LAAN-A-XR-E033A

SHIMADZU
Excellence in Science

Application News

No. X259A

X-Ray Analysis

High-Speed Residual Stress Measurement by X-Ray Diffraction (Linear Guide)

– OneSight™ Wide-Range High-Speed Detector –

Residual Stress Measurement of Metals

Stress measurement by X-ray diffraction can be used to measure the residual stress of mechanical components such as spring materials and piston rings, and is therefore used for strength evaluation and heat treatment management for automobile components and the like which require high durability. Here, we introduce an example of high-speed measurement of the residual stress in a linear guide using the OneSight wide-range, high-speed detector and stress measurement attachment.

OneSight Wide-Range High-Speed Detector

The OneSight wide-range high-speed detector (Fig. 1 and 2) consists of a semiconductor array with more than 1000 channels. Compared with the conventional scintillation detector, higher-speed measurement is achieved due to its sensitivity, which is more than twenty times that of the scintillation type.

In residual stress measurement by X-ray diffraction, where one peak of interest is targeted, it is effective to utilize the "One-Shot mode" in which the detector is fixed using a wide acquisition angle that includes the target peak position.

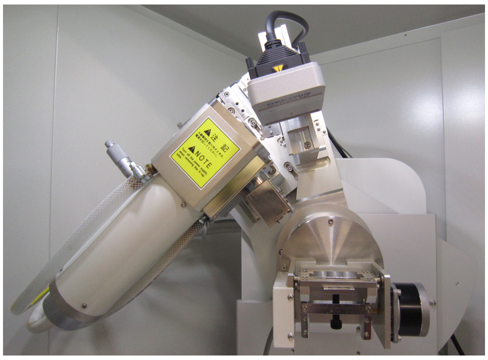


Fig. 1 XRD-7000 Equipped with Stress Measurement Attachment and OneSight™

Fig. 2 OneSight and Stress Measurement Attachment (Enlarged)

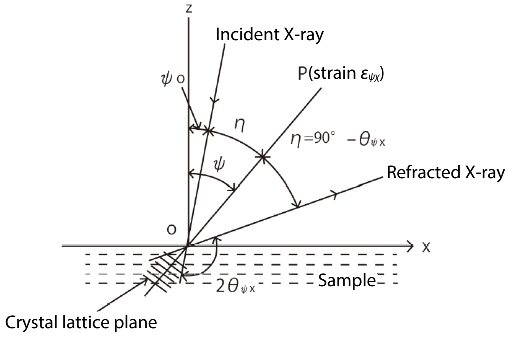
Measurement Principle of Residual Stress

Assuming a plane of a sample surface as defined by the x axis, specifically the direction of stress measurement, and the z axis, defined as the sample normal direction, if the strain in the OP direction derived from the slope of the z-axis and the angle θ is $\varepsilon_{\psi X}$, and $\theta_{\psi X}$ is the x-ray diffraction angle, the strain in the x direction is given by the following expression.

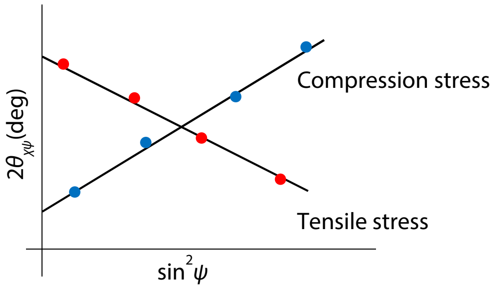
$$\sigma_x = \frac{E}{1+\nu} \times \frac{\partial(\varepsilon_{\psi x})}{\partial(\sin^2\psi)} = -\frac{E}{2(1+\nu)} \times \cot\theta_0 \times \frac{\partial(2\theta_{\psi x})}{\partial(\sin^2\psi)} \cdot \frac{\pi}{180} \text{[MPa]}$$

Here,

E : Longitudinal elastic modulus
ν : Poisson's ratio
$\theta_{\psi X}$: X-ray diffraction angle specific to a particular crystal lattice plane perpendicular to the OP direction
θ_0 : Diffraction angle when the material is in a non-strain state



Regarding the ψ point, after $2\theta_{\psi X}$ is measured, if $2\theta_{\psi X}$ is plotted with respect to $\sin^2\psi$, theoretically, a straight line is obtained.



From this slope (M), the stress value σ_x can be determined using the following expression.

$$\sigma_X = K \cdot M \text{ [MPa]}$$

$$\begin{cases} K = -\dfrac{E}{2(1+\nu)} \times \cot\theta_0 \cdot \dfrac{\pi}{180} \text{[MPa/deg]} \\[2ex] M = \dfrac{\partial(2\theta_{\psi x})}{\partial(\sin^2\psi)} \text{[deg]} \end{cases}$$

Residual Stress Measurement of Linear Guide

We measured the residual stress around the hole of the linear guide using the side-inclination method. The measurement conditions are shown in Table 1. A 20-second integration time was used for each ψ angle point. From the $2\theta_{\psi x}$ - $\sin^2\psi$ diagram in Fig. 5, it is shown that the specimen has a residual stress of -273 MPa at the measurement site.

