Effect of γ′ Particle Size on Creep Strength for Ni-Based Superalloy Udimet 520

Kenya Ikeda[1, *1] and Yoshihiro Terada[1, *2]

[1]*Department of Materials Science and Engineering, School of Materials and Chemical Engineering, Tokyo Institute of Technology, Yokohama 226-8502, Japan*

In this study, we researched the effect of intra-granular γ' particle size on high-temperature creep strength for the wrought Ni-based superalloy Udimet 520, which is widely used as a high-temperature structural material. The creep strength is enhanced at high temperatures as the size of γ' precipitates within the γ matrix becomes smaller under the constant fraction of γ' phase; that is to say, the precipitation strengthening is operative at higher temperatures.

Keywords: *nickel-based superalloy, microstructure, creep, gamma-prime phase, precipitation strengthening*

1. Introduction

In recent years, there has been an increasing demand for the reduction of carbon dioxide, which accounts for a large proportion of greenhouse gases that are believed to have a significant impact on climate change. In the industrial field, higher temperatures are being used to improve thermal efficiency(1). Ni-based superalloys have superior high-temperature strength, oxidation resistance, and corrosion resistance, and are widely used as structural components under high-temperature and high-pressure conditions such as in jet engines for aircraft and gas turbine components for thermal power generation(2). By increasing their high-temperature strength, it is expected that the performance of engines and generators can be further improved.

Precipitation strengthening, which is one of the strengthening mechanisms of metallic materials, occurs when precipitated particles prevent the gliding motion of dislocations. At room temperature, the relationship between strength and precipitated particles size can be discussed by shear stress due to the particle shearing mechanism and the Orowan looping mechanism(3). However, at high-temperature, dislocation climb can be operative, and small particles are presumed to be bypassed in a short time. There are few reports on the relationship between creep strength and precipitated particles size. The objective of this study is to clarify the effect of γ' particle size on creep strength for Ni-based superalloy Udimet520, which used as a high-temperature structural material(4).

2. Experimental

The specimens were wrought Ni-based superalloy Udimet 520. The alloy specimens were firstly solution-treated at 1393 K for 4 h, followed by the aging treatment at 1173 K for 10 h, 100 h, and 1000 h water quenched, respectively. Therefore, the grain size will be the same for all specimens and the γ' volume fraction will be constant since all aging times because they are in the over-aged region(5). Creep tests were carried out for the three kinds of aged specimens at 1073 K under a stress of 250 MPa. FE-SEM observations was carried out for each specimen.

3. Results and Discussion

3.1 Microstructure

Figure 1 shows the FE-SEM images of Udimet 520 aged at 1173 K for 10 h and 1000 h. The grain size of both aged specimen is 250 μm, and the grain boundaries were completely covered by the γ' phase. The γ' phase precipitated spherical in the 10 h-aged specimen and cuboidal in the 1000 h-aged specimen, while maintaining coherency within the grain, with the particle size, d, of 98 nm in the 10 h-aged specimen and 405 nm in the 1000 h-aged specimen. It is factors influencing the creep results are ascribed to the intra-granular γ' particle.

3.2 Creep curves

Figure 2 shows the creep curves of the aged specimens. The strain immediately after the stress application was about 0.002 for all aged specimens, and the increase in strain became larger as the aging time increased.

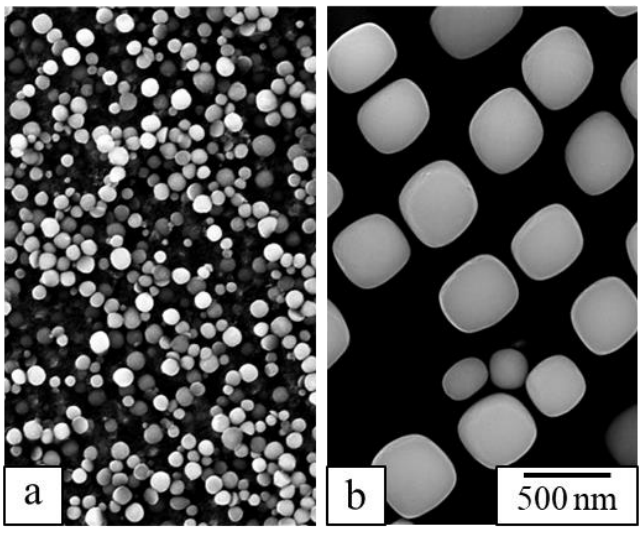

Fig. 1 FE-SEM images of Udimet 520 aged at 1173 K for 10 h (a) and 1000 h (b).

*1 Graduate Student, Tokyo Institute of Technology
*2 Corresponding Author, E-mail: terada.y.ab@m.titech.ac.jp

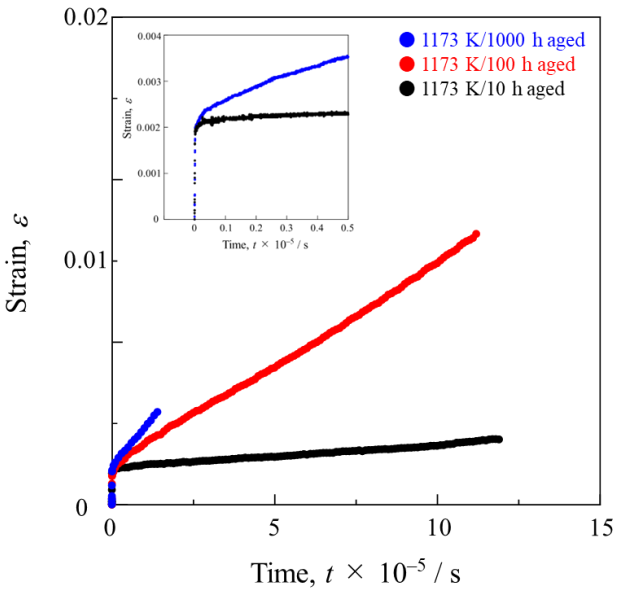

Fig. 2 Creep curves of Udimet 520 aged at 1173 K for 10, 100, and 1000 h. Creep tests were carried out at 1073 K/250 MPa.

