“Punch-and-Coat”: a novel approach to mechanically strong 2G HTS Roebel cables

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Outline

- Brief overview of SuperOx
  - Company's path and development plans
  - New equipment
  - 2G HTS wire basic properties
  - 2G HTS wire mechanical properties
- Roebel cables
  - Coat-and-Punch
  - Punch-and-Coat
  - Cables supplied

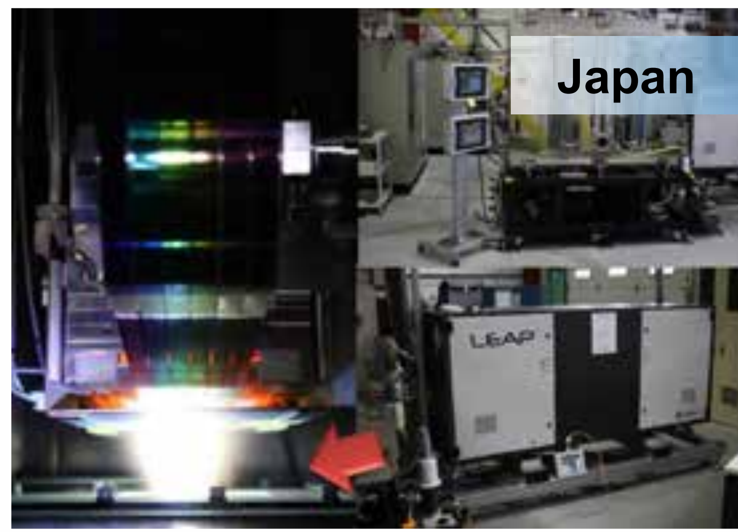
SuperOx: 2G HTS path

+ Structure: SuperOx (Russia), SuperOx Japan LLC (Tokyo)

+ Manufacture: 2G HTS wire on the market since 2012

+ Customise: the widest selection of finishing options available

+ Integrate: develop and market ready HTS solutions



2G HTS wire: layer architecture

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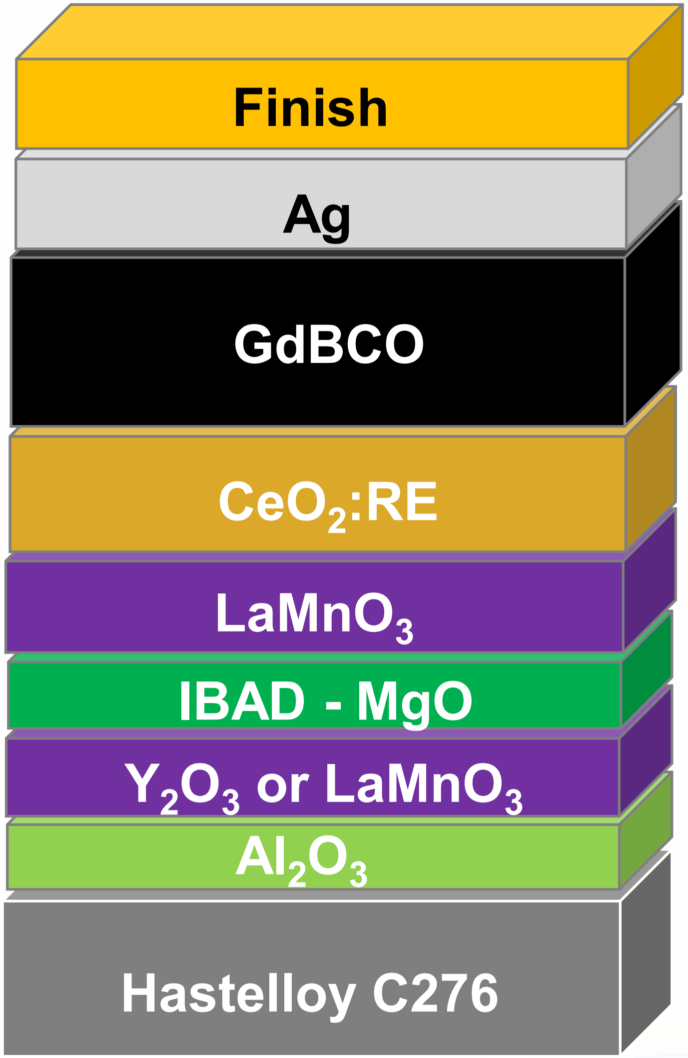


Customised finish tailored to application

DC sputtering (custom thickness)

PLD-2 (1-3 microns)

PLD-1 (100-200 nm)

Dual-Chamber: PLD system

RF sputtering (30-50 nm)

IBAD with RF sputtering (5-7 nm)

RF sputtering (30-50 nm)

RF sputtering (50 nm)

Single Chamber: RF sputter + IBAD

Cold rolled & electro polished (60-100 microns)

Production status and development

SuperOx

Originally: 2011-2015						
Moscow	Substrate			Ag	Cu	Finish
Tokyo		Buffer	HTS	Ag		

At present: 2016						
Moscow	Substrate	Buffer	HTS	Ag	Cu	Finish
Tokyo		Buffer	HTS	Ag	Cu	

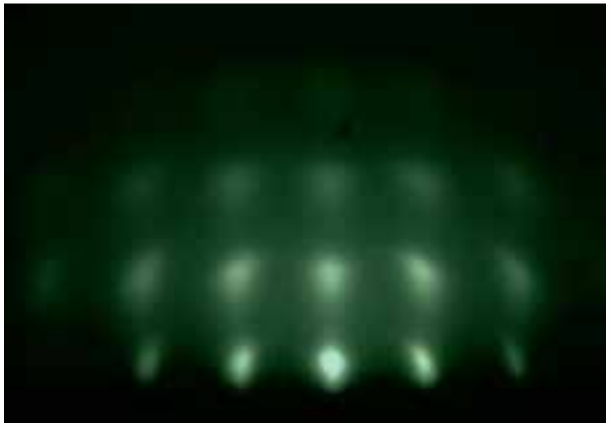
Next						
Moscow	Substrate	Buffer	HTS	Ag	Cu	Finish
Tokyo	Substrate	Buffer	HTS	Ag	Cu	Finish

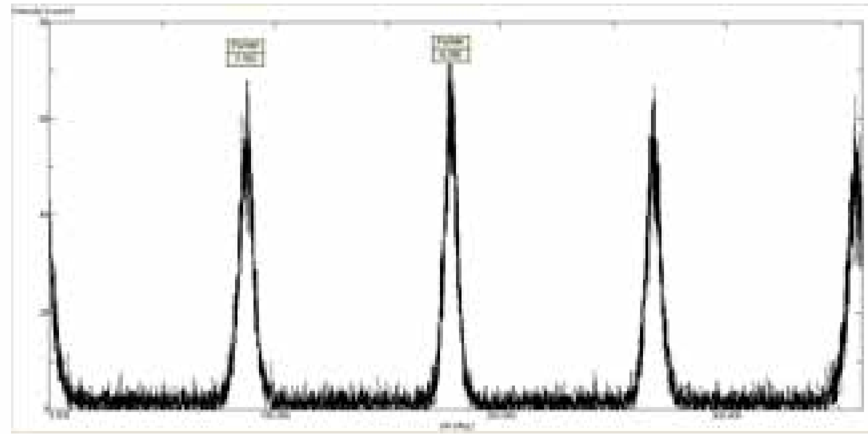
Decisions to increase throughput are driven by demand

New equipment in Moscow

2015: new buffer layer deposition line installed in Moscow
PLD-HTS system to be commissioned by the end of 2016

