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Developments in Fuel Fabrication at CNL



IAEA Technical Meeting on Advances in Fuel
Fabrication Technologies

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Ike Dimayuga, Lin Xiao
Canadian Nuclear Laboratories
Chalk River, Canada



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Chalk River Laboratories: largest science & technology lab in Canada

- 9,000 acres in size, 200 acres lab complex
- 15 nuclear facilities, 70 major buildings
- 3,000 employees



Currently undertaking major rebuild and refurbishment to modernize the site.

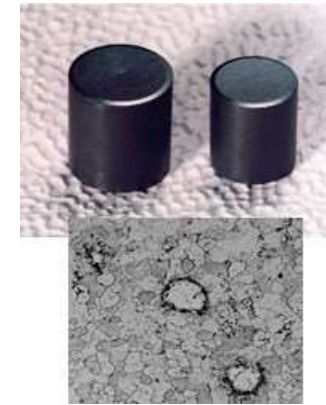
Outline

- Introduction
- Novel materials and techniques for fuel fabrication
- Advanced cladding alloys
- Direction for future work
- Summary



Nuclear Fuel Development at CNL

- Canada's nuclear fuel S&T, including fabrication, out-reactor testing, irradiation testing, and post irradiation examination reside at CNL.
- Fuel development include U, MOX, Th, U-Mo, U-Si for use in Canadian research and power reactors.
- Leveraging extensive experience to work on advanced fuels for SMRs.



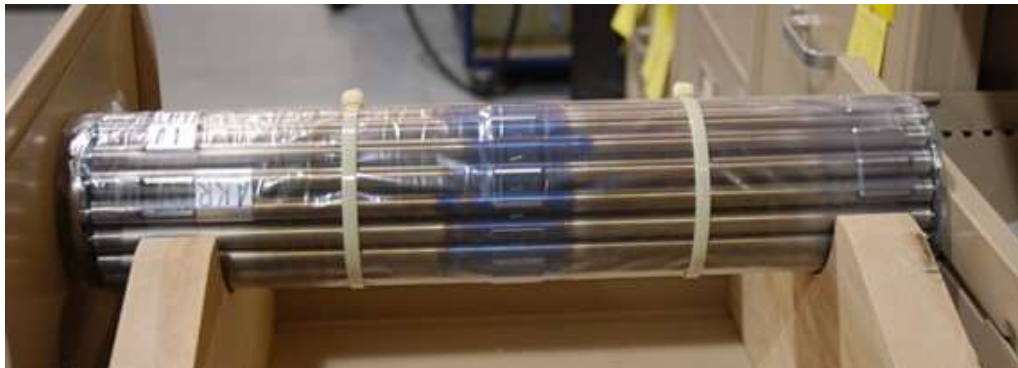
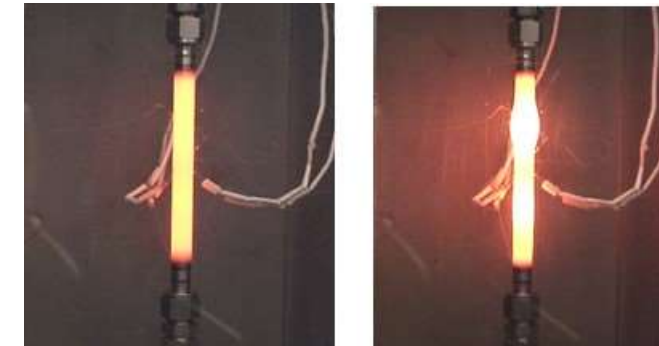
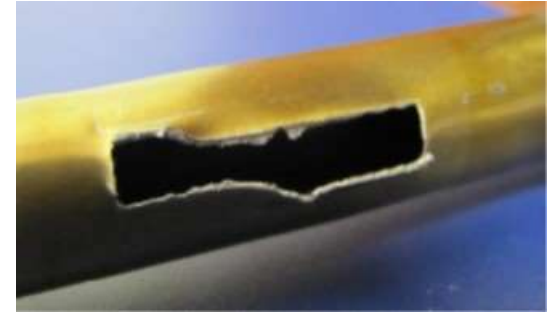
New Filler Material for Brazing

- Beryllium (Be) is currently used as the filler metal for brazing appendages on the sheaths of CANDU fuel elements.
- Because of its toxicity, occupational exposure limits for Be were reduced to very low levels (by up to 40 times).
- To ensure that:
 - continuation of fuel supply remains unaffected, and
 - fuel fabrication processes continue to comply with health and safety standards.
- ✓ A COG project was launched to perform out- and in-reactor testing of candidate materials.



New Filler Material for Brazing

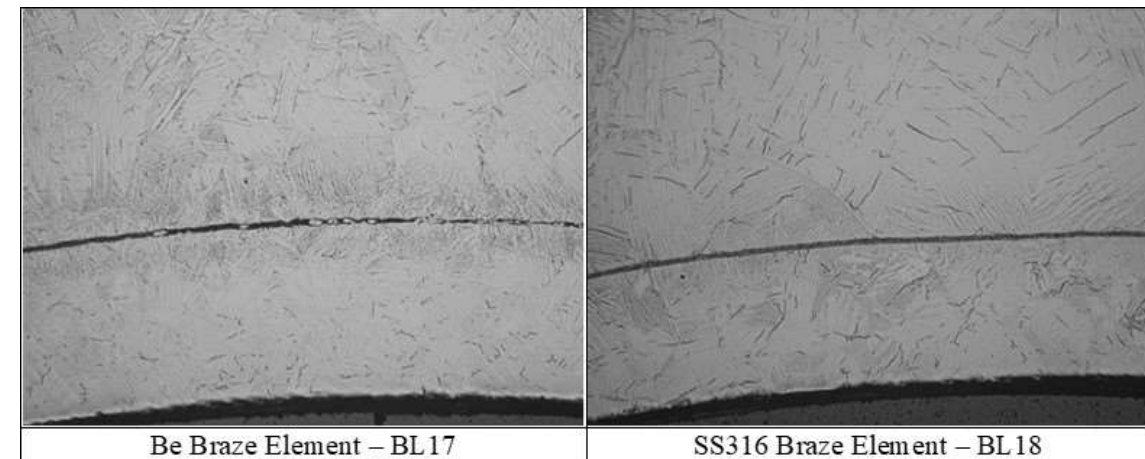
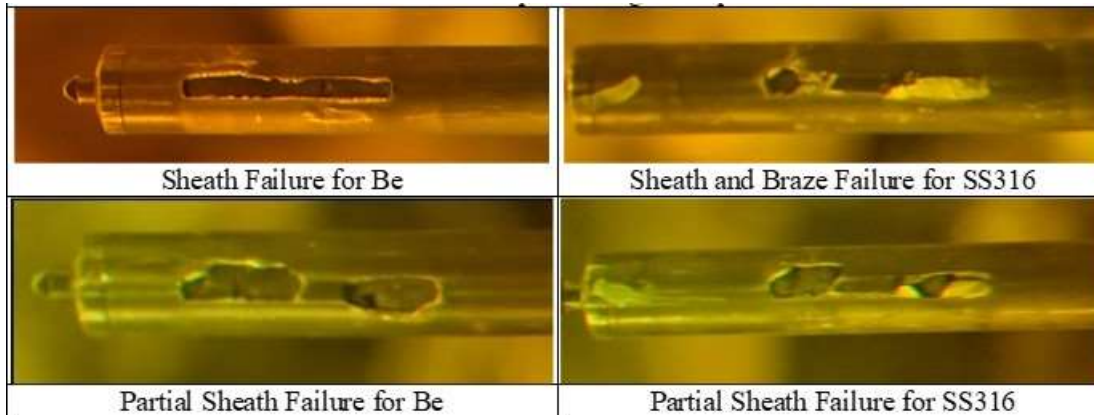
- Series of out-reactor tests show that stainless steel 316 is promising to replace beryllium.
 - Mechanical testing
 - High temperature transient tests
 - Corrosion tests
- ✓ Irradiation test was performed in the NRU reactor to directly compare performance of Be vs SS316.



