocity. Professor John Campbell has often pointed out the propensity for turbulent flow at velocities above 1 m/s, and the likelihood that high velocities will lead to harmful oxide folds. Still, by applying tilt pouring techniques to better control velocity at the onset of flow, and/or by applying appropriate filters as flow control devices and to remove oxide films close to the point where melt enters the casting cavity, high quality gravity-poured aluminum castings are possible.

**Static top-pouring**

Static top-pouring is the permanent mold version that has been a mainstay since aluminum’s commercial introduction at the turn of the 20th century. The process remains standard for most high-volume automotive pistons and cylinder heads. Still, static top-pour is also the method most likely to contain turbulence-related defects.

However, with the incorporation of ceramic-foam filters and their ability to smooth melt flow (Fig. 1), opportunities become available to top-pour with significantly fewer entrapped oxides and other quality detractors. Combining filters with down-sprue and runner designs proposed by Prof. Campbell has made it possible to pour reasonably high-integrity aluminum castings, perhaps most suitable for a variety of less-critical automotive applications.

Static top-pouring has another downside too, an ever-diminishing effective metal head as fill progresses. Unless the pour height is specifically increased (adding to the turbulence issue), little pressure remains to assist fill or shrinkage feeding the uppermost reaches of the mold cavity. One solution is to top off upper risers with hot metal. A more effective means to offset both the turbulence and diminishing metal head issues is tilt pouring.

**Tilt pouring**

Tilt pouring essentially removes the effect of free fall at the beginning of the pouring process. With care, a cup or basin can be filled while in a horizontal position with free fall limited to only a few centimeters. When tilting at an appropriate rate is initiated, melt flows from the basin to far extremes of the mold cavity, also with minimum free fall turbulence. Those extremes ultimately become the low points in the mold after tilting is complete (Fig. 2). The basin then usually be-
INTRODUCING THE MTS LANDMARK SERVOHYDRAULIC TEST SYSTEM

The new MTS Landmark™ System marks the optimization of the world's most widely deployed servohydraulic testing technology. Highly configurable and scalable, it integrates all the high-performance attributes that MTS test systems are renowned for into a new highly stiff, ergonomic and easy-to-maintain load frame.

» Durability
» Fatigue Crack Growth
» High Cycle Fatigue
» Low Cycle Fatigue
» Fracture Toughness
» Tension, Compression and more

Contact MTS today and learn how the new MTS Landmark System can help you meet a full spectrum of static and dynamic material and small component test requirements - now and well into the future.

www.mts.com/landmark
info@mts.com

MTS MATERIAL TESTING SOLUTIONS
be certain.
comes the reservoir of hot metal for feeding shrinkage as the uppermost areas of the casting solidify. Tilt pouring is applied to simple single-station devices, as well as to large multi-station carousels.

LOW-PRESSURE PERMANENT MOLD

Basic low-pressure process

The low-pressure permanent mold (LPPM) process is, in fact, a style of permanent or semi-permanent mold, thus the term LPPM, but it can also work with sand molds to make limited-production prototypes or high integrity parts for aerospace and the like. The process is illustrated in its basic form in Fig. 3 and is briefly described as follows:

- In most versions, a mold is positioned above a hermetically sealed furnace. However, in at least one version the mold resides adjacent to the open well of an unsealed and unpressurized furnace, and melt is moved into the tool by the force of an electromagnetic pump.
- Molten metal bottom-fills the mold cavity through a riser tube by pressurizing the melt surface (or by applying an electromagnetic force), thus creating a pressure imbalance (AP between melt and mold cavity) sufficient to force melt to rise into the mold at a controlled flow velocity.
- Pressure is maintained on the melt surface until the casting fully solidifies.
- Pressure is then released, allowing excess melt in the riser tube to recede back into the furnace.

Cast-weight to trimmed-weight yield in LPPM is typically 95 to 98%. This basic version of low pressure was developed in the 1940s to cast beer barrels, and soon became a popular means to cast other products, including aluminum cylinder heads. LPPM has been used extensively since the early 1970s to cast styled aluminum wheels and other automotive products such as cross members and engine blocks. LPPM and its variations quite easily accommodate disposable internal sand cores.

The key advantages of LPPM are that it is a natural bottom-filling process, thus fill turbulence is minimized; and it provides a strong natural directional solidification from cavity extremes back to the hot riser fill positions. Another advantage in terms of productivity is that, by using either multiple riser tubes or a feeding manifold, multi-cavity casting of smaller parts such as knuckles and control arms is quite feasible. The process also does not have the projected-area restrictions that apply to the high-pressure processes often chosen for high-integrity chassis and suspension components.

