Analysis of the size effect for the development of residual stress in shot peened specimens made of steel S690Q

J. Maisenbacher[1], T. Strauß[1], J. Donges[2], J. Gibmeier[1]

[1]*Institute for Applied Materials, KIT Karlsruhe, Engelbert-Arnold-Straße 4, 76128 Karlsruhe, Germany*

[2]*HASYLAB G3, DESY, Notkestraße 85, 22607 Hamburg, Germany*

The goal of this investigation was to determine whether residual stress that build up during shot peening depends on the size of the mechanically treated specimens. This is important for the mechanical surface treatment of micromechanical components, which is planned. For that purpose samples made of steel and of Si_3N_4 were shot peened (micropeening), however only results of the steel samples are presented in this report. Cylindrical disks made of steel S690Q with diameters 2 up to 10 mm and a height of 2 mm were micro peened under constant parameters for each set of disks and – using synchrotron X-ray diffraction at beamline G3 at HASYLAB, DESY – analysed considering their residual stress state.

The specimens were shot peened using three different shot agents (glass beads, EKR, abrasive agent) but otherwise constant parameters. Results of two shot agents are shown here. Each specimen was shot at nozzle to surface distance of 10 mm with a feed rate of 2 mm/s and a line distance of 1 mm. The shot pressure was constantly held at 7 bar. At the G3 beamline at HASYLAB, DESY the specimens were analysed at an energy of 6928.9 eV, which had been determined from a LaB_6 spectrum, and using a primary aperture size of $1\times1\ mm^2$ to ensure a reasonable count rate even at higher inclination angles. Employing a scintillation counter the lattice spacings of the {211} planes were investigated by scanning the position of the respective Bragg reflexes in 2θ from 97° to 102° at a step width of 0.02° and by varying the penetration depth and the measurement direction by also tilting χ from 0 to 85° in a symmetric beam guidance. Assuming the absorption of iron (μ=431,72 1/cm) the mean penetration depth hence varied from τ_{min}=2,01 μm to τ_{max}=23,15 μm. The sample surface irradiated by the synchrotron X-ray beam was masked by means of a thin lead foil prior to the diffraction stress analysis.

The diffraction spectra were fitted by using a Pearson VII function after background subtraction. As an example, plots of line positions 2θ vs. $\sin^2\psi$ are shown on the left hand side of **figures 1** and **2**. Obviously, the slope of the plots obtained from the larger specimens does not differ much over the majority of the penetration depth compared to the respective smaller specimens, as expected. Only for high ψ angles (i.e. low penetration depth), a slight decrease of the slope can be found for the 2 mm diameter sample, however, the effect seems more or less distinct depending on the shot agent. On the right-hand side of **figure 1** and **2**, the development of the residual stress depending on the surface distance is shown, obtained by applying the 2θ-$\sin^2\psi$ derivative method [1] to the refraction data.

The observed difference between the smaller and the larger disks is probably not based on the different specimen diameters. The left-hand plots suggest that the deviation only occurs at low penetration depths, or rather high ψ angles where the geometrical spot size on the specimens is larger than for less steep inclination angles. Hence, almost certainly the edge regions of the specimens were irradiated were residual stresses as induced by shot peening cannot hold up for mechanical reasons and a residual stress gradient in lateral direction has to occur. As specimens of only 2 mm diameter exhibit a higher relative amount of irradiated ´edge area´, the residual stress gradient at the edge of the sample will definitely strongly affect the results. This is further backed up by analysing the measured peak positions using the ´conventional´ $\sin^2\psi$ method [2] neglecting the large inclination angles where strong deviation to the linear fit is observed. By this means, robust residual stress data for a mean information depth can be evaluated. The specimens of each respective group exhibit average residual stresses that lie within the error margin of each other.

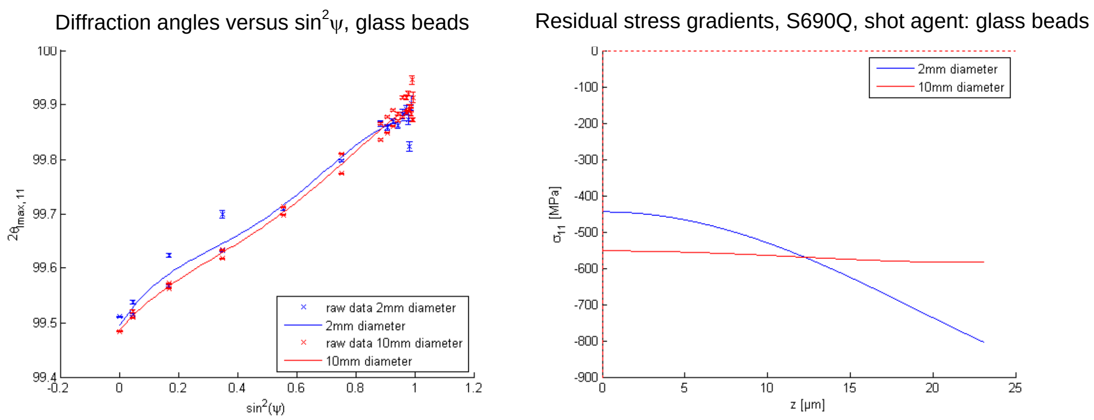

Figure 1: polynomial of 4th degree fitted to diffraction angles (left) residual stress gradients as obtained from fit (right); blue plots are the 2mm diameter specimen; red plots are the 10mm diameter specimen

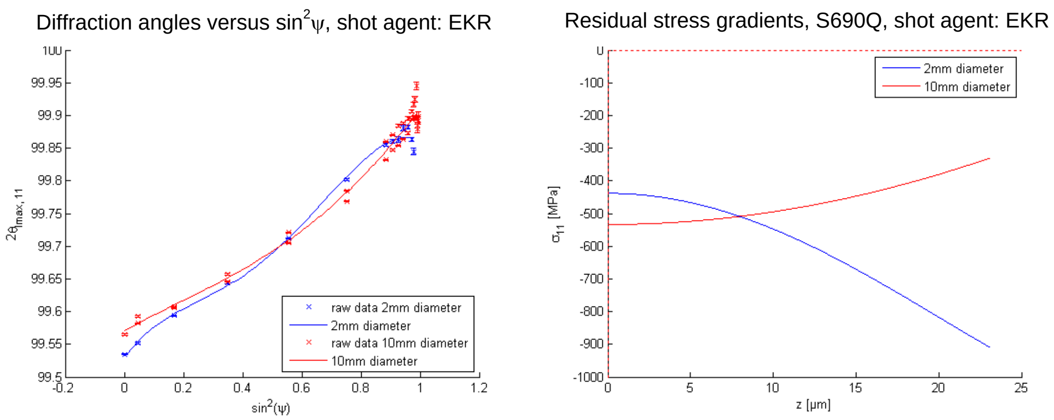

Figure 2: polynomial of 4th degree fitted to diffraction angles (left) residual stress gradients as obtained from fit (right); blue plots are the 2mm diameter specimen; red plots are the 10mm diameter specimen

Thus, stress gradient analyses carried out obviously give erroneous results and do not represent the local residual stress state induced by (micro) shot peening. Due to the integral character of the diffraction residual stress analyses the lateral stress gradient that must occur at the sample edge strongly affect the results for large sample tilts. Based on the results presented here no clear effect of the sample size on the residual stress after shot peening can be derived. For this purpose, more local analyses must be carried out using a much smaller beam cross section, which is not feasible at the bending magnet beamline G3 at acceptable measuring times. However, the different shot peening media results in clearly differing residual stress depth gradients, when focusing only on the ∅ 10 mm sample for comparison.

References

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