EAN 2020
58th conference on experimental stress analysis

On a Possible High-Resolution Residual Strain/Stress Measurements by Three Axis Neutron Diffractometer

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Keywords: Neutron diffraction, Three axis setting, High resolution, Bent crystal monochromator, Bent crystal analyzer

Abstract. New unconventional high-resolution neutron diffraction three axis set-up for strain/stress measurements of rather large bulk polycrystalline samples is presented. Contrary to the conventional two axis set-ups in this case the strain measurement on the sample situated on the second axis is carried out by rocking the bent perfect crystal (BPC) analyzer situated on the third axis of the diffractometer. The neutron signal is registered by a detector. This new set up provides a considerably higher resolution (~5x) which, however, requires much longer measurement time. Therefore, it can be effectively used, namely, for bulk gauge volumes and/or plastic deformation studies on the basis of analysis of diffraction line profiles.

Introduction

Residual stresses are typical phenomena associated e.g. with welding of any kind of structural material. Stresses are generally responsible for the deformation of welded structures during production and subsequently influence the behavior of these structures during service [1-3]. However, they also occur when external load or some shape forming is applied on the sample.

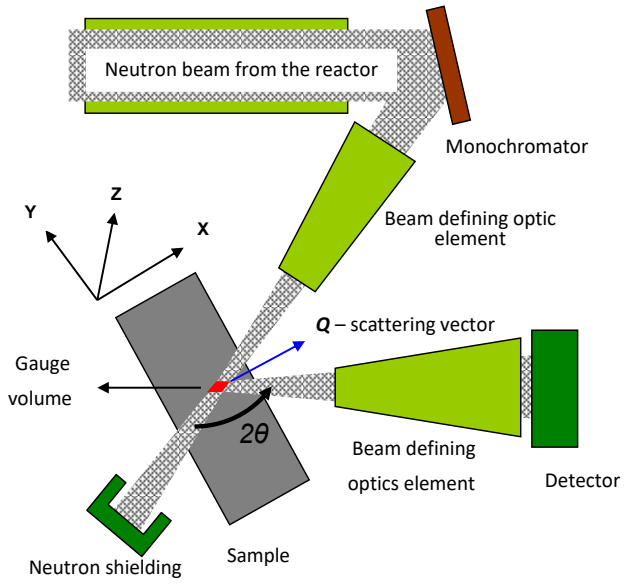

Fig. 1: Schematic drawing of the conventional strain scanner.

In our contribution, a new unconventional high-resolution neutron diffraction three axis set-up for strain/stress measurements of rather large bulk polycrystalline samples is presented. Contrary to the conventional two axis strain/stress scanner (see Fig. 1) three axis set-ups carried out by rocking the bent perfect crystal (BPC) analyzer situated on the third axis of the diffractometer and the neutron signal registered by a point detector (see Fig. 2) [4,5]. By a proper adjustment of the curvature of the analyzer the three axis set-up exploits focusing in momentum space. The high-resolution determination of the lattice changes is achieved even on large irradiated gauge volumes (see Fig. 2b.

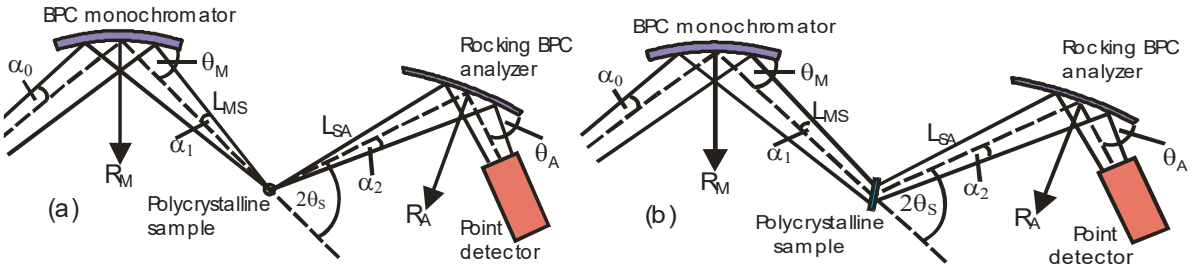

Fig. 2: Scheme of the three axis diffractometer performances employing BPC monochromator and analyzer operating with bar samples in vertical – (a) and/or in horizontal position – (b) with a point detector (R_M, R_A - radii of curvature, θ_M, θ_A - Bragg angles).

