Materials Science & Engineering A 662 (2016) 303–307

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Comparison of intergranular strain formation of conventional and newly developed nickel based superalloys

J.N. Wagner [a,*,1], M. Hofmann [b], S. Van Petegem [a], C. Krempaszky [c], M. Hoelzel [b], M. Stockinger [d]

[a] Paul Scherrer Institute, Materials Science and Simulation, NUM/ASQ, 5232 Villigen PSI, Switzerland
[b] Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II), TU München, Lichtenbergstr. 1, 85747 Garching, Germany
[c] Lehrstuhl für Werkstoffkunde und Werkstoffmechanik, TU München, Boltzmannstr. 15, 85747 Garching, Germany
[d] Böhler Schmiedetechnik GmbH & Co KG, Mariazeller Straße 25, 8605 Kapfenberg, Austria

ARTICLE INFO

Article history:
Received 24 November 2015
Received in revised form
2 March 2016
Accepted 14 March 2016
Available online 15 March 2016

Keywords:
Nickel based superalloy
Neutron diffraction
Mechanical characterization
Intergranular residual strain
In-situ tension test
Residual stresses

ABSTRACT

In this paper we report about the formation of intergranular strains in superalloy Haynes 282 studied by neutron diffraction during uniaxial tensile testing. The results gained from the initial bar material are compared to results of a peak-aged sample state at ambient temperature. A comparison of the results with data from a fully aged IN 718 alloy sample shows that intergranular strains are much lower in Haynes 282 than in the conventional nickel based superalloy. In contrast to IN 718 the formation of intergranular residual strains between bar material and heat treated sample state shows no significant differences. The relevance of the results to the macroscopic residual stress analysis by neutron diffraction on both continuous wavelength and spallation neutron sources is discussed in detail.

1. Introduction

Conventional nickel based superalloys are mainly used for high temperature applications. For example Inconel 718 (IN 718, chemical composition given in Table 1) shows excellent mechanical properties (yield strength, ductility, creep strength) at temperatures up to 650 °C and is thus often used as structural materials in the high temperature regions of gas turbines. In polycrystalline materials the mechanical behavior is based on the presence of a multitude of precipitates within the fcc matrix phase, namely γ' (fcc, $Ni_3(Al,Ti)$), γ'' (bct, Ni_3Nb) and δ-phase (orthorhombic, Ni_3Nb) [1].

Increasing effort has been put into developing new materials in the last couple of years, in order to raise the operation temperature in power engines for increased fuel efficiency. New materials have to combine high temperature creep strength, oxidation resistance and thermally stable microstructures with good fabrication properties, such as ductility and weldability. Besides new material classes, such as Nb-Si-X or Re based alloys, the recently developed nickel based superalloy Haynes 282 is considered as a substitute for conventional nickel based superalloys like Rene-41 and Waspaloy [2,3]. The machinability of Haynes 282 for example by radius end milling is comparable to the machinability of aged IN 718 [4] while having very good creep resistance [2]. The excellent mechanical properties of Haynes 282 are based on a high solid solution hardening favored by the alloying elements Co, Cr and Mo. The chemical composition of Haynes 282 is given in Table 1. Aging of this alloy leads to the precipitation of the nano crystalline γ' phase (fcc, $Ni_3(Ti,Al)$) [5]. Cast Haynes 282 also exhibits the tetragonal σ phase (Cr, Ni, Mo and Co) [6].

It is well known that additional phases in materials may influence the build up of residual strains on different length scales. The proper determination of macroscopic stresses is crucial for predicting the service life time of components. A powerful method for the determination of stresses and strains is neutron diffraction. Due to the high penetration depth of neutrons information may be gained non-destructively up to a depth of several centimeters. It turned out, that in the diffractometric determination of macroscopic stresses, the residual stresses and strains occurring on the microstructural level between grains (intergranular stresses/strains) may lead to an erroneous estimation of macroscopic residual stresses and thus of the service life time predictions of high performance components [7,8]. Consequently, a lattice parameter, which is not or only little affected by intergranular strains should be used for macroscopic residual stress analysis by diffraction. For

* Corresponding author.
E-mail address: julia.wagner@kit.edu (J.N. Wagner).
[1] Present address: KNMF and IAM-WK, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

http://dx.doi.org/10.1016/j.msea.2016.03.059
0921-5093/

Table 1
Chemical composition of Haynes 282 and IN 718 in wt%.

	Ni	B	Cr	Co	Fe	Mn	Mo	C	Al	Ti	W	Si
IN 718	Bal.	0.005	19	–	19	–	3.1	0.03	0.55	0.95	–	–
Haynes 282	Bal.	0.003	19.7	10.1	0.2	0.03	8.4	0.06	1.5	2.1	$\lesssim$0.01	$\lesssim$0.05

Haynes 282 the formation of intergranular and interphase residual strains and stresses is largely unknown. The evolution of intergranular strains with increasing stress is directly observable in in-situ diffraction experiments, where a defined macroscopic stress state, applied through a mechanical test rig, is being subtracted from the measurement results [9]. The remaining strains are caused by intergranular stresses [10].

