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C-axis Tensile Strength of 2G HTS

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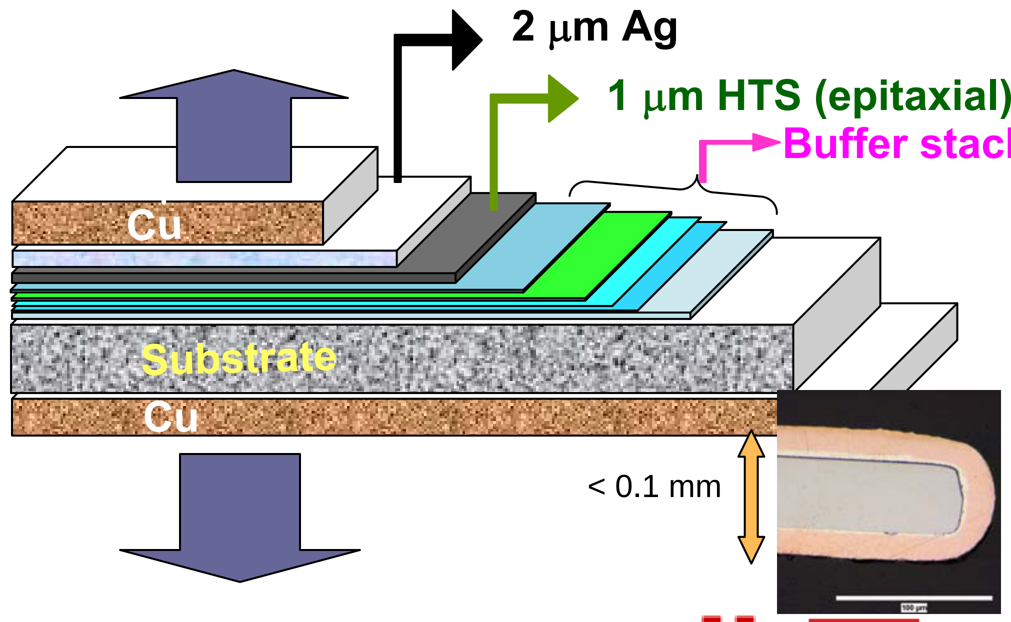
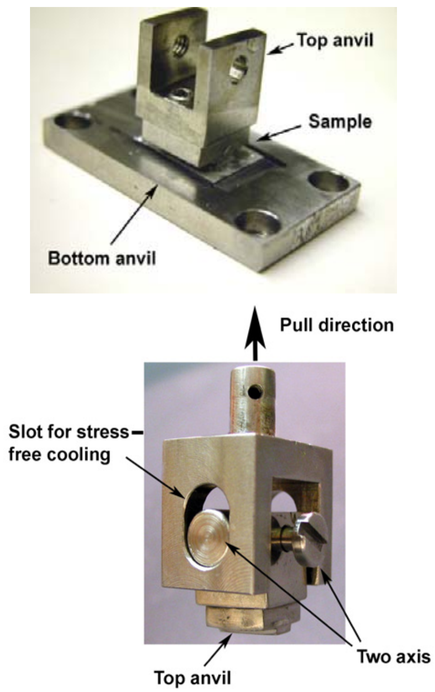
Origin of c-axis tensile stress in large-scale applications

