Experimental report

19/01/2017

Proposal: **1-02-179**

Council: 4/2015

Title: In situ measurement of surface modification mechanisms in the deep rolling process

Research area: Engineering

This proposal is a new proposal

Main proposer: **JEREMY EPP**

Experimental team: Heiner MEYER
JEREMY EPP

Local contacts: Thilo PIRLING

Samples: 42CrMo4

Instrument	Requested days	Allocated days	From	To
SALSA	6	6	27/11/2015	03/12/2015

Abstract:

The new Collaborative Research Center "Process Signature" of the University of Aachen and Bremen concentrates on the study of physically based, process-independent surface modification mechanisms in order to achieve predictive machining processes with defined surface modifications. The focus of the experimental work in this study lies on the deep rolling process, which is widely used as a finishing step on components, improving the surface properties through cold working. In situ neutron diffraction mesurements on samples of steel grade 42CrMo4 in hardened state will be taken during load by the deep rolling tool in the experimental setup. With the expected results, an experimental description of the deep rolling process will be possible, outlining the strain and stress fields induced by the tool and the development of the residual stresses through plastic deformation in the processed surface and volume below. These results will be used to achieve a physically based prediction of property modifications due to mechanically induced strains.

ILL Experimental Report SALSA Proposal Nr. 1-02-179

In situ measurement of surface modification mechanisms in the deep rolling process

H. Meyer[1], J. Epp[1], T. Pirling[2]

1: Stiftung Institut fuer Werkstofftechnik, Bremen, Germany ; 2: Institut Laue-Langevin, Grenoble, France

Abstract

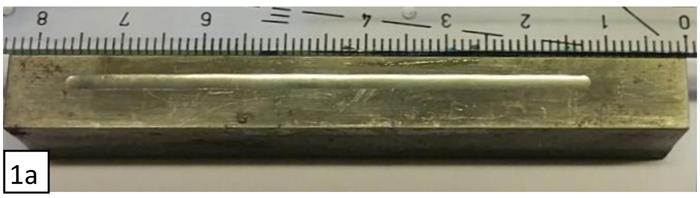
A deep rolling frame was mounted in the SALSA instrument to investigate the internal material load field and its interaction and influence on the achieved residual strain state in the processed track during the process itself. Samples of steel AISI4140H were processed with a ball roller in two different heat treatment states and different applied contact forces. Measurements of normal, transversal and longitudinal strain profiles were done for a volume around the contact point during processing. A neutron diffraction imaging approach was used to determine material changes from the surface up to several millimeters inside material in a single measurement.

Introduction

In processing of materials, resulting material modifications and residual strain state are connected to the applied external parameters and the achieved internal material load. In the deep rolling process, the rolling tool is applied at a constant force and while moving over the surface, a compressive surface residual strain state along surface directions is created. Depth and amount of created strain in the material depends on the external parameters force and contact geometry, while the introduced internal material load can be more directly correlated to the achieved residual strain state. Thus a measurement of the strain field through intersecting measurement points for three orthogonal directions of strain is required for a detailed understanding of the process influence in the material.

Experimental details

The samples were 10 x 20 x 84 mm (W x H x L) blocks of electrochemically polished AISI4140H steel, in ferritic-pearlitic (FP) state (Air cooled -1,7K/min, 850°C/2h) and in quenched and tempered (QT) state (850°C/2h quenched to 60°C oil, tempered at 400°C/4h,). They were processed in quasi-static condition with feed rate up to 0.6 mm/h at 200 bar (2000 Newton) for FP and 350 bar (3400 Newton) for QT state with a 13 mm silicon nitride (Si_3N_4) ball roller tool, producing a single track on the surface (Fig.1b). An example of a processed FP sample is shown in Fig.1a.



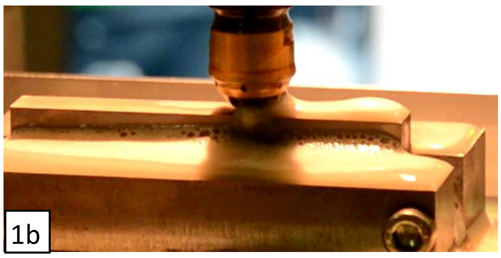


Fig.1a. Single track machined at 2000 N on FP sample 1b. Deep rolling tool on sample during processing

The measurements were done with a neutron diffraction imaging approach in order to achieve fast analysis. The sample is illuminated by a vertical neutron beam from the contact point of the roller up to a depth of several millimeters beneath. At the diffraction angle, a cadmium slit of 0.56 mm slit width was placed in the diffracted beam horizontally at a distance of around 70 mm from the contact point in front of the detector collimator. The slit works as an aperture for the diffracted signal. This produces an upside-down optical image of the diffraction angle over depth on the detector, which has been calibrated with the measurement of a narrow Fe wire, placed horizontally in the beam and measured at different heights. This setup gives information about magnification and resolution of the system. The setup for longitudinal measurements is shown in the SALSA instrument in Fig.2a, as well as a sketch of the system components in Fig.2b.

