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On a Possibility of High-Resolution Neutron Scattering Observations of TiAl Substructure

P. Mikula [1,a], A. Michalcová [2], V. Ryukhtin [1]

[1] *Nuclear Physics Institute ASCR, 250 68 Řež, Czech Republic*
[2] *Department of Metals and Corrosion Engineering, University of Chemistry and Technology, 166 28 Prague 6, Czech Republic*
[a] *mikula@ujf.cas.cz*

Abstract: In this contribution, we present the feasibility of using two unconventional neutron scattering methods, namely, high-resolution neutron diffraction and small-angle neutron scattering, for substructure studies of TiAl alloys. The first one permits the finer studies of the diffraction line profiles and the second one the size distribution of pores on a rather large scale. The feasibility experiments were carried out on the three TiAl samples of the $\phi = 9$ mm diameter which were made from the 3D printed material of gamma titanium aluminides (Ti48Al2Cr2Nb) loaded on the bulk Ti substrate.

Keywords: neutron diffraction; small-angle scattering; TiAl alloy; porosity; plastic deformation.

1 Introduction

Thanks to their excellent properties (e.g. low density, superior strength, creep, and oxidation resistance, the γ-TiAl alloys are considered as one of the most promising materials fulfilling the demands for next-generation high-temperature materials in the aerospace, automotive and energy industries etc. [1, 2]. The material density of γ-TiAl alloys is approximately half of the conventional Ni-based superalloys, their use can significantly reduce the weight of aircraft and automobile engines, and therefore, also to decrease the emission of greenhouse gases, as well as reduce fuel consumption. It is clear that much attention is paid to the investigation of the influence of the technological preparation of the TiAl alloys on their properties strongly dependent, naturally, on their structure. In our contribution, we present the results of the first studies of the high-resolution neutron powder diffraction profiles and porosity by small-angle neutron scattering (SANS) on three samples of TiAl alloy in relation to their technological preparation. However, the problem could be that Ti and Al have an opposite sign of the neutron scattering amplitude making a relatively small structure factor for diffraction on the crystalline grains resulting in a low detector signal.

2 Experimental Details and Results

The TiAl samples of the cylindrical form, all of a diameter of ϕ=9 mm, were prepared. The manufacture of specimens was carried out by using a printing device InssTek MX-LAB producing the spot size, the height of the layer and the hatch distance. Laser power, speed of the printing and dwell time were 130 W, 849 mm/min and 3.5 sec, respectively. Parameters related to the samples were: Both S1 (a preheat of the platform on 500 °C) and S2 (without a preheat) - the 800 mm spot size, the 150 mm height of the layer using the cladding head SDM 800 and the 500 mm hatch distance and S3 (no preheat) - the 400 mm spot size, the 250 mm height of the layer using the cladding head SDM 400 and the 300 mm hatch distance.

2.1 Neutron Diffraction

The neutron diffraction experiment was carried out by a high-resolution three-axis setting as schematically shown in Fig. 1 [3-5]. Following the sketch (for small widths of the samples), a maximum resolution can be

achieved for minimal dispersion of the whole system which can be achieved by the optimization of the curvature of the bent perfect crystal monochromator and analyzer [3]. The diffraction profiles are obtained by rocking the BPC analyzer and registering the detector signal for individual angular steps.

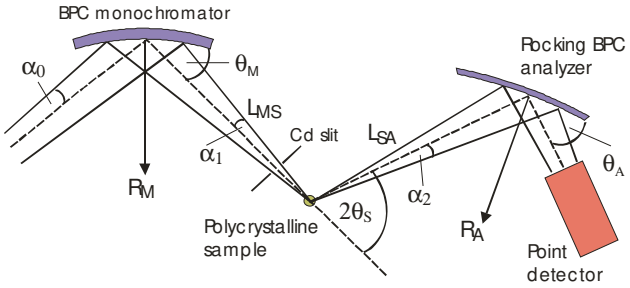

Fig. 1: Three-axis diffractometer setting employing BPC monochromator and analyzer as used in the experiment (R_M, R_A - radii of curvature, θ_M, θ_A - Bragg angles and L_{MS} and L_{SA} - distances).

2.2 Small-Angle Neutron Scattering (SANS)

Figure 2 shows the scheme of the high-resolution SANS diffractometer with a PSD detector [6, 7]. It is designed for the measurements of neutron small-angle scattering in the high Q-resolution mode. In contrast to the conventional double-crystal arrangements, the fully asymmetric diffraction geometry on the elastically bent Si analyzer is employed in order to transfer the angular distribution of the scattered neutrons to the spatial distribution. Then, it enables to analyze the whole scattering curve by a one-dimensional position sensitive detector. The instrument is mainly suited to the investigation of structural or compositional inhomogeneities in materials in the size range of 0.05 μm – 2 μm, mainly porous materials and large precipitates in alloys. The remote control of the curvatures of the monochromator and analyzer crystals makes it possible to tune the instrument resolution easily in the Q range from $2\text{x}10^{-3}$ to $2\text{x}10^{-1}$ nm^{-1}, according to the expected size of investigated inhomogeneities.