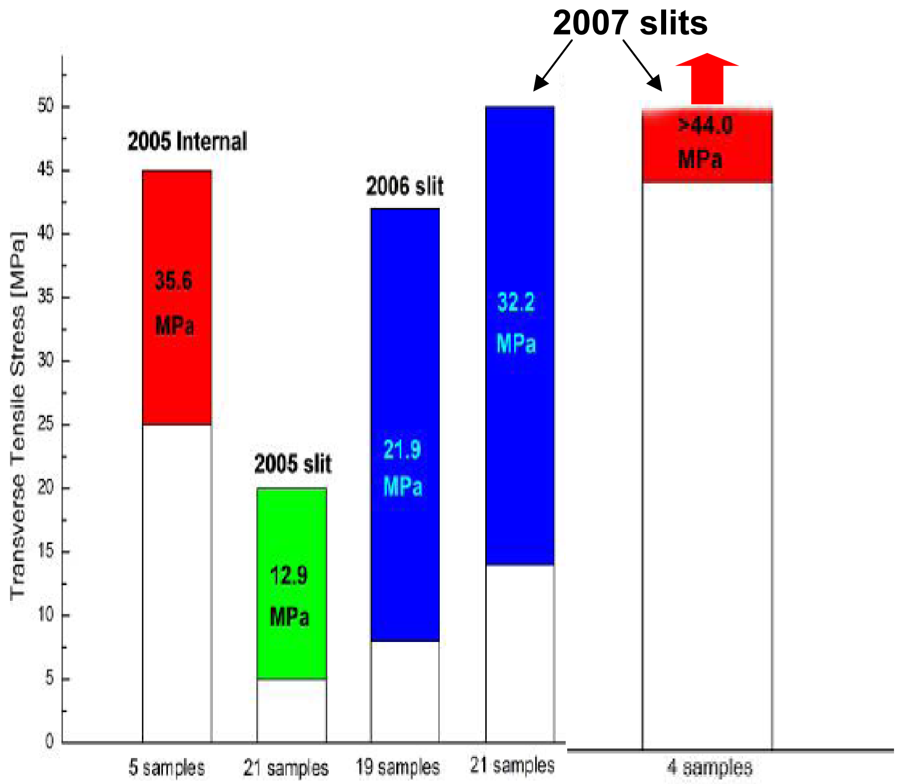
- Among all real-world applications in which 2G HTS wire will be eventually used as the key material to achieve high performance and energy efficiency, coil-based applications require 2G HTS to withstand c-axis tensile stress due to multiple origins:
  - Mismatch in thermal expansion: substrate vs. ceramic layer vs. Cu
  - Radial forces due current – field interaction
  - High-speed rotational forces
  - Coil fabrication related reasons
- Those stresses are estimated to be at the level of a few to a few tens of MPa. More accurate modeling needs to be developed



MOCVD/IBAD-MgO based 2G HTS show c-axis tensile strength up to 50+ MPa



N. Cheggour, D. van der Laan, C. Clickner, and J. Ekin
2007 DOE Peer Review



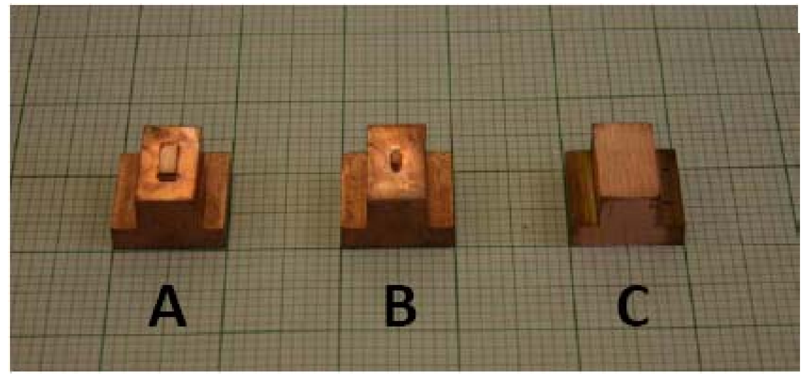
NIST developed a c-axis pulling test method and systematically tested MOCVD/IBAD-MgO based 2G HTS showing year-to-year improvement in c-axis tensile strength:

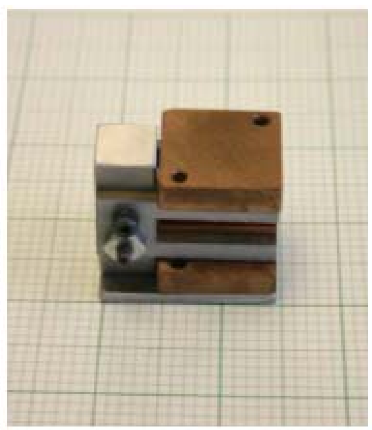
- High c-axis tensile strength above 50 MPa – bonding in multilayer interfaces can be very strong
- Reason for the spreading in the range from 15 MPa to 50+MPa unclear: error in test or non-uniformity in the conductor?

