Non-destructive residual stress profiling in large bearing components

The bearing producer SKF wanted to check the internal stresses in large bearings in a non-destructive manner at the Swedish beamline at DESY in Hamburg. The objective was to use hard X-rays to obtain non-destructive residual stress depth profiles from large rollers.

CHALLENGE

Heat treatment of steel is used to tailor the material properties for specific applications. For bearings, the most important property is hardness. As a side effect, the heat treatment also induces residual stress in the material, which has to be kept under control. X-ray diffraction is a frequently used technique to control stress, but conventional laboratory sources can not probe to depths exceeding micrometers. For large steel samples, in this case rollers for bearings weighing about 15 kg each, laboratory X-rays do not possess the penetration depth to probe stresses in all directions.

The region of interest is normally located around 100 µm into the component – this is where the highest applied stress is found. To find the optimum heat treatment parameters, the outer 400 µm of the roller were analyzed in a non-destructive fashion.

Synchrotron radiation can generate hard X-rays, over 100 keV, with the highest brilliance. Now even deep-laying parts of the bearing can be probed and formerly hidden stress states can now be accessed. It is also a high-precision experiment: a residual stress of 20 MPa corresponds to a lattice displacement of about 100 femtometers, which is about 1/2000th of an interatomic plane distance in steel.

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DESY.

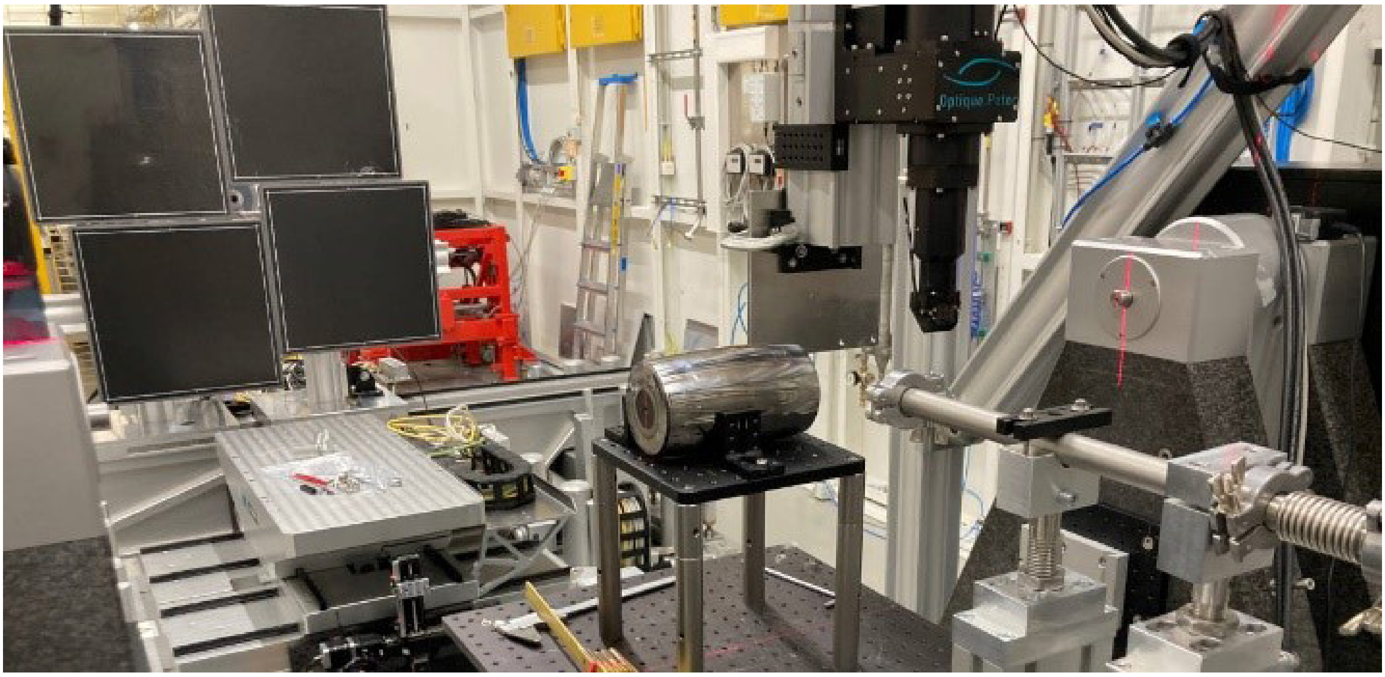

Figure 1: Left: Setup of the sample in the beamline. The beam enters through the stainless tube (lower right) cuts through the roller (middle) and is caught by four large area detectors (top left).

METHOD

In this case, high energy X-ray diffraction (XRD) was used to probe the residual stress state on the inside of the bearing roller in a non-destructive manner. The roller was mounted on a high precision sample stage. A series of diffractograms was then recorded as the sample was moved into the beam, creating a depth profile with micrometer-resolution.

