

THE EFFECT OF PRIMARY γ' DISTRIBUTION ON GRAIN GROWTH BEHAVIOR OF GH720LI ALLOY

Maicang Zhang, Jianxin Dong, Zhongnan Bi, Qiuying Yu
University of Science and Technology Beijing, Beijing, 100083, P R China
Yuchun Zhang
Northeastern Special Metals Co. (Group), Fushun, 113001, P R China

Keywords: GH720Li alloy, primary γ' distribution, grain growth

Abstract

In this paper, a series of hot compression tests were carried out under different hot deformation parameters, covering the temperature range of 1000°C to 1170°C, strain rate range of 0.01s⁻¹ to 1s⁻¹ and compression reduction of 30%, 50%, and 70%. After that, all specimens were heat treated under the standard heat treatment schedule of GH720Li to investigate its hot deformation characteristics, especially the grain growth behaviors. The further OM and SEM observations were adopted to investigate the interaction mechanism of the primary γ' distribution and grain growth for GH720Li alloy. The results show that for GH720Li alloy, when hot deformed below γ' solvus, the banded or bi-model structure always occurs; while hot deformed near or over γ' solvus, the uniform grain size distribution can be obtained. Further microstructure analysis shows that the bi-model or banded grain size distribution in GH720Li alloy is mainly due to the nonuniform re-dissolving of primary γ' during heating process; while the uniformity of primary γ' phase is determined by the uniformity of elements in this alloy. In other word, the homogenizing process for ingot is the key reason for later grain size control.

Introduction

GH720Li (UDIMET 720Li) is a high strength nickel-based superalloy being considered for applications for modern gas turbines and aero-engines. The chemical composition of this alloy is related to that of GH720 (UDIMET 720) from which it is derived, but differs from it with respect to the chromium, carbon and boron levels. Till now, a lot of studies [1-6] have been done for GH720Li alloy including the solutioning and precipitating of γ prime phase, the ingot to billet conversion process control, the heat treatment schedule optimizing, the mechanical behavior under service conditions, etc. However, the microstructure of GH720Li consists of primary, secondary and tertiary γ' due to its special heat treatment schedule. Primary γ' lies at the γ -grain boundaries and

prevents γ -grain growth by the action of Zener pinning. Obviously, when hot deformation is conducted below the γ' solvus, the characteristics of primary γ' may affect the microstructure evolution even the mechanical properties of GH720Li alloy to somewhat extent.

In this paper, a series of hot compression tests were carried out under different hot deformation parameters, covering the temperature range of 1000°C to 1170°C, strain rate range of 0.01s⁻¹ to 1s⁻¹ and compression reduction of 30%, 50%, and 70%. After that, all specimens were heat treated under the standard heat treatment schedule of GH720Li to investigate its hot deformation characteristics, especially the grain growth behaviors. Further OM and SEM observations were adopted to investigate the interaction mechanism of the primary γ' distribution and grain growth for GH720Li alloy based on the physical metallurgy theory, which may give great help to industrial grain size control of this alloy.

Experimental Procedures

The tested materials were cut from the billet bar of 90 mm in diameter manufactured by Northeastern Special Metals Co., China. The billet bar was hot forged from an original ingot of 180 mm in diameter melted by VIM and VAR processes and homogenizing at 1190°C for 24 hours. The chemical composition (wt,%) were as follows: C, 0.01; Cr, 16; Co, 15; Mo, 3; W, 1.25; Ti, 5.16; Al, 2.64; Mn, 0.02; Si, 0.04; Cu, 0.01; B, 0.015; Zr, 0.035; Fe, 0.11; S, 0.001; P, 0.005 and Ni bal.

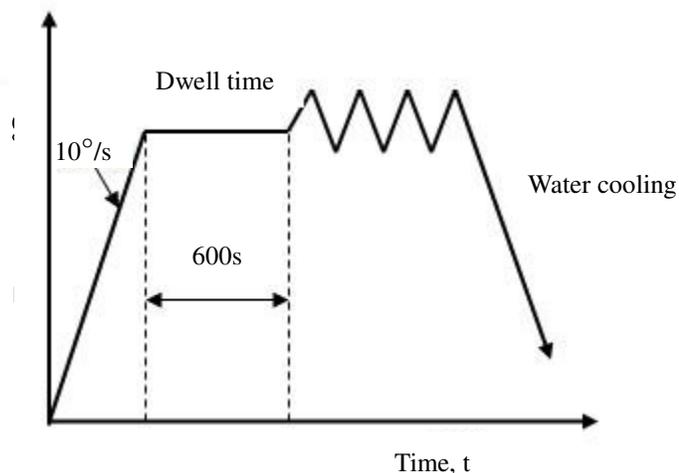


Fig. 1 heating scheme of experiments

The billet material was cut to specimens of 8 mm in diameter and 12 mm in height. Then all the specimens were heated to different temperatures and deformed at different

strain rate and different reductions by using hot working simulator GLEEBLE 1500D. The heating scheme (See Fig.1) and the hot working parameters are as follows: The deformation temperatures are from 1000 to 1170°C with the increase interval 30°; the deformation strain rate and compression reduction are 0.01 s⁻¹, 0.1 s⁻¹, 1 s⁻¹ and 30%, 50%, 70%, respectively.

