Densificaction of $Bi_2Sr_2CaCu_2O_x$ round wires before wind and react overpressure (OP) processing

M. Matras*, J. Jiang, E. Hellstrom, U. Trociewitz, D. Larbalestier

Applied Superconductivity Center, National High Magnetic Field Laboratory, Tallahassee, USA

CERN, Geneva, Switzerland

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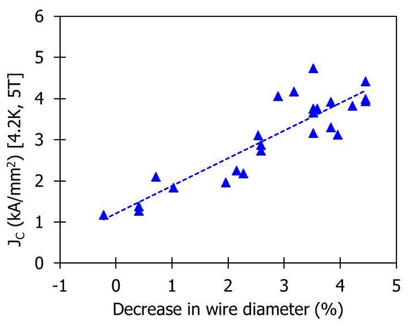
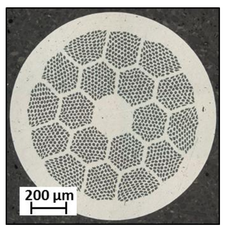
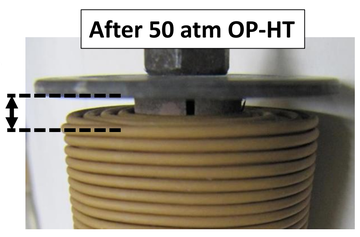
Motivation: 3.8 % wire shrinkage during coil OP processing

- To reach high J_C, $Bi_2Sr_2CaCu_2O_x$ (2212) has to be isostatically compressed with overpressure (OP) up to 50 atm during the partial-melt heat treatment (OP-HT) to reduce filament porosity. It results in about 3.8 % decrease in wire diameter.
- The decrease in wire diameter leads to a loose winding pack in solenoid magnets and may cause motion and deformation during the OP heat treatment.



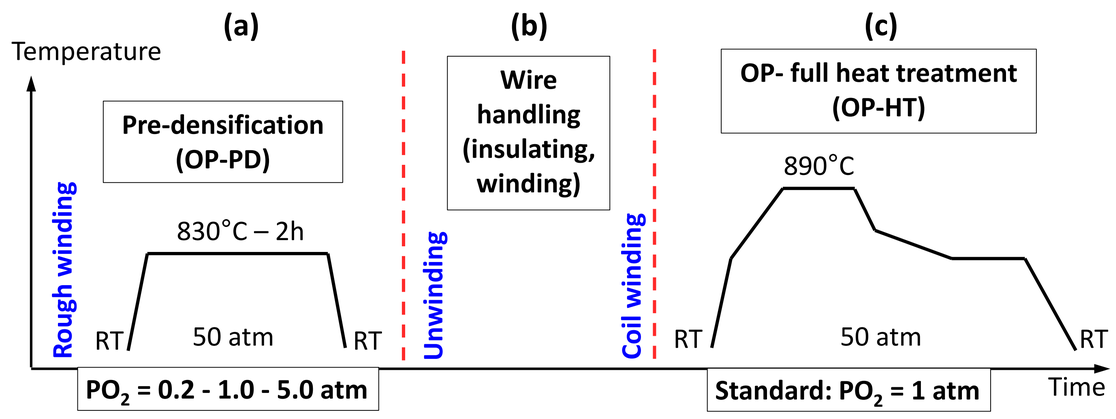




We describe and study a process to pre-densify the wire before winding and heat treat the coil with pressure. We found that:

- the process reduces wire diameter shrinkage to 0.7 % during OP-HT.
- Dense wire can be wound into 10 mm diameter coil with no 2212 leak after OP-HT and no I_C degradation
- I_C was increased by 22% by increasing PO_2 during OP-PD

Process to densify 2212 wire before coil winding



(a) OP-PD:

- 50 atm with PO_2 = 0.2, 1, or 5 atm
- Powder doesn't melt

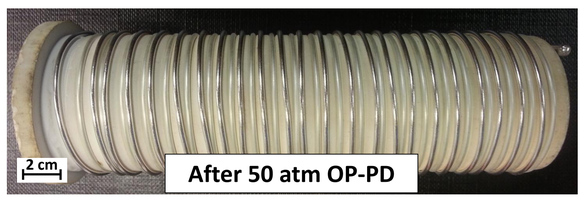
(b) Wire handling and coil winding:

- Diameter measurement of dense wire (winding over five 15 cm dia. pulleys)
- Dense wire was cut into four 50 cm sections and wound into 5, 10, 20 and 30 mm diameter coils.

