Journal of Alloys and Compounds 657 (2016) 341–347

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

The process analysis of seeding-grain selection and its effect on stray grain and orientation control

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A R T I C L E I N F O

Article history:
Received 3 August 2015
Received in revised form
27 September 2015
Accepted 28 September 2015
Available online xxx

Keywords:
High temperature alloys
Crystal growth
Microstructure
EBSD

A B S T R A C T

A combined technique denoted as seeding-grain selection (SGS) was designed for fabricating single crystal turbine blades. The microstructural evaluation during SGS process was metallographically analyzed in both starter section and spiral section of this technique. Four zones with distinct dendritic morphologies were identified in seed melt back region. After epitaxial propagating from melted seed and branching through the spiral passage, the lined-up dendritic pattern was observed at the outlet of the passage. The effectiveness of the technique on stray grain and orientation control was also assessed by Electron Back-Scattering Diffraction (EDSD) technique. The results indicated that the technique can control stray grain with no detrimental effect on crystal orientation.

1. Introduction

Nickel-base superalloys are widely used in aircraft and power-generation turbine engines in single crystal (SX) form cast by directional solidification [1–5]. The primary aims of producing SXs are to eliminate grain boundaries that limit creep ductility [2,6–8] and to orient the elastically soft [001] orientation parallel to the maximum load to minimize cyclic stresses during thermal cycling [9–11].

There are two prevalent techniques for fabricating SX blades with main difference in the origin of the SX structure. Grain selection technique is based on the process of competitive growth of one grain from a set of columnar grains to form final axial [001] texture. This SX selecting process is realized in a grain selector featuring with a starter block assembling with a spiral passage [12–18]. The advantages of this technique are that it provides castings with quite perfect SXs and it is convenient to implement. However, the disadvantages of low accuracy of the [001] orientation to stress axis and incapable of obtaining other specific orientations than [001] render the technique impossible to use in the circumstances where accurate orientation is strictly required for property assurance [9,11] and other orientations are required for special purpose. Seeding technique is then introduced in these scenarios [19–22] by using specially orientated seed at the bottom of the mold to transfer the orientation to newly propagated dendrites during directional solidification process. Stray grain occurred due to sharply changed thermal conditions in melt-back region, however, narrows the process window of the technique to low withdrawal rates level [23–26].

Therefore, in present work a combined seeding-grain selection (SGS) technique was designed and utilized to fabricate SX turbine blades. The metallographical analysis was conducted to investigate the structural evolution process. Also, the effectiveness of the technique on stray grain control and orientation assurance was also assessed.

2. Experimental

2.1. Coordinate system and geometry of spiral grain selector

The coordinate system defined by using a simplified turbine blade with a platform (Fig. 1 (a)) can be seen in front-view (Fig. 1(b)) and top-view (Fig. 1(c)). The origin of coordinate locates in the centre of platform base with X axis parallel to the left-right edge of platform, Y axis parallel to the bottom-up edge of platform and Z normal to platform. θ_1 is defined as the deviation angle of [001] to Z axis, while θ_2 is defined as the deviation angle of [100] (or its projection) to X axis. θ_1 and θ_2 was then used in characterization of relative orientation of seeds in SGS technique. In order to investigate the processes of SGS technique, a spiral grain selector with

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http://dx.doi.org/10.1016/j.jallcom.2015.09.249
0925-8388/© 2015 Published by Elsevier B.V.

