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Influence of the Delta Phase in the Microstructure of the Inconel 718 subjected to "Delta-processing" Heat Treatment and Hot Deformed

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Abstract

Inconel 718 (IN718) is a nickel base alloy widely used in the aerospace industry due to its mechanical stability at elevated temperatures. Stable δ phase with acicular morphology weakens the IN718, however, it has been found that a spherical morphology distributed in the grain boundaries acts as an anchor preventing grain growth during hot deformation. The delta processing (DP718) is a saturation of δ phase in the alloy by thermal treatment followed by thermomechanical working to control the grain growth and morphology during deformation. Two specimens (A and B) of IN718 alloy were solubilized for 1h at 1100°C WQ and aging at 900°C for 24hWQ thermal treatment, following by thermomechanical deformation. Sample A was deformed at 0.001 s -1 and sample Bat 0.01 s-1, both deformations were carried out at 960°C and the final microstructures were characterized by optical microscopy and scanning electron microscopy (SEM) in order to evaluate morphology and grain size distribution.

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Keywords: Delta processing, Inconel 718, delta phase δ

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1. Introduction

The IN718 is an alloy of the nickel-based family; it is widely used in the aerospace and power generation industries, due to its excellent mechanical properties at elevated temperatures and good corrosion resistance. IN718 is reinforced by solid solution and precipitation of second phases, mainly by different heat treatments. The hardening mechanism is mainly contributed by the phase precipitates γ' Ni3Al (cubic or spherical shape) and γ” Ni3Nb. The metastable γ” phase transforms to the Ni3Nb-δ phase during exposure at temperatures above 650°C. In the manufacturing processes of superalloys, the microstructure control is critical for the development of optimal mechanical properties [1].

The properties of IN718 are sensitive to the microstructure, particularly on grain size. Stable δ phase presence promotes grain refinement during hot working and prevents grain growth during heat treatment. Spherical δ phase influences the mechanical properties as well as creep resistance [2].

It has been reported that the DP718 can produce fine grain uniformity and improved properties required for advanced components of gas turbines and aerospace components[3]. Compared to conventional solubilization and direct aging processing for transformation and precipitation of phases, it may provide a significant improvement in the strength properties and low cycle fatigue, by controlling the grain size during forging .The DP718 was derived from a process known as "Minigrain" used mainly in the conversion process ingot-billet-bar[4].

The objective of this work is to find a relationship between the grain size and δ phase formation in a IN718 subjected to DP718.

2. Experimental Procedure

IN718 specimens were obtained from a cylinder of 150mm high and 100mm diameter deformed in two steps. First step: 50% deformation at 1000°C and Second step: 23% deformation at 980°C with a final height of 40 mm as shown in Figure 1. The principal chemical composition of IN718: Ni 53.79, Cr 17.96, Fe 18.72, Nb 5.41, Al 0.51, Ti 1.01, Mo 2.88, Nb + Ta 5.42, weight percent.

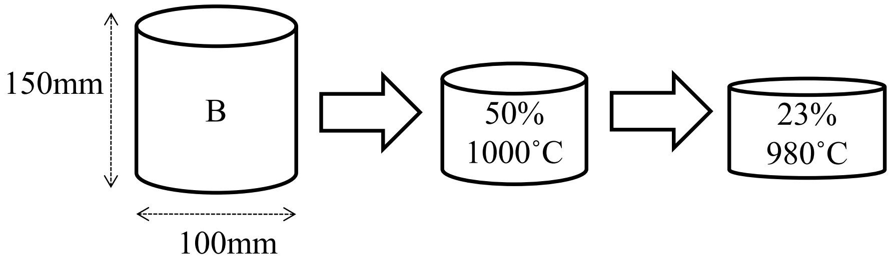

Figure 1. Deformation conditions hydraulic press.

After deformation the samples were cut in half and a slab was obtained which underwent macro-etching to obtain deformation flow patterns. Grain size regions at the cross section of the cylinder are indicated in Figure 2. Flow localized deformation is observed in the central area and edges, while the upper and lower zones show a limited flow due to heat exchange by the contact of the workpiece with the tools and friction at the interfaces. Samples A and B (Figure 2a)) from the top of the slab were machined and the specimens were subjected to DP718.

Table 1 shows a comparison between the standard precipitation heat treatment and DP718 heat treatment used in this research. Specimen A was deformed at 0.001s-1 and B at 0.01s-1, both reductions were carried out at 960°C.

Table 1 Comparison of thermal treatment (standard and DP718).

