Slurry-Based Semi-Solid DIE CASTING

A new process for the fabrication of high-quality, semi-solid-formed components offers advantages over components made via traditional semi-solid manufacturing methods.

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Direct slurry forming (DSF) is a semi-solid forming process that eliminates capital cost expenditures, reduces the number of steps required, and hence reduces the cost of semi-solid formed components relative to other semi-solid forming processes. Semi-solid forming continues to make inroads in the manufacture of mechanically demanding and pressure-tight aluminum components because of its ability to provide near-net-shape components with properties far exceeding those of other casting technologies. For these reasons, semi-solid formed components have increasingly become a preferred alternative for forgings, components machined completely from billet, and investment castings.

Traditional semi-solid metal processing typically involves continuously casting metal bar stock with a special microstructure, storing and/or shipping this material, cutting it to length, reheating to the semi-solid state, transporting to the forming press, and forming the product.

The DSF process eliminates many of these steps by producing a large quantity of semi-solid slurry from molten metal, and by maintaining a constant supply at the forming press. Process complexity is reduced, capital equipment is eliminated, and specialty raw material is avoided. DSF provides the high-density, heat-treatable, pressure-tight components possible with traditional semi-solid processing, but at lower cost. The process, enabled by accurate temperature control and thorough mixing of the slurry, is fully integrated with existing vacuum die casting equipment and is currently in service for the manufacture of automotive fuel rails (Fig. 1).

This article describes the behavior of semi-solid metals, details the process steps, and compares it with die casting and conventional semi-solid processes.

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Two factors typically about heat removal of the slurry temperature the required Two factors heavily influenced the design of the slurry furnace – the required heat removal rate, and the need to maintain a near-constant temperature of the bath. Based on the production rates and temperature differences, it was found that about 20 kW of heat extraction were needed in the most extreme case. Additionally, because an average of 90 kg (200 lb) of molten aluminum is added every ten minutes, the bath temperature may not vary more than ±1°C (±2°F). Each of these requirements dictated a furnace with large volume and high surface area. A cylindrical furnace one meter in diameter and one meter tall could contain 2000 lb of slurry and remove 7 kW/m². With a temperature difference of 50°C (90°F) between liquid and slurry, specific heat of 60 kJ/kg for liquid aluminum, and latent heat removal of 77 kJ/kg, this configuration could meet the design needs.

The second step of the process is maintaining the slurry in a homogeneous, isothermal state as it awaits forming. In addition to the thermal requirements for creating a slurry discussed above, it is necessary to provide adequate shearing forces to the mixture to create the rounded solid particles and prevent agglomeration of the solids.

In the arrangement described here, where heat is removed through the walls of the furnace, aluminum alloy would typically form dendrites at the outer walls, and these dendrites would grow inward as solidification progressed. If the average temperature of the bath were maintained constant, the result would be complete segregation: a solid shell of low-alloy aluminum surrounding a high-alloy liquid center.

However, the goal is a uniform mixture of fine-grained solid particles in a liquid matrix. This result can be achieved by regularly scraping the walls of the furnace during solidification, breaking growing dendrites from the wall, and moving them into the bulk of the bath. With sufficient shearing action, these dendritic structures are moved through the melt and coarsened into rounded structures by the flow of liquid around them. Figure 3 illustrates the viscous consistency of the resulting slurry.

Equally important to creating the solid portion of the slurry is keeping it uniformly distributed within the mixture. Because of density differences between solid and liquid phases, the solid particles in aluminum alloy A356 (a low-iron, aluminum-silicon casting alloy not typical in die-casting) will settle downward over time, resulting in a high con-
This is a semi-solid slurry forming furnace. The impeller has inclined rotating blades that force the flow of material upward in the melt. The scraping rotor shears growing dendrites off the walls and into the melt.

Fig. 4 — This diagram shows the design of the slurry forming furnace. The impeller has inclined rotating blades that force the flow of material upward in the melt. The scraping rotor shears growing dendrites off the walls and into the melt.

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Comparison with die casting

The DSF process has a number of advantages over conventional semi-solid forming techniques, some of which are outlined below:

- Less energy is required during processing because metal is heated only once. No reheating is necessary, as the semi-solid is formed only one time.
- Complexity is reduced because no multistation heating systems are needed, and no heated billets must be handled.
- Flexibility is increased because alloy modifica-
Capital cost is reduced because no sawing equipment, special induction heating systems, or robotic handling is necessary.

Industrial implementation

The DSF process has been in production at Gibbs Die Casting for over 18 months. Automotive fuel rails that can be found on the Zetec engines (Fig. 6) of Ford Focus automobiles are slurry cast. Many other parts have been prototyped, including compressors, compressor heads, motor mounts, pistons, and clutch covers. The parts vary from thin-walled to thick-walled, pressure-tight to mechanically demanding, and single to multi-cavity. Figure 5 shows a variety of parts sampled with this process.

DSF lends itself well to high-volume automotive applications where leak tightness is required, where improved mechanical properties are required over die castings, or where costs must be lower than other processes such as forgings or welded assemblies. The near-net-shape capabilities of semi-solid forming combined with DSF offer an exciting new cost competitive manufacturing solution.

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