Optimizing 2212 with Overpressure (OP) Processing

Eric Hellstrom, Matt Boebinger, Ernesto Bosque, Peng Chen, Anca-Monia Constantinescu, Erin Flagler, Jianyi Jiang, Tak Kametani, Hom Kandel, Jun Lu, David Larbalestier, Maxime Matras, Ulf Trociewitz

Applied Superconductivity Center
National High Magnetic Field Laboratory
Florida State University

Collaborations with BNL, FNAL, LBNL, and OST

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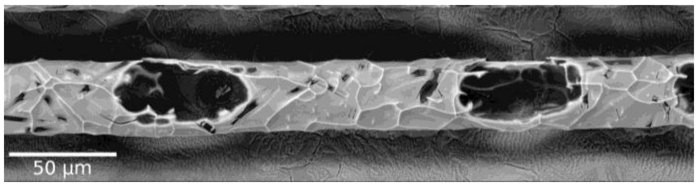
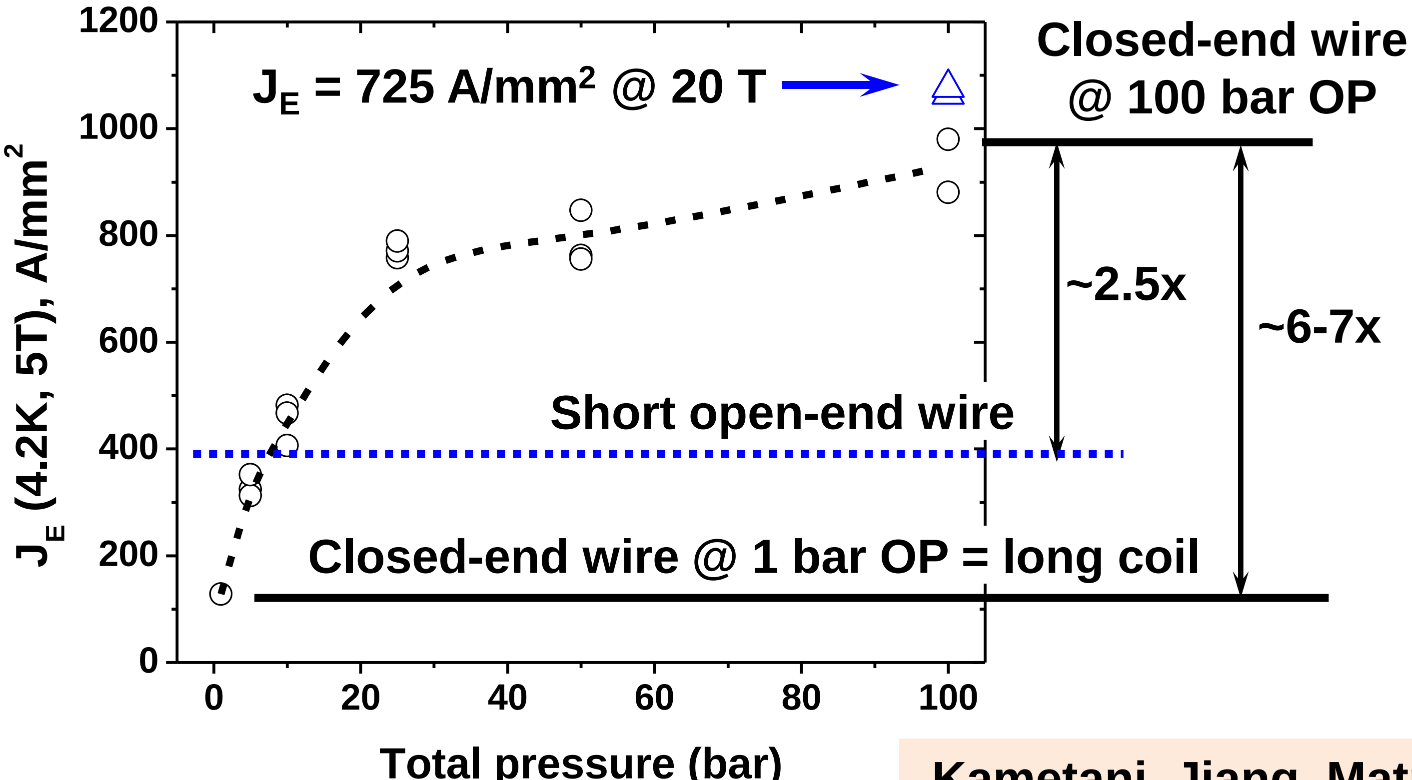
Overview

- Why 2212 needs overpressure (OP) processing
- J_E is now useful for accelerator magnets
- Questions that drive research at ASC
- Update on OP furnaces at ASC

Removing bubbles with overpressure (OP) processing more than doubles J_E

Gas-filled bubbles due to powder being only 60-70% dense → **Squeeze wire to remove bubbles**