Heat Treatments	
Solubilized treatment	Age Treatment
1 Standard- 1100°C 1h/ AC	720◦C, 8h 50◦C/30min 620◦C, 8h/ AC
2 DP718- 1100°C 1h/ WQ	900°C x 24H WQ

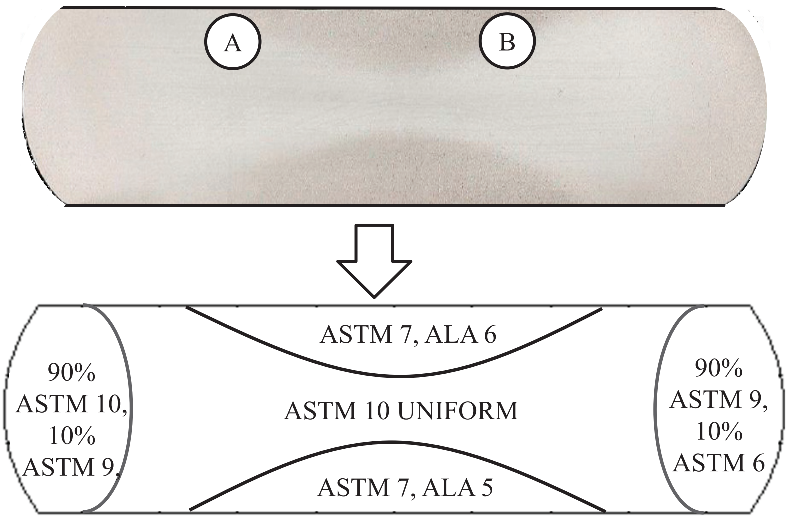

Figure 2. Schematic cross-sectional area of the deformed cylinder, a) chemical macroetch image, A and B samples b) scheme of average grain sizes.

3. Results

The evolution of microstructure for specimen A is shown in Figure 3; it exhibits a uniform grain size ASTM 7 after 2 forging steps from industrial wrought condition and before heat treatment (DP718)(a), after solubilized and aged (DP718) it can be seen in b) and d) a grain size increase to ASTM 3 As Large As (ALA) 2 with formation of δ widmanstätten structure, while a grain size refinement ASTM 30%5, 70%4 after thermomechanical work it is showed in c) and e),in addition a intergrowth of bands of δ widmanstätten structure, higher twins concentration, recrystallized grains and δ precipitates concentration at grain boundaries were observed.

The microstructural evolution of sample B is presented in Figure 4,where a) shows a metallographic image from a deformed slab and a non-uniform grain size ASTM 90%11, 10%8 ALA 6 was measured, this region exhibits localized flow deformation, therefore the grain size is much finer than B specimen, b) and d) show a grain size ASTM 6 ALA 5 with higher concentration of twins and intergrowth bands of δ widmanstätten structure after heat treatment (DP718), c) and e) show a finer grain size ASTM 70%7, 30%6 with intergrowth of bands of δ widmanstätten structure in the compression direction. These results are in agreement with previous investigations [5,6].

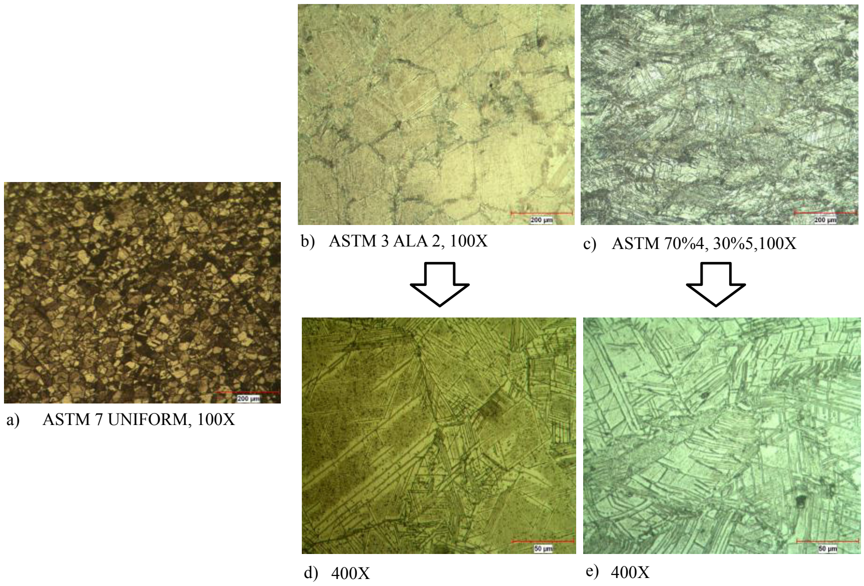

Figure 3. Microstructural evolution of specimen A; a), b)before and after heat treatment (DP718) at 100X respectively, c) after deformation at 100X, d)after heat treatment (DP718) at 400X and e) after deformation at 400X.

