Small-scale Experiments on the Recrystallization of Alloy 718 and their Transferability to Industrial Production

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Introduction

Nickel-based alloy 718 is the most widely used superalloy in aerospace applications [1]. Precise grain size control during hot deformation is essential for ensuring the mechanical integrity of aerospace-grade components. Despite extensive knowledge of hot deformation and recrystallization behavior, producing billet material with the required microstructure remains challenging. At lower temperatures, the presence of the δ phase can significantly restrict dynamic recrystallization [2]. In contrast, deformation above the δ-solvus temperature promotes complete recrystallization but may also lead to excessive grain growth beyond specification limits [2]. Therefore, thermomechanical processing at lower temperatures combined with subsequent heat treatments is often required to achieve the desired microstructure, necessitating a thorough understanding of metadynamic recrystallization and grain growth.
Grain growth in alloy 718 has already been studied with a novel experimental setup: a DSI Gleeble thermomechanical simulator integrated with a laser-ultrasound system [3]. It was shown in [4], that dynamic recrystallization in steels can be studied in situ with a comparable setup. In the present study this approach is applied to metadynamic recrystallization in alloy 718. The results are compared to microstructural analyses of billets during and after ingot breakdown.

Material and method

Cylindrical specimens (12 mm height, 10 mm diameter) were extracted from a 350 mm diameter nickel-based alloy 718 billet and tested in a DSI Gleeble 3800 thermomechanical simulator (strain rate of 1 s^{-1}, true strain 0.5). A set of samples was held at the deformation temperature for 600 s prior to quenching to investigate metadynamic recrystallization (MDRX). An additional set was deformed at 900°C and subsequently heated to 1000°C and 1020°C, simulating deformation during ingot breakdown followed by a furnace heat treatment.
Grain size evolution was monitored during testing using GLUS, a combination of Gleeble testing and in situ laser ultrasonics (LUS) for continuous microstructural characterization. The principles of grain size determination from LUS measurements and the implementation of GLUS during deformation are described in detail in [5] and [4], respectively. Since the calibration curve reported in [5] was established using a wide variety of carbon steel and stainless steel, a thermal correction was applied to account for the high nickel content of alloy 718.
Selected specimens were sectioned, ground, polished, and characterized using a Zeiss Gemini SEM 450 scanning electron microscope equipped with an EBSD detector. The resulting scans were analyzed with AZtec Crystal and the mean line intercept grain size calculated with Olympus Stream software.

Results

Microstructural analysis using SEM revealed a uniform mean grain size of 26 µm when twin boundaries were excluded and 14 µm when twin boundaries were included. The IPF-Z map of the initial condition is shown in Figure 1.

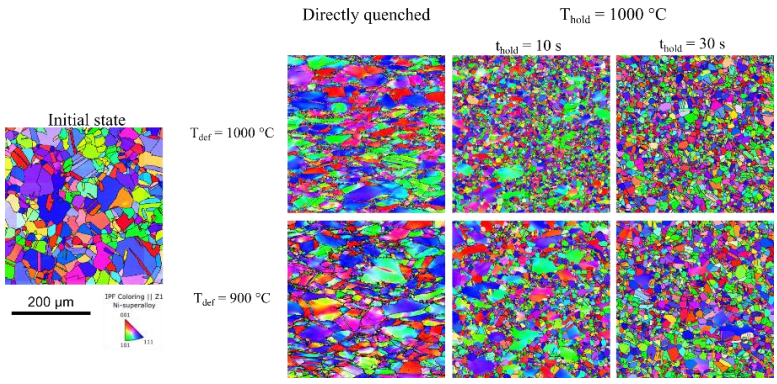

Figure 1: Inverse pole figure maps form EBSD scans of alloy 718 in the initial state and after deformation at 1000°C and 900°C with different subsequent holding times at 1000°C.

