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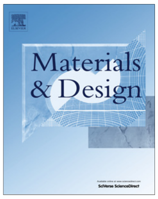

Microstructural characteristics of forged and heat treated Inconel-718 disks

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ABSTRACT

Microstructure evolution from center to edge of the as-forged and heat treated Inconel-718 disks was investigated. Specifically, the evolution of primary carbides, grain size, γ'', γ', δ, and secondary carbide particles was the focus of the current study. In fact, characterization of these microstructure features is essential for models predicting the creep and fatigue lives of the alloy. Accurate and reliable revealing of the grain boundaries in as-forged and heat treated Inconel-718 was made possible in this study by development of a new method. From microstructure investigations, nonuniformities in grain size, volume fraction, size and inter particle spacing of precipitates from center to edge were observed in both as-forged and heat treated disks. The microstructure nonuniformities resulted in significant variation in hardness from center to edge of the disks.

1. Introduction

Inconel-718 is a Ni–Fe–Cr superalloy widely used as disk material in gas turbine and jet engines with service temperatures up to 650 °C because of its high temperatures strength and corrosion resistance [1–3]. The nominal chemical composition of Inconel-718 in wt.% is 52.50 Ni–18.50 Fe–19.00 Cr–5.10 Nb–3.00 Mo–0.50 Al–1.01 Ti–0.08 C [3,4]. This alloy gains its high temperature strength mainly through precipitation of body-centered tetragonal (BCT) γ'', Ni_3Nb, dispersed in the γ matrix [1]. Also, face-centered cubic (FCC) γ', $Ni_3(Al, Ti)$, supply additional strength for the alloy [5]. γ'' usually precipitates at higher aging temperatures (720 °C) whereas γ' precipitates at lower ones (620 °C) [6]. For the fully heat treated alloy, *i.e.* solution heat treated and double aged, the volume fraction of γ'' and γ' are 20% and 5%, respectively [7,8]. The solvus temperatures of γ'' and γ' are about 900–920 °C [3]. γ'' particles are metastable and over long term exposure to temperatures above 650 °C, transform into the stable form of Ni_3Nb, *i.e.*, the δ phase, leading to degradation of mechanical properties [1,2,9]. Alloying elements such as Fe, Cr, Mo, Al, and Ti also strengthen the alloy through solid solution mechanisms [9]. In addition, MC-type carbide, M being mostly Nb, and orthorhombic δ, Ni_3Nb, precipitate at grain boundaries and inhibit grain boundaries sliding at high temperatures thereby improving creep properties [5]. Aluminum and Cr form the protective impermeable Al_2O_3 and Cr_2O_3 oxide films that supply the corrosion resistance for the alloy [9].

Inconel-718 disk is manufactured through casting, forging, and heat treatment. The microstructure changes induced during the manufacturing process affects the performance of the alloy during service. Reliable revealing of different microstructural features is a key element for process optimization and development of material based finite element models that predict the service capabilities such as fatigue and creep lives.

In order to predict the fatigue and creep lives in Inconel-718 disk, it is essential to characterize and quantify the various microstructural features in the alloy. Specifically, grain size, the morphology of primary and secondary carbides, γ'', γ', and δ precipitates, their sizes and volume fractions, as well as their inter particle spacing at the grain boundaries (δ and secondary carbides) are the key input parameters for creep life modeling [10]. Comprehensive review of the literature indicated that characterizing and quantification of all of the microstructure constituents in Inconel-718 have been rarely carried out. The focus has been mainly on grain size evolution with temperature, strain, and strain rate of deformation on *lab scale* samples where deformation conditions have been carefully controlled [11–13].

The lack of quantitative data on microstructure of Inconel-718 can be partly due to difficulties encountered in revealing various microstructure constituents. For example, at the early stages of the current study, it was found that revealing clearly the grain boundaries in solution heat treated and/or hot forged Inconel-718 was very difficult when classical approaches proposed in

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handbooks were used. Similarly, in a recent work [13], it can be observed that grain boundaries are not clearly revealed in Inconel-718 hot forged at 1100 °C and 0.1 s^{-1} to strain of 0.03 and 0.05. Lack of proper revealing of grain boundaries is an important impediment in the reliable estimation of the grain size and morphology as a function of thermomechanical processing conditions.

Hence, at the early stages of the present work a method was developed which allowed reliable and repeatable revealing of grain boundaries in samples extracted from different locations of as-forged and heat treated disks. The disks were sectioned from a nonisothermally forged Inconel-718 billet and a heat treatment was applied on one of them. Furthermore, metallography procedures were developed to reveal and determine reliably the size, volume fraction, and inter particle spacing of other microstructural features such as primary carbides, γ'', γ', δ, and secondary carbide particles in different locations of the disks. Such data are key inputs for models predicting the creep life of the disks as presented in another publication.

