

## Novel Method for Casting High Quality Aluminum Turbocharger Impellers

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### ABSTRACT

A turbocharger essentially consists of a turbine and an impeller wheel connected on a common shaft. The turbocharger converts waste energy from the exhaust into compressed air, which is pushed into an engine to produce more power and torque, as well as improving the overall efficiency of the combustion process. The compression ratio for modern diesel engines can be up to 5:1, which can be only achieved using 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 creates high stresses at locations such as blade roots and around the bore, and so impellers normally fail from fatigue. Therefore, it is vital to minimize defects while fabricating turbocharger impellers.

Current methods for producing aluminum turbocharger impellers are plaster casting or by forging + machining. However, both of these current methods have serious drawbacks. Plaster cast impellers tend to have both surface and interior defects that limit performance and life, while forged + machined impellers are expensive.

A new technique for producing high quality turbocharger impellers is semi-solid casting. This casting process injects metal that is approximately 50% solid and 50% liquid into a re-usable, hardened steel die using a state-of-the-art die casting machine. A combination of controlled die filling and a high intensification pressure produces high quality

impellers - various tests are presented that demonstrate the castings are essentially free of porosity and other defects.

Semi-solid cast impellers have been in commercial production for about four years. The technology to produce the impellers, which is protected by a pending world-wide patent, is described in detail. Of interest is a special die design, which is required to cast the fourteen intricately-shaped impeller blades. Part of the steel die is ejected from the casting machine along with the cast impeller, and a special station is utilized outside of the machine to disassemble the die cartridge. After removing the casting, the cartridge is then reassembled and reinserted into the casting machine. Several steel cartridges are utilized to maximize productivity.

To optimize strength and fatigue resistance, the semi-solid cast impellers are fully heat treated to the T6 temper. Mechanical and fatigue properties of the semi-solid cast impellers are presented, and both are significantly better than impellers produced by conventional plaster casting. Semi-solid impellers have a comparable fatigue life to their forged + machined counterparts, although production costs are lower for semi-solid impellers.

### INTRODUCTION

In simple terms, a turbocharger consists of a turbine wheel and an impeller on a common shaft. Waste energy from the exhaust turns the turbine, causing the impeller to provide compressed air to the engine. This allows the engine to produce more power and torque, as well as improving the

overall efficiency of the combustion process. Turbochargers can be used in both gasoline and diesel engines, but the semi-solid cast impellers described in this paper are currently used only in diesel engines.

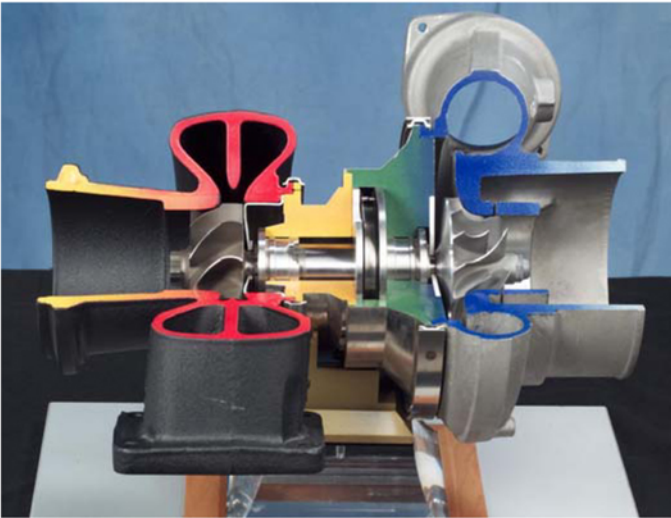


**Figure 1. Section through a turbocharger<sup>(1)</sup>**

The compression ratio for a modern diesel engine can be up to 5:1, which can be only achieved using a specific design of impeller and at very high rotation speed (up to 150,000 rpm for small impellers). The complex geometry and very high running speeds of impellers creates high stresses at locations such as blade roots and around the bore, and so impellers normally fail from fatigue. Therefore, it is vital to minimize the defects in impellers.

Impellers for turbochargers are typically produced from aluminum alloys by either plaster casting or by forging + machining. Plaster casting is the most common process for producing turbocharger impellers. Plaster casting is the lowest cost approach, but the castings have limited mechanical properties and fatigue life due to the presence of defects in the castings.

Forging + machining was developed as an alternate technique for fabricating aluminum impellers. The limited net-shape capability of the forging process means that all surfaces of the impellers have to be machined - machining the blades is obviously a time consuming and costly process. However, the fatigue life of forged + machined impellers is significantly better than those produced by plaster casting.