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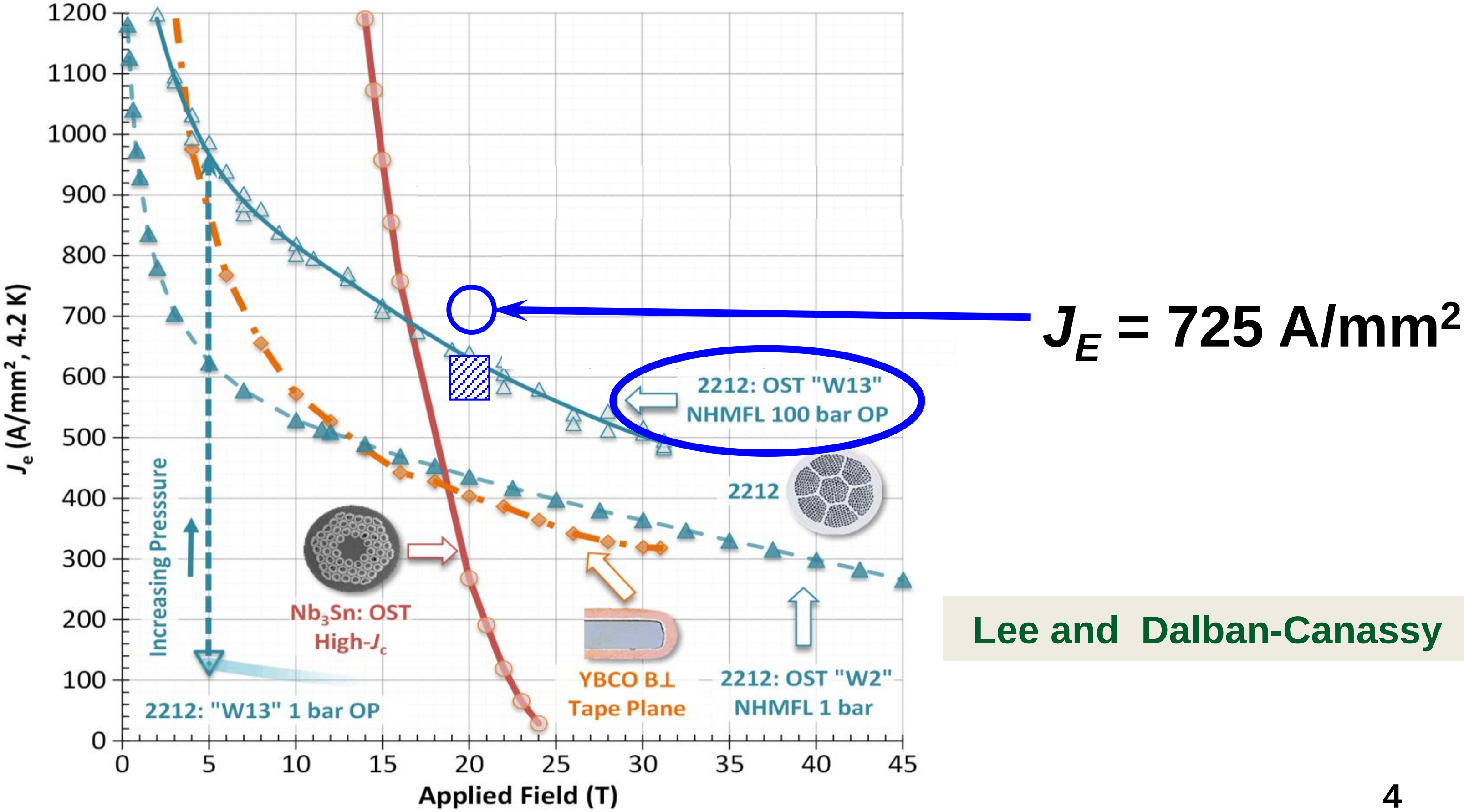
High J_c and J_E in OP wire (4.2 K, 20 T)
J_E = 640 A/mm² J_c = 2500 A/mm²



Lee and Dalban-Canassy

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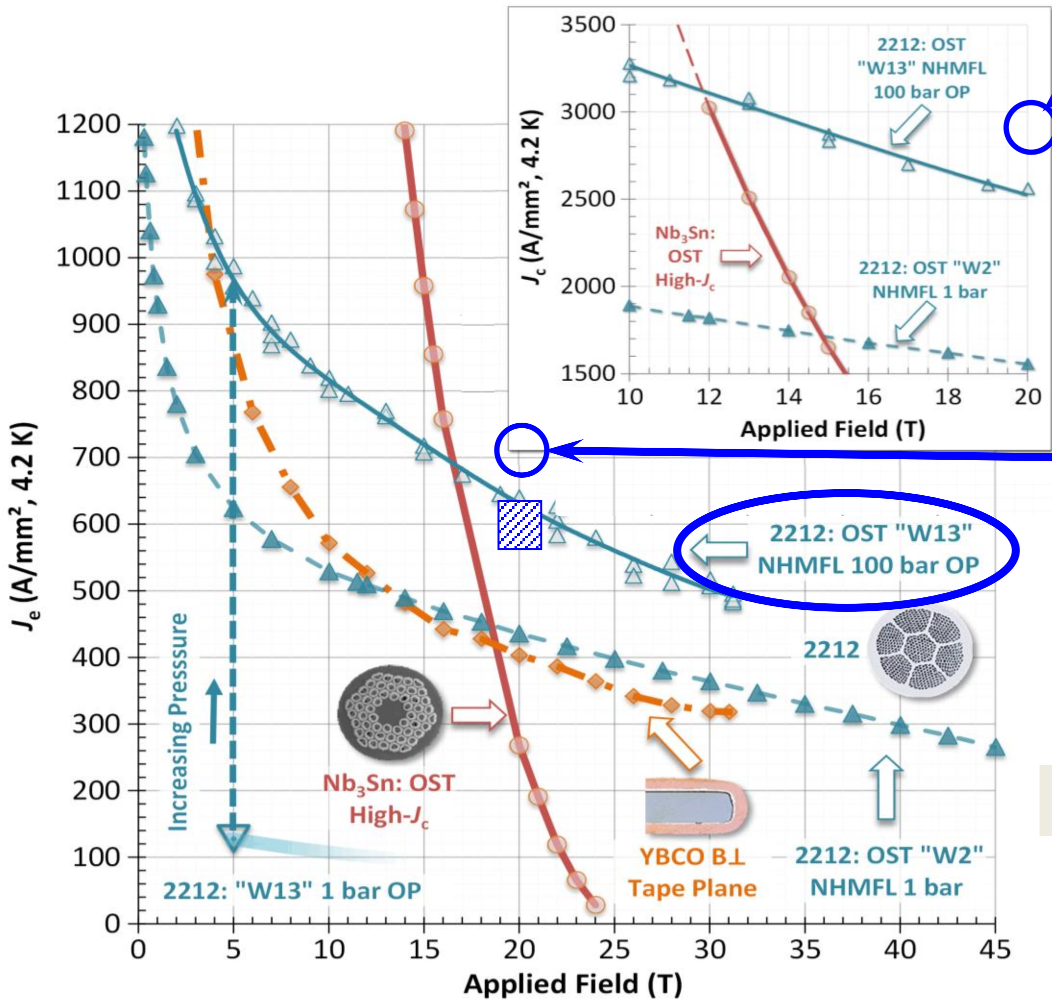


