Semi-Solid Casting of Aluminum Turbocharger Impellers

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Fatigue life of the semi-solid cast impellers is much better than conventional castings.

Semi-solid casting is capable of producing very high quality aluminum components, but over the years the process has achieved only limited commercial penetration. Part of the reason is that the majority of semi-solid castings are heat treated to the T5 temper, which results in mechanical properties similar to those of sand and permanent mold castings. One of the reasons for the predominance of T5 heat treating with semi-solid castings is the avoidance of the tricky solution heat treatment with T6 heat treating, and the quality issues, especially blistering, that are possible with semi-solid castings.

However, when semi-solid castings are fully heat treated to the T6 temper, the mechanical properties achievable are far superior to those of other casting processes. This results from a combination of fast solidification rates due to un-coated metal molds, and the minimization of internal defects. In the T6 condition, the mechanical and fatigue properties of semi-solid aluminum castings approach those of wrought products. In fact, these semi-solid castings have recently replaced more expensive forged + machined components in several commercial applications. An example of one such application is that of aluminum turbocharger impellers (Fig. 1).

Turbocharger Impellers

A turbocharger essentially consists of a turbine wheel and an impeller connected on a common shaft. The turbocharger converts waste energy from the engine by using exhaust gases to drive the turbine wheel, causing the impeller to compress air and push it into the engine. The extra air allows an engine to produce more power and torque, as well as minimizing emissions by improving the overall efficiency of the combustion process.

The compression ratio for modern diesel engines can be up to 5:1, a ratio that can be achieved only by a complex impeller design and very high rotation speeds (up to 150,000 rpm for small impellers). The complex geometry and very high running speeds of impellers generates high stresses at locations such as blade roots and around the bore. Therefore, impellers normally fail from fatigue, making it vital to minimize defects while fabricating turbocharger impellers.

Current methods for producing aluminum turbocharger impellers are plaster casting or by forging + machining. Plaster casting is the lowest-cost approach, but the impellers have limited mechanical properties and fatigue life due to the presence of oxide defects in the castings. Forging + machining provides parts with longer fatigue life, but the limited net-shape capability of the forging process means that all surfaces of the impellers must be machined, a time-consuming and costly process.

Semi-Solid Cast Impellers

The thixocasting semi-solid casting process was chosen to produce the impellers. As shown by the process schematic in Fig. 2, in thixocasting a pre-cast billet is reheated to a temperature at which the slug is approximately 50% solid and 50% liquid. The advantage of the process is the product consistency that results from a pre-cast billet manufactured under the same ideal continuous processing conditions as those for forging or rolling stock. The billet feed material is produced from primary aluminum.
in batches as large as 40,000 pounds. These pre-cast billets provide billet-to-billet and lot-to-lot chemistry, cleanliness, and microstructural repeatability comparable to forging and rolling stock. The ability to produce consistent product is much easier compared to pouring castings from the liquid in single doses. Thus, as long as the casting process is suitably controlled, semi-solid components produced by the thixocasting approach have very consistent properties.

A real-time controlled die casting machine casts the impellers, and the semi-solid slugs are injected into a reusable, hardened steel die. The runner system of the impeller is designed to strip away the surface oxide from the semi-solid slug. The combination of a highly viscous semi-solid feed material and real-time controlled injection ensures the semi-solid metal fills the die cavity in a non-turbulent manner (see Fig. 3), preventing oxide formation by ensuring that the air pre-existing in the cavity is not mixed with the metal, but instead is pushed ahead of the metal front and eliminated from the die cavity through strategically placed vents. After the die is filled, the plunger continues to pressurize the cast-

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**Fig. 2** — Schematic of the thixocasting semi-solid casting process.

**Fig. 3** — Sections through impellers showing lack of porosity. a: Machined surface. b: Machined and penetrant tested, and viewed under ultraviolet light.
ing at more than 1000 bar to feed solidification shrinkage.

The combination of controlled die filling and a high intensification pressure eliminates porosity from the castings. Figure 3a shows a machined surface through an impeller, while Figure 3b shows penetrant testing of a machined surface, through the hub of the impeller, demonstrating the lack of porosity in the impellers.

**Tooling**

Clearly the shape of the impeller, including the 14 intricately-shaped blades, is very complex for production in a metal mold. Figure 4 shows a CAD model of the steel tooling necessary to manufacture the impeller. The blade shape is essentially cast net-shape, and the tolerances of the steel tooling are such that machining of the tooling required the installation of a temperature-controlled machining cell. The steel tooling is ejected from the die along with the cast impeller, and a special station is utilized adjacent to the casting machine to

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**TABLE 1 — TYPICAL MECHANICAL PROPERTIES OF SEMI-SOLID CAST IMPELLERS**

<table>
<thead>
<tr>
<th>0.2% YS, MPa</th>
<th>UTS, MPa</th>
<th>Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>338</td>
<td>400</td>
<td>8</td>
</tr>
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disassemble the tool. The technology to produce the impellers is the subject of a world-wide patent application, and Aluminum Complex Components has an exclusive world-wide license to practice the technology.

**Impeller Properties**

The impellers are cast from a high-strength aluminum alloy. To optimize strength and fatigue resistance, the semi-solid cast impellers are fully heat treated to the T6 temper. Careful choice of die design, casting parameters, and die and plunger lubricants avoids detrimental blistering during T6 heat treating. Samples for tensile testing are machined from the center of the impellers, and the table shows the typical mechanical properties of semi-solid cast impellers.

**Figure 5** shows a comparison of the fatigue life of impellers produced by casting, forging, and semi-solid casting. This shows that the fatigue life of the semi-solid cast impellers is much better than conventional castings, and has a comparable fatigue life to that of the forged + machined impellers. Furthermore, a functional test has measured the fatigue life of actual impellers, and results show that the fatigue life of the semi-solid impellers is similar to that of the forged + machined parts.

![Fatigue strength at 10^7 cycles, MPa](image)

**Fig. 5 — Fatigue data for castings, forgings and semi-solid castings.**

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