In-situ GLUS measurements showed that, at a deformation and holding temperature of 900°C, no changes in the microstructure occurred during the 600 s holding period (Figure 2a). In contrast, deformation and subsequent holding at higher temperatures ($T_{deformation}$ = $T_{holding}$ = 1000°C, 1030°C, and 1050°C) initially resulted in a decrease in grain size due to recrystallization, followed by an increase after a few seconds as a result of grain growth. The time required for the completion of recrystallization, defined as the time to reach the minimum grain size, decreased with increasing temperature, reaching 7 s, 5 s, and 2 s at 1000°C, 1030°C, and 1050°C, respectively (Figure 2a). After 600 s of holding, the final grain size increased from 14 µm at 1000°C to 30 µm and 35 µm at 1030°C and 1050°C, respectively.

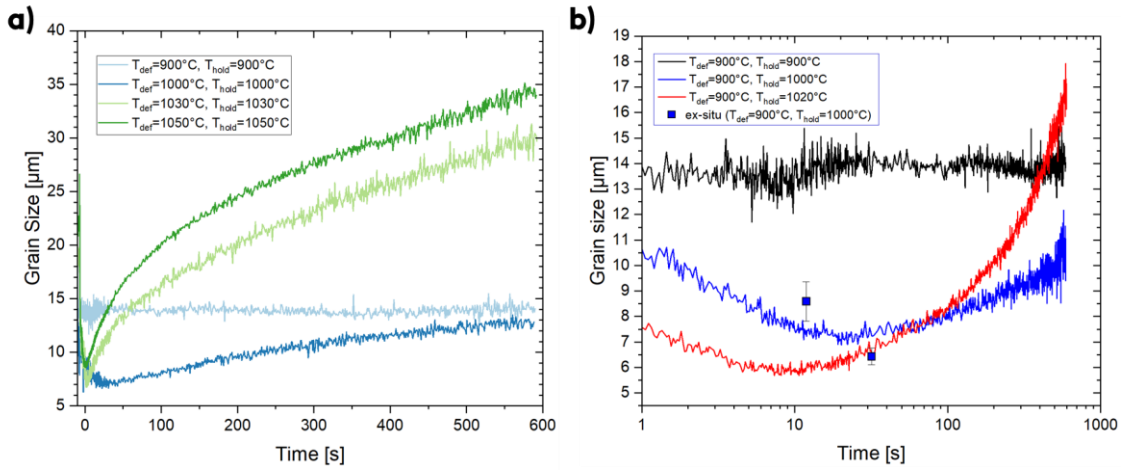

Figure 2: Grain size evolution determined from in-situ GLUS measurements (lines) and ex-situ measurements (squares) as a function of holding time. a) Results of tests with T_{def} = T_{hold}. b) Results of tests with T_{def} =900°C and subsequent holding at different temperatures.

Deformation at 900°C followed by holding at 1000°C and 1020°C for 600 s exhibited similar trends: increasing the holding temperature reduced the time required for the completion of metadynamic recrystallization and increased the final grain size (Figure 2b). Selected samples were deformed at 900°C and subsequently held at 1000°C for 10 s and 30 s before quenching to enable ex-situ grain-size analysis by SEM. The results show good agreement with the GLUS measurements, as illustrated by the squares in Figure 2b.

The same observation was made in billets during and after ingot breakdown. Significant cooling near the surface resulted in incomplete recrystallization, whereas the billet center exhibited complete recrystallization due to the higher temperatures maintained in this region. For all regions full recrystallization was achieved after subsequent heat treatment.

Discussion

The experiments show that no significant metadynamic recrystallization occurs during holding at 900°C after deformation. In contrast, holding at 1000°C results in recrystallization, irrespective of whether the deformation temperature was 900°C or 1000°C. This behavior can be attributed to the onset of δ phase dissolution, which promotes the growth of recrystallized grains. Higher temperatures facilitate the recrystallization process and accelerate its completion. However, the complete dissolution of the δ phase at temperatures above 1020°C leads to pronounced grain growth.

A comparison of the in-situ GLUS measurements with the ex-situ microstructural analyses shows good agreement. Consequently, GLUS enables a highly detailed investigation of the recrystallization process while significantly reducing the number of experiments required for comprehensive microstructural characterization.

The knowledge gained from these small-scale experiments can be used to optimize the large-scale ingot-breakdown process.

References

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