Metallurgical Analysis of different processing technologies on tensile behavior of GH4169 superalloy

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Abstract. By the measurement of tensile property and microstructure observation, the different effect of 1MJ counter-blow hammer forging and 800MN die forging on the disc were investigated. In order to obtain final forging temperature, hot compression tests under 920~1030°C at 0.08 true strain were performed on GH4169 superalloy. The results showed that at the same processing parameter, ASTM 10 grain and granular δ were obtained by count-blow hammer forging, UTS is 1563Mpa; ASTM 8 grain and needle-like δ phase segregation were obtained by die forging, UTS is 1408Mpa. According to evolution of microstructure under isothermal compression, in one case that final forging temperature of count-blow hammer is about 1000°C, while it is 930°C under die forging. The microstructure of the forging is strongly related to the fabrication process, increase the preheating temperature of the die as much as possible, increase the pressing rate, excellent mechanical property can be obtained by die forging.

1. Introduction
GH4169 alloy has been used widely in aerospace, aircraft because of its high strength, excellent ductility, good formability and weldability etc [1-3], especially which was used to fabricate turbine blades and disks by forging processing, and that over 50% more than other type of superalloy in aeronautical engine [4,5]. The uniform GH4169 alloy with a grain size of about ASTM 10 grades, an appropriate amount of δ phase in the form of granules and short rods dispersed in the grain boundary has excellent properties blow 650 °C [6,7]. Compared with other nickel-based superalloys, the microstructure and properties of GH4169 alloy are very sensitive to the hot working process [8-10]. Mechanical property has been controlled by microstructure, and which has strongly related to processing. Counter-blow hammer forging is traditional processing to produce forging of high-temperature alloy, however, it has the disadvantage is hard to fabricate the alloy which need high mechanical property with uniform microstructure. The hot die forging process has been developed intensively in the past decades to manufacture fine grain [11-14].

This work aims at better understanding the relationship between fabrication processing and mechanical property with metallurgical analysis. 1MJ count-blow hammer and 800MN die forging were used to product turbine disk. After DA treatment, the tensile property was measured and microstructure was investigated.

2. Experiment materials and method
Trial material was obtained from the GH4169 bar was manufactured in Special steel business Unit of Fushan steel group. The main chemical composition of Inconel 718 trial material is shown in table 1.
The melting process of the alloy was VIM+ESR (Ar protected). After homogenization the ESR ingot was forged into octagon bar (220mm), then the octagon bar was forged into turbine disk bar by 1MJ counter-blow hammer according to Fig.1 and 800MN die forging processing follow Fig.2. The heat treatment system is direct ageing, AC+720 °C, 8 h (Furnace cooling at a rate of 50~55 °C/h) 620 °C, 8 h, AC were carried out on following Fig.3. The specimen were prepared by EDM and polished for tensile test according to Fig.4. The tensile experiment was carried out on the MTS tensile test equipment. The isothermal - compression experiment was carried out on the Gleeble 3500 equipment. Optical microscope (OLYMPUS GX51, Japan) and scanning electron microscopy with backscatter electron (FEI, NanoNova450, USA) were used to investigate microstructure of specimen. The metallographic sample adopts electrolytic corrosion, the corrosive liquid is: 80%HCl+13%HF+7%HNO₃, the operating voltage is 3V. Commercial software Image Pro plus was used to evaluate volume of delta phase quantitative after isothermal-compression experiment.

**Table 1. Chemical composition of GH4169 superalloy (wt%)**

| C   | Si   | Mn   | S   | P   | Cr  | Ni  | Mo  | Nb  | Ti  | Al  | Fe  |
|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.022 | 0.06 | 0.02 | 0.003 | 0.003 | 19.02 | 53.18 | 3.06 | 5.41 | 1.0 | 0.53 | 17.65 |

Fig.1 the processing of 1MJ Counter-blow Hammer

Fig.2 the processing of 800MN Die forging

Fig.3 The processing for direct ageing of GH4169 turbine disk
3. Results and Analysis

SL-CH-1 is a 1MJ hammer to prepare a sample of the turbine disk test ring for tensile strength test, SL-D-1 is a sample of a turbine disk test ring prepared by an 800MN hydraulic press for tensile strength test, Table 2 shows tensile test results. The results show that the samples prepared by the hammer are better than the press die forgings.

Fig.5a and b shows the microstructure and morphology of grain and δ phase in the sample SL-CH-1, respectively. The grain grade of sample SL-CH-1 is ASTM 10.0, and spherical δ phase particles appear in the interior of grains and grain boundaries. For comparison purpose, Fig.6a and b shows the microstructure and morphology of grain and δ phase in the sample SL-D-1, respectively. The grain grade of sample SL-D-1 is ASTM 7.5, and there are a lot of long stick δ phase in the grain boundaries and a little of spherical δ phase particles in the interior of grain. Fig.7a and b shows precipitation phase γ’ and γ” in the interior of grains, there are a lot of γ’ and γ” in sample SL-CH-1, and only γ’ phase is found in sample SL-D-1, there is no plate-like γ” phase in the zone. The amount of δ phase in the interior of grain decreases the quantity of γ” strengthening phase, which is the main influence factor of the tensile property in this work.