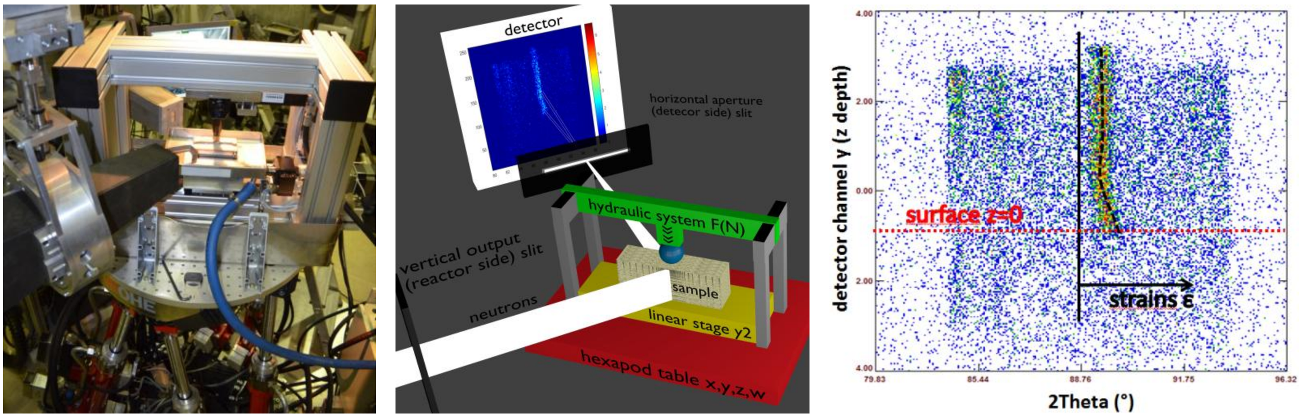


Fig.2a. Setup in SALSA b. Sketch of system components c. Signal peak on detector

Three sample directions were measured, along the longitudinal, transversal and normal orientations. Since the internal material load field and residual strain in the region of the track is line symmetric to the track, only one half of the volume was analyzed by the method. For this, a grid of 16 positions for measurements in each direction was defined. This includes positions in front of the roller from material that is processed as well as already processes parts of the track with residual stresses. Additionally several measurements were taken from the side close to the contact point. Each measurement gives the spatially-resolved diffraction signal from the surface to the core, or in the case of normal measurements, parallel to the surface at a constant depth. The internal material load effects that introduce (residual) strains into the material can be observed as deviations of the diffraction signal along the 2theta-axis from the line shape. The signal coming from the core region makes d_0 determination directly possible, because no significant strains are present. The exact determination of the surface position is also possible from the signal intensity cutoff. An example for the effect of high internal material load strains at a transversal (0,0) measurement under the roller is shown in Fig.2c, where a deviation of the diffraction signal at the lower end to higher 2Theta angle occurs.

Results and discussion

For the data analysis, peak position and FWHM values can be extracted from each detector line along the detector channels in Fig.2c through the use of pseudo-voigt (PV) fits. To increase peak intensity and reduce noise, several lines of the y-detector channels can be binned together.

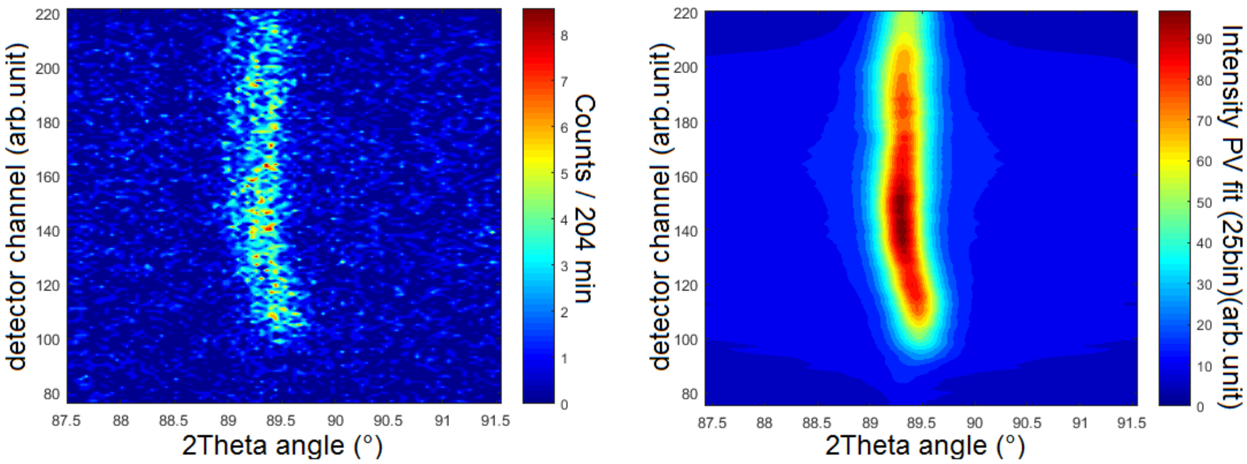
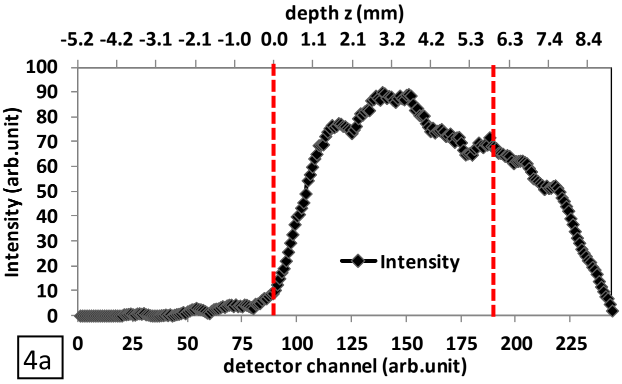


