

基于涂层导体的准各向同性高温超导导 股线研究进展

王 银 顺

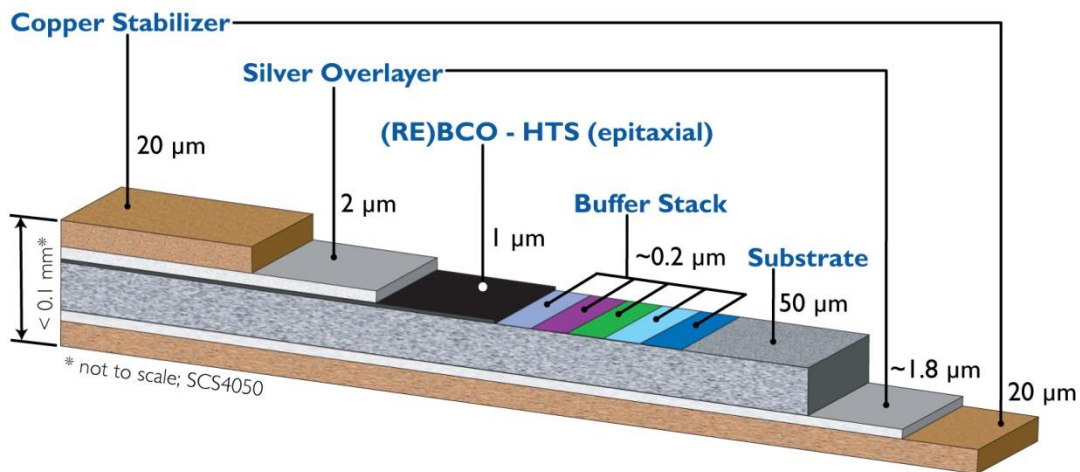
2016年4月28日

一、背景

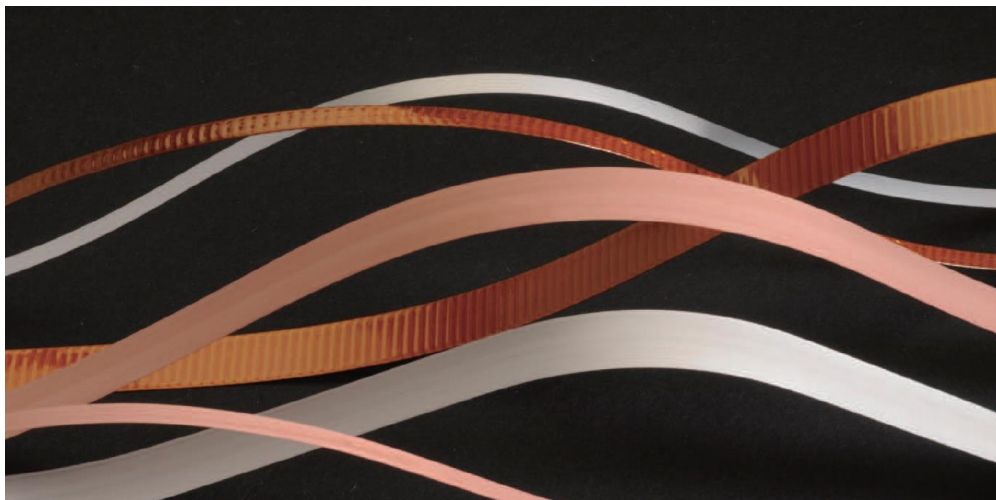
二、国内外研究进展

三、结论与展望

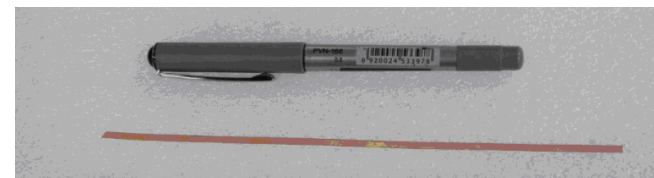
一、背景

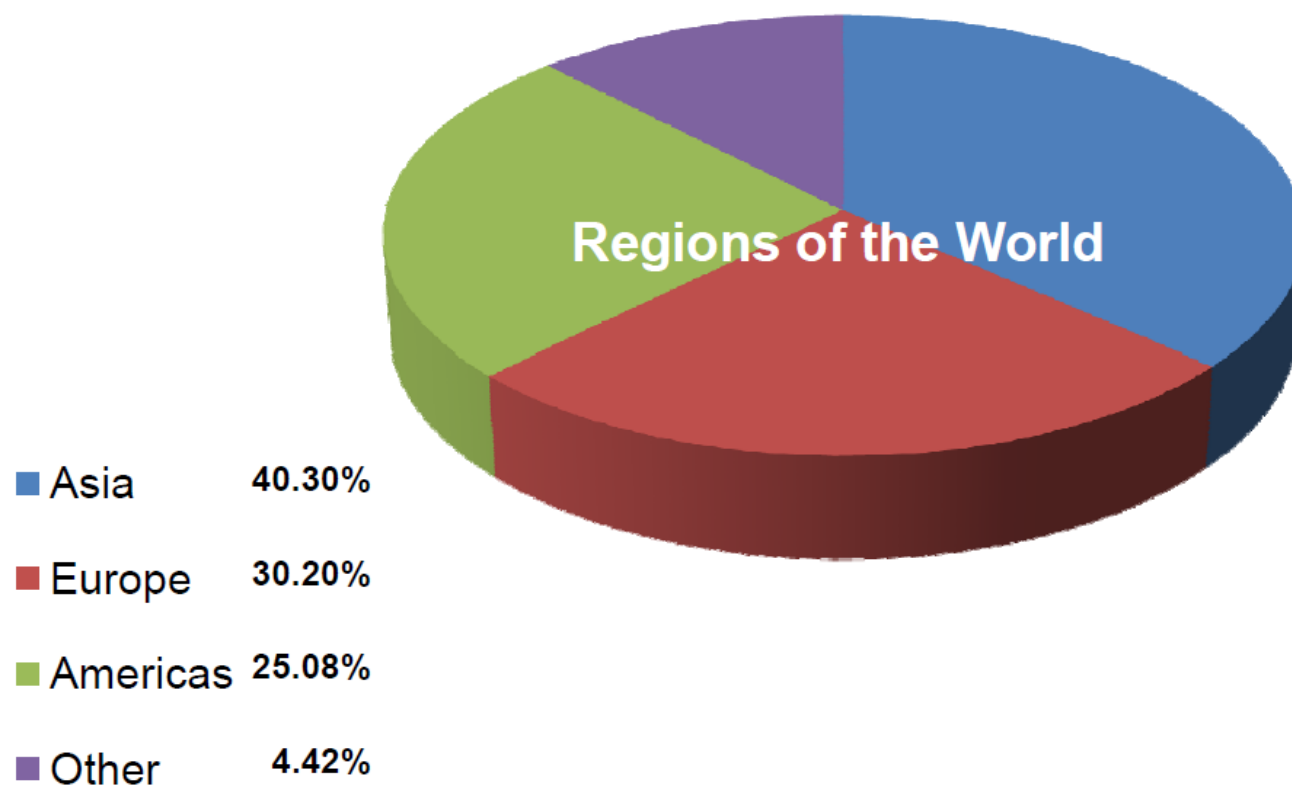


载流能力比铜大两个量级



tape = SS (50 μm) surrounded by Cu (25 μm + 25 μm)

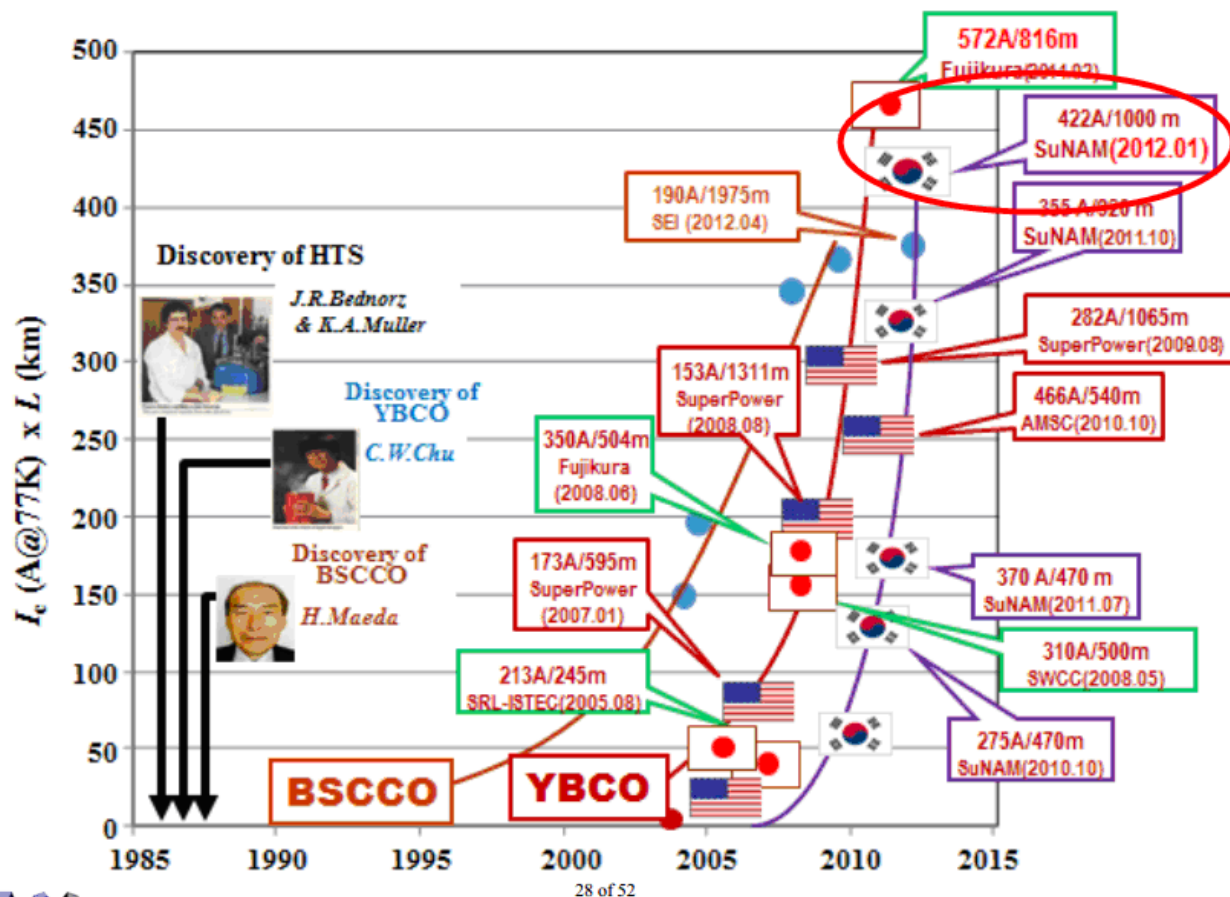




Development of HTS 2G Wire

IEEE/CSC & HSAS SUPERCONDUCTIVITY NEWS FORUM (4th Edition), October 2013

Paper based on this presentation was published by Superinductor Science & Technology (SuST), DOI:21.10.1.1044018 (2014)