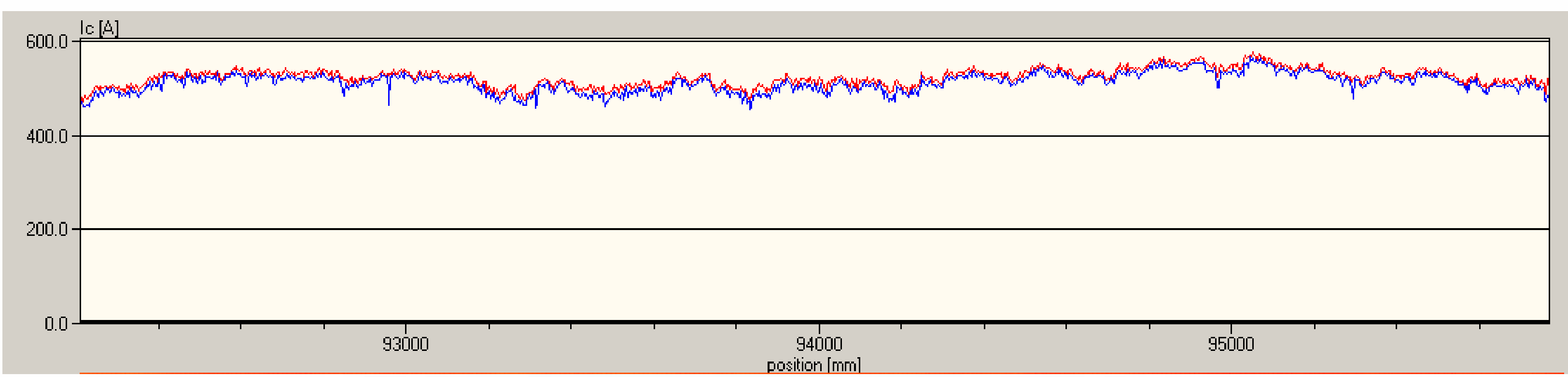
Moscow: buffer layer line commissioned





Good IBAD-MgO RHEED patterns

$\Delta\phi$ (110) LMO < 7^{o}



I_c over 500 A demonstrated with PLD-HTS

2G HTS wire: 12 mm width

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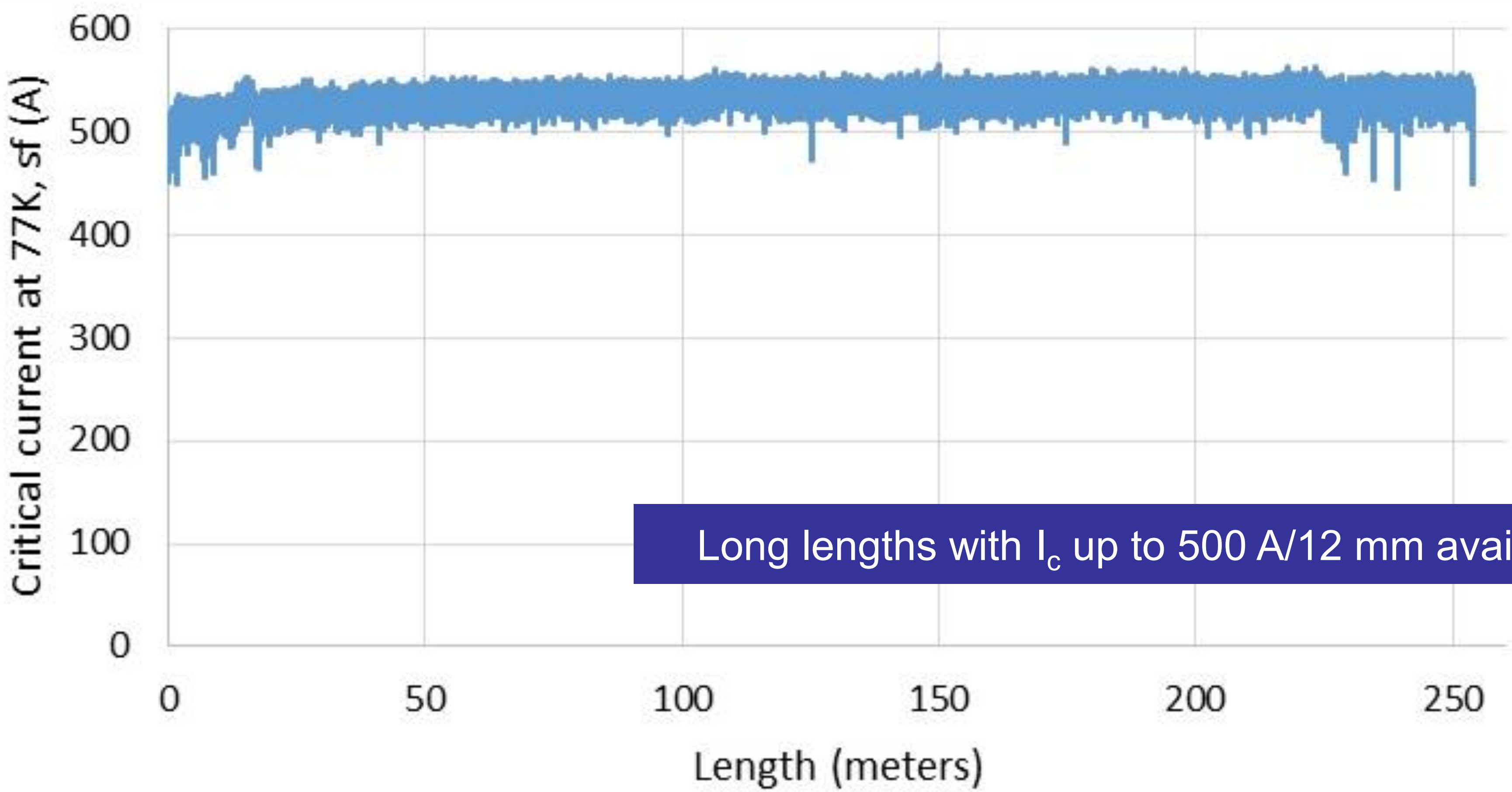