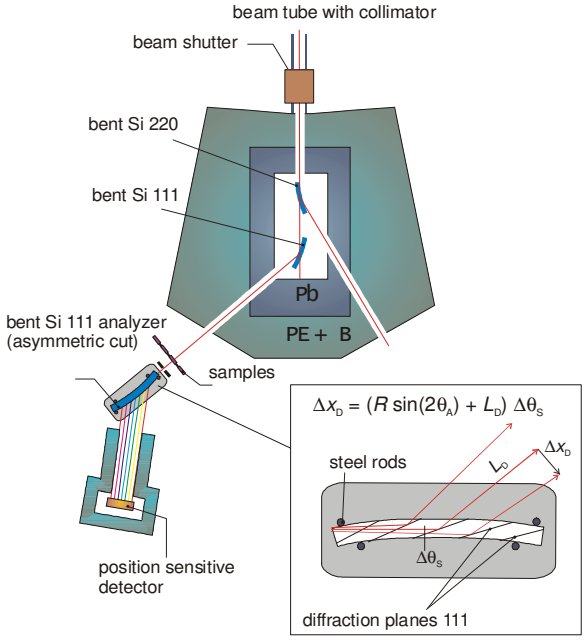

Fig. 2: Schematic diagram of the high-resolution double-bent-crystal SANS diffractometer [6, 7]. The inserted part shows the transformation of the scattering angular deviation on the position coordinates.

2.3 Experimental Results

2.3.1 Diffraction Analysis

First, a powder diffraction spectrum was taken on one of the samples, in order to see the basic structure of the material (see Fig. 3). For this we used medium-resolution powder diffractometer MEREDIT [8] also installed at the Řež's reactor. The analysis of the spectrum confirmed the existence of the single γphase of the TiAl alloy. Then, we analyzed the second peak with the high-resolution setting. Figure 4 shows the analyser rocking curves demonstrating how the technology preparation of the samples could reflect their *FWHM*s.

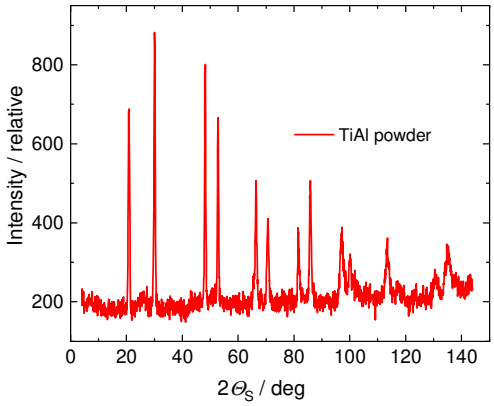

Fig. 3: Powder diffraction spectrum taken on the TiAl powder sample.

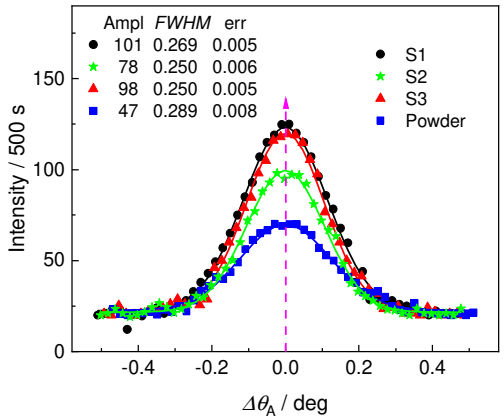

Fig. 4: Analyzer rocking curves related to the individual TiAl samples of the diameter of ϕ = 9 mm: (a) – sample S1, (b) – sample S2, (c) – sample S3 and (d) – powder sample.

2.3.2 SANS Analysis

Figure 5 shows the size-distribution functions $D(R)$ of the pores obtained by the analysis of the SANS data.

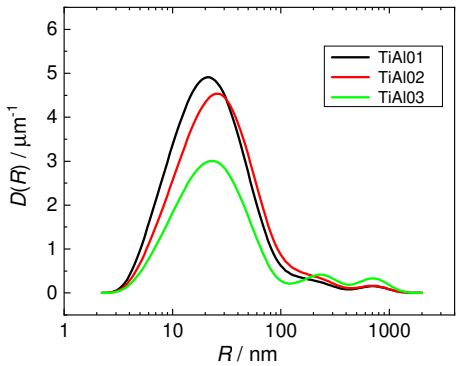

Fig. 5: Size-distribution functions of pores for the individual samples as obtained by the SANS method and analysis.

3 Conclusion

Three chosen TiAl samples were prepared by the printing device InssTek MX-LAB from the powder material and investigated by the high-resolution three-axis diffractometer when looking for the *FWHMs* of diffraction profiles and then, by the neutron small-angle scattering instrument looking for the size distribution of the contained pores as a result of an influence of the technology preparation. Inspection of Fig. 4 reveals that *FWHM*s related to the samples S2 and S3 are equal within the experimental error which points out that the used sample preparation has nearly the same influence on their plastic deformation. However, the sample S2 was poorly compacted and crumblier. On the other hand, it has a rather strong influence on the size distribution of pores (see Fig. 5). In this way it should be mentioned that the former instrument is also suitable for studies of polycrystalline alloys containing several phases having close lattice spacings as was demonstrated earlier on Inconel 718 alloy [9] while the second instrument is generally suited for investigation of structural or compositional inhomogeneities in materials in the size range from 0.05 μm to 2 μm, namely, porous materials and large precipitates in alloys. Finally, it can be stated that both presented high-resolution neutron-scattering methods can offer additional useful support to complement the structural information achieved by using the other conventional characterization methodologies (e.g. with electron microscopy techniques) and can be interesting for potential external users who are dealing with the structure of TiAl alloys and would like to apply for a beam time by means of the CANAM project at some of the instruments [10].

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