Experimental report

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Proposal: 1-02-199 **Council:** 4/2016

Title: Residual stress analysis for multiphase materials with depth gradients of the strain free / independent lattice parameter d0

Research area: Engineering

This proposal is a new proposal

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Samples: Fe (steel samples) as indicated precisely in the proposal

Instrument	Requested days	Allocated days	From	To
SALSA	8	8	30/11/2016	08/12/2016

Abstract:

For neutronographic residual stress analysis it is essential to provide correct reference data of the strain free material state, i.e. the lattice parameter D0. There exists an increased interest for non-destructive determination of near surface residual stress gradients for the application of neutron diffraction stress analyses by means of through surface strain scanning. Causal for residual stress gradients are often processes that induce a chemical gradient of the lattice parameters like e.g. nitriding or case hardening of steel. Moreover, the most technical materials are multi-phase materials. This in total leads for thermal and/or mechanical treatment processes to specific gradients of the phasespecific micro residual stresses. With regards to the preparation of samples to determine the local depth distribution of D0 it is mostly unknown if the residual stresses are sufficiently released through the mechanical sectioning for that they can be regarded as being ´stress free´. This problem and the effect of local distributions of phase specific micro residual stresses on the lattice parameter D0 will be the focus of the herein proposed research project.

Experimental Report – Proposal No. 1-02-199

Residual stress analysis for multiphase materials with depth gradients of the strain free / independent lattice parameter d_0

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Aim of the project is to develop a basic understanding on the effect of local phasespecific micro residual stresses on the determination of the strain independent lattice parameter and providing an approach for the reliable modelling of the surface effects for coarse multiphase materials and for materials states with chemical gradients in the near surface region, corporately a measuring and evaluation strategy for non-destructive analysis of near surface residual stress gradients for problematic material states will be developed. In the current research project fundamental investigations on the effect of phasespecific micro residual stresses on the reference value d_0 will be carried out with special focus on additional chemical gradients. For this purpose defined residual and applied stress states will be applied for multiphase materials with variations in the phase contents. For this first approach various fine grained duplex steels will be studied, which clearly differ in the amount of the phase contents. Furthermore, the transfer of the findings to material states will be realized, where an additional chemical gradient in the near surface region occurs. Modell material in this respect is case hardened steel with variations in the carbon content in the outer layers and of the hardening depth (CHD). Finally, based on the experimental results and the accompanying numerical simulations, recommendations for appropriate sample preparations and for the measuring and evaluation strategy as well as simulation tools for correction of the surface effect for multi-phase materials with gradients of the local microstructure will be provided.

On that basis, correct depth distributions of the reference lattice parameter D_0 should be determined. The systematic neutron studies is the centerpiece of a collaborative research project, which is currently granted (for 3 years) by the German research foundation (DFG) with the partners TU Munich and KIT, Karlsruhe in cooperation with the Czech research foundation (GACR) with the partner Nuclear Physics Institute, Řež. Hence, the objective of this cooperation is the reliable determination and simulation of the surface effects that occur during immerging of the measuring gauge volume in the sample surface of coarse multiphase materials and for the existence of chemical gradients in the near surface layers, to enable an effective correction of the experimental data.

Measurement setup:

In this first approach we focused on the investigation of duplex steel type X2CrNiMoN22-5-3 (1.4462), which provides a phase composition of about 50% ferrite and 50% austenite in the as received state. In-situ loading experiments were carried out by means of a 4-point-bending experiment using bending bars with dimension160 × 15 × 10 mm. The phase-specific stress distributions were determined for purely elastically and defined elasto-plastically loaded samples. Further the triaxial phase-specific residual stress distribution over the bending height

was determined after release of the load subsequent to the elasto-plastic loading. The loading was controlled by a strain gauge at the outer fiber of the bar. The bending device was mounted on the 90° Eulerian cradle available at the SALSA experiment.

