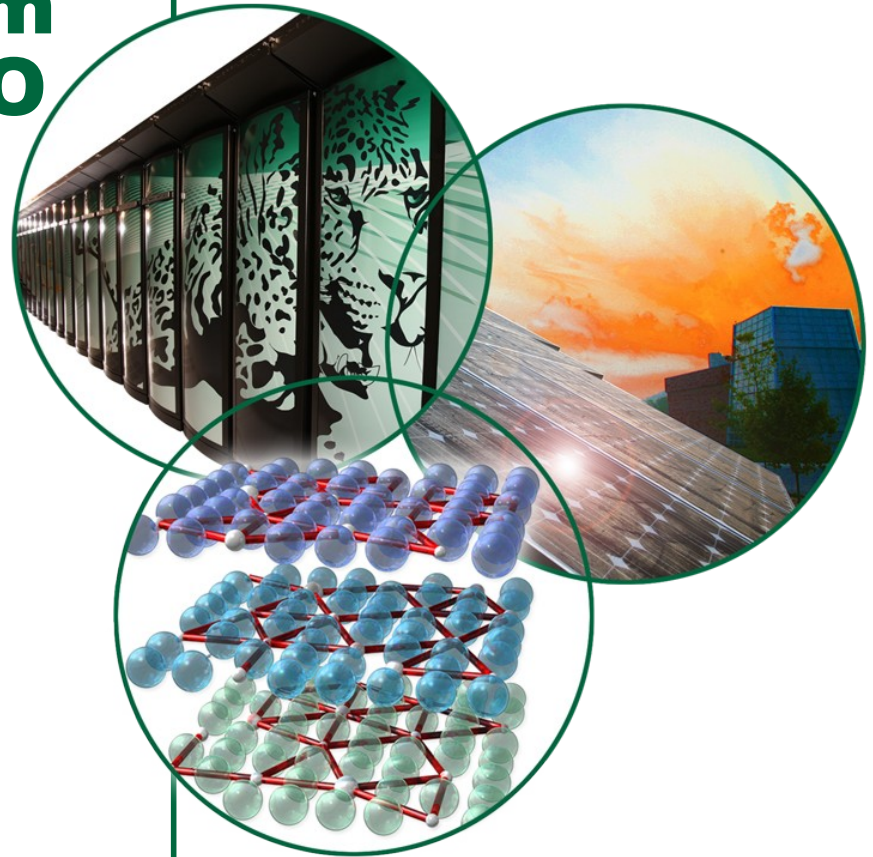


Voltage distribution and mechanical strength in splice joints made from as-manufactured YBCO coated conductors

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Motivation of work lies in need to understand factors that go into fabrication of coated conductor splices

- Splices will always be needed by either wire manufacturers to some degree, but more often by end-users of YBCO coated conductors
- To date, the systematic evaluation of coated conductor splices has not been performed with respect to electrical AND mechanical properties
- As part of base program in Conductor Design at ORNL, splice fabrication has been investigated with participation of both wire manufacturers and device manufacturers
 - Collaboration with NIST leverages their mechanical expertise to assure that final information on splice joint includes both electrical and mechanical properties

