Recent Progress of Application-Oriented DI-BSCCO Wires

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Outline

1. Concepts of reinforced DI-BSCCO

- ✓ ***Lamination with pre-tension technique and tough Ni-alloy tapes***

2. Updated status of "Type HT-NX"

- ✓ ***I_c performance and mechanical strength***

3. R&D activities

- ✓ ***Improvement of splice structure with Type HT-NX***

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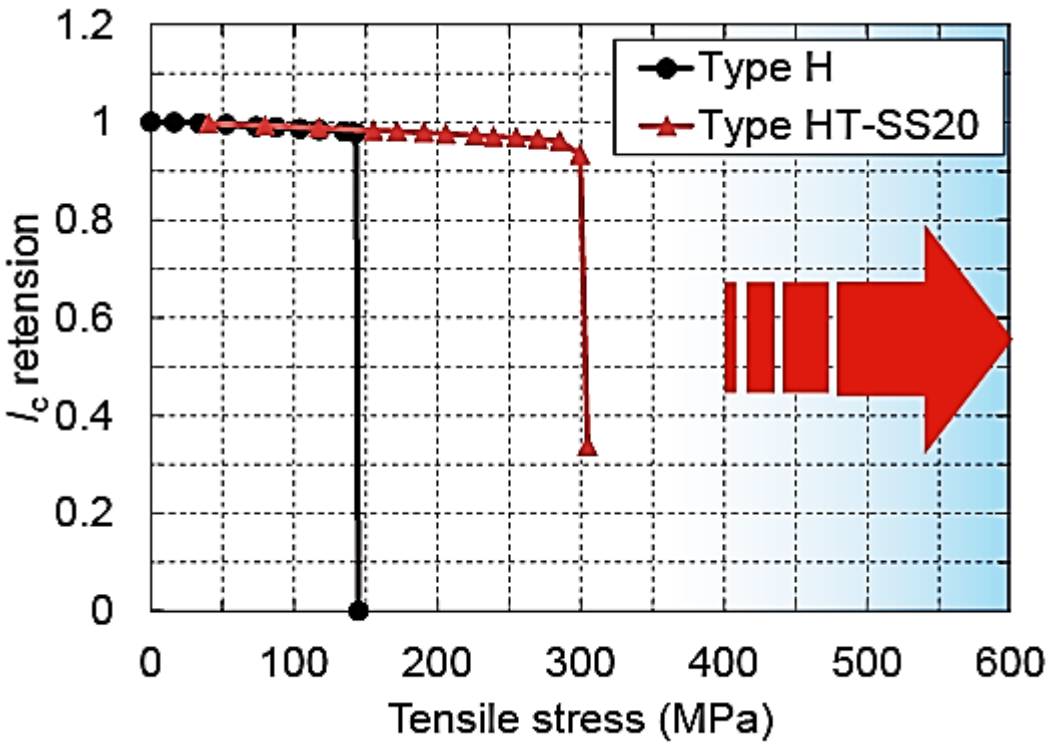
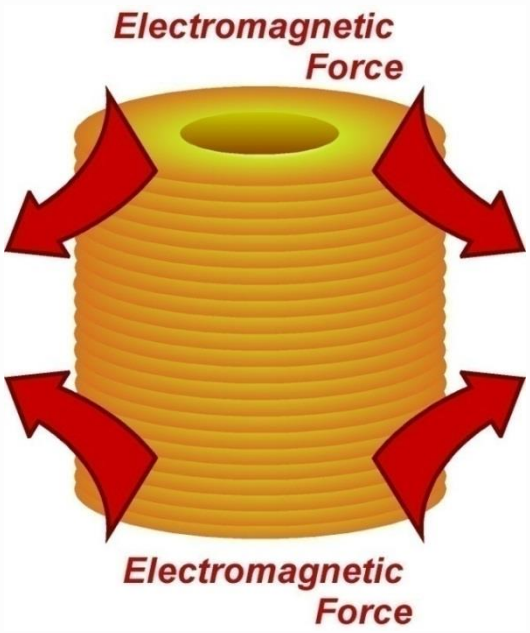
Development of high strength Bi-2223 wire (Type HT-NX)

Bi-2223 (DI-BSCCO) were not widely used in the field of high magnetic field (>20 T) coil market because its strength was too low for the hoop stress.



Tensile stress properties of standard Type H and Type HT-SS at 77 K.



We needed to develop a new Type HT that can be tolerant with pretty high tensile stress (>400 MPa) generated in a high field magnet.

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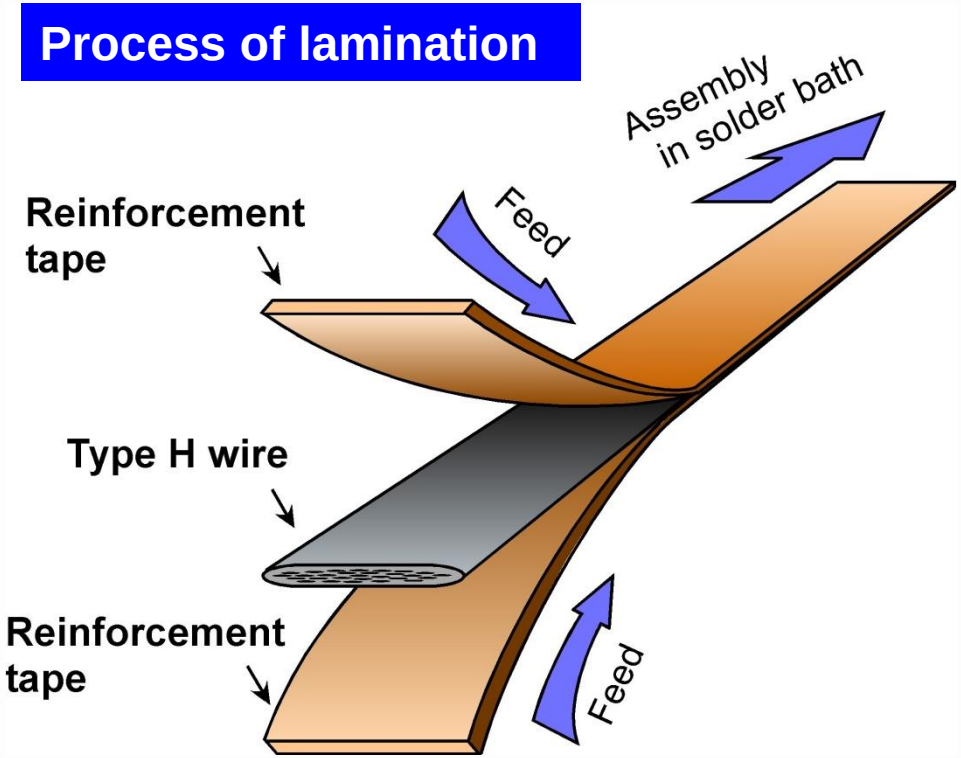
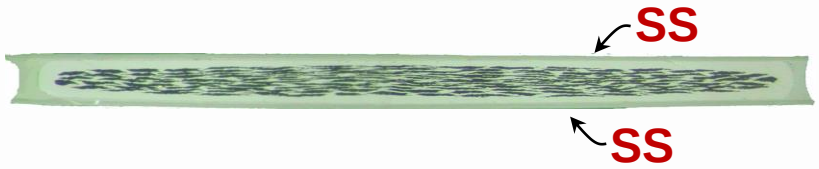
Type HT (mechanically-reinforced Type H)

