ID :293

Fine residual stress distribution measurement of steel materials by the SOI pixel detector with synchrotron X-rays

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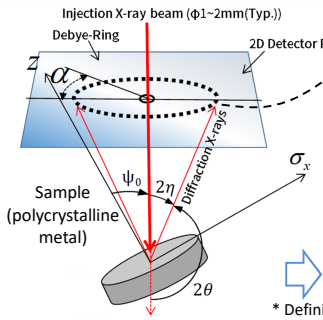
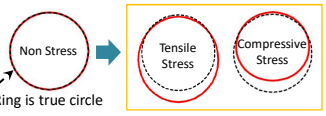
Introduction

Residual Stress measurement (Cos α method)





Debye-Ring formed by diffraction of X-ray beams on the surface (~10^1 μm) of polycrystalline metal.

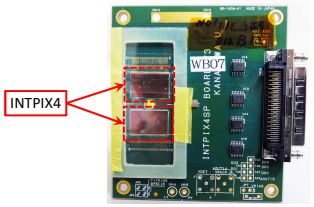
Debye-ring's deformation is related to the status of residual stress on crystal structure.
This deformation is sensitive to stress of tilt direction σ_x.
Variation rate of grating interval (Δd = strain by residual stress) can be calculated from Debye-ring's deformation. And Δd can converted to amount of residual stress by Hooke's law.

Residual stress can be evaluate from Debye-ring's deformation without destruction.

* Definition of stress amount's positive and negative :
Tensile side is positive, Compressive side is negative.

See also :
ID 256 (T. Sasaki et al.)
ID 327 (S. Mitsui et al.)

SOI Pixel detector in new measurement system



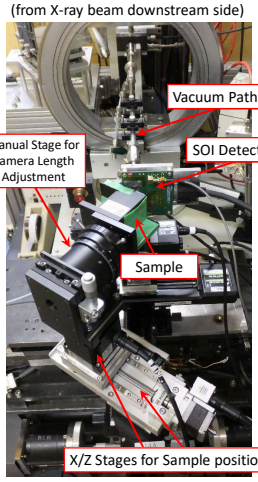
We are now developing the residual stress measurement system based on the cos α method using the two-dimensional detector. The silicon on insulator (SOI) pixel detector, named INTPIX4, was implemented as this system's two-dimensional detector.
(Left photo is Wire-bonding (WB) implementation type board.)

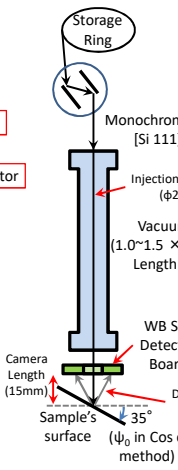
INTPIX4 has 14.1mm × 8.7mm sensitive area/chip which consists of Column 832 × Row 512 of 17μm × 17μm size pixels.

Setup of Residual stress measurement

Period : 2019/12/01 AM9:00 JST - 12/05 AM9:00 JST
Place : Photon Factory BL-14A
Energy : 5.415 keV Monochromatic
PF-Ring (Storage Ring) Mode :
Top-Up (HYBRID 30mA + 420mA)
Injection X-ray beam :
Diameter : ϕ2.5mm
Intensity (estimation) :
~4 × 10^8 photons/sec
in whole beam area

Setup's photo
(from X-ray beam downstream side)





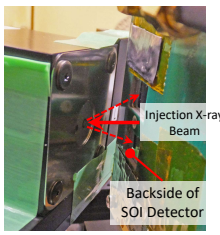


Photo of SOI Detector and Sample
(from left side of setup's photo)

Sample
Material : Steel
Diffraction plane : (h, k, l) = (2, 1, 1)
- Sinto (新東工業) residual stress standard specimen for X-ray measurement (3 types)
  Nominal value (Avg. of 5 tests of center point) :
  -384.0 MPa, -785.5 MPa, -1517.7 MPa
  *Results of -384.0 MPa were shown in this Poster.
- Sinto Fe Powder specimen
  for beam center calibration

