Study of bending behavior in Nb_3Sn strands

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1.1 Background

The superconducting property of Nb_3Sn strands is very sensitive to strain. The transverse electromagnetic loading has been considered as a major origin of the degradation of Nb_3Sn cable-in-conduit conductor (CICC) due to the periodic local bending. The degradation of each strand due to this bending should be evaluated to calculate the performance of a CICC. Thus, an analytical model considered with **the plastic deformation of copper and filament breakages** was developed.

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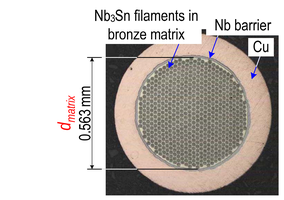
1.2 Objectives

- **Evaluation of bending strain distribution and filament breakage in Nb_3Sn strands using neutron diffraction measurement and numerical model.**
- **Critical current calculated by proposed model** shows agreement with the measurements.

5. Conclusion

- The Bending strain of Nb_3Sn strands can be measured by the neutron diffraction technique quantitatively and non-destructively. The procedure using the convolution between the profile of non-bent Nb_3Sn strand and bending strain distribution was applied.
- In addition, the neutron diffraction profile of the bent Nb_3Sn strand shows the filament breakage quantitatively.
- Numerical model is developed to calculate the strain distribution, the filament breakage and Ic characteristic of bent strands.
- Ic behavior of the test strand is corresponding to the HTRM with filament breakage starting from 0.6%.

2.1 Bent Nb_3Sn Strand



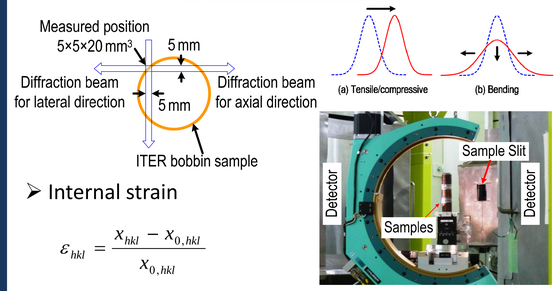
PARAMETERS	Bronze-route
Strand diameter	0.822 mm
Twist pitch	15 mm
Twist direction	Z-direction
Cu / non-Cu	0.99
Filament material	Nb-1%Ta
Filament diameter	3.0 μm
Number of filaments	11077

- Apparent bending strain $\varepsilon_{b,\,curvature}$ is calculated from the curvature.

$$\varepsilon_{b,curvature} = \frac{d_{matrix}}{D} - \frac{d_{matrix}}{D_0}$$

2.2 Neutron Diffraction

Experimental Set-up



- Internal strain

$$\varepsilon_{hkl} = \frac{x_{hkl} - x_{0,hkl}}{x_{0,hkl}}$$

- Strain-free material is **non-bent Nb_3Sn strand**.
- Nb_3Sn(211) was selected to perform the profile fitting as larger peak.

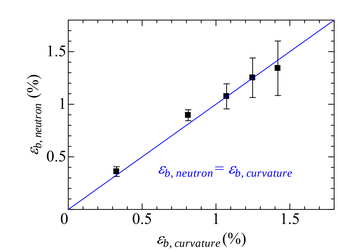
Evaluation of Bending Strain

- The profile of bent strands, $h(\varepsilon)$, is considered as a convolution between the profile of the non-bent strand, $f(\varepsilon)$, and the bending strain distribution, $g(\varepsilon)$.

$$h(\varepsilon) = \int f(e)g(\varepsilon - e)de$$

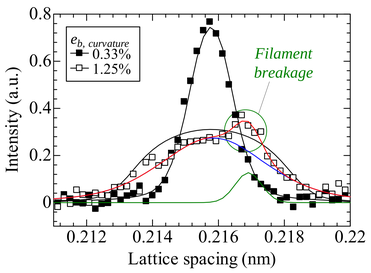
$$g(\varepsilon) = \begin{cases} \dfrac{2}{\pi\varepsilon_b}\cos\left\{\sin^{-1}(\varepsilon/\varepsilon_b)\right\} & (-\varepsilon_b \le \varepsilon \le +\varepsilon_b) \\ 0 & (\varepsilon < -\varepsilon_b, \varepsilon_b < \varepsilon) \end{cases}$$

Evaluation of Bending Strain

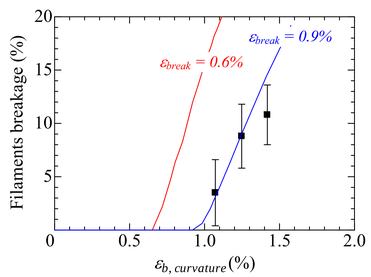


- Bending strain evaluated by the neutron diffraction is agreed with the apparent bending strain calculated from the curvature if there are no filament breakages.

3. Filament Breakage



Profile for filament breakage

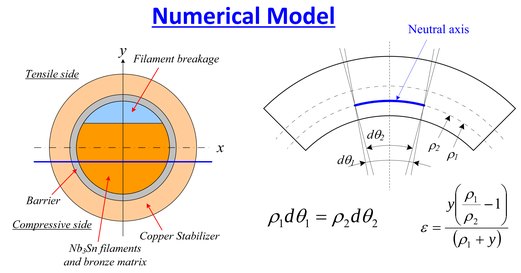


Volume fraction of filament breakage

- Filament breakage may be started from less than that of 0.9% since it is incidentally occurred.

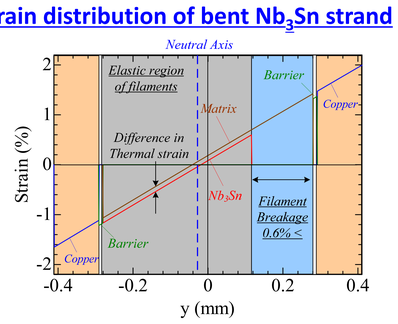
4. Numerical Analysis

Numerical Model



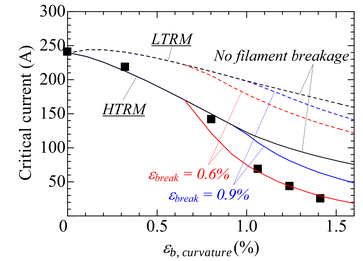
- Copper and matrix: elastic – plastic behavior.
- Nb_3Sn and Nb: elastic behavior.
- Neutral axis is determined as $\int_A \sigma dA = 0$
- Thermal strain and filament breakage are considered.
- *Jc(B, T, ε)*: Scaling law for ITER strands.

Strain distribution of bent Nb_3Sn strand



- Apparent bending strain $\varepsilon_{b,\,curvature}$ is 1.25%
- Filament breakage starts from 0.6% strain.
- Thermal strain is -0.1% in Nb_3Sn at 293K.

Ic characteristics of bent Nb_3Sn strand



- Low Transverse Resistive Model (LTRM) and High Transverse Resistive Model (HTRM) proposed by J. Ekin are considered as models.
- The measurement result is corresponding to **the HTRM with filament breakage starting from 0.6%** for the tested strand.