Process of lamination



Bare wire (Type H)

Type HT-SS
(Reinforced with Stainless Steel)



Type HT-CA
(Reinforced with Cu-alloy)

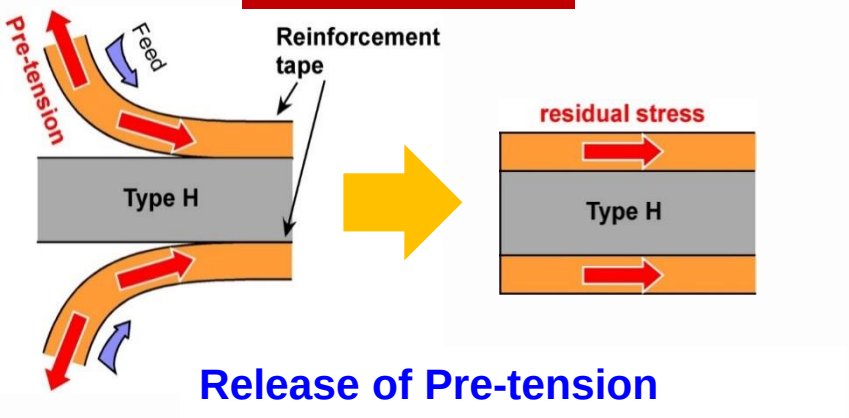
Type HT ***(Type H with Toughness)*** **is laminated with reinforcement tapes. They are firmly bonded with Type H, and de-lamination never occurs, as long as the wire temperature is kept below 200 degree C.**

Development of 3-ply technique

Pre-tension and thermal mismatch

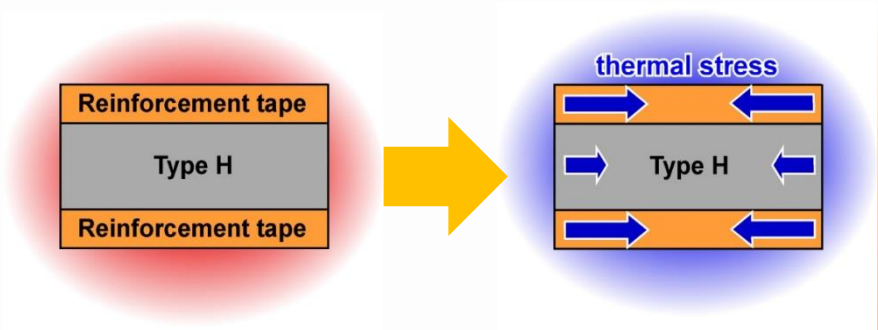
can give residual compressive strain to a bare tape.

Pre-tension



Release of Pre-tension

Thermal mismatch



Cooling down

Higher compressive strain is applied to Type H due to relaxation to equilibrium in Type HT after removing higher pre-tension.

Higher compressive strain is applied to Type H due to higher thermal mismatch between the reinforcement tapes and Type H.

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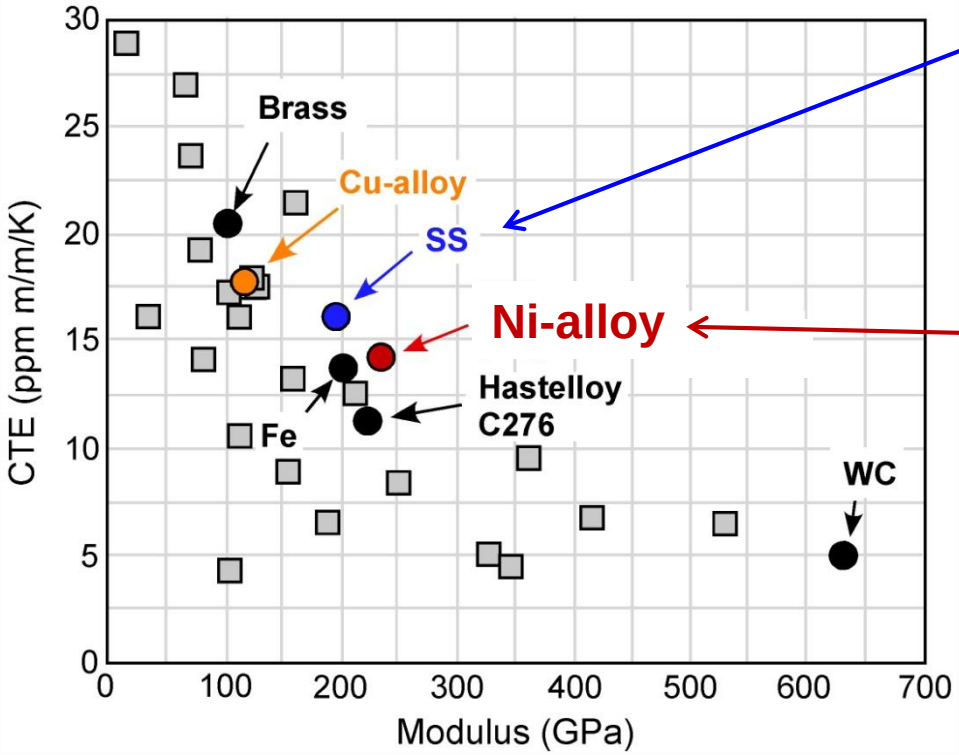
Effort for developing better metallic material