Braze Filler Material	Hydrogen Content, ppm
Beryllium	16.2
SS316	21.3
Inconel-600	136
Inconel-625	139
Ni-2%Be	155

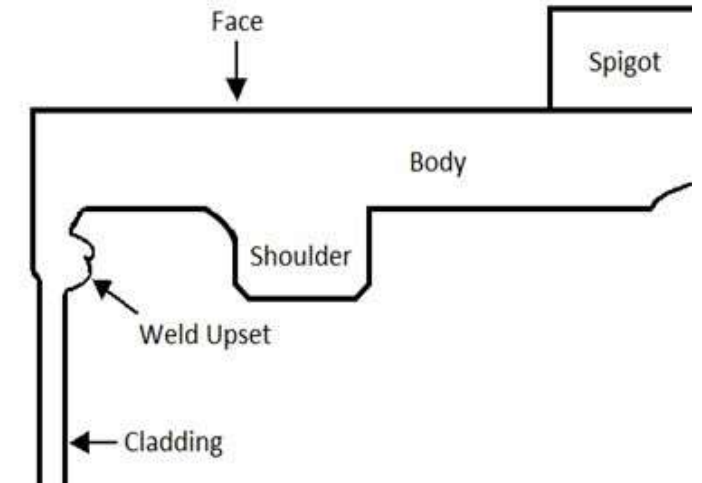
New Filler Material for Brazing

- Post-irradiation examination after operating at powers of $\sim 50 \text{ kW/m}$ to burnup of 180 MWh/kgHE
 - Hydrogen uptake was higher for SS316
 - Mechanical property was comparable (torque & microhardness)
 - Microstructure, particularly hydride distribution, is similar
- ✓ Demonstrated SS316 as a suitable replacement braze filler material to Be, with no performance-related issues



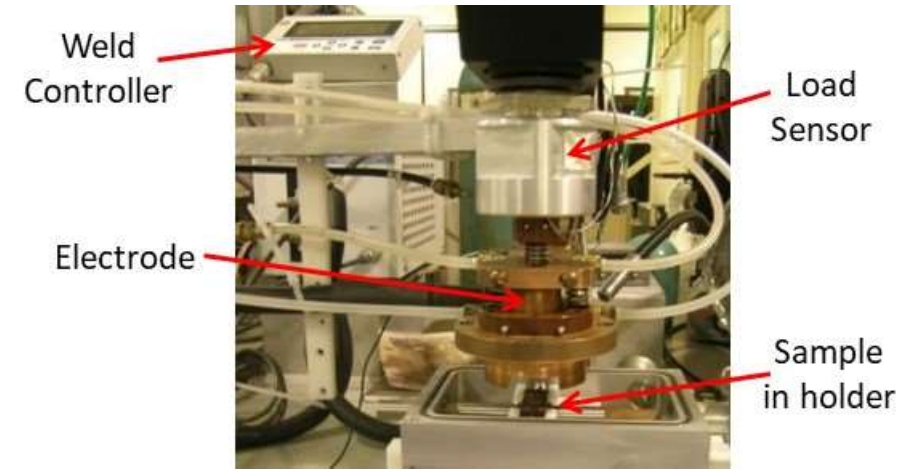
New Joining Techniques for Fuel Fabrication

- Issue: Need to improve current joining techniques (resistance welding of endcap-sheath and endcap-endplate) and induction brazing of appendages to sheath.
- Objective: To determine the feasibility of using alternative joining techniques for CANDU fuel fabrication.
- ✓ A COG project was launched to perform scoping trials using laser welding and resistance brazing.



New Joining Techniques for Fuel Fabrication

- Status: Completed scoping trials.
- Next Steps: Data analysis and reporting.
- ✓ Promising results to be communicated to industry regarding laser welding and resistance brazing.

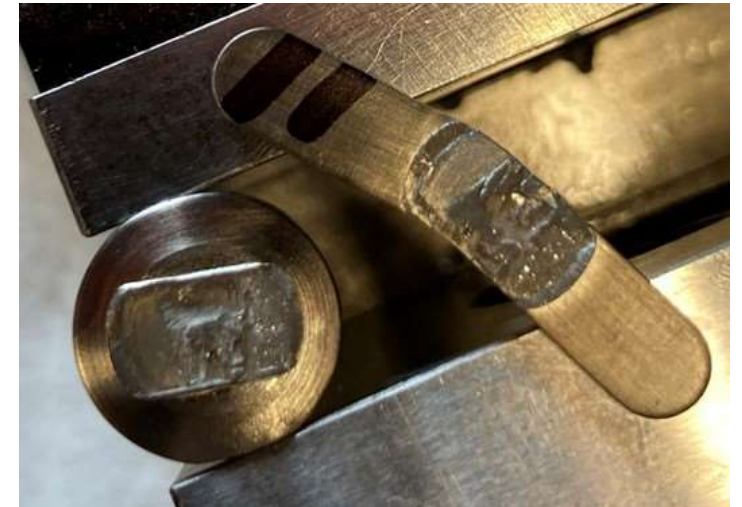


1. Vacuum Control
 2. Working Chamber
 3. Optical System
 4. Mounted PC
 5. Desktop
 6. Compressed Gas (Argon)
- * Not pictured: vacuum unit*