In this study we report on the formation of intergranular strains in the nickel based superalloy Haynes 282 studied by neutron diffraction during tensile testing. The results of the bar material and the fully aged material are compared to results obtained on fully aged IN 718 samples. The {*hkl*} dependent Young's modulus is discussed in detail for all three sample states. In contrast to observations made for IN 718 the formation of intergranular strains seems to be not affected by the aging process. Additionally, accumulation of intergranular strains is less pronounced in Haynes 282 than in IN 718. Conclusions are drawn regarding the impact of the results on the macroscopic residual stress analysis by neutron diffraction.

2. Material

To study the evolution of intergranular micro stresses under mechanical load and temperature, round tensile test specimens of Haynes 282 were produced by EDM (electrical discharge machining). One sample of the initial bar material was used in its original state to serve as reference material. Further test samples were solution annealed at 1080 °C for 2 h and air cooled (AC) down to room temperature. The annealing was followed by an aging heat treatment: 8 h at 780 °C followed by AC to room temperature. The heat treated samples are referred to sample state HeatTreat, whereas the bar material is referred to sample state BarMaterial. All samples have a gauge diameter of 6 mm and a gauge length of 40 mm. For comparison similar round tensile test specimens of IN 718 were tested. The samples were heat treated with the sequence: 2 h at 975 °C followed by AC, 8 h at 718 °C, cooled to 621 °C within 2 h, hold there for 8 h followed by AC. The samples have a gauge diameter of 6 mm and a gauge length of 40 mm.

2.1. Sample microstructure

High resolution powder diffraction patterns were recorded at the neutron powder diffractometer SPODI [11] to characterize the microstructure of the two Haynes 282 samples and the IN 718 sample. The patterns were analyzed by Rietveld (aged sample state of Haynes 282) and LeBail (bar material of Haynes 282 and IN 718 sample) refinement routines using the software package FullProf [12].

Haynes 282. Fig. 1 shows the patterns for Haynes 282. Sample state HeatTreat shows clearly superlattice Bragg reflections resulting from the precipitated γ' particles. The lattice parameter of the γ matrix slightly changed due to the precipitation of γ' from $a_{bar} = 3.5959$ Å to $a_{HT} = 3.5917$ Å (Table 2). The lattice parameter of the fcc γ' phase is $a_{\gamma'} = 3.5909$ Å resulting in a lattice mismatch of the γ' phase relative to the γ matrix of only 0.03%. The volume fraction of the γ' phase is about $V_{\gamma'} = 12.5\%$ ($V_{\gamma} = 87.5\%$).

IN 718. In the neutron diffraction pattern of IN 718 Bragg reflections of γ' and δ phase could be identified. The lattice parameters of the γ matrix ($a_{IN\ 718} = 3.5972$ Å) and the γ' phase ($a_{\gamma'} = 3.5900$ Å) result in a lattice mismatch of 0.20% (Table 2). The microstructure of this sample state is described in greater detail in [13].

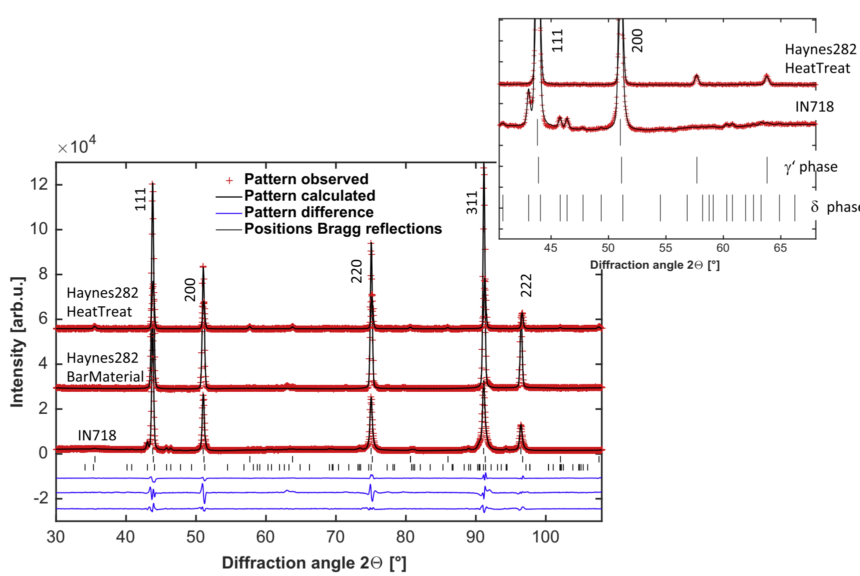

Fig. 1. (left) High resolution neutron diffraction powder patterns and the results of corresponding LeBail fits of sample states HeatTreat and BarMaterial of Haynes 282 and the heat treated state of IN 718. The markers indicate the Bragg reflections of the γ matrix (top marker line), for the γ' phase (second marker line) and for the δ phase (bottom marker line). The inset on the right shows a zoom in of the left patterns around the γ matrix reflections (111) and (200). For the heat treated state of Haynes 282 clear reflections of the γ' phase are observable. For the IN 718 sample γ' phase is only seen by asymmetries of the γ reflections, however clearly visible are δ phase reflections.