Evaluation of thermal strain induced on components of Nb_3Sn strand during cool down

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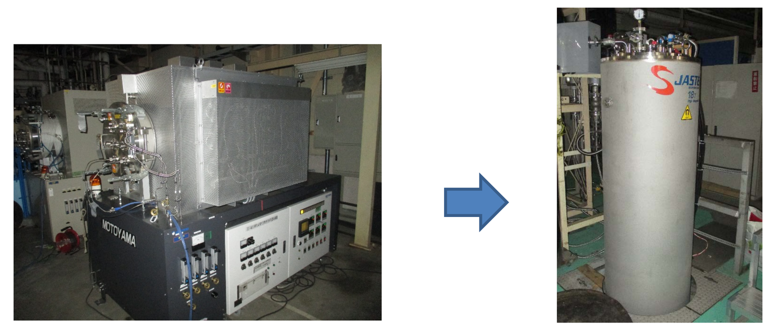
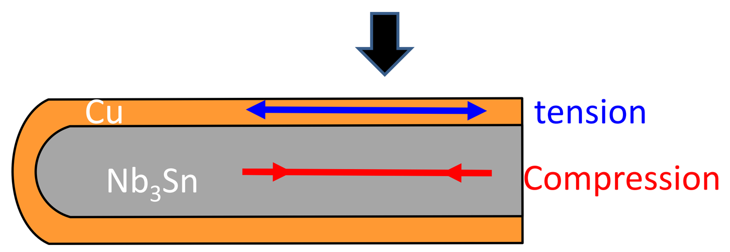
1. Background

Thermal strain on Nb_3Sn filaments is considered to largely influence on initial performance of a cable in conduit conductor(CICC). For prediction of the conductor performance, initial thermal strain of the Nb_3Sn strand was calculated from comparison of fully characterization (critical current, field, temperature, strain) with critical current of which strands were used for the CICC, but it was not directly measured. It is important to know thermal strain state in the Nb_3Sn strand to predict conductor performance.



923 K for heat treatment → 4 K for cooldown



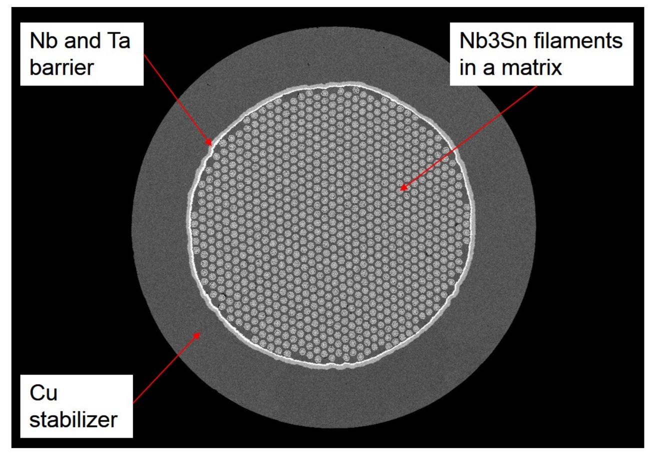
Objectives

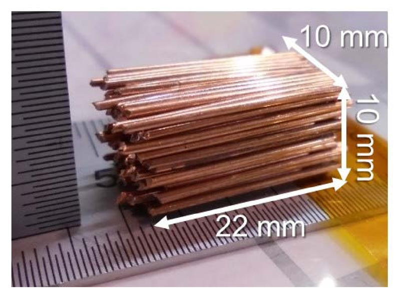
- ☐ Thermal strain measurement on ITER bronze-route Nb_3Sn strand.
- ☐ Comparison measured results and calculated results from stress balance in the Nb_3Sn strand.

6. Conclusion

- ☐ Thermal strain of the Nb_3Sn strand for ITER CS in 10-300 K was measured by neutron diffraction in KOWARI at ANSTO.
- ☐ The compressive thermal strain was observed in Nb_3Sn and the Nb/Ta barrier.
- ☐ The thermal strain of Nb_3Sn in axial direction of the strand was -0.111% at 300 K and -0.209% at 10 K, respectively.
- ☐ Transverse strain of Nb_3Sn was almost not changed from 300 K.
- ☐ Calculated thermal strain of Nb_3Sn under stress balance in axial direction agreed with measured values if the strain was applied in less than 600 K. However, the thermal strain of Nb/Ta barrier was different between calculated and measured values.