SuNAM

28 of 52

(by Dr. Izumi @ ISTEC-SRL)

一、背景

●涂层导体商业化：国际上生产厂家

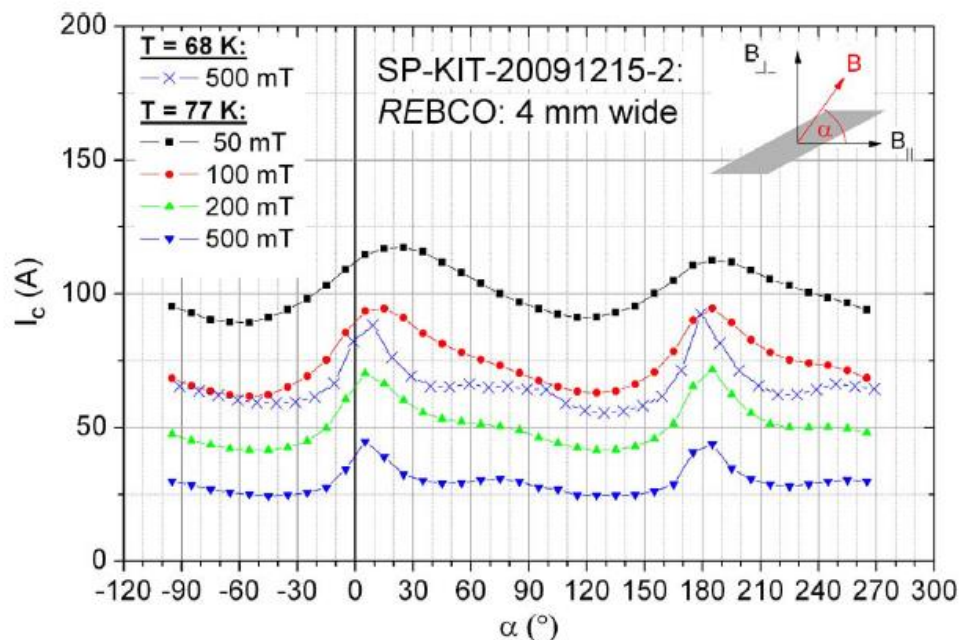


中国：上海超导公司，上海上创超导科技公司，苏州新材料研究所有限公司

●涂层导体商业化：加工速度达到 2 0 0 m/hr, 临界电流 I_c 达到794A/cm.

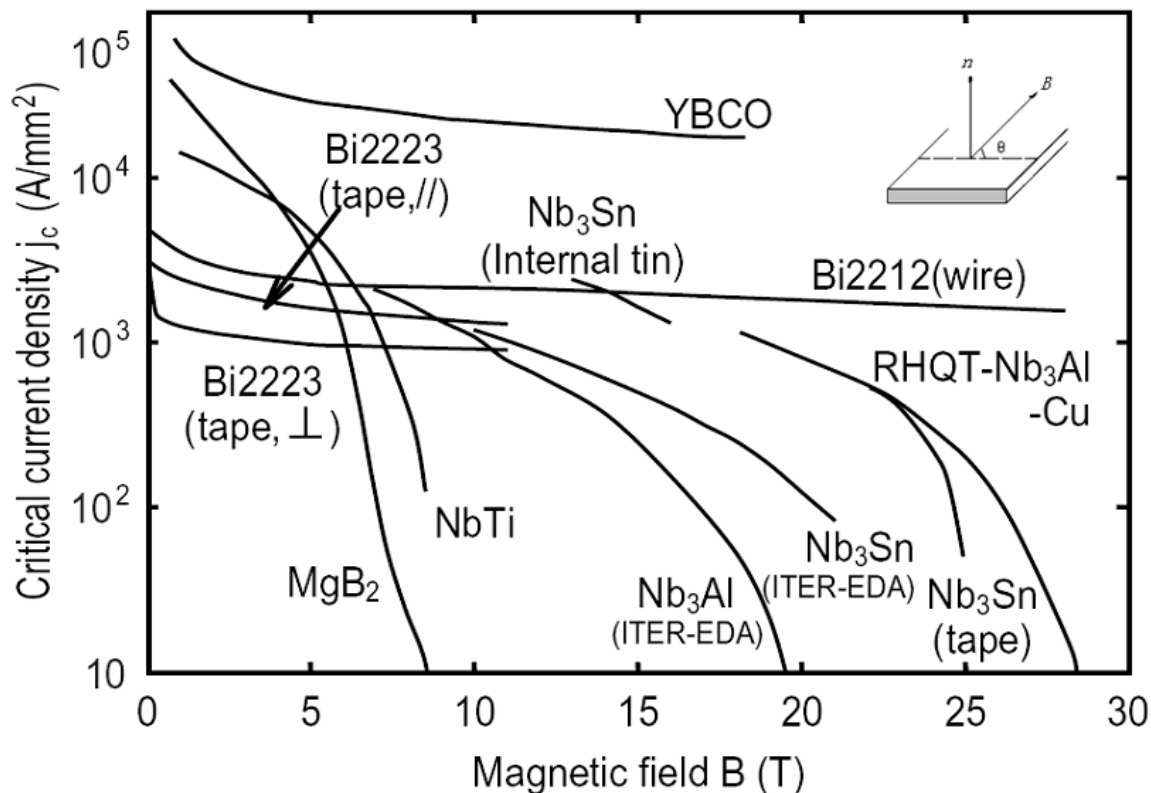
J. H. Lee, et al., *Supercond. Sci. Technol.*, vol.27, no. 4, 2014, Art. ID. 044018

缺点：临界电流具有很强的各向异性



缺点：单根载流有限，升流困难，均流困难；
除了电力装置应用困难外，在强磁场方面也遇到过困难。

HTS/LTS 临界电流密度随磁场大小和方向变化



一、背景

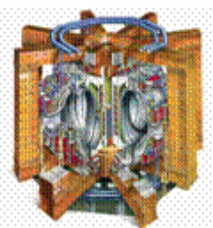
强磁场应用之一： ITER



Tore Supra

25 m^3

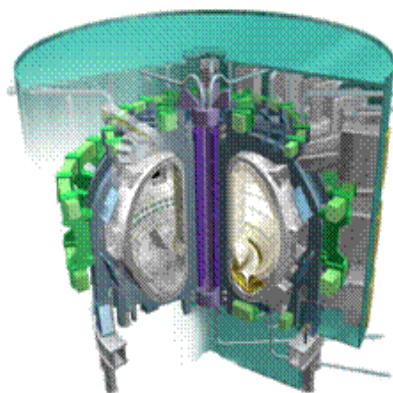
$\sim 0 \text{ MW}_{th}$



JET

80 m^3

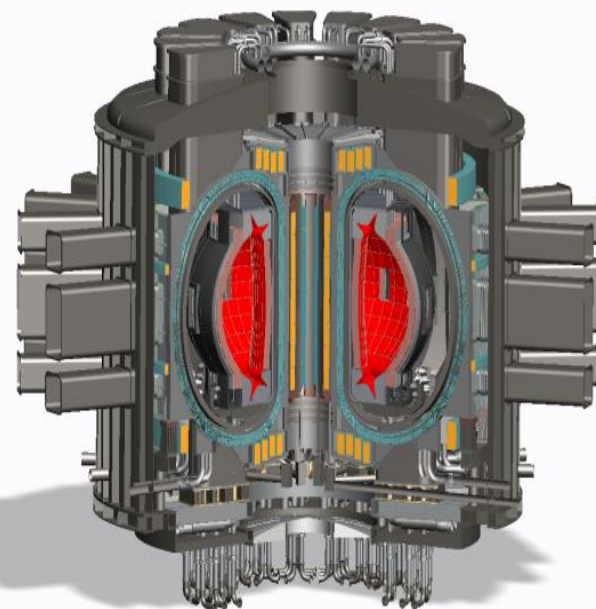
$\sim 16 \text{ MW}_{th}$



ITER

800 m^3

$\sim 500 \text{ MW}_{th}$



DEMO

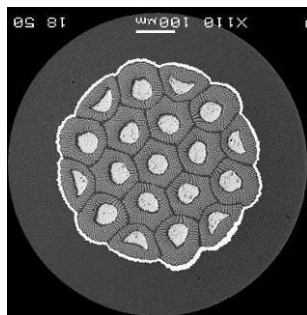
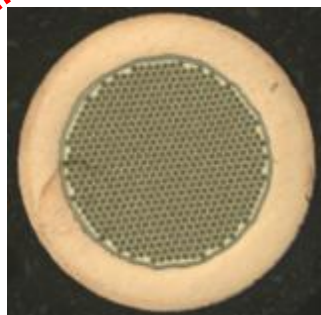
$\sim 1000 - 3500 \text{ m}^3$