Outline of presentation

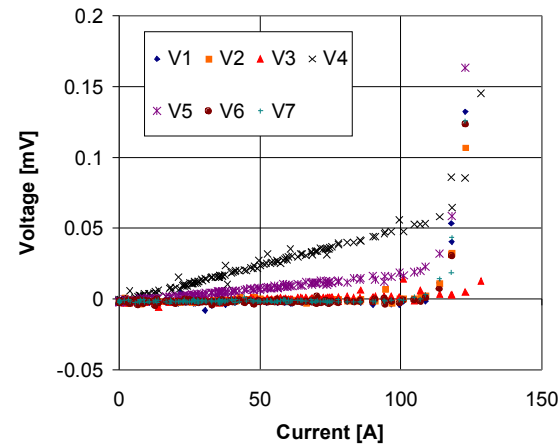
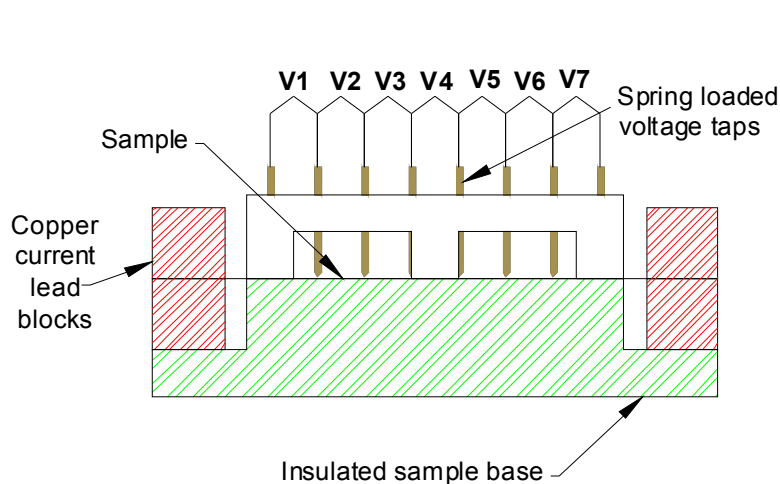
- **Experimental setup and procedures**
 - **Electrical characterization**
 - **Mechanical characterization**
- **Joint fabrication**
- **Results**
 - **Voltage distribution in splice joints**
 - **Splice joint resistance**
 - **Mechanical Integrity of splice joints**
- **Conclusions**

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Testing geared to characterization of splice joint while minimizing sample handling

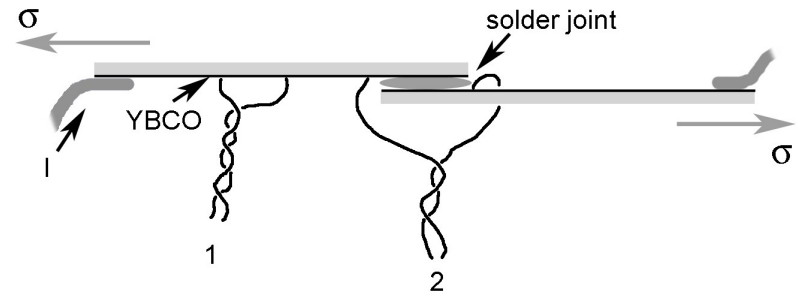
- Electrical measurement needed to characterize sample, but allow for mechanical measurement to be done on same sample
 - Copper blocks with indium foil for current contacts
 - Spring loaded pins
 - Minimize impact of additional soldering
 - Distribution voltage tap allows for measurement of splice resistance along length



Example of voltage profile along splice length in YBCO coated conductor splice

Mechanical testing involved comparison of joint resistance to conductor performance as a function of stress

- Within each group, a representative set was screened for mechanical properties.
- Two set of voltage contact monitor the change in the performance of the tape (1) and the splice joint resistance (2)
- Axial stress was increased stepwise and the sample was measured at (1) or (2) until a significant change occurred in either area



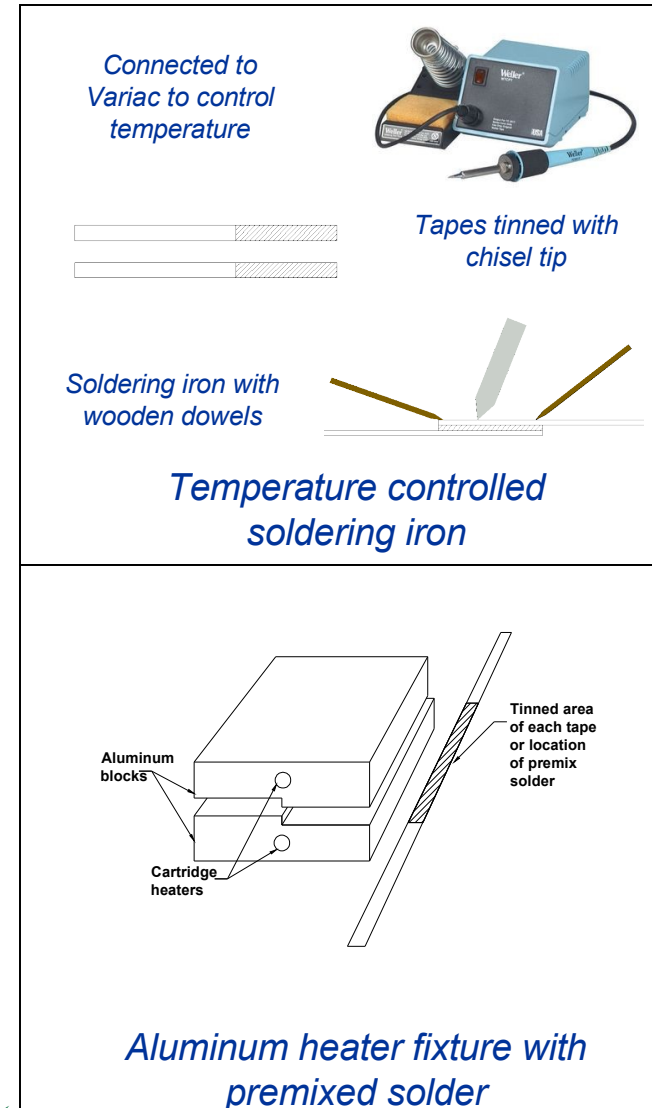
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Variations in solder fabrication investigated in 2.54-cm long YBCO coated conductor splice joints