Long lengths with I_c up to 500 A/12 mm available

2G HTS wire: 4 mm width

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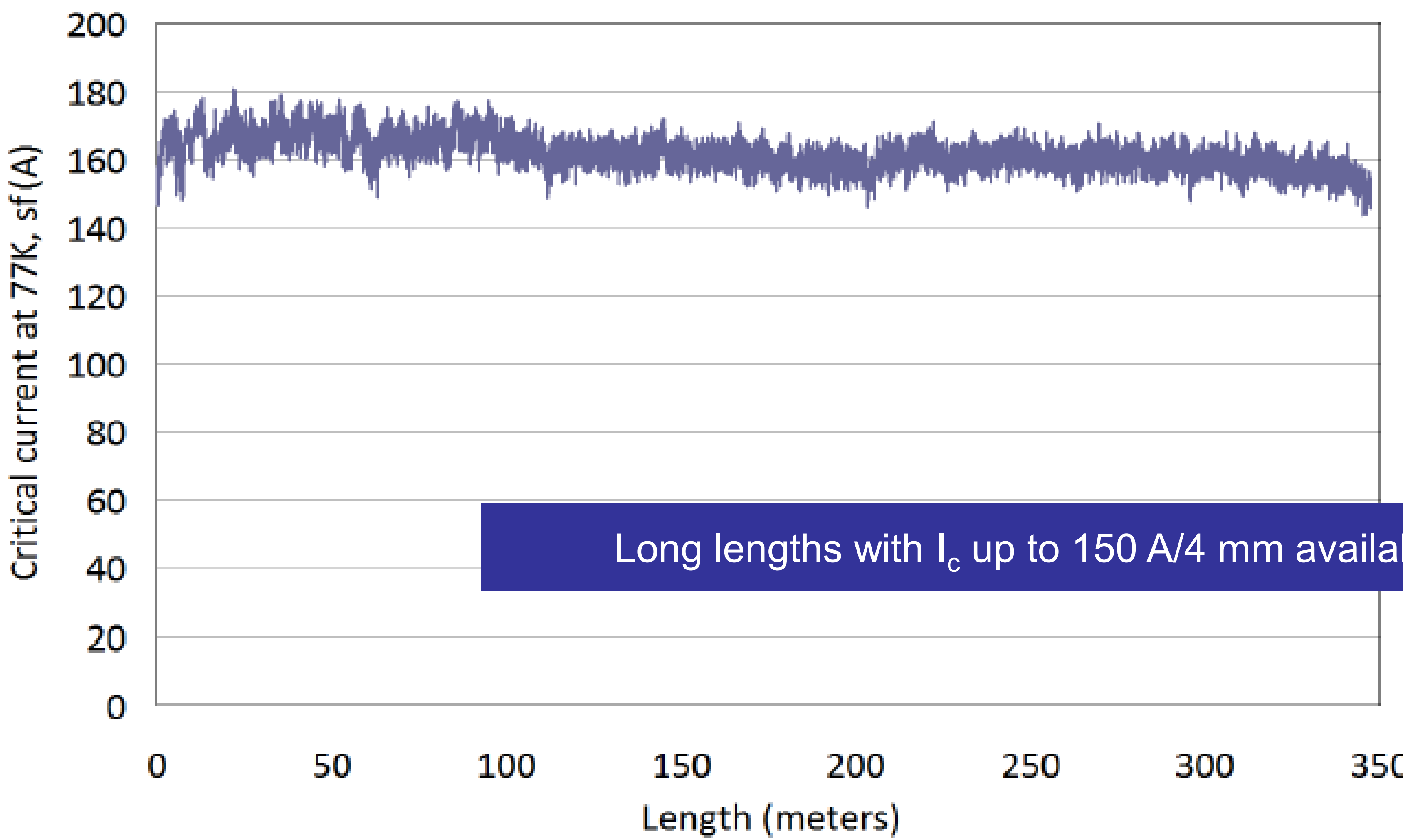
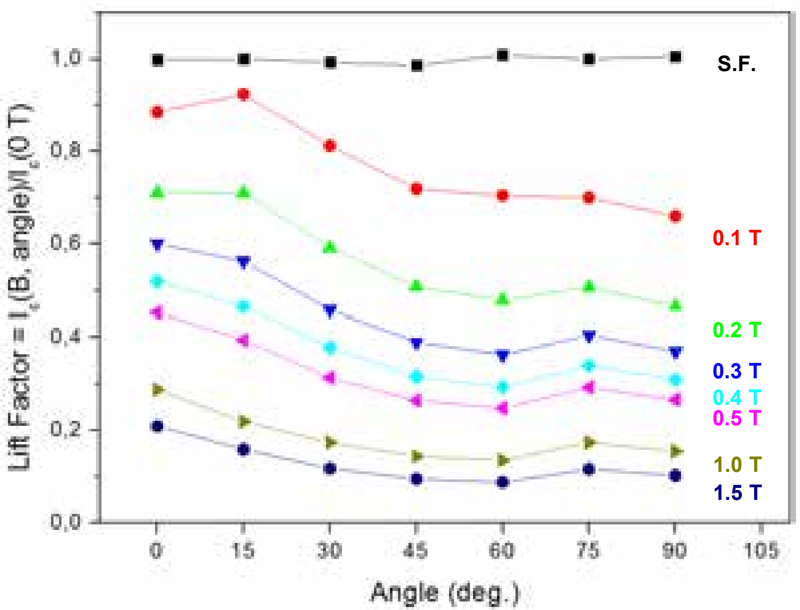
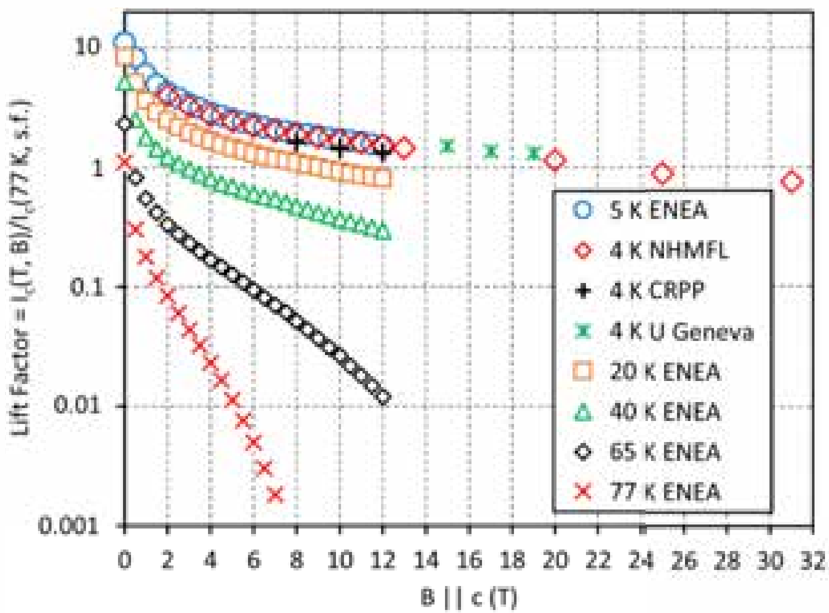


Long lengths with I_c up to 150 A/4 mm available

2G HTS wire: performance in magnetic field

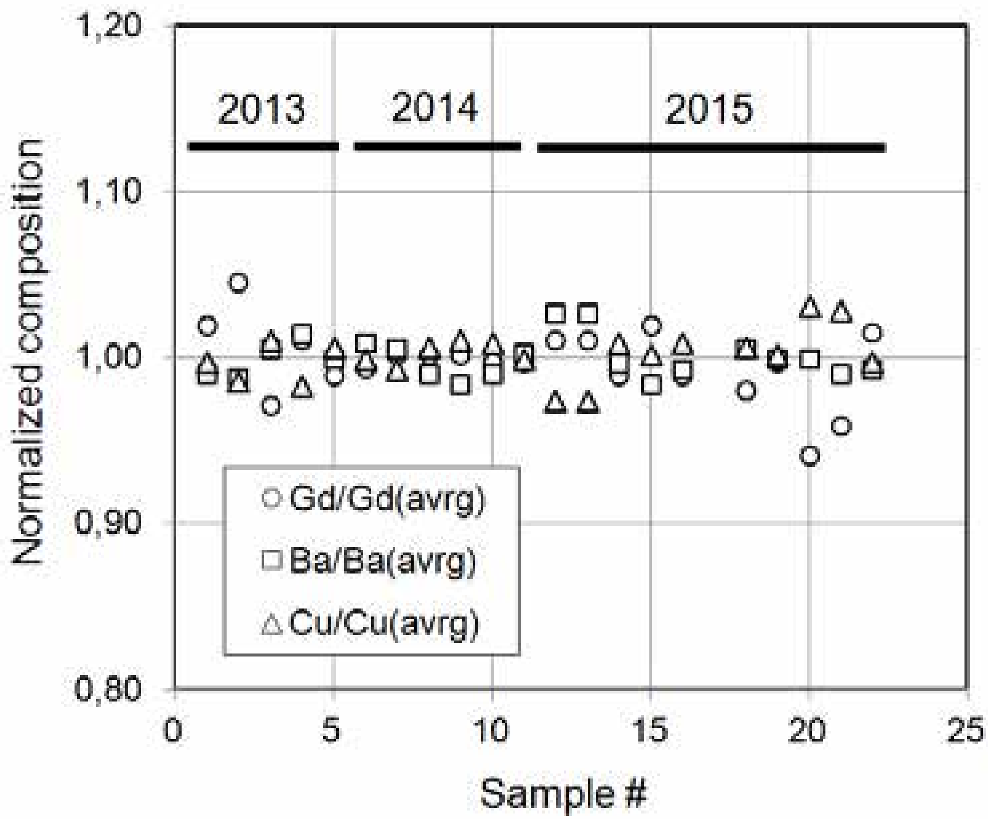




Low angular anisotropy

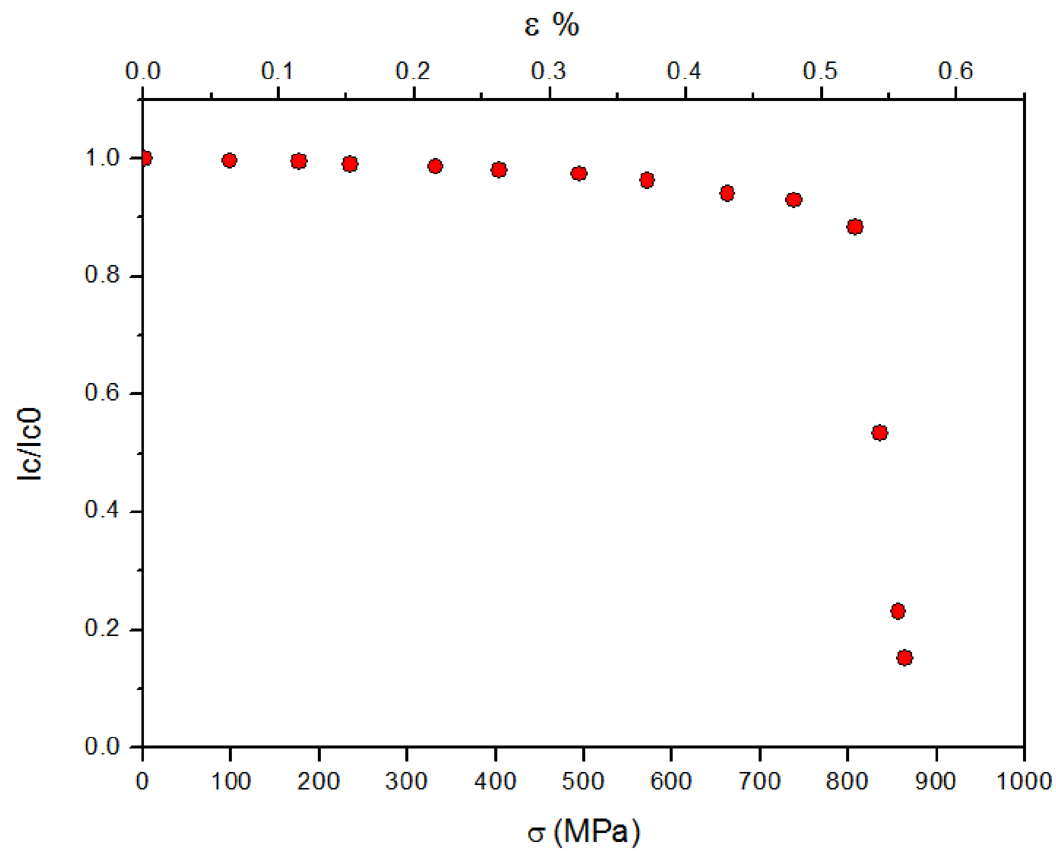
Reproducible lift factors

2G HTS wire: consistent HTS composition



Consistent composition and microstructure of the PLD-GdBCO layer over years of production results in consistent wire performance

