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Hot deformation behavior of delta-processed superalloy 718

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ABSTRACT

Flow stress behavior and microstructures during hot compression of delta-processed superalloy 718 at temperatures from 950 to 1100 °C with strain rates of 10^{-3} to $1\,s^{-1}$ were investigated by optical microscopy (OM), electron backscatter diffraction (EBSD) technique and transmission electron microscopy (TEM). The relationship between the peak stress and the deformation conditions can be expressed by a hyperbolic-sine type equation. The activation energy for the delta-processed superalloy 718 is determined to be 467 kJ/mol. The change of the dominant deformation mechanisms leads to the decrease of stress exponent and the increase of activation energy with increasing temperature. The dynamically recrystallized grain size is inversely proportional to the Zener–Hollomon (*Z*) parameter. It is found that the dissolution rate of δ phases under hot deformation conditions is much faster than that under static conditions. Dislocation, vacancy and curvature play important roles in the dissolution of δ phases. The main nucleation mechanisms of dynamic recrystallization (DRX) for the delta-processed superalloy 718 include the bulging of original grain boundaries and the δ phase stimulated DRX nucleation, which is closely related to the dissolution behavior of δ phases under certain deformation conditions.

1. Introduction

Nickel-based superalloy 718 is an age hardening alloy strengthened predominately by gamma double prime (γ''-Ni_3Nb) phases. At a certain temperature, metastable γ'' phases would transform to stable delta (δ) phases with orthorhombic ordered structure. Because of its good mechanical properties at elevated temperatures up to 650 °C, superalloy 718 has been widely used in the fabrication of critical parts for modern aeroengines [1]. With the development of aeronautical technology, some critical components in aeroengines, such as gas turbine disks exposed to relatively high stresses, require the materials with both high tensile strength and superior low-cycle fatigue property. Under the service conditions, the gas turbine disks manufactured by superalloy 718 easily suffer from the damage of high temperature low-cycle fatigue, which seriously influence the service life of the parts.

The properties of superalloy 718 are sensitive to the microstructure, especially to the grain size [2], which can be controlled by the thermomechanical processing. It has been shown that the presence of orthorhombic δ phase during hot working of superalloy 718 can avoid undesirable grain growth and favor achieving fine grains. Compared with conventional processing, a delta-processed superalloy 718 (DP718) technique, which an intentional δ phase precipitation cycle and subsequent thermomechanical processing are used, can provide more uniform fine grain billets [3]. Significant improvements in strength and low-cycle fatigue properties necessary for advanced gas turbine components are thus obtained.

In the past few decades, the hot deformation behavior of superalloy 718 has been extensively studied using hot torsion or hot compression experiments [4–9]. But the investigations concerning the DP718 technique have not been fully reported yet [10–12], and the researches about the hot deformation behavior of delta-processed superalloy 718 were still limited [13,14]. Moderate fraction of δ phase has been demonstrated to benefit the impact toughness and ductility as well as eliminate the gap sensitivity [15–17]. The δ phases distributed along grain boundaries can also provide resistance to creep fracture [18,19]. However, few investigations were reported about the dissolution behavior and morphology evolution of δ phases during hot deformation up to date [20]. In the present study, the uniaxial compression tests were performed on delta-processed superalloy 718 at various strain rates and temperatures. The dependence of flow behavior and microstructural evolution on deformation temperature and strain rate was established by introducing the Zener–Hollomon (*Z*) parameter. The evolution of δ phases during hot deformation as well as the mechanisms of dynamic recrystallization (DRX) for

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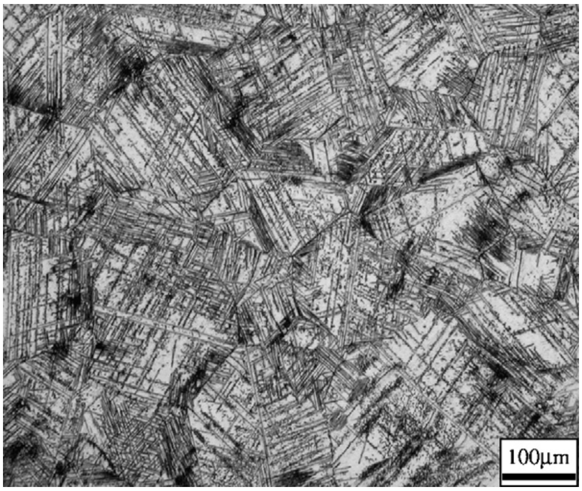

Fig. 1. Optical microstructure for the delta-processed superalloy 718.

delta-processed superalloy 718 was analyzed. The effect of δ phase on the hot deformation behavior of superalloy 718 was also discussed.