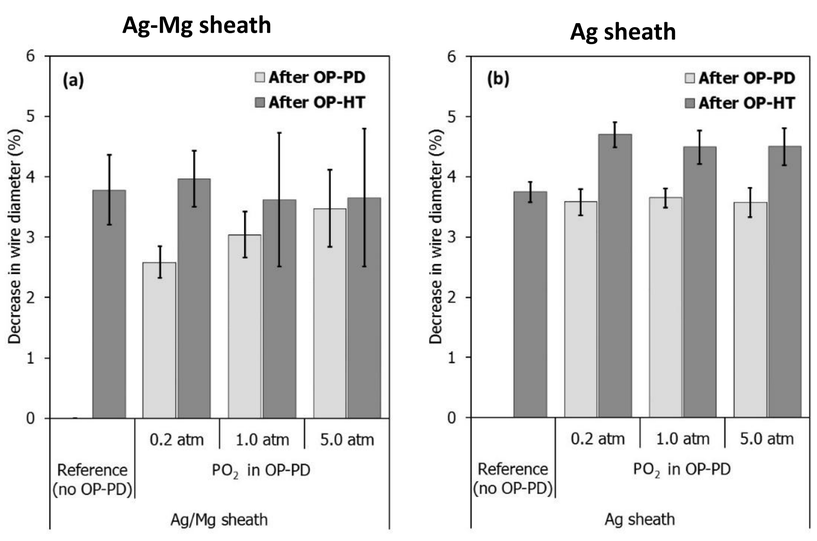
(c) OP-HT:

The coils of dense wire were sealed and OP-HT at 50 atm with PO_2 = 1 atm.

Ø 1.2 mm Ag-Mg and Ag-sheathed wire



Successful process: after OP-PD wire shrinks by 0.7 % in OP-HT



Change in wire diameter

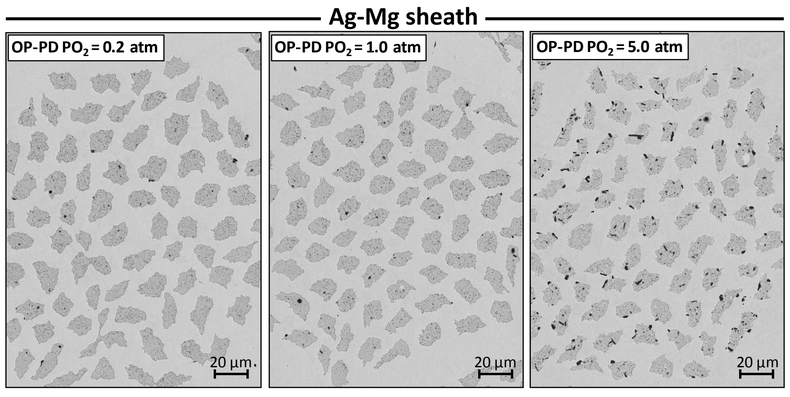
Ag-Mg sheathed wire:

- OP-PD: $\Delta Ø$ = -3.1 ± 0.6 %
- OP-HT: $\Delta Ø$ = -3.8 ± 1.0 %
- $\Delta Ø_{OP\text{-}PD}$-$\Delta Ø_{OP\text{-}HT}$ = 0.7 %

Ag sheathed wire:

- OP-PD: $\Delta Ø$ = -3.6 ± 0.2 %
- OP-HT: $\Delta Ø$ = -4.6 ± 0.3 %
- $\Delta Ø_{OP\text{-}PD}$-$\Delta Ø_{OP\text{-}HT}$ = 1.0 %