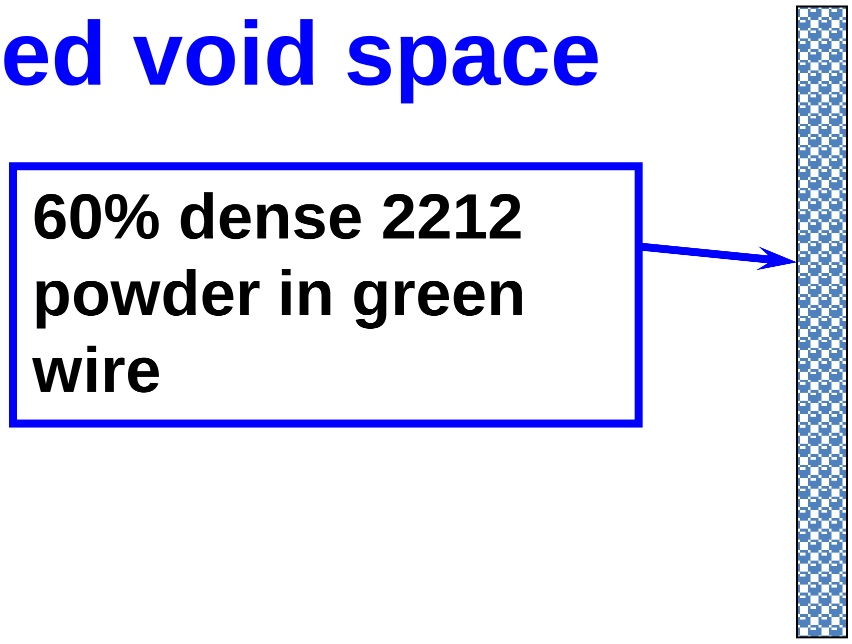
J_c = 2900 A/mm²

J_E = 725 A/mm²

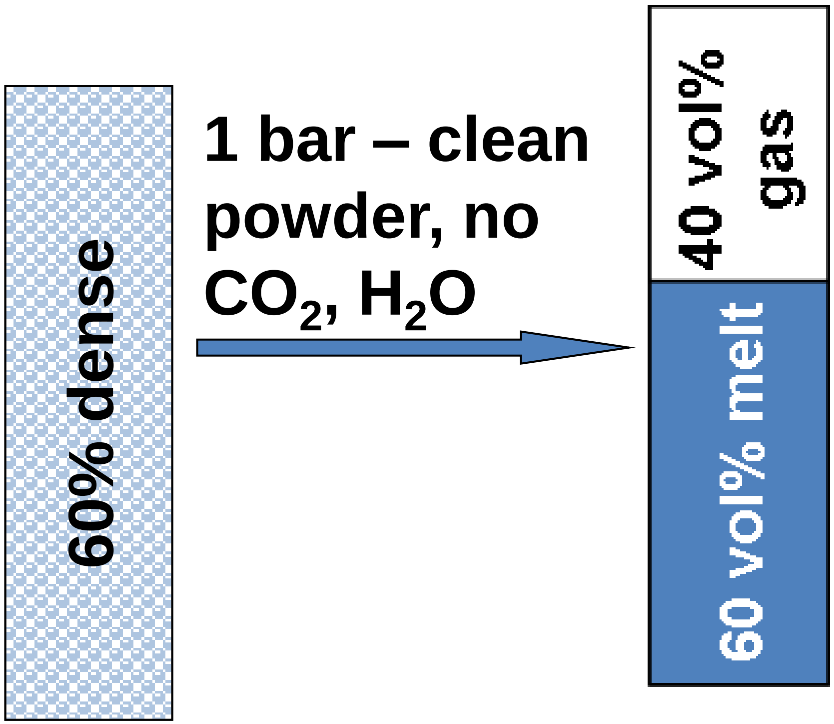
Lee and Dalban-Canassy

What can happen to 2212 filaments during melt processing?

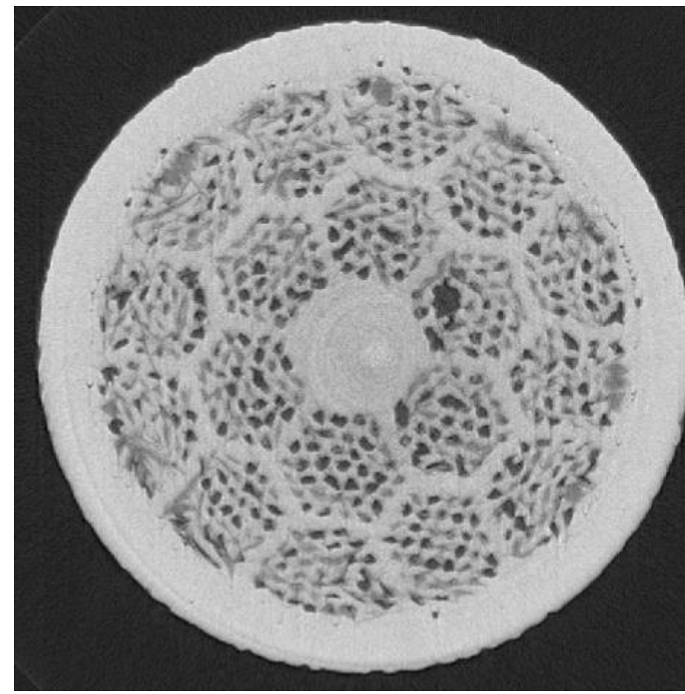
- **Maximum packing density of 2212 powder in filaments is 60-70%**
- **Focus on the 30-40 vol% of the filament that is gas-filled void space**



Best case with 1 bar processing: 30-40% gas bubbles in filament



Kametani



Scheuerlein

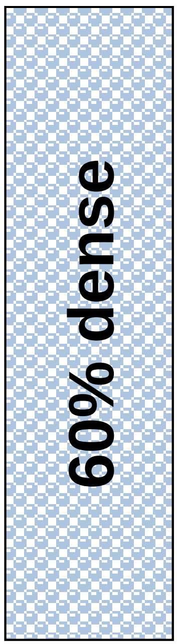
Real-time, *in situ* x-ray microtomography shows how bubbles form and grow during heat treatment

- **Video shows filaments in 2212 wire during heating and cooling in 1 bar air**

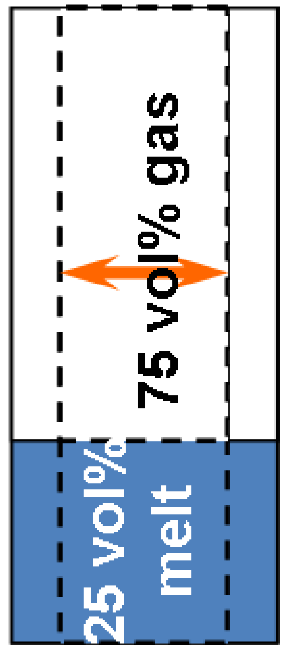
Scheuerlein

Worst case with 1 bar processing: dedensification and leakage

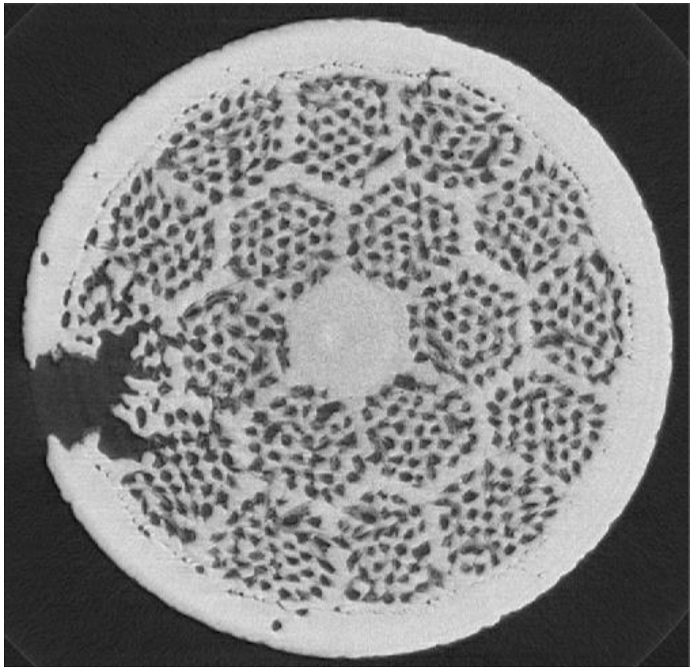
Internal gas pressure expands filament hole



