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ARTICLE

Effect of Deformation Process on Superplasticity of Inconel 718 Alloy

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Abstract: After grain refinement through hot-forging and δ-phase precipitation and recrystallization heat-treatment processes, the high temperature tensile experiments were carried out to investigate the effect of heat treatment and deformation process on the superplasticity of Inconel 718 alloy. Two tensile processes were used as follows: the maximum m value superplastic deformation method and the strain-reduced superplasticity deformation process based maximum m value method. The results indicate the fine and homogeneous grain structure of Inconel alloy is obtained by hot forging, δ phase precipitation and recrystallization heat treatment processes, and the δ phase can play a role in controlling grain size during recrystallization annealing and hot deformation. Upon stretching by the above two processes at 950 ºC, the percentage elongations of Inconel 718 alloy are improved from 340% and 566%, respectively. The results show that the higher value of percentage elongation can be obtained by the strain-induced superplastic deformation process based maximum m value method.

Key words: Inconel 718 alloy; superplasticity; deformation process

Inconel 718 alloy is an aged hardenable Ni-Cr-Fe based wrought superalloy. The metastable body centered tetragonal coherent precipitate γ'' (Ni_3Nb) phase and the face-centered cubic coherent precipitate γ' (Ni_3AlTi) phase are strengthening phases, and the γ'' phase is the major strengthening phase. The equilibrium phase corresponding to the γ'' phase is the orthorhombic incoherent δ (Ni_3Nb) phase[1,2]. Inconel 718 is an important material used for aero-engine turbine disks due to its high strength, plasticity and good fatigue resistance, corrosion resistance etc.

Inconel 718 alloy is a difficult-to-deformation material due to its great deformation resistance and narrow hot-working temperature range. The higher manufacturing cost and rejection rate of complex parts of the superalloy currently restrict its application. The study[3] found that Inconel 718 alloy also exhibits some superplasticity, which provides an access to the integral forming technology of complex parts of the alloy. The ultra-fine microstructure suitable for superplastic forming can be obtained by the special thermomechanical treatment process such as large deformation and heat treatment process[4,5]. As well known, it is difficult and costly to fine the grain of Inconel 718 alloy, which directly affects the extensive application of the superplastic forming technique in this alloy. Superplastic tensile deformation such as constant velocity or constant strain rate is the traditional experiment method used by most researchers. Lu Hongjun et al. [4] found that ultrafine-grained sheets of Inconel 718 alloy were obtained by higher cold-rolling reduction and annealing treatment. The maximum elongation of 368.2% was obtained in the alloy deformed at 940 ºC with an initial strain rate of 6.1×10^{-4} s^{-1}. Han Xue et al. [5] observed that the grains of Inconel 718 alloy were fined using hot deformation and multiple heat treatment, and an elongation of 467% was obtained in a tensile test at 1000 ºC and a strain rate of 1.14×10^{-4} s^{-1}. Mukhtarov et al. [6] found that nanocrystalline structure was formed in Inconel 718 bulk semi-products by multi-axis forging, and the elongation of 350% was obtained at 600 ºC under a strain rate of 1.5×10^{-4} s^{-1}. In addition to refining structure only, is there any new forming

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technique to improve the superplasticity of the alloy? The author and coworker investigated that the superplastic ability of some alloys can be improved using the maximum *m* value superplastic deformation method or the strain-reduced superplasticity deformation process based the maximum *m* value method，which has been evidenced in the previous experiments of titanium alloys[7,8]. In this paper, combined with hot deformation and heat treatment processes, the maximum *m* value superplastic deformation method and the strain-reduced superplasticity deformation process based the maximum *m* value method were adopted to investigate the superplasticity of Inconel 718 alloy.

