POLDI – Time-of-Flight Diffractometer for Engineering

Non-destructive residual stress characterization and deformation behaviour

POLDI is an instrument which is used to characterize the spatially resolved residual stress distribution in typical engineering components, using neutron diffraction. Neutrons can penetrate to greater depths than X-rays or synchrotron radiation in most engineering materials, allowing non-destructive residual stress determination from the near surface to deep within the bulk, depending on the particular material. The deformation behaviour of typical engineering materials, particularly multi-phase and composites, can be studied during in-situ loading, providing information on load sharing and internal stress accumulation.

Introduction

A knowledge of residual stress components is essential for both materials engineering and materials sciences, in various applications, for the investigation of fatigue phenomena or stress corrosion, subsequent study of prevailing deformation mechanisms, or providing reliable input data for the validation of FEM analysis.

Industrial applications and services

These are primarily in railway, automotive, aerospace, civil and nuclear engineering, medical applications, high voltage engineering and power generation.

Typical elements which are predestined for analysis with the neutron scattering method of POLDI are found amongst almost all engineering materials, such as alloys of Iron (Fe) and Steel, Nickel, Aluminium (Al), Copper (Cu), Magnesium and Zirconium (Zr),and Ceramics such as Alumina, Zirconia, Silicon Carbide, Silicon Nitride and Tungsten Carbide.

As typical effective applications for the determination of residual stresses with the POLDI method at PSI, we provide sound expertise for:

- Welding technology – laser, fusion, friction
- Surface treatment – peening, cladding, hardening
- Casting and forging technology

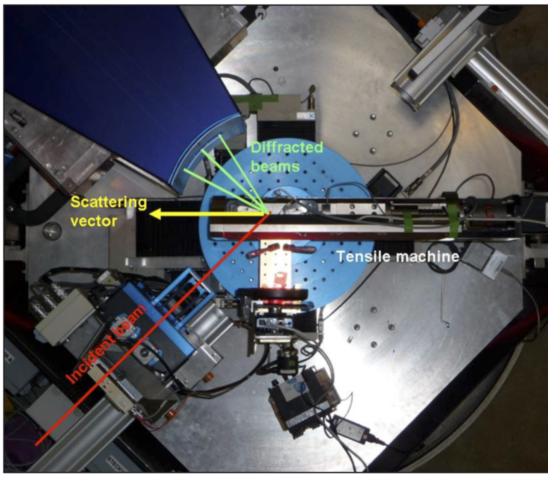
With a maximum load of up to a ton, the basic sample table of the POLDI facility allows the non-destructive testing not only of small specimens, but also of real large machine parts, such as engine and machine components, high-duty mechanical components, bearings, turbine blades, disks, rings, castings, forgings, coatings and jet engine components.

Case study (I) – Residual stress evolution in railway wheels during service:
Railway wheel, 400 kg, die–forged steel, measurement of radial strain components at a depth of 12.5 mm at the POLDI installation after the end of its life at 510'000 km.

Determination of the residual strain depth profile after 61'000 km, at several positions across the radius.

Scientific applications

TThe deformation mechanisms of specific phases and crystal orientations in single-phase, multi-phase and composite materi-



In-situ loading on POLDI, measuring the deformation mechanics of bainitic steels.

als can be studied in-situ during tensile loading on POLDI. Currently, a 10 kN stress rig is available.

Load sharing in composite or multi-phase materials (Al/SiC, Duplex stainless steels) Cu/Nb nano composites.