Mechanical properties: tensile strength



High tensile strength ensured by Hastelloy substrate

Mechanical properties: tensile strength

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Supercond. Sci. Technol. 28 (2015) 045011 C Barth *et al*

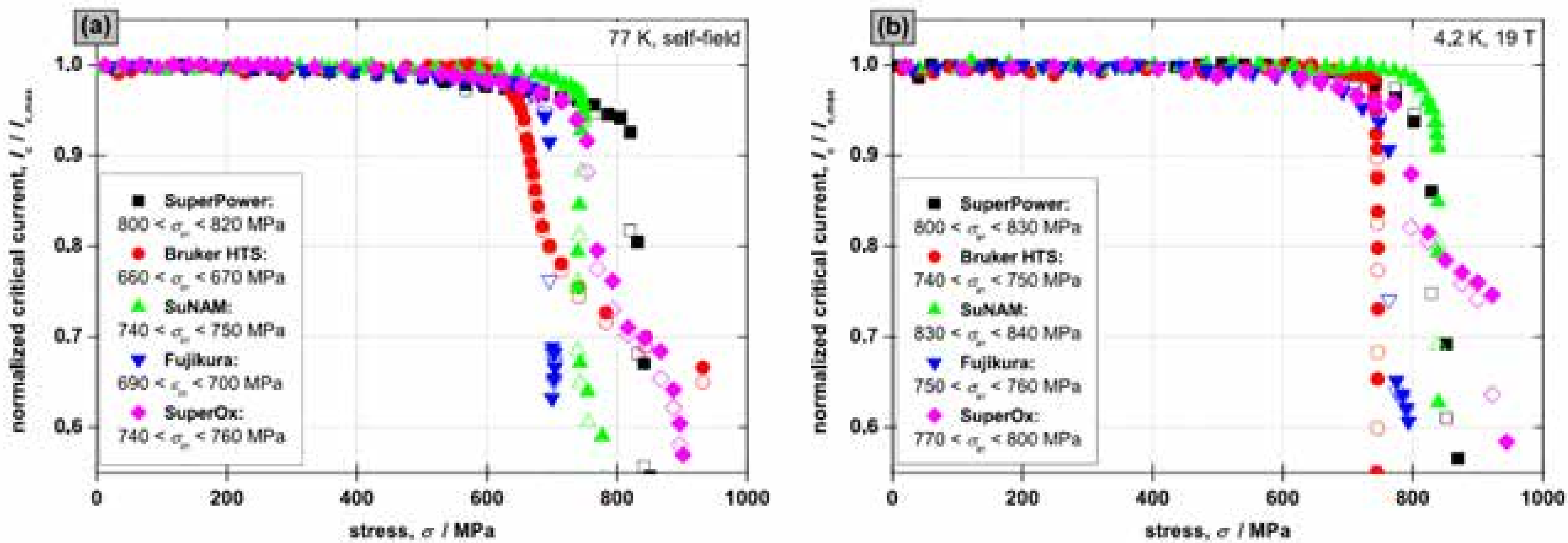
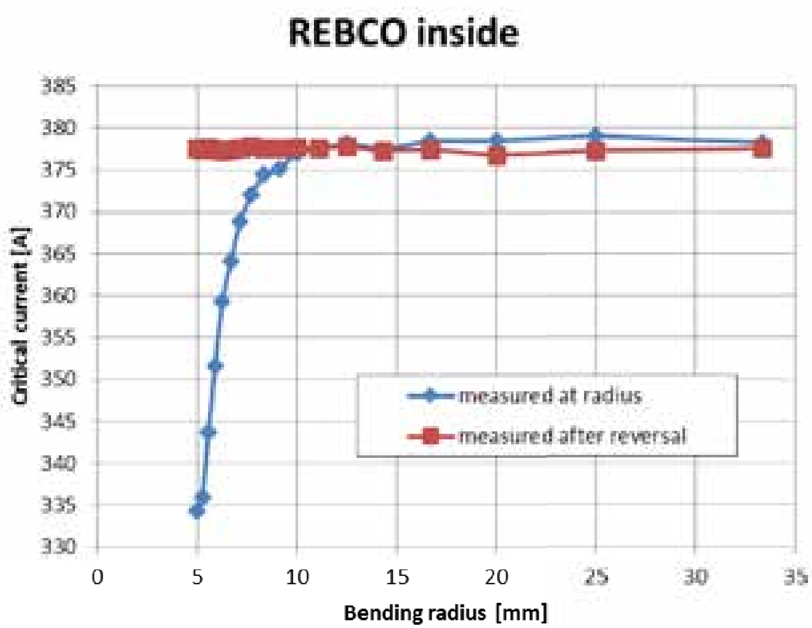
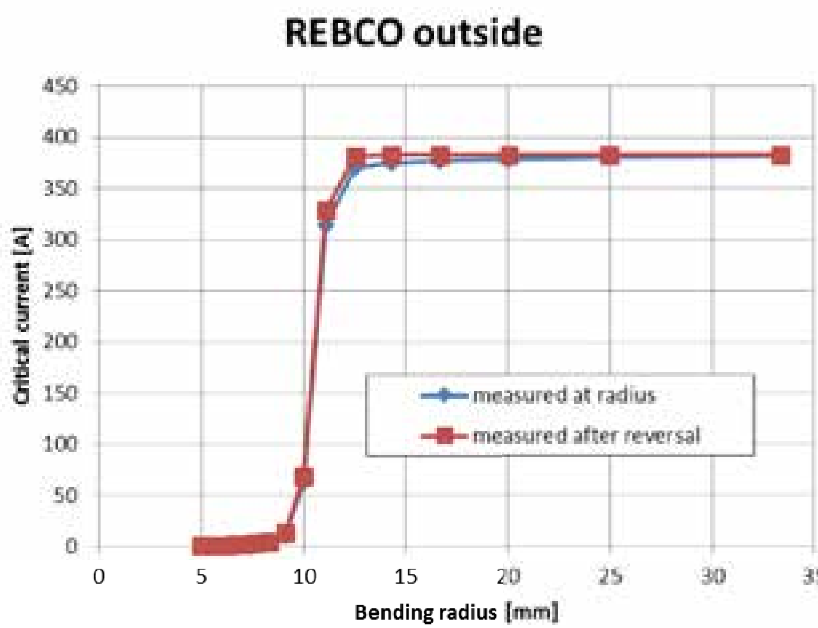


Figure 10. Stress dependence of various industrial REBCO tapes. Normalized critical current $I_c/I_{c,max}$ versus stress σ and irreversible stress limits σ_{irr} at 77 K, self-field in graph (a) and at 4.2 K, 19 T in graph (b).