SOI Detector's settings
INTPIX4 (300μm thickness FZn type wafer)
Sensor Bias Voltage : +200 V
Exposure Time : 200 sec (100 ms/frame × 2000 frames)
Scan Time : 320 ns/pix
Sensor node reset : 4 μs with 300 mV Ref. Voltage
CDS Reset : 5 μs with 350 mV Ref. Voltage
Readout Board : SEABAS 2

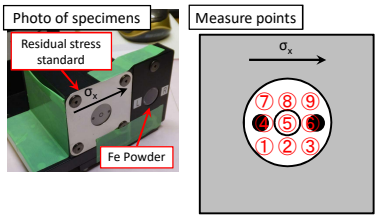
Experimental results

2D mapping

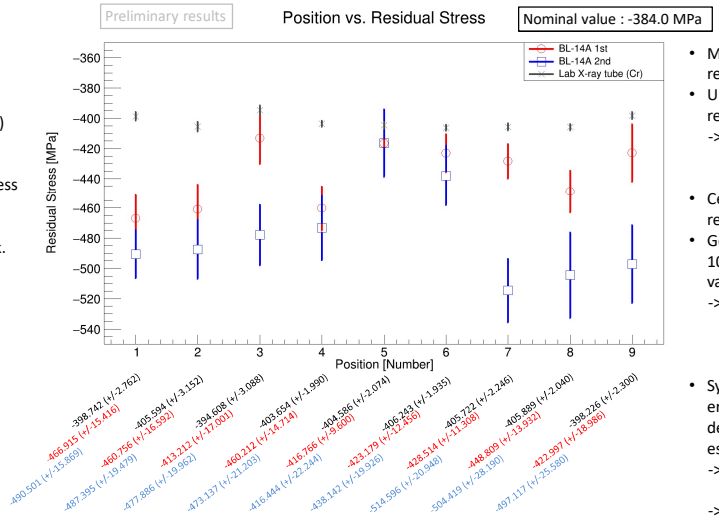
Procedure
1. Measure Debye-ring of Fe Powder specimen (Sinto).
2. Measure Debye-ring of Residual stress standard specimen (Sinto). (2.5 mm step, 3 × 3 points including center point. Shown below.)
3. Calculate Injection beam center from Debye-ring of Fe Powder specimen.
4. Calculate distribution of amount of residual stress on Residual stress standard specimen from Debye-ring of each point.

* -384.0 MPa specimen was measured twice for reproducibility check.

Photo of specimens / Measure points



2.5 mm step, 3 × 3 points including center point.
No.5 is center of specimen.



- Middle 3 points shows good reproducibility.
- Upper 3 points and lower 3 points reproducibility are worse than middle.
  ->There is a possibility it was caused by instability of tilt angle. (Effective for Camera length and ψ_0 angle)
- Center region (No.5) shows good reproducibility and fit to Lab's data.
- Generally Synchrotron data shows 10 – 100 MPa stronger compressive stress value than Lab's data.
  ->This is not heavy confliction, but we need to consider about what cause this. (Ex. Effect of Higher energy X-rays in Lab setup.)
- Synchrotron X-ray beam's data has larger error caused by lack of intensity. (real detection efficiency is 10 time lower than estimation.)
  ->Need to check optics and detector's true detection efficiency.
  ->Check Energy spectrum of Lab's X-ray tube.

Conclusion

Conclusion
- X-ray Residual Stress measurement (Cos α method) is non-destructive residual stress evaluation technique using Debye-ring's deformation.
- We tried to measure residual stress by synchrotron's monochromatic X-ray beam (5.415keV) at Photon Factory BL-14A.
- Synchrotron X-ray beam's data has larger error caused by lack of intensity, however, the experimental results are not conflicting to existing result measured by Laboratory's X-ray tube (Cr Kα)

For the future
Check and fix (if necessary) about :
- Lack of intensity
- Analysis algorithm
- Setup's instability
- Optics and detector's true detection efficiency.
- Energy spectrum of Lab's X-ray tube.