Fig. 3a Acquired neutron diffraction image 3b. PV-Fit of data with 25 line binning in channel

The experimental data of transversal strain direction at the position directly under the roller ball (0,0) in FP material was binned to a 25 line section at each channel. The original data is displayed in Fig.3a, while the result of the data binning and applied fitting function is shown in Fig.3b



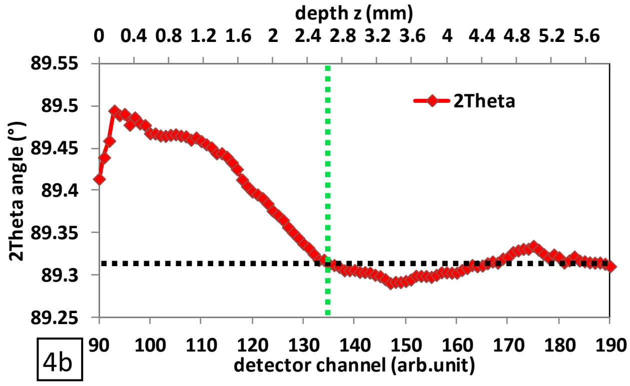
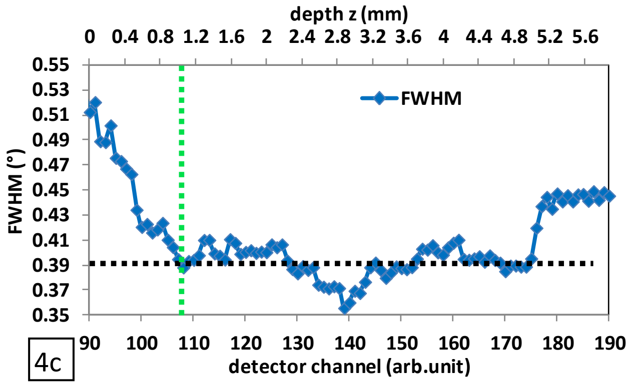


Fig.4a Intensity of the maximum over detector channel for the fitted PV functions

Fig.4b. 2Theta position from peak fit in red bounded area

Fig.4c. FWHM of the PV function over channel (depth z) in selected area



As can be seen from Fig.4a, the intensity of the of the peak signal can be used to define the region to be analyzed, with a lower cutoff at channel 95 for the surface region and a higher cutoff at channel 190 in the depth of the material. When evaluating peak position and FWHM values from the surface to the depth, an increase in peak position values in the 2theta range is seen (Fig.4b), with a zero crossing at channel 135. FWHM (Fig.4c) shows a similar increase to channel 90, but the zero crossing is closer at channel 105. With the calibration from the Fe-wire, we evaluated that a 2 mm pin movement could be translated to a vertical displacement of 34 channels. Thus compressive strains are detected under the contact point up to a depth of around 2.6 mm, while the FWHM increase due to plastic deformation is only detectable up to 1 mm.

The method allows a spatially-resolved calculation of the strains, when good data quality is achieved through long counting or higher binning (which will result in a loss of spatial resolution). The collected data are currently further processed in order to determine 3D strain and stress fields in the region under load and after the process.

Facilities

Although the neutron diffraction imaging concept increased the amount of measured positions for a single measurement, the low count rate made long measurement cycles necessary. This was further complicated by a lower reactor power during the allocated cycle from Nov. 27, 2015 to Dec. 4, 2015. Another problem encountered was a persistent software error where certain measurement points in the job queue were counted but not saved into the file by the program, thus losing valuable information for some positions. For the complex slit, source and detector system, detailed support by the instrument scientist was given, for which we are very grateful.