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Neutron diffractometer RSND for residual stress analysis at CAEP

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ABSTRACT

Residual Stress Neutron Diffractometer (RSND) has been built at China Academy of Engineering Physics (CAEP) in Mianyang. Due to its excellent flexibility, the residual stress measurement on different samples, as well as in-situ study for materials science, can be carried out through RSND. The basic tests on its intensity and resolution and some preliminary experimental results under mechanical load, demonstrate the high quality of RSND.

1. Introduction

Neutron diffraction stress analysis is one of the most powerful techniques for measuring nondestructively internal stress in three dimensions deeply inside polycrystalline materials [1]. This technique can be used to precisely measure a lattice spacing based on Bragg's law:

$$\lambda = 2d \sin \theta, \tag{1}$$

where λ is the wavelength of neutron beam, d and θ are the lattice spacing and the Bragg angle (or a half of the diffraction angle 2θ) corresponding to a particular reflection plane ($h\,k\,l$). The elastic strain is determined by Hooke's low considering the variation of the lattice spacing: $\varepsilon=(d-d_0)/d_0=\sin\theta_0/\sin\theta-1$, where d_0 and θ_0 are the lattice spacing and corresponding Bragg angle under the stress-free condition.

Besides the residual stress measurement, neutron diffraction is also a powerful tool for the in-situ study of materials science under thermo-mechanical loading conditions. The new neutron diffractometer RSND at CAEP was designed with high-level automation and high-sample adaptation for residual stress measurements on various engineering specimens and in-situ studies for crystal materials.

2. Instrument description

RSND is located at the end of a thermal neutron guide, layout of which is shown in Fig. 1. The main components of RSND diffractometer are listed in Table 1. The construction of RSND was finished on September 3rd, 2012. A double focusing silicon single crystal Si monochromator is employed to ensure the high intensity and resolution with the accessible wavelengths from 0.12 nm to 0.28 nm, which satisfy measurements of various lattice spacing [2].

The diffractometer resolution $\Delta d/d$ is about 1.91×10^{-3}, which is obtained by a standard Fe-sample experiment. The Si(3 1 1) monochromator is set at the take off angle $2\theta_M=90^\circ$ to provide the neutron wavelength $\lambda=0.231$ nm. The Fe(1 1 0) peak is gained on the diffraction angle of 69.44°, which is shown in Fig. 2.

The uniquely designed sample table can handle the mechanical load up to 500 kg with high position accuracy. A MK-200N two-dimensional position sensitive detector (2D-PSD) is used with the active area of $200\times200\ \text{mm}^2$ and a spatial resolution of about $1.8\times1.8\ \text{mm}^2$. The calibrated efficiency of this detector is 72.1% at wavelength $\lambda=0.231$ nm. An oscillating radial collimator of 200 mm length is positioned in front of the 2D PSD. The oscillating radial collimator, which is made from gadolinium oxide (50 μm) and epoxy resin (100 μm), is optimized for 1100 mm sample-detector distance to improve the measurement accuracy, the angle between foils of the radial collimator is 0.217°. The oscillating time of periods ($1/f$) is set to 30 s, and the oscillating range is $\pm1^\circ$, which can efficiently decreases the background, and disturb the peak intensity little.

Due to the flexible mechanical movement with an air-cushion mode, the incident slit-sample, the monochromator-sample-detector and the detector slit-sample distances are adjustable, which enable the RSND to optimize the measurement set-up according to the sample species and size. Gauge volume location is gained by the slits system. The laser and the high-resolution digital camera is employed for the optics alignment, detailed instrument configuration of this part is shown in Fig. 3.

