Investigation on Orientation Control of Single Crystal Blades Through a Using of Heterogeneous Seeds

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Abstract: As the increasing demand for high temperature performance of the Ni-based single crystal blades, the orientation consistency of the blades has become more and more important. In this work, Ni-W heterogeneous seed was used to prepare the Ni-based single crystal superalloys and the microstructure at remelting interface under different conditions was analyzed. The results showed that lots of fine cellular grains with the basically consistent orientations and compositions were existed in front of the remelting interface under the high-rate solidification (HRS) method, while was not happened under the liquid metal cooling (LMC) condition. Based on the calculation of the constitutional undercooling, it was proved that the HRS method with a small temperature gradient could produce an enough constitutional undercooling at the front of remelting interface to form fine cellular grains. At last, using the heterogeneous seeds, four single crystal blades with the same three-dimensional orientation were successfully produced, which fully improved the preparation efficiencies and orientation quality of the blades, proving the possibility of industrial application for heterogeneous seeds.

Keywords: Directional solidification; Single crystal; Orientation control; Seeds method

1 Introduction

Ni-based single crystal superalloys have been widely used in aero engine and turbine blades due to their excellent mechanical properties, creep and fatigue resistance [1]. However, with the increase of the aeroengine inlet temperature, Ni-based single crystal superalloys with random secondary orientation are no longer sufficient to meet the needs in some circumstances where the accurate orientation is strictly required for properties assurance [2].

However, traditional seeds have usually a complex alloying composition and a large crystallization temperature interval, therefore, it is difficult to avoid the heterogeneous nucleation of stray grains because of dendrite fragmentations in pasty zone. For this reason, Toloraiya and Azhazha et al. [3] found that Ni-W heterogeneous seed could obtain a completely cellular structure at a large withdraw rate and significantly reduced the formation of stray grains to improve the success rate of preparing single crystals. In addition, Zhao et al. [4] studied the planar-cell-dendritic instability transition at the remelting interface of Ni-W heterogeneous seeds and observed the existence of fusion zone. And then, Guo et al. [5] studied the formation mechanism of the fusion zone for Ni-W heterogeneous seed under the high-rate solidification (HRS) condition and found that Ni-W heterogeneous seed effectively avoided the formation of stray grains at remelting interface compared to traditional homogeneous seeds and lots of fine cellular grains were existed in front of the fusion zone.

Based on the investigations above, it can be seen that some important results have been achieved in the preparation of the single crystal blades by heterogeneous seeds. However, the researches above are mainly focused on the primary orientation control and the composition analysis on the remelting interface. The investigations on the three-dimensional orientation control, the microstructural evolution at the remelting interface, the preparation of the single crystal blades, are still severally lacking.

2 Experimental procedure

Material used in this work were first-generation single crystal superalloy DD3 and Ni-20 wt.% W alloy. All seeds were prepared by liquid metal cooling (LMC) directional solidification at 1550 °C and 10 $\mu m \cdot s^{-1}$ and were polished into a cylinder with a diameter of 7 mm and a height of 30 mm. All samples were cut parallelly and vertically from the seed axis, and were polished, etched with the solution of 50% H_2O, 25% HNO_3,25% HF. JXA-8100 and ZEIS SUPRA 55SEM equipped with Electron Probe Micro-analyzer (EPMA) and EBSD were used to observe the microstructures of the samples.

3 Result and discussion

When under the HRS and LMC condition, it was seen that lots of fine cellular grains competed with each other were present above the fusion zone under HRS condition (**Fig. 1a**), while these fine cellular grains were not observed under the LMC condition (**Fig. 1b**).

Aimed to understand the formation mechanism of these fine cellular grains, the constitutional undercooling was calculated as shown in **Table 1**. It was clear that when under the HRS condition, G/R was less than $\Delta T/D_{eff}$, showing a great constitutional undercooling existed in front of the remelting interface, while under the LMC condition, it was in contrast.