$\sim 2000 - 4000 \text{ MW}_{th}$

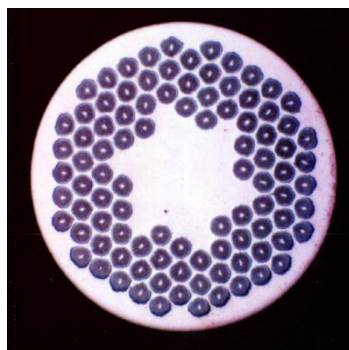
- Dominant self heating ----->

一、背景

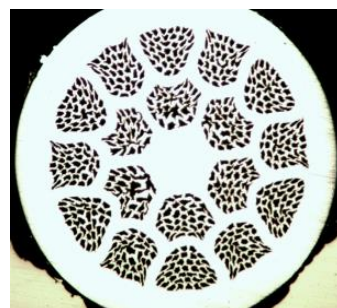
目前超导线



Nb₃Sn



Nb₃Al



Bi2212

CICC导体

Nb₃Sn



TF Conductor



有报道：未来ITER用高温超导体取代现有低温超导体

CICC导体



二、进展

国际上提出的导体结构



CD cable-法国Nexans



Rutherford 电缆



德国 KIT

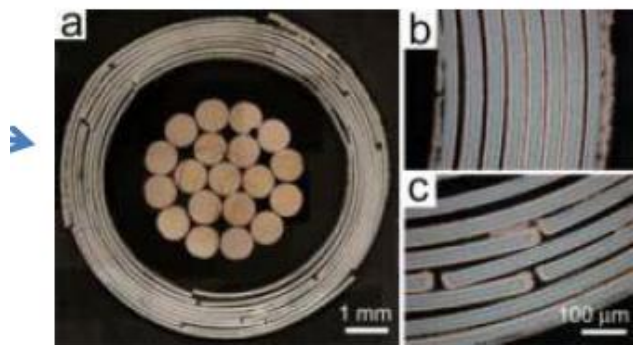
Roebel Strand



二、进展



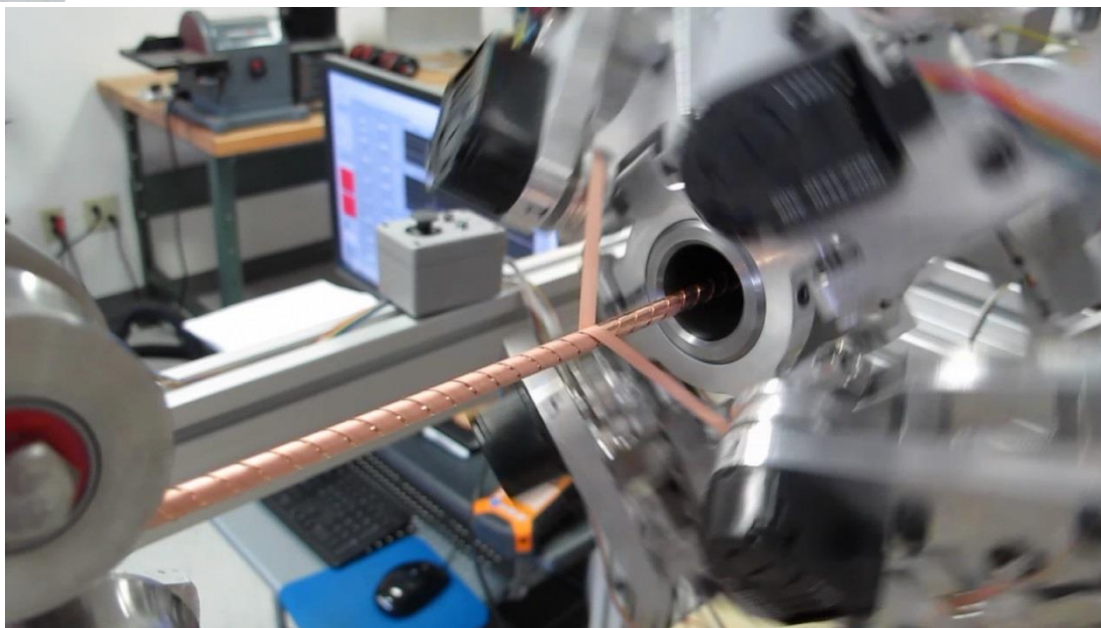
主视图



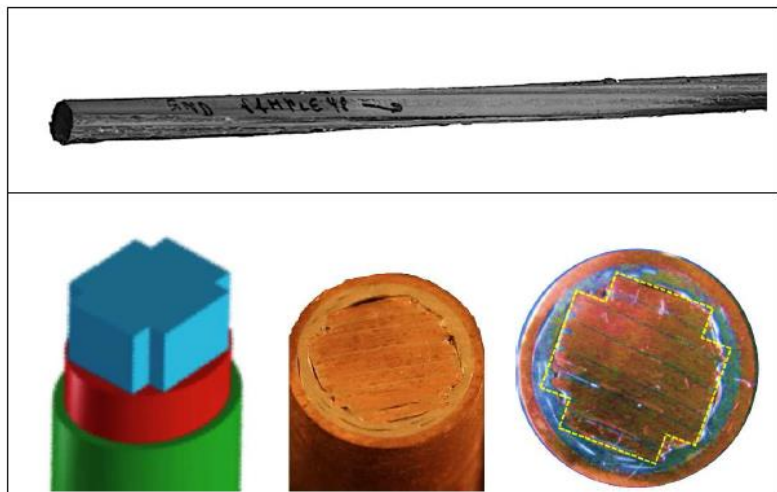
放大的侧视图

美国 NISM

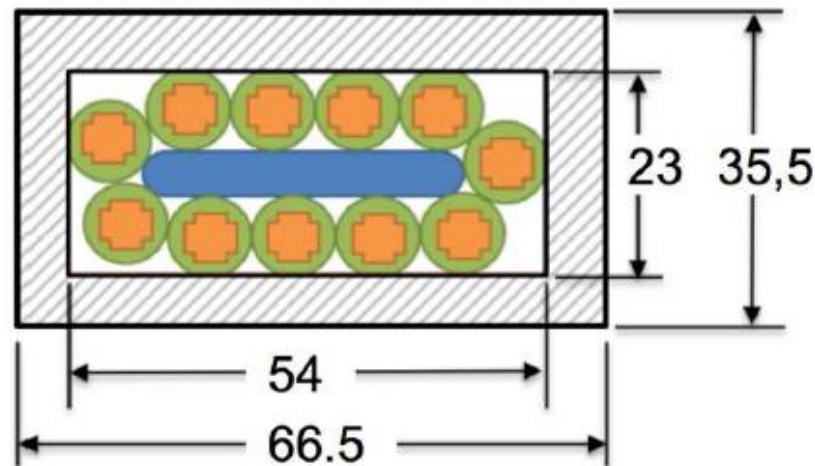
紧凑型高温超导电
缆导体 (CORC)



二、进展



德国(HTS-CroCo)



HTS CroCo导体组成的Rutherford电缆概念

二、进展

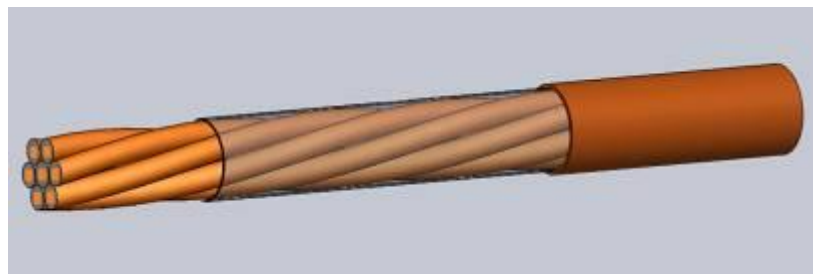
美国 MIT



[Round Twisted Stacked Conductor (TSTC)]

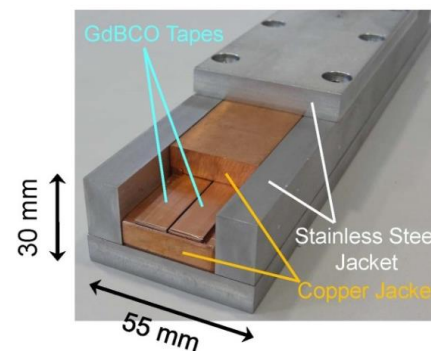
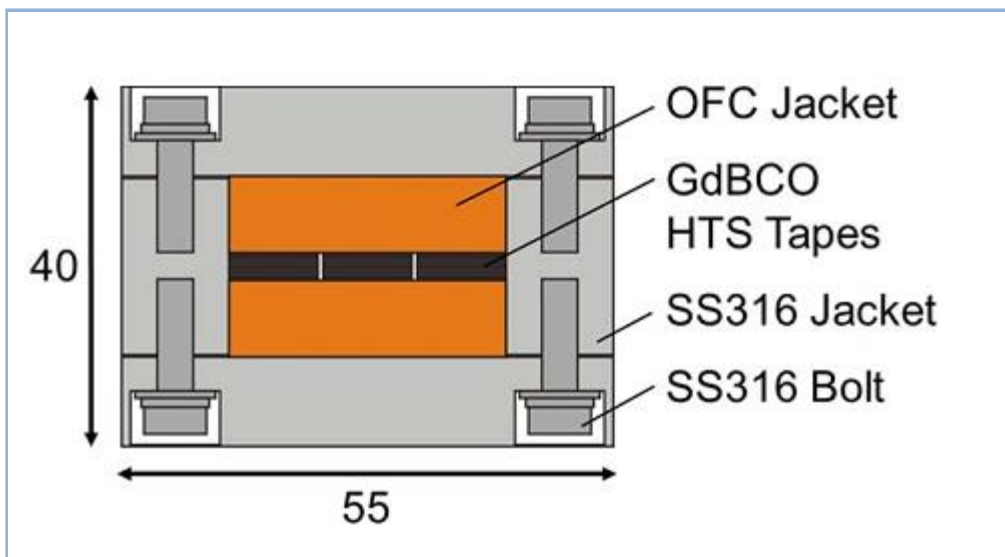


