International Journal of the Physical Sciences Vol. 6(30), pp. 7073 - 7077, 23 November, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.245
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Effects of annealing parameters on grain-growth behavior of HAYNES®-718 superalloy

Zainul Huda[1]*, Tuan Zaharinie[2] and Syed Humailul Islam[1]

[1]College of Engineering, King Saud University, Riyadh, Saudi Arabia.
[2]Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.

Accepted 26 September, 2011

Annealing heat-treatment experiments at temperatures in the range of 1050 to 1150°C (1323 to 1423K) for durations in the range of 20 min to 22 h were conducted for HAYNES® 718 superalloy plate. Grain sizes for the as-received and the annealed samples of the superalloy were measured by application of quantitative metallographic techniques. The grain-growth exponents, *n*, for the kinetic relationship ($dD/dt = kt^n$) were then computed, and the *n* values were found to lie in the range of 0.067 to 0.183. The microstructures of the as-received and annealed samples were critically compared for applications of the superalloy at high temperatures.

Key words: Superalloy, grain growth, kinetics, microstructure, gas-turbines.

INTRODUCTION

Despite the technological importance of the control of grain growth in superalloys, a relatively limited research has been reported in this area (Tian et al., 2009; Huda, 2004; Huda and Ralph, 1990; Radhakrishnan and Thompson, 1993). No previous quantitative study on the grain-growth kinetics of HAYNES® 718 superalloy has been reported. This research paper, therefore, aims to study the effects of annealing parameters on the grain-growth kinetics by computing the grain-growth exponents during annealing at temperatures in the range of 1323 to 1423K for the investigated 718 Ni-base superalloy.

Superalloys are extensively used in hot sections of gas-turbine engines owing to their excellent creep and hot-corrosion resistance at high temperatures (Huda, 2009; Satyanarayana et al., 2008; Kovan et al., 2008; Sims et al., 1987). In particular, 718 nickel-base superalloy has a lower cost when compared with the other superalloys resulting in wider spread use of this superalloy (Xiaoa et al., 2006). Grain growth occurs in polycrystalline materials to maintain its thermodynamic stability by reducing its grain boundary energy, and hence, by reducing total energy of the system (Gladman, 2004). Grain boundary area is in high energy state and this energy is proportional to the driving force for the grain growth. Therefore, the driving force varies as the inverse of the grain size (Cotterill 1976; Huda and Zaharinie, 2009; Liu et al., 2006).

METHODOLOGY

The staring material (SM) (HAYNES® 718 Ni-Base Superalloy) was acquired from Haynes International Inc. Alloys, USA. The SM was in the form of rolled plate; the chemical composition of the SM is 53.1 Ni, 18.4 Cr, 3.07 Mo, 1.0 Ti, 0.56 Al, 0.003 B, 0.054 C, 0.09 Si, 0.16 Co, 0.10 Cu, 0.26 Mn, traces of P and S and remainder Fe.

Thirteen (13) samples from the SM were sectioned by use of diamond-wheel cut-off machine (facilitated with cooling fluid during cutting operation) so as to conduct metallographic investigations on the rolling plane. Twelve (12) samples were given grain-growth annealing heat treatments at temperatures in the range of 1050 to 1150°C (1323 to 1423K) for durations in the range of 20 min to 22 h by use of a Carbolite tube atmosphere-controlled furnace (filled with nitrogen gas) facilitated with a digital temperature control system (Table 1). The metallographic specimens for the thirteen (13) samples were prepared by metallographic grinding, polishing and etching. Metallographic etching was accomplished by using etching solution of 20% hydrochloric acid + 80% methanol. The photomicrographs for the metallographic specimens were taken by the use of an optical microscope linked with a computerized imaging system using the i-Solution software. The average grain diameters for the as-received and heat-treated samples were measured; and the grain-growth exponent *n* for the alloy was computed at various temperatures.

*Corresponding author. E-mail: drzainulhuda@hotmail.com.

Table 1. Grain size data resulting from various annealing parameters.