1 bar – dirty powder: CO_2, H_2O



- Malagoli
- Shen



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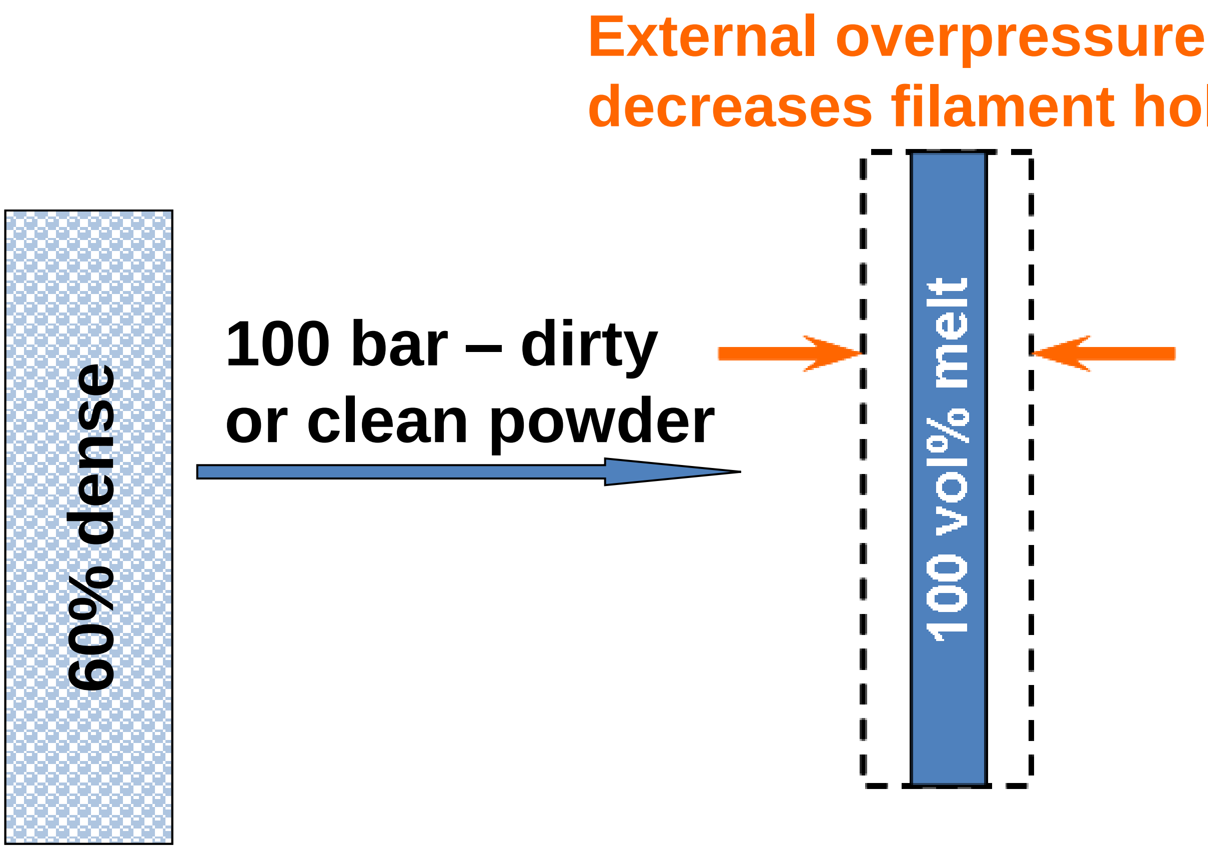
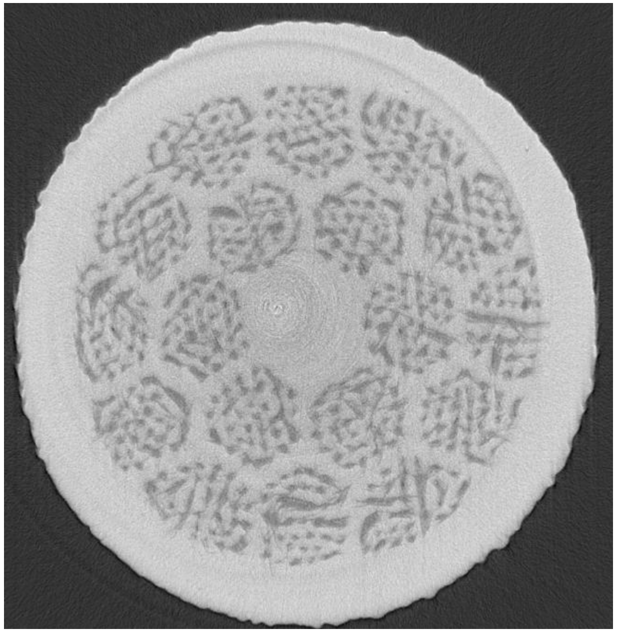
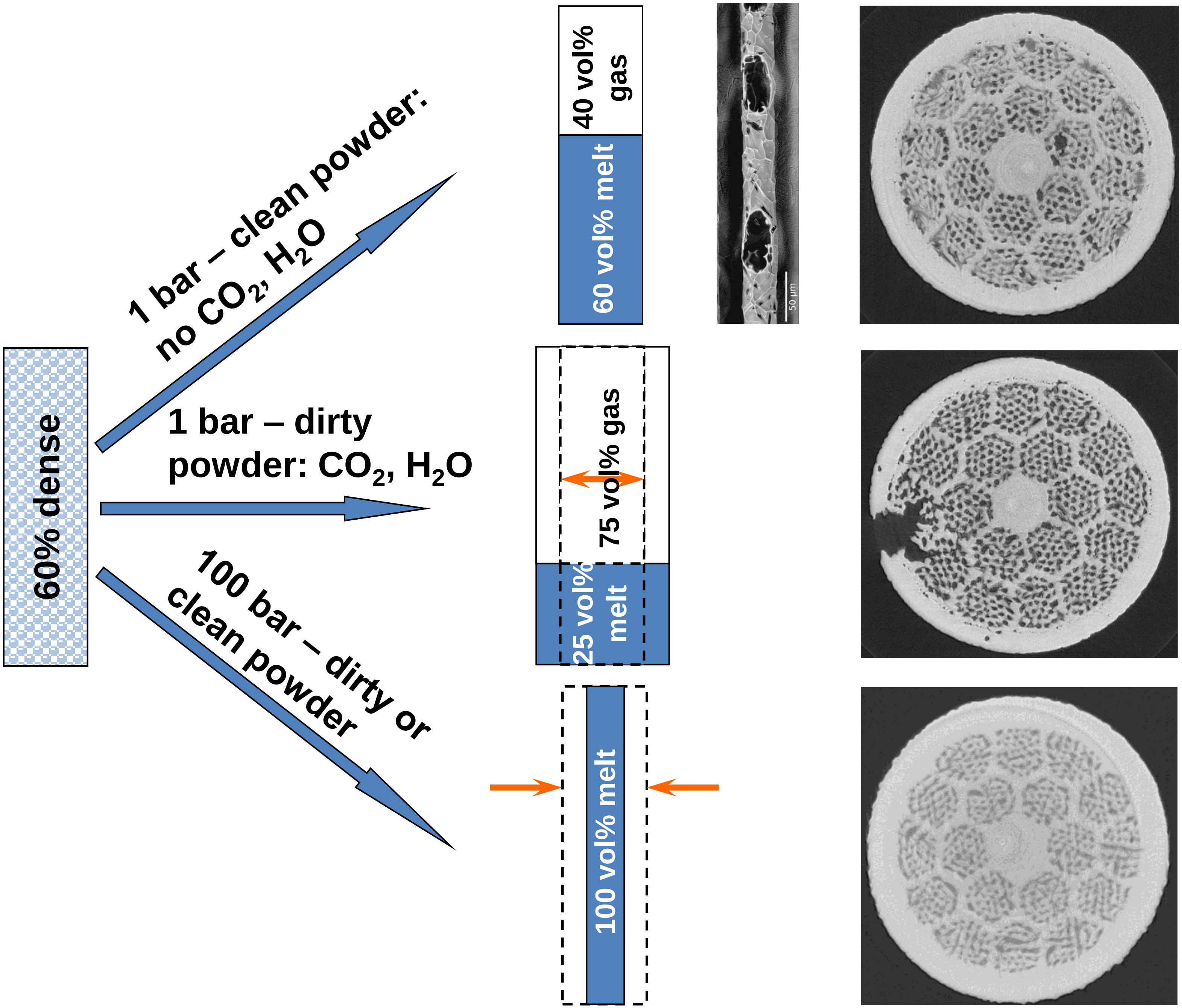
Best processing: apply overpressure to squeeze Ag so filament hole matches 2212 volume ⇒ 100% dense