直接堆叠导体的CICC 导体



大电流电缆导体概念

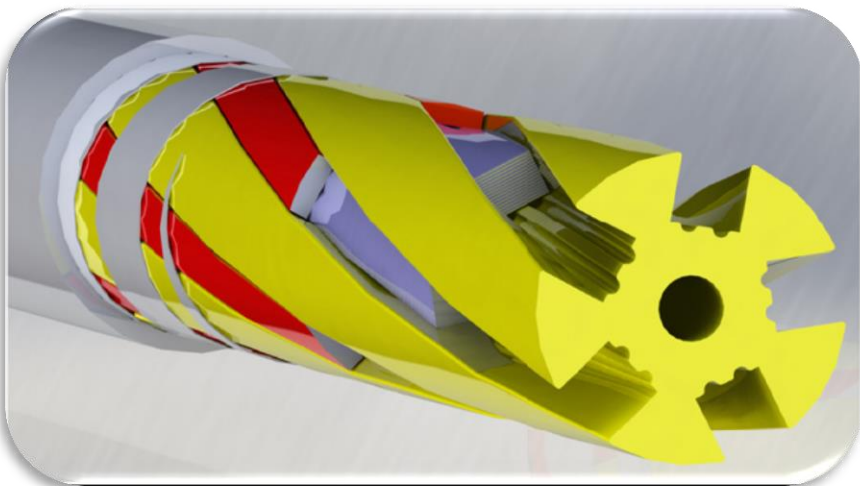
二、进展



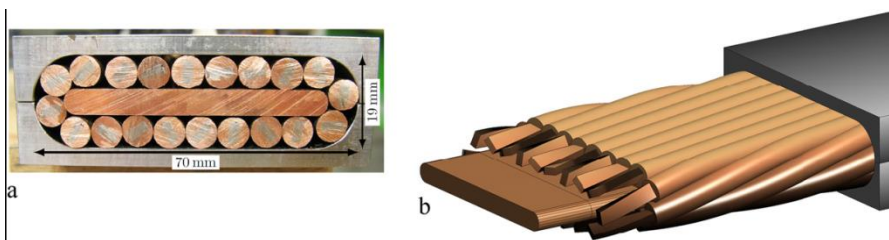
日本 NIFS

100kA-class HTS conductor

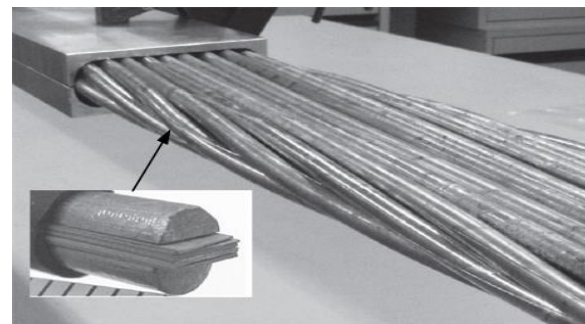
二、进展



意大利,瑞士



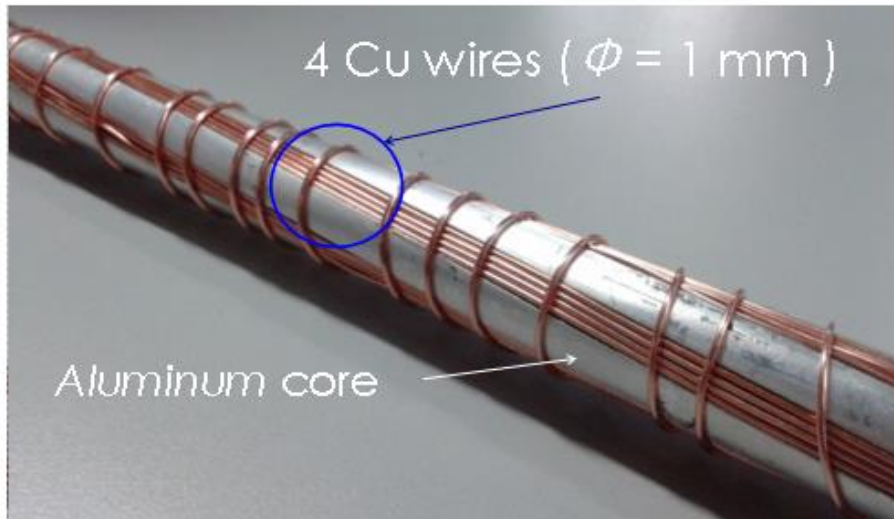
瑞士



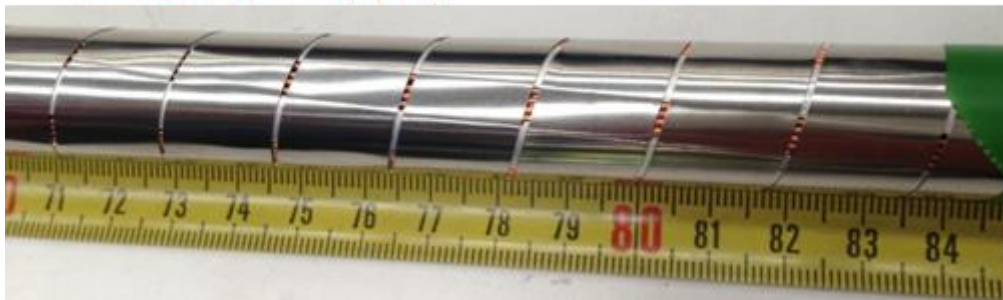
瑞士, 意大利63kA, 13T

二、进展

cable after stack deposition into the ducts with Cu wire spacers



cable after wrapping

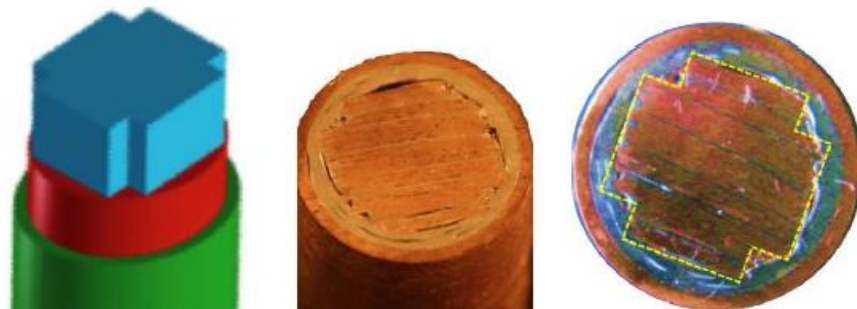


150 m

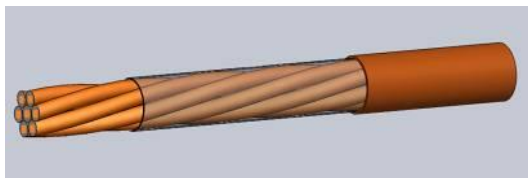
二、进展



美国MIT

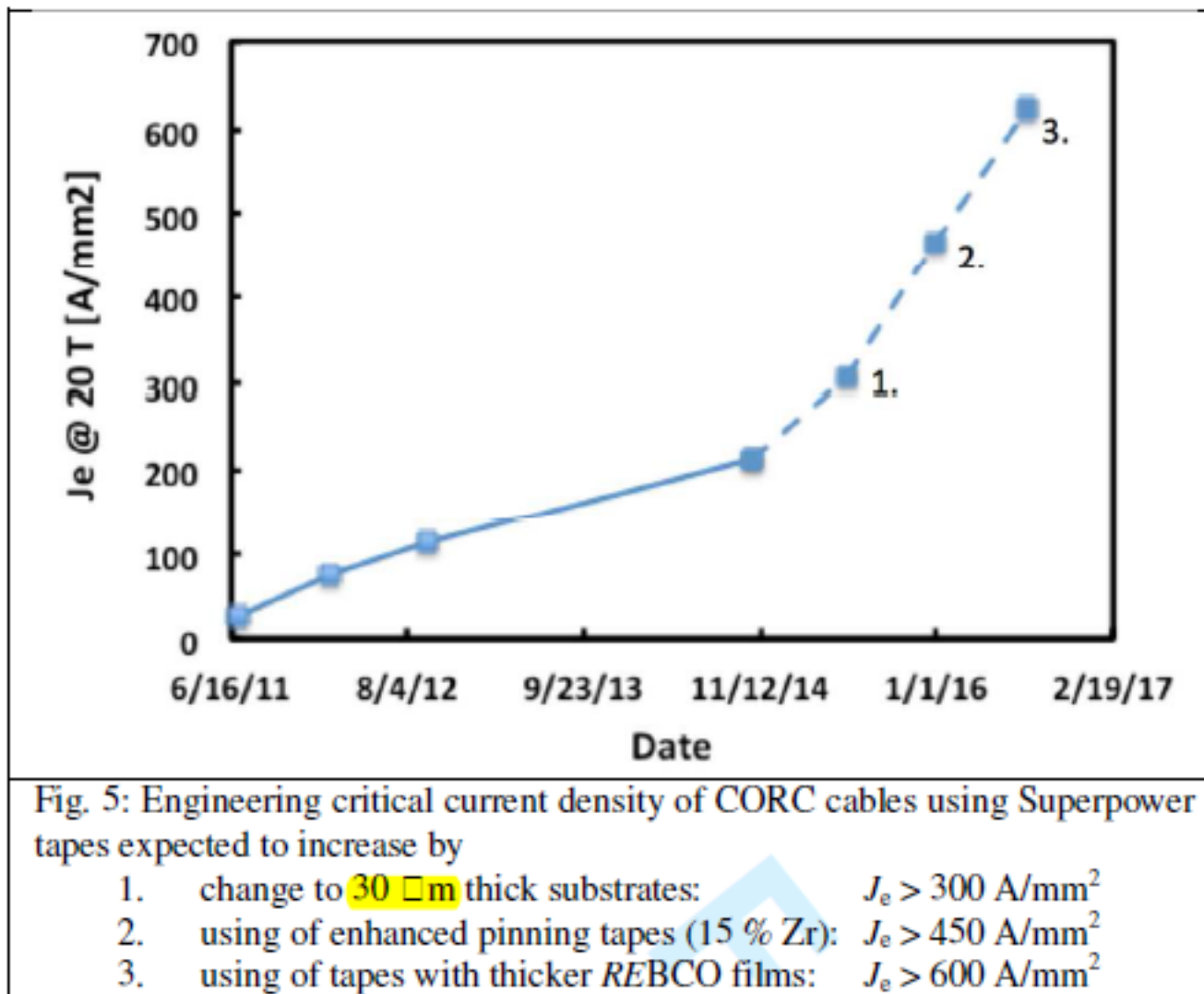


德国 KIT



美国 MIT 概念

共性缺点：临界电流仍然各向异性

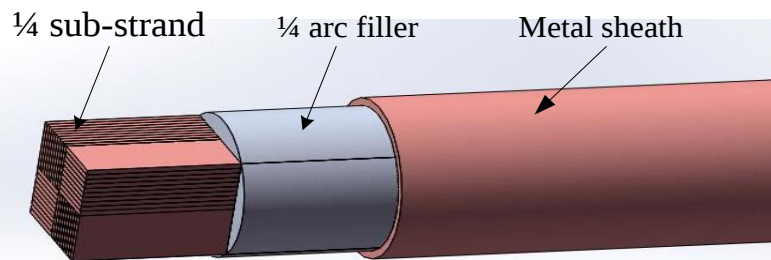


共性缺点：

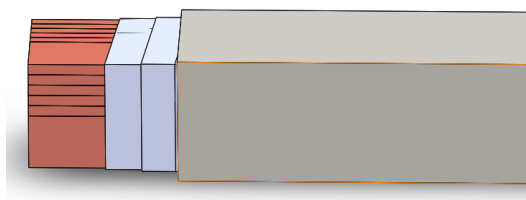
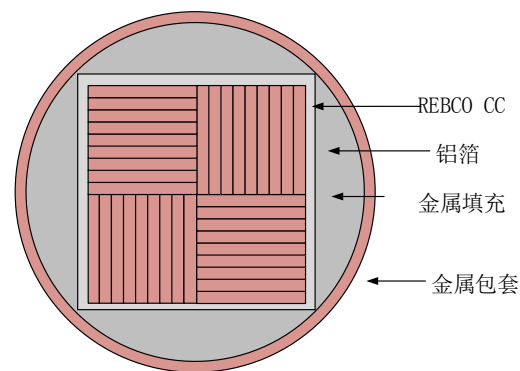
在导体横截面上临界电流仍然各向异性

二、进展

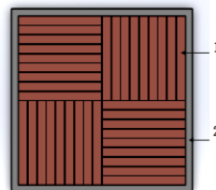
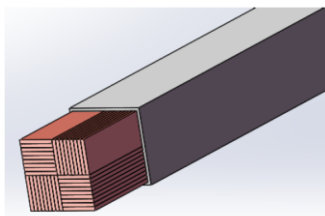
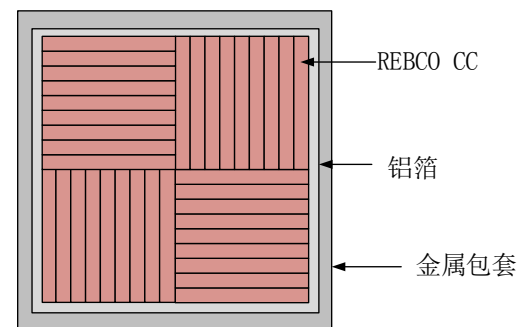
提出概念-准各向同性超导线-华北电力大学(NCEPU)



