Formulation of Enhanced Ceramic Shell Moulds for Investment Casting

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Single crystal turbine components are an integral part of a gas turbine engine and achieve increased thermal efficiency of the jet engine by being able to operate at higher working temperatures. These single crystal (SX) turbine blades have complex geometries and are produced from an investment casting process[1] which creates components of high dimensional accuracy and near-net shape geometries.

In investment casting, a ceramic core used to define the internal cooling passages is placed into a die and wax injected to create a sacrificial replica or pattern of the turbine blade. An assembly of several patterns is dipped into a slurry, composed of fine mesh refractory filler and colloidal binder systems, then sprinkled with coarse refractory stucco and dried to form a shell coat. A ceramic shell mould is created by adding subsequent layers of the fine refractory material and stucco to give a shell mould of sufficient thickness (figure 1). Once built the expendable wax is removed typically by steam autoclave to leave a hollow shell, which is fired and then filled with molten metal under vacuum. Finally removal of the ceramic shell after casting is achieved by mechanical and chemical methods to obtain the components.

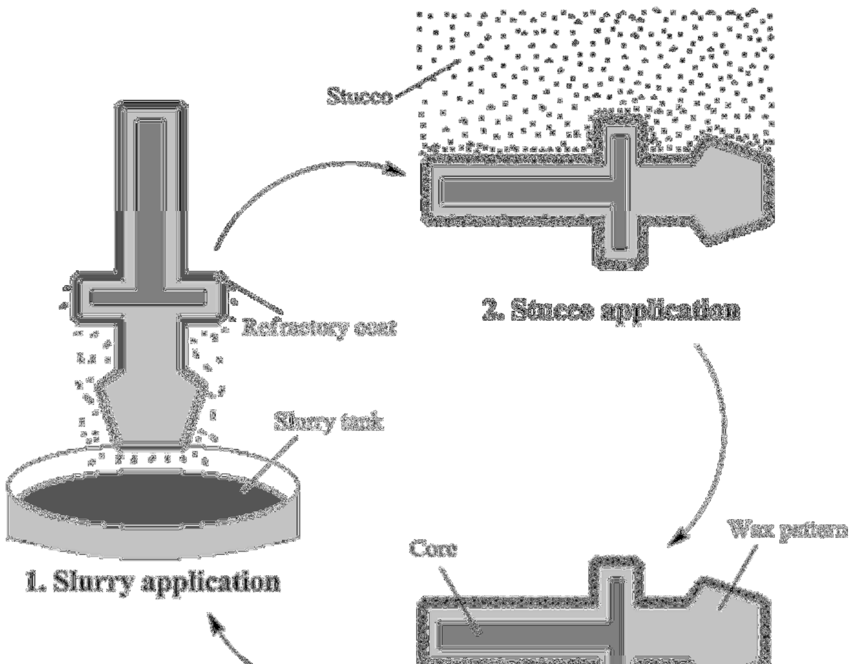

Figure 1 - Process of forming a ceramic shell mould by the cycle of adding refractory coats; through application of slurry and stucco followed by drying each coat.

Construction of the shell mould is a crucial part of the investment casting process and its thermo-mechanical properties define the quality of the cast blades and whether any dimensional/metallurgical defects are present. Non-conforming SX blades caused by strain-induced recrystallisation (RX) and high angle boundaries

(HAB) are scrapped at great cost. Therefore the demand to produce defect free SX turbine blades and reduce manufacturing costs has led to improve current casting quality by optimisation of mechanical and physical properties of the ceramic shell mould.

The ceramic slurry is composed of a binder system, refractory filler and additives, with there being three types of slurry systems used to coat the assembly and form the shell mould. A primary coat slurry which is inert to liquid metal and used to give a smooth surface finish, a primary +1 coat which fills any gaps left by the prime coat, and several back-up coats which build shell thickness and strength. A current back-up slurry system uses zirconium silicate (zircon) as the filler which is a naturally occurring mineral with impurities and is subject to property variation and supply cost fluctuations. Zircon is also an environmental concern with potential changes in UK legislation for zircon-containing shell waste disposal (due to zircon containing radioactive traces) and so subsequent increase in landfill costs. Another back-up system uses mullite and nylon-fibres rather than zircon as the filler to give greater shell strength prior to casting but this also makes the shell too strong for certain components, forcing RX defects.

The aim of this project is to formulate an enhanced shell mould system for the casting of SX blades, which is compatible with existing primary slurry formulations and uses synthetic raw materials of consistent quality. The following research objectives are to:

1) Benchmark thermo-mechanical properties of existing shell systems and develop a baseline for new shell systems to reduce the level of RX defects.
   - Develop high temperature compressive strength and creep behaviour tests on new systems.

2) Substitute the use of non-engineered materials (zircon) to remove the risk of long term material issues.
   - Perform a literature/supplier review of alternate filler materials.
   - Investigate the use of alumina, alumino-silicate and composite systems.

3) Carry out casting trials of chosen high temperature strength/creep resistant materials.
   - Develop understanding of shell material properties on cast performance.
   - Select material formulations for targeted high temperature strength/creep properties based on cast trial feedback.

1. Pattnaik, S., D.B. Karunakar, and P.K. Jha, *Developments in investment casting process - A review.* Journal of Materials Processing Technology, 2012(212): p. 2332 - 2348.