After doing that, the as-forged specimens were all heat treated according to the following processing: 1110°C /4hrs, OC+650°/24hrs, AC+760°/16hrs, AC. Then all specimens were electro-polished and electro-etching. Finally, the OM and SEM equipments were used to evaluate the microstructure evolution, especially the grain size distribution.

Additionally, in order to study the solutioning and precipitating rate of γ' phase in GH720Li alloy, a portion of solution annealing tests were also conducted. The annealing temperatures are from 1150 to 1200° for 30 min with water cooling.

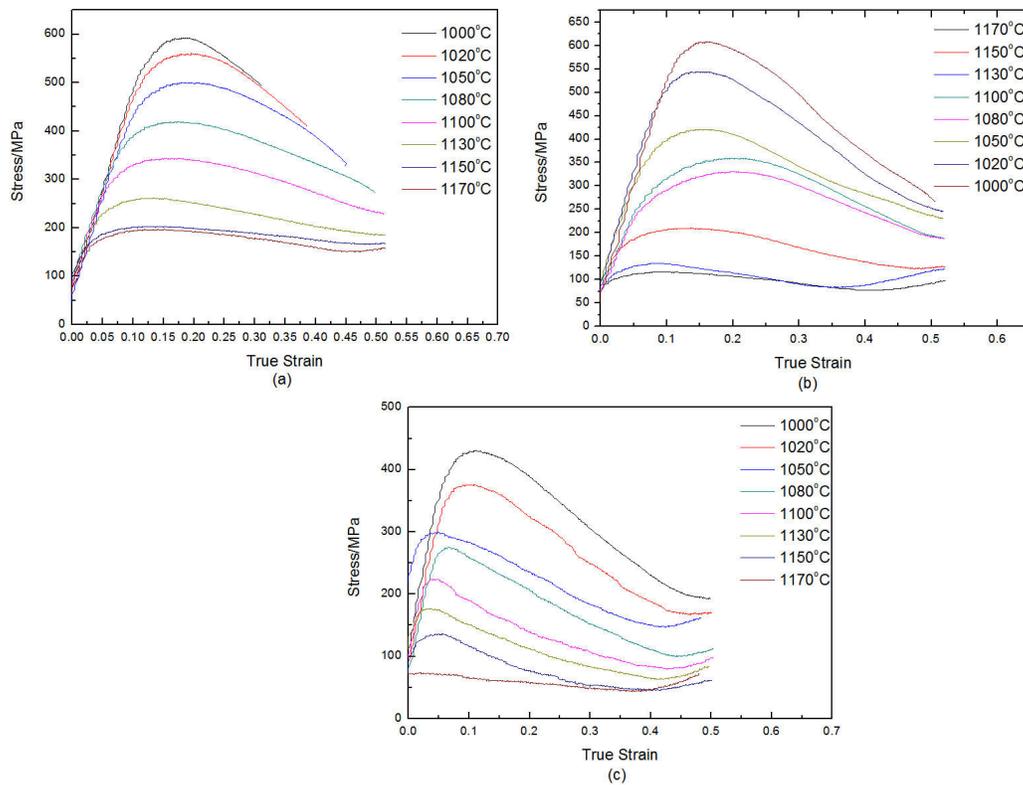


Fig.2 Hot deformation behaviors under different conditions

(a)0.01s⁻¹ (b) 0.1s⁻¹ (c)1s⁻¹

Results

Hot deformation characteristics of GH720Li alloy

The hot deformation characteristics of GH720Li alloy were illustrated in Fig.2. From Fig.2a, 2b, and 2c, we can obtain that although GH720Li is a typical hard to deformation superalloy, its hot working behaviors are the same as other Ni-base superalloys. The stress-strain curves are typical DRX type under almost all conditions. There are three stages in its stress-strain curves: during the initial stage, work hardening effect induced by dislocation pile-up is the primary reason, the flow stress increases quickly with the strain increasing; when softening effect induced by DRX can exceed the working harden effect, the flow stress curves get to the peak; finally, the stable stage occurs when the two different interaction mechanism get to a balance.

Microstructure evolution under different forging conditions

1)The recrystallization characteristics under the lower temperatures (1000-1100°C)

Fig.3 shows that when GH720Li alloy was hot forged at relative lower temperature of 1000°, a bi-model grain size distribution occurs. In other word, A new banded structure including the coarse grain region and the fine grain region forms. the average grain size of coarse zone is about ten times than that in fine grain zone. Also, the shape and distribution of the banded structure correspond with the flowline of the cylindrical samples. When deformation temperature increases, the banded structure is somewhat decreasing. This phenomenon can be observed from Fig. 4. In Fig. 4 a, 4c and 4e, the coarse grain zone decreases when forged under temperature of 1050° at all compress reductions; while in fine grain region, all is the equiaxed fine grain. In general, when forged at lower temperature, the banded structure always exists in GH720Li alloy.