Alignment fixtures developed and anvil configuration explored to improve reproducibility

Several anvil configurations explored to generate proper failures

- Anvil A: 40 mm2
- Anvil B: 9.14 mm^2 (HTS)
- Anvil C: 288 mm^2 (Substrate)



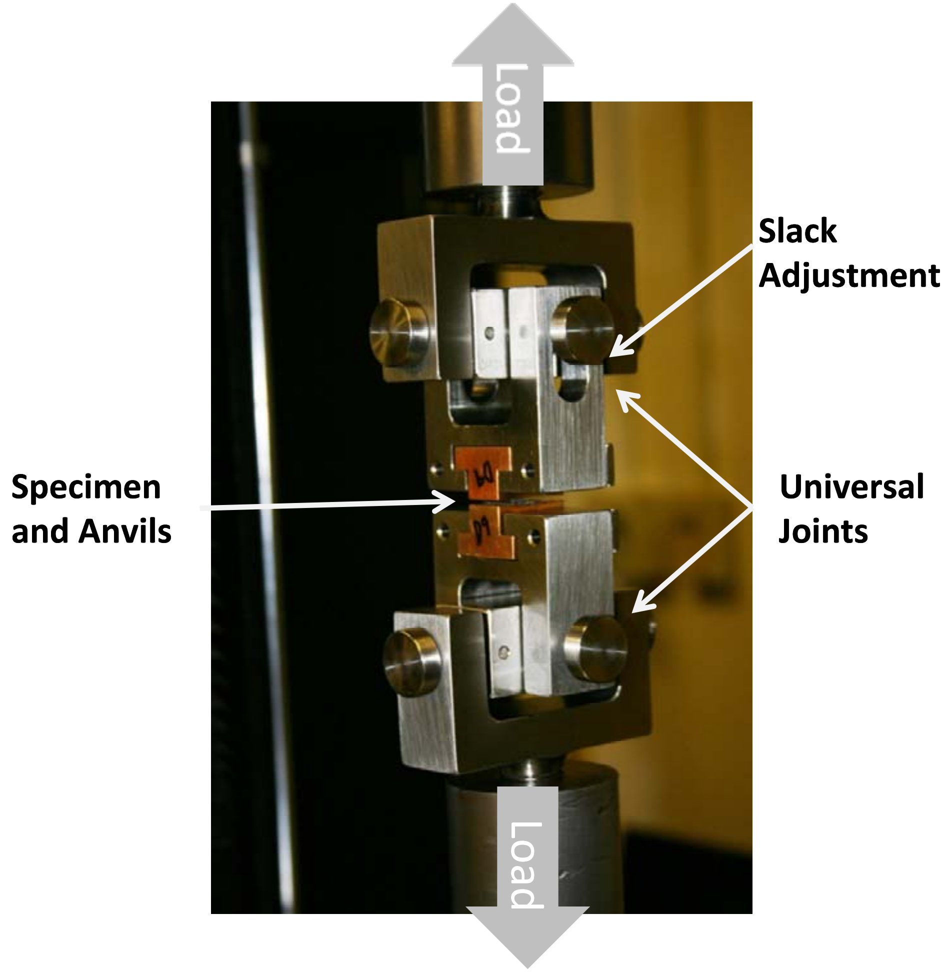


Alignment fixtures developed

- Ensure anvil location on tape
- Ensure anvils are square
- Speeds sample preparation

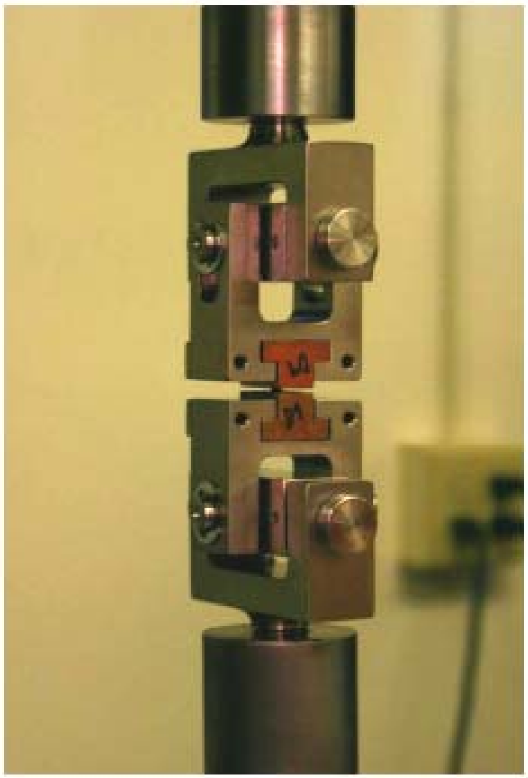
NIST c-axis pulling test method modified to improve performance and ease of use

- Dual universal joints
  - Eliminates all bending
  - Ensures load is only normal to tape adjustment
- Slack adjustment
  - Stress free specimen mounting
- Replaceable specimen anvils
  - Ease of mounting in test fixtures
  - Minimizes disposable parts
  - Simplifies specimen preparation