- 2212 decomposition is observed after OP-PD with PO_2 = 5 atm.
- Similar results are observed with Ag-sheathed wire



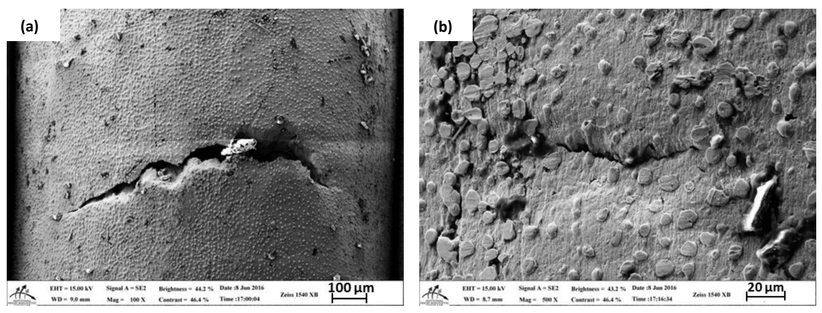
Dense wire winding ability depends on PO_2 during OP-PD

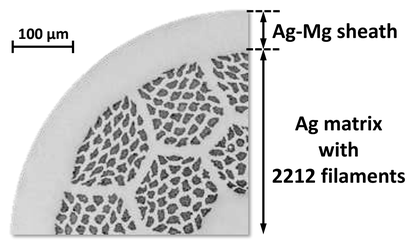
Dense Ag-Mg sheathed wire shows higher ductility with increasing PO_2 during OP-PD

Wire sheath	PO_2 for OP-PD	Can the OP-PD wire be wound into a coil? Coil diameter (mm)				Is the coil leak-free after OP-HT? Coil diameter (mm)			
		5	10	20	30	5	10	20	30
Ag-Mg	Reference (no OP-PD)	Y	Y	Y	Y	Y	Y	Y	Y
	0.2 atm	**No**	Y	Y	Y	*	Y	Y	?
	1.0 atm	**No**	Y	Y	Y	*	**No**	Y	Y
	5.0 atm	Y	Y	Y	Y	**No**	Y	Y	Y
Ag	Reference (no OP-PD)	Y	Y	Y	Y	Y	Y	Y	Y
	0.2 atm	Y	Y	Y	Y	Y	Y	Y	?
	1.0 atm	Y	Y	Y	Y	Y	Y	Y	Y
	5.0 atm	Y	Y	Y	Y	**No**	Y	Y	Y

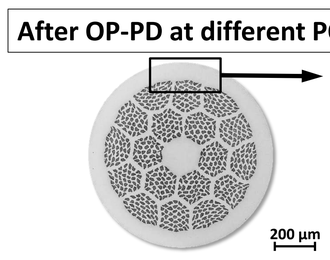
* Coils were not OP-HTed

Macro and micro cracks form in sheath of dense Ag-Mg 2212 wire OP-PD with 0.2 atm PO_2