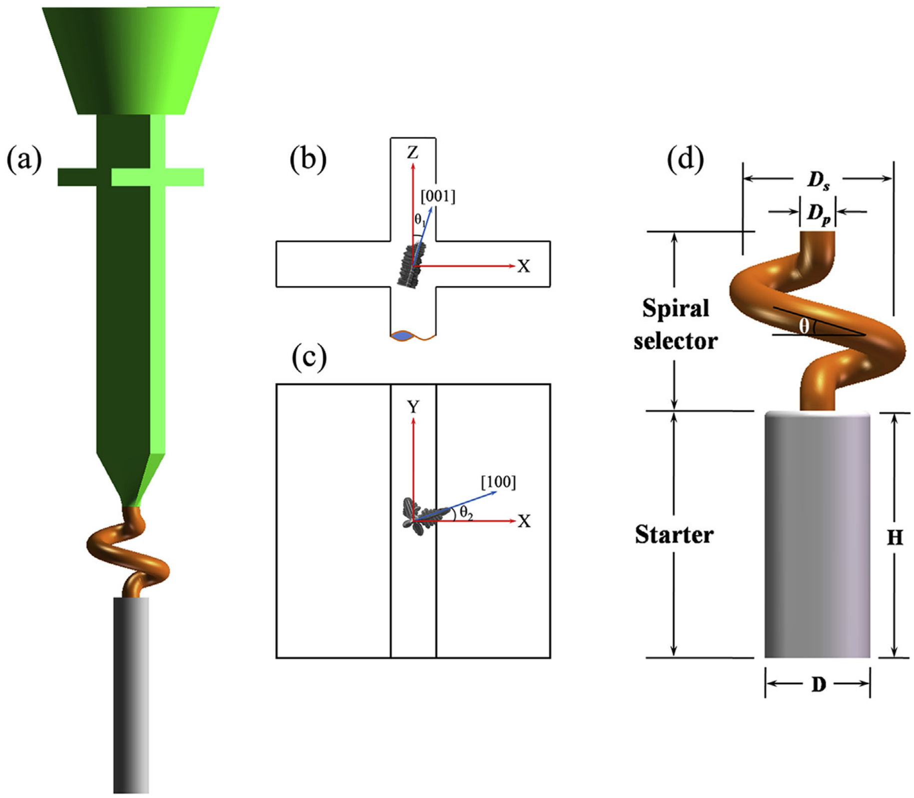

Fig. 1. Schematic illustration of blade assembly with spiral grain selector (a), defined θ_1,θ_2 corresponding to coordinate system(b), (c) and geometry of spiral grain selector (d).

geometry shown in Fig. 1(c) was used with all key parameters being listed in Table 1.

2.2. Molds and seeds preparation

Each components of the casting was prepared by injecting molten wax into corresponding mold. These wax components were then assembled to the entire casting as shown in Fig. 1(a). The assemblies were then coated with ceramic slurry consisting of a binder and filler material (80% alumina and 20% silica) with additions of wetting and antifoaming agents to improve slurry rheology. Then the surface was stuccoed with coarse ceramic grit to adhere to the wet coating and harden it. To build up the shell thickness, six layers were successively built, including the primary coating, and 2-h intervals were used to dry every successive layer. After the shell was constructed, the molds were then dewaxed in a steam autoclave, and subsequently fired at a temperature of 800 °C to partially sinter the ceramic shell. Finally, the shell mold was then mounted on a water-cooled copper chill in the center of the furnace chamber, as shown in Fig. 2.

Seeds used in SGS were pre-fabricated by traditional spiral grain selection technique. The pre-fabricated single crystal rod was then cut into ϕ12 mm × 40 mm cylinders with desired orientation. The seeds were pluged into the mold from the bottom openning, and adjusted until the expected relative orientation of seeds to coordinate system satisfied (Table 2). The seeds were then fixed in mold.

Table 1
Geometries of spiral seeding grain selector.

Parameters	D (mm)	H (mm)	D_S (mm)	D_P (mm)	θ (deg)
SGS	12	55	22	5	23

2.3. Experimental procedure

The material used in this study was the first generation SX Ni-base superalloy DD403. The chemical composition of DD403 is listed in Table 3. The SX castings were prepared using a modified Bridgman directional casting furnace. It owns the capability for solidification in the conventional Bridgman mode or LMC mode with use of liquid metal as cooling medium. The main chamber of the single crystal growth system is showed in Fig. 2 that it consists of a vacuum-induction melting unit, a thermal retardation unit, and a cooling zone. The furnace is capable of casting 2 kg of Ni-base superalloy into 250 mm tall molds on a 75 mm diameter chill plate.

During the process of directional solidification, the furnace chamber was evacuated to a partial pressure of approximately 10^{-3} bar. The ceramic mold with seed prefixed at the bottom firstly mounted on a water-cooled copper chill plate was then preheated to 1550 °C by graphite heating elements. After the ingot was melted, the liquid melt was poured into the preheated mold cavity at 1500 °C and held for 10 min to stabilize. Finally, the ceramic mold was withdrawn from the furnace at a pre-determined withdrawal rate of 100 μm/s.

2.4. Microscopy

Following directional solidification, the residual mold was removed from casting body. The casting was thereafter cleared and macro-etched for macroscopically inspecting solidification defects. Macro-etching was conducted by submerging the casting into a