Journal of Metallurgical and Materials Engineering, Vol.31, No.2, 2021.

Influence of the Solution Heat Treatment on the Behavior of γ′ Precipitates and Microhardness of Dendrite Core and Inter-Dendritic Regions of Cast Superalloy GTD-111.

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1- Introduction

Increasing the operating temperature of gas turbines to improve their efficiency has been made the use of heat-resistant alloys inevitable. Turbine blades are equipment that service at high temperatures and made from nickel, nickel–iron, and/or cobalt based superalloys. One of the most famous nickel base superalloys that used in the manufacturing of single crystal blades is GTD-111 superalloy. This alloy is age-hardened by precipitation of γ′-phase, $Ni_3(Al,Ti)$, which is a coherent precipitate in the Ni-rich matrix phase. The microstructure of these alloys consists of different phases such as reinforced gamma prime (γ′), carbides and eutectic γ-γ′ phases in the gamma (γ) matrix. Each of which is essential to achieve the desired properties. Although the strength of the superalloys is determined by the theses phases, but characteristics of γ′-precipitate such as its size, morphology and volume fraction influence the properties of the superalloy significantly. This should be noted that the elastic strain energy between the precipitate and matrix and γ′ nucleation rate are dependent on factors such as solutioning temperature and cooling rate which affects the shape and number of precipitates. So information about the dissolution and deposition temperature of γ′ precipitates is necessary for design suitable heat treatment cycles in different conditions.

2- Experimental

The laboratory specimens used in this study were made from a cast ingot of nickel-based superalloy GTD-111. The ingot was melted by a vacuum induction melting furnace and then casted. To determine the starting and finishing of the γ′ solutioning temperature of γ′ precipitate in the GTD-111 cast specimens, the thermal analysis test was performed from ambient temperature to 1300 ℃ with the rate of 20 ℃/ min. According to the results of this test, different heat treatment temperatures were selected. The cast specimens of GTD-111 superalloy heat treated according to the heat treatment cycles designed in Table 1. Microstructure of specimens after etching was investigated by using of a scanning electron microscopy. Also, for measuring of volume fraction, density and size of the γ′ precipitates was used from the Clemex Image analysis software. Hardness of different heat treated specimens was measured by using Vickers micro-hardness method.

Table 1: Heat treatment cycles applied to GTD-111 superalloy

solutioning temperature (˚C)	solutioning time (min)				Cooling environment
1100	60	120	180	240	AC
1120	60	120	180	240	AC
1150	60	120	180	240	AC
1180	60	120	180	240	AC
1200	60	120	180	240	AC
1230	40	60	-	-	AC

3- Results and Discussion

The primary microstructure of the cast superalloy is a dendritic structure. Primary γ′ precipitates were created during solidification and affected from cooling rate. Non-equilibrium conditions during solidification caused non-favorable morphology and volume fraction of γ′ precipitates in the cast structure. Therefore, the effect of solutioning temperature on the variations of shape, morphology and volume fraction of γ′ precipitants in the core and inter dendritic zones was evaluated, Heat treatment according to the 1100℃/2h/AC cycle results in formation of irregular coarse cubical γ′ precipitates in both core and inter-dendritic regions

Increasing the solution temperature up to (1120 ℃/ 2h/AC), solved areas of primary γ′-precipitate between dendrite core and inter-dendritic regions were increased. The agglomeration of γ′ precipitates and changing morphology of these precipitates from cubic to oval shape.

After heat treatment at 1150℃/2h/AC, the morphology of γ′ precipitates in the dendrite core region was spherical and larger than the cast samples and heat treated samples at lower temperatures. Furthermore, the morphology of inter-dendritic γ′ precipitates was flower like.

After heat treatment at 1180℃/2h/AC, primary γ′ precipitates at the dendrite core areas were completely solved and new γ′ were precipitated during cooling to the room temperature. In the areas of inter dendritic, γ′ precipitates was not dissolved completely. The size of the remained γ′ precipitates was around 898nm that was larger than the γ′ in the as-cast and heat-treated at lower temperatures specimens.

After heat treatment at 1200℃/2h/AC, large precipitates in the dendrite core, were completely dissolved in the matrix. Due to the supersaturation of the matrix phase, the spherical γ′ precipitates were

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precipitated during cooling from 1200℃. These precipitated γ′ was coarse than formed γ′ in 1180 ℃/2h/AC specimen. At the inter-dendritic regions, the size of the remaining γ′ precipitates was reduced to 675 nm, the area-fraction of γ′ in this region was reduced also. Therefore, it can be said that the dissolution of the precipitates also occurred in the inter-dendritic regions.

Heat treatment at 1200℃/4h/AC resulted in complete dissolution of primary γ′ had not occurred. Therefore, for more complete dissolution, to achieve a higher level of homogeneity, and to dissolve initial γ′ and eutectic phases, the samples were heat treated at 1230℃ for 40 minutes. The results showed that after heat treatment at 1230℃/40min/AC, the microstructure of the alloy was significantly more uniform than previous cycles. It was also revealed that the initial γ′ particles were dissolved completely in the matrix and the number and size of the eutectic phases also reduced due to the higher dissolution rate at 1230℃ temperature.

Microhardness results showed that the microhardness did not change by the heat treatment temperature of the heat treatment process, but the hardness was affected by the area fraction of remaining γ′ precipitates and precipitated γ′ during cooling in the core and inter-dendrites regions. The highest hardness values were obtained at 1200 ℃ and the lowest at 1120 ℃ heat treated specimens respectively.