A downside to LPPM is the repeated rise and fall of melt in the riser tubes, which create opportunities aside from fill turbulence for the introduction of oxides. This is offset or overcome by some practitioners by maintaining sufficient pressure on the melt between shots to prevent melt from receding more than a centimeter or so below the fill level; and/or inserting a filter between the riser tube and casting cavity to prevent the passing of whatever oxides are formed due to melt level changes in the tubes.

Vacuum riserless/pressure riserless casting

The vacuum riserless/pressure riserless casting (VRC/PRC) process is illustrated in Fig. 4. This variation on low-pressure casting was developed
by Alcoa and re-designed in the 1990s by CMI/A-CMI as a robust technology in the high-volume automotive foundry environment. As in the basic low pressure process,
  • a mold is located above a hermetically-sealed furnace, but
  • the mold cavity communicates with the melt through not one but several riser tubes;
  • the bottom mold half (the drag or cover half) forms the top-plate of the furnace, so
  • the coupling distance between the melt and mold cavity is quite short; and
  • melt level in the furnace is kept constant each casting cycle by replenishing the furnace with a quantity of new melt equivalent to the weight of the just-cast shot.
Casting yield is typically 95+%. At Madison Precision Products Inc., VRC/PRC casts structural components such as knuckles, link arms, and sub-frames.

The key advantages of VRC/PRC are
  • The close coupling between melt and casting allows cooler melt temperatures without danger of miss-fills.

### Casting process comparisons

<table>
<thead>
<tr>
<th>Capabilities</th>
<th>Mechanical properties</th>
<th>Casting size</th>
<th>Net shape</th>
<th>Piece count per hour</th>
<th>Capital costs</th>
<th>Tooling costs</th>
<th>Total relative cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent mold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static gravity</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Tilt</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>LPPM</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>VRC/PRC</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>CPC/PCPC</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>High pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squeeze</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Rheocast</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>High-vacuum</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

In the context of the table: regarding capabilities, 5 means best, largest, or highest, whereas 1 means worst, lowest, or smallest; regarding costs, 5 means best or lowest, whereas 1 means worst or highest.

ASM International and the North American Die Casting Association present this intensive one-day workshop bringing together some of the world’s foremost experts in the fields of dies, coatings, surface treatments, and failure mechanisms.

**Surface Engineering for High Performance Die Casting Tooling**, April 23, 2008 — conveniently located at the Hilton Garden Inn, Chicago O’Hare Airport.

The program will include three in-depth panel discussions on topics including:
  • Heat Treatment
  • Ion Nitriding
  • Ion Implantation
  • PVD & CVD
  • Test Methods
  • Application/Lessons Learned

Get practical information you can use.
  • Reduce downtime
  • Reduce soldering
  • Extend die life
  • Increase productivity
  • Reduce cost

Register today.
Advance registration closes April 7, 2008.
www.asminternational.org/diecasting2008

Book your hotel by calling 847.296.8900.
• Multiple small riser tubes allow multiple casting cavities and/or multiple fill and feed locations into a cavity, thus shortening fill and feed paths.
• Vacuum ahead of flowing melt as the cavity fills facilitates complete filling, even into remote pockets, and minimizes formation of oxides and absorption of hydrogen during fill.

A possible downside to VRC/PRC is the vacuum that assists filling and minimizes defects; unless perfectly controlled, vacuum can also draw ambient air through leaking riser tubes and unsealed mold joints to create bubble defects.

Counter-pressure/pressure, counter-pressure

The counter-pressure casting (CPC) and pressure, counter-pressure casting (PCPC) processes are illustrated in Fig. 5. These are actually variations on the basic low-pressure process. However, they differ from low pressure in that
• the entire furnace and mold cavity are initially pre-pressurized; then
• a slight pressure difference (~equivalent to the difference normal to LPPM) is created to allow melt to flow through the riser tube and into the mold cavity, where it
• solidifies under a somewhat higher pressure than is typical of LPPM, whereupon
• all pressure is released and melt remaining in the riser tube returns to the furnace.

Two advantages of CPC over LPPM are first, that pressure on the flow front during cavity fill reduces turbulence; and second, small blind risers can feed under pressure into remote solidification sites that are susceptible to shrinkage.

For more information: John L. Jorstad, JLJ Technologies, 9112 Donora Drive, Richmond, VA 23229; tel: 804/747-0550; jorstad@aol.com.

Fig. 5 — CPC/PCPC schematic (Diagram courtesy Intermet).