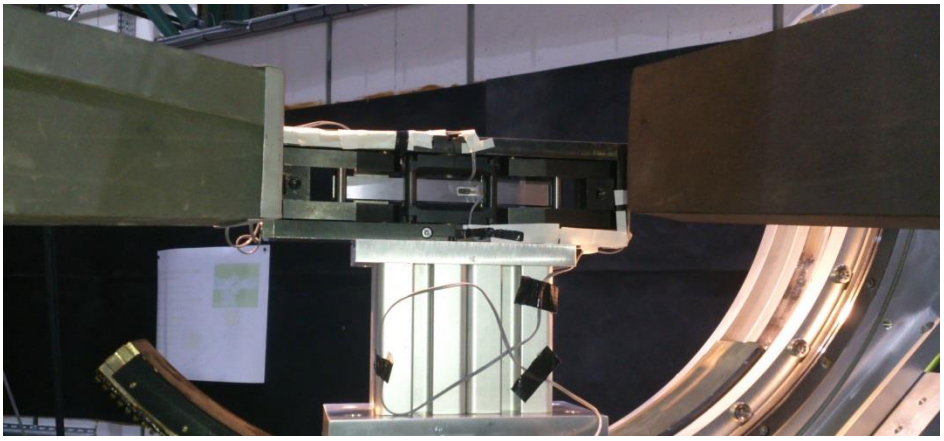

Figure 1: 4-point-bending device with sample and strain gauge mounted on Eulerian cradle

A nominal gauge volume of 0.6 × 0.6 × 10 mm was used (the 10 mm in longitudinal direction of the bar, i.e. in loading axis), which was defined by radial collimators at the primary and secondary beam paths. By this means various lattice planes were measured for the phases austenite (γ) and ferrite (α) in the three spatial directions as indicated in table 1 using a neutron wavelength of 1.6 Å. The crosses (X) mark were sufficient diffracted intensity allowed for peak determination. This is due to the rather strong texture (the ODF shows a pole density up to 45 !) of the hot rolled bar stocks. Fig 2 shows exemplary pole figures of austenite measured by XRD on the cross section.

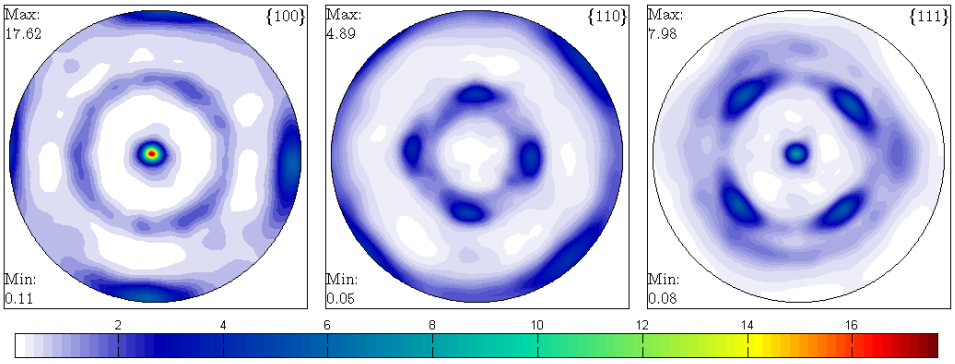

Figure 2: Pole figures for austenite measured by XRD on the cross section of the bar stock

Table 1: Measured lattice planes

	planes {hkl}	transmission (longitudinal dir.)	reflection (normal dir.)	transmission (χ=90°) (transverse dir.)
ϒ-Fe	220	-	X	X
	311	X	X	X
	222	X	-	X
α-Fe	211	-	X	X
	220	X	X	X

Four different load stages were measured: (i) without load (initial state as reference), (ii) elastically deformed (0.22% strain), (iii) plastically deformed (approx. 1.75% total strain) and (iv) the relaxed bars after unloading subsequent to step (iii). In addition, d_0 reference samples, i.e. cuboid samples (edge length of about 1.5 mm) with a circumferential notch that were sampled by EDM wire-cutting from bending bars, which were subjected to a defined elasto-plastic deformation prior to the beamtime - measured using the identical set-up.