Higher pre-tension (≥ 80 N) will be available for reinforcements with

- ***high CTE (Coefficient of Thermal Expansion)***
- ***high toughness (high Modulus & Yield stress).***

Modulus - CTE window (Metal & Alloy)



Stainless steel (cold rolled)

CTE	16.0ppm m/m/K
Modulus	193 GPa
Yield stress	1200MPa

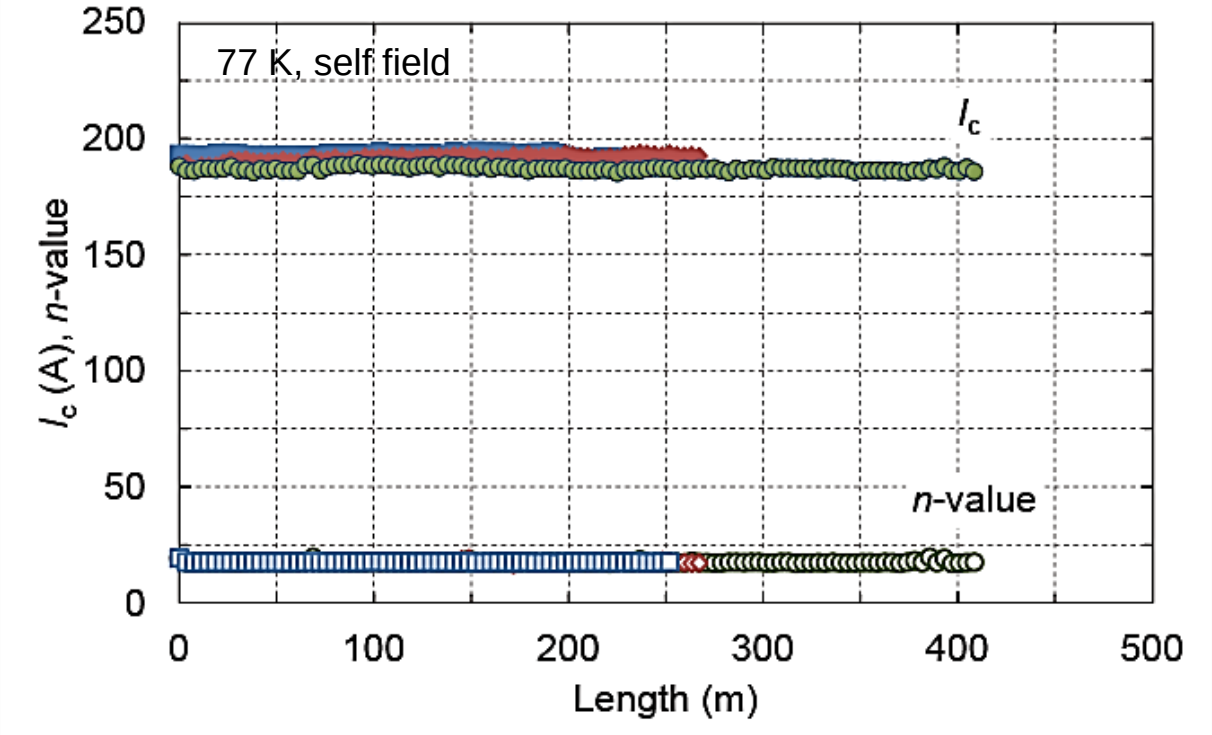
Ni-Alloy (cold rolled)

CTE	14.6ppm m/m/K
Modulus	233 GPa
Yield stress	2000MPa

Ni-alloy seems to be a promising material for reinforcement.

Productivity and Shipment

I_c and n-value distribution of typical Type HT-NX wires in several hundreds meters long



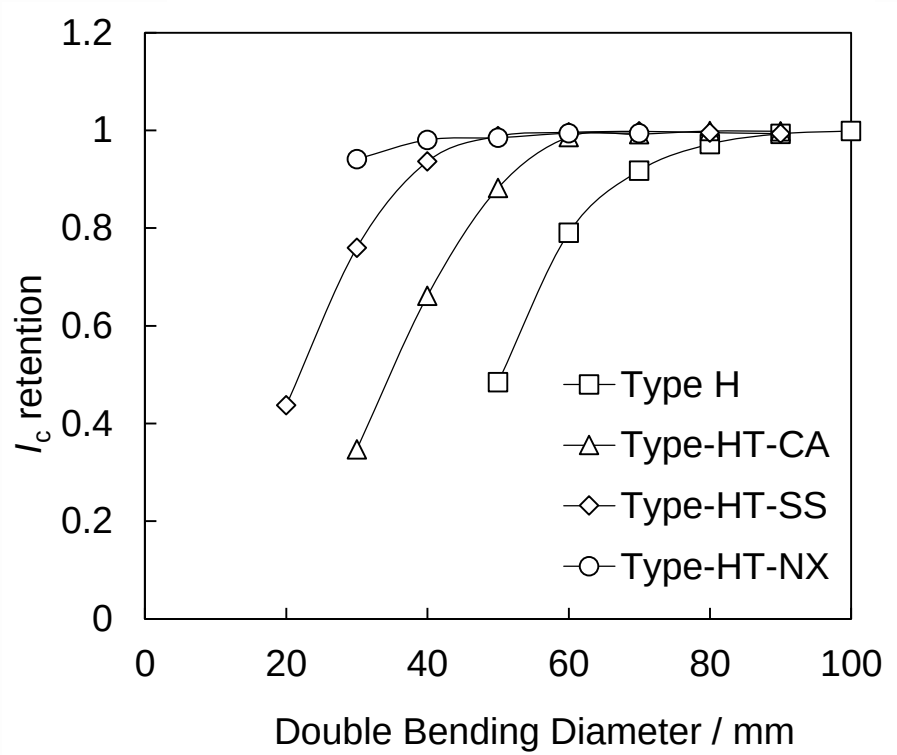
I_c and n-value are very uniform in hundreds meters long wire.