2. Sample





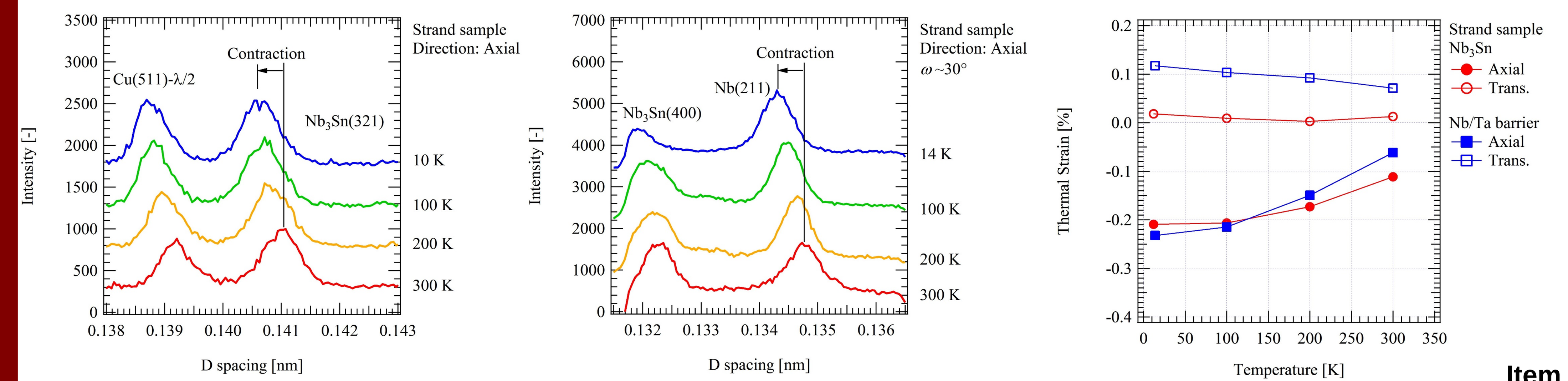
Bundled strand sample

Filaments Barrier

Item		Value
Type		Bronze-route
Diameter		0.83 mm
Number of filaments		17347
Barrier material		Nb/Ta
Barrier thickness		9 mm
Cu/non-Cu ratio		1.0
Volume fraction	Cu stabilizer	48.6%
	Bronze matrix	30.4%
	Filament	17.6%
	Nb barrier	2.3%
	Ta barrier	1.1%

- ☐ Bronze-route Nb_3Sn strand for ITER CS was prepared for thermal strain measurement by using neutron diffractometer.
- ☐ The barrier is composed by Nb and Ta.
- ☐ After the heat treatment , Sn concentration is 1.0-1.5wt% in the bronze matrix.
- ☐ Cu and bronze were dissolved, and filament and barrier were extracted from the strand as d_0 sample with stress free state.

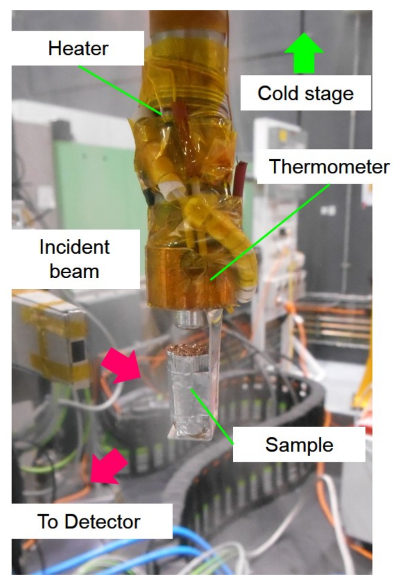
4. Results

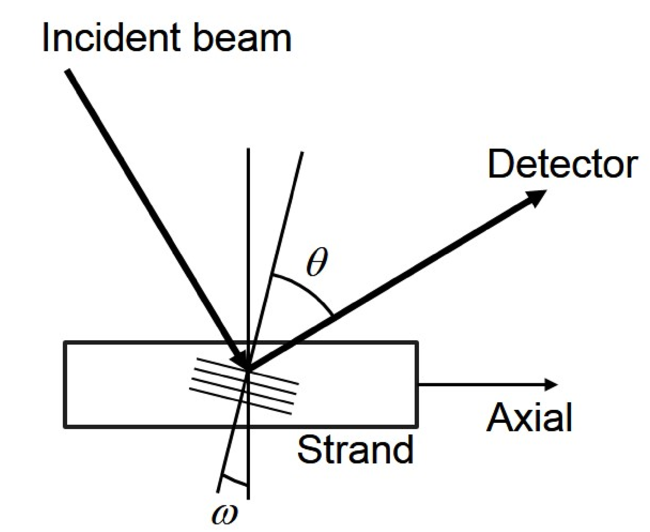


- ☐ The thermal strain of Nb_3Sn was -0.111% at 300 K and -0.209% at 10K in axial direction, respectively.
- ☐ The axial thermal strain was -0.062% and -0.232% at 300 K and 14 K in the Nb/Ta barrier respectively.
- ☐ Compared with axial thermal strain, variation of the transverse thermal strain was very small in Nb_3Sn of the strand sample