圆截面

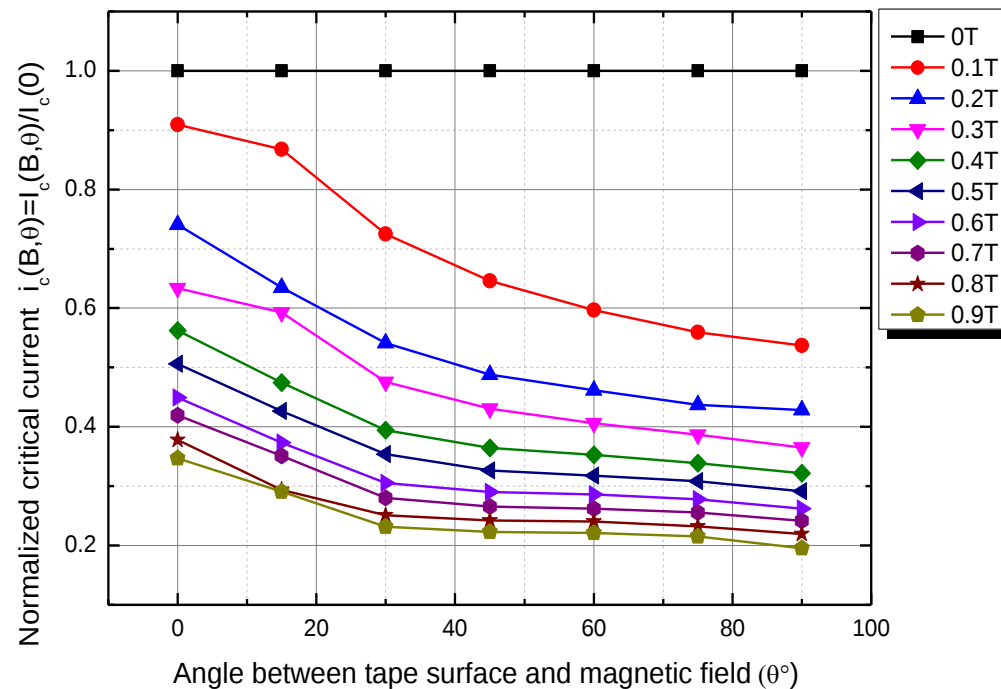
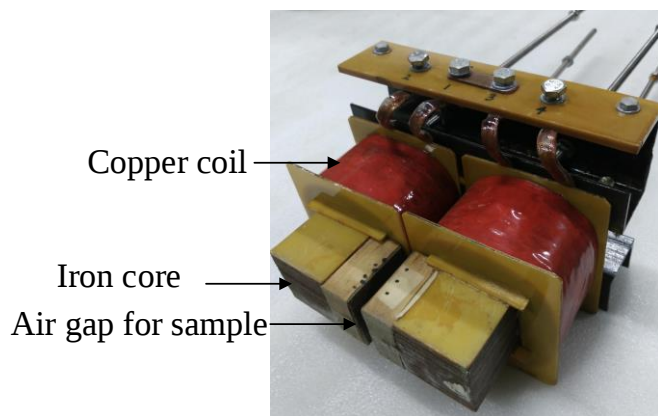
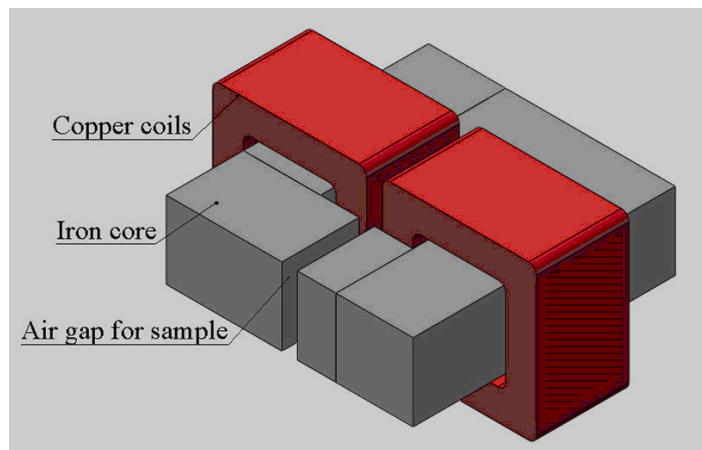


方截面



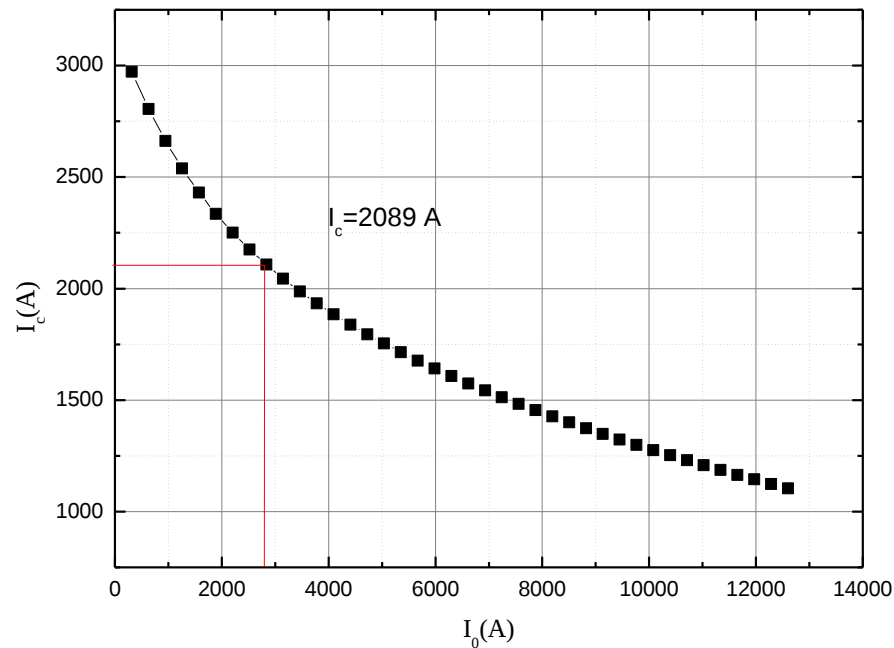
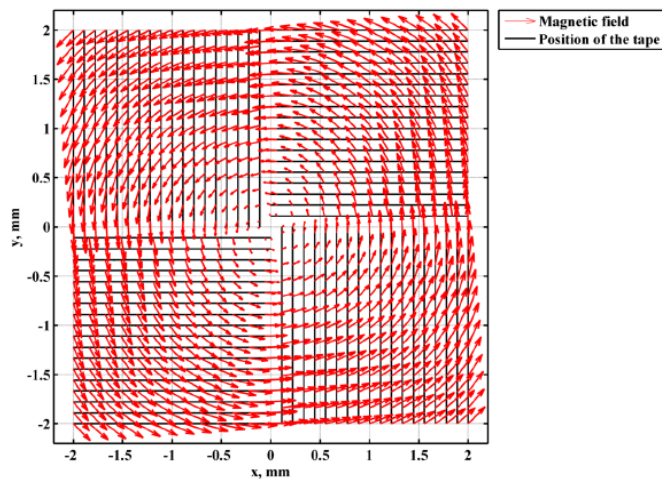
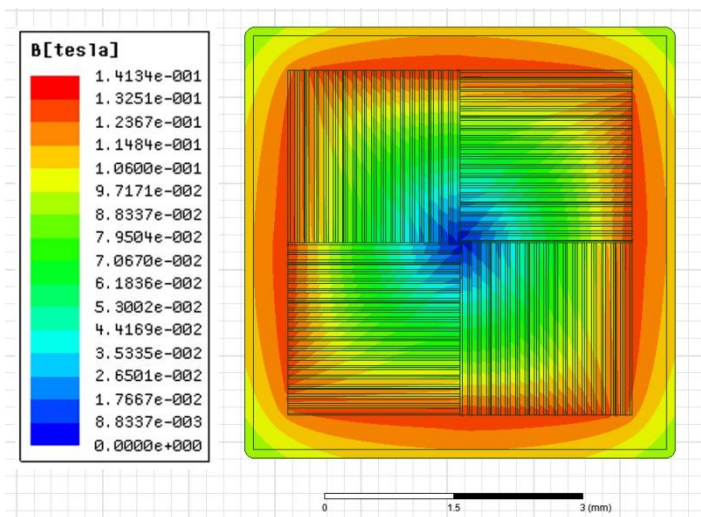
二、进展

超导带电磁各向异性



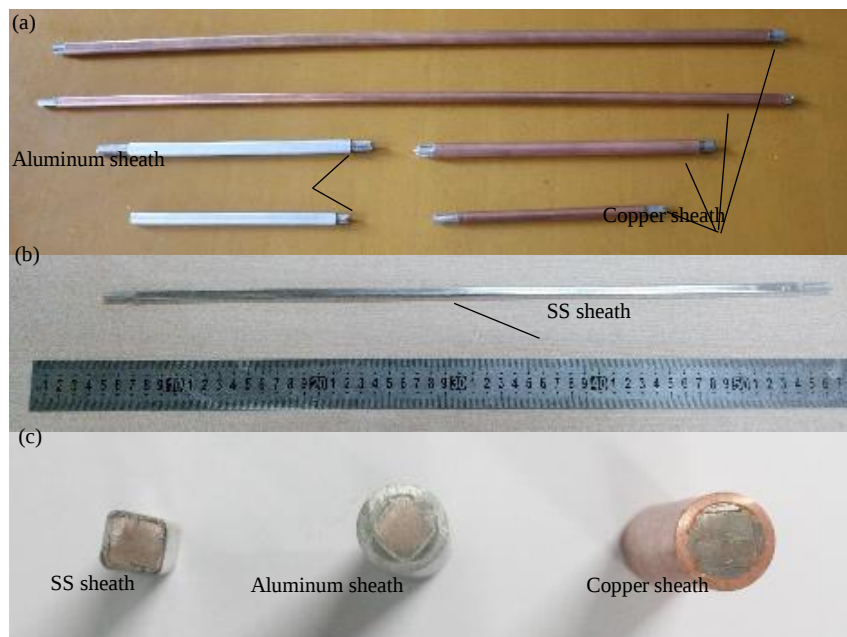
二、进展- 股线电磁设计

磁场分布



二、进展- 短样制作

超导带-SuperPower



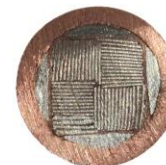
超导股线主要参数

Sheath material	copper
Arc Fillers	Aluminum
Over cross-section	round
Outer Diameter/mm	7.5
No. of tapes	4×18 (72)
Thickness/mm	0.8