Table 1 Analytical Conditions

Mode	One-Shot mode (Using stress measurement attachment, Side-inclination Method)
Instrument	XRD-7000
X-ray target	Cr
Tube voltage – tube current	40 kV – 40 mA
Monochromatic	V filter
Measurement range	146.9 to 165.3 degrees (Goniometer 2 θ fixed angle: 156.1 degrees)
ψ angle	ψ = 0, 16.8, 24.1, 30, 35.3, 40.2, 45 degrees
Integration time	20 seconds for each ψ angle (Total 140 seconds)
Detector	OneSight wide-range high-speed detector
Measurement plane	α-Fe 211

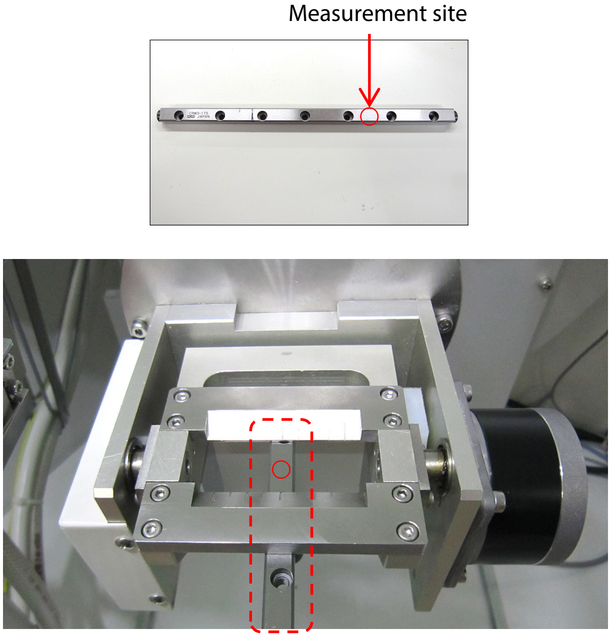


Fig. 3 Sample (Linear Guide)

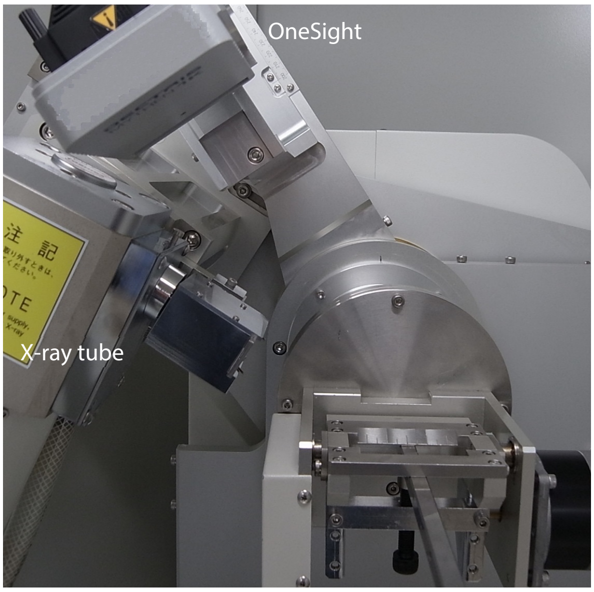


Fig. 4 Goniometer with Mounted Sample

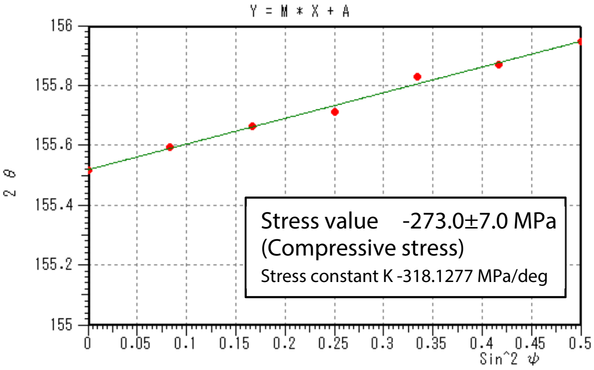


Fig. 5 $2\theta_{\psi x}$ - $\sin^2\psi$ Diagram (Linear Guide)

OneSight is a trademark of Shimadzu Corporation in Japan and/or other countries.

First Edition: Jun. 2015
Second Edition: Apr. 2019

SHIMADZU

Shimadzu Corporation
www.shimadzu.com/an/