OP decreases wire diameter



Scheuerlein



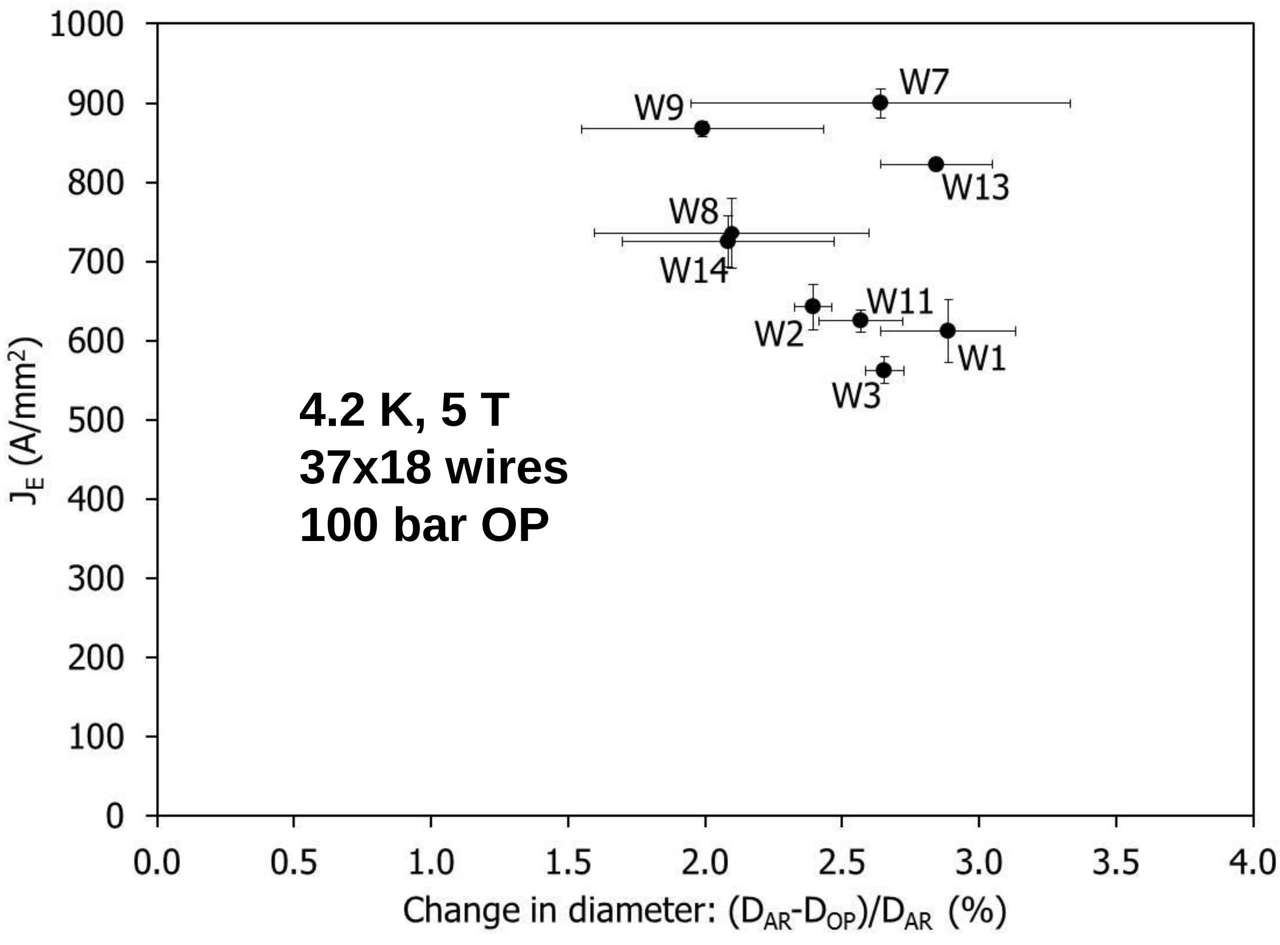
60% dense
1 bar – clean powder: no CO_2, H_2O
1 bar – dirty powder: CO_2, H_2O
100 bar – dirty or clean powder
40 vol% gas
60 vol% melt
50 µm
75 vol% gas
25 vol% melt
100 vol% melt

Questions driving our 2212 studies

In some cases we repeat earlier studies now using OP processed (dense) samples.

