Conical slits for depth-resolved residual stress analysis with high-energy X-rays

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Different diffraction techniques are being used for the analysis of residual stresses in the bulk. The advantage of X-rays from a synchrotron source is the high intensity enabling high spatial resolution or fast measurements. The possibility of fast measurements can be used either for producing large two and three-dimensional strain maps or for *in situ* analyses of fast processes. In the year 2000 conical slits (CS) were proposed for depth-resolved diffraction measurements [1]. CS have several concentric slits that are focussed on a spot within the sample by their conical shape (Fig. 1). With CS complete diffraction rings can be measured, except for small regions where material is required for the mechanical stability of the slits. Thus, CS enable depth-resolved residual stress analysis using a monochromatic X-ray beam with a high photon energy. CS for cubic as well as hexagonal crystal structures were obtained from Institut für Mikrotechnik Mainz (IMM) and were tested at the HZG beamline HEMS (High-Energy Materials Science) at PETRA III.

The adjustment of a CS is relatively simple with a hexapod. In the first step, a diode is placed behind the centre hole of the CS and the CS is scanned horizontally and vertically through the beam to place the focal spot in the beam. In the second step, the rotation of the CS is optimized. This is easily done with a hexapod, because virtual axes of rotation (defined by the Pivot point) can be placed at the focus point, so that by rotating the CS the focus point will not be moved out of the X-ray beam. The width of the conical slits was 20 µm. The energy spread of the beam as defined by the bent Si (111) monochromator was 0.78% at an energy of 63.4 keV. Thus, the depth resolution only depends on the cross-section of the beam. The depth resolution was determined by scanning a 0.5 mm thick Fe foil parallel to the beam across the focus point of the conical slit and recording the diffraction pattern on a Mar345 image plate. The program FIT2D was used for data reduction [2]. The Fe (110) peak, transmitted by the first ring of the conical slit, was fitted with a Gaussian profile. The full width at half maximum (fwhm) of the peak area was used as a measure for the depth resolution. Fig. 2 shows the results for different beam cross-sections.

The results show that a depth resolution of about 0.8 mm was achieved with the set-up (Fig. 2). It is limited by the energy spread of the beam. The results also show that such measurements can be done with a beam size of 25 µm × 25 µm with reasonable exposure times. However, increasing the beam cross-section to 50 µm × 50 µm does not decrease the depth resolution, but increases the

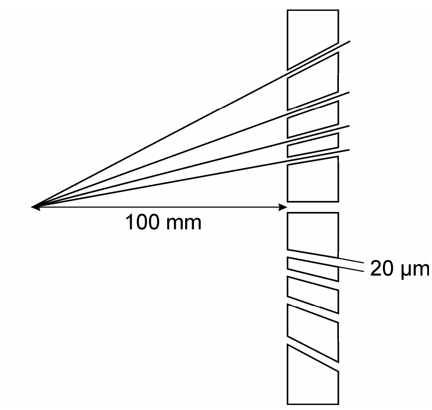

Figure 1: Sketch of a conical slit with several concentric rings focussed on a spot.

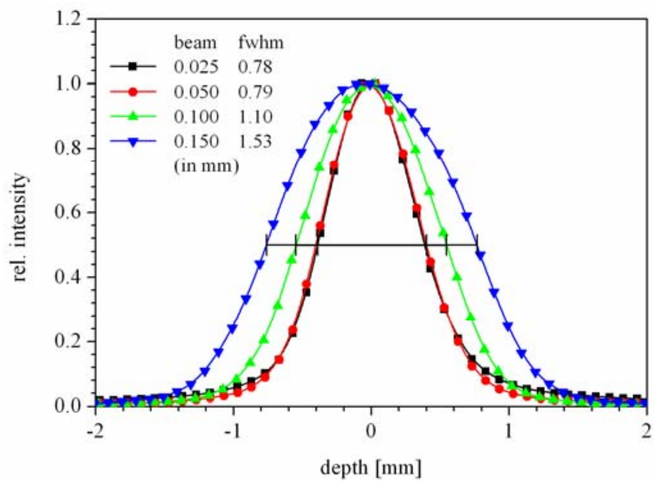

Figure 2: Intensity as a function of position of a thin Fe sheet for different beam cross-sections, showing the depth resolution.

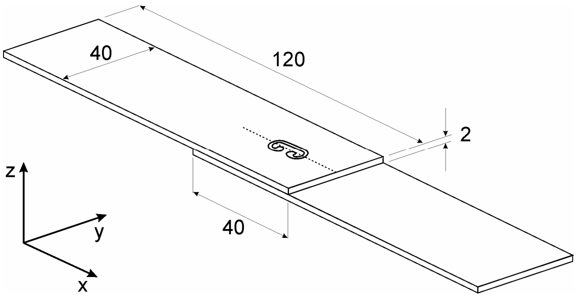

Figure 3: Sketch of the laser beam welded overlap joint of 2 mm thick steel sheets in which residual stresses were determined.

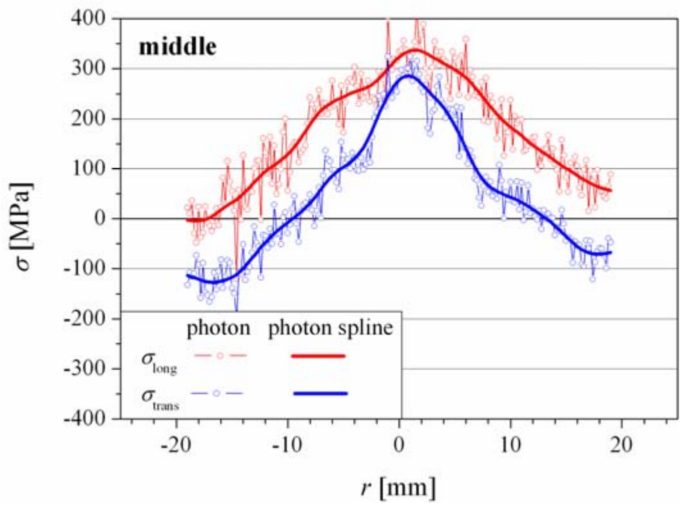

Figure 4: Residual stresses in *x* and *y*-direction along the scan line, which was in the middle between the two sheets.

intensity by a factor of four.

After the adjustment and determination of depth resolution, the set-up was used for the determination of the distribution of residual stresses in a laser beam welded overlap joint of steel sheets (Fig. 3) [3]. A beam cross section of 50 µm × 50 µm yielding a depth resolution of 0.8 mm was used for the measurement. Residual stresses can have a detrimental influence on the fatigue performance of welded material, thus their knowledge is important for assessing materials properties and performance.

The results show that the high spatial resolution of the X-ray measurement in principal can reveal more details of the residual stress distribution when large stress gradients are present (Fig. 4). However, the residual stress results are quite noisy, which is due to an insufficient grain statistics. The solid line is a spline interpolation drawn as a guide for the eye. The statistical error due to the uncertainty of peak position determination is only about 25 MPa. The sample was already shifted by 2 mm in *y*-direction during every exposure for improving the grain statistics. Despite this, only a relatively small number of diffracting grains are in the gauge volume, although the steel is relatively fine-grained. The reason is the small beam cross-section and the low divergence of the beam.

This situation can only be further improved when a different strategy for enhancing the grain statistics can be applied, like e.g., sample rotations. Such sample rotations have to be done precisely around an axis through the gauge volume, otherwise the spatial resolution would be diminished. Thus, another hexapod would be needed for sample positioning, because only a hexapod gives the required flexibility for rotation axes.

References

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