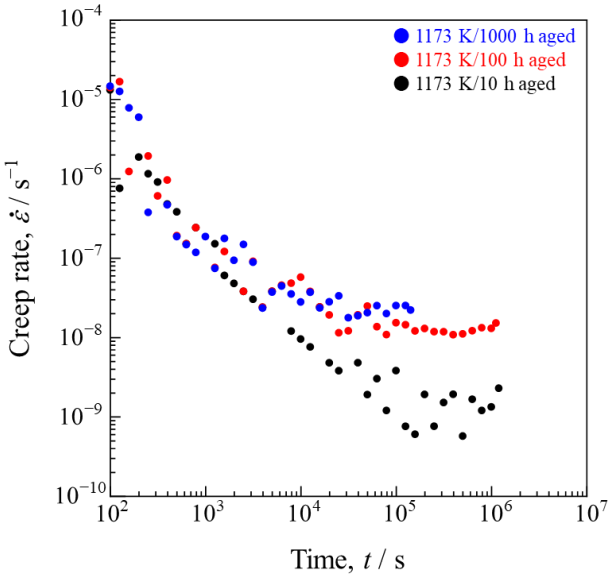

Fig. 3 Creep rate vs. time of Udimet 520 aged at 1173 K for 10, 100, and 1000 h. Creep tests were carried out at 1073 K/250 MPa.

Figure 3 shows the creep rate–time curves for each aged specimen. The creep rate of all aged specimens decreased with the start of the creep test and accelerated after the minimum creep rate. The minimum creep rate was 6.4×10^{-10} s^{-1} for the 10 h-aged specimen, 1.1×10^{-8} s^{-1} for the 100 h-aged specimen, and 2.0×10^{-8} s^{-1} for the 1000 h-aged specimen. The 10 h-aged specimen show the significant decrease in creep rate during the transient stage, while the decrease in creep rate becomes less significant for the 100 h and 1000 h-aged specimens.

3.3 Creep strength and gamma-prime diameter

Figure 4 shows the relationship between the minimum creep rate and the γ' particle size. The minimum creep rate increased continuously with increasing γ' particle size, from 6.4×10^{-10} s^{-1} at d = 98 nm to 2.0×10^{-8} s^{-1} at d = 405 nm. The overall result is organized as an upward convex curve. From the results, it is clarified that the precipitation strengthening in the γ matrix during high temperature creep is becomes emphasized for smaller size of intra-granular γ' particles.

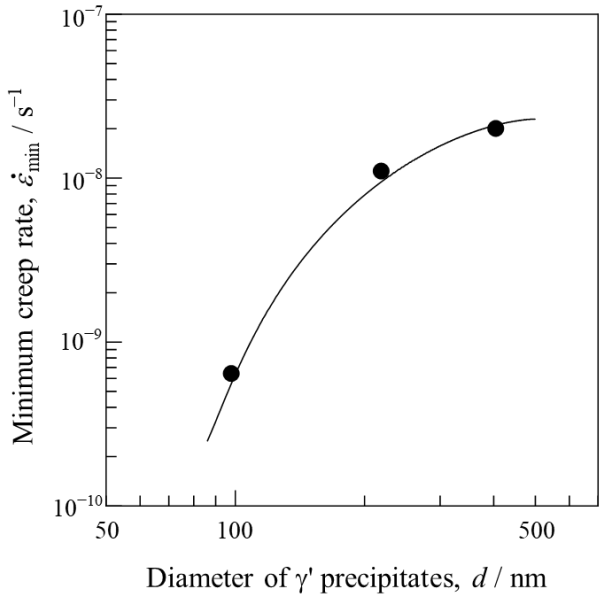

Fig. 4 Minimum creep rate vs. γ′ diameter of Udimet 520 aged at 1173 K for 10, 100, and 1000 h. Creep tests were carried out at 1073 K/250 MPa.

4. Conclusions

In this study the effect of intra-granular γ' particle size on creep strength at high temperatures was investigated for Udimet 520. The creep strength at high temperatures decreased continuously with increasing particle size of the intra-granular γ' precipitates. As the γ' particle size increased from 98 nm to 405 nm, the minimum creep rate increased by a factor of about 31. These results indicate that the amount of precipitation strengthening in the γ matrix during high-temperature creep is emphasized with smaller intra-granular γ' particle size.

References

1) M. Fukuda: J. Smart Process. **3** (2014) 78-85.
2) H. Harada and T. Yokokawa: Materia Japan **42** (2003) 621-625.
3) S. Chatterjee, Y. Li, G. Po: Int. J. Plast. **145** (2021) 103062-103083.
4) R. C. Reed: *The Superalloys*, (Cambridge University Press, Cambridge, 2006).
5) Y. Yamaguchi, R. Tajima and Y. Terada: Mater. Trans. **61** (2020) 2185-2194.