- **Is there any clear evidence that one powder is better than another?**
- **How uniform along the length does OP leave the samples?**
- **Do billets with less C and H require lower OP pressure?**
- **What is the optimum filament diameter (d_f) for optimum J_c?**
- **Can we do a better ODS on both Ag/Mg and Ag/Al than we are doing at present?**
- **How do we measure powder quality?**

1 - Q: Is there clear evidence that one powder is better than another?



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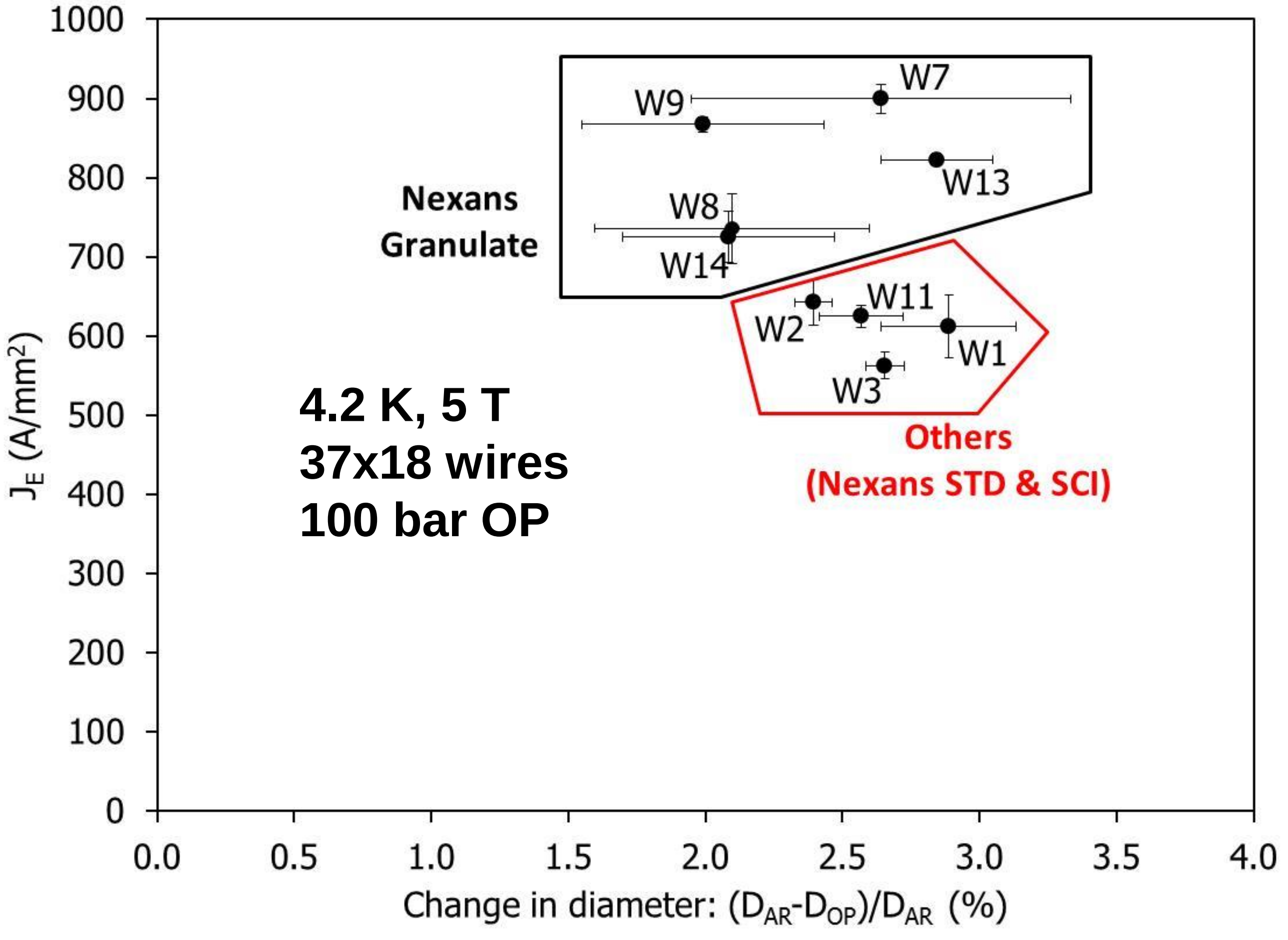
1 - Q: Is there clear evidence that one powder is better than another?

A: Nexans granulate gives highest J_E after OP processing.



Potential new powder sources

- **Metamateria**
- **nGimat**
- **SMS**

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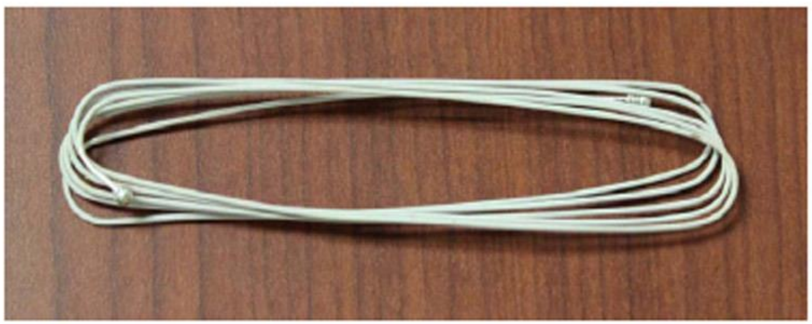
2 - Q: How uniform along the length does OP leave the samples?

A: I_c across 1 m sample shows $\pm$ 1.1% standard deviation

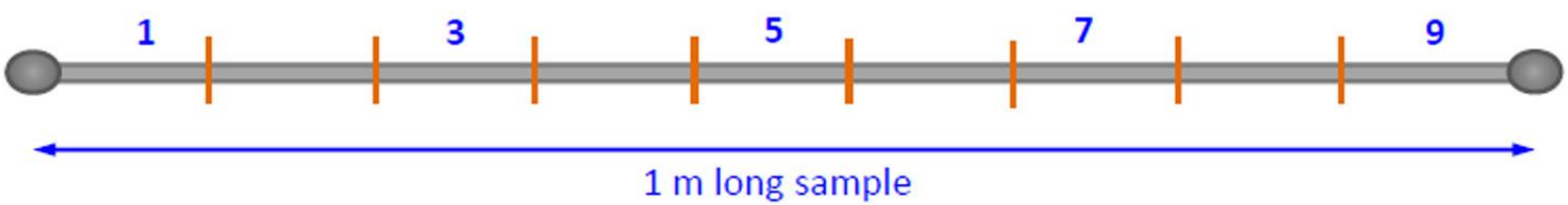
1 m long wire vs. 8 cm long witness with closed ends and processed at 100 atm