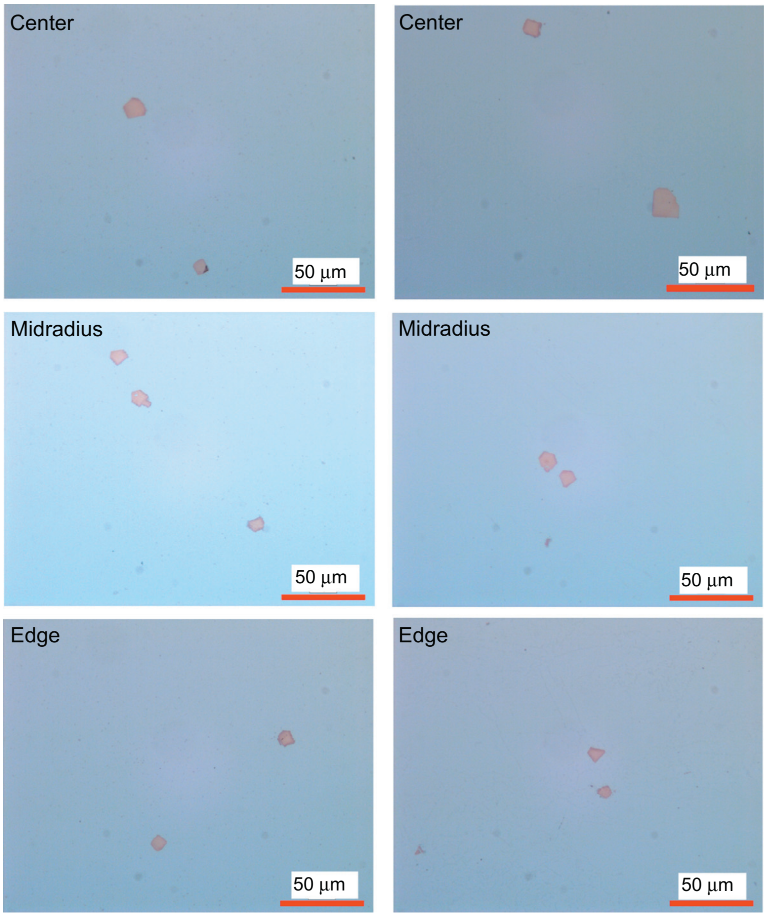
2. Experimental material and procedures

Two Inconel-718 disks, 32.4 cm in diameter were received. They were sectioned from a nonisothermally forged Inconel-718 billet. One of the as-received disks was in the as-forged condition and the other in the heat treated condition, *i.e.*, solution heat treated and double aged. The solution heat treatment was performed at 954° for 1 h followed by air cooling. The double aging was carried out at 718 °C for 8 h, followed by furnace cooling to 621 °C at a rate of 56 °C/h, second aging at 621 °C for 8 h, and then air cooling to room temperature.

Metallography samples were extracted from the center, midradius, and edge of the as-forged and heat treated disks by wire electrodischarge machining. After mounting, automated grinding and polishing procedures were used to prepare the samples for microstructure studies. The details of grinding and polishing procedures are provided in Table 1. For grinding 320, 600, 800, and 1200 SiC papers were used. After grinding, the samples were polished on a MD Nap cloth for 2 min while using 1 μm diamond suspension as polishing solution. Final polishing of the samples was carried out with colloidal silica suspension (OP-S) on a vibratory polisher for 12 h. Characterization of primary carbides was carried out in the as-polished condition using optical microscopy (OM). To reveal

Table 1
Details of grinding and polishing procedures.

Grinding/ polishing surface	Abrasive	Disk/ holder rotation speed (rpm)	Force per sample, N	Lubricant	Rotation direction of holder relative to disk	Time (min)
SiC Paper	320 Grit	200/150	25	Water	Same	1
SiC Paper	600 Grit	200/150	25	Water	Same	1
SiC Paper	800 Grit	150/150	25	Water	Same	1
SiC Paper	1200 Grit	150/150	25	Water	Same	3
MD Nap cloth	1 μm	150/150	20	Blue lubricant	Opposite	2



As-forged Heat treated

Fig. 1. As-polished microstructures of the samples extracted from the as-forged and heat treated disks presenting the primary carbides in the center, midradius, and edge.