High tensile strength ensured by Hastelloy substrate

Mechanical properties: bend tests

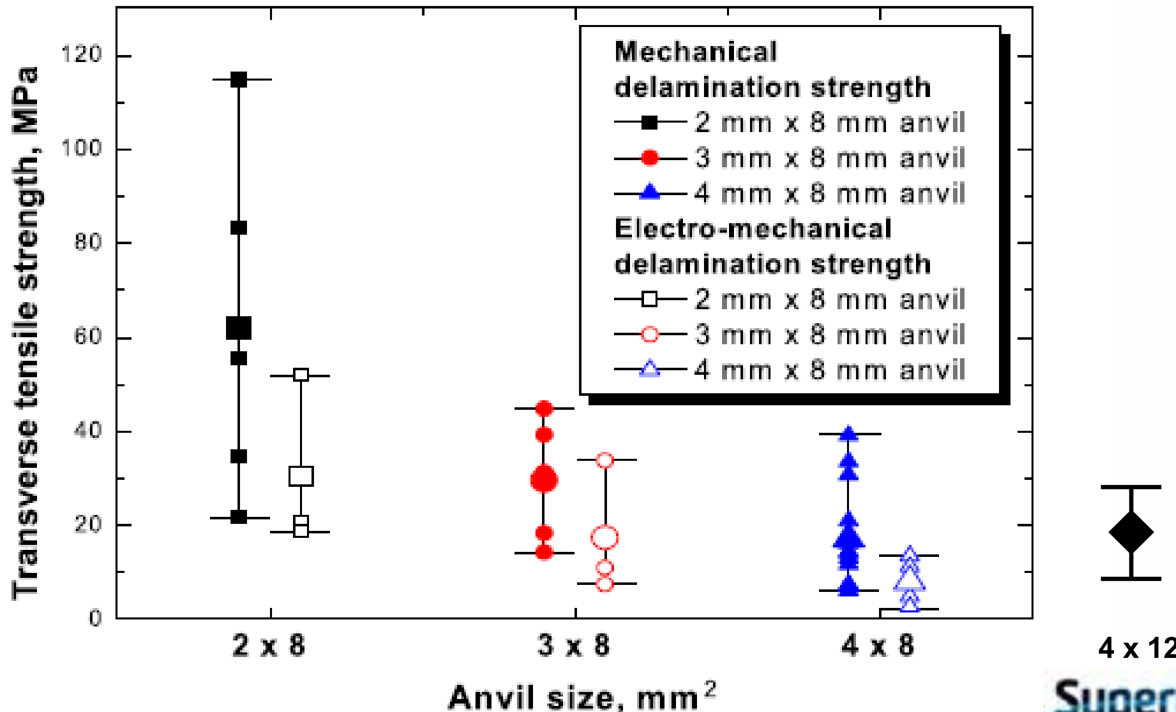




Tight bending radii are possible

2G HTS wire: delamination strength

Characterization of transverse tensile stress response of critical current and delamination behaviour in GdBCO coated conductor tapes by anvil test



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1. Delamination IS AN ISSUE in 2G HTS wire
2. Large variation of delamination strength among different wires and within one wire

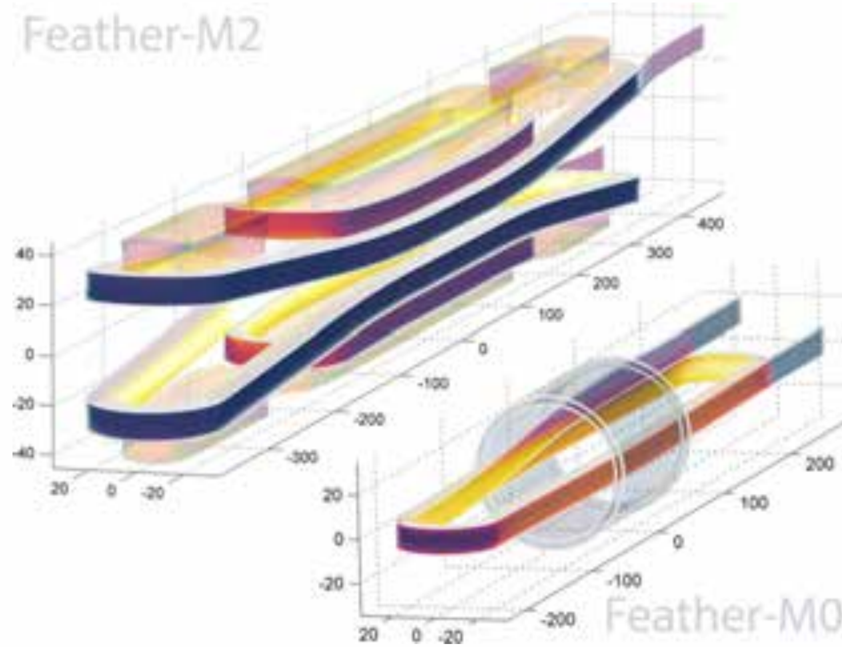
2G HTS wire: specifications

Parameter	Value	
Production Length	up to 500 meters	
Substrate Thickness	60–100 µm	
Tape width	4 mm	12 mm
Critical Current @ 77K, s.f.	100-150 A	300-500 A
J_e at 4.2 K, 20 T	> 400 A/mm^2	> 400 A/mm^2
Current Uniformity	±10%	±10%

Customisation:

+ Variable silver thickness
+ Variable copper thickness
+ Lamination
+ Insulation
+ Artificial pinning centres
+ Solder plating
+ Low resistance splices
+ … just ask

Roebel cables for EUCARD-2 programme



G. Kirby, CERN

At CERN, 5 T HTS inserts into 16 T LTS dipoles are wound with Roebel cables.
20+ T dipoles will enable FCC 80 km circumference instead of 100 km

Roebel cables: Coat-and-Punch

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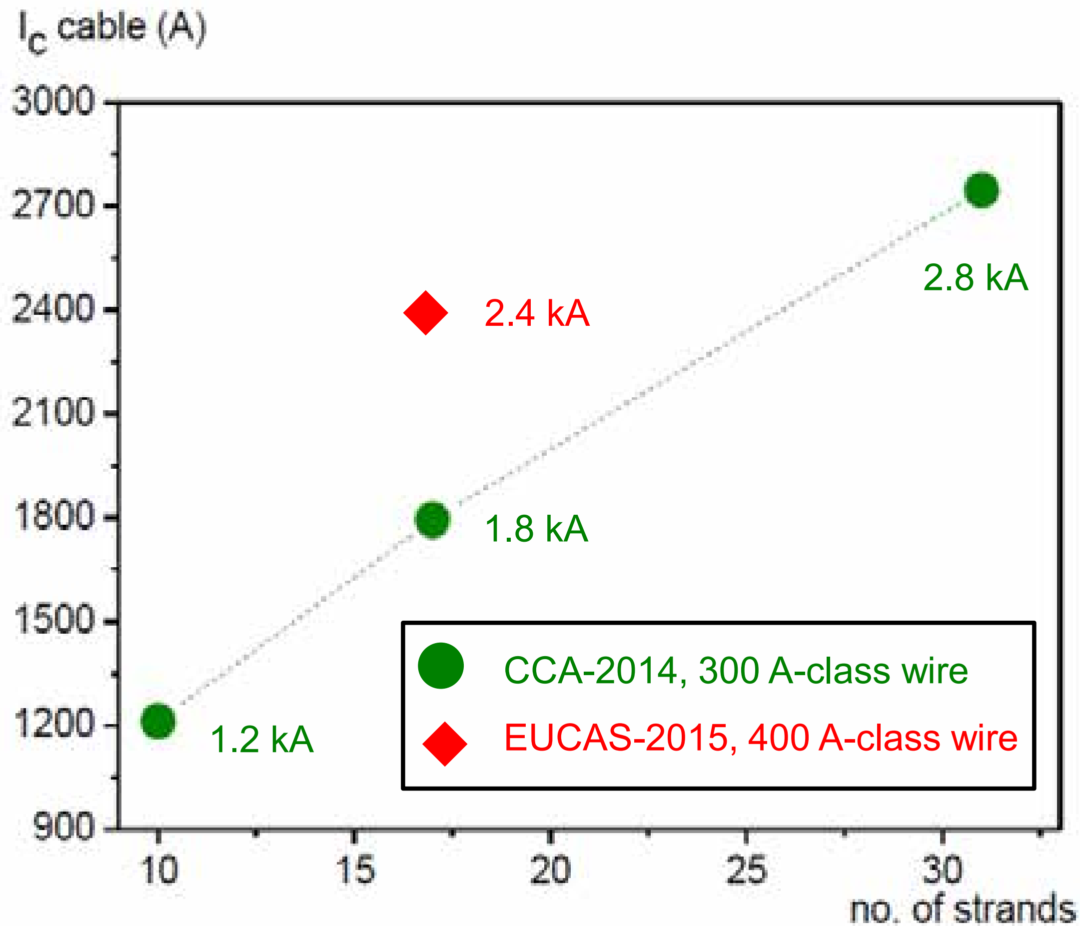
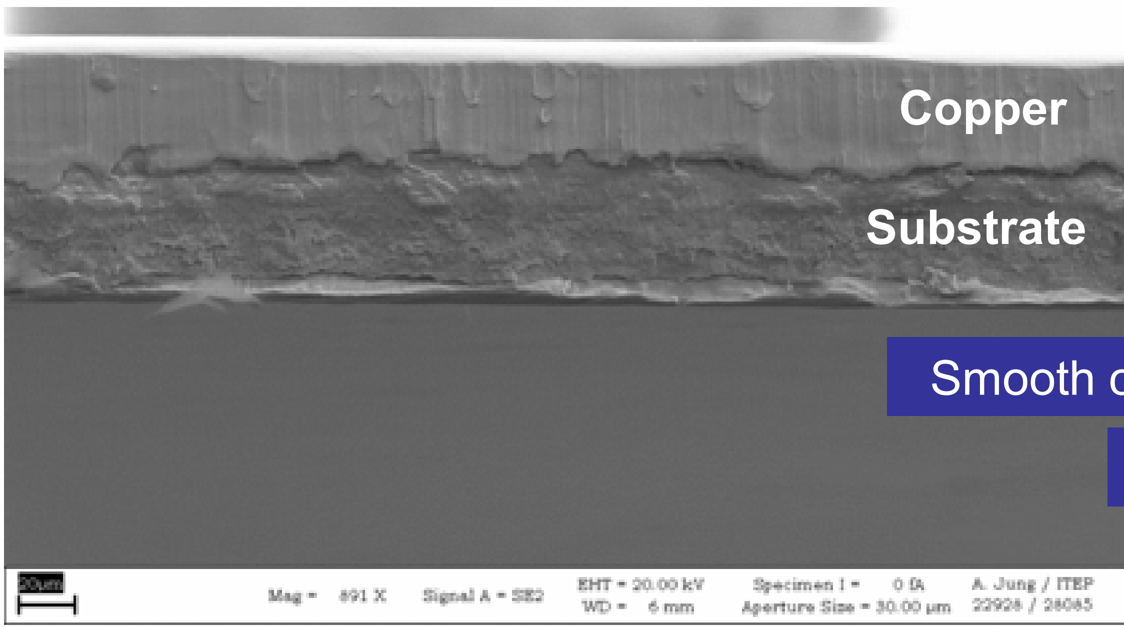
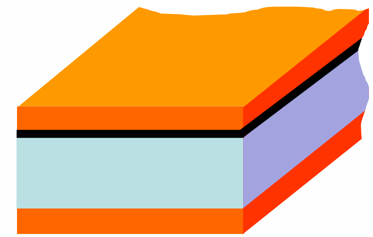
Coat-and-punch results