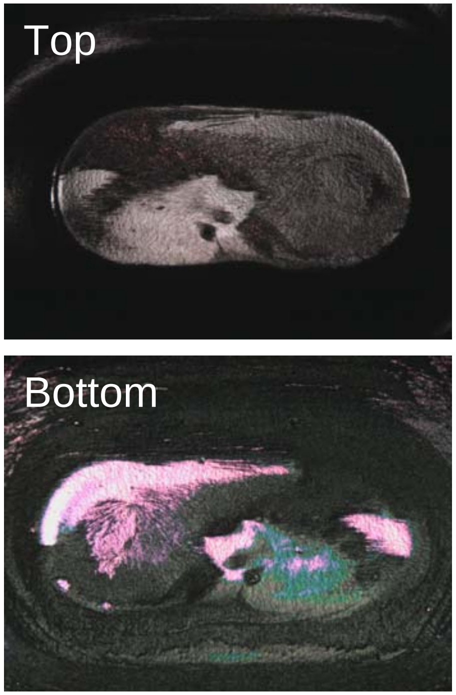
0.25 mm/min load rate

New configuration accommodates testing at room temperature and at 77 K



Room temperature configuration

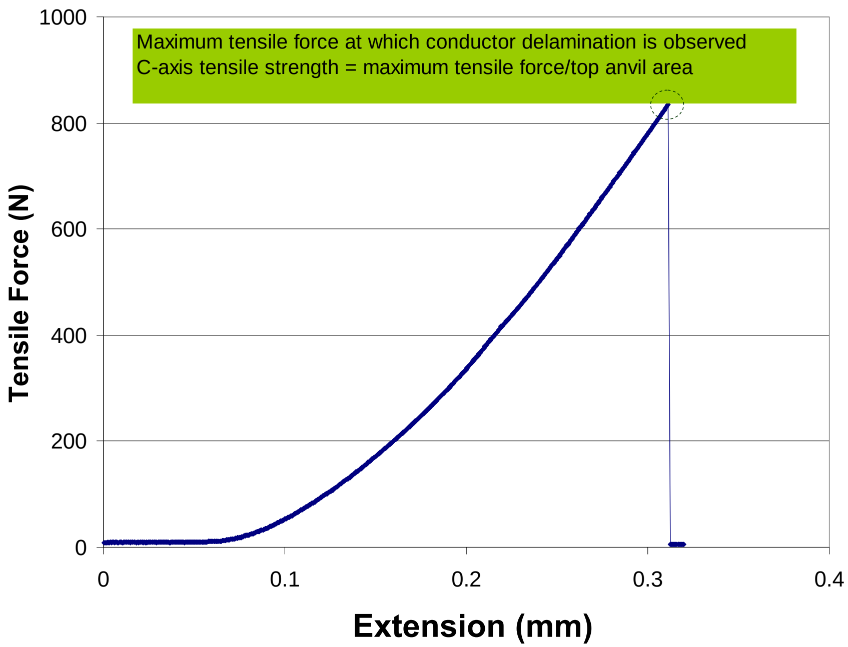
Cryogenic temperature configuration

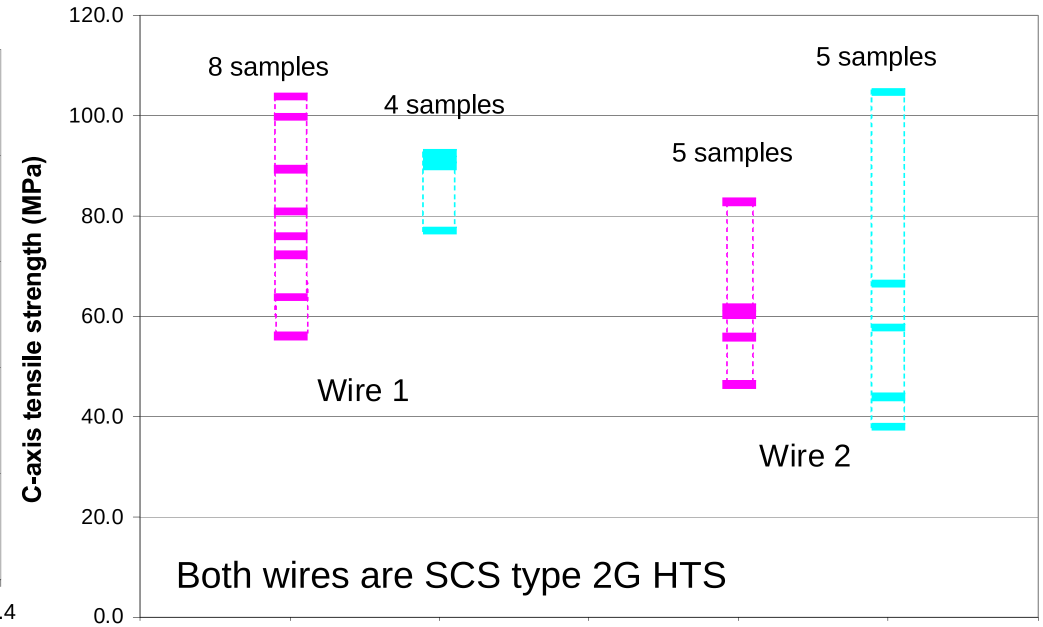


Typical delamination mode:

- Upper part of the multilayer structure including HTS attached to top anvil