***For shipment**

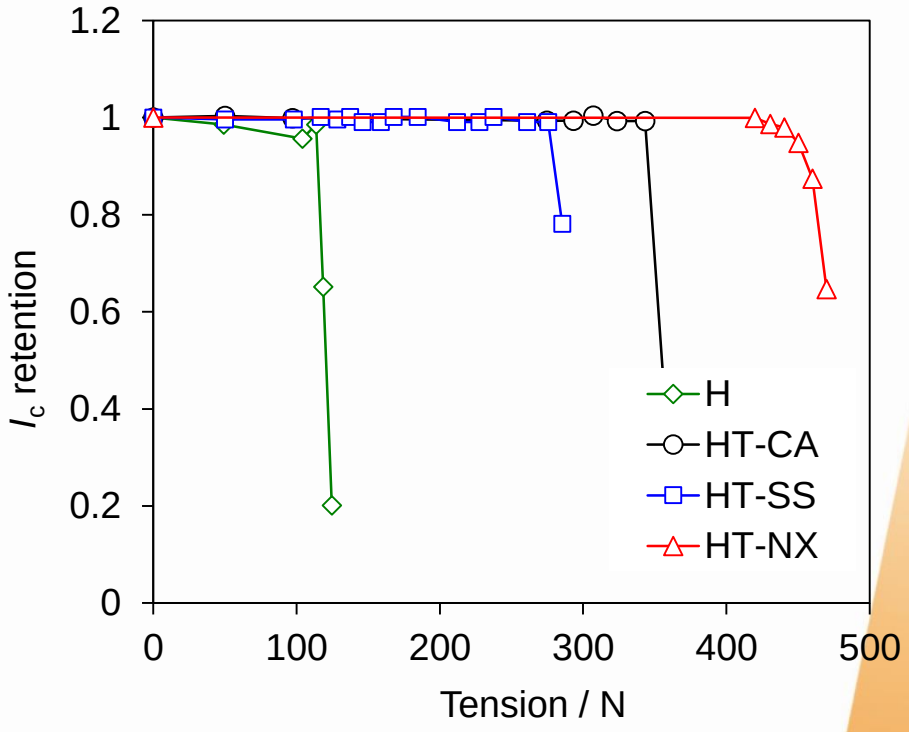
Sumitomo ships Type HT-NX with unit length 200 m surely.
In near future, unit length more than 500 m will be produced.

Strength results of Type HT-NX at R.T.

Double bending diameter at R.T. dependences of I_c



Tension at R.T. dependences of I_c



Critical DB diameter (@R.T.)

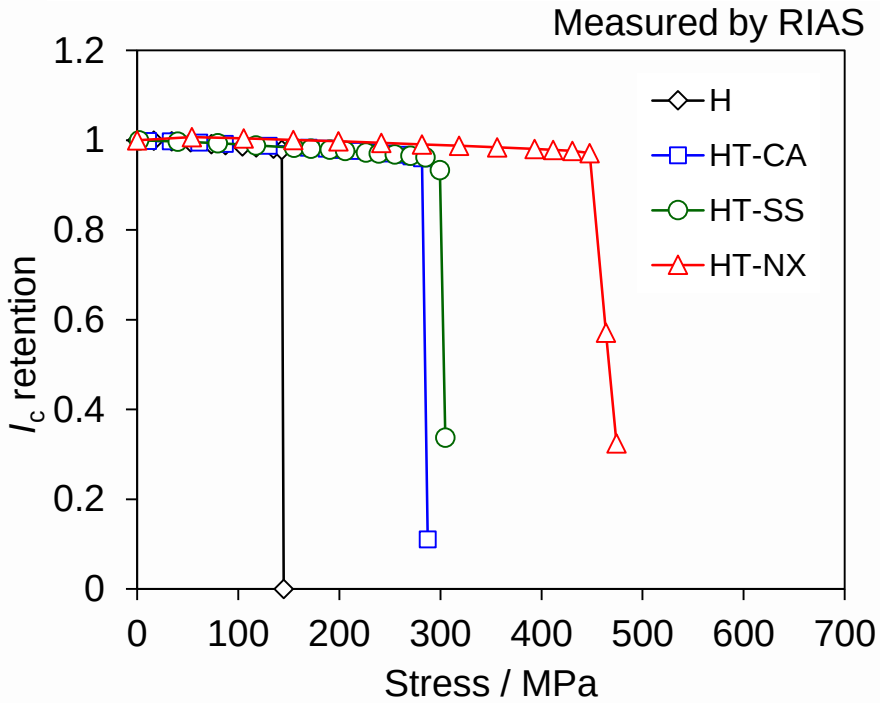
- ✓ **35 mm : Type HT-NX**
- ✓ **60 mm : Type HT-CA**
- ✓ **45 mm : Type HT-SS**
- ✓ **80 mm : Type H**

Critical tension (@R.T.)