Sample ID	Annealing parameter	Grain size (μm)
A-1	1323K/20 min	17
A-2	1323K/2 h	53
A-3	1323K/8 h	57
A-4	1323K/22 h	60
B-1	1373K/20 min	20
B-2	1373K/2 h	56
B-3	1373K/8 h	60
B-4	1373K/22 h	64
C-1	1423K/20 min	52
C-2	1423K/2 h	87
C-3	1423K/8 h	99
C-4	1423K/22 h	129

RESULTS AND DISCUSSION

Microscopy

The optical micrographs for the as-received and annealed samples are shown in Figure1a to d. It can be observed from the microstructure of the as-received 718 nickel-base superalloy (Figure 1a) that clearly, there are two distinct phases: austenite (γ) matrix and gamma-prime (**γ'**) particles. The gamma-prime phase imparts high-temperature strength to the superalloy (Huda, 2009; Monajati et al., 2004). Now we observe microstructures of the annealed samples (Figure 1b to d); which shows the absence of the second-phase (**γ'** particles). A comparison of the optical micrograph of the as-received materials with those for heat-treated samples leads us to the conclusion that the γ'-solvus temperature for the investigated superalloy is below 1050°C (1323K). Since the presence of the **γ'** particles in the microstructure is important for creep strength, we can relate this conclusion to the high-temperature applications of the HAYNES® 718 superalloy as follows. When designing a machine element involving the selection of this superalloy in the hot-sections of the machine (for example, gas-turbines), the operating temperature (to which the superalloy component is subjected) must be below 1050°C (1323K). However, if the operating temperature is designed to exceed the γ'-solvus temperature (say 1200°C), it must be ensured that thermal barrier coatings are used (TBC) on the HAYNES® 718 superalloy component (Huda, 2009; Sims et al., 1987).

Data analysis

Table 1 presents the grain size data resulting from various annealing parameters used in the heat treatment. The pre-growth mean grain diameter was computed to be 13 micron for the as-received superalloy.

A look at the data in Table 1 clearly indicates that the grain size increases with increasing temperature and time. Figure 2 shows the grain-growth behavior resulting from various annealing parameters at temperatures in the range of 1323 to 1423K for time-durations in the range of 20 min to 22 h for the investigated superalloy.

The isothermal curves in the graphical plot (Figure 2) lead us to establish that the grains first grow rapidly and then more slowly with increase in grain size at a particular temperature. This kinetic behavior which shows that the rate of grain growth varies inversely as the grain size enables us to express the kinetics of grain growth is as follows:

$$\frac{dD}{dt} = \frac{k}{D} \qquad (1)$$

where D is the mean grain diameter after an annealing time *t* at a particular temperature.

On integration, Equation 1 takes the form:

$$D_t - D_0 = kt^n \qquad (2)$$

where D_0 is pre-growth grain diameter, D_t is grain diameter at any instant *t* during grain growth, *n* is grain growth exponent and *k* is constant depending on metal's composition and annealing temperature.

In logarithmic form, Equation 2 can be expressed as follows:

$$\log(D_t - D_0) = \log k + n \log t \qquad (3)$$

By the application of Equation 3, we plotted a graph of

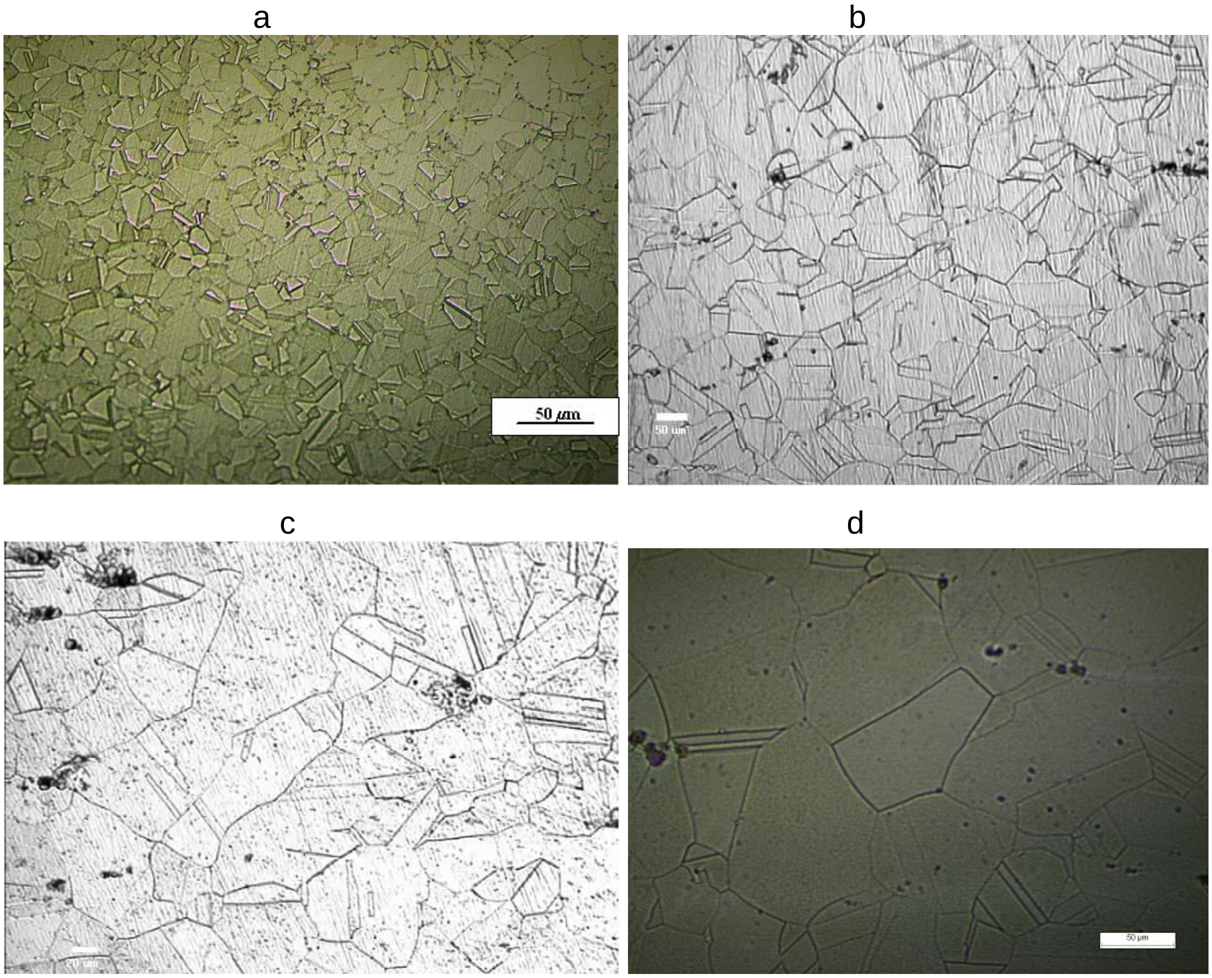

Figure 1. Optical micrographs for (a) as-received superalloy, (b) sample annealed at 1323K/8 h, (c) sample annealed at 1373K/8 h, (d) sample annealed at 1423K/20 min.

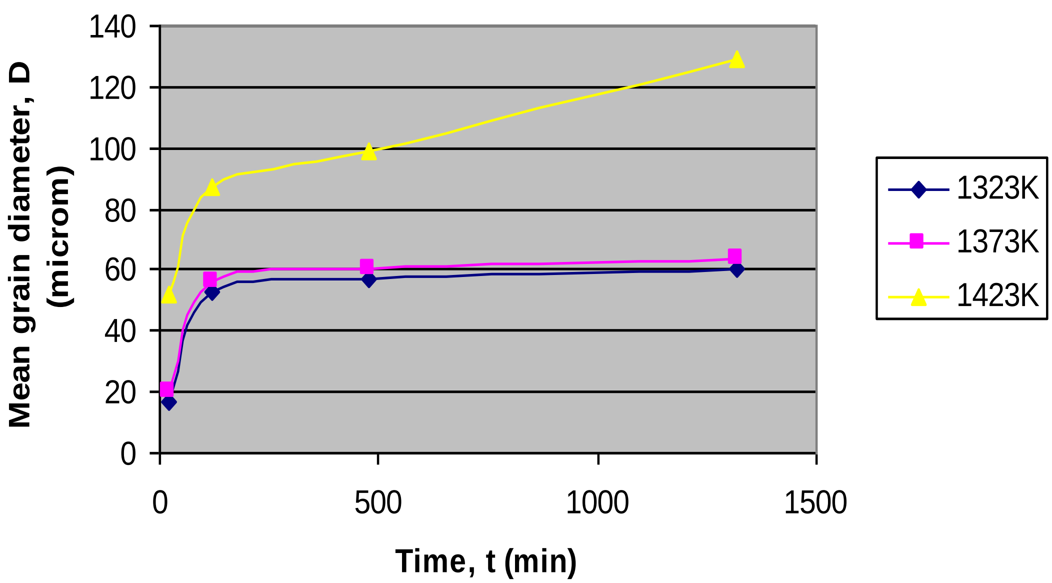

Figure 2. Effects of annealing parameters on grain size of the superalloy.