New Joining Techniques for Fuel Fabrication

- Preliminary results



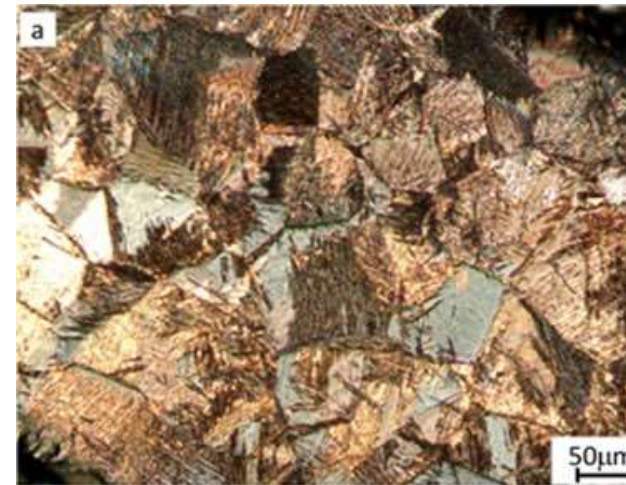
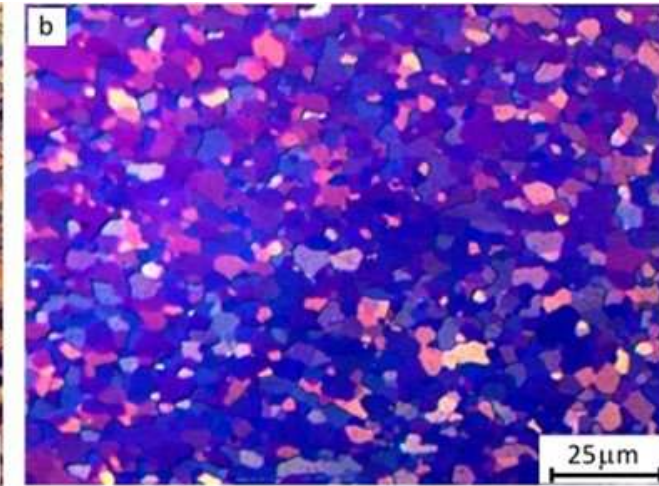
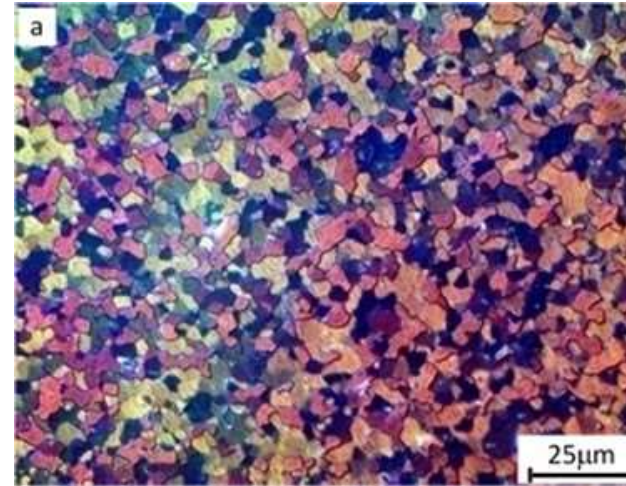
Advanced Cladding Alloys

- Zr-Nb alloys: generally 1 wt% Nb, e.g., ZIRLO, M5, E110, relative to Zircaloy-4, has improved corrosion resistance during normal operating conditions, especially at higher burnup levels and higher coolant temperatures.
- Objective - to assess the feasibility of using Zr-Nb alloy for fuel sheath in PHWRs.
 - Assess the potential deleterious effect of a Heat Affected Zone (HAZ) produced during PHWR fuel manufacturing (i.e., brazing and welding) on the mechanical properties of Zr-Nb alloys.
 - Examine microstructural changes and comparing mechanical and corrosion properties of as-received and brazed/welded Zr-Nb materials.



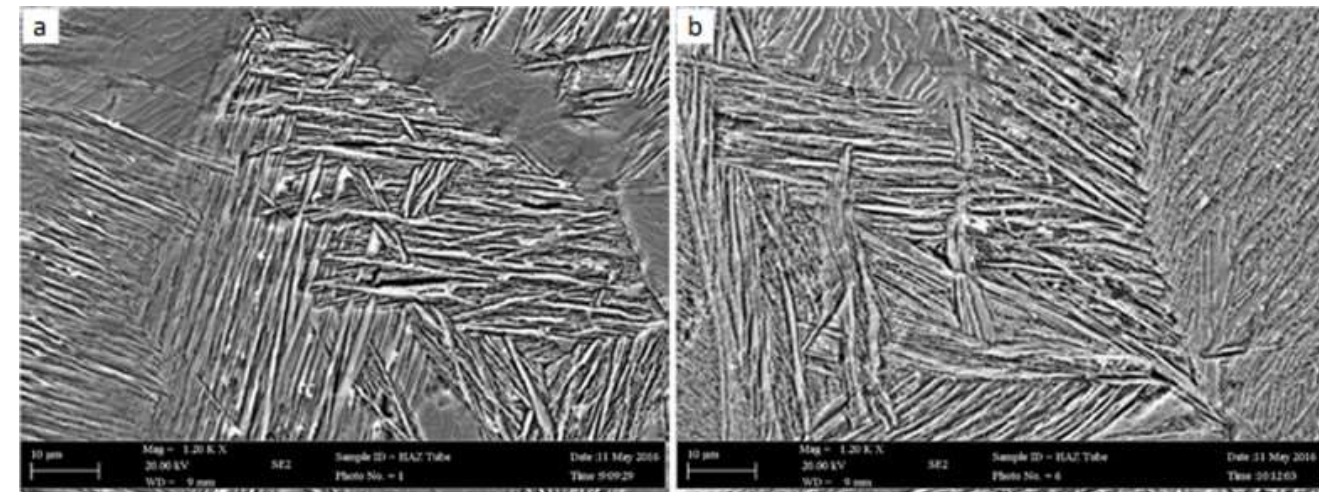
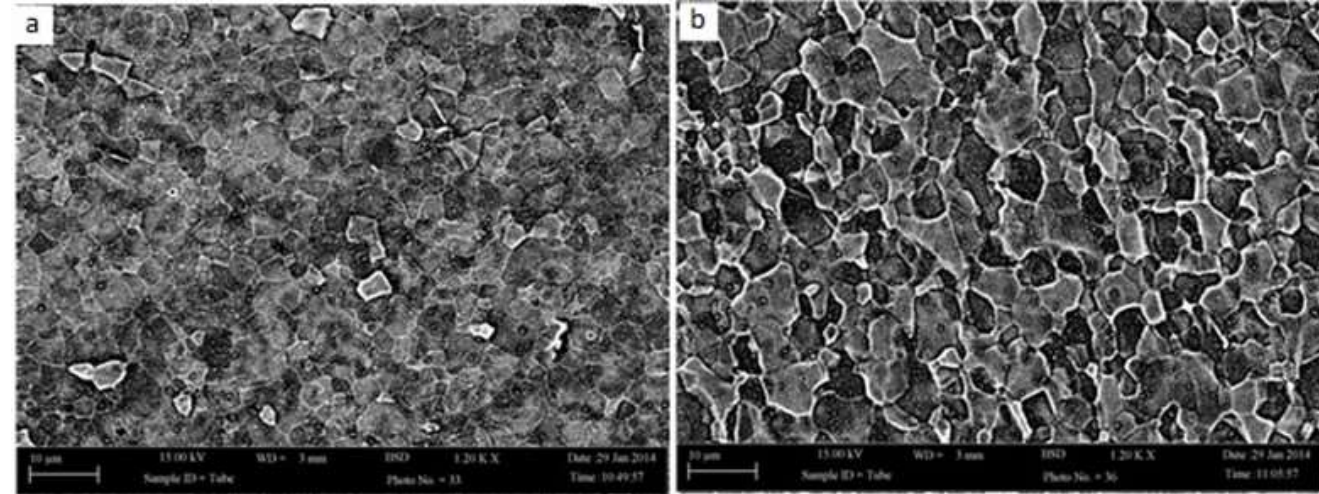
Zr-Nb Cladding Alloys