Starting with wire manufacturer's recommendations, different aspects of splice joint fabrication were explored in commercially available YBCO coated conductor

- YBCO coated conductor (I_c between 80 A and 100 A)
 - AMSC : 344C – copper stabilizer (4.4-mm wide, 50 microns)
 - AMSC : 344B – brass stabilizer (4.4-mm wide, 110 microns)
 - AMSC : 348C – copper stabilizer (4.8-mm wide, 50 microns)
 - SP : SCS4050 – copper surround stabilizer (4.0-mm wide, 20 microns)
- Solder
 - Heated to 5-10°C above melting point
- Tape orientation
 - HTS-HTS (faces closest to YBCO soldered together)
 - HTS-Sub (face closest to YBCO soldered to face closest to substrate)
- Fabrication method



Solders used to determine whether they have impact on electrical or mechanical properties

Solder	Composition	Melting Point [°C]	Resistivity at 300 K [$\mu\Omega\text{-cm}$]	Shear Strength at 300 K [MPa]
In-Bi	67%Bi 33%In	109		
In-Sn	52%In 48%Sn	118	14.7	11.2
In	100%In	157	7.2	6.1
Sn-Pb-Bi	43%Sn 43%Pb 16%Bi	163	21.0	44.1
Sn-Ag	96.5%Sn 3.5%Ag	221	10.7	18.6

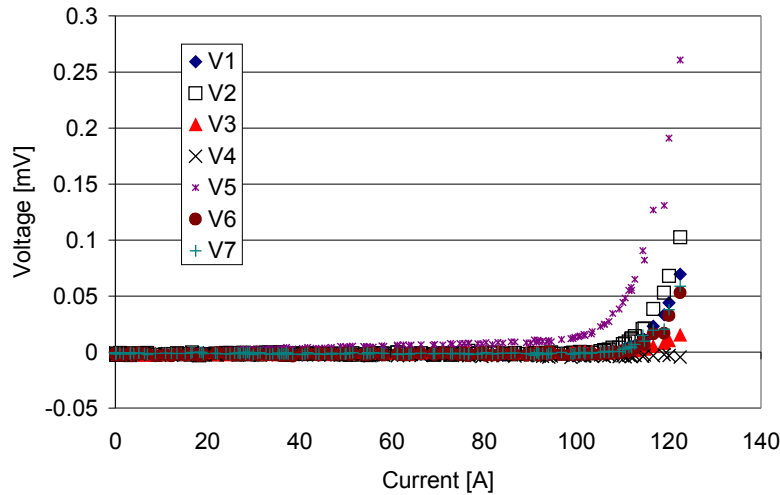
- **All splices made from first four solders**
- **Premixed solder used for Sn-Pb-Bi and Sn-Ag**
- **It should be noted that the shear strength of solders considerably less than the tensile strength of coated conductors**

