Energy-selective neutron imaging

Radiography and Tomography

Introduction

Neutron imaging acts in a similar way to X-ray imaging as a powerful technique for non-destructive materials testing.

Due to the different interaction mechanism of neutrons and X-rays with matter, neutron imaging delivers complementary information to X-rays of an object's internal structure.

Energy-selective neutron imaging takes advantage of the energy dependency in the transmission of the neutron through matter, and has been developed and installed on the cold neutron imaging beam line ICON at PSI.

This new technique provides additional insight into the composition and crystallographic structure of polycrystalline materials not accessible with conventional neutron imaging, and includes both radiography (2D) and tomography (3D).

Physical background

The transmission characteristics of neutrons in materials are determined by its general attenuation power, its elemental composition and individual structural properties. Latter factor exhibits a very specific dependency on the neutron energy. Thus selecting neutrons of a well defined energy for the purpose of imaging may be advantageous. More specifically, the transmission of monochromatic neutrons changes abruptly when the energy of the neutrons is below a certain threshold, the so-called Bragg edge. This threshold is both function of the material's structure and grain orientation. Hence, comparison of the neutron transmission at different neutron energies allows conclusions on the structure and grain orientation of the material under investigation.

Experimental setup

In neutron imaging the standard experimental setup consists of the neutron source, the sample and a 2D neutron area detector.

For the purpose of energy-selective imaging an additional energy selector allows to change and scan the energy of the neutrons probing the sample.

Principle of neutron imaging

Only those neutrons that are transmitted through the sample reach the detector in ideal experimental conditions, while neutrons absorbed or scattered by the sample do not contribute to the signal.

Transmission is readily obtained as the ratio of beam intensities with and without sample in the beam.

Energy-selective neutron imaging

Depending on the chosen neutron energy and the material properties, structural parameters of the material can either be derived from transmission data or can be visualized with high spatial resolution.

Energy-selective neutron imaging offers some options for significantly enhancing the image contrast in the following ways:

- by selecting the neutron energy in such a manner that the contrast between the different metals in a sample is highest
- by selecting a suitable neutron energy in the Bragg region to visualize the grain orientation and texture properties (e.g. in welds).

This also enables a tomographic scan to be made at the best energy, in order to visual-