- Effect of brazing and welding on the microstructures of Zr-Nb alloys
- As-received (recrystallized) vs brazed microstructures; brazing cycle:
 - specimens in a quartz tube purged with argon gas
 - induction heating the specimens to about 1150C in 100 s.
 - after heating, the specimen was cooled in an argon atmosphere to 700C in 20 s.
- Increase in grain size – 4 μm to 66 μm



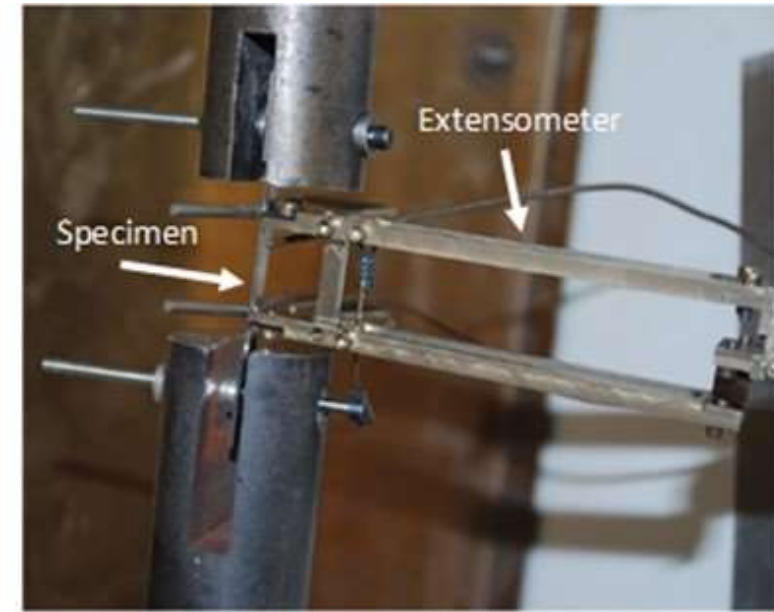
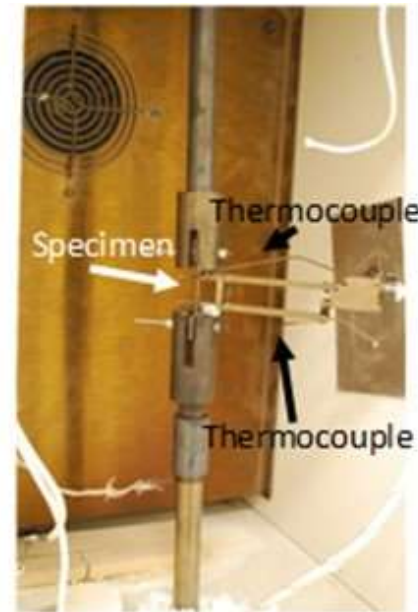
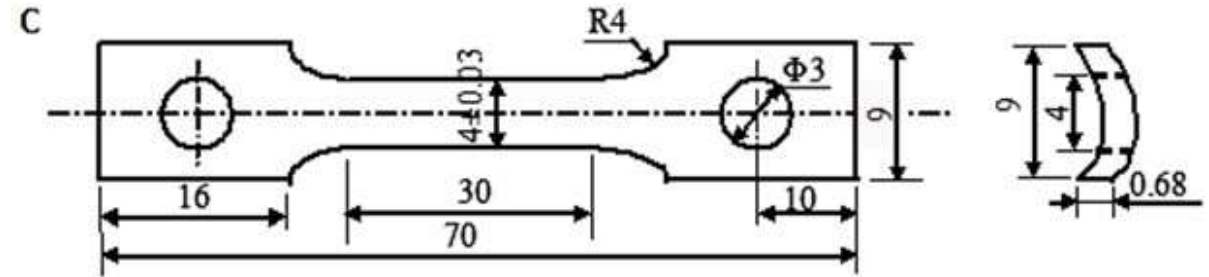
Zr-Nb Cladding Alloys

- Effect of brazing and welding on the microstructures of Zr-Nb alloys
- In addition to grain size, the morphology of precipitates was determined through SEM.
- Number of precipitates was significantly reduced and the size of precipitates increased.