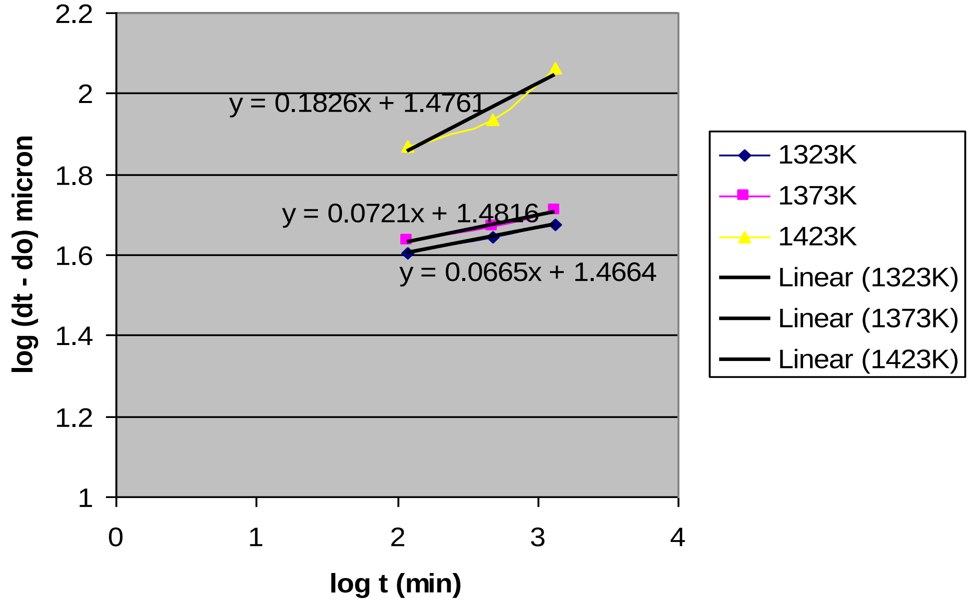

Figure 3. Graphical plots of log $(D_t - D_0)$ versus log *t* for the superalloy.

log (D_t – D_o) versus *log t*, as shown in Figure 3. The gradient of each slope shows the values of rain growth exponent, *n*. Hence, the application of Equation 3 and the graphical tools (Figure 3) enable us to compute *n* values in the range of 0.067 to 0.183 at temperatures in the range of 1323 to 1423K.

The three isothermal lines in Figure 3 indicate that the grain-growth exponent *n* increases from 0.067 to 0.183 as temperature increases from 1323 to 1423K. This kinetic behavior of grain growth can be subsequently explained. The grain-boundary mobility increases with increasing temperature; which in turn results in less-restricted migration of grain boundaries thereby promoting grain growth. This explanation is further justified by this author's investigation of grain-growth kinetics in a powder-formed IN-792 superalloy; whereby *n* values have been reported to have increased from 0.020 to 0.164 as the temperature increased from 1493 to 1543K (Huda, 2004).

For pure metal, the ideal grain growth exponent, *n* is 0.5 (Cotteril, 1976; Huda, 1991). The lower *n* values (n = 0.067 to 0.183) for the investigated superalloy as compared to those for pure metals (n = 0.5) indicates that the grain growth is highly restricted due to the solute drag effects (Ralph et al., 1992). Additionally, the grain-growth kinetic behavior *n* < 0.4 is expected for a highly alloyed metal (Takasugi, 1985; Simpson et al., 1971).