- Lower part of the multilayer structure incuding substrate attached to bottom anvil

C-axis tensile stress test results by anvil method





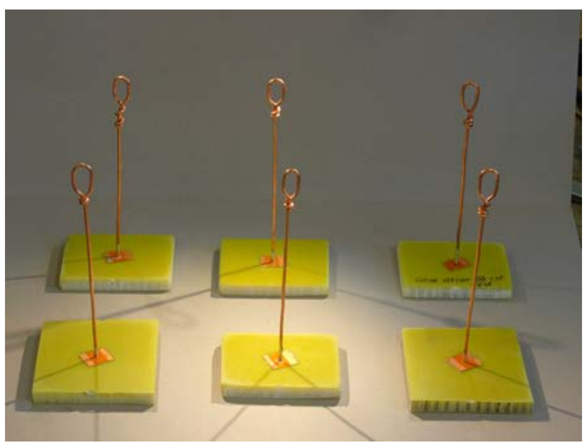
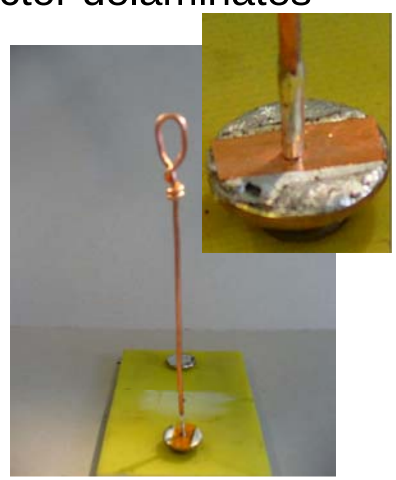
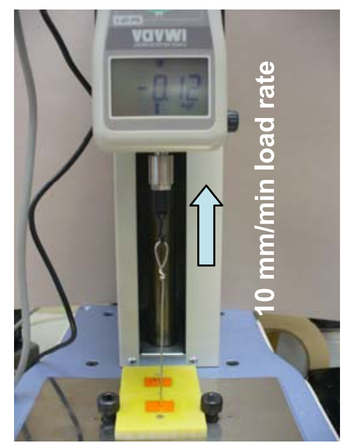
C-axis tensile stress measurement value shows some variation within each wire

- Wire 1: 56 - 104 MPa @ Room Temp, 77-93 MPa at 77 K
- Wire 2: 46 - 83 MPa @ Room temp; 38 - 105 MPa