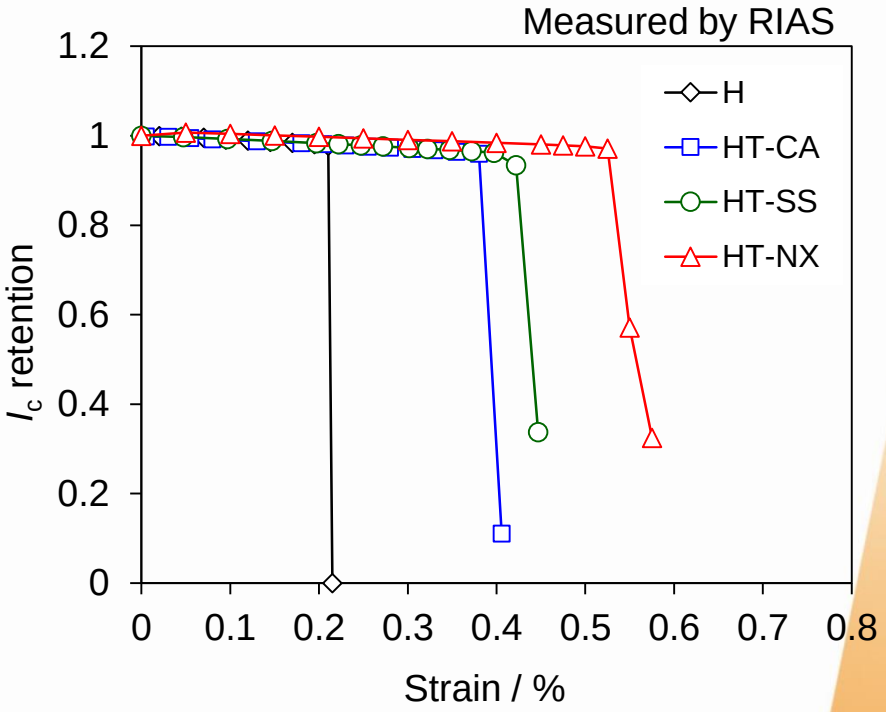
- ✓ **449 N : Type HT-NX**
- ✓ **344 N : Type HT-CA**
- ✓ **277 N : Type HT-SS**
- ✓ **114 N : Type H**

Strength results of Type HT-NX at 77 K

Tensile stress at 77 K dependences of I_c



Strain at 77 K dependences of I_c



Critical tensile stress (@77 K)

- ✓ **443 MPa : Type HT-NX**
- ✓ **287 MPa : Type HT-SS**
- ✓ **283 MPa : Type HT-CA**
- ✓ **131 MPa : Type H**

Critical strain (@77 K)

- ✓ **0.53 % : Type HT-NX**
- ✓ **0.39 % : Type HT-SS**
- ✓ **0.38 % : Type HT-CA**
- ✓ **0.22 % : Type H**

Collaborative study:
Toyama Univ. Dr. K. Kasaba

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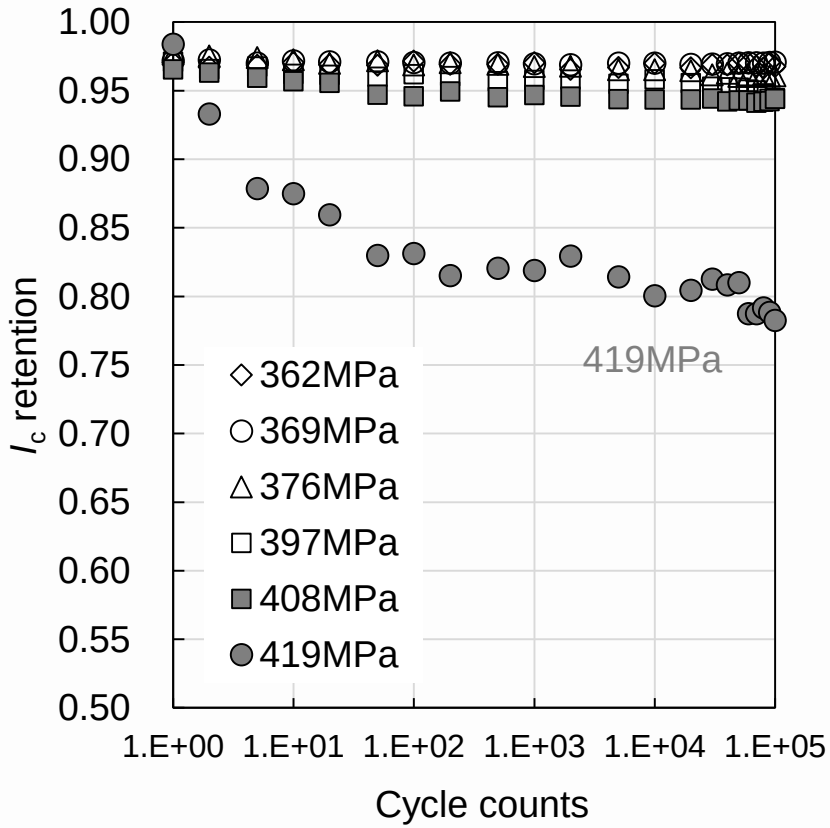
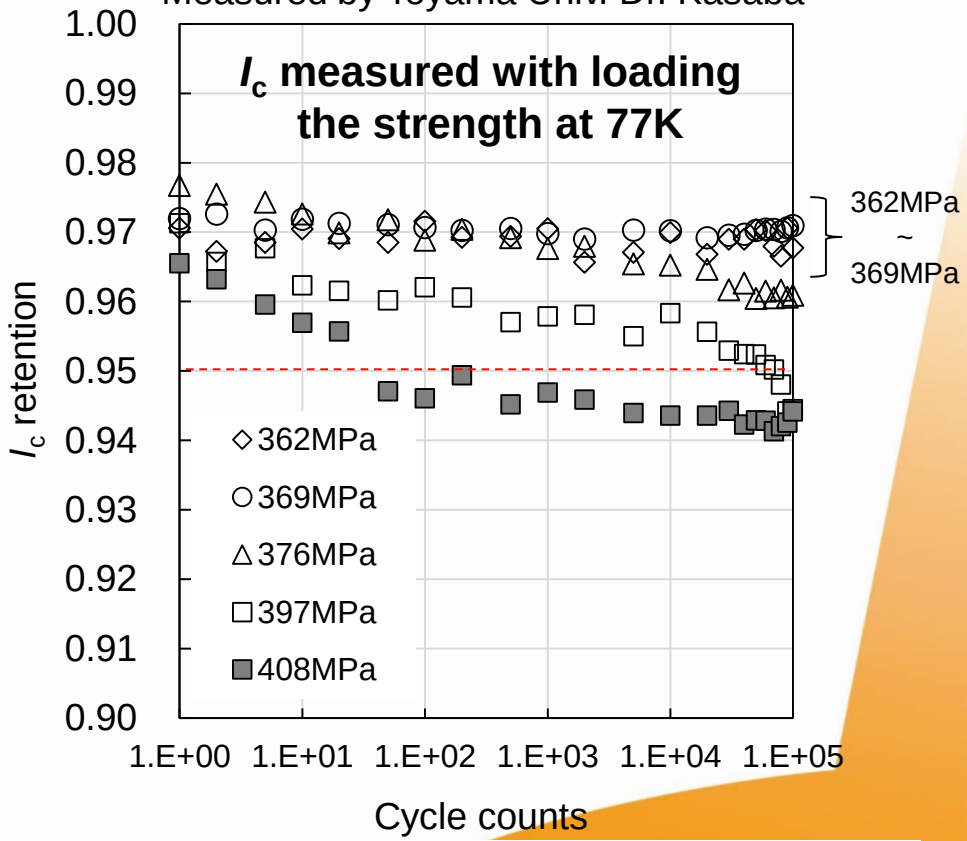
Fatigue test of Type HT-NX at 77K