1 Experiment

The material in this experiment was as-rolled Inconel 718 alloy bar, whose composition is (wt%) 53.51 Ni, 18.39Cr, 17.37Fe, 5.34Nb, 2.97Mo, 0.99Ti, 0.50Al, 0.35Co, 0.10Si, 0.05Mn, 0.024C, 0.02Ta, 0.008N, 0.006S, 0.004B, 0.001O, 0.0005S and 0.0008Mg. The original microstructure of the material is shown in Fig.1. Optical microstructure picture shows that the grain sizes are not uniform, and the average size of the grains is about 40 μm. Meanwhile twin crystal structure is visible distinctly.

The free forging process was carried out on Inconel 718 alloy bar with decreasing temperature from 1050 ºC to 950 ºC. The cylindrical billets were cut from the forgings, and heat-treated in box resistor-stoves. Based on the characteristics of Inconel 718 alloy, the microstructures can be controlled by *δ* phase precipitation and recrystallization heat-treatment. Given that the peak temperature of *δ* phase precipitation appears at 890~900 ºC and *δ* phase begins to dissolve at about 980 ℃, the precipitation treatment of *δ* phase and recrystallization heat-treatment are generally carried out at 890 and 950 ºC, respectively[9,10]. So the heat-treatment process used in this experiment included two processes as follows：890 ºC/10 h + 950 ºC/1 h + air cooling and 890 ºC/10 h + 950 ºC/3 h + air cooling.

The tensile specimens were machined from the cylindrical billets after heat treatment, as shown in Fig.2.

The tensile experiments of high temperature were conducted using the SANS-CMT 4104 electrical universal material testing machine equipped with a high temperature heating-furnace and a computer control system, by which dynamical measuring of the strain-rate sensitivity index and automatical adjusting deformation velocity were realized during the deformation.

The isothermal hot tensile tests of Inconel 718 alloy were carried out at 950, 980 and 1020 ºC. The maximum *m* value superplastic deformation method and the strain-reduced superplasticity deformation process based the maximum *m* value method were used during tensile deformation.

The maximum *m* value superplastic deformation method can be realized by means of real-time controlling deformation velocity based on dynamical measuring of *m* value to obtain a higher *m* value at any instant during the hot deformation. In general, the higher the *m* value is, the better the superplasticity of the materials is. The main parameters of the maximum *m* value superplastic deformation method were as follows: initial tensile velocity v_0 was 0.8 mm/min， increment value of the speed jump △*v* was 0.09 mm/min， and interval of the speed jump △*t* was 6 s.

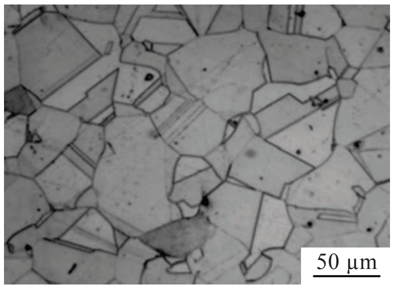

Fig.1 Original microstructure of Inconel 718 alloy

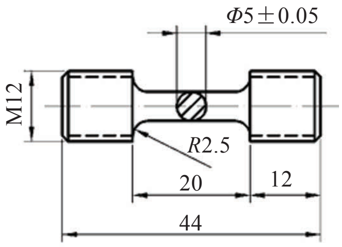

Fig.2 Dimension of tensile specimen

The basic principle of the strain-reduced superplasticity deformation process was that a certain degree of pre-strain was firstly applied to the materials followed by holding for a period of time to refine grains and soften materials by recovery and recrystallization, and then better plasticity may be obtained during the subsequent superplastic deformation. The main parameters of the strain-reduced superplasticity deformation process were as follows: tensile velocity of pre-strain *v* was 0.8 mm/min, pre-strain *ε* was 0.2, holding time after pre-strain *t* were 10, 20 and 30 min. After holding, the tensile deformation then was carried out immediately by the maximum *m* value superplastic deformation method.

2 Results and Discussion

2.1 Microstructures after forging and heat treatment

The microstructure of Inconel 718 alloy after forging is shown in Fig.3. The original grains have been broken and the grain boundaries aren't obvious. The intermetallic compound *δ* phase has been precipitated at the grain boundary and wherein short rod or granular structure appears, and