Item			Thermal strain
Nb_3Sn (321)	300 K	Axial	-0.111%
		Trans.	0.001%
	10 K	Axial	-0.209%
		Trans.	0.018%
Nb/Ta (211)	300 K	Axial	-0.061%
		Trans.	0.071%
	14 K	Axial	-0.232%
		Trans.	0.118

3. Diffraction measurement



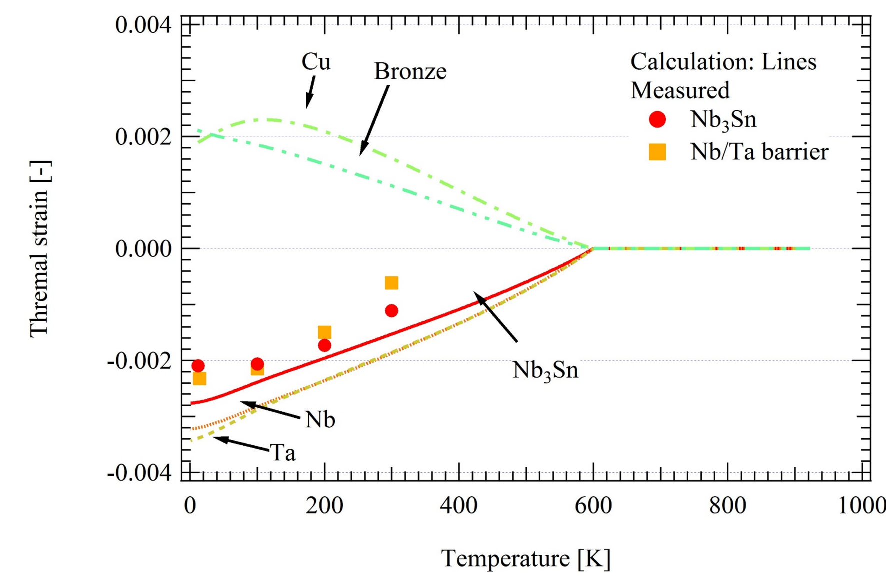


- ☐ An angular dispersive neutron diffractometer KOWARI at Australian Nuclear Science and Technology Organisation (ANSTO), was used to measure thermal strain.
- ☐ Strain of the components in the samples is observed as peak shift in the diffraction profiles.
- ☐ 2q ~ 90º to get good accuracy of the profile.
- ☐ Neutran diffraction measurement was carried out between 300 -10 K.
- ☐ To evaluate the thermal strain, *d*-spacing of $Nb_3Sn(321)$ and Nb/Ta(211) planes were measured on the strand sample and the d_0 samples (only filament and barrier sample).
- ☐ Thermal strain

$$\varepsilon_{hkl}(T)=\frac{d_{hkl}(T)}{d_{0,hkl}(T)}-1$$

d_{hkl} :*d*-spacing of (hkl) plane
$d_{0,hkl}$:*d*-spacing of (hkl) plane of d_0 sample

5. Calculate dthermal strain



- ☐ Assumption
  - Axial stress was balance in the strand
  - Thermal strain was not induced in more than 600 K
  - Nb_3Sn, Nb, Ta → Elastic
  - Cu, bronze → Elasto-plastic

- ☐ Thermal strain of the component *i*

$$\varepsilon_i(T)=\varepsilon_s(T)-\int_{T0}^{T}\alpha_i(T)dT$$

e_i :Thermal strain in component *i*
e_s :Thermal contraction of the strand
a_i :Coeffient of thermal expansion of *i*

- ☐ Elasto-plastic stress-strain curve of copper and bronze

$$\frac{1}{\sigma_i(T)}=\frac{1}{E_i(T)\varepsilon_i(T)}+\frac{1}{Aq_i\{\varepsilon_i(T)\}^{1/n_i}}$$

s_i: Axial stress of componenti
E_i: Young's moduli
q_i, n_i, A: Selected constants

- ☐ Stress equilibrium on axial direction in the cross secsion of the Nb_3Sn strand

$$\sum_i V_i\sigma_i=0$$

V_i: Volume fraction of component *i*
q_i, n_i: selected constants

- ☐ On Nb_3Sn, behavior of calculation results agreed with measured values.
- ☐ ~0.1% difference was found in Nb/Ta barrier between calculation and measurement.

Presented at the Magnet Technology Conference , 2017 Oct. 27 – Sep. 1, Amsterdam, Netherland; Session: Loq-Tc Wires and Cables; Program I.D. number: MT25-Wed-Af-Po1.08-11