✓ Test condition

Wire: HT-NX (0.03mm^t, Mass-produced product)
Temperature: 77K Tensile loading: 362 MPa～419MPa (Spec. 400MPa@77K)
Number of Cycles: up to 100,000 cycles



Measured by Toyama Univ. Dr. Kasaba



Up to 370MPa (93% of 400MPa), no degradation of I_c until 10^5 cycles

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Specifications of DI-BSCCO

	Type H	Type HT-SS	Type HT-CA	Type HT-NX
Average Width	4.3+/-0.2mm	4.5+/-0.1mm	4.5+/-0.1mm	4.5+/-0.2mm
Average Thickness	0.23+/-0.01mm	0.29+/-0.02mm	0.34+/-0.02mm	0.31+/-0.03mm
Reinforcement tape	–	Stainless steel ($0.02mm^t$)	Copper alloy ($0.05mm^t$)	Nickel alloy ($0.03mm^t$)
I_c (77K, Self Field)	170A, 180A, 190A, 200A			
Critical Wire Tension * (RT)	80N **	230N **	280N **	410N **
Critical Tensile Strength * (77K)	130 MPa **	270 MPa **	250 MPa **	400 MPa **
Critical Tensile Strain * (77K)	0.2% **	0.4% **	0.3% **	0.5% **
Critical Double Bending Diameter * (RT)	80mm **	60mm **	60mm **	40mm **

* 95% Ic retention, * * Typical value

- ✓ Type HT-NX has released since April, 2015
- ✓ The tensile strength of Type HT-NX is 1.5 times higher than those of Type HT-SS and Type HT-CA
- ✓ ave. 300m Type HT-NX is available unit length for shipment now

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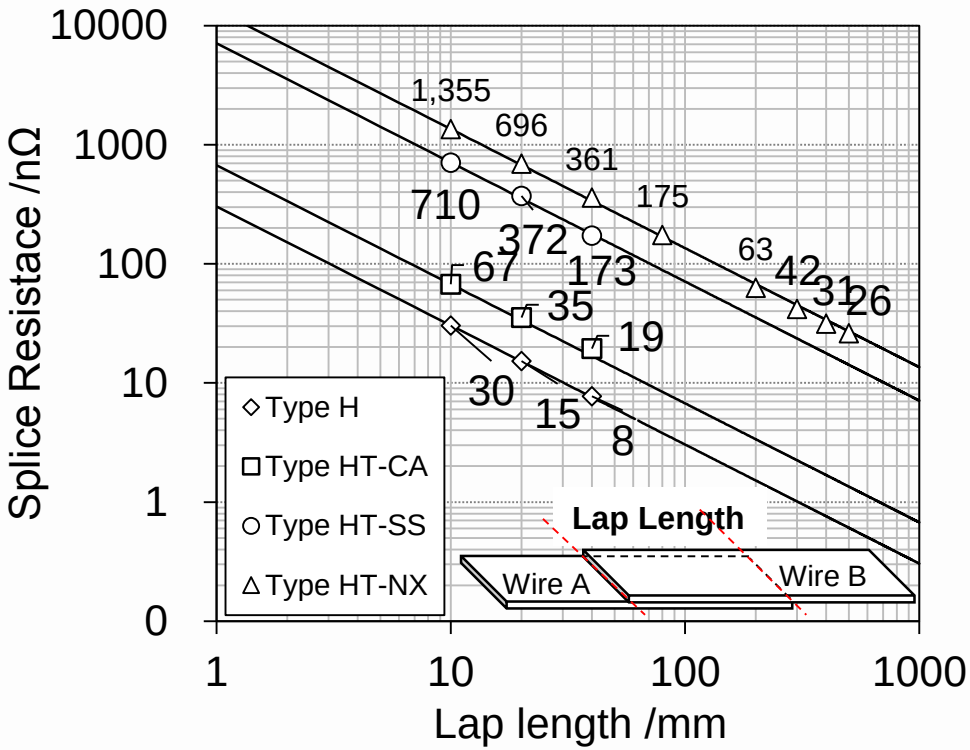
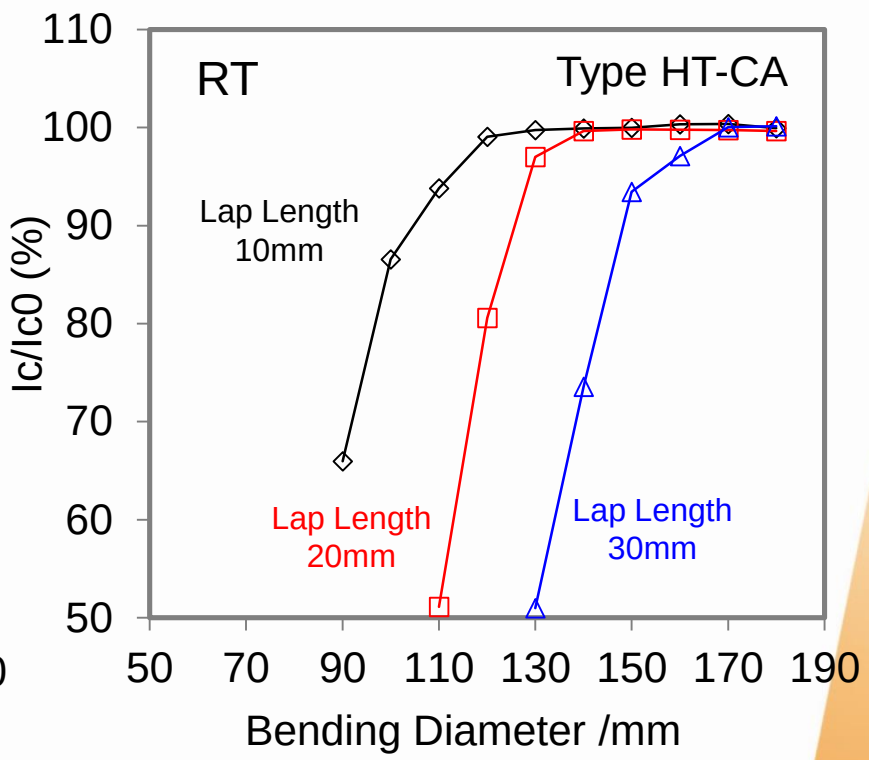
Splice Resistance of Type HT-NX