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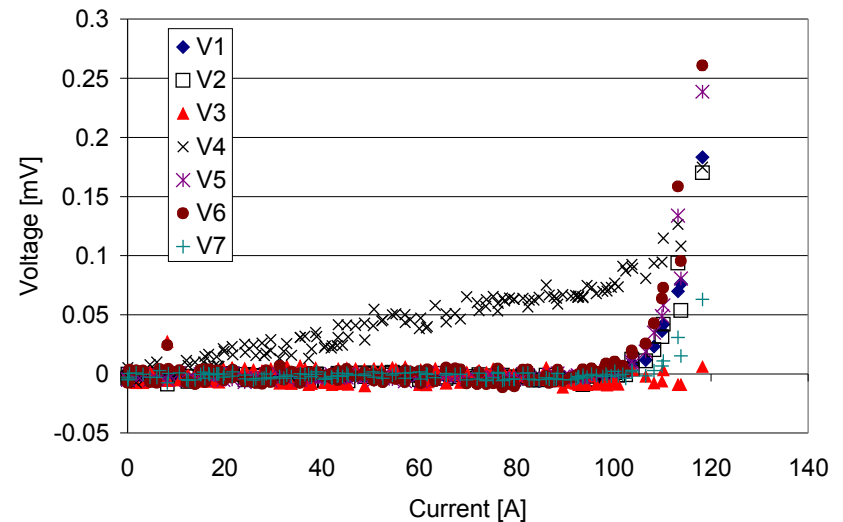
Only small percentage of splice joint length contributes to splice joint resistance

IS005



**4-mm wide SP SCS4050
In-Sn solder
HTS-HTS orientation**

SP1IS008



**4-mm wide SP SCS4050
In-Sn solder
HTS-Sub orientation**

Results are similar in AMSC splice joints

Splice joint resistance impacted by tape orientation and stabilization in AMSC tapes

- **Tape orientation causes a significant rise in splice joint resistance**
- **Stabilization material increases resistance**
- **Fabrication method leads to similar joint resistance**

Coated conductor	Stabilization material and thickness	Joint orientation	Solder	Joint fabrication	Average splice joint resistance [$\mu\Omega$]	Standard deviation in resistance [$\mu\Omega$]
348 AMSC	Copper; 50 μm	HTS-HTS	InSn	Soldering iron	0.063	0.022
		HTS-Sub	InSn	Soldering iron	1.043	0.284
		HTS-HTS	SnPbBi	Soldering iron	0.061	0.030
		HTS-Sub	SnPbBi	Soldering iron	1.010	0.308
344 AMSC	Copper; 50 μm	HTS-HTS	InBi	Soldering iron	0.170	0.086
344 AMSC	Brass; 110 μm	HTS-HTS	SnPbBi	Heater block	0.153	0.029
		HTS-Sub	SnPbBi	Heater block	2.723	0.291
		HTS-HTS	InSn	Soldering iron	0.182	0.025
		HTS-HTS	In	Soldering iron	0.198	0.061
		HTS-HTS	InBi	Soldering iron	0.625	0.576

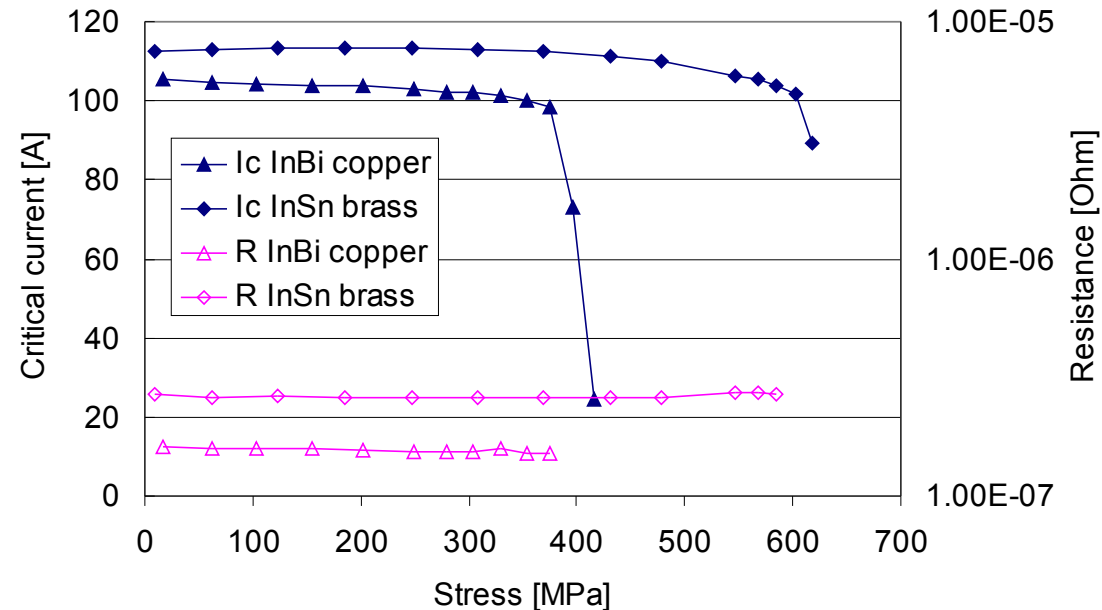
Similar behavior observed in splice joints made with SuperPower materials