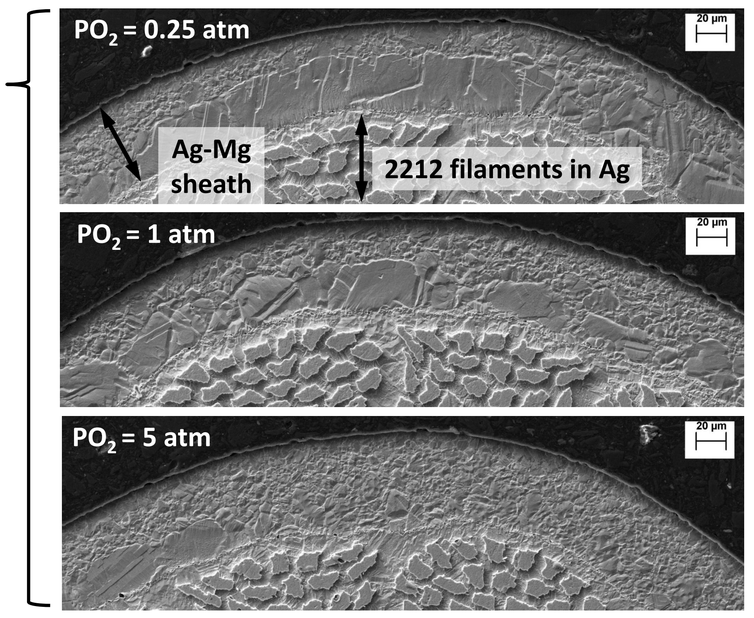




Increasing PO_2 during OP-PD decreases the grain size of the sheath



- Higher PO2 forms MgO particle before Ag grain growth occurs in the sheath.
- MgO pins the Ag grains and slows down their growth
- Higher pO2 may just pull Mg and MgO to the surface due to higher activity of O



Scanning electron microscope images of chemically etched wire cross section

No J_C degradation (+22 % J_C with PO_2 = 5 atm during OP-PD)

Ag-Mg sheathed wire

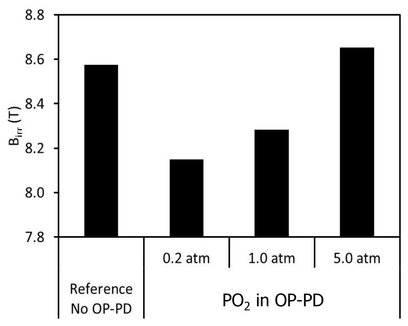
PO_2 during OP-PD	ΔJ_C (%)	
	Straight section	Curved section
0.2 atm	-31.7	-38.0
1.0 atm	2.1	-1.3
5.0 atm	22.0	22.8

PO_2 during OP-PD	J_C (A/mm²)	
	Straight section	Curved section
Reference (no OP-PD)	4303.5	4262.9
0.2 atm	2939.0	2667.7
1.0 atm	4394.9	4249.1
5.0 atm	5248.4	5282.9

Ag sheathed wire

PO_2 during OP-PD	ΔJ_C (%)	
	Straight section	Curved section
0.2 atm	-6.7	-8.3
1.0 atm	3.0	7.9
5.0 atm	9.3	3.7

PO_2 during OP-PD	J_C (A/mm²)	
	Straight section	Curved section
Reference (no OP-PD)	4219.8	4266.5
0.2 atm	3935.1	3870.1
1.0 atm	4346.6	4555.0
5.0 atm	4614.3	4376.2



- J_C of wires OP-PD with PO_2 = 1 atm are identical
- Ag-sheathed wire shows no clear dependence on PO_2 during OP-PD
- Ag-Mg-sheathed wire shows a strong increase in J_C with increasing PO_2
- Ag-Mg sheathed wire shows an increase in H_{irr} after 5 atm PO_2 OP-PD +OP-HT suggesting an increase in oxygen concentration in 2212

Conclusions

- Densification before winding process has been successfully demonstrated:
  - Decrease in wire diameter during OP-HT is reduced from 3.8 % to 0.7 %.
  - Dense wire can be wound into coils as small as 20 mm in diameter without cracking or 2212 leaks after OP-HT.
  - J_C is not decreased by the process (PO_2 = 1 atm)
- Ag-Mg-sheathed wire:
  - increasing PO_2 in the OP-PD increases J_C significantly (up to 22% with PO_2 = 5 atm compared to wire without OP-PD).
  - The increase in J_C with increasing PO_2 in OP-PD seems to be linked to the oxide dispersion strengthening mechanism (that varies with PO_2)
  - OP-PD with 5 atm PO_2 might be added to Ag-Mg sheathed 2212 coil OP processing since it to increased J_C by up to 22 % in these experiments.
- Ag-sheathed wire: Densification and J_C do not vary with PO_2 used in OP-PD.

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