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Microstructure evolution of high-performance Ni-Base superalloy GTD-111 with heat treatment parameters

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The Ni-base superalloys possess high stability and strength at high temperatures and for this reason they are used in manufacturing of gas turbine hot components. GTD-111 is one of them employed in manufacturing of the first stage blades of high power gas turbines. The alloy gains its appropriate microstructure and high temperature strength through precipitation hardening mechanism. Heat treatment parameters such as: time and temperature of homogenization, partial solution and aging temperatures, and cooling rate from homogenization and solution temperatures affect the microstructure of this alloy. In this paper the effects of some heat treatment parameters on microstructure were investigated. It was cleared that with long time homogenization at 1200°C local melting of γ - γ' eutectics occurs and in conclusion, the volume percent of the eutectics decreases. Also, it was shown that size, shape and volume fraction of primary γ' particles are largely influence by the cooling rate following homogenization and partial solution treatments.

1. INTRODUCTION

The Ni-base superalloy GTD-111 is used in manufacturing of the first stage blades of powerful gas turbines (over 125MW). The blades work at critical condition of creep, corrosion and fatigue for more than 70,000 hrs. The alloy requires good physical, mechanical and corrosion properties because of its severity of service condition. Since the mechanical properties of the alloy are due to its microstructure properties and these properties are affected by heat treatment, determination of the effects of heat treatment parameter on microstructure is worth of studying.

The microstructure of GTD-111 consists of several phases: austenite matrix (γ), ordered and coherent precipitate (γ'), different carbides, γ - γ' eutectics and small amount of TCP phases such as: η, σ, and Laves[1,2]. The superalloy is strengthened by precipitation hardening. Heat treatment parameters affect on alloying elements distribution, precipitates distribution and their morphologies and contents. Precipitation heat treatment of the alloy consists of two stages: solution treatment and aging. Solution treatment causes dissolving of precipitates and homogenization of alloying elements in microstructure[3]. Solution heat treatment may carried out at over 1200°C, this type of solution is called full solution or homogenization and may have deleterious effects such as: local melting of eutectics and reduction of primary γ' percentage which in turn changes mechanical properties of the blades. Therefore, the temperature of solution treatment is decreased to prevent the deleterious effects. This type of treatment is called partial solution. The partial solution temperature of an alloy depends on the tendency of the alloy to the formation of harmful phases such as: η, σ, and Laves. In an alloy like IN738LC, that the tendency is low, the partial solution temperature is low (1120°C). But in an alloy like IN939 having high percentage of Co and Ti and high tendency to the formation of η, the treatment is carried out at 1160°C [4,5]. During partial solution some part of the large γ′ precipitates remains undissolved. Bhowal et al.[6] showed that large γ′ particles are lower at higher solution temperature and their sizes depend on cooling rate after solution treatment.

Aging treatment in Ni-base superalloys is applied in order to nucleation and growth of secondary γ′ precipitates. Balikci et al.[7] proposed two mechanisms for growth of γ′ precipitates: coalescence of the small particles to the larger once and extraction of dissolved elements, like Al and Ti, from the saturated solid solution matrix and to the precipitates. Over aging causes increasing of the precipitate particles and consequently, decreasing in the number of them and increasing of the spacing. The growth of the particles causes decreasing of creep resistance of superalloys[8].

2. EXPERIMENTAL PROCEDURES

Effects of some heat treatment parameters such as: time and temperature of the homogenization treatment, cooling rate from homogenization temperature and cooling rate from partial solution temperature on the microstructure of the Ni-base superalloy GTD-111 has been investigated. First, some cast specimens from GTD-111 ingots were obtained. The chemical composition of the alloy is shown in Table 1. The specimens were heat treated with different cycles. To be sure about temperature, a thermocouple attached to the specimens was used. The specifications of the different heat treatment cycles applied to the specimens are presented in Table 2. Microstructures of all samples were examined using optical and electron microscopy. Quantitative analyzing of the microstructures was performed by image analyzer. γ′ weight percent was obtained by electrolytic extraction procedure[9].

Table 1
Chemical Compositions of GTD-111 Superalloy (in wt.%).

Ni	Cr	Co	Ti	W	Al	Ta	Mo	Fe	C	B
Bal.	13.5	9.5	4.75	3.8	3.3	2.7	1.53	0.23	0.09	0.01

3. RESULTS AND DISCUSSION

It has been reported that the full solution temperature for γ′ precipitates in GTD-111 is about 1180 to 1235°C [7,10-12]. Therefore, the minimum homogenization temperature at which all of the γ′ precipitates are dissolved in γ matrix is 1180°C. Comparison of the specimens heat treated with cycles A and B shows that dimensions of the primary γ′ particles are less than that of cycle B. The volume percent of primary γ′ in the specimens heat treated with cycles A and B is less than that of standard heat treated specimens. Figure 2 shows microstructure of specimen heat treated with cycle A. The difference in γ′ volume percent is due to the higher cooling rate from the homogenization temperature. It was shown that decreasing cooling rate the primary γ′ size and its volume content increases. Cooling rate after homogenization treatment is an effective parameter in nucleation and growth of γ′ precipitates [14,15]. Higher cooling rate, also, causes inhomogeneous distribution of γ′ particles in γ matrix.

