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Simulation and Experimental study of Recrystallization Kinetics of Nickel Based Single Crystal Superalloys

Zhonglin Li, Qingyan Xu*, Baicheng Liu

School of Materials Science and Engineering, Key Laboratory for Advanced Materials Processing Technology, Ministry of Education, Tsinghua Unveristy, Beijing 100084, China

Abstract

Hot compression tests on cylinders using nickel-based single crystal superalloy DD6 were conducted to introduce the stored energy for recrystallization. Annealing was carried out at different temperatures for different time to investigate the kinetics of recrystallization of DD6. The experimental results show that the recrystallization rate increases gradually with temperature. The stress, strain and stored energy distribution of single crystal superalloy were modeled based one macroscopic phenomenon-based elastic-plastic model, considering the orthotropic properties of SX superalloys. Recrystallization microstructure on the cross-section perpendicular to the cylinder axis was simulated using cellular automaton (CA) method. The model can predict experimental results.

Keywords: single crystal, superalloys, recrystalliztion, kinetics, simulation

1. Introduction

Nowadays, single crystal superalloys have been used widely in the manufacture of turbine blades. The disadvantage is that the blades from single crystal superalloys become very more difficult to cast, and great care

* Corresponding author. Tel.: +86-10-62795482; fax: +86-10-62773637.
E-mail address: scjxqy@tsinghua.edu.cn

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should be taken to prevent defects such as freckles[1], recrystallization[2] and so on. Recrystallization can introduces high-angle grain boundaries and degrades the creep[3-5] and fatigue[6] properties significantly.

Recrystallization is intolerant in single crystal component, and can be ascribed to the plastic deformation during manufacturing process[7-8] which introduces high stored energy. Most of previous work on recrystallization of SX superalloys focuses on annealing conditions[2, 9-10], microstructural features[11] and mechanical properties. Xie et al.[12] investigated the orientational dependence of deformation and recrystallization in a Ni-based single crystal superalloy. Wang et al.[13] studied the effect of eutectics on the deformation and recrystallization behavior in SX superalloy CMSX-4. Their samples were deformed by indent.

Till now, a lot of simulation on recrystallization has been conducted[14-18], but most about aluminium, magnesium and steel. Little work has been done on simulation of recrystallization of SX nickel-based superalloys. One simulation on recrystallization of SX superalloys was reported by Zambaldi et al.[19] in 2007. However, the kinetics used in their CA model and simulated results didn't obviously conform to the reality. Besides, growth kinetics of recrystallization of SX superalloys has not been well researched and discussed. In this paper, a macroscopic phenomenon-based deformation model will be used to obtain the driving force for recrystallization. CA simulation of recrystallization will also be utilized to investigate the growth kinetics of recrystallization.

2. Experimental Procedure

2.1. Single-crystal Superalloy Materials

The second generation single-crystal superalloy DD6 in as-cast condition was used for the experiments. The composition is given in Table 1. The material exhibits a two-phase microstructure, revealing coherent and cuboidal γ'-precipitates are surrounded by γ-matrix. Dendritic morphology presents in as-cast microstructure of this material, fine and regular cubic gamma prime phase in dendritic core regions, coarse and irregular cubic gamma prime phase in interdendritic regions. Bulky eutectic structure appears in interdendritic regions.

Table 1. Nominal composition of alloy DD6

Element	*Ni*	*Cr*	*Co*	*Mo*	*W*	*Ta*	*Re*	*Nb*	*AL*	*Hf*
wt.%	Balance	4.3	9	2	8	7.5	2	0.5	5.6	0.1

2.2. Hot Compression

In this research, hot compression tests were chosen to obtain 10%~12% plastic strain, as a prerequisite for recrystallization in single crystal superalloys. Cylinder pieces of diameter 6 mm and length 10mm was cut using Electrical Discharge Machining (EDM) from as-cast test bars of SX DD6 of diameter 15 mm and length 300 mm. Compressive testing was carried out by Gleeble1500D (thermal physical simulator) at 980 ºC at a strain rate of 3×10-3 s-1. Great care was taken to ensure that only test pieces within 15° of <001> along the axis were employed for the compressive testing. The test pieces were heated by 15 ºC/s and held for 1 minute before compression.

2.3. Solution Heat Treatment

Every compression sample was cut into two same smaller cylinders using EDM, and tubed in silica glass under inert argon atmosphere to avoid oxidation. The samples were annealed at temperatures 1280 ºC, and cooling was done in air. The annealing times were 10min, 1h, 2h and 4h.

2.4. Electron Back Scatter Diffraction Observation

In order to investigate the grain structure evolution during recrystallization, the middle section face of cylinder pieces was ground to a 2000# finish and then electropolished using perchloric acid (90%) and dehydrated alcohol (10%) to provide a deformation-free flat surface in order to collect high-quality Kikuchi pattern maps used for grain