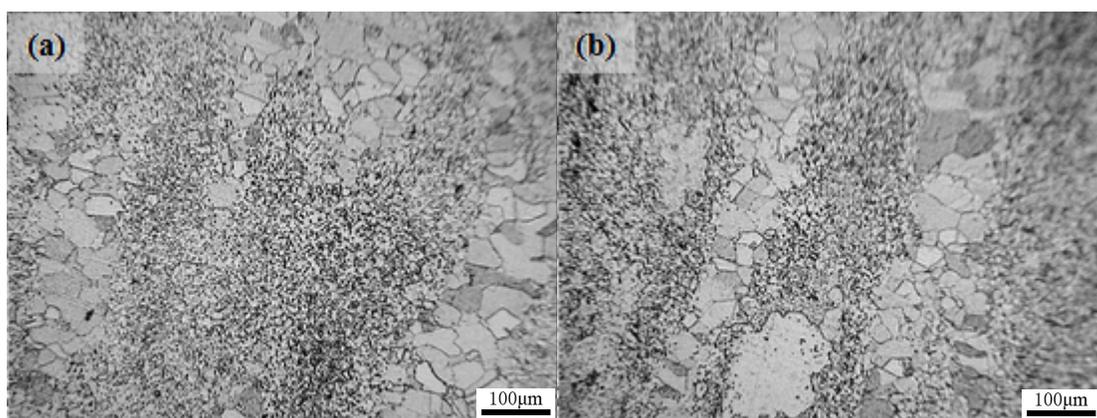


Fig.3 Grain size distribution of GH720Li under the strain rate of $1s^{-1}$ (1000°C) at different reductions (a), (b) 30%; (c) 50%; (d) 70%