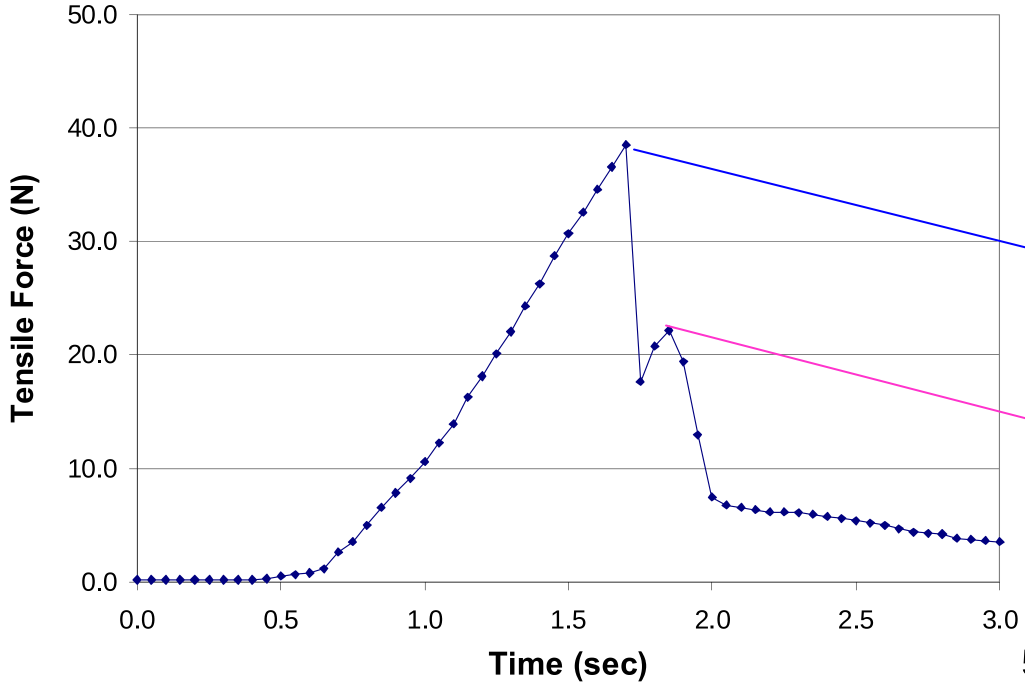
No systematic difference between c-axis stress values at room temp and 77 K

An alternative c-axis tensile test method also developed to measure strength at small regions

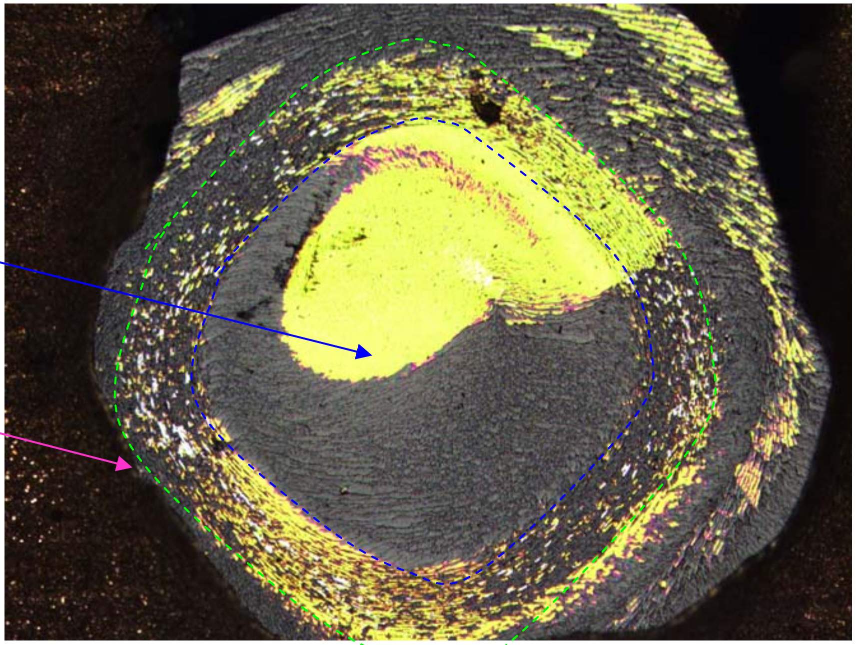
- Solder-pin method - test procedure developed
  - Place a Kapton tape mask with a pre-cut hole in size of about 1-1.5 mm by 1-1.5 mm on the cleaned wire surface. Solder a solder pin in size of 1.5 mm in diameter normal to HTS side of the wire surface, and then glue or solder the substrate side of the wire to a bottom plate.
  - Mount the sample assembly to a commercial tensile tester, applied tensile force, record the load curve and observe the delamination situation
  - Examine the delamination region with OM, record the size of the debond zone and calculate the tensile stress at which conductor delaminates

