Residual Stress Tensor for Multi-Axial Loading Conditions at NRSF2

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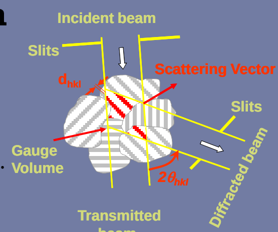
Introduction



Measurement of residual stress evolution in various materials using neutron diffraction is now a well established process. However, interplanar strains are normally determined in three orthogonal directions, axial, radial and hoop for example. Furthermore, the bulk of the past research corresponds to samples deformed in pure tension or complex stress from welds.

In reality, the stress state is complex and involves a combination of normal and shear stresses. Strains in three orthogonal directions does not necessarily correspond to principal strains.

Our research establishes experimental procedures and analytical interpretation of a residual stress/strain tensor using neutron diffraction both for in-situ and ex-situ conditions. Using the NRSF2 facility at HFIR, a complete strain tensor for three *hkls* are determined in ex-situ conditions for this research. Comparative results of measured residual strain on identical steel hollow cylindrical samples subjected to tension and torsion are included showing the significant effect of stress path for identical loading conditions (based on strain invariant).

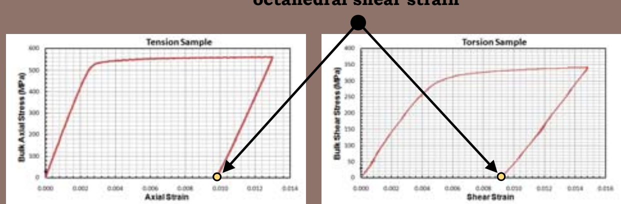
Sample Information

- Material: 12L14 steel

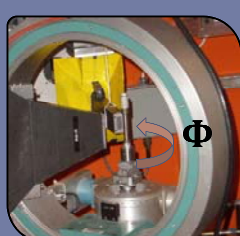
AISI Number	Chemical compositions (%)				
	C max	Mn	P	S	Pb
12L14	0.15	0.85-1.15	0.04-0.09	0.26-0.35	0.15-0.35

- Loading conditions: Pure Tension & Pure Torsion

Both deformed samples subjected to identical octahedral shear strain



Experimental Details



The samples are mounted on a Huber orienteer such that the gauge volume is centered at the intersection of the two axes of rotation.

To solve the tensor at least six independent rotations of the gauge volume is required.

Up to 30 independent combinations of Φ and Ψ were used in the experiment. (Φ = -45, 0, 30, 60, 90 & Ψ = 0, 30, 60, 90, 120, 150).

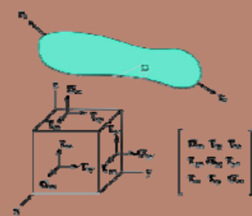
A least squares reduction is used to solve for the strain tensor.

A 1mm x 1mm x 1mm gauge volume was precisely aligned halfway through the cylinder wall.

Planes selected for measurement were specifically chosen based on past research that indicates that these planes are weakly (BCC Fe 110 & 211) and strongly (BCC Fe 200) affected by intergranular strains

Background Information

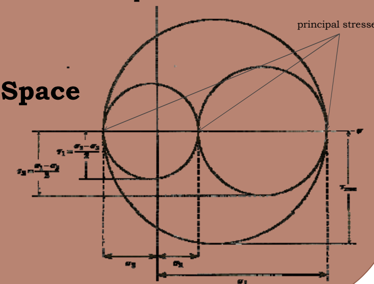
Stress at a Point



Diffraction experiments yield d-spacing changes along the directions of the scattering vector providing strain in that directions. To obtain a Strain tensor at a point one needs six such independent measurements.

A strain and hence a stress tensor consists of a matrix of nine values, six of which are independent.

Mohr's Circle – Stress Space



A strain/stress tensor can be visually represented in 2-D, using principal components plotted in Mohr's space as shown.

One can obtain stress or strain on any plane from Mohr's circle.

3-D Residual Strain Measurements

(all values in microstrain)

$$\varepsilon_{\phi\psi}(x,y,z) = \frac{d_{\psi\phi}(x,y,z) - d_0}{d_0}$$

d_0 determined from a powder sample

$$\varepsilon_{\phi\psi} = \varepsilon_{xx}\cos^2\phi\sin^2\psi + \varepsilon_{xy}\sin 2\phi\sin^2\psi + \varepsilon_{yy}\sin^2\phi\sin^2\psi + \varepsilon_{zz}\cos^2\psi + \varepsilon_{xz}\cos\phi\sin 2\psi + \varepsilon_{yz}\sin\phi\sin 2\psi$$

Sample Subjected to Pure Tension

Strain Tensors

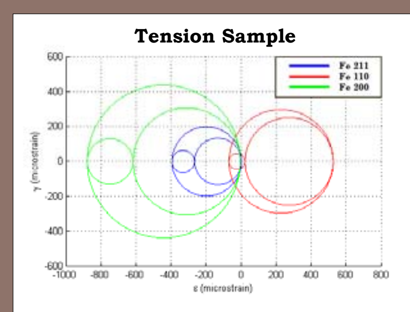
$$\varepsilon_{110} = \begin{Bmatrix} -16 & -44 & 54 \\ -44 & -24 & 15 \\ 54 & 15 & 521 \end{Bmatrix}$$

$$\varepsilon_{200} = \begin{Bmatrix} -844 & 79 & -65 \\ 79 & -641 & 64 \\ -65 & 64 & -14 \end{Bmatrix}$$

$$\varepsilon_{211} = \begin{Bmatrix} -269 & 22 & -3 \\ 22 & -390 & -3 \\ -3 & -3 & 3 \end{Bmatrix}$$

Measured γ_{oct}

$\gamma_{oct_{110}} = 262 \quad \gamma_{oct_{200}} = 367 \quad \gamma_{oct_{211}} = 166$



Sample Subjected to Pure Torsion

Strain Tensors

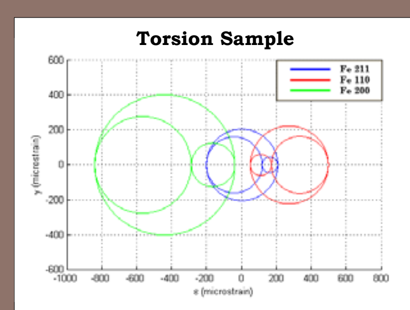
$$\varepsilon_{110} = \begin{Bmatrix} 86 & 39 & -40 \\ 39 & 267 & 173 \\ -40 & 173 & 368 \end{Bmatrix}$$

$$\varepsilon_{200} = \begin{Bmatrix} -668 & 179 & -249 \\ 179 & -360 & 59 \\ -249 & 59 & -137 \end{Bmatrix}$$

$$\varepsilon_{211} = \begin{Bmatrix} -118 & 130 & -57 \\ 130 & 89 & 77 \\ -57 & 77 & 155 \end{Bmatrix}$$

Measured γ_{oct}

$\gamma_{oct_{110}} = 189 \quad \gamma_{oct_{200}} = 335 \quad \gamma_{oct_{211}} = 176$



Conclusions/Future Work

- Significant effect of loading path (tension vs. torsion) was observed on the residual strain/stress evolution for BCC Fe based steel alloy.
- The differences of residual strain for tension vs. torsion were quantified for three *hkl* planes and considerable effects was noticed for complex loading conditions.
- In-situ measurements are being planned on the same material at NRSF2 and Vulcan using a custom fabricated and portable multi-axial device in 2010.
- We are excited for the Vulcan commissioning ☺.