Conclusions

The values of the grain-growth exponent, *n,* were computed to be in the range of 0.067 to 0.183 at temperature in the range of 1323 to 1423K for the investigated superalloy. An explanation for increase of *n* value with increase in temperature in terms of grain-boundary migration has been presented. The γ'-solvus temperature was found to be below 1050°C (1323K) for the investigated 718 superalloy. This finding was related to the high-temperature applications of the superalloy as follows. When designing a machine element involving the selection of the HAYNES® 718 superalloy in the hot-sections of the machine (for example, gas-turbines), the operating temperature (to which the superalloy component is subjected) must be below 1050°C (1323K). However, if the operating temperature is designed to exceed around 150°C higher than the γ'-solvus temperature (that is, 1200°C), it must be ensured to use the thermal barrier coatings (TBC) on the HAYNES® 718 superalloy component.

ACKNOWLEDGEMENTS

The authors (ZH & SHI) gratefully acknowledge the Research Centre, College of Engineering, King Saud University, Saudi Arabia for financial support for this research paper. The authors (ZH & TZ) are also grateful to I.P.P.P unit of University of Malaya, Malaysia for PJP financial grant (Project No. FS124/2008B) for the reported research.

REFERENCES

Cotterill P (1976). Recrystallization and Grain Growth in Metals. *Krieger Publ. Co*., pp. 1-410.

Gladman T (2004). Grain Size Control, *Woodhead Publishers Ltd*, Cambridge, UK., pp. 1-183.

Huda Z (2009). Metallurgical Failure Analysis for a Blade Failed in a Gas-Turbine Engine of a Power Plant. *Mater. Design,* 30: 3121-3125.

Huda Z (2004). Influence of Particle Mechanisms on the Kinetics of Grain Growth in a P/M Superalloy. *Mater. Sci. Forum,* 467-470: 985-990.

Huda Z, Ralph B (1990). Kinetics of grain growth in powder-formed IN-792: A nickel-base superalloy. *Mater. Charact.,* 25(2): 211-220.

Huda Z, Zaharinie T (2009). Kinetics of grain growth in 2024-T3: an aerospace aluminum alloy. *J. Alloys Compds*, 478: 128-132.

Huda Z (1991). PhD Thesis, Brunel University of West London, U.K.

Kovan V, Hammer J, Mai R, Yuksel M (2008). Modeling by artificial neural network of high temperature fatigue life of oxide dispersion strengthened nickel-based superalloy PM 1000. *Materials at High Temperatures,* 25(2): 81-88.

Liu F, Yang G, Wang H, Chen Z, Zhou Y (2006). Nano-scale grain growth kinetics. *Thermochimica Acta,* (443): 212-216.

Monajati H, Jahazi M, Bahrami R, Yue S (2004). The Influence of Heat Treatment Conditions on γ' Characteristics in Udimet® 720. *Mater. Scie. Eng. A*., 373: 286–293.

Radhakrishnan B, Thompson RG (1993). Kinetics of Grain Growth in the Weld Heat-Affected Zone of Alloy 718. *Met. Trans* A 24A, 2773–2785.

Ralph B, Shim KB, Huda Z, Furley J, Edirisinghe M (1992). Effects of Solutes and Second-Phase Particles on Grain-boundary Migration and Grain Growth. *Mater. Sci. Forum,* 94-96, 129-140.

Satyanarayana DVV, Omprakash CM, Jagadeesan B, Das N (2008). Effect of section thickness on creep and stress rupture behaviour of DS CM247 nickel base superalloy. *Materials at High Temperatures,* 25(1): 17-26.

Simpson CJ, Aust KT, Winegard WC (1971). Activation energies for normal grain growth in lead and cadmium base alloy. *Metallurg. Mater. Trans. B,* 2: 987–993.

Sims CT, Stoloff NS, Hagel WC (1987). *Superalloys II*, John Wiley & Sons, USA., pp. 1-615.

Tian G, Gia C, Liu J, Hu B (2009). Experimental and simulation on the grain growth of P/M nickel-base superalloy during the heat treatment process. *Mater. Design*, 30(3): 433-439.

Takasugi T, Izumi O (1985). Recrystallization and Grain Growth of Co_3Ti, *Acta Metallurg.,* 33: 49–58.

Xiaoa L, Chenb DL, Chaturvedia MC (2006). Effect of boron and carbon on thermomechanical fatigue of IN 718 superalloy: Part I. Deformation behavior. *Mater. Sci. Eng. A*, 437: 157–171.