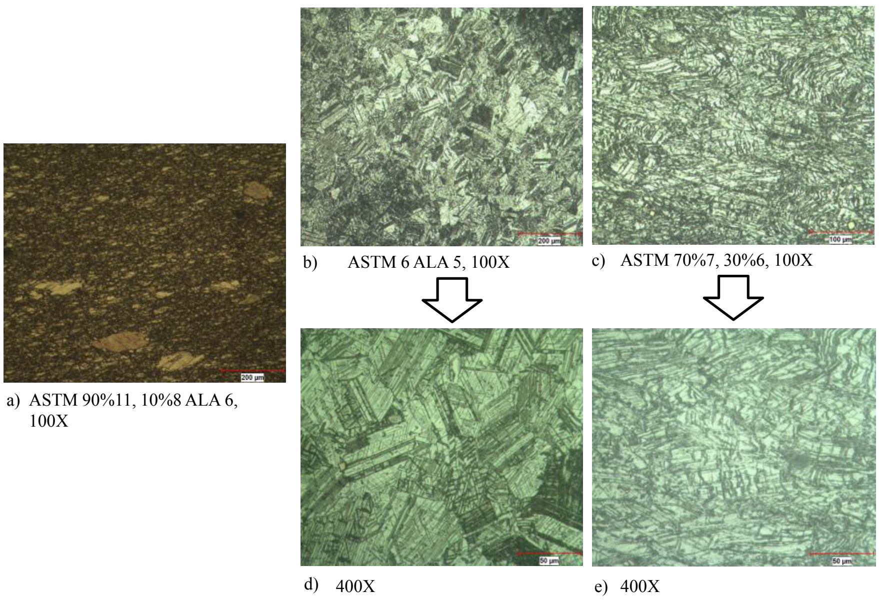

Figure 4. Microstructural evolution of specimen B; a), b) before and after heat treatment (DP718) at 100X respectively, c) after deformation at 100X, d) after heat treatment (DP718) at 400X and e) after deformation at 400X.

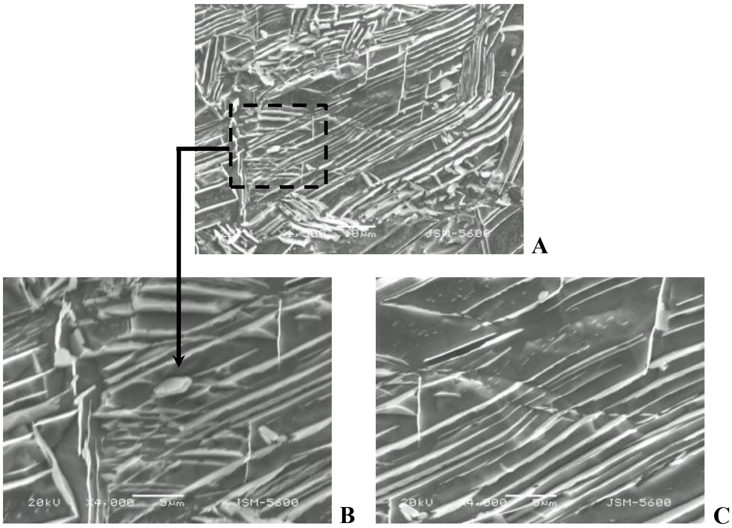

Figure 5.SEM metallographic images of A specimen; a) 1500X, b) and c) 4000x

The electron microscope images (SEM) for the sample A are presented in Figure 5; a) δ phase needle type morphology and some δ phase breakage was found due to deformation at high temperatures, b) and c) show magnified images of δ phase needles formation. Semiquantitative analysis (EDX), exhibits the Nb amount in weight percent of 22% in the selected precipitated, however a more accurate element study has to be obtained to validate the Nb content in the δ phase.

B specimen SEM images are shown in Figure 6 with even clearer images of δ interface in a δ widmanstätten structure; a) needle acicular morphology δ phase was observed, although δ phases spherical morphology spread across the matrix are also observed. The upper left box shows the needles δ phase breakage due to hot pressing work, b) shows in more detail the acicular and spheroidal morphologies and needles δ phase fragmentation, this is consistent with previous research [7].

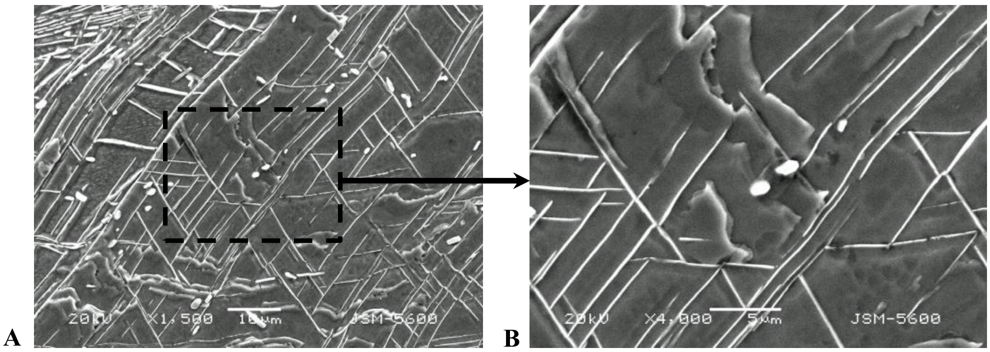

Figure 6. SEM metallographic images of B specimen; a) 1500X, b) 4000X

4. Conclusions

Metallographic characterization by optical microscopy indicates a grain growth after heat treatment (DP718) with a grain size control after hot deformation due to δ phase distribution at grain boundaries.

Metallographic characterization by SEM and EDX indicates the saturation of δ phase due to DP718 processing. The presence of δ widmanstätten banded structure and their fragmentation during deformation suggests that δ needle-like can change to spheroidal morphology and the presence of δ phase in both grain boundaries and within the grains can control the grain growth during high temperature compression.

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