Development of Nb₃Sn for FCC at BRUKER



27.06.2019 / Brussels / C. Bühler

This work is supported by CERN under FCC-GOV-CC-0157 KE4187/TE/FCC



Key Topics of the Nb₃Sn Development Program





Conductor Design

- PIT/RRP[®] Hybrid
- Internal Oxidation
- Other APC Approaches

Metal Forming

- Powder Rheology
- Filament Roundness
- Heat Management

Cost Savings

Pre-Materials

٠

٠

- High-Speed Processing
- Material Efficiency

Internal Oxidation Overview of Concepts



- Four monofilament layouts that include an oxygen source (red) at different locations
- Each with different diffusion pathways for Sn and oxygen
 - Each with different core compositions

Broad spectrum of compositions

Presentation will focus on -core concepts

intOx-**core**

Sn and O source central + mixed

intOx-**ring**

Sn and O source entral + separated



Sn and O source fully separated

intOx-shell



intOx-**split**

Sn and O source fully separated



Innovation with Integrity

Results: Screening Conductors Morphology





- The filament type is intOx-core where Oand Sn-source are mixed centrally
- Six core-compositions were tested in Nb1Zr and Nb2.5Ti each
- Huge changes in morphology can be observed
 - Dark, Nb-rich oxide ring around bronze droplet
 - Suppressed coarse grain and core A15 fraction
 - Surprisingly large fine grain areas

Nb1Zr monofilaments after heat treatment for 300 h at 640°C

Results: Screening Conductors Morphology *O-high*





Results: Screening Conductors Grain Size





Innovation with Integrity

Results: Screening Conductors Precipitates





- Precipitates on grain boundary surfaces
 - Equivalent precipitate Diameter: 7 nm
 - Average neighbor distance : 55 nm
- No intracrystalline precipitates observed
- Assumed composition TiO₂
- Precipitates also observed for Nb1Zr
- TEM and APT analysis will show composition, interface and distribution
- Probably result of oxidation of Zr/Ti after Nb₃Sn formation
 - Therefore no effect on grain size

Do these precipitates act as artificial pinning centers?

Innovation with Integrity

*I*_c(*B*) Measurements intOx-core





*I*_c(B) Measurements intOx-core





- Normalized pinning curves indicate higher point pinning component
- Location on grain boundaries probably a hindrance for effective precipitate spacing
- No significant shift of F_{p,max} to higher fields due to the lack of grain refinement

- At the same reduced field of b=0.5, J_{c,layer} is increased by ~ 40%
- Performance increase due to higher J_{c,layer} and ~ 10 % higher fine grain fraction

Ternary alloys are indispensible

Innovation with Integrity

WIP

Summary and Outlook for internal oxidation





Summary and Outlook for internal oxidation



Fine grain fraction	Nograin	intOx-ring/shell/split co	ncepts
Internal Oxidation is only one part of the			
at	R&D agre	ement	s on of
J _{c,1}	More information	on:	
C,	Conductor Hom	ogeneity	
Sligh	Hybrid Conduct	ors	
pinni	Other APC Appr	oaches	
	Internal Oxidation	on w/ Ternary Alloys	
Alro	High Speed Proc	cessing	lleve
poter state of	In the Fu	uture	ed to eve
IntUx-con		manufactured	parable B _{c2}







Innovation with Integrity

We thank CERN for their support and funding of this project under FCC-GOV-CC-0157KE4187/TE/FCC **Our special thanks go to:**

Amalia Ballarino Simon C. Hopkins Luca Bottura Bernardo Bordini Arnaud Devred Lucio Rossi

Dear colleagues from the Institute for Technical Physics (ITEP) at the Karlsruhe Institute of Technology (KIT) thank you for your advices and extensive support for the PhD thesis within this work

Our special thanks go to:

Sandra Kauffmann-Weiss Bernhard Holzapfel Martin Heilmaier Dear colleagues from Bruker, thank you for your time, the support and your knowledge that make this project possible. **Our special thanks go to:** Matheus Wanior

Bernd Sailer Vital Abächerli Klaus Schlenga Manfred Thöner

Oxidation of Nb-Sn intermetallics





Oxidation of Nb-Sn intermetallic can lead to a more efficient release of Sn from a Sn-rich core:

Example:

$$NbSn2 \rightarrow Nb3Sn + 3Sn \qquad / 39,8 \frac{mmol}{cm^3} \quad \begin{array}{l} \text{Only releases 80\%} \\ \text{of all contained Sn} \end{array}$$
$$NbSn2 + Sn02 \rightarrow Nb02 + 3Sn \quad / 47,5 \frac{mmol}{cm^3} \quad \begin{array}{l} \text{Releases 100\% of} \\ \text{all contained Sn} \end{array}$$

back

Additional: intOx-core Phase Formation



625°C*

640°C*



Innovation with Integrity

Additional: intOx-core VSM





Innovation with Integrity

Additional: intOx-core Grain Sizes