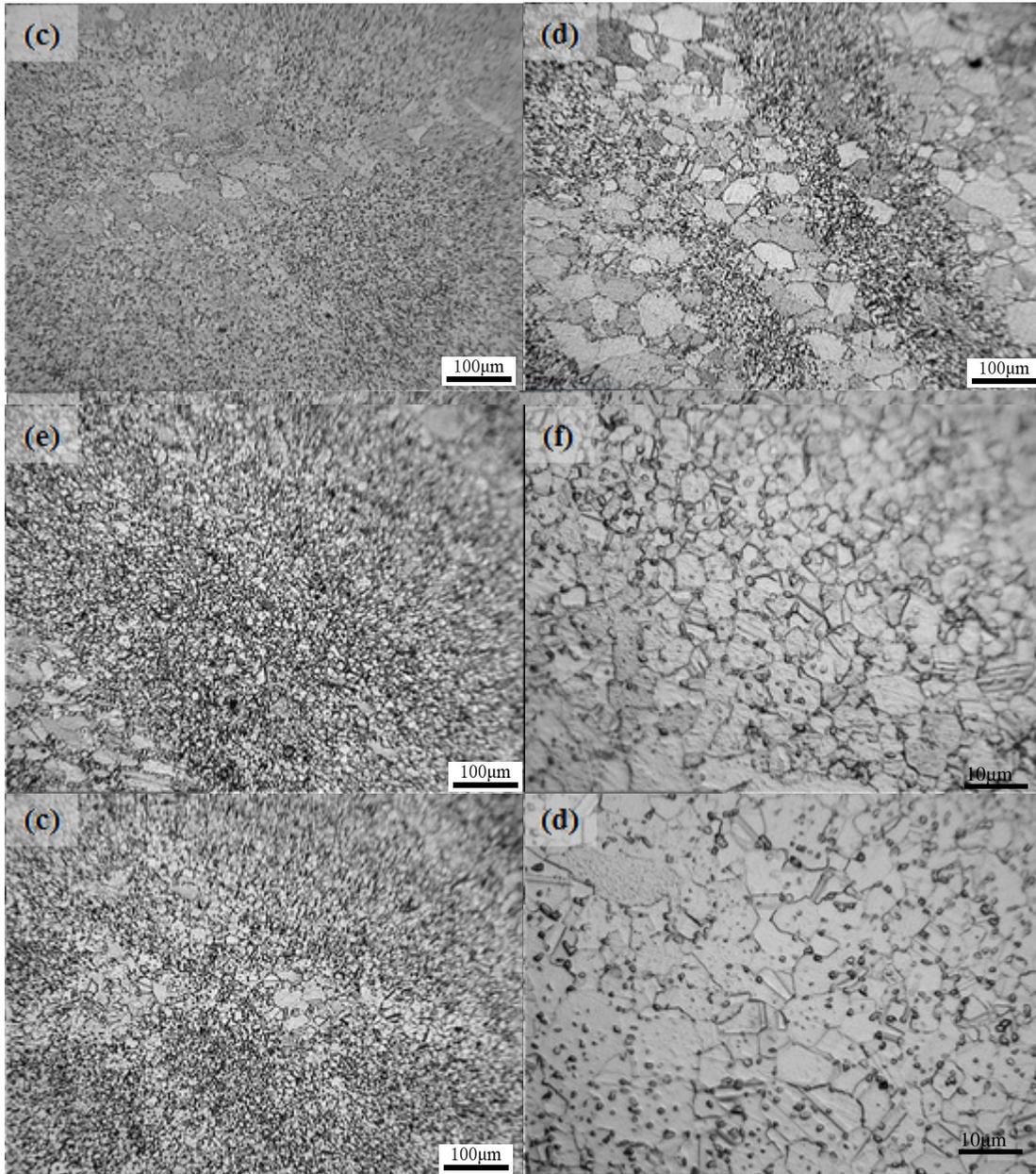


Fig.4 Grain size distribution of GH720Li alloy under different conditions (strain rate $0.1s^{-1}$, temperature $1050^{\circ}C$) (a), (b) 30%; (c), (d) 50%; (e), (f) 70%

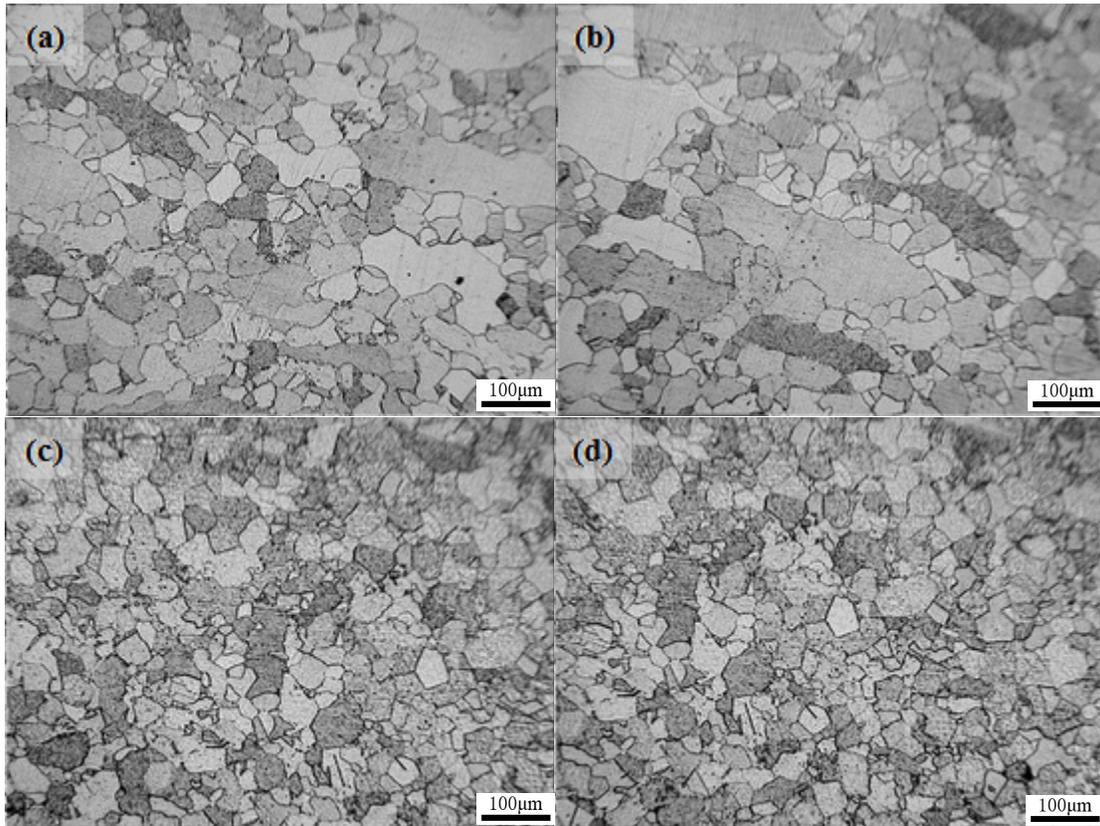


Fig.5 Grain size distribution of GH720Li alloy under different conditions (strain rate $0.1s^{-1}$, temperature $1130^{\circ}C$) (a), (b) 30%; (c), (d) 50%

2) The recrystallization characteristics under the higher temperatures ($1130-1170^{\circ}C$)

Figs5-7 is grain size distributions for GH720Li alloy under the forging temperature of 1130° , 1150° and 1170° , respectively. The experimental results show that when deformation temperature is up to the solutioning point of its strengthening phase γ' , about 1160° , the grain size is getting uniform than that in the lower temperature range. Especially when hot working temperature is over the phase transformation point, the grain size is still uniform but becoming somewhat larger. The main reason is due to they γ' phase solutioning with the temperature increasing in this alloy, resulting in the poor action of Zener pinning at grain boundary. In other word, the migration of grain boundary and the dynamic recrystallization are both getting easier in the higher hot working temperature than that in the lower temperature.

