ASAXS on Iron Carbides of Steel

U. Vainio, L. Zippelius[1], and W. Song[2]

FS-DO at DESY, Notkestr. 85, 22607 Hamburg, Germany

[1]University of Edinburgh, Edinburgh, UK [2]Department of Ferrous Metallurgy, RWTH Aachen University, Intzestr. 1, 52072 Aachen, Germany

Iron carbides in steels play a very important role in determining the mechanical properties of the materials. Kang et al. [1] recently reported that the precipitate microstructure not only determines the static mechanical properties (hardness, strength and ductility) in the material, but also its dynamic response during rolling contact fatigue. Precipitate shearing, particle dissolution, dislocation cell and nanocrystal formation as well as matrix/carbide debonding are features commonly observed throughout bearing life. Typically, these microstructural changes are initiated at a scale of only a few nanometers, yet, they can cause cracks that grow up to several millimeters during ongoing loading. Iron carbide particles have sizes in the nanometer range, and for such size scales anomalous small-angle X-ray scattering (ASAXS) can provide us element sensitive structural information.

Samples were measured at beamline B1 of DORIS III synchrotron storage ring using ASAXS. The scattering patterns were recorded during several beamtimes using Pilatus 300k and Pilatus 1M single photon counting detectors (from DESY detector pool, Dectris) with X-ray energies close to the iron K-absorption edge. Beam size at the sample was 0.8 mm × 0.5 mm. Sample-to-detector distances of 885 mm and 3585 mm were used.

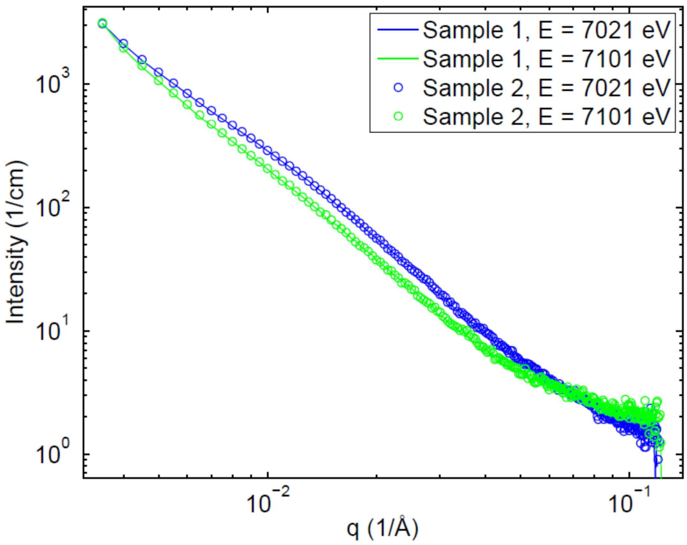

Figure 1: Small-angle X-ray scattering curves at from two samples produced with the same processing conditions. SAXS measured at two different X-ray energies (7021 and 7101 eV) below and close to the Fe K-absorption edge are shown. This figure illustrates the perfect reproducibility of both the metallurgical process as well as the ASAXS measurements.

Figure 1 shows an example of two measurements of one steel treated with a special thermal treatment to produce carbides. The intensity in the hump observed in the middle of the curve depends strongly on X-ray energy. This is due to the very fine differences between the electron densities of different carbide phases. After subtracting an energy-dependent constant background from the curves, the tail part of the curves, corresponding mostly to size scales 0.2–5 nm, was fitted with a power law ($I(q) \propto q^{-\alpha}$) for different samples produced in different temperatures. This detailed analysis of curves measured at 6856 and 7105 eV showed that the power-law exponent α was independent of energy and mostly within the range 2.3 and 2.7, with the mean being -2.428 ± 0.004. Such non-integer power-law exponent could arise from very polydisperse compact objects, but more likely, it is caused by rough, porous or flaky structures as explained by the fractal theory [2]. This result combined with finer analysis will give us detailed information on the carbide nanostructure within the steel.

References

[1] J.H. Kang, B. Hosseinkhani, P.E.J. Rivera-Díaz-del-Castillo, Mater. SACI. Technology **28**, 44 (2012).

[2] H.D. Bale and P. W. Schmidt, Phys. Rev. Letters **53**, 596 (1984).