Experimental resolution

The experiment was carried out on the three axis neutron optics diffractometer installed at the Řež research reactor LVR-15. Si(111)-monochromator and Si(311)-analyzer single crystals had the dimensions of 200x40x4 mm^3 and 20x40x1.3 mm^3 (length x width x thickness), respectively. After the adjustment of the diffractometer setting for an optimum resolution as the first step, the resolution of the experimental setting was studied for different thicknesses of the standard samples (see Fig. 3). The width of the slit situated just before the sample was 10

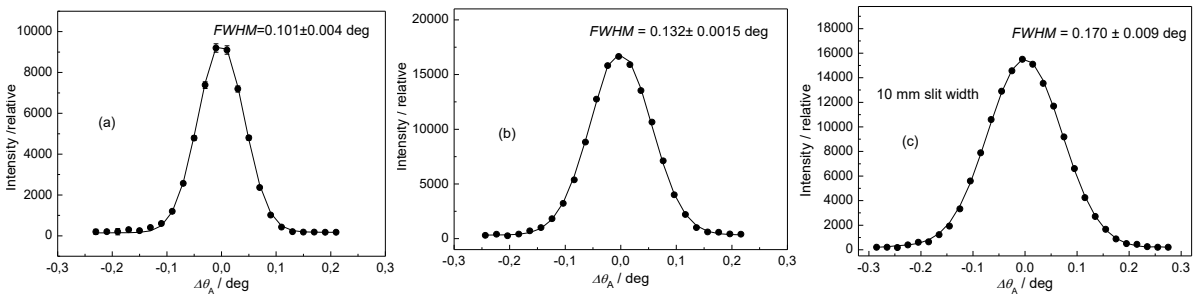

Fig. 3: Analyzer rocking curves for the virgin α-Fe(110) samples of (a) - ϕ=5.1 mm and (b) - ϕ=8 mm situated in the vertical position and the sample of (c) - ϕ=8 mm in the horizontal position (see Fig. 2b).

mm and in the case of Fig 3c represents the irradiated width of the horizontally installed sample. This trick can be used for the sake of comparison, because the vertical dimension of the sample does not play a principal role with respect to the resolution of the experimental setting. It can be seen from Fig. 3 that the width of the sample (represented by the diameter or by the slit width) plays an important role, however, in all cases it is sufficiently high for observation not only peak shifts resulting from elastic strains, but also for microstructural (dislocation density, mean grain size) studies of plastically deformed samples on the basis of diffraction profile analysis. By using the PSD detector instead of the point detector, it is possible to reconstruct the 2D profile of the neutron beam after the analysis by the analyzer crystal (see Fig. 4). In this case both the $\Delta\theta_A$ and Channel number scales are relative.

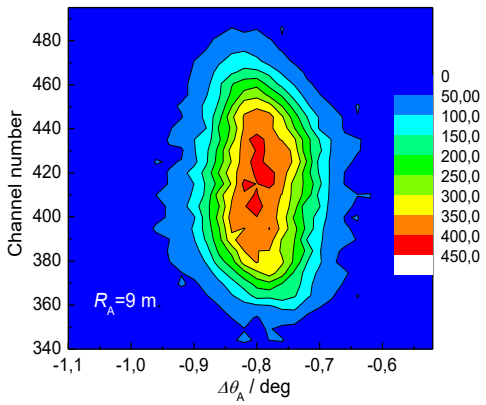

Fig. 4. 2D imaging of the analyzed beam for the virgin sample of ϕ=8 mm used in vertical position.