Roebel cables: Coat-and-Punch

Standard way: coat-and-punch





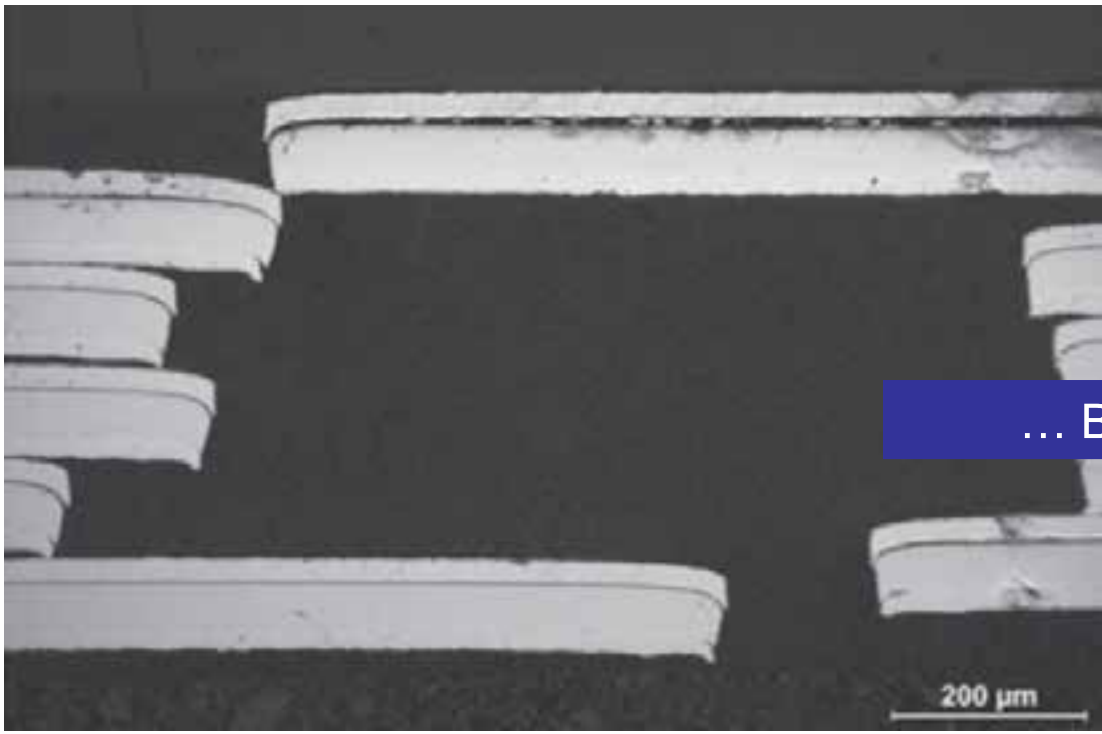
Smooth cross-section of the punched edge