Preliminary results

Figure 2 shows a first example of lattice strain distributions vs. the bending height of the defined loaded bars. On the left hand side the strain distributions for the component in longitudinal direction, i.e. the loading direction, of the {220} ferrite reflections are shown. On the right hand side results for the {311} austenite phase are plotted. For this first evaluation approach the d-spacings determined for the bending bar for the initial condition, i.e. prior to the loading. The data clearly indicate that in spite of the strong texture meaningful results were determined within this first approach. In both phases tensile lattice strain were determined on the tensile loaded side and compressive stresses on the compressive loaded side, while the plastic deformation leads to a strong gradient in the vicinity of the neutral fiber and a plateau on both sides beyond that region. Further, after unloading of the bars a characteristic residual strain distribution was determined in both phases with 3 intercepts with the abscissa and tensile residual strain on the formerly compressive loaded side and vice versa – results as expected for 4-point bending experiments. However, it seems that regardless of the multiphase microstructure predominantly macro residual stresses are induced. Further, the neutral fiber might be slightly shifted away from the ideal zero position.

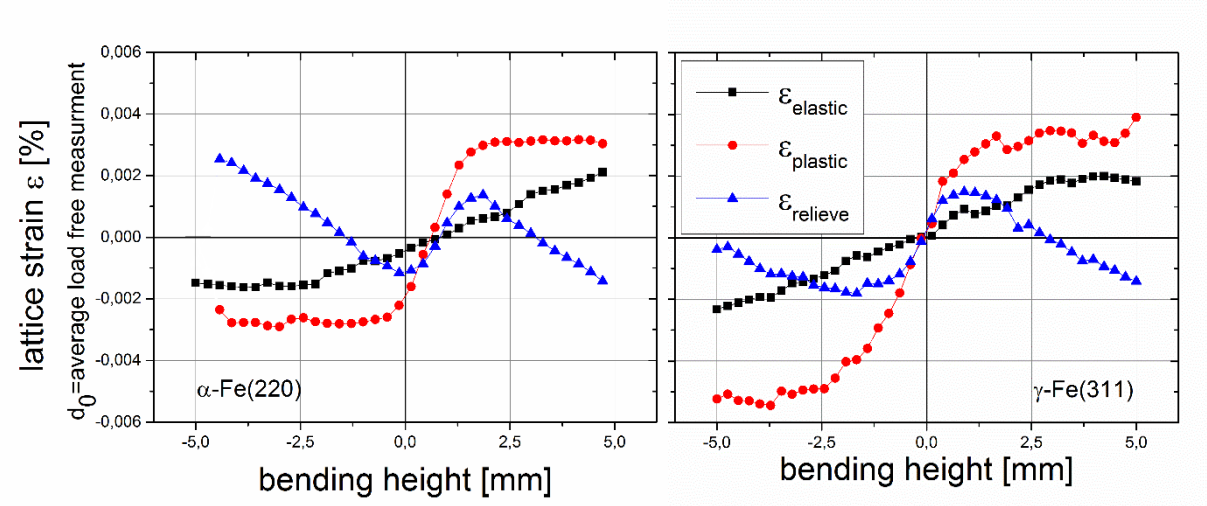

Figure 2: Examples of the measurements' results in longitudinal direction of the bending bar; left for a measurement of the {220} planes of the α-ferrite phase and right for the {311}- planes of the γ-austenite phase. The lattice strain distributions are referenced to the mean value of the strain-free sample (initial state) prior to the in-situ bending experiment.

Further data evaluation (for all lattice planes considered) will focus on taking the local crystallographic texture information and the local phase composition into account. Finally, the local tri-axial phase specific stress distribution vs. the bending height coordinate will be. In a continuation beamtime the effect of the phase content will be studied for similar investigations on duplex steel type 1.4460 (composition: 30% austenite-70% ferrite).