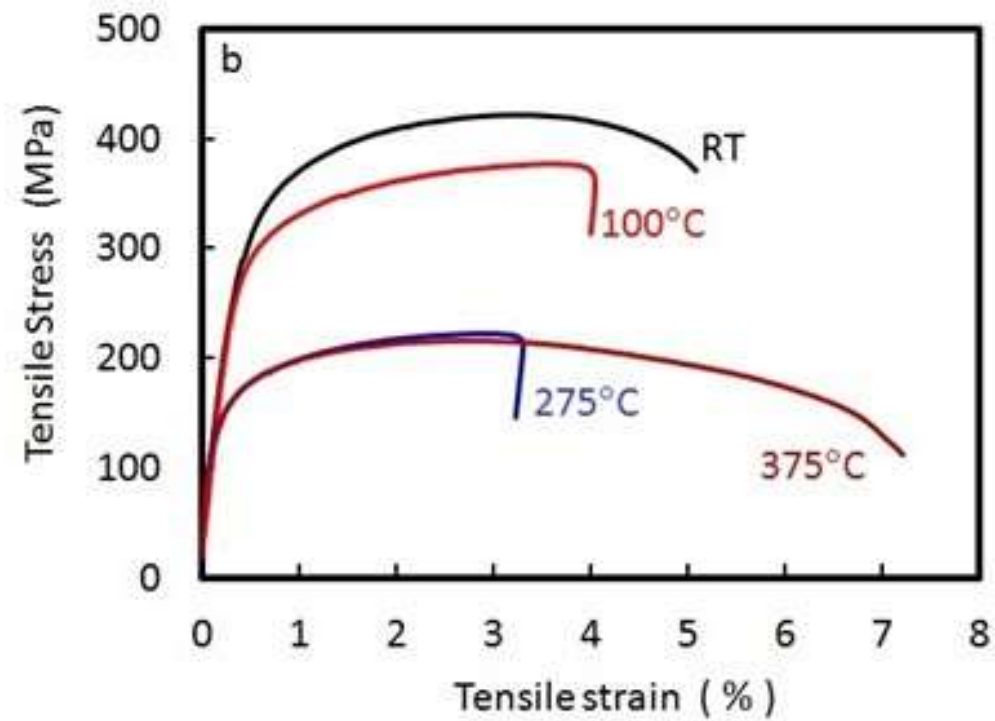
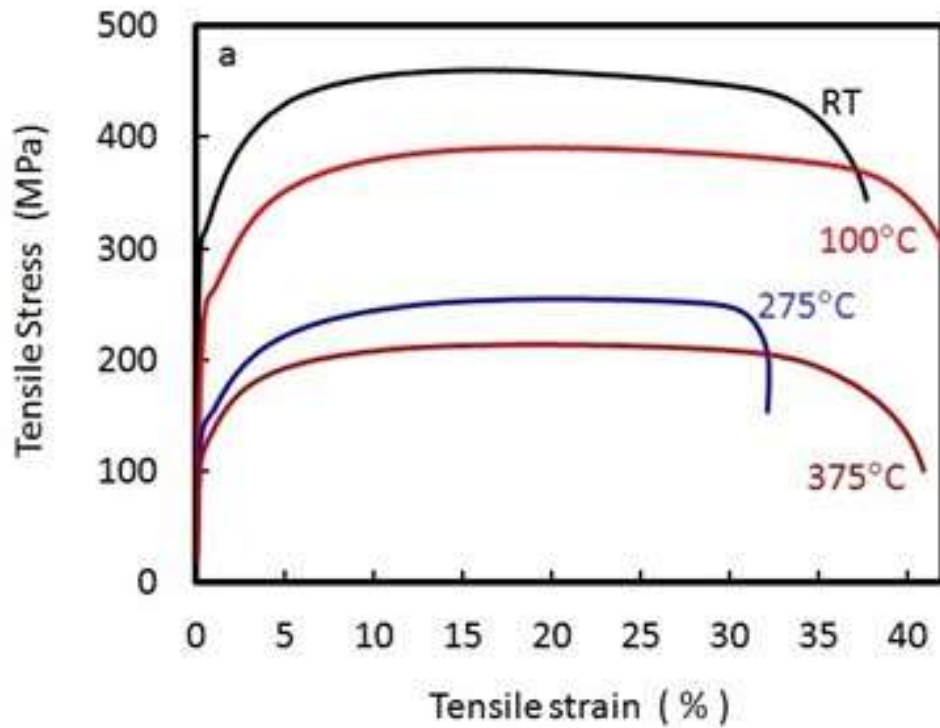
Zr-Nb Cladding Alloys

- Effect of brazing and welding on the tensile properties of Zr-Nb alloys
- Tube specimens were pulled in the axial direction.
- For each test condition (RT to 375 C; strain rate = 5.0×10^{-4} /s), 3 specimens were tested, then averaged to ensure consistency.
- Sample preparation and testing done according to ASTM standards.



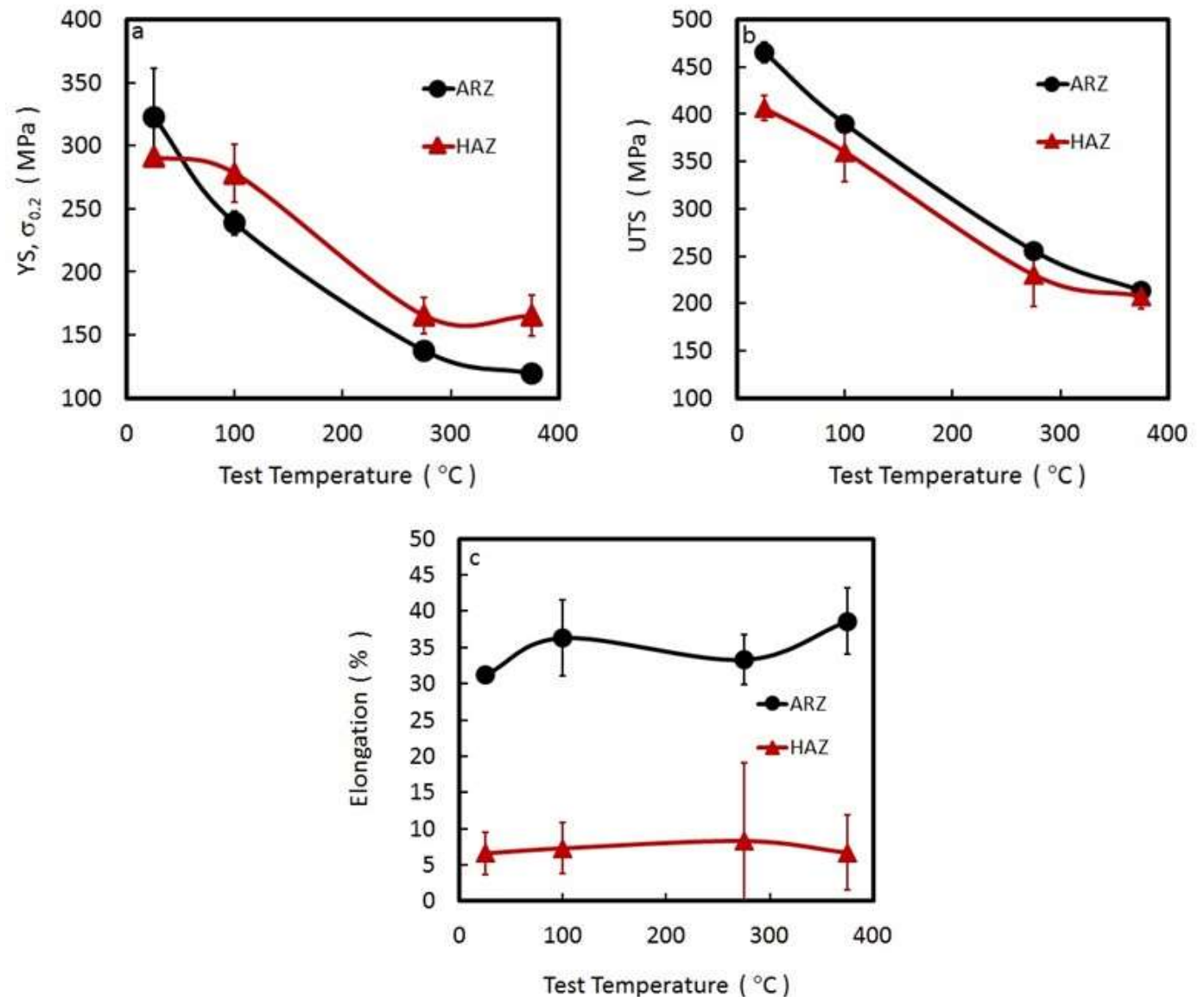
Zr-Nb Cladding Alloys

- Effect of brazing and welding on the tensile properties of Zr-Nb alloys
- For both as-received and heat treated specimens, increasing temperature led to reduced tensile strength.