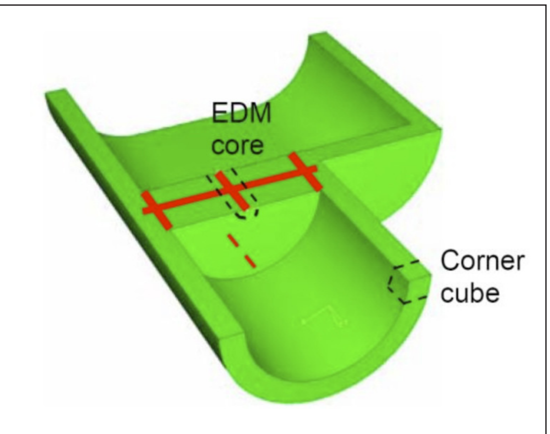
The understanding of internal stress build-up (inter-granular and inter-phase stresses) during tensile or compressive loading regimes – monotonic, cyclic or steady-state (creep, stress relaxation).

The advantages of neutrons

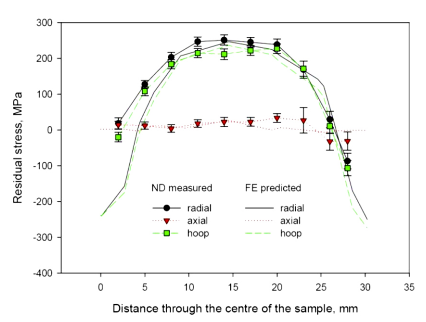
Neutron diffraction/scattering is a very powerful method for strain field measurements, because:

- it is non-destructive.
- it has good spatial resolution in three dimensions (3D) and a gauge volume of the order of cubic millimetres.
- it can penetrate to greater depths than methods using X-rays (≤10 µm) or synchrotron X-rays (≤200 µm), which are fairly restricted to near-surface analysis.
- the large penetration depth of neutrons, of up to 50–100 mm in metals, allows the measurement of an entire 3D strain field to a depth of 20–40 mm.
- it offers an accuracy of 50 microstrains – $\Delta d/d = 50 \times 10^{-6}$.
- the same order of magnitude can be measured in the bulk material in terms of lattice spacing.

Case study (II) – Residual stress in an aerospace aluminium alloy pump casing



Validation of Finite Element Modelling (FEM) calculations of quenching residual stresses. Residual strains measured in three principal directions and the triaxial residual stress state calculated. Results exhibit very good agreement, validating the FEM method.



Courtesy of C. Truman, University Of Bristol, UK

Method

Residual stresses are determined from the measurement of residual strain in the material. The residual strain is measured by monitoring the strain of the lattice planes that make up the crystal lattice of crystalline materials.

In essence, the crystal lattice of crystalline materials – such as metals, ceramics and some polymers – is used as an atomic strain gauge.

The basis of elastic strain measurements is the Bragg equation:

$$\lambda = 2d \cdot \sin(\Theta)$$

where $\boldsymbol{\lambda}$ is the neutron wavelength, $\boldsymbol{d}$ the lattice plane distance and Θ the Bragg angle. The time of flight t_{tof} of a neutron is proportional to its wavelength, and inversely proportional to *v, the neutron velocity:*

$$t_{tof} \sim \frac{1}{v} \sim \lambda$$

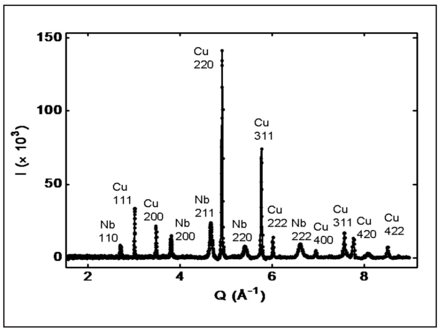
The strain, ε, can be measured from the time t which the neutrons scattered in a Bragg reflexion need for their flight path (time-of-flight method), and the strain is given by:

$$\varepsilon = \frac{\Delta t}{t} = \Delta d / d_0$$

Using the appropriate elastic constants of the material, the measured strain can be converted to a stress by Hooke's law.

POLDI – the instrument

POLDI is a so-called neutron Time-Of-Flight (TOF) diffractometer. For strain scanning experiments, TOF diffractometers available at PSI have considerable advantages compared with constant wavelength diffractometers. The stresses in multiple phases can be characterized by measuring the full diffraction pattern.



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