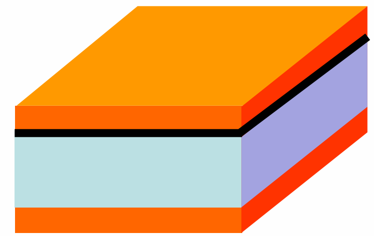
Cu gets smeared over HTS layer

Well, most times …

Roebel cables: Coat-and-Punch

Standard way: coat-and-punch

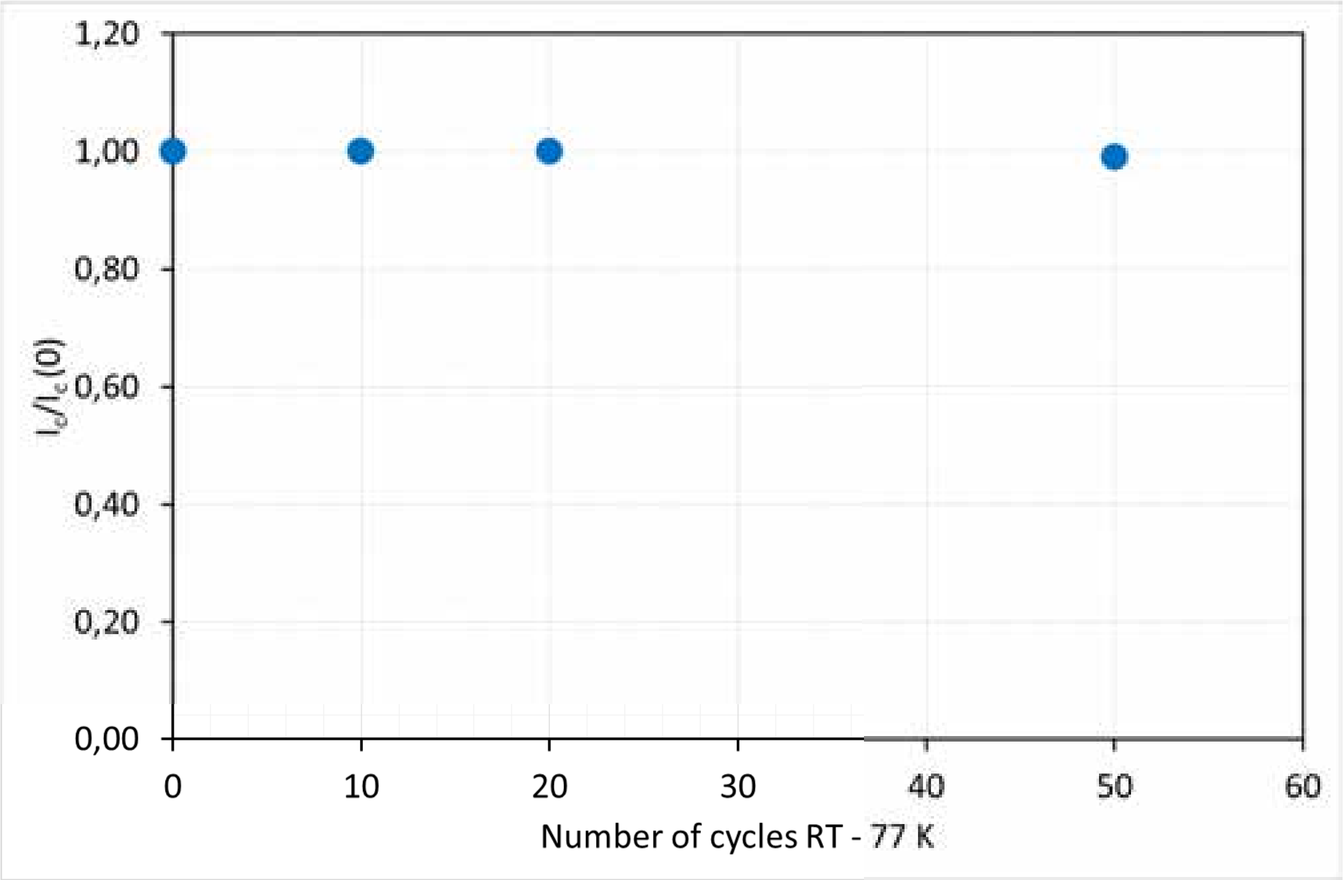




… But sometimes delamination occurs

S. Otten et al., SUST 28 (2015) 065014

Roebel cables: Coat-and-Punch



Good section: no degradation in thermal cycling

Roebel cables: Coat-and-Punch

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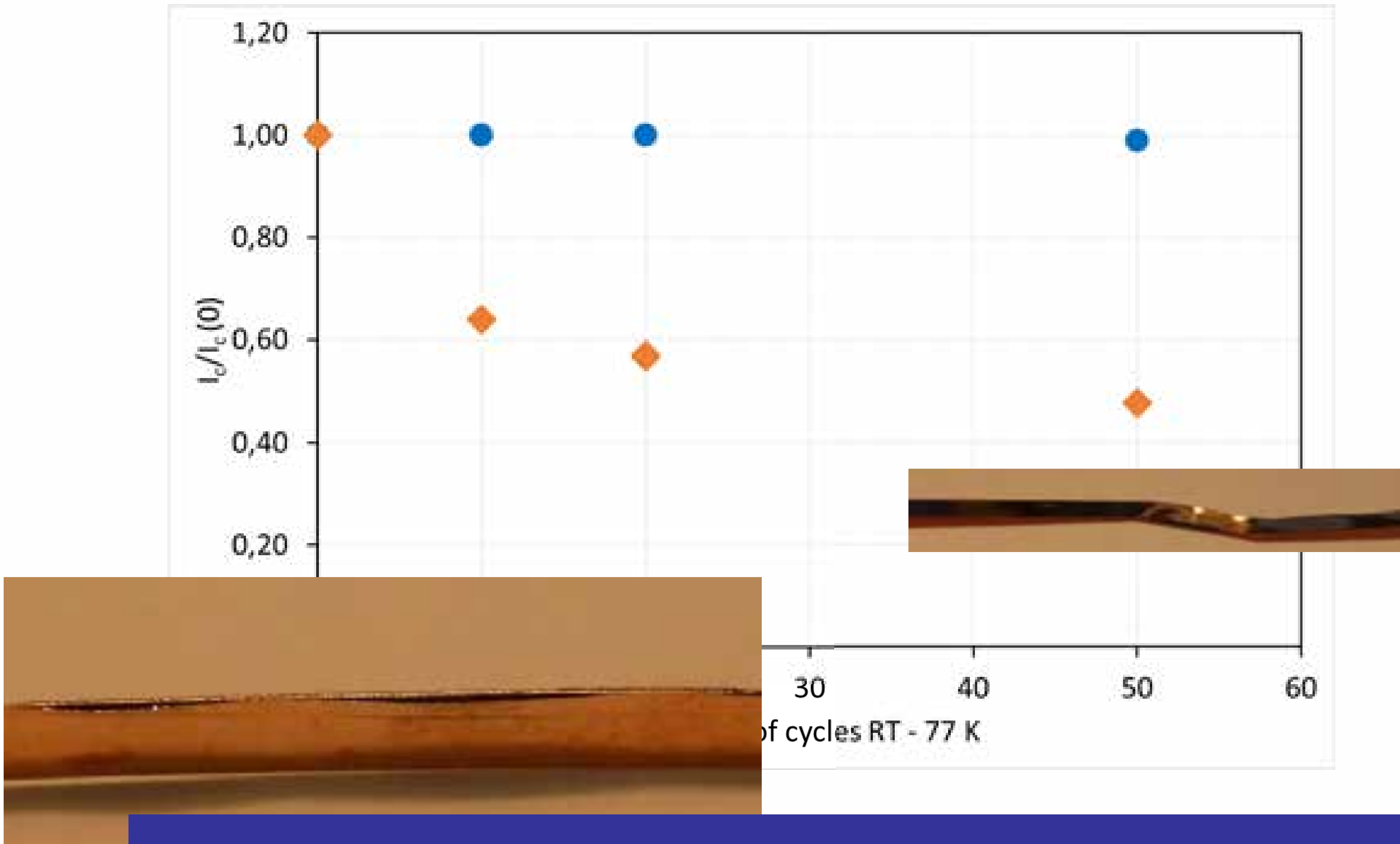
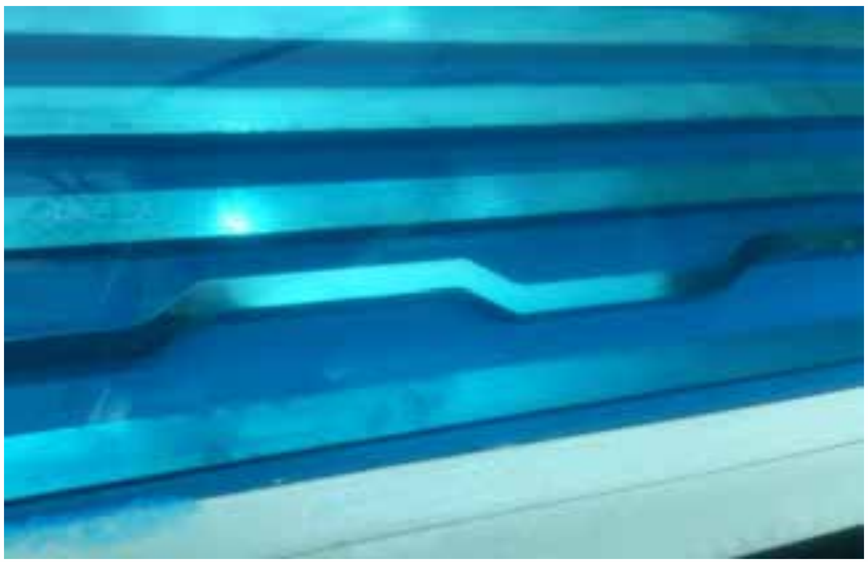


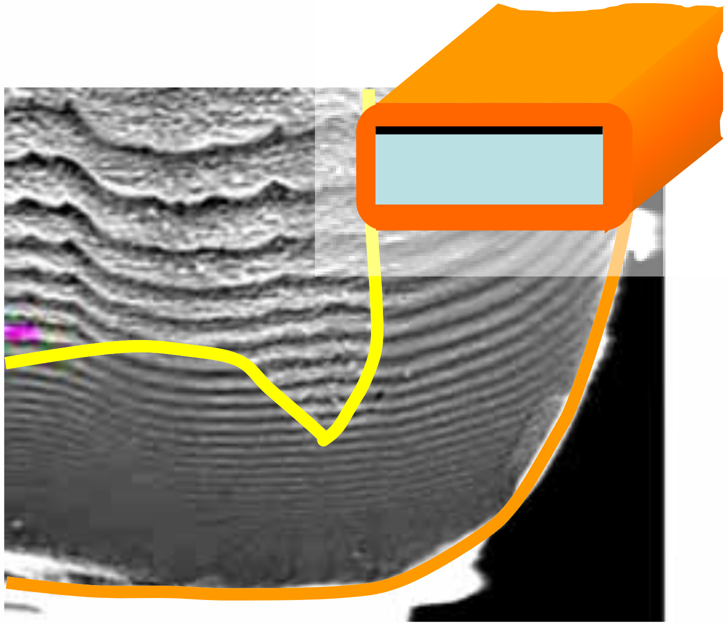
Poor section: significant degradation/delamination in thermal cycling