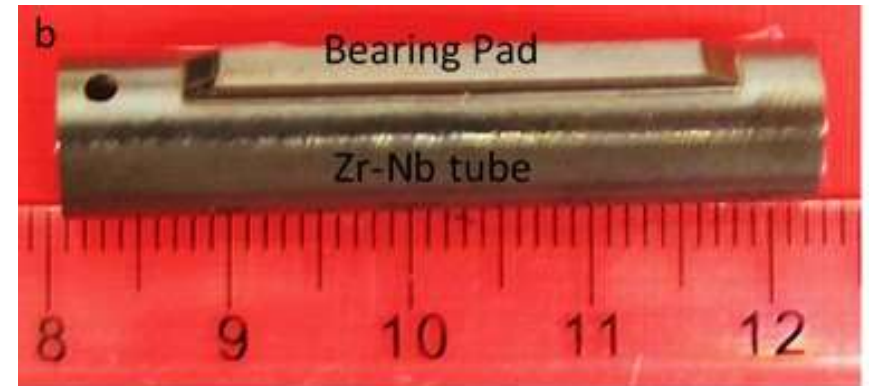
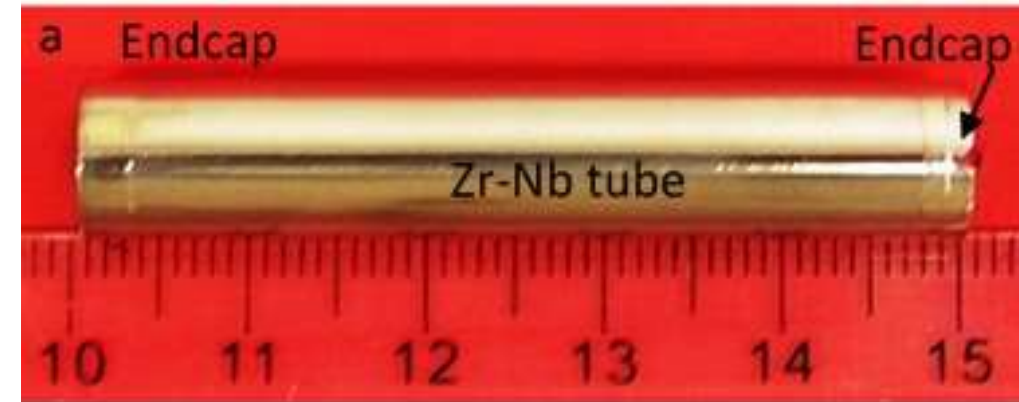
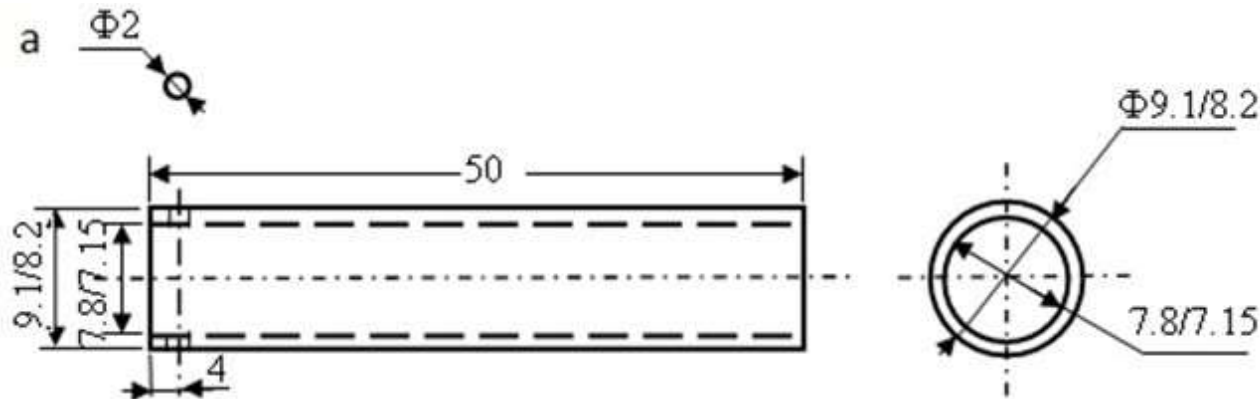
Zr-Nb Cladding Alloys

- Effect of brazing and welding on the tensile properties of Zr-Nb alloys
- Heat treatment brought about slight changes in YS and UTS.
- Heat treatment led to a significant decrease in ductility.



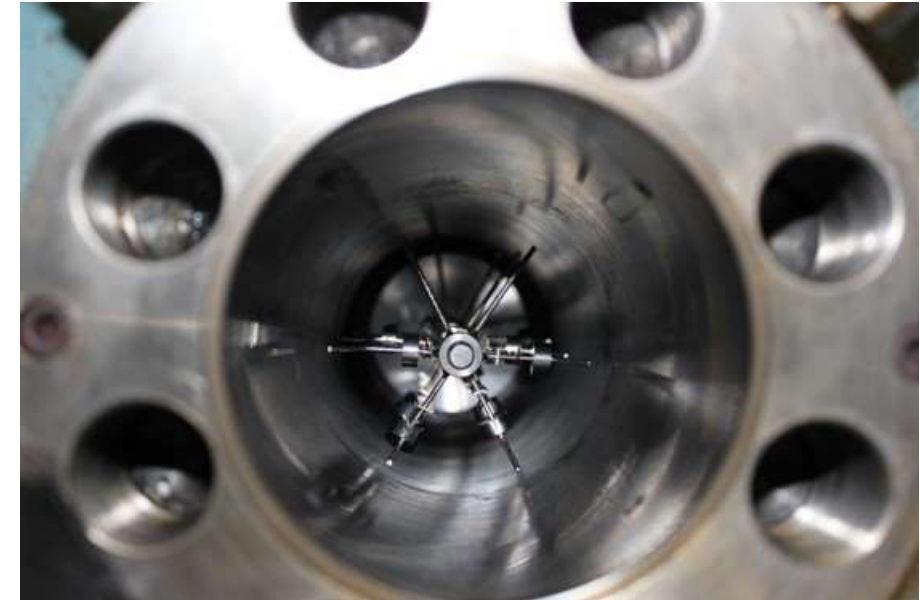
Zr-Nb Cladding Alloys

- Effect of brazing and welding on the corrosion properties of Zr-Nb alloys relative to Zr-4
- Heat treated samples to simulate brazing, as well as actual brazed and welded samples.