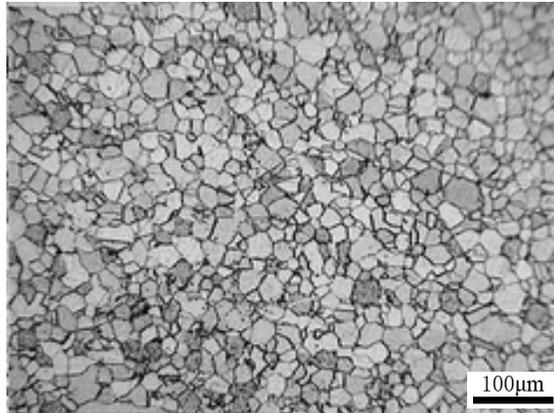


Fig.6 Grain size distribution of GH720Li alloy under different conditions (Strain rate $0.1s^{-1}$, temperature $1150^{\circ}C$, and reduction 70%)

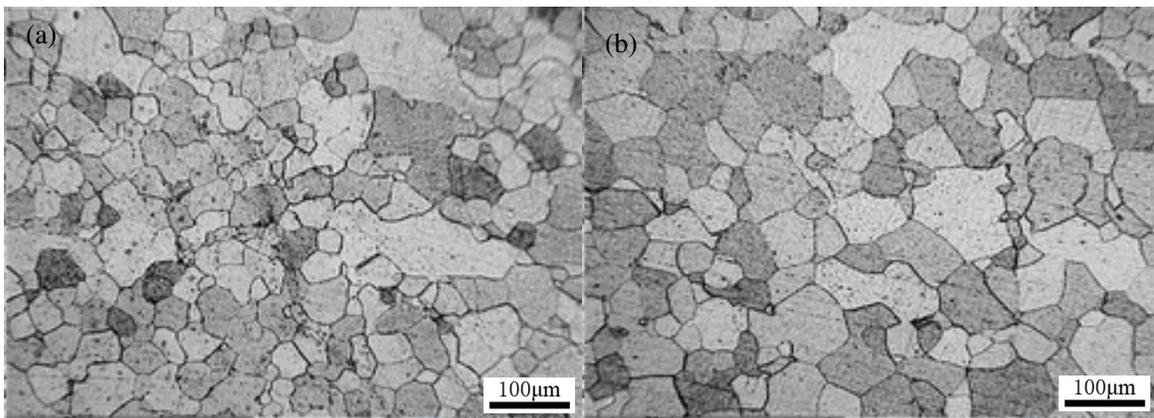


Fig.7 Grain size distribution of GH720Li alloy under different conditions (strain rate $0.1s^{-1}$, temperature $1170^{\circ}C$) (a) 50 %;(b) 70%

Discussions

Effect of the hot working parameters on the banded structure

The above mentioned OM observations show that when hot working is carried at the temperature below $1100^{\circ}C$ (Fig.8a), the abnormal grain growth or the bi-model grain size distribution (i.e. the coarse grain region and the fine grain region) always occurs; when forging temperature is up to $1170^{\circ}C$ (Fig.8b) or above $1150^{\circ}C$, the uniform grain size distribution is obtained. In other traditional wrought superalloy [7,9], such as IN 718, Waspaloy, etc. the banded structure seldom occurs during their hot working processes.

However, the abnormal grain growth is often met in their engineering practice. Many researchers did lots of works on the dynamics of DRX in hot deformation process for steels, titanium alloys, superalloys, etc.[7,8,9], but few have done on the abnormal grain growth. Benson[10] etc. ever put forward a mathematical model base on Hillet, Hunderi and Ryum to describe the effect of initial grain size distribution on abnormal grain growth in Rene 88DT alloy, but its application limits to the so-called critical grain growth which mainly occurs in the very small strain (lower than 10%) or the relative large strain (near70-80%) in engineering. For GH720Li alloy, the bi-model grain distribution may occur under the different reductions (30%, 50%, 70%) at the lower forging temperatures. This phenomenon is perhaps related to the phase transformation nature of GH720Li but

