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Modification of projection-type X-ray microscope for stress imaging

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Introduction

It is extremely important to evaluate mechanical failures of infrastructure materials using non-destructive techniques. One of the most promising ways is stress analysis by means of the X-ray diffraction technique using the $\sin^2\psi$-2θ procedure, which is the measurement of the Bragg peak position (2θ) as a function of the sample orientation (ψ) [1]. Since the technique gives only an average value, one has to carry out an XY scan of the sample in order to obtain the stress distribution. This is not practical because of the very long measuring time. This report describes the modification of the instrumentation of a projection-type X-ray microscope [2], which is a tool for efficient imaging.

Theoretical background

X-ray stress analysis is based on the use of lattice spacing as a strain gauge. For each inclination of the sample, defined by two angles φ and ψ, the strain ε in the direction normal to the diffraction planes, is related to the corresponding lattice spacing d, which is linked directly to the diffraction angle 2θ by Bragg's law. The relation between the strain ε and the stress tensor components is then derived through a micro mechanical approach to the material. Using the equilibrium conditions of the free surface, i.e., plane stress, the following equation, called the $\sin^2\psi$ law, is obtained:

$$\sigma_x = \frac{E}{1+\nu}\frac{\partial(\varepsilon_{\phi\psi})}{\partial(\sin^2\psi)} \qquad (1)$$

where σ, E and υ are the stress of interest, Young's modulus and Poisson's ratio. So far, most experiments have been performed with a fixed X-ray wavelength. This means that the 2θ angular scan should be performed to determine the diffraction angle for each ψ angle, which has been usually scanned by changing the inclination of the sample to the incident X-ray beam. On the other hand, one might notice that equation (1) can be rewritten as

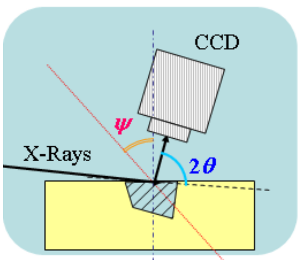
$$\sigma_x = \frac{E}{1+\nu}\frac{1}{\lambda_O}\frac{\partial\lambda}{\partial(\sin^2\psi)} \qquad (2)$$

where λ and λ_0 are the X-ray wavelengths giving Bragg peaks at certain diffraction angles, for the cases with and without strains, respectively. This indicates that the stress is given by the incident X-ray wavelength scan to find the Bragg peaks at certain several detector angular positions (2θ), which can control ψ even when the sample is completely fixed.

Modification of instrumentation

2D diffraction imaging can be performed even without an XY scan of the sample, when a projection-type X-ray microscope is employed. Quite a wide incident X-ray beam (typically, 8mm(H)×0.2mm(V)) arrives at quite small angle incidence, around 1 deg., to irradiate the whole view area of the sample. The detector is a CCD camera with an internal collimator plate. The camera can be fixed, as diffraction peaks are obtained by a monochromator scan instead of a normal angular scan of the detector. One can see which parts of the sample become bright when the X-ray wavelength comes across the expected Bragg condition.

Figure 1 shows a schematic view and also photos of the projection type X-ray microscope modified for residual stress imaging. So far, the experiments have been usually done at around 90 deg, which has the advantage of minimizing the distance from the sample surface to the detector. The main modification of the instrumentation made here is to fit the microscope for variable 2θ angles (60~120 deg). The distance of the camera needs to be lengthened to avoid mechanical interferences with the sample when the angle diverges from 90 deg.



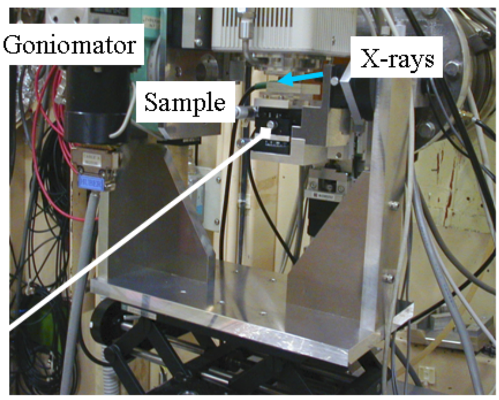


Figure 1 Projection-type X-ray microscope specifically modified for stress imaging experiments. The experiment consists of repeated exposures during the incident X-ray wavelength scan. The scans are performed for different ψ, i.e., 2θ angle. The incident angles of X-rays are fixed the whole time.

References

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[2] K.Sakurai and M.Mizusawa, *Photon Factory Activity Report 2003*, **#21,** p.260 (2004).
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