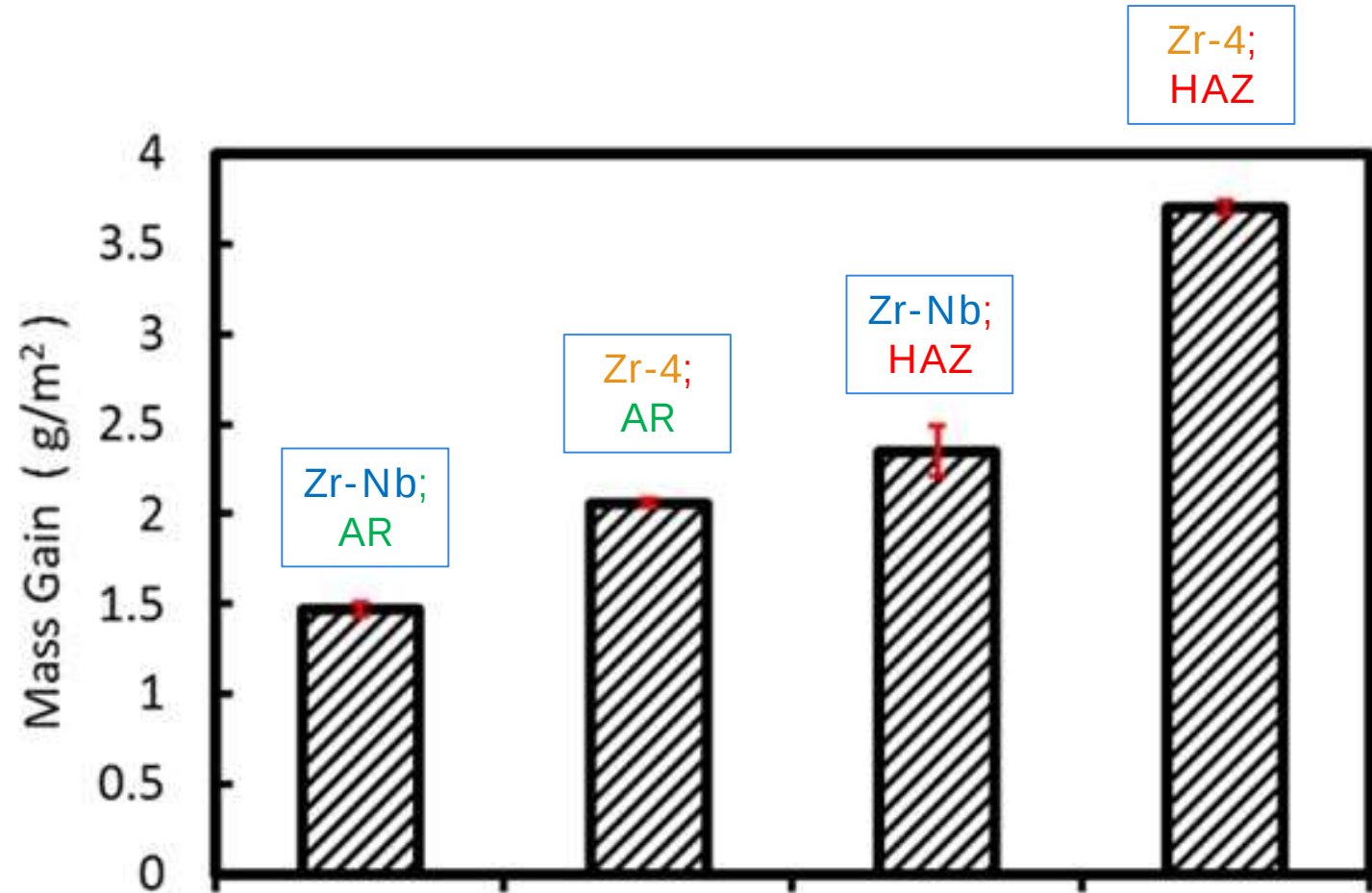
Zr-Nb Cladding Alloys

- Corrosion testing in a 316SS autoclave with a volume of 2 liters (33 cm height x 9 cm diameter).
- Specimens in a tree mount inside the autoclave – 3 Zr-Nb and 3 Zr-4 samples at AR condition, plus another set of 3 Zr-Nb and 3 Zr-4 samples at HAZ condition.
- The tests were conducted in steam at a temperature of 400° C and pressure of 10 MPa for a period of 72 hours.



