Experimental report

23/04/2024

Proposal: 1-02-364 **Council:** 10/2022

Title: Deformation mechanisms in Ti-5Al-5Mo-5V-3Cr

Research area: Materials

This proposal is a new proposal

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Samples: Ti-5Al-5V-5Mo-3Cr

Instrument	Requested days	Allocated days	From	To
D20	4	3	12/05/2023	15/05/2023
SALSA	6	0		

Abstract:

We aim to carry out neutron diffraction studies on Ti-5Al-5V-5Mo-3Cr under mechanical load using our own 50 kN tensile rig. Samples prepared by different thermal processing routes, namely "water quech" (WQ) and "beta-annealed, slow cooled and aged" (BASCA) will be investigated. The processing routes result in different microstructures and phase compositions.Thus, the effects of initial microstructure and phase composition on stress-induced phase transitions as well as the evolution of lattice strains and textures will be illuminated. We aim to determine diffraction elastic constants, single-crystalline elastic constants and the stress distribution between the phases in the elastic regime. In addition, the proposed experiments are necessary to establish an EPSC model describing the mechanical behavior. We require neutron diffraction for this task since neutrons offer much better grain statistics compared to X-rays and we expect that even coarse grained samples processed by BASCA route can be analyzed. This is of particular importance for the determination of elastic constants as well as EPSC modelling

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Experimental Team (Users): Markus Hoelzel, Michael Hofmann, Erik Walz (Technical University of Munich)

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Instrument: D20

Background

Titanium alloys are widely used in aircrafts, biomedical applications, chemical and offshore industries and consumer products as they offer high strength at low weight in combination with good corrosion resistance. The near β-Ti alloy Ti-5Al-5V-5Mo-3Cr was developed for applications in aircrafts, in particular landing gears. The deformation mechanisms of Ti-5Al-5V-5Mo-3Cr need to be understood in detail with respect to the microstructure and phase composition. In-situ neutron diffraction studies enable important insights into the deformation mechanisms of alloys. In particular, phase transformations, evolutions of texture and strains can be observed directly under the influence of applied stress.

An in-situ XRD synchrotron investigation of water-quenched (pure β) Ti-5Al-5V-5Mo-3Cr revealed the phase transformation behavior under uniaxial compression [1]. This work yielded a quantitative analysis of phase fractions as function of strain and the texture analysis regarding the orientation relationship between α'' and β phases as well as conclusions for the load partitioning between α'' and β phases. Despite this profound work, there are still important open questions and research needs. In particular, a quantitative analysis of the load transfer between α'' and β phases during the different stages of elastic and plastic deformation would be desirable. In addition, the investigations should be extended to well-known processing routes like solution treated and aged" (STA) or "beta-annealed, slow cooled and aged" (BASCA). These thermal treatments result in a α (*$P6_3/mmc$*) + β (*Im-3m*) microstructures, enabling higher ductilities compared to water quenched (WQ, pure β) samples.

Preliminary Work

Diffraction studies on various titanium alloys under mechanical load were successfully performed on D20 to obtain diffraction elastic constants and all single-crystalline elastic constants in both α and β phases using model assumptions [2]. The determination of single-crystalline elastic constants and the load partitioning between the phases, as well as EPSC modelling, has been carried out by a self-designed software "DISEMM"[3], which is used also for the proposed studies.

Different thermal treatments (WQ, STA and BASCA) on Ti-5Al-5V-5Mo-3Cr samples have been applied to achieve diverse microstructures leading to altering mechanical properties. Microstructural investigations were carried out by electron microscopy and EBSD. Using a tensile rig it has been observed that STA treatments offer the ultimate tensile strength while the BASCA process route leads to higher ductility. Diffraction studies on STA samples by synchrotron XRD under mechanical load revealed phase fractions, single-crystalline elastic

constants of both α and β phases as well as the stress distribution between these phases. However, the XRD analysis of WQ and BASCA samples is significantly impeded by grain statistics since these thermal processing routes lead to coarse grains.

Experiments and Data Treatment

Experiments were carried out on D20 using the Ge115 monochromator at 90° for 1.54 Å. We used our own 50 kN tensile rig (Fig. 1) on Ti-5Al-5V-5Mo-3Cr samples of 6 mm diameter prepared by "BASCA" heat treatment and water quench, respectively. In the elastic regime the tensile rig was used in load controlled manner but changed to position controlled before reaching the plastic regime. As a result of the collaboration between the instrument control groups at MLZ and ILL, the main parameters of the tensile rig (load, position, extension, chi) could be controlled directly from the NOMAD software on D20. This was made possible by the SECoP interface.