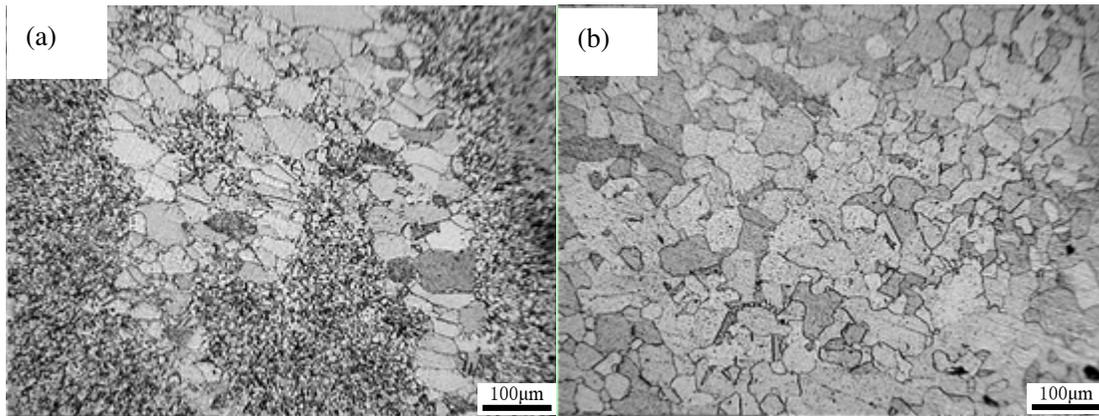


Fig. 8 OM morphology of GH720Li under different hot working parameters of (a) 1000°C and (b) 1170°C at 30% compression reduction was not the same as Benson studied abnormal grain growth in Rene 88DT.

Based on the Thermo-calc software and its Ni-base databank, the pseudo-phase diagram for GH720Li alloy is calculated (see Fig.9) thermodynamically. Fig9. shows that, there is a portion of γ' phase when hot formed lower than its solutioning point, about 1160°; although few portion of $M_{23}C_6$, MB_2 , M_3B_2 , sigma phase and mu phase would precipitate under the thermodynamically equilibrium state, they may affect the grain size distribution to little extent. The main factor may be the γ' phase distribution because there are three types of γ' phase under standard heat treatment state: primary, secondary and tertiary γ' (ref. Fig.10); and there still exists portion of primary γ' phase at the traditional forging temperature.

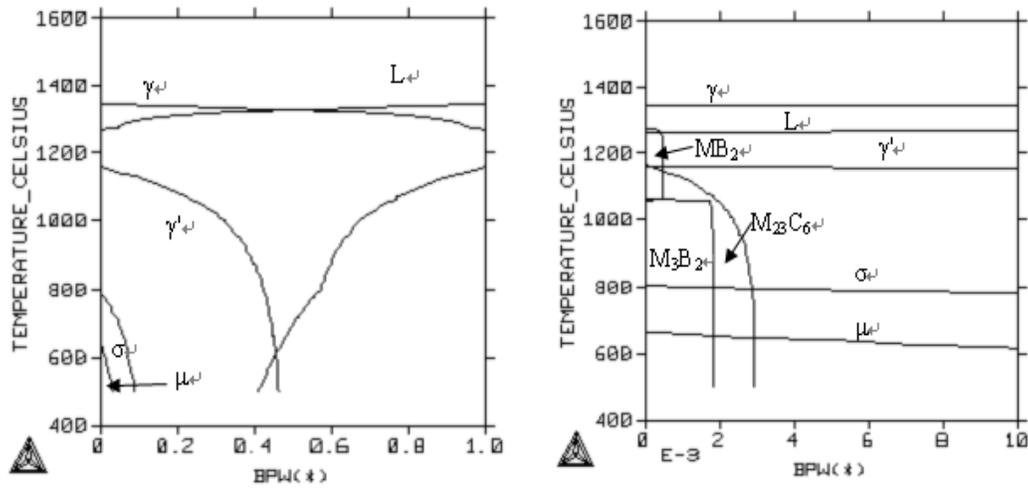


Fig. 9 Pseudo-phase diagram of GH720Li alloy (b) local of (a)

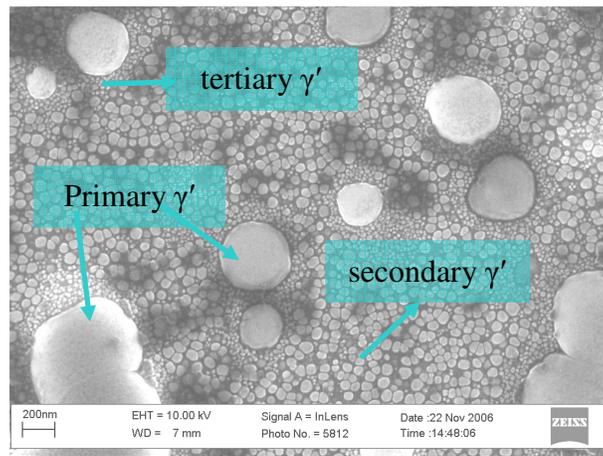


Fig. 10 The typical γ' phase in GH720Li alloy

During hot working process, such as ingot to billet conversion, forging, rolling etc., the γ' phase solutioning point is a very important parameter. Traditionally, alloys can be hot deformed in their single phase window or austenite region in order to get the best plasticity. With the development of hot working processes, forging or rolling based on microstructure control is becoming more important in the recent years. The above investigations show that if hot forged near or over the γ' solvus, there is a uniform grain size distribution in GH720Li components, or the vice versa. However, the higher deformation temperature may cause the coarse grain, which will affect the fatigue property to a great extent. Thus, it is essential to investigate the forming mechanism of the banded structure for GH720Li alloy.