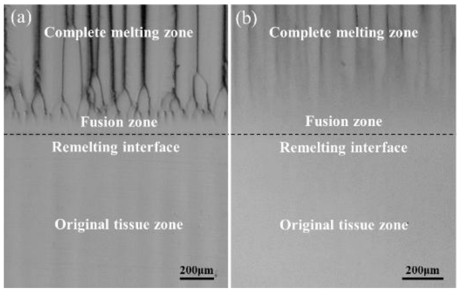

Fig. 1. Vertical microstructures of remelting interface prepared by HRS (a) and LMC (b) conditions.

Table 1. Constitutional undercooling under HRS and LMC methods

	G/R (k·s·m^{-2})	$\Delta T/D_{eff}$ (k·s·m^{-2})
HRS	2-6×10^{7}	174×10^{7}
LMC	>200×10^{7}	174×10^{7}

At last, a novel high-throughput mold capable of producing four single crystal blades via seeding-grain selection technique was designed. The mold structure and the casting process was simulated by the finite element analysis in the ProCAST software as shown in **Fig. 2**. It was clear that the 3D-orientation of the four blades were all controlled by one seed.

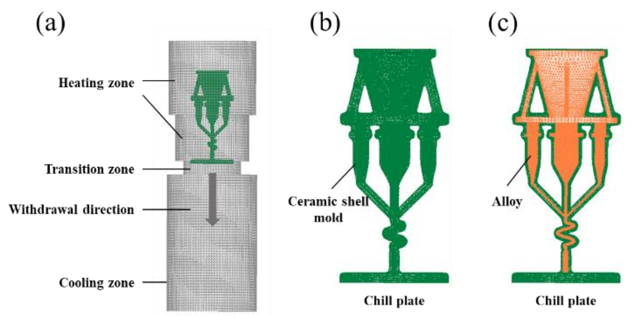

Fig. 2. Casting system (a), ceramic shell (b), and alloy (c) in the grid model.

Using this high-throughput mold, four single crystal blades with the same 3D orientation were successfully produced using this high-throughput mold via heterogeneous seed. There were no stray grains formed during the crystal growth, which fully proved the feasibility of the industrial application for heterogeneous seeds.

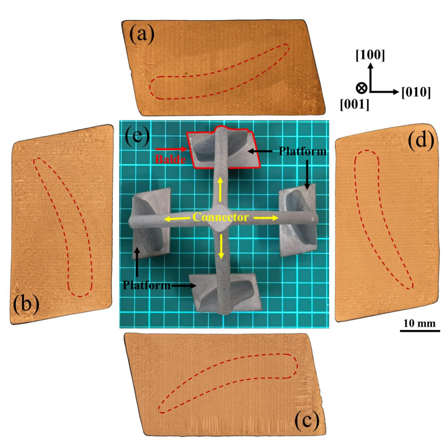

Fig. 3. The main structure of the casting (e) and the platform morphology (a)-(d).

4 Conclusion

1. The cause of the fine cellular grains which existed in front of the growth interface is verified as constitutional undercooling.

2. Four single crystal blades with the same 3D-orientation were successfully produced by one heterogeneous seed.

5 Acknowledgments

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References

[1] GL Erickson, K Harris, RE Schwer. Directionally Solidified and Single-Crystal Superalloys, Metals Han, ASM International, Ohio, 1990.
[2] N Matan, DC Cox, MA Rist, et al. Creep of CMSX-4 superalloy single crystals: effects of misorientation and temperature, Acta Mater 47 (1999) 1549-1563.
[3] VM Azhazha, VY Sverdlov, AN Ladygin, et al. Self-Organization Processes in the Cellular Structure Formation of Ni-W Alloys, J Surf Invest-X-Ray+ 2 (2008) 156-165.
[4] NR Zhao, JG Li, JL Liu et al. Solidification interface in growth of single crystal superalloys by seeding technique, J Mater Eng Perform 11 (2007) 24-27.
[5] J Guo, JG Li, JD Liu, et al. Formation Mechanism of Fusion Zone in Growth of Single Crystal Superalloys with Low-Segregated Heterogeneous Seed, Acta Metall Sin 54 (2018) 419-427.