

## Investment Casting of Superalloys

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The investment casting or 'lost-wax' process is used for the production of superalloy components of complex shape, e.g. turbine blading or nozzle guide vanes. For parts of complicated shape with complex internal cooling passages, machining from a solid block is not an option. Moreover, the use of a casting means that thermal-mechanical working is not required - this can be difficult for the superalloys since the working temperatures required are often so high that incipient melting becomes a risk. The disadvantage of using a casting route is that lengthy heat-treatments are required to eliminate the micro-segregation induced by casting.

The following steps are employed. First, a wax model of the casting is prepared by injecting molten wax into a metallic 'master' mould -- if necessary (for hollow blades) by allowing wax to set around a ceramic core, which is a replica of the cooling passages required. These are arranged in clusters connected by wax replicas of runners and risers; this enables several blades to be produced in a single casting. Next, an investment shell is produced by dipping the model into ceramic slurries consisting of binding agents and mixtures of alumina, silica and zircon, followed by stuccoing with larger particles of these same materials. This operation is usually repeated 3-4 times until the shell thickness is adequate. Finally, the mould is baked to build up its strength. The first step involves a temperature just sufficient to melt out the wax - usually a steam autoclave is used. Further steps at higher temperature are employed to fire the ceramic mould. After preheating and degassing, the mould is ready to receive the molten superalloy, which is poured under vacuum at a superheat of 1500°C. After solidification is complete, the investment shell is removed and the internal ceramic core leached out by chemical means, using a high pressure autoclave. It is clear from this description that many steps are required. Fortunately, in most modern foundries considerable amounts of automation have been introduced.

When investment casting was first applied to the production of turbine blading, equiaxed castings were produced by the 'power down' method which involved the switching off of the furnace after pouring of the molten metal. However, it has been found that the creep properties are improved markedly if the process of directional solidification is used. After pouring, the casting is withdrawn at a controlled rate from the furnace - as in the conventional Bridgman crystal-growing method. A speed of a few inches per hour is typical - so that the solid/liquid interface progresses gradually along the casting beginning at its base. This has the effect of producing large, columnar grains which are elongated in the direction of withdrawal, so that transverse grain boundaries are absent. In a variant of this process, the grain boundaries are removed entirely - so that a casting is produced in single crystal form. Most typically, this is done by adding a 'grain selector' to the very base of the wax mould, typically in the form of a pig-tail shaped spiral; since this is not significantly larger in cross-section than the grain size, only a single grain enters the cavity of the casting, which is then in monocrystalline form. Alternatively, a seed can be introduced at the base of the casting; provided the processing conditions are chosen such that this is not remelted, growth occurs with an orientation consistent with that of the seed.

With this technology, it has proven possible to cast turbine blade aerofoils with complicated patterns of cooling channels. Over time, significant improvements have been made to the cooling configurations. For example, the early cast equiaxed HP blades introduced in the 1970's had single pass cooling configurations. The air had a relatively short path inside the blade before being exhausted, which limited its potential to absorb heat through contact with the metal; this was despite the incorporation of extensive numbers of film cooling holes which are typically drilled using Nd-YAG lasers. The latest generation blades use a multi-pass or 'serpentine' configuration in which the flow passes through longer passages before being exhausted. This maximizes the heat pick-up of the cooling air, enabling increases to the main stream gas temperatures and reductions in the required cooling flow. These improvements in cooling technologies have allowed the turbine entry temperature of a typical large turbofan engine to be increased by about 250°C with associated improvements in engine efficiency.

Superalloy melting processes are continuously being developed and refined. For example, the electron beam cold hearth refining process shows promise for the production of 'superclean' superalloys for aerospace grades. In the field of investment casting, new types of ceramic shell are being developed which will make the process cheaper and reduce the eventuality of casting defects.

For further information, try 'Investment Casting', P.R. Beeley and R.F. Smart (editors), The Institute of Materials, London, (1995).