Semi-solid casting is a new process for fabricating aluminum impellers, and has been used commercially for four years or so (Figure 2). This paper will describe the processing conditions used for commercial production, present data on performance characteristics, and provide information on

various tests used to evaluate and monitor the quality of the semi-solid cast impellers



**Figure 2. 85 mm diameter semi-solid cast aluminum turbocharger impeller**

## BACKGROUND

Most casting processes use fully liquid metal as the feed material. Semi-solid casting is different, as it uses a feed material that is between 25-50% solid and 50-75% liquid. Semi-solid casting maintains many of the advantages of the die casting process, including near-net shape capability, high speed production, excellent dimensional repeatability, tight tolerances and the ability to cast thin walls. However, semi-solid casting provides significantly better structural and mechanical integrity than die casting. Semi-solid casting reduces or eliminates the residual porosity present in die castings, due to a combination of a non-turbulent die filling process, and by applying high pressure during solidification to feed solidification shrinkage. The reduction of residual porosity in semi-solid cast components provides significantly better mechanical properties than die castings, allowing components to meet quality requirements for safety critical structural and pressure tight applications. Semi-solid cast components have been used in many markets, including automotive, motorcycles, bicycles, recreational, defense, aerospace, electronic and fluid transportation.

There are three distinct semi-solid casting processes used commercially for the production of components - thixocasting, rheocasting and thixomolding<sup>(2)</sup>. All three require a special, "globular" microstructure at the semi-solid casting temperature, consisting of globular solid particles surrounded by a matrix of liquid. The processes generally differ in the manner in which this globular semi-solid structure is generated. With the thixocasting process, the globular microstructure is generated in pre-cast bars and slugs cut from the bars are re-heated into the semi-solid

temperature range. With rheocasting, the globular microstructure is usually developed adjacent to the casting machine as a liquid is cooled into the semi-solid temperature range. At least 20 different rheocasting processes are either under development or in commercial production around the world<sup>(2)</sup>. Thixomolding uses a machine similar in design to a plastic injection molding machine, but thixomolding can only be used for magnesium alloys.

Therefore, a decision had to be made whether to cast the impellers using thixocasting or rheocasting. Due to the stringent operating conditions for turbocharger impellers, it was decided that quality should be the main criterion for the choice of process. Campbell<sup>(3)</sup> has developed one measure of the quality capability of a casting process by proposing ten casting rules that are required for the production of reliable castings, and suggests that these rules should be used along with conventional technical specifications such as alloy composition, casting temperature, strength requirements, etc. For castings produced by semi-solid processes, however, the rules need to be applied not only to the die filling process, but also during the generation of the globular microstructure in the feed material. Campbell's rules, as applied to semi-solid castings, can be summarized as follows:

- Good quality melt
- Prevent liquid and semi-solid front damage, including no fall requirement
- No stopping of the semi-solid metal front during die filling
- Prevent bubble damage
- Avoid outgassing from lubricants used in the casting mold
- Minimize shrinkage porosity
- Avoid convection damage
- Minimize segregation
- Minimize residual stresses
- Provide location points

A well designed thixocast component can meet all of these rules, and therefore has the capability to produce an extremely high quality casting. Most rheocasting processes, however, violate the second rule relating to liquid metal damage. For example, most rheocasting processes pour the liquid metal into some kind of container, where the liquid is cooled into the semi-solid temperature range. Pouring violates the “no fall requirement” and has the potential to entrap gases and oxides. In addition, many rheocasting processes treat the liquid metal in a turbulent manner during the generation of the globular semi-solid slurry, again with the possibility of entrapping gases and oxides into the semi-solid slug. Therefore, thixocasting was chosen for the production of the semi-solid cast impellers.

## SEMI-SOLID CAST IMPELLERS

This section provides information about the processing used to semi-solid cast the impellers. [Figure 3](#) shows a schematic of the thixocasting process.

<[figure 3](#) here>

The feed material for the thixocasting process is produced using a six-strand, horizontal dc casting unit. Magnetohydrodynamic (MHD) stirring is used on each strand to prevent the formation of dendrites, instead producing the globular structure required for semi-solid casting. Although generation of the globular microstructure involves vigorous stirring, this stirring is performed well below the surface of the melt, and so the stirring does not entrap air and oxides into the metal (and does not violate Campbell's rules).

Slugs of the appropriate size are cut from the MHD cast bars. A carousel-style induction heater ([Figure 4](#)) is used to re-heat the slugs to the semi-solid temperature range. The heater incorporates a series of solenoid-wound induction heating coils connected in series, has 24 pedestals and operates at a frequency of approximately 1,000 Hz. Each slug stands on a ceramic pedestal and indexes through the coils, until at the last position the slug is at a temperature and liquid fraction suitable for semi-solid casting. Total heating time is approximately 10 minutes. The temperature of each slug is measured and recorded using a type-K thermocouple, and any slug outside the required temperature range of 569-578°C is discarded.



*Figure 4. Carousel induction heater for billet re-heating*

Once the slugs are at the appropriate temperature, they are transferred to the shot sleeve of a horizontal die casting machine. A real-time controlled Buhler die casting machine is used to cast the impellers. The machine utilizes an