Qualification of an inner surface Barkhausen noise sensor for residual stress measurements of single-lip deep drilled AISI 4140 by means of X-ray diffraction

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Keywords: residual stress measurement, deep drilling, X-ray diffraction

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Quenched and tempered steels, like AISI 4140 (42CrMo4+QT), are often used for fatigue-loaded components like rails or injectors of common rail systems. These parts are usually produced by machining processes and the performance of these parts is significantly influenced by the surface near microstructure and material parameters. Hence, subsequent production steps, like deep rolling or autofrettage, are commonly performed to induce a beneficial microstructure and residual stress state.

Nickel et al. investigated the capability of an optimised single-lip deep drilling process to create the desired bore wall characterisics, and substitude the time and cost intensive subsequent production steps [1].

Baak et al. showed, that the degradation process of deep drilled specimens of AISI 4140 caused by fatigue load can be characterised by means of magnetic Barkhausen-noise (MBN) measurements. The degradation can be described, independently of the drilling parameters and stress amplitude, by a quadratic equation (Figure 1) [2].

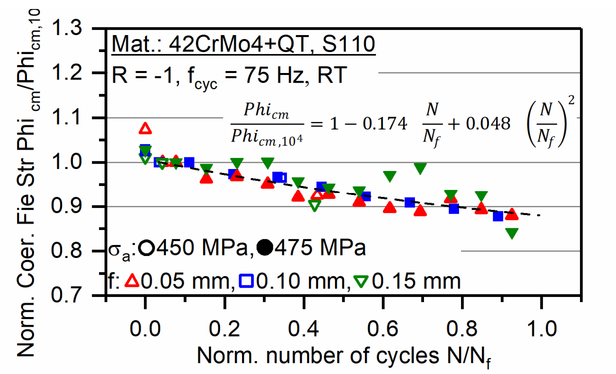

Figure 1. Normalised coercive field strength versus normalised number of cycles for constant amplitude tests on AISI 4140 specimens and amplitudes of 450 and 475 MPa. [2]

Since a wide range of material parameters and microstructural properties influences the micro-magnetic parameters, a separation of effects is of fundamental importance. Especially the stability of residual stresses within the fatigue tests has a major influence on the expected fatigue life. To find the link between the MBN and the residual stresses, measurements with established measuring systems are inevitable. In this study, specimens of the same kind were measured in the initial state and three increasing fatigue states by means of MBN and X-ray diffraction (XRD) measurements.

The MBN measurements were carried out using a "FracDim" testing system provided by Fraunhofer IKTS and a custom built inner surface sensor. The sensor consists of a standard sensor to excite the alternating magnetic field and a sensor element that can be placed insinde the d = 5 mm bore hole, to detect the MBN at the crucial inner surface.

For XRD measurements, the bore surface had to be exposed by milling. Due to the small diameter of the bore the measurement was perfomed with a primary CrKα-beam gated trough an elliptical glass capillary with a resulting in a focal spot diameter of approximately 120 µm at the diffractometers's centre.

Figure 2 shows the coercive field strength Phi_{cm} versus the axial residual stresses σ_{rs}. A clear correlation of Phi_{cm} and σ_{rs} can be observed for 0%, 10% and 50% of the estimated fatigue life. The specimen fatigued to 90% of the estimated fatigue life shows an exeptional drop in Phi_{cm}, which is due to the initiation of fatigue (macro-) crack growth.

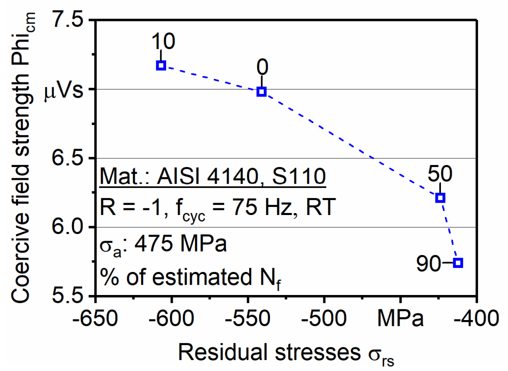

Figure 2. Coercive field strength versus residual stresses of four fatigue states in constant amplitude tests on AISI 4140 specimens and amplitude of 475 MPa.

Acknowledgments: Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – project number 320296624.

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[2] Baak, N.; Schaldach, F.; Nickel, J.; Biermann, D.; Walther, F.: Barkhausen noise assessment of the surface conditions due to deep hole drilling and their influence on the fatigue behaviour of AISI 4140. Metals 8 (9), 720 (2018) 1-12.