Experimental setup with laser unit for real space residual stress determination using beam limiting masks and the X-ray camera MAXIM

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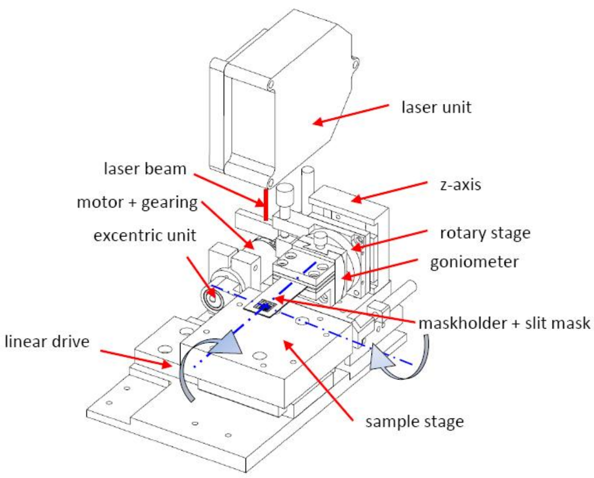
Residual stresses may have beneficial or detrimental influences on the mechanical properties and lifetime of technical components since they have to be superimposed to load stresses [1]. Due to that reason their determination and assessment is essential for many engineering applications. Widely used methods for the evaluation of residual stresses are X-ray diffraction techniques. Conventional Laplace methods thereby determine mean stress values within the X-ray penetration depth τ. In case of small variations of the residual stresses over τ, the discrepancies between real space stresses $\sigma(z)$ and the measured ones $\sigma(\tau)$ are negligible. This assumption usually does not hold when determining stress in depth distributions of e.g. surface treated alumina samples where steep stress gradients can often be observed. For bulk specimens an inverse Laplace transform of the discrete data can be accomplished. However the transformation often yields erroneous results, in particular for scattering experimental data. The use of highly absorbing beam limiting masks can be a suitable way to overcome these problems as long as in the irradiated volume, defined by the mask design, no significant change of the residual stress state occurs. The idea for such masks was theoretically described by Predecki [2] in 1993. The practical implementation led to the conceptual design of one mask for each measurement depth and tilt angle ψ [3]. Experiments carried out at DESY during the last years could demonstrate that the procedure is able to detect interferences from gauge volumes beneath the sample surface for defined slit geometries [4] and motivates further improvements of the measurement technique.



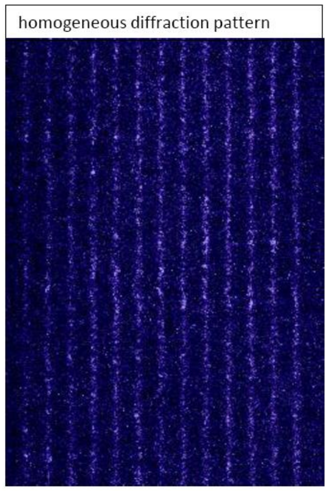


Figure 1: Sketch of the positioning stage for sample and slit mask used for experiments with the X-ray camera MAXIM at beamline G3 (left). A laser unit is used to measure the position of z-axis during the X-ray experiments. The sample oscillation beneath the slit mask yields a significantly better homogeneity of the diffraction pattern (right).

Problems with the parallel positioning of the absorbing masks above the samples surface by the 5-axes positioning stage featuring precise micrometer skews should be solved using a laser unit (see Figure 1). Turning the positioning stage clockwise through 90° the laser unit measures the position of the slit masks. By a lateral translation of the maskholder the parallelism of the mask to the samples surface can be checked.. After turning back to the basic position the laser unit measuring the position of z-axis and the X-ray experiments can be started. For the experiments a deep ground alumina ceramic was used which is well characterised concerning its residual stress state. The measurements at the {116} reflection of the alumina were carried out at the HASYLAB beamline G3 using monochromatic synchrotron radiation equivalent to $CoK\alpha_1$. The beamline is equipped with the position sensitive CCD camera MAXIM – featuring a resolution of 1 Megapixel – which applies a Multichannel-plate (MCP) for two-dimensional collimation of the diffracted beam [4]. The CCD-MCP-system provides a spatial resolution down to 13 micron/pixel which is necessary due to the narrow slits in the masks. The camera images with sample oscillation clearly show the slit structure of the masks for crystallites which fulfil the Bragg condition (see Figure 1).

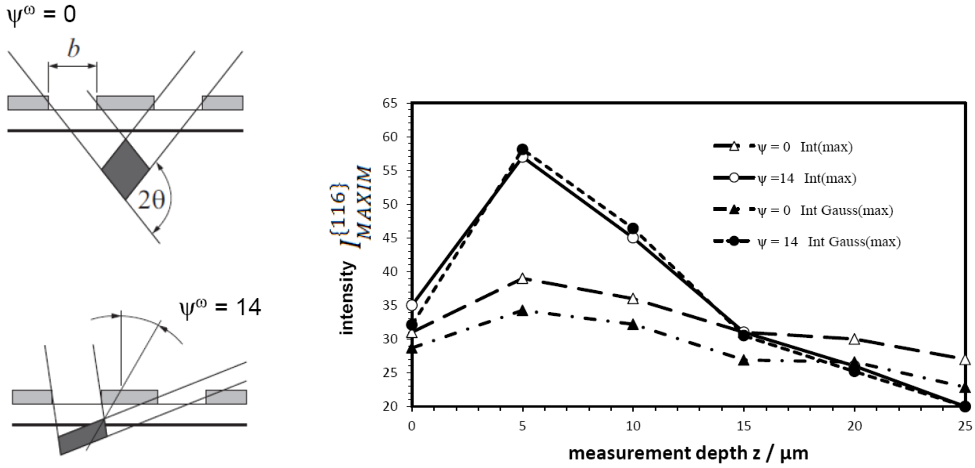


Figure 2: Schematic illustration of two X-ray limiting masks and different ψ–angles with the geometry defining gauge elements (left). The maximum integral intensity of several diffraction peaks after 2θ-scanning originating from different depths are shown in the right plot.

With the described setup a series of measurements in different depths beneath the samples surface was carried out. The laser unit makes it possible to repeat the same depth steps under different ψ–angles. To get nearly the same hight of the gauge elements different masks with different slit distances are used. In Figure 2 the resulting maximum intensities from the interferences of the {116} lattice planes are shown vs. the scanning depth. To analyse the depth dependency of the strain the gauge volumes were scanned through the immediate surface layer down to 25µm by z-axis shift of the stage controlled by the laser unit. It comes out that the maximum intensities from both ψ–angles are at the same depth and decrease to larger measurement depths. Beside the peak positions their integral intensities were calculated and compared with simulation results, where the decrease of intensity clearly correlates with the X-ray attenuation with increasing measurement depth. The recent results and comparable ones published in [4] reveal that the method is able to achieve information from defined depths in a sample material.

We thank HASYLAB at DESY for beamtime and the beamline scientists Jörn Donges and André Rothkirch for their valuable assistance during and after our experiments.

References

[1] B. Scholtes, DGM Informationsgesellschaft, Oberursel, 1991
[2] P. Predecki, B. Ballard, X. Zhu, Adv. in X-Ray Analysis 36 (1993), 247-255
[3] T. Manns, J. Gibmeier, B. Scholtes, Mater. Sci. Forum Vols. 524-525 (2006), 31-36
[4] T. Manns, A. Rothkirch and B. Scholtes, Powder Diffraction, Volume 24 (2009), Issue S1, S77-S81
[5] T. Wroblewski et al., Nucl. Instrum. Meth. A428 (1999), 570-582