The forming mechanism of the banded structure for GH720Li alloy

Fig.11 is the further high resolution SEM analysis for the above-mentioned bi-model grain growth phenomenon. In the fine grain region, there exists primary, secondary and tertiary γ' , and primary γ' lies on the fine grain boundary; while in the coarse grain region, there only exists secondary γ' . The different primary γ' distribution induces the banded contrast in different region, resulting in the banded structure in forgings.

According to the above analysis, the bi-model or banded grain size distribution always occurs at the forging temperature below the γ' solvus of GH720Li. This phenomenon is mainly due to the nonuniform re-dissolving of primary γ' during heating process. Thus, control the uniformity of primary γ' phase is essential to control the uniformity of grain size of GH720Li alloy.

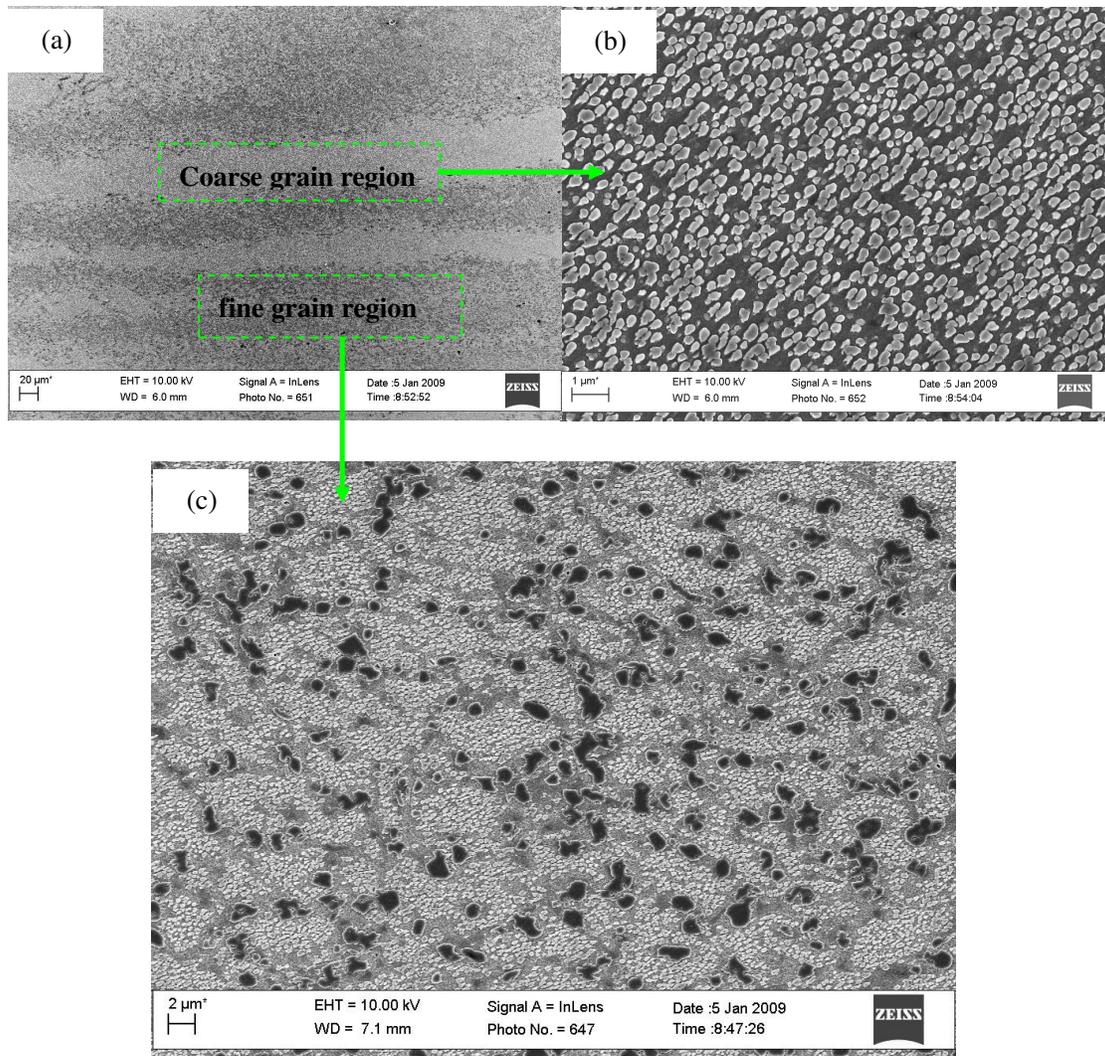


Fig. 11 the primary γ' distribution of GH720Li in different region under hot working parameters of 1000°, 30% reduction (a) the banded structure; (b) the coarse grain region; (c) the fine grain region