Splice resistance is inversely proportional to the lap length of the spliced wire





- ✓ **Splice resistance of the Type HT-NX wire is higher than any other Type HT series because the resistivity of the Ni alloy reinforcement material is high.**
- ✓ **Longer lap length reduced the splice resistance but bending property become worse.**

★ **<u>Reducing the splice resistance</u> without the deterioration of mechanical properties of the spliced wire is important.**

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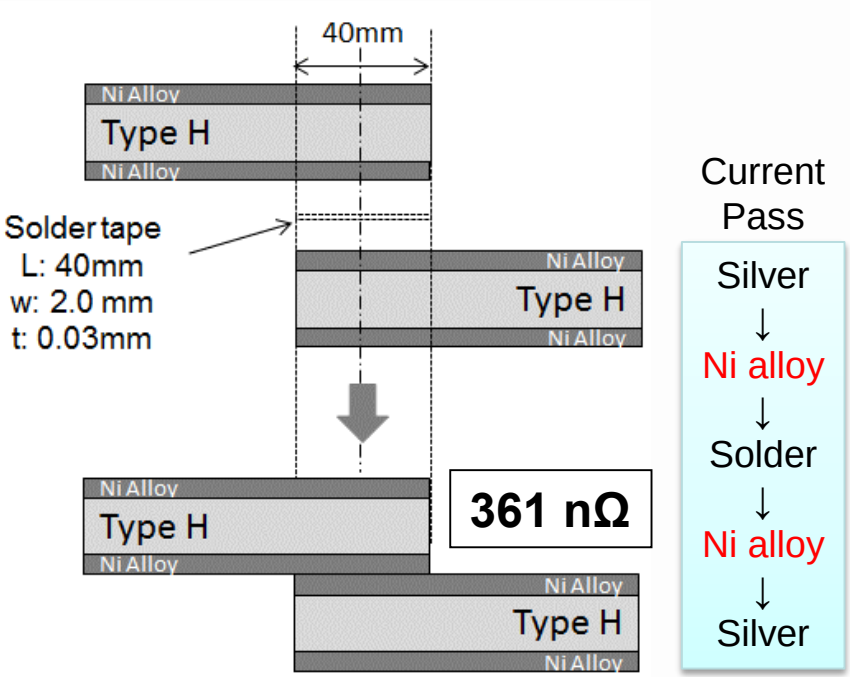
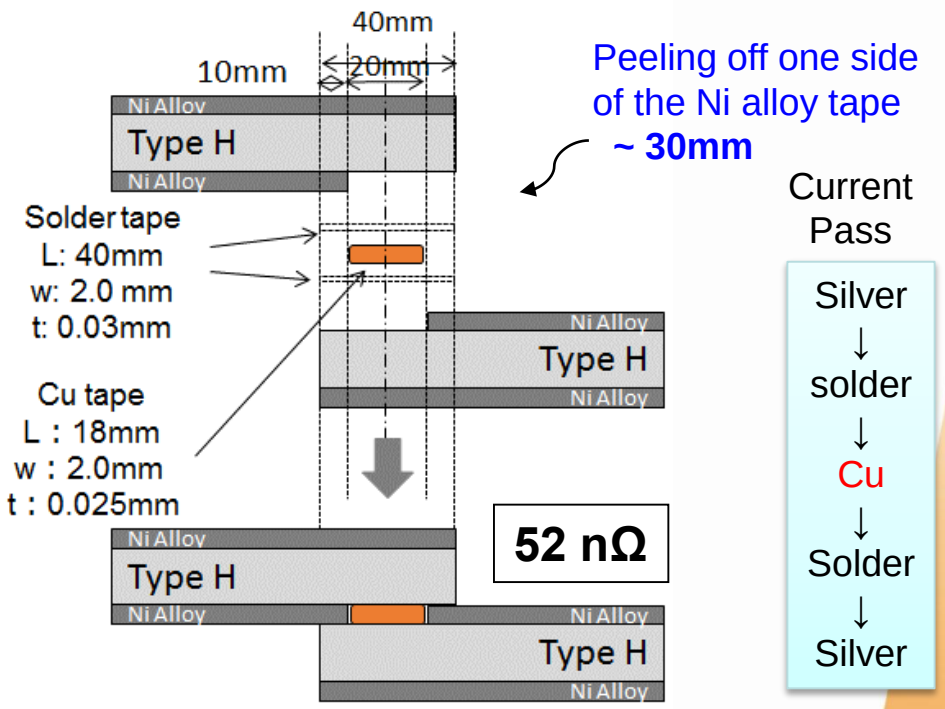
Splice Structure for Type HT-NX