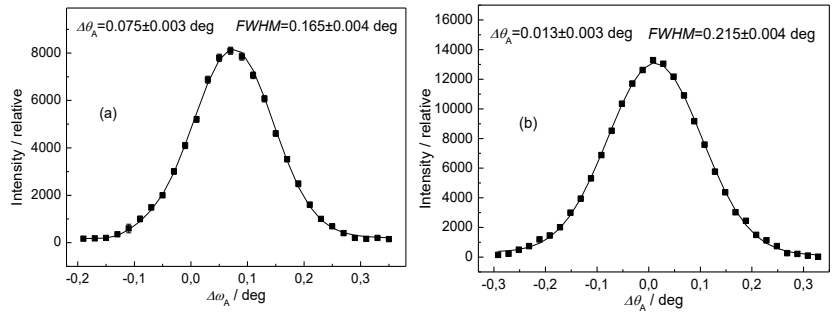

Fig. 5. Analyzer rocking curves for the deformed α-Fe(110) steel wire installed in the vertical – (a) and horizontal position – (b).

In the next step a plastically deformed α-Fe(110) steel wire (shear deformation 23 %, drawing deformation 23.2 %, ϕ=4.28 mm) was used. The corres-ponding experimental rocking curves are shown in Fig. 5. If we compare them with the curves shown in Fig. 3, it can be seen that the effect of plastic de-formation on the *FWHM* of the rocking curve and the dif-fraction profile itself is clearly visible and sufficient for a possible application of the diffraction profile analysis. If the samples are situated at the diffractometer with a high accuracy, the relative change of the lattice constant $\Delta d_S/d_0$ (strain) can be derived from the shift $\Delta\theta_A$ of the rocking curve (see Fig. 5). With the help of the Bragg condition in our case the values $\Delta\theta_A$=0.075±0.003 deg and $\Delta\theta_A$=0.013±0.003 deg correspond to $\Delta d_S/d_0$=(-1.50±0.03)x10^{-3} (radial component) and $\Delta d_S/d_0$=(-0.26±0.03)x10^{-3} (longitudinal component), respectively (d_0 is the lattice spacing of the virgin sample).

Conclusion

New alternative high-resolution neutron diffraction method which can be successfully exploited namely, in the strain/stress measurements on bulk samples exposed to an external load (e.g. in tension/compression rig, in aging machine etc.) is presented. The bulk samples e.g. of the diameter of several millimetres can be investigated in the vertical as well as horizontal position. In comparison with the conventional two axis neutron diffraction strain/stress scanners [6-8] the three axis alternative provides a considerably higher $\Delta d/d$ resolution permitting also microstructure studies (root-mean-square microstrains as well as the effective grain size) as a function of macroscopic strain from applying shape analysis of the neutron diffraction peak profiles [9,10]. On the other hand the presented alternative is much more time consuming. However, contrary to conventional two axis neutron diffraction bulk gauge volumes of the samples e.g. of the width of 5-10 mm can be studied (when keeping a requested high resolution) and can be successfully used, namely, in measurements on samples under the thermomechanical load (including the oscillating loads). It can be stated that the presented three axis neutron diffraction setting can offer an additional support to complement the information achieved by using the other conventional characterization methodologies.

Acknowledgements

Measurements were carried out in the CANAM NPI CAS Řež infrastructure (MŠMT project no. LM2015056). The presented results were also supported in the frame of LM2015074 infrastructure MŠMT project "Experimental nuclear reactors LVR-15 and LR-0". Furthermore, J. Šaroun and V. Ryukhtin acknowledge support from the Czech Academy of Sciences in the frame of the program "Strategie AV21, No.23" and P. Mikula acknowledges support from ESS participation of the Czech Republic – OP (CZ.02.1.01/0.0/0.0/16_013/0001794). We thank Ms. B. Michalcová for significant assistance in measurements and basic data processing.

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