Table 2
Specifications of the different heat treatment cycles.

Aging			Partial Solution			Homogenization			
Cooling Rate (°C/min)	Time (hrs)	Temp. (°C)	Cooling Rate (°C/min)	Time (min)	Temp. (°C)	Cooling Rate (°C/min)	Time (min)	Temp. (°C)	Cycle
25	24	845	25	120	1120	18	240	1200	A
25	24	845	25	120	1120	5	240	1200	B
25	24	845	32	120	1120	18	120	1200	C
25	24	845	25	120	1120	5	120	1200	D
25	24	845	32	120	1120	---	---	---	E
25	24	845	25	120	1120	---	---	---	F
25	24	845	18	120	1120	5	120	1180	G
25	24	845	18	120	1120	5	240	1180	H
25	24	845	18	120	1120	5	120	1200	I

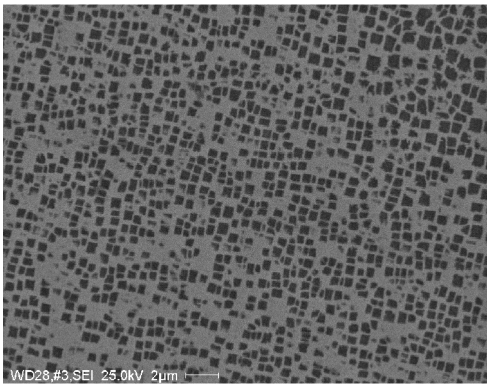

Figure 1. Microstructure of specimen heat treated with cycle A

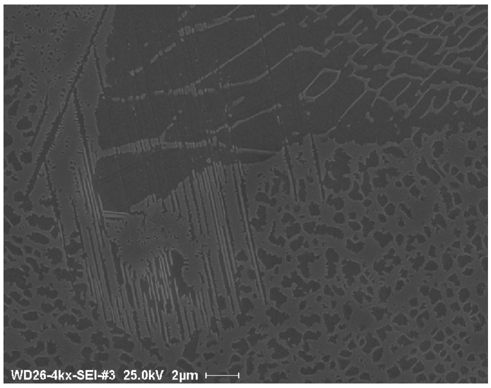

Figure 2. Microstructure of specimen heat treated with cycle F

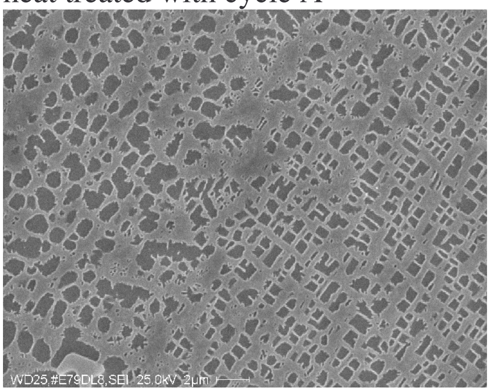

Figure 3. Microstructure of specimen heat treated with cycle H

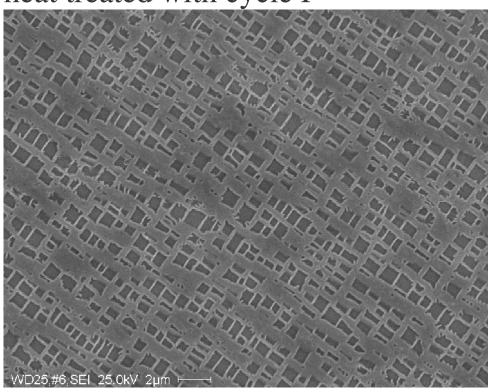

Figure 4. Microstructure of specimen heat treated with cycle I

With decreasing homogenization time from 4hrs to 2hrs (cycles C and D) no any important changes in microstructure were observed. It should be mentioned that Henderson and McLean[13] reported that with heat treatment at 1200°C /2hrs γ' precipitates in IN738LC could be completely dissolved although, after cooling, even in water, they precipitated again in fine particles shape. Inhomogeneous distribution of γ' precipitates in group C specimens is produced due to higher cooling rate from the full solution temperature. Needle-like phases are formed near some inclusions and eutectic phases in the specimens C. Also, primary γ' volume percent is lower in these specimens. Inversely, in specimens heat treated without homogenization (cycles E and F), non homogeneity of γ' distribution was observed. Additionally, γ - γ' eutectic percent increased and TCP phases were observed since full solution treatment can dissolve partially γ - γ' eutectics and deleterious phases. Figure 2 shows the microstructure of specimen heat treated with cycle F.

The results of this investigation showed homogenization at 1180°C even for 4 hours (cycle H) could not produce a homogeneous microstructure (Fig. 3). Although, Hale[10] has claimed that homogenization of GTD-111 at 1180°C for 2 hours gives higher creep properties. Consequently, 2-hour homogenization treatment is enough to produce a homogeneous solid solution.

Cooling rate after partial solution treatment also affects primary and secondary γ' particle size, distribution and volume fraction. Specimens I, cooled with lower rate from partial solution treatment posses larger primary γ' with more volume content. Figure 4 shows the microstructure of specimen heat treated with cycle I.

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