The rollers were placed in a letter-box shaped beam, 5 x 44 µm, with 97.25 keV energy. This made it possible to record a non-destructive depth profile in the surface of the roller.

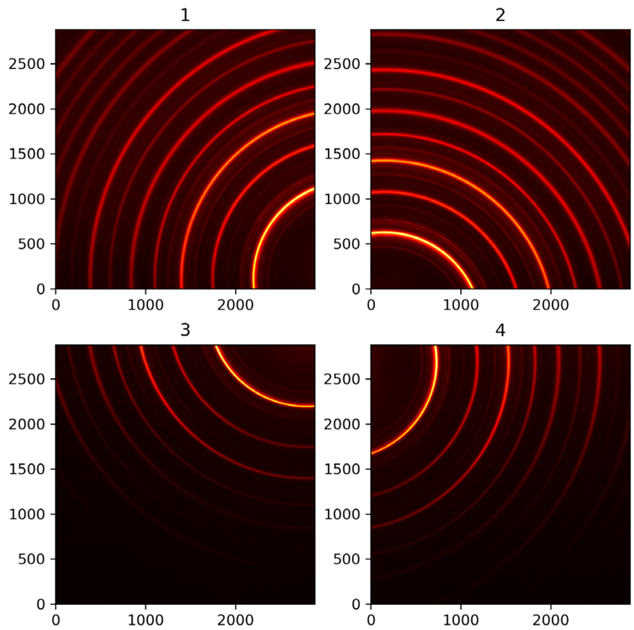

Figure 2: Full diffraction patterns (log thermographic scale) as detected by the 4 large area 2D-detectors in Figure 1. It is possible to quantify both ferrite and austenite peaks thanks to the large dynamic span of the detectors.

ANALYSIS

The access to non-destructive residual stress depth profiles, as well as additional information on the phase balance in the sample, were a valuable addition to finding the optimum heat treatment process. Once the beam is set up, the measurement is quite fast – the exposure time per frame was only two seconds. The residual stress state was probed as profiles with 5 µm steps down to a depth of about 400 µm, which is enough to go through the region of highest mechanical load.

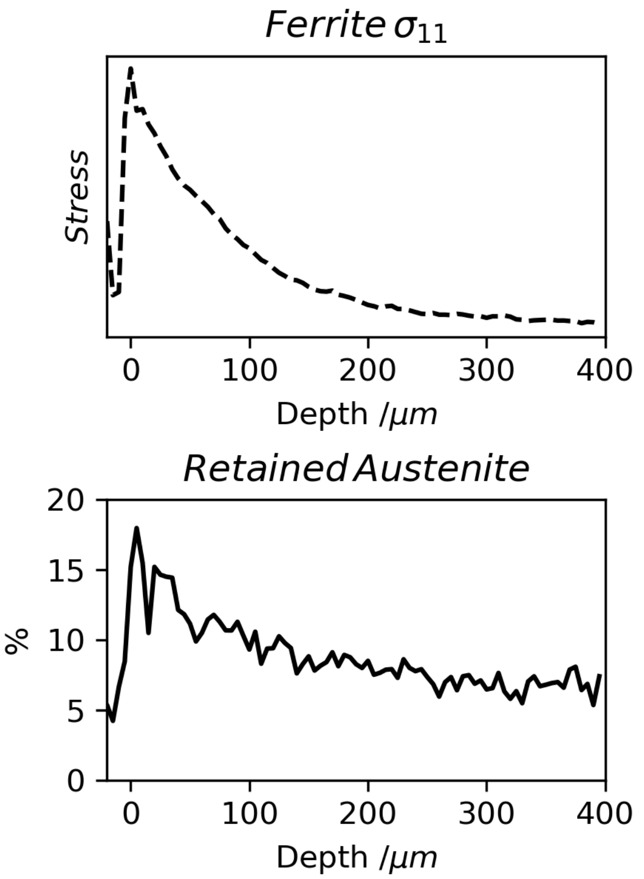

Figure 3: Example profiles for stress perpendicular to the surface, as well as retained austenite as a function of depth (arbitrary scales).

BENEFITS

The benefit of using synchrotron radiation for probing the large samples is that the stress state is not disturbed by material removal. The findings in this study were not possible without high energy X-rays, specialized equipment allowing moving. Especially regarding near-surface (50-300 µm) phenomena, this is information that cannot be accessed by a laboratory XRD. With the set of samples investigated, there was sufficient feedback to allow for adjusting the heat treatment process.

"The accessibility of large scale facilities opens up new possibilities in understanding the material in larger components," says Assoc. Prof. Claes Olsson, Senior Technologist at SKF.

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