1 m long wire with insulation after 100 bar OP HT



Presented at MT-23 and EUCAS-2013

Section	1	3	5	7	9	witness
J_E [4.2K, 5T] (A/mm^2)	817.9	816.2	825.4	798.8	813.6	759.3



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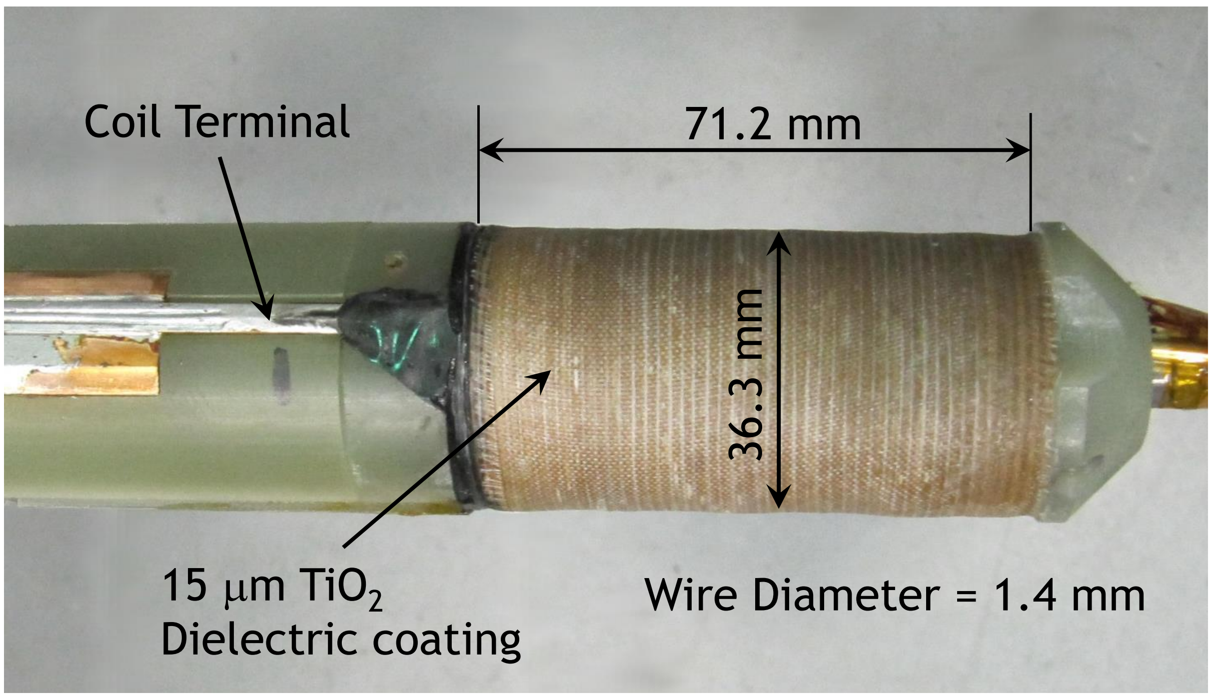
OPed 2212 coil at 10 bar - generated 2.6 T in 31.2 T background = 33.8 T

10 bar OP processing

- **Pressure was only high enough to prevent wire from expanding**
- **Did not compress Ag sheath and remove bubbles**
- **Insulation - ~15 μm thick TiO_2**

