Effect of sheath material and reaction overpressure on Ag extrusions into the TiO₂ insulation coating on Bi-2212 round wire

I. Hossain¹,², J. Jiang¹, M. Matras¹,², U. P. Trociewitz¹, J. Lu¹, F. Kametani¹,², D. Larbalestier¹,²,³, E. Hellstrom¹,²,³

¹National High Magnetic Field Laboratory, Florida State University, Tallahassee, Florida, USA.
²Materials Science and Engineering, Florida State University, Tallahassee, Florida, USA.
³Department of Mechanical Engineering, FAMU-FSU College of Engineering, Florida State University, Tallahassee, Florida, USA.

Our Motivation:
- TiO₂ has emerged as a suitable insulation material for Bi-2212 round wire.
- However, a large Bi-2212 test wire with TiO₂ insulation suffered severe electrical shorting after overpressure heat treatment (OPHT) due to frequent silver "extrusions" through gaps in the TiO₂.
- In this study, we tried to understand what caused the Ag extrusions and how we can prevent them.

What we did:
- Standard heat treatment at 50 bar overpressure (OPHT) or at 1 bar using Ag-0.2 wt% Mg alloy sheathed Bi-2212 wires (hereafter Ag(Mg) wire) was carried out to understand the role of pressure in Ag extrusions. 1 bar oxygen partial pressure (PO₂) was maintained in both cases.
- Standard OPHT of pure Ag sheathed Bi-2212 wires were also performed to investigate the effect of sheath material.
- Densification of Bi-2212 wires occur during OPHT. To understand what happens if we densify the wire before coating with TiO₂, we carried out a predensification (PD) heat treatment of Ag(Mg) wire at 50 bar (800°C for 2 hours, 1 bar PO₂) followed by insulation with TiO₂ and 50 bar OPHT (PD+OPHT).

Coil cross section

<table>
<thead>
<tr>
<th>Predensification heat treatment (at 50 bar)</th>
<th>Standard heat treatment (at 50 bar or 1 bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Time</td>
</tr>
<tr>
<td>800°C</td>
<td>2h</td>
</tr>
<tr>
<td>500°C</td>
<td>1h</td>
</tr>
</tbody>
</table>

Bi-2212 with TiO₂ insulation coating

- Wire diameter generally reduces by around 4% during OPHT. PD allows 80% of this shrinkage due to densification to occur before full OPHT.
- High angle annular dark field scanning transmission electron microscopy (HAADF-STEM) revealed the distribution of MgO in the Ag(Mg) wire after the usual full OPHT.

Things we observed using SEM and HAADF-STEM:

Effect of pressure: 50 bar OPHTed Ag(Mg) wire:
- Frequent Ag extrusions through the TiO₂ insulation layer was evident in 50 bar OPHTed Ag(Mg) wires.
- Ag extrusions were randomly distributed throughout the sheath-insulation interface. Their size and shape were uneven.

Effect of pressure: 1 bar processed Ag(Mg) wire:
- No extrusions through the insulation layer were found.

Effect of sheath material: 50 bar OPHTed pure Ag sheathed wire:
- Pure Ag sheathed wires were free from extrusions just like 1 bar processed Ag-Mg sheathed wire.

HAADF-STEM analysis: 50 bar OPHTed Ag(Mg) wire:
- Variation in the distribution of magnesium oxide (MgO) was found between different grains in the Ag(Mg) sheath.
- In general, the density of MgO decreases towards the wire surface.
- The Ag extrusions through the insulation were found to be devoid of MgO.

Effect of Predensification: 50 bar PD+OPHTed Ag(Mg) wire:
- No Ag extrusions into the gaps of TiO₂ were found in this wire but quasiperiodic undulations appeared at different places under the insulation layer.

Our conclusions:
- Ag extrusions occur only when Ag(Mg) wire undergoes the full heat treatment at substantial overpressure with TiO₂ insulation.
- Ag extrusions through the Ag(Mg) sheath are MgO-free, or at least lack MgO precipitates compared to the bulk of the sheath, suggesting that extrusion occurs due to local, heterogeneous deformation of the outer sheath under hydrostatic overpressure.

Acknowledgement: This work at the NHMFL was supported by the National Science Foundation Cooperative Agreement No. DMR-1157490 and the State of Florida and also by the US Department of Energy Office of High Energy Physics under grant DE-SC0010421. We are grateful to the members of ASC for their valuable input.

CEC/ICMC 2017, July 9-13, Madison, Wisconsin, USA