Roebel cables: Punch-and-Coat

Novel alternative: punch-and-coat

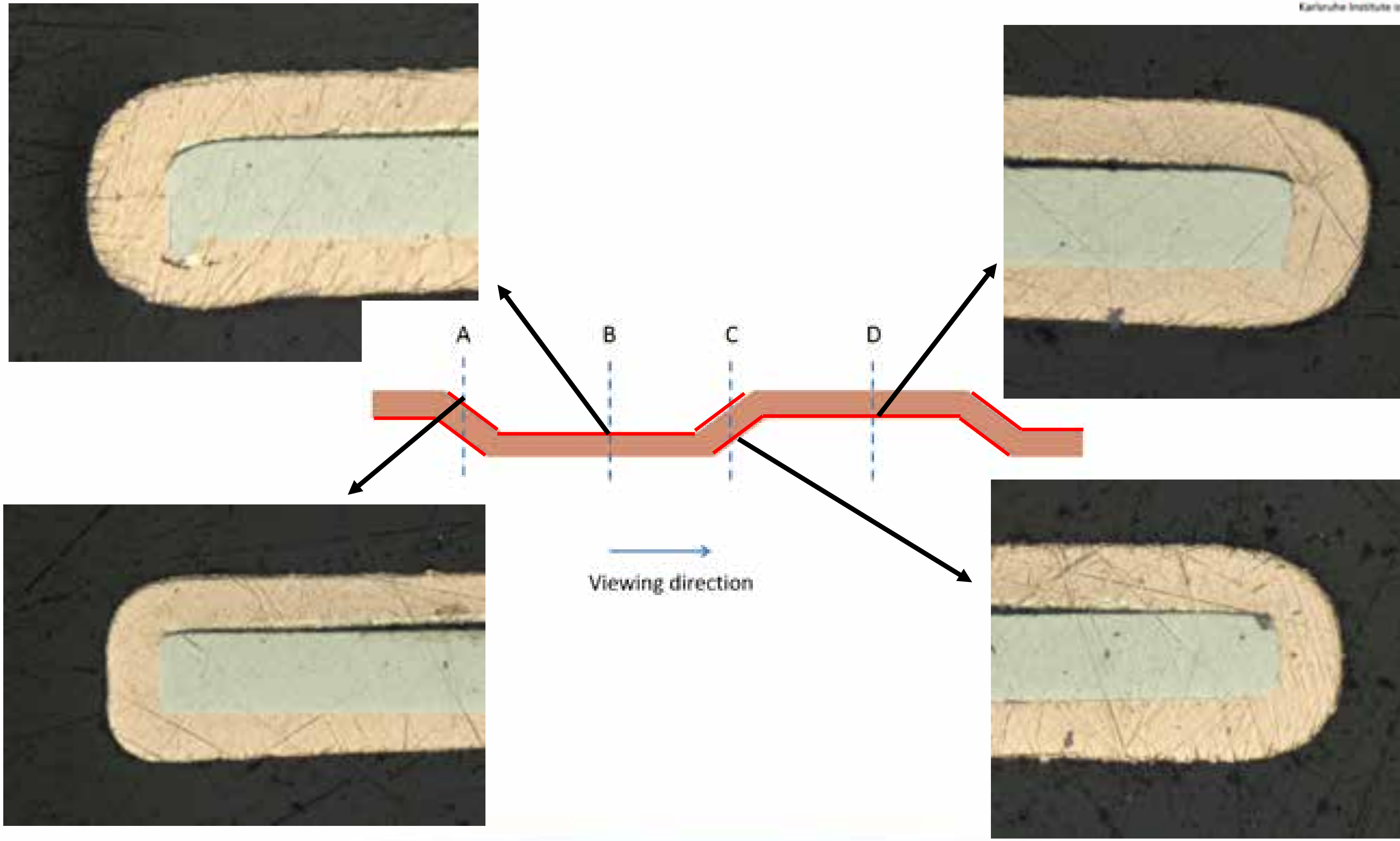


Cu-plating of a punched strand

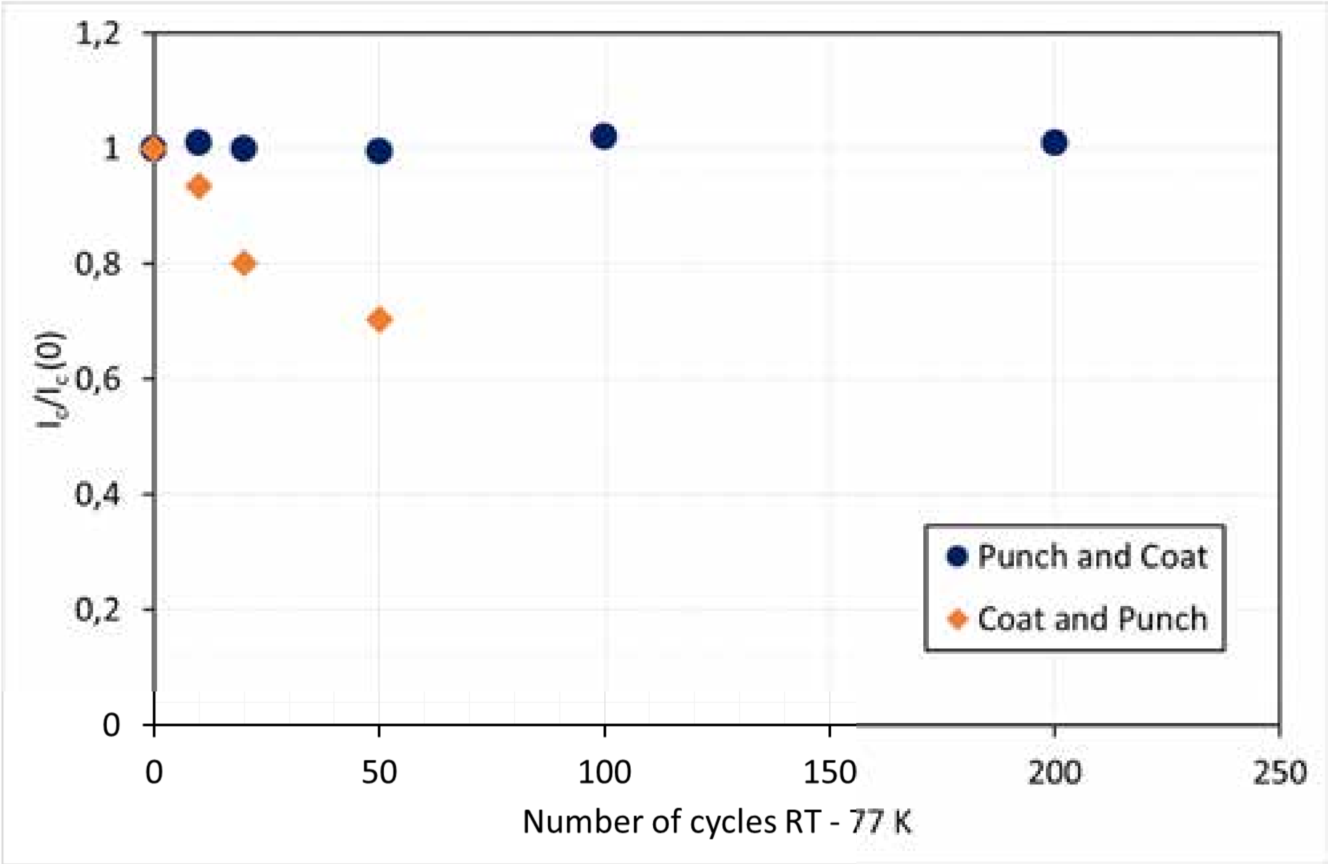


HTS layer fully enclosed
Sharp punch burr smoothened

Roebel cables: Punch-and-Coat



Roebel cables: PnC vs. CnP



PnC vs. CnP: superior degradation/delamination stability in thermal cycling

PnC Roebel cables: accepting orders

SuperOx acquired own machinery for Roebel cable fabrication

Accepting orders on advanced PnC Roebel cable

Commercial PnC Roebel cables

Jul 2015: 2.5 m PnC cable provided to CERN for testing

Dec 2015: 35 m PnC cable supplied to CERN for Feather 2 coil

Summary

• Punch-and-Coat Roebel cables provide superior degradation/delamination stability in thermal cycling

• For PnC fabrication, it is essential that all processes are combined within one company

• SuperOx is accepting orders
on advanced Punch-and-Coat Roebel cables

THANK YOU FOR YOUR ATTENTION

www.superox.ru