- Again tape orientation causes a significant rise in splice joint resistance
- Overall resistance lower than AMSC tape, but the stabilization thickness is smaller
- With respect to fabrication, resistance lower and smaller standard deviation

Coated conductor	Stabilization material and thickness	Joint orientation	Solder	Joint fabrication	Average splice joint resistance [$\mu\Omega$]	Standard deviation in resistance [$\mu\Omega$]
SCS4050	Copper; 20 μm	HTS-HTS	In-Sn	Soldering iron	0.079	0.057
		HTS-Sub	In-Sn	Soldering iron	0.727	0.060
		HTS-HTS	Sn-Ag	Soldering iron	0.058	0.028
		HTS-Sub	Sn-Ag	Soldering iron	0.526	0.110
		HTS-HTS	Sn-Ag	Heater block	0.026	0.005

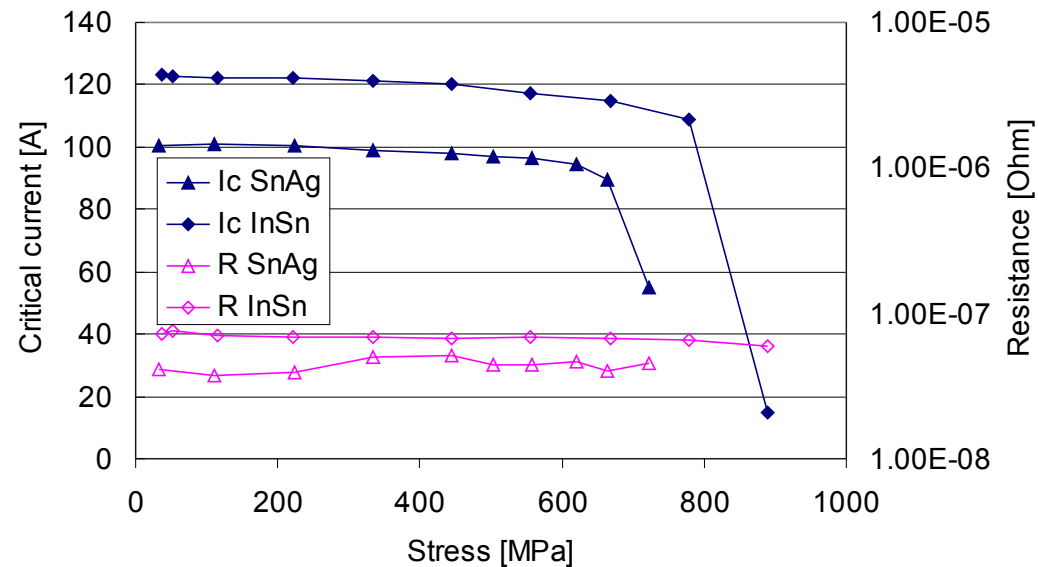
Splice joint resistance showed no change in splice joints fabricated with AMSC conductors

- Splice joint characterized
 - InBi solder on copper laminated 344 superconductor
 - InSn solder on brass laminated 344 superconductor
- No significant change in resistance observed
- Difference in performance of splice related to the change in stabilization material



Similar effect shown in splice joints fabricated with SuperPower conductors

- Like AMSC splice joints, no change in splice joint resistance
- On samples with premixed Sn-Ag solder, no change in mechanical performance observed.



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Conclusions

- **Low resistance splices with high mechanical strength fabricated**
 - Resistance and mechanical strength not dependent on type of solder used on samples tested to date.
- **Some dependence on splice joint resistance with respect to**
 - Tape orientation
 - Stabilization thickness and material
- **Use of premixed solder showed slight improve splice joint resistance with reduction in number of steps of fabrication**
- **Additional work being done on integrating lessons learned to develop field splice technique**