conventional

Overlapped Splice



Peeling Splice

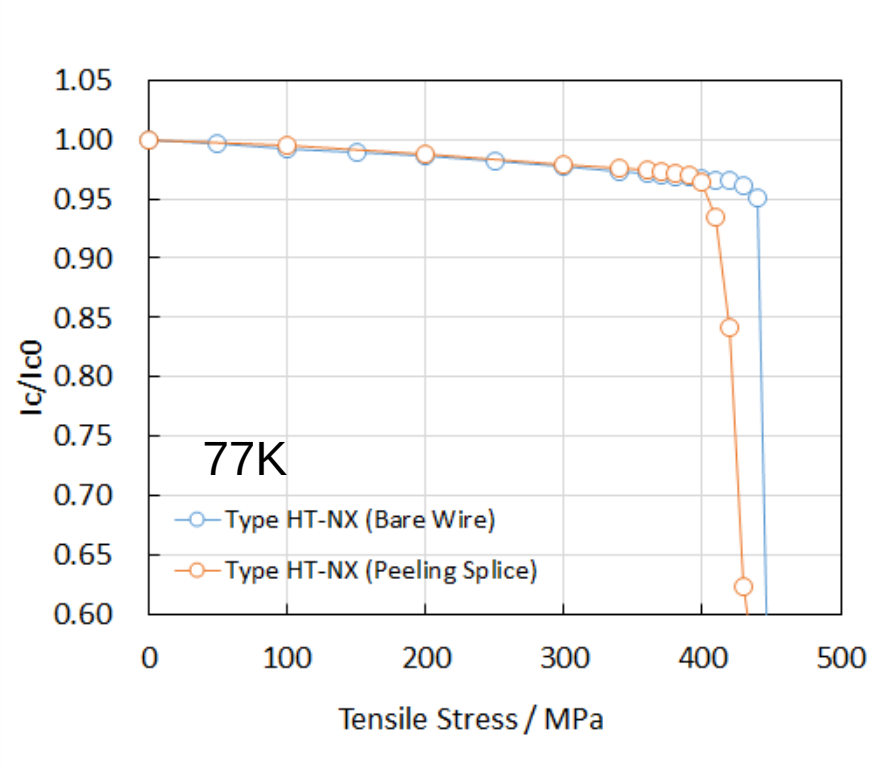


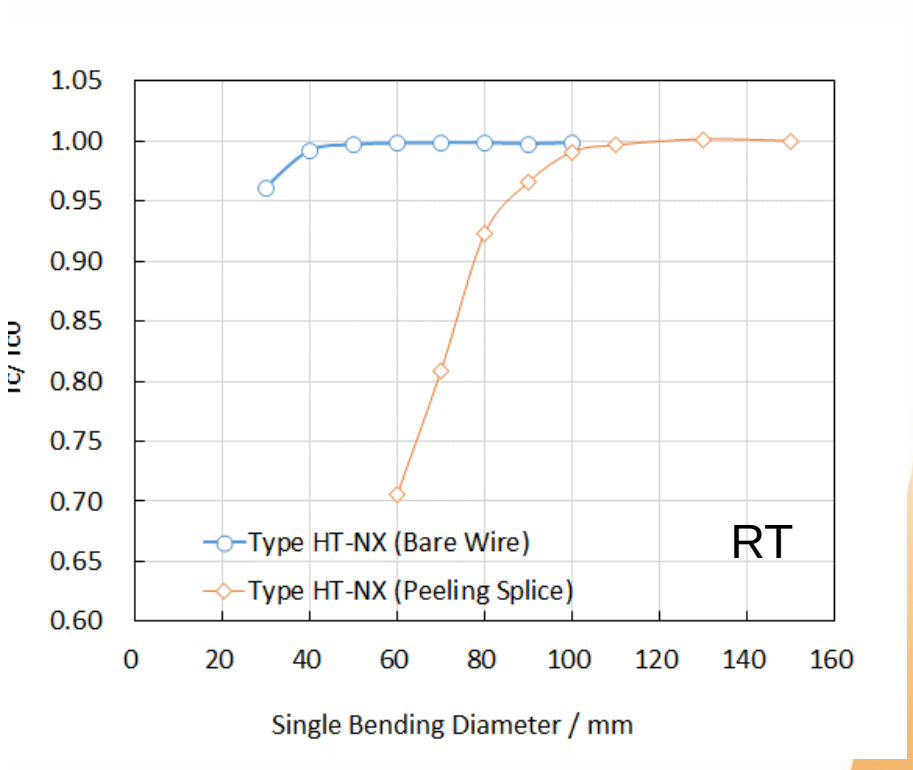
Longitudinal cross-section images of a over-lapping splice structure

★ Splice resistance of the overlapped splice wire is **361nΩ**. Splice resistance of new spliced Type HT-NX (with Cu tape) was **52nΩ** at 77K .

⇒ Splice resistance reduced 86% to compare with conventional Spliced Type HT-NX

Strength of the peeling splice Type HT-NX





Critical tensile stress of the Type HT-NX wire itself was **440MPa** at 77K.
Critical tensile stress of peeling splice wire was 405MPa.That is 92% of the original wire.
Critical single bending diameter of peeling splice was 85mm.

New structure has shown remarkably lower resistance without deteriorating the mechanical properties.

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Summary

New release!

	Type H	Type HT-SS	Type HT-CA	Type HT-NX
Average Width	4.3+/-0.2mm	4.5+/-0.1mm	4.5+/-0.1mm	4.5+/-0.2mm
Average Thickness	0.23+/-0.01mm	0.29+/-0.02mm	0.34+/-0.02mm	0.31+/-0.03mm
Reinforcement tape	—	Stainless steel (0.02mm^t)	Copper alloy (0.05mm^t)	Nickel alloy (0.03mm^t)
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Critical Tensile Strain * (77K)	0.2% **	0.4% **	0.3% **	0.5% **
Critical Double Bending Diameter * (RT)	80mm **	60mm **	60mm **	40mm **

* 95% Ic retention, * * Typical value

- ✓ Type HT-NX was launched in April, 2015.
- ✓ Unit length of Type HT-NX: max. 200m (present)
  max. >500m (in near future)
- ✓ Splice with low resistance (52 nΩ) and high strength (critical tesile stress 405 MPa, critical bending diameter 85 mm) has been developed for Type HT-NX.

Thank you for your attention.