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Numerical Simulation of CM247SX Single Crystal High Pressure Turbine Vane

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Abstract

Numerical simulation of single crystal high pressure turbine vane is carried out with an objective to investigate the effects of process parameters such as (i) process temperature, (ii) mould withdrawal rate, on thermal profiles, mushy zone, cooling rate and temperature gradient of the casting. The grain structure modelling is performed by Cellular Automation Finite Element (CAFE) module of the commercial finite element based software. Scanning electron microscopy of the experimentally cast single crystal vane is characterized. The simulation studies have shown that the increased process temperature and mold withdrawal rate led to increased temperature gradient and cooling rate of the vane. Conditions for the formation of undesirable stray grains is determined.

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Keywords:numerical simulation, single crystal, turbine vane, superalloy, investment casting.

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1. Introduction

Nickel based super alloys are extensively used for turbine blades, vanes, disks and other engine components at elevated temperatures due to their excellent creep strength and oxidation resistance [1,2].Solidification rate (V) and temperature gradient (G) for a given composition of super alloy will determine whether a solid/liquid interface can adopt cellular or planar or dendritic shape during directional solidification. Directional solidification process is employed frequently for blades used in gas turbine engines [3,4] as the columnar grain structure is made to align parallel to the major stress axes.Single crystal turbine blades and vanes have the advantage of being able to operate at a much higher temperature than polycrystalline turbine blades. Given the ability to increase turbine efficiency with higher temperatures, the development of these blades and vanes is crucial. Creep is a common cause of failure in turbine vanes and blades thus the life limiting factor [5] When temperatures of a material under high stress are raised to a critical point, the creep rate quickly increases. [6]. Creep and intergranular fracture due to weak boundaries at elevated temperature are the contributing factors for part failure [7]. The single crystal structure has the ability to withstand creep at higher temperatures than polycrystalline turbine blades or vanes due to the absence of grain boundaries.

During the past one decade analytical models with accurate simulation capabilities have emerged and contributed in enhancing better understanding of solidification process that enabled prediction of grain structure [8]. Vacuum induction investment casting is a technique for manufacture of single crystal turbine blades and vanes. The process requires ceramic molds to withstand temperature as high as 1773K for at least an hour of duration. This puts a demand for high premium ceramic moulds and cores. Outcome of the process depends on geometry and process related parameters. Size and geometry of furnace are often decided based on productivity requirements. Processing temperature, mould withdrawal rate, orientation, insulation schemes, grain selector can be varied in order to optimize the process to achieve defect-free castings with desired microstructure. Optimization of the casting parameters based on trial-and-error experimental methods and evaluation for achieving desired properties and microstructure often turned out to be time consuming and expensive. Finite element method based computational techniques on coupled solidification, heat flow, fluid flow, microstructural development and mechanical properties provide cost effective solutions and enhances the understanding of the process to a new higher level. Objective of this research is numerically simulate vacuum investment single crystal high pressure turbine vane to investigate the effects of process temperature, withdrawal rate, mould size, orientation on thermal gradient, cooling rate, temperature profiles and grain structure, using a finite element based software with cellular automation finite element program.

2. Methodology and materials

Vacuum investment cast Single crystal high pressure turbine (HPT) vane with internal core has been modelled using a finite element method based software. The methodology essentially consisted of the following steps: (i) geometric modelling, (ii) meshing and repair, (iii) applying boundary and initial conditions, (iv) solving numerically and (v) experimentally vacuum investment casting HPT vane.

2.1 Geometrical model

The model consists of two parts namely vane outer profile and core. Geometrical representation of the vane, core, sprue, pouring cup, chill plate are shown in Figure 1. A chill plate of size 200 mm diameter was employed. The geometrical model of furnace is shown Figure 2. The model exhibited three-fold rotational symmetry as it included three vanes, hence one-third portion of the model was constructed. The models were then exported in “iges” format in two parts, one part consisted of the cast, components and other consisted of furnace components. The iges file was loaded into intermediate software named “Geomesh environment” for inspection and correction of errors. The corrected model was exported with “.gmrst” extension.