Test result by solder-pin method



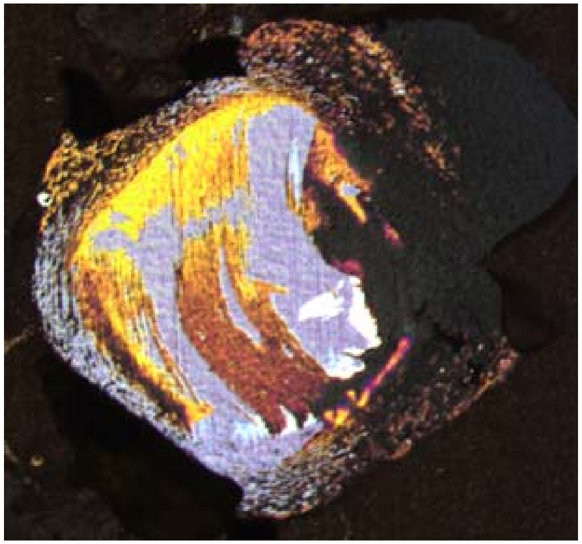
Typical load curve on a SCS4050 with 20 μm x 2 copper



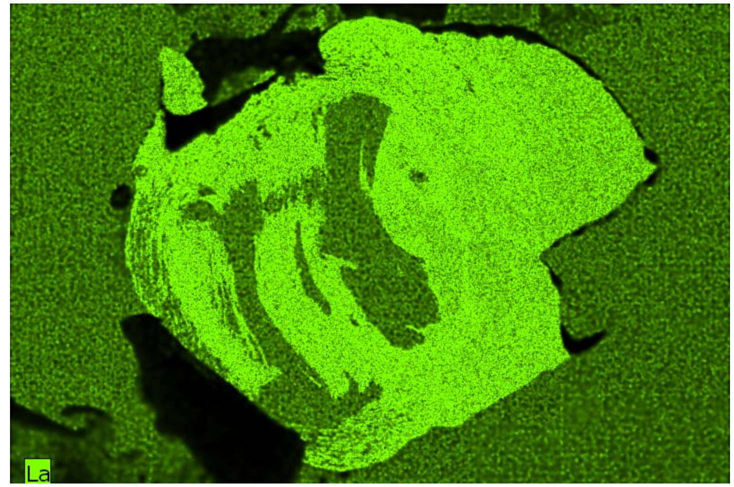
5 x Optical Image of the lower part of the multiplayer structure after pull test clearly reveals a debond zone surrounded by a dissipation zone

- Local property at small region and small tensile force
- Informative features observed in load curve and the image of the delaminated region:
  - 1st peak load correspond to the debond of the multilayer structure; c-axis tensile strength can be derived using the debond zone area
  - 2nd peak load correspond to the tear off of top Cu stabilizer layer

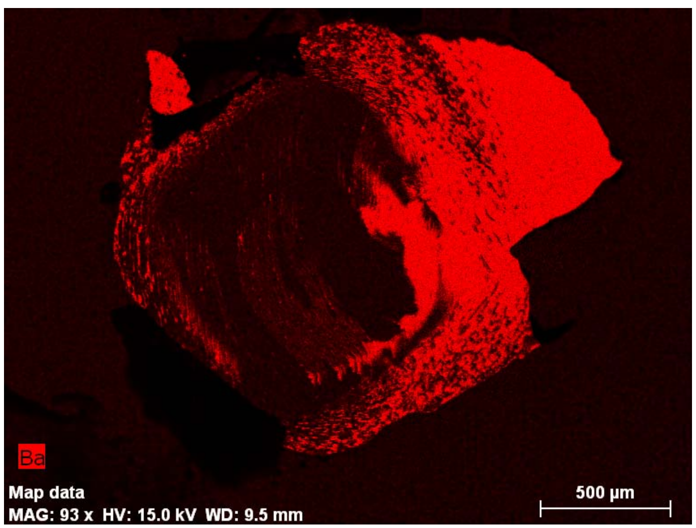
SEM-EDS study to identify delaminated interface