二、进展- 临界电流特性



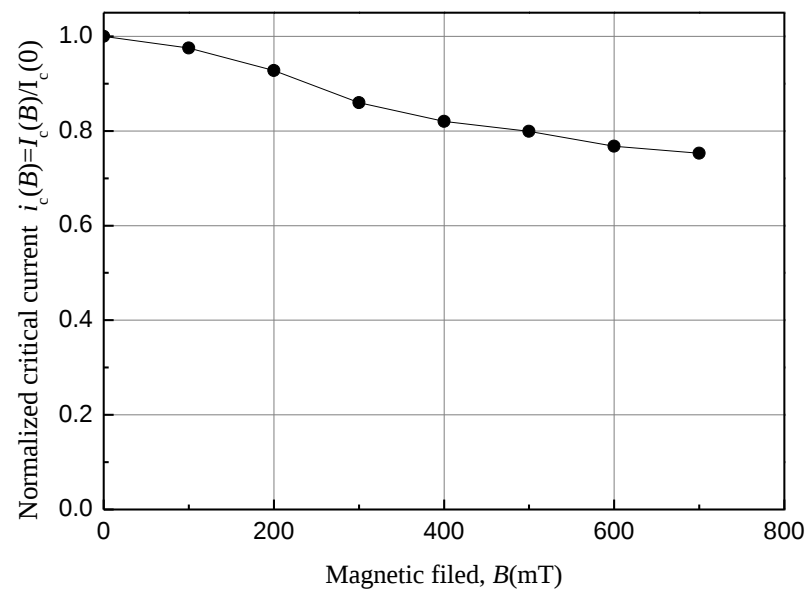
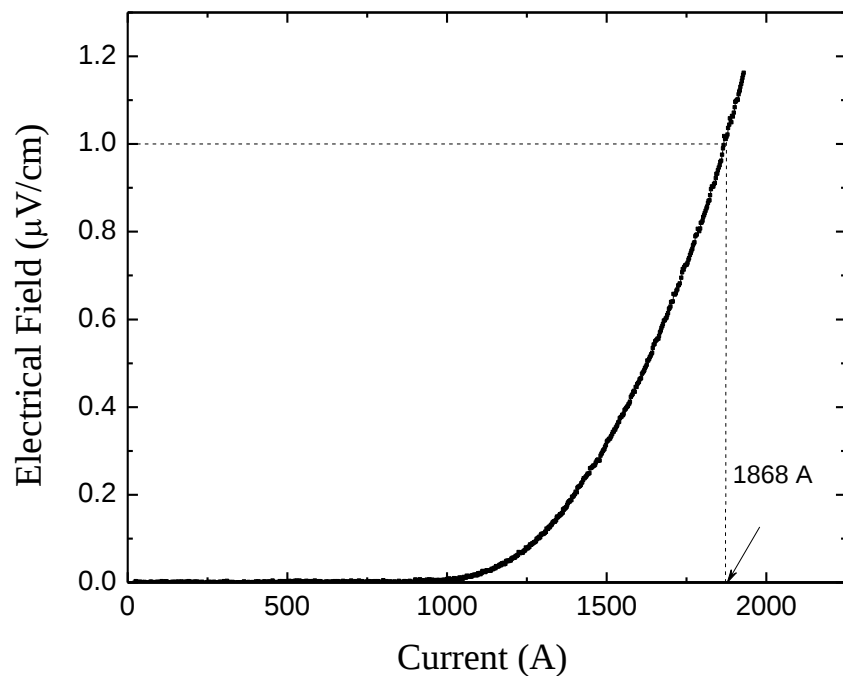
(a)



(b)

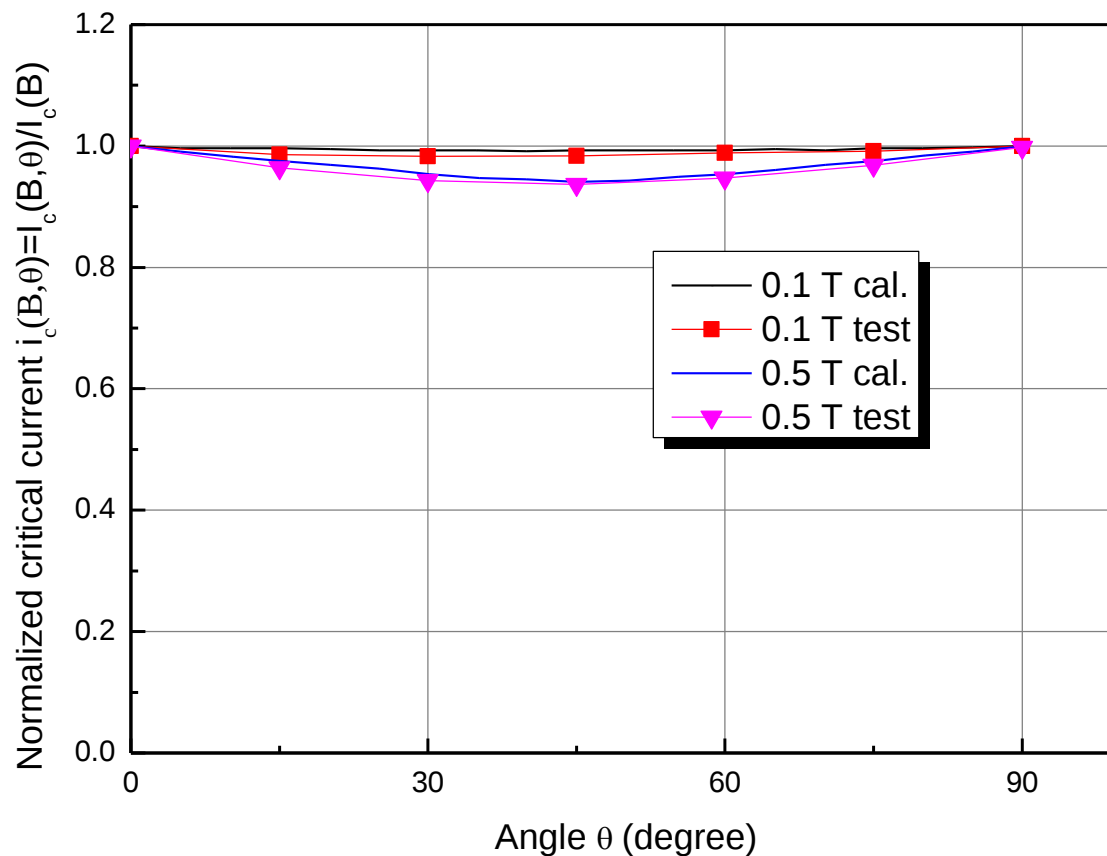


二、进展- 临界电流特性



模拟值2089A, 实验值1868, 90%.误差10%。.

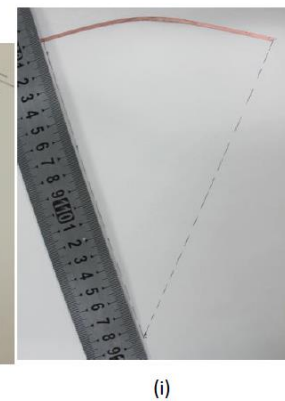
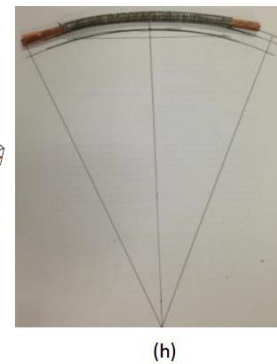
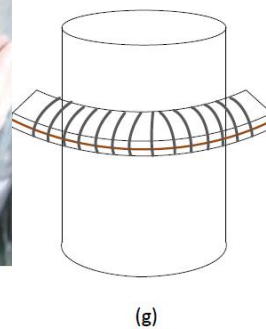
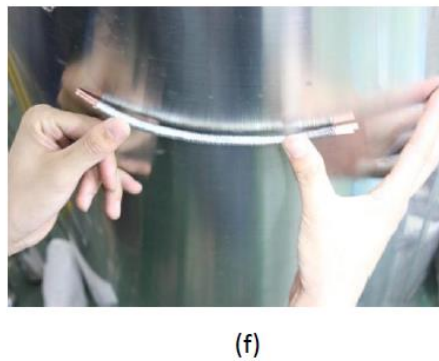
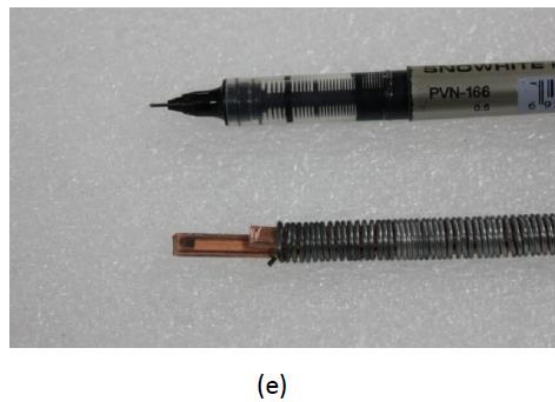
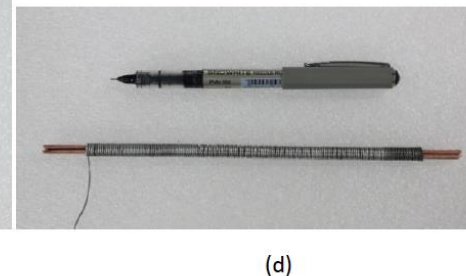
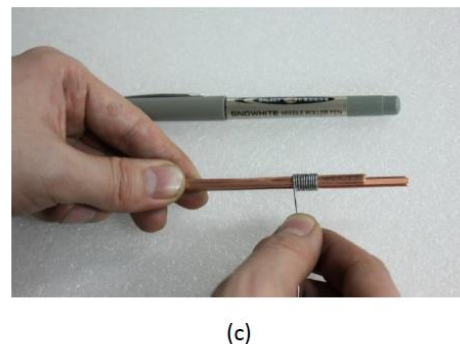
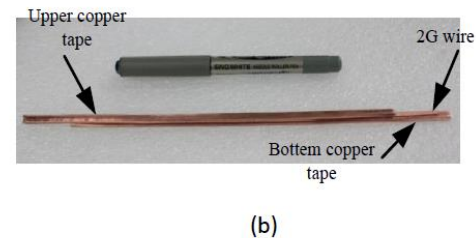
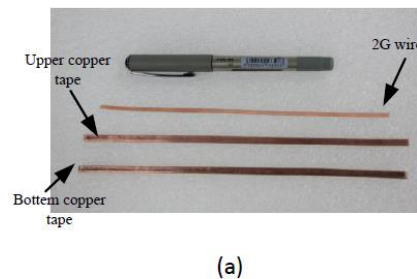
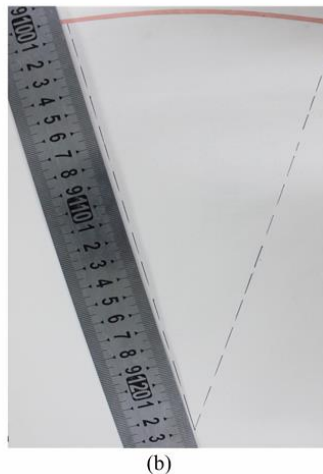
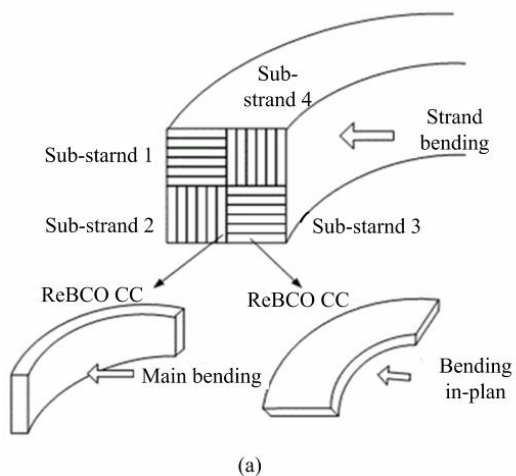
二、进展- 临界电流特性



临界电流各向异性<5%.