Fig. 12 is the γ' phase distribution under 1200°C and 30min solution annealing and water cooling. The result indicates that even water cooling can not prohibits γ' phase precipitating in GH720Li (U720Li) during its cooling process, which is in agreement with the report by Jian Mao, Kehn Min Chang[6] etc. This reveals two parts of important information related to hot working process for GH720Li alloy. On one hand, γ' phase in GH720Li alloy nucleates and grows quickly; on the other hand, if hot worked below γ' solvus, there are several metallurgical mechanisms co-exist and interact one another, such as the plastic forming, the dynamic recrystallization and the γ' phase precipitating. And the primary γ' phase pinning at the grain boundary may dominate the dynamic recrystallization process, affecting the grain size distribution to a great extent.

In general, the bi-model or banded grain size distribution in GH720Li alloy is mainly due to the nonuniform re-dissolving of primary γ' during heating process; and the uniformity of primary γ' phase is mainly determined by the distribution of elements in γ' phase such as Al, Ti in this alloy. As we all known, the distribution of elements is closely related to the homogenizing process for ingot of each material. thus, the homogenizing schedule for GH720Li ingot is the main reason for later grain size control such as ingot to billet conversion process, disk forging process, etc.

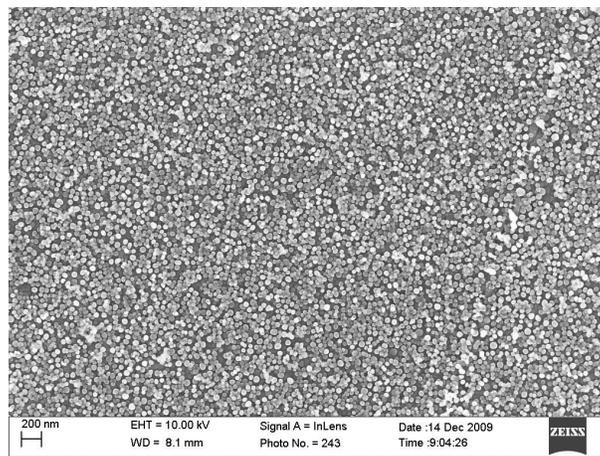


Fig12. γ' phase distribution under 1200°,30min solution annealing and water cooling

Conclusions

- For GH720Li alloy, when hot deformed below γ' solvus, the banded or bi-model structure always occurs; while hot deformed near or over γ' solvus, the uniform grain size distribution can be obtained.
- The bi-model or banded grain size distribution in GH720Li alloy is mainly due to the

nonuniform re-dissolving of primary γ' during heating process; While the uniformity of primary γ' phase is determined by the uniformity of elements in this alloy. Thus, the homogenizing process for ingot is the main reason for later grain size control.

Acknowledgements

The authors would like to thank the Chinese Iron and steel research Institute and Northeastern Special Metals Co. for providing materials investigated. The authors would also like to thank the National Key Laboratory in University of Science and Technology Beijing for experimental equipments support.

References

1. M Fahrman and A Suzuki, "Effect of Cooling Rate on Gleeble Hot Ductility of Udimet Alloy 720 Billet", SUPERALLOY 2008, 2008, pp311-315.
2. R Couturier, H Bulet, S Terzi, etc., "Process Development and Mechanical Properties of Alloy U720Li for High Temperature Turbine Disks", SUPERALLOY 2004, 2004, pp351-359.
3. R J Mitchell, M C Hardy, M Preuss, etc., "Development of γ' Morphology in P/M Rotor Disc Alloys During Heat Treatment", SUPERALLOY 2004, 2004, pp361-370.
4. M Preuss, J Q Fonseca, B Grant, etc., "The Effect of γ' particle size on the deformation in an advanced polycrystalline nickel base superalloy", SUPERALLOY 2004, 2004, pp405-414.
5. J Thebault, D Solas, C Rey, etc., "Polycrystalline Modelling of Uimet 720 Forging", SUPERALLOY 2004, 2008, pp985-992 .
6. J Mao. PhD Dissertation, "Gamma Prime Precipitation Modeling and Strength Responses in Powder Metallurgy Superalloys", University of West Virginia, August, 2002.
7. Y. Wang, W.Z. Shao, L.Zhen. "Flow behavior and microstructures of superalloy 718 during high temperature deformation". Materials Science and Engineering A, 2008, 497, pp 479-486.
8. T Sakai, J J Jonas. "Dynamic recrystallization: mechanical and microstructural considerations", Acta Met, 1984, 32, pp189-209.

9. Shen G, "Modeling microstructural development during the forging of Waspaloy." Metallurgical and Materials Transactions A, 1995, 26A, 7, pp1795-803.
10. William Earl Benson, "A Model to Describe the Effect of Initial Grain Size Distribution on Abnormal Grain Growth with Application to Rene88DT", PhD Dissertation, University of Virginia, August, 1998.