| Specimen No.  | temperature | UTS/Mpa | YS/Mpa | A/%  | Z/%  |
|---------------|-------------|---------|--------|------|------|
| SL-CH-1(1MJ)  | 23℃         | 1563    | 1314   | 17.2 | 37.2 |
| SL-D-1(800MN) | 23℃         | 1408    | 1240   | 16.0 | 27.6 |

Fig.5. The microstructure of SL-CH-1, (a) grain;(b) δ phase

Table 2. Tensile property of GH4169 alloy under different forging processing.
The content and morphology of δ phase are strongly dependent on temperature, Fig.8a~l shows the morphology of δ phase under 920℃~1030℃ isothermal – compression. The stick-like δ phase is main characterize in grain boundaries and a little of it in the interior of grain under 920℃ and 930℃; the continuous spherical δ phase particles appear in grain boundaries (GB) under 940℃~960℃; the discontinuous spherical δ phase particles in GB is main characterization under 970℃~990℃; 1000℃~1020℃, the content of δ phase has decreased sharply, there is no δ phase in part of GB; 1030℃, δ phase was dissolved and a little spherical δ phase particles was found in interior of grain. According to evolution of microstructure under isothermal compression, in one case that final forging temperature of count-blow hammer is about 1000℃, while it is 930℃ under die forging.
4. Conclusion

The microstructure has huge influence on mechanical behavior, GH4169 superalloy mechanical properties have a strong relation to grain size, the volume and shape of delta phase, even distribution. The final forging temperature is more important than other process parameter because it can change volume of delta phase and grain size. Increasing the preheating temperature of the die as much as possible, increase the pressing rate, excellent mechanical property can be obtained by die forging.

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References

[1] Y. R. Yang. The Development and Application of Deform GH4169 alloy (Inconel718). The investigated corpus of GH4169 alloy application. Ed. 621, 1996, 16-21(In Chinese).

[2] J. Y. Zhuang, J.H Du, Q. Deng et al. The deform Super alloy GH4169, Peiking: Metallurgical Industry Publishing Company, 2006, 1-3(In Chinese).
[3] J. Y. Zhou, C. K. Liu, W. X. Zhao, et al. Prior Particle Boundary of PM FGH96 Superalloy and Its In-situ High-Cycle Fatigue at Elevated Temperature[J]. Journal of Aeronautical Materials. 2017, 37(5): 83-89.

[4] M.W. Mahoney. Superplastic Properties of Alloy 718. “Superalloy 718 Metallurgy and Applications”, eds. E.A.Loria, TMS, 1989, 391-405.

[5] Alexis Nicolaï, Jean-Michel Franchet, Nathalie Boczo, et al. Metallurgical Analysis of Direct Aging Effect on Tensile and Creep Properties in Inconel 718 Forgings[J]. The Minerals, Metals & Materials Society 2020. S. Tin et al. (eds.), Superalloys 2020, The Minerals, Metals & Materials Series.

[6] A. Chamanfar, L. Sarrat, M. Jahazi, et al. Microstructural characteristics of forged and heat treated Inconel-718 disks[J]. Materials and Design 52 (2013) 791–800.

[7] R. Noel, D. Furrer, G. Shen, et al. Microstructural evolution and control in superalloy forgings[J]. Acta metallurgica Sinica (English letter), 9(1996)6 437-442.

[8] Y. Desvallées, M. Bouzidi, F. Bois, et al. Delta phase in Inconel 718: Mechanical properties and forging process requirements[J]. Superalloys 718,625,706 and Various Derivatives Edited by B.A. Loria. The Minerals, Metals & Materials Society, 1994.

[9] S. Mahadevan, S. Nalawade, J.B. Singh, et al. Evolution of δ phase microstructure in alloy 718[J]. 7th International Symposium on superalloy 718 and derivatives. Edited by: E.A. Ott, J. R. Groh, A Banik, I. Dempster, T. P. Gabb, R. Helmink. TMS-2010.

[10] H. Yuan, W. C. Liu. Effect of the δ phase on the hot deformation behavior of Inconel 718[J]. Materials Science and Engineering A 408 (2005) 281–289.

[11] K. Wang, M.Q. Li, J. Luo, et al. Effect of the δ phase on the deformation behavior in isothermal compression of superalloy GH4169[J]. Materials Science and Engineering A 528 (2011) 4723–4731.

[12] S. Azadian, L.Y. Wei, R. Warren. Delta phase precipitation in Inconel 718[J]. Materials Characterization 53 (2004) 7–16.

[13] Y. Zhang, X. B. Huang, Y. Wang, et al. Delta phase and deformation fracture behavior of Inconel 718 alloy[J]. Superalloys 718, 625,706 and various derivatives Edited by E. A. Loria, TMS-1997.

[14] H.Y. Zhang a, S.H. Zhang a, M. Cheng a, et al. Deformation characteristics of δ phase in the delta-processed Inconel 718 alloy[J]. Materials Characterization, 2010, 49-53.