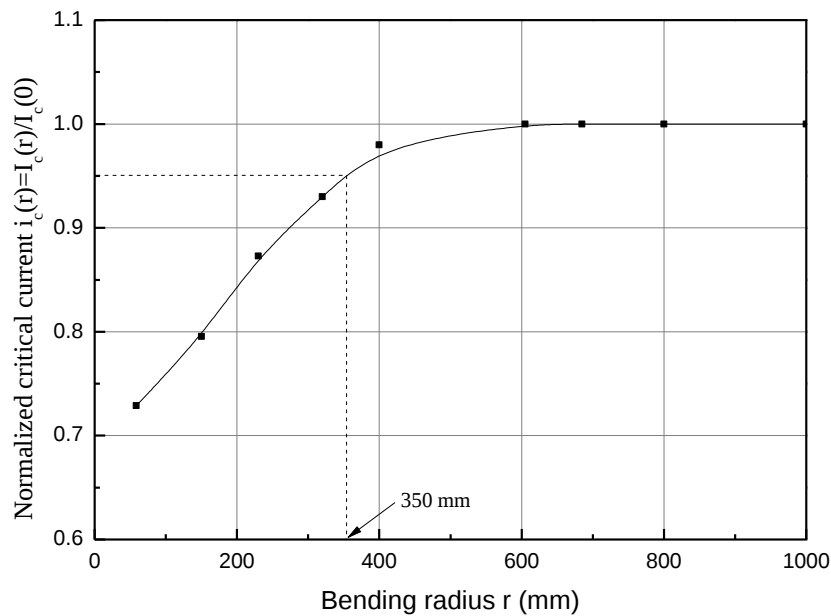
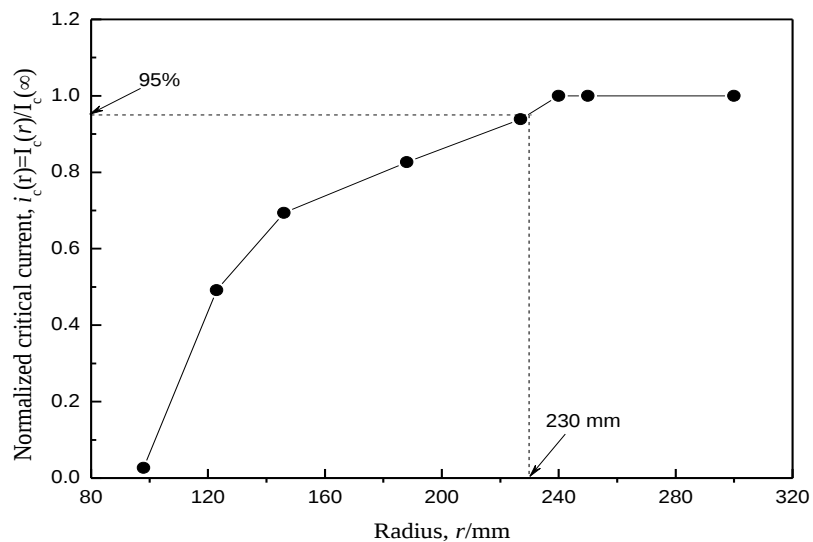
二、进展-机械特性-超导带侧向弯曲

弯曲特性

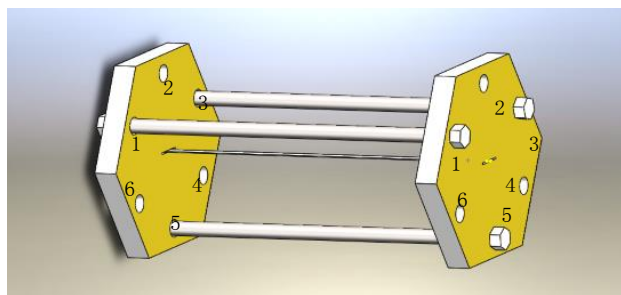


二、进展- 弯曲特性-超导带侧向弯曲、股线弯曲

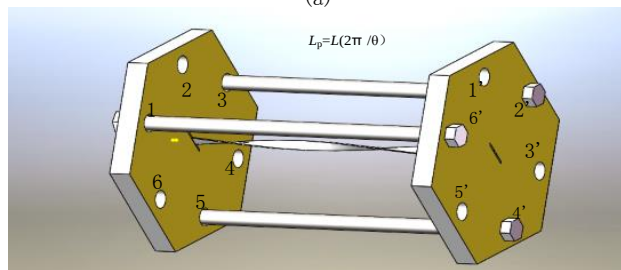
LAPS



二、进展-扭绞-超导带材、股线



(a)



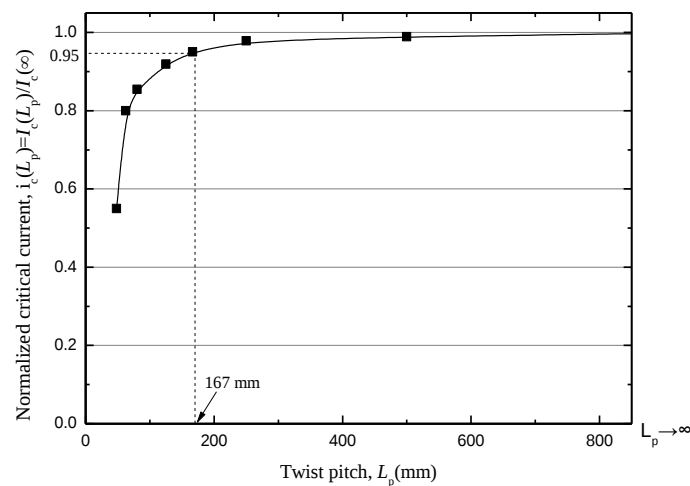
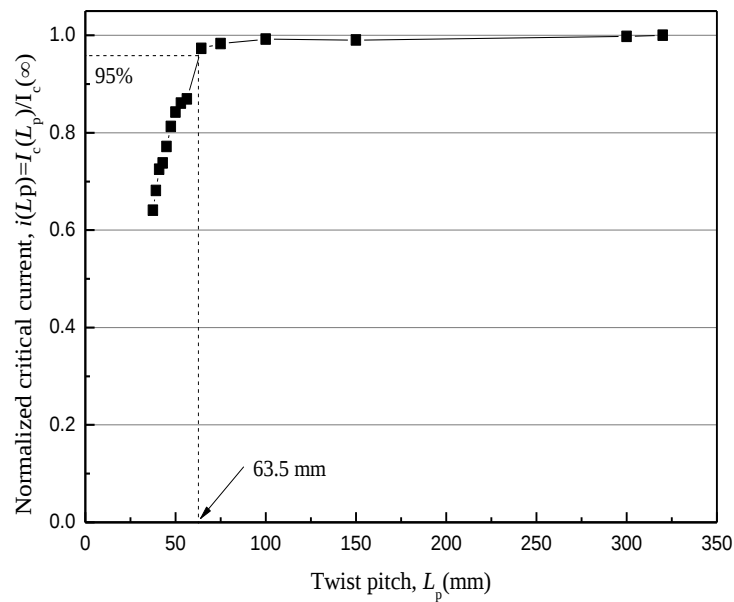
(b)

