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Original Research Article

Analysis of temperature distribution in shell mould during thin-wall superalloy casting and its effect on the resultant microstructure

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ABSTRACT

This work focuses on the influence of temperature distribution in a shell mould during investment casting of thin wall parts on macrostructure, chemical composition of microstructural constituents and γ/γ' misfit parameter. A reduction of production costs is associated with the optimization of precision casting technology of aircraft engine critical parts, including control of the solidification front in thin-walled castings of nickel superalloys.

Appropriate lost-wax casting parameters lead to the creation of coarse grained structure, desired for high-temperature service applications. As a result of non-equilibrium solidification, substantially large chemical inhomogeneities in the dendrite core and interdendritic spaces are formed. Interdendritic spaces are occupied by constituents formed as a consequence of segregation of alloying elements, namely eutectic islands γ/γ', borides, carbides, and an intermetallic compound of Ni and Zr. Dendrite cores consist of cubic-shaped γ' precipitates surrounded by Ni-rich γ channels. Low lattice misfit influences cubic morphology of γ' precipitates, which is favourable for jet engine application because it can guarantee good creep resistance.

1. Introduction

Precipitation strengthened nickel-based alloys called also superalloys are widely used in the aerospace industry as components in the hot section of engines. Today, the construction of aircraft engines without the use of materials from this group is impossible, as evidenced by the fact that nearly half of the mass of currently produced units are nickel alloys [1,2]. One of the representatives of this group is Inconel 713C, precipitation strengthened by the γ' intermetallic phase. This alloy is extensively use in the aerospace, but also in the energy and oil & gas industries due to its unique combination of high strength at service temperature, excellent oxidation and hot corrosion resistance. This exceptional set of mechani-

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cal properties originates from many alloying elements like Nb, Al and Cr that create a solid solution and precipitation strengthening, and also the creation of protective layer of oxides on the inner surface. Normally, nickel superalloys, after the casting process, are subjected to heat treatment (solution + ageing), however Inconel 713C achieves high properties directly after casting i.e. in the "as cast" condition [3,4]. Optimization of the casting process is therefore crucial to achieving much higher mechanical properties than in previously produced parts. Investment casting, also known as lost-wax casting, is the only commercially used technique for fabrication of turbine blades and vanes which are one of the most important structural components of jet engines [5,6]. Manufacturing of such complex components is always a great challenge. Increased efficiency of engines can be obtained with new more complex geometry and thinner walls. Innovations, however, are impeded by the complexity of the fabrication process, which leads to an increasing amount of metallurgical discontinuities. These parts have to fulfill strict quality requirements in order to withstand high mechanical loads at temperature even up to 1050 °C for several thousand hours [7,8]. One of the most important steps in the investment casting process is shell fabrication, because, during the solidification, the interfacial heat transfer between the metal and the shell mould is ones of the most important factors that influence the microstructure and strength of resulting casting product [9]. Example of the geometry which is usually chosen to produce testing plates for microstructural and thermal analysis is H-type gating system like in Fig. 1.

One of the basic technological problems is cracking and deformation of ceramic mould at high temperature, whereas the main influence is the type of material that is used and the shape of mould. Results of the research will allow determining the precise effect of the ceramic layers thickness (the number of layers) on the temperature distribution in the shell mould during preheating, as well as during the pouring and solidification of nickel-based superalloy thin-walled casting. These data are necessary to determine the influence of the geometrical characteristic of the mould on temperature distribution, hence, also on the solidification process. Obtained results will also be helpful to determine the correct preheating time of the mould. This knowledge will contribute to a substantial reduction of the cost of manufacturing of casting, not just in the aviation industry, but also other castings of machine components.

There is still is a lack of information about influence of shell mould design, the temperature distribution in moulds and casting parameters on the microstructure of equiaxed Ni-based superalloys. Scientific papers focus on cracking during welding, the influence of pouring temperature on microstructure and degradation during creep but reports about the relation of temperature distribution in shell moulds to microstructure is still rare [10,11]. The aim of work was to investigate the influence of temperature distribution in a shell mould during investment casting on microstructure and misfit γ/γ' parameter of Inconel 713C superalloy.

2. Experimental procedure

The Inconel 713C nickel superalloy was used as the experimental casting and the gating system. The material was provided by Canon Muskegon Company. Result of chemical composition analysis obtained by optical emission spectroscopy (OES) is presented in Table 1. The mould was prepared in the Investment Casting division of CPP Corp. and all

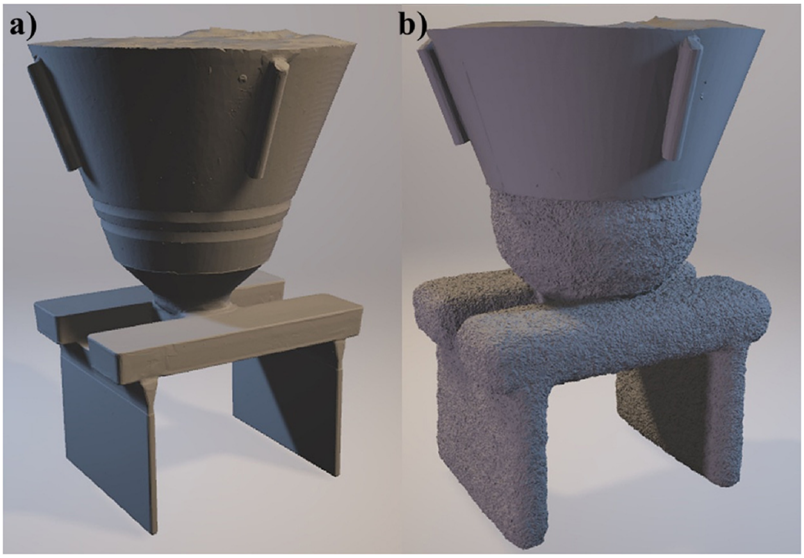

Fig. 1 – Geometry of wax model: (a) before; (b) after coating.

Table 1 – Chemical composition of Inconel 713C.

Element	Cr	Al	Mo	Nb	Ti	C	Zr	Co	B	S	P	Ni
wt.%	14.24	5.93	4.29	2.45	0.92	0.11	0.08	0.04	0.012	0.003	0.004	Bal.