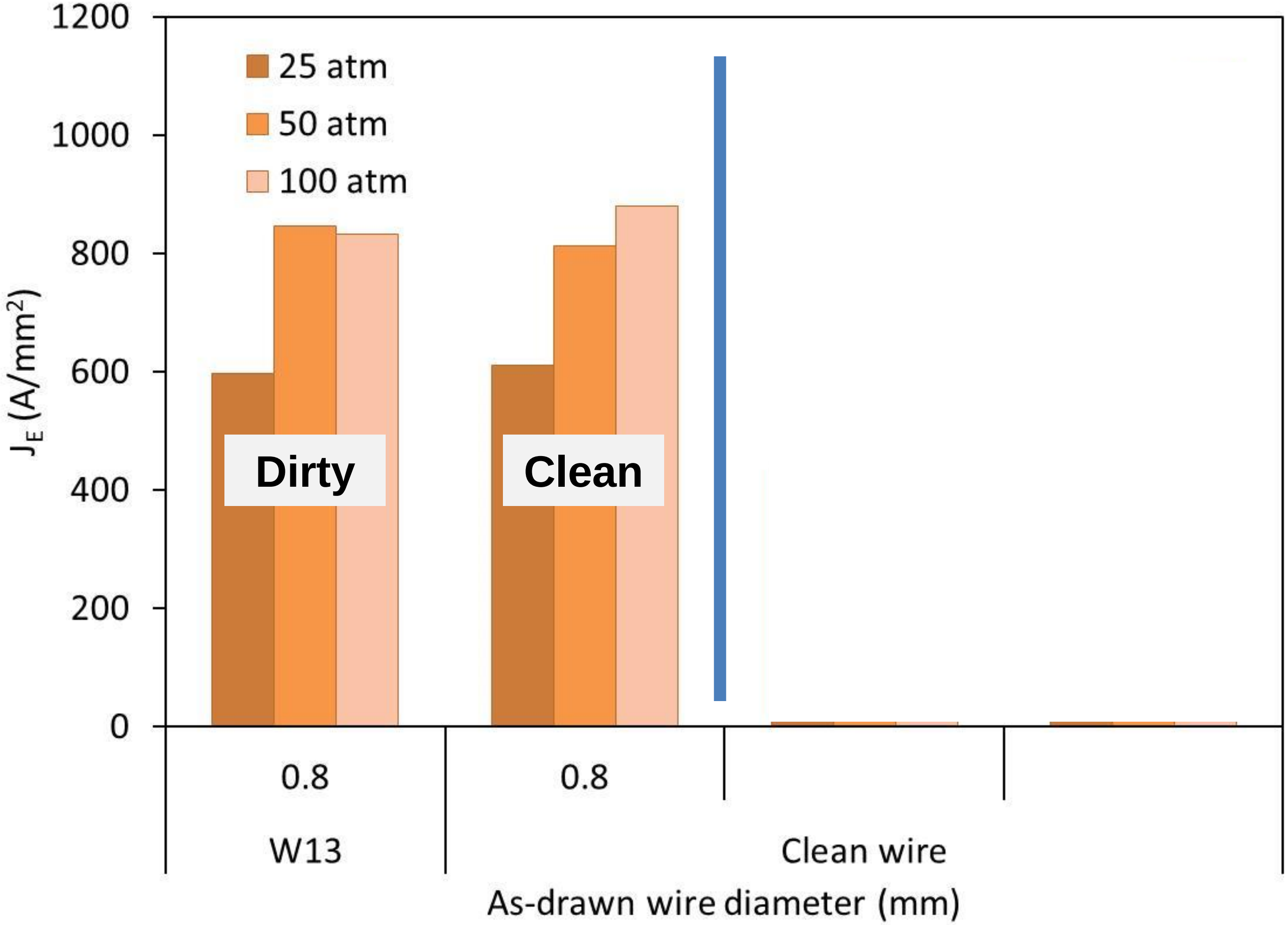


Wire dia. (mm):	1.40
nGimat Insulation (mm):	0.015
Turn-turn non-tightness (mm):	0.085
layer-layer tightness (mm):	-0.065
Inner Radius (a1) (mm):	7.25
Outer Radius (a2) (mm):	18.17
Height (2b) (mm):	71.21
Radial Layers (-):	8
Turnss/Layer (-):	47
Total turns (-):	376
Conductor Length (m):	30.03

Trociewitz

3 - Q: Do billets with less C and H require lower OP pressure?

A: No marked difference in densification at 25 bar between high and low C + H wire



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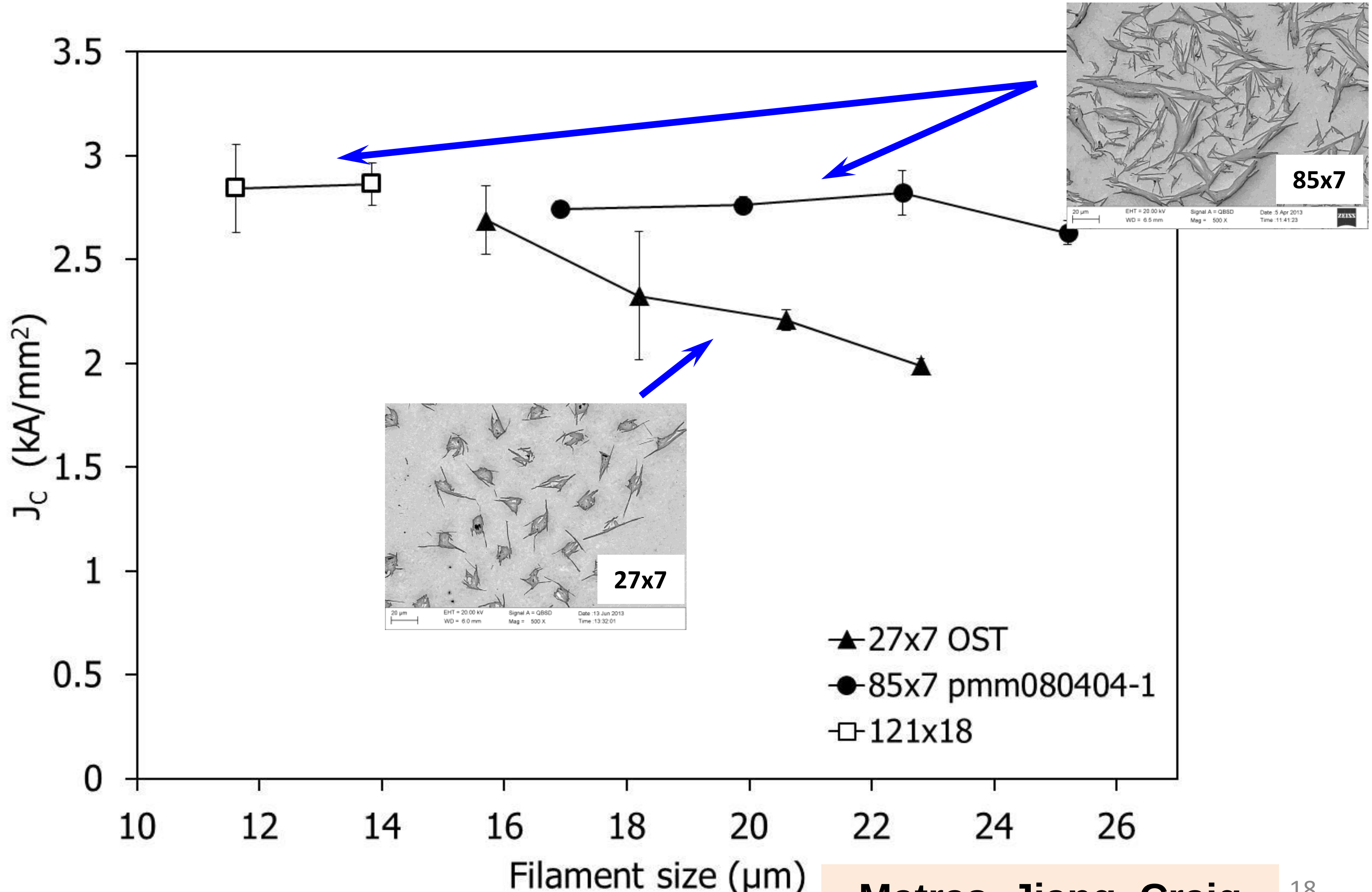
4 – Q: What is the optimum filament diameter (d_f) for optimum transport J_c?

A: J_c decreases with decreasing diam in 27x7 wire with discrete filaments. Inconclusive for wires with extensive bridging.



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5 – Q: How do we measure powder quality?
A: No specific answer yet.

- **Overall composition**
- **Phase assemblage**
- **Purity – no extra chemical species (Ba, Fe …)**
- **C and H (and S) content – gas formers**
- **Particle shape and size distribution**
- **The gold standard for powder quality is J_c and J_E in wire.**
  - **Build subscale, multifilamentary wires.**

Update on OP furnaces at FSU

Max pressure	Hot Zone		Type of heating	Comments
	Diameter	Length		
100-200 bar	25 mm	10 cm	Hot wall (external)	Will be used for PhD studies
25 bar	48 mm	10 cm	Hot wall (external)	In use
75-120 bar	45 mm	25 cm	Hot wall (external)	Starting to be used regularly
100 bar	170 mm	50 cm	Cold wall (internal)	Commissioning

100 bar OP furnace for large coils

Hot Zone:
16 cm ϕ, 50 cm

Furnace is being commissioned

- **Controlling uniform hot zone**
- **Maintaining total pressure in system**
- **Measuring and controlling pO_2 during heat treatment**
- **Mixing gases in chamber during heat treatment**

Summary

- Overpressure processing makes 2212 a viable candidate for accelerator magnets
  - Round wire geometry
  - $J_E(B, \theta)$
  - Flexible, multifilamentary architecture
  - Can be easily cabled
    - Rutherford
    - 6-on-1