$$L_p = L \left(\frac{2\pi}{\theta} \right)$$

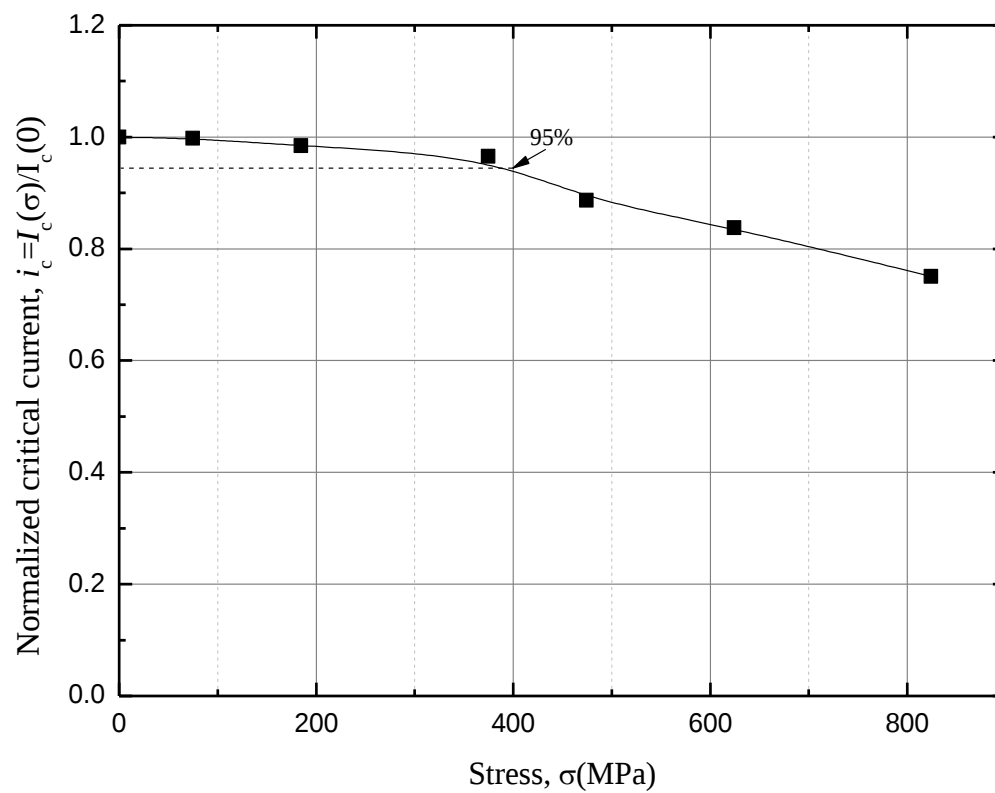
超导带材

超导线

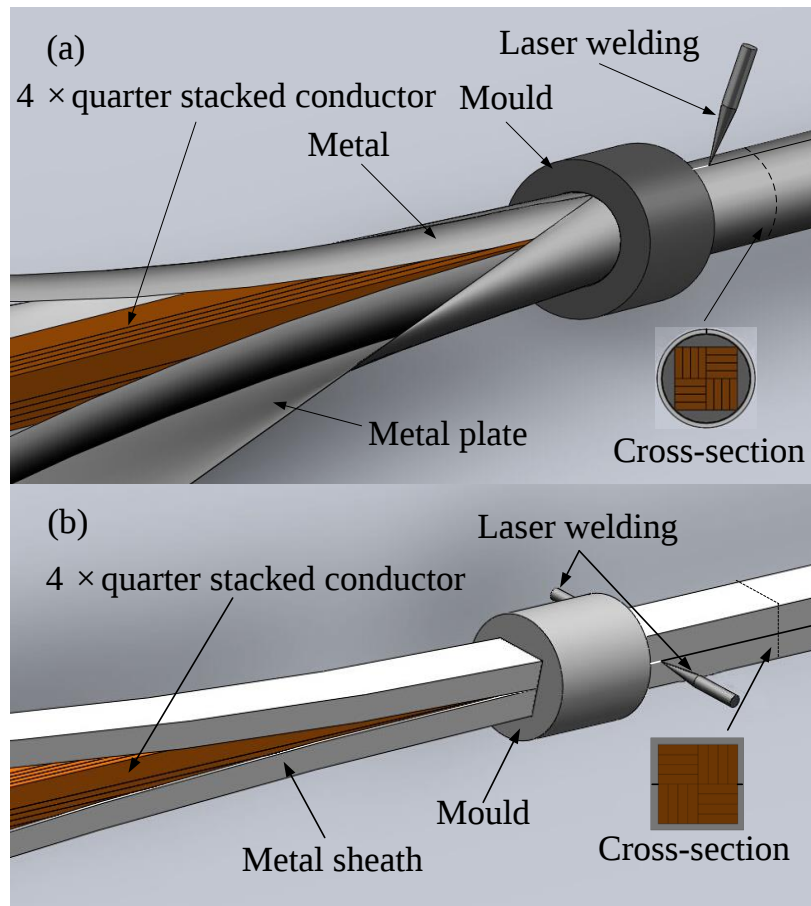
热处理改善弯曲特性？



二、进展-拉伸特性

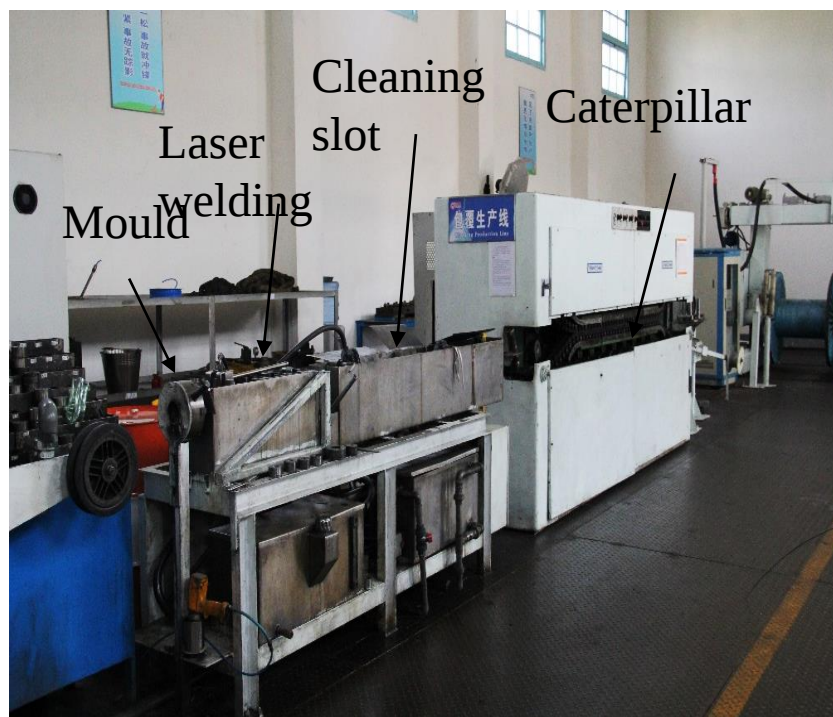


二、进展- 实用长度加工工艺

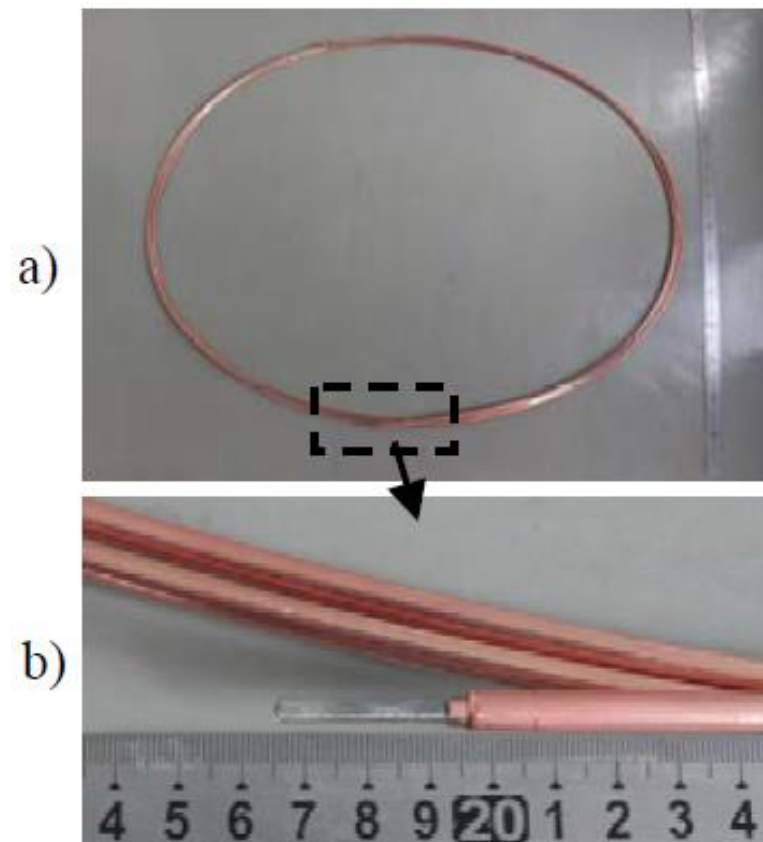


(a)圆截面；(b)方截面

二、进展-实用长度加工工艺



中天科技(ZTT)光缆生产线稍加改造

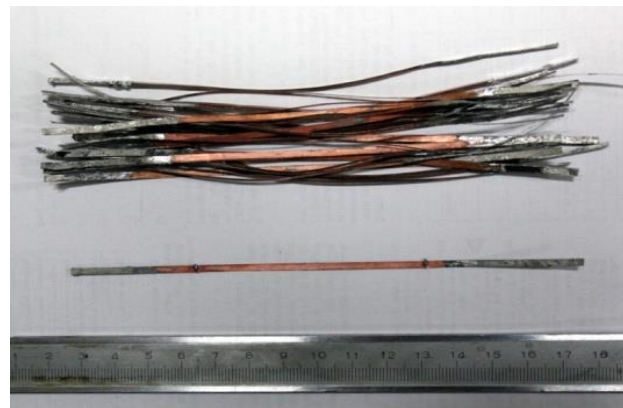


10m铜包套圆截面超导线

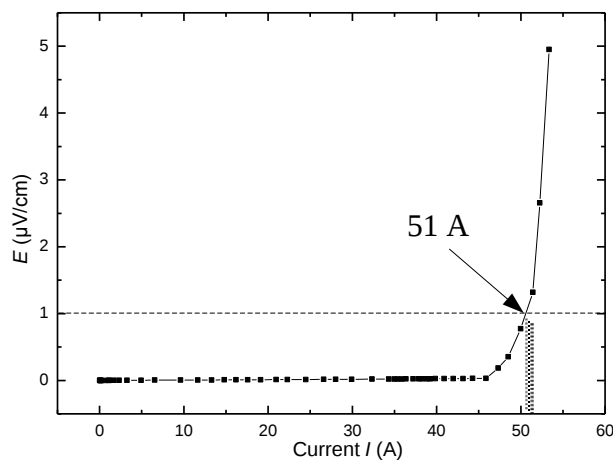
2.6 工艺安全性检验-股线复试



拆除铜端子的超导股线芯



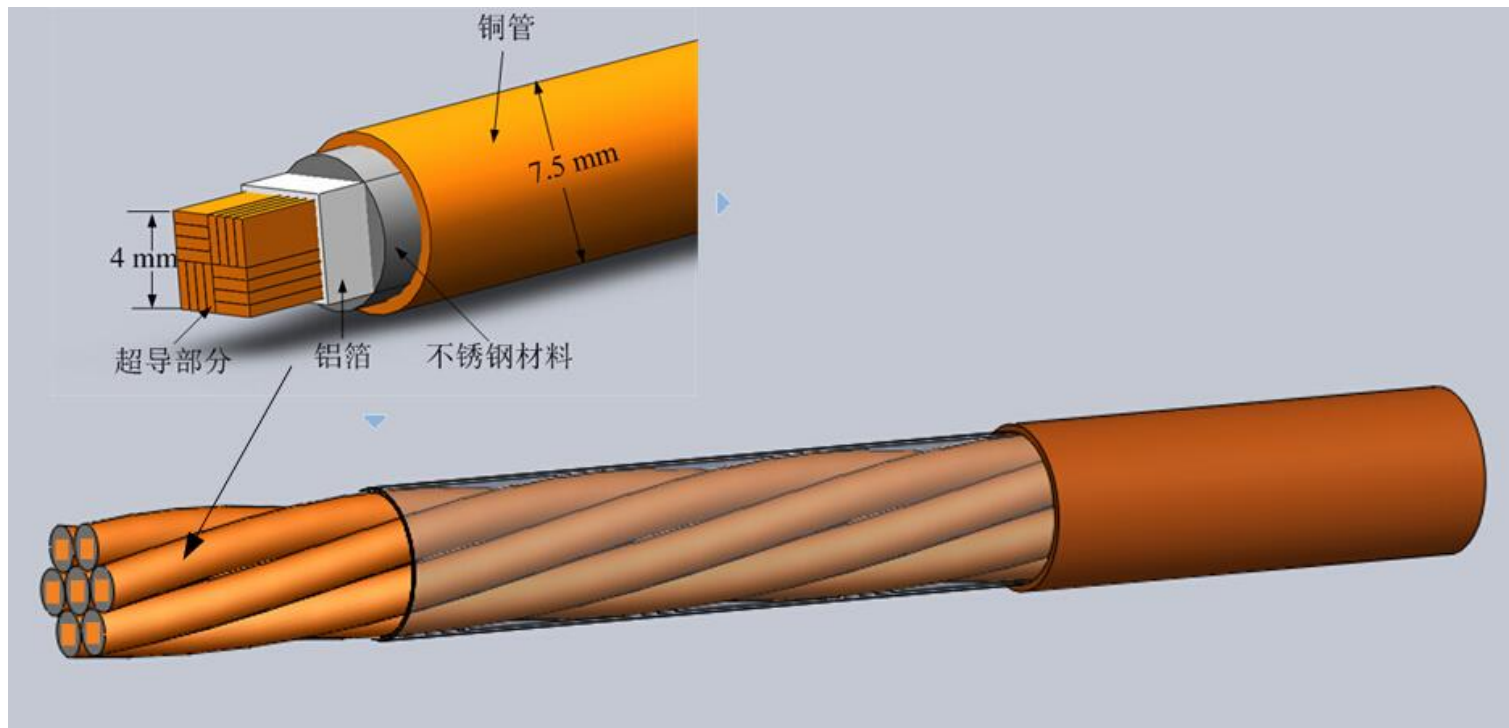
从股线拆分的超导带材



复试临界电流 $I_c=51A$
与当初厂家给出值吻合

工艺可行

二、进展-概念设计



- 基于涂层导体，高温超导股线；
- 股线的设计方法和工艺；
- 导体导体的机械特性（弯曲、拉伸、扭绞）；
- 实用长度超导股线的技术。

- 提高机械强度：股线弯曲半径、扭矩小于涂层导体（带材），找寻提高机械特性的方法，如退火热处理。
- 稳定性：理论实验研究股线稳定性、交流损耗、失超及恢复特性。
- 低温电磁特性：低温高磁场下的电磁特性及稳定性、交流损耗。
- 200kA股线：发展应用于高磁场超大电流容量的高温超导股线。

**衷心感谢各位专家的
批评和指正！**