Intensity measurement was carried out with a ^{235}U fission chamber and a high-efficiency (96% for the neutron wavelength=0.18 nm) ^{3}He

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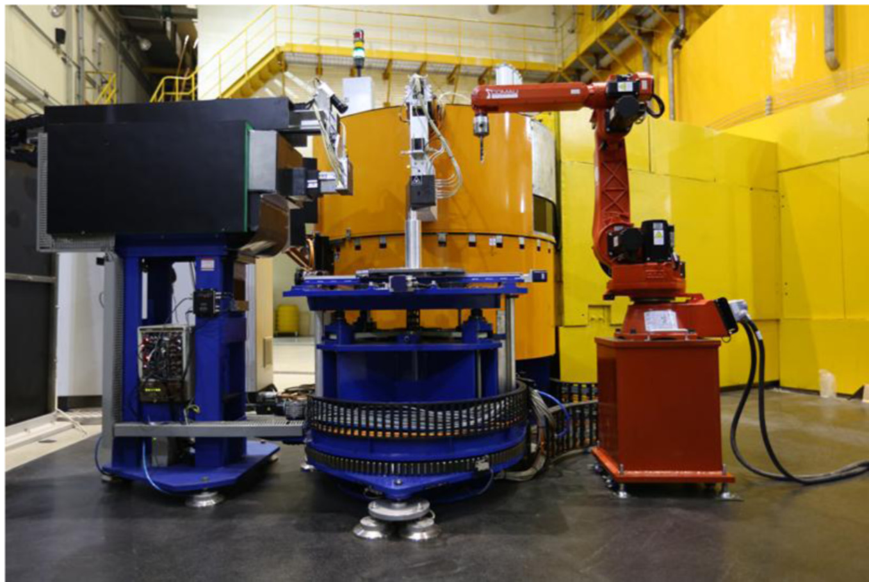

Fig. 1. RSND with high-level automation and high-sample adaptation at CAEP.

Table 1
Specifications of RSND diffractometer.

Model	Constant wavelength
Monochromator	Double focusing Si bent perfect crystal
Reflected plane	Si(3 1 1), Si(5 1 1)
Monochromator take-off angle ($2\theta_M$)	50–120°
Wavelength range	0.12–0.28 nm
Diffraction angle (2θ)	0–140°, accuracy ±0.01°
Neutron flux at sample position	4.7×10^6 n/cm²/s (λ=0.158 nm)
Resolution of spectrometer	$\Delta d/d \sim 1.91\times10^{-3}$ (λ=0.231 nm)
Gauge volume	$0.5\times0.5\times0.5$–$5\times5\times10$ mm³
Sample stage	
Maximum loading	500 kg
Translation X–Y	±300 mm, Positioning accuracy ±0.05 mm
Elevation Z	500 mm, Positioning accuracy ±0.1 mm
Rotation around Z axis	0–360°
Tilt angle along to X axis	±30° For 30 kg
Movement ranges	
Monochromator-sample distance	1600–2400 mm
Incident slit-sample distance	0–1130 mm
Detector slit-sample distance	0–1200 mm
Detector-sample distance	800–1500 mm
Detector (MK-200N PSD)	
Active area	200×200 mm
Spatial resolution	1.8×1.8 mm²
Detection efficiency	72.1% For wavelength of 0.231 nm
Sample environment	
Stress rig	0–15 kN, Accuracy ±10 N, bidirectional uniaxial tension or compression
Furnace	25–500 °C, Accuracy ±3 °C
Eulerian cradle (texture measurement)	Under construction

counter. The neutron flux on sample position is 4.7×10^6 n/cm²/s at wavelength λ=0.158 nm with the reactor power of 20 MW. We sum specifications of RSND in Table 1.

3. Strain measurement

A round-robin strain test has been carried out by RSND with the aluminum ring-and-plug sample from VAMAS (Versailles project on Advanced Materials and Standards) [3], as shown in Fig. 4. In this experiment, 0.172 nm neutron beam was chosen by the Si(3 1 1) monochromator with the take-off angle $2\theta_M$=63.5°. The Al(3 1 1) peak locates at the diffraction angle of about 89.5°. By setting the incident slit and diffracted slit as 2×2 mm², a cubic gauge volume of $2\times2\times2$ mm³ was obtained to provide a good spatial resolution. As shown in Fig. 5, the hoop strain distribution of the aluminum ring-and-plug sample measured by RSND is consistent with the previous experimental data of the same sample by Kowari [4] at ANSTO (Australia Nuclear Science and Technology Organization).

4. In-situ experiment

To carry out the in-situ experiment with particular environmental conditions, a stress rig has been designed to provide