2. Experimental

The chemical compositions (wt.%) of superalloy 718 used in this investigation are as follows: Cr, 18.09; Fe, 17.69; Nb + Ta, 5.43; Mo, 3.07; Ti, 0.97; Al, 0.46; Co, 0.18; Si, 0.078; Mn, 0.065; Cu, 0.065; C, 0.040; $S < 0.001$; $P < 0.007$; Ni, balance. Cylindrical specimens for compression tests with diameters of 8 mm and heights of 12 mm were machined from an as-received wrought billet with a diameter of 252 mm. All the specimens were taken from the midradius of the billet in order to minimize the scatter of initial states. The specimens were first annealed at 1100 °C for 30 min, and then aged at 900 °C for 24 h, followed by water quenching. The initial microstructure of the aged alloy is shown in Fig. 1. There are a large amount of needle-shaped δ phases precipitated from the grain boundaries towards the center. The average grain size and the fraction of δ phases are measured to be about 180 μm and 12.8%, respectively.

Hot compression tests were conducted using a Gleeble-1500 thermomechanical simulator at temperatures from 950 to 1100 °C with strain rates from 10^{-3} to $1\,s^{-1}$. The specimens were heated to the deformation temperatures at a rate of 10 °C/s and then held for 2 min. Nominal strains of 0.03, 0.05, 0.1, 0.2, 0.3 and 0.5 were applied on the specimens, respectively. Each specimen was quenched immediately in water after deformation so as to preserve the deformed microstructures. The variation of true stress with true strain was obtained from the controlling computer equipped with an automatic data acquisition system.

The deformed specimens were sectioned parallel to the compression axis for microstructure analysis. After polished mechanically and etched electrolytically with a solution consisting of 13% HF, 7% HNO_3 and 80% HCl, the optical metallographic examination was performed on a Zeiss optical microscope equipped with an Automatic Structure Analysis Software. Electron backscatter diffraction (EBSD) measurements were carried out using a JEOL 733 electron probe equipped with Channel 5 software provided by HKL Technology. The samples for EBSD investigation were machined and polished electrolytically with 20% solution of H_2SO_4 in methanol. The foils for transmission electron microscopy (TEM) were prepared firstly by hand grinding to a thickness of 50 μm and then thinned using a twin-jet technique in the electrolyte of 10% solution of $HClO_4$ in ethanol. TEM examination was performed on a Philips TENCAI-20 microscope operated at 200 kV.

3. Results and discussion

3.1. Flow stress–strain behavior

True stress–true strain curves of the delta-processed superalloy 718 obtained at different temperatures from 950 to 1100 °C with various strain rates from 10^{-3} to $1\,s^{-1}$ are shown in Fig. 2. It can be seen that the flow stresses rapidly reach to a peak at low strains, then followed by slowly decreasing no matter the deformation conditions. Stable flow stresses are obtained at low strain rates and high temperatures. Such features of the flow curves for delta-processed

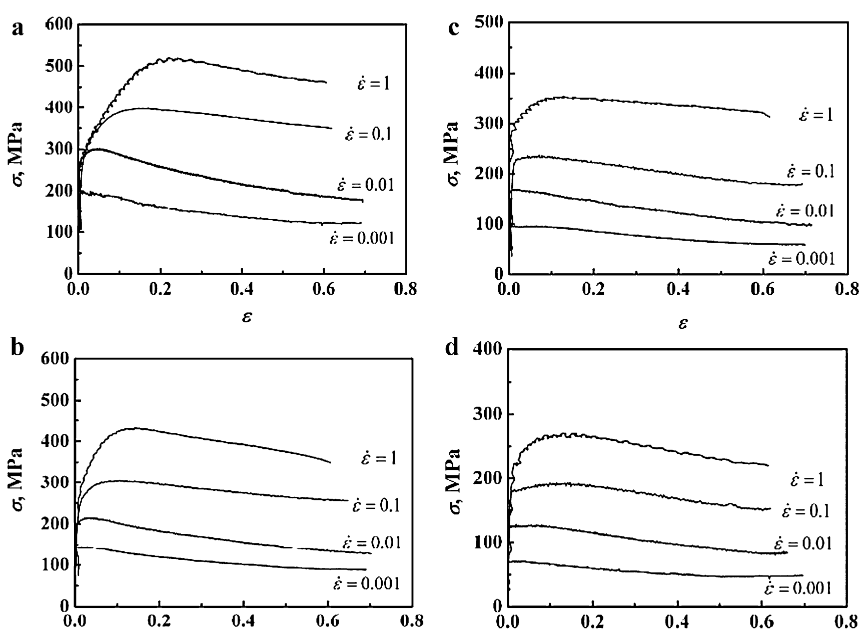

Fig. 2. True stress–strain curves for the delta-processed samples compressed at (a) 950 °C, (b) 1000 °C, (c) 1050 °C, (d) 1100 °C.