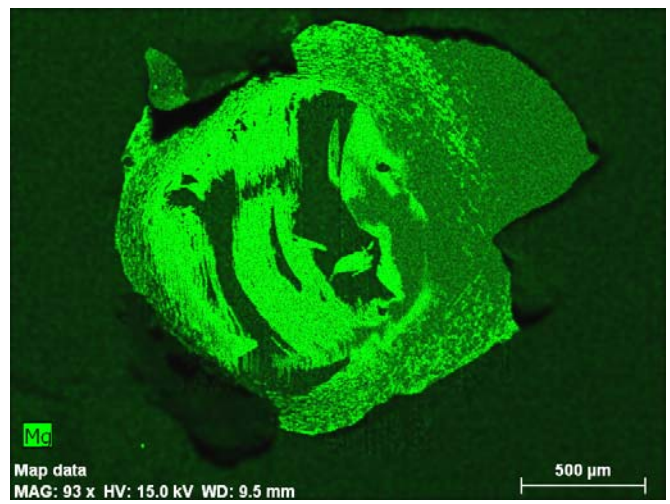
OM photo of delaminated region



EDS mapping - La

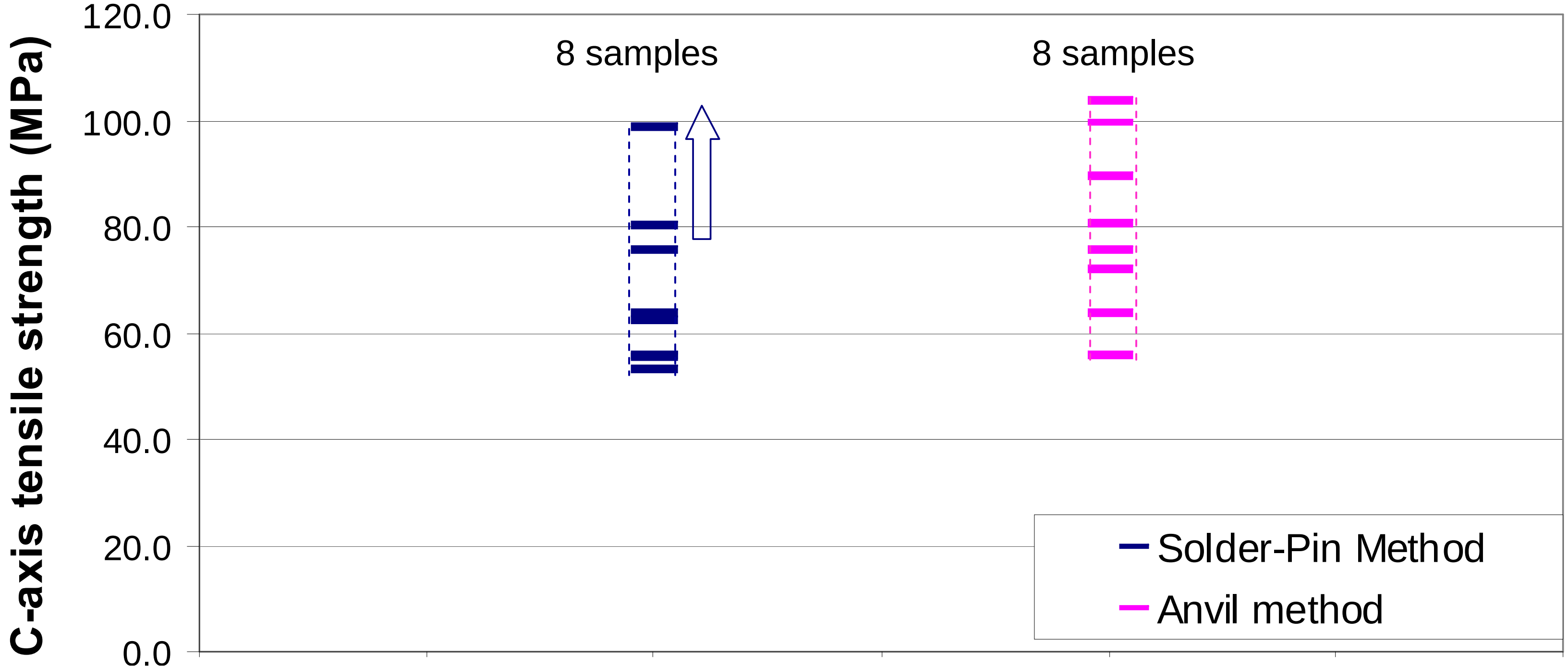


EDS mapping - Ba



EDS mapping - Mg

Test results on Wire 1 from two methods



C-axis tensile strength above 50 MPa and similar range of data points obtained from solder-pin method with test area of 1-2 mm^2 and anvil method with test area of 9-10 mm^2

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Conclusion

- Two methods of testing the c-axis tensile strength of 2G HTS are presented. The test results based on both methods show that there is some variation in c-axis tensile strength in 2G HTS while it can be as high as 100+ MPa
- The delamination regions from the c-axis pulling test reveal very informative features including debond zone and dissipation zone
- Interfaces at which delamination occurs at the peak load are exposed in the debond zone. Identifying those interface using OM and SEM-EDS and investigating their microstructure may help to find the reason for the variation of c-axis tensile strength in 2G HTS