The data were analysed using the Rietveld programs MAUD and FullProf, in particular for the phase fractions. Our self-designed software DISEMM [3] was used to obtain diffraction elastic constants, single-crystalline elastic constants and phase stresses, i.e. quantifying the load partitioning in the phases during loading in the elastic and plastic regime. Based on the measured lattice strains and obtained elastic constants, phase fractions and texture an EPSC modelling will be set up to analyze activities of slip systems as function of strain.

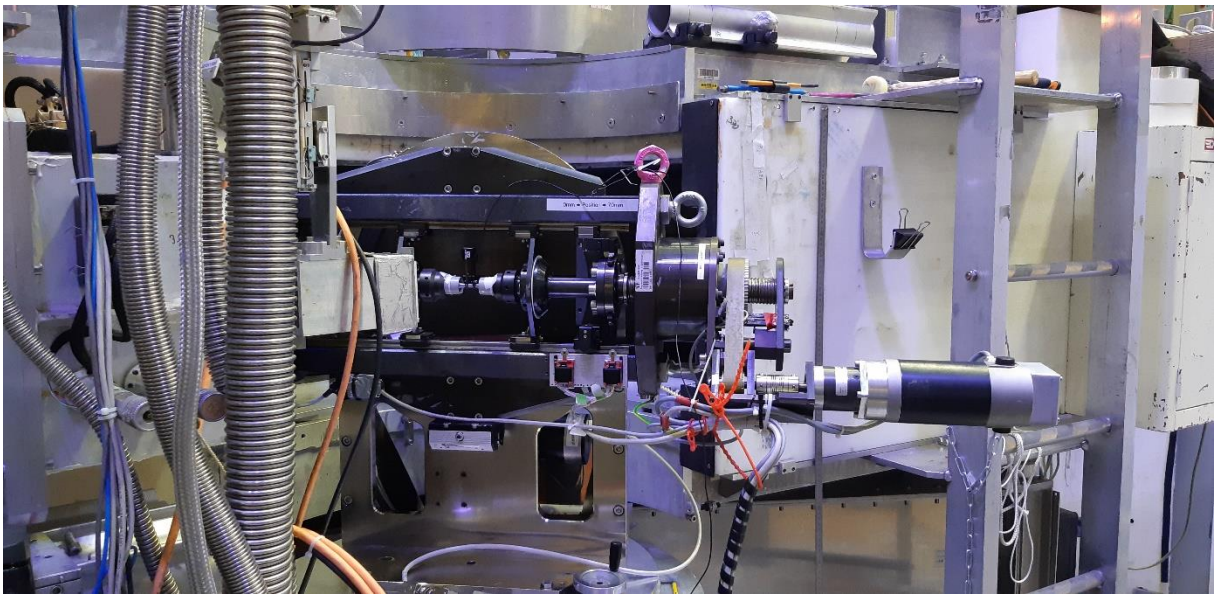

Fig 1: The rotatable load frame on diffractometer D20

Results

The results of the study will be published in detail in a peer-reviewed journal. For this reason, only a few qualitative results are presented here. In contrast to our previous synchrotron studies, even the very coarse grain samples did not show any texture effects - in terms of grain

statistics. This allowed the data to be evaluated in a straightforward manner. The elastic constants derived for the alpha and beta phases fit very well with our previous study on Ti-6246 samples. As the Ti-5553 samples treated via the STA and BASCA processing routes have higher amounts of beta phase compared to Ti-6246, there is a greater load transfer between these phases. If the elastic constants obtained in different two-phase titanium alloys are corrected according to the load distribution between the phases, the elastic constants obtained are in fairly good agreement, despite differences in chemical composition and microstructure. The elastic constants are used as basic input parameters for an elasto-plastic self-consistent modelling to describe the lattice strains over the entire elastic and plastic regime.

Acknowledgement

We gratefully acknowledge the support of the ILL staff in carrying out the experiment and implementing our tensile rig into instrument control.

References

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[2] Heldmann, A., Hoelzel, M., Hofmann, M., Gan, W., Schmahl, W.W, Griesshaber, E.,Hansen, T., Schell, N. & Petry, W. (2019). J. Appl. Cryst. 52, 1144–1156.

[3] Heldmann, A., Hofmann M., Hoelzel, M, J. Appl. Cryst. (2022). 55, 656–662