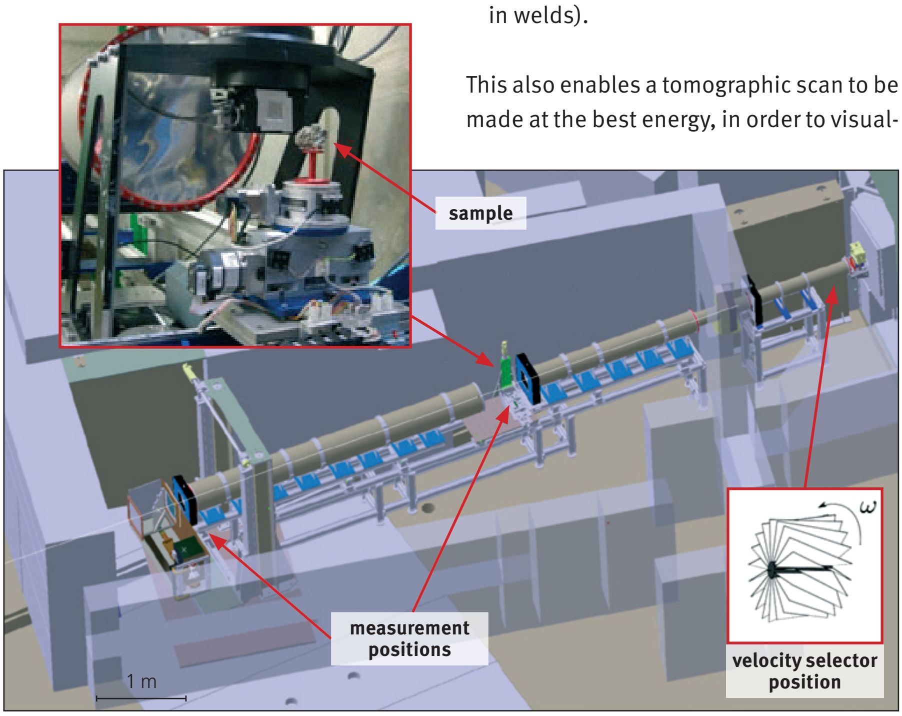

Figure 1: **ICON beamline**

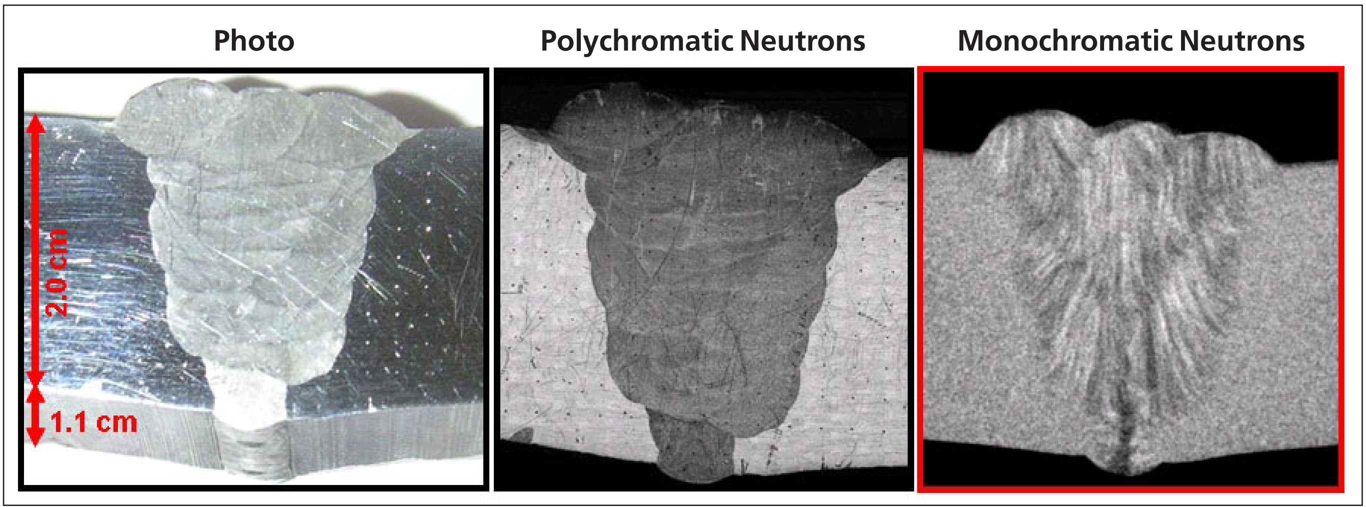

Figure 2: **Steel weld: comparison of conventional metallographic preparation, neutron imaging using polychromatic neutrons and monochromatic neutrons.**

ize crystallographic structures and compositions of larger bulk material in 3D.

Advantages

Contrary to X-rays, neutrons provide high contrast for light elements, such as hydrogen, lithium or boron, and allow better penetration of metallic materials, providing information not accessible with conventional X-ray radiography.

Sample properties can be directly visualized and quantified over the macroscopic sample volume.

This technique of energy-selective neutron radiography additionally provides significant advantages for:

- the quantification and visualization of crystallographic structure and composition across the whole sample
- simultaneous high-energy and spatial resolution
- a wide range of sample types which can be investigated
- considerably lower exposure times compared to other methods.

Applications

Results of energy-selective imaging are shown for a steel weld (austenitic steel) extracted from a pressure vessel. Figures 2 and 3 compare conventional and energy-selective imaging, respectively.

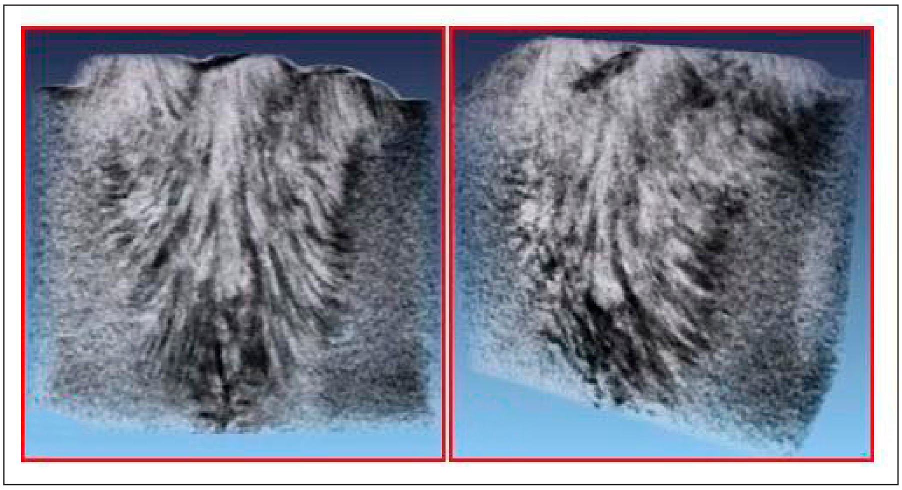

Figure 3: **Energy-selective neutron tomography of the same weld, using monochromatic neutrons in two perspectives.**

The transmission maps shown depict the bulk structure of a sample screened with two different monochromatic neutron beams.

The method reveals considerable inhomogeneity of the grain structure inside the weld. Such rapid scanning enables the sample to be examined in a considerably shorter time than by using elaborate metallographic methods.

It is planned to develop and introduce this technique as a refined screening method, useable for the rapid quality checking of metallic welds, solder joints, cast metals or other polycrystalline materials.

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NUM-F03-A-10, 10.2010