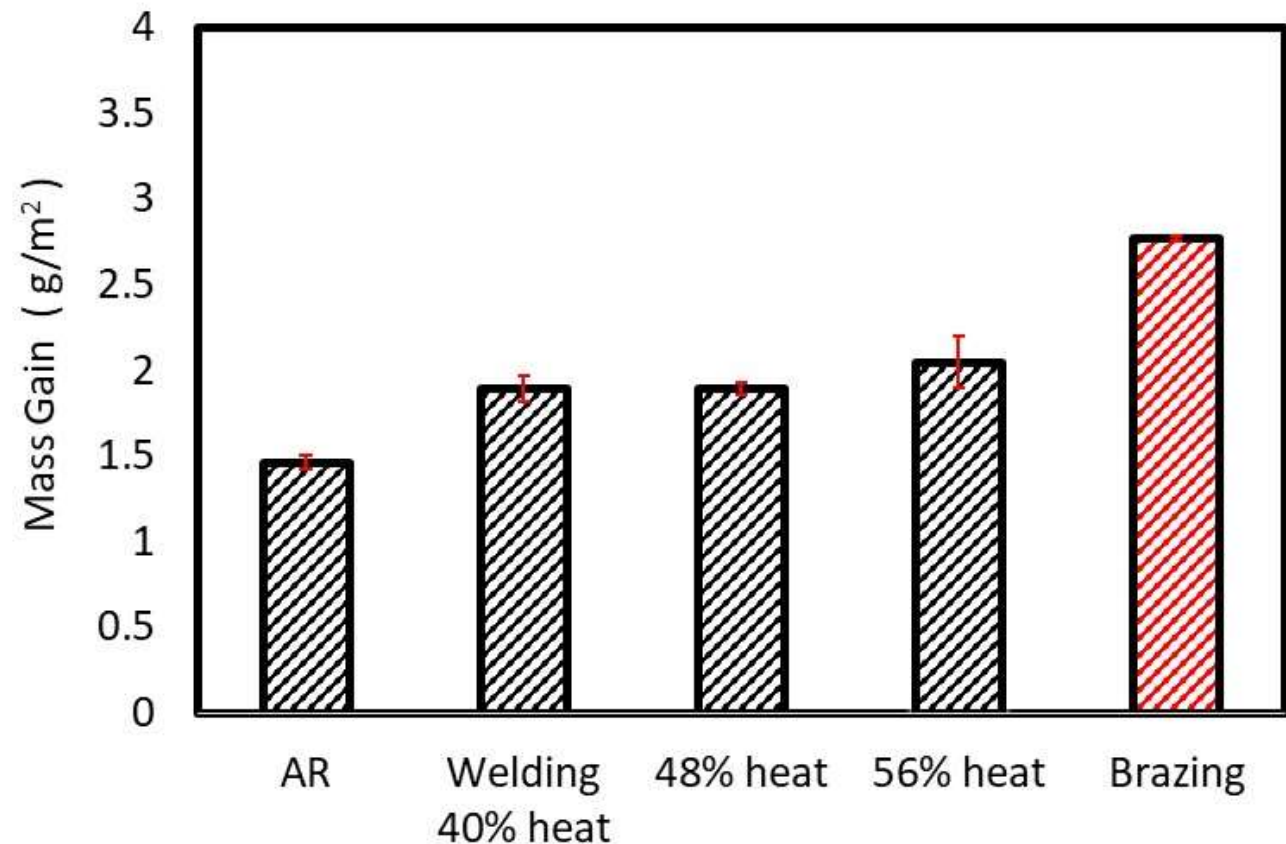
Zr-Nb Cladding Alloys

- Corrosion properties assessed through mass gain.
 - Corrosion resistance of Zr-Nb superior to that of Zr-4 in both the AR and HAZ conditions.
 - Mass gain of AR Zr-4 tubes was 40% higher than AR Zr-Nb tubes, while mass gain of HAZ Zr-4 tubes was 60% higher than HAZ Zr-Nb tubes.
 - Brazing has a detrimental effect on the corrosion properties of both Zr-Nb and Zr-4 tubes, but effect on Zr-4 appears to be more severe.



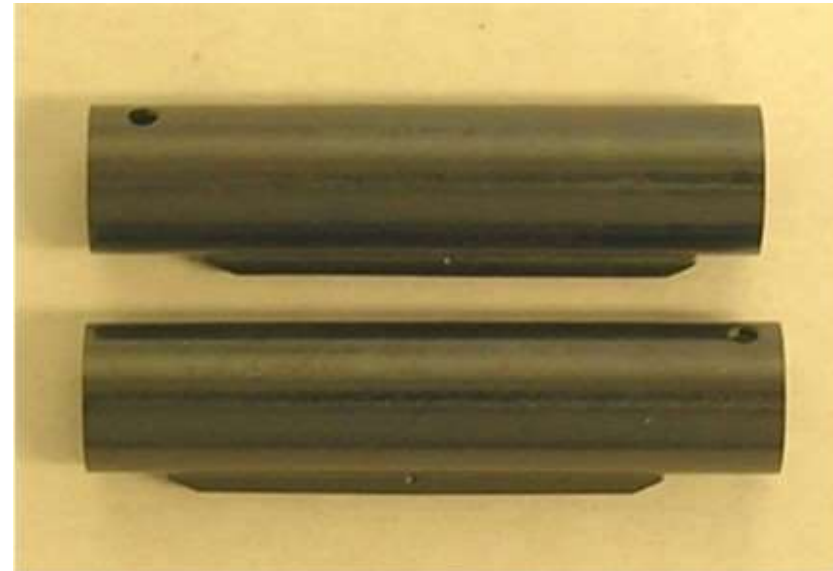
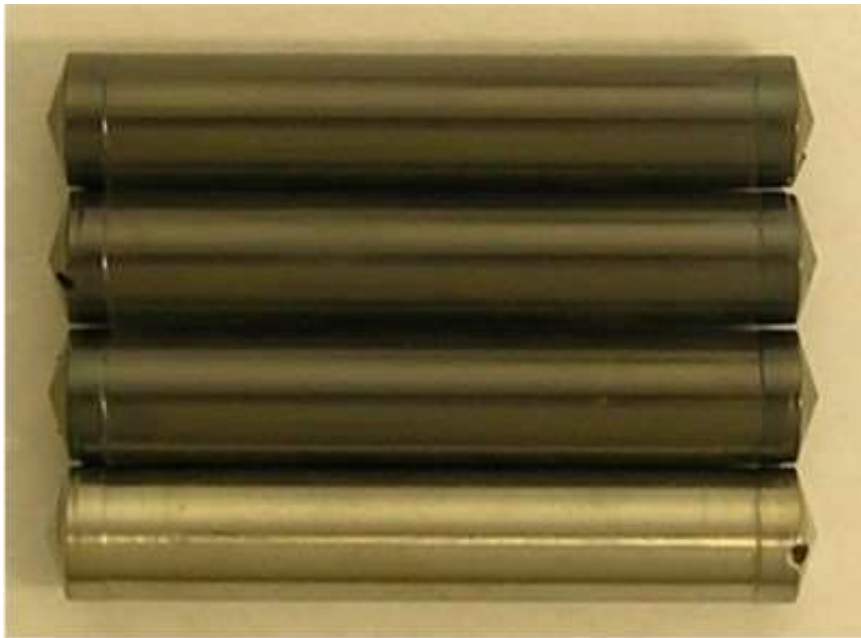
Zr-Nb Cladding Alloys

- Corrosion properties of actually welded and brazed Zr-Nb samples.
 - Welded samples exhibited higher mass gains relative to the as-received samples.
 - Slight increase in mass gain as the heat of the weld is increased.
 - Effect of actual brazing on Zr-Nb appears to be most significant.



Zr-Nb Cladding Alloys

- Mechanical and corrosion properties of Zr-Nb alloys negatively affected by welding and brazing.
- Prior to adoption in PHWR's, need to develop alternative joining techniques to minimize detrimental effects on Zr-Nb.



Future Work

- Optimize brazing conditions for using SS316 as filler material.
- Continue development of joining techniques as applied to Zr-4 and other advanced cladding alloys
 - Explore other joining techniques to minimize negative effect on Zr-Nb
 - Obtained samples of Fe-Cr-Al alloy for welding trials using laser welding
 - Zircaloy-4 tubes coated with Ti-Al and CrN for welding trials using resistance welding and laser welding.
- Promising results to be communicated to industry and followed up with more production-scale tests.



Summary

- Fuel development activities are on-going at CNL building up on decades of experience and expertise on research and development of experimental and advanced fuels for PHWR's and other reactors.
- These R&D activities are in various areas of technology, including new filler materials for brazing,, novel and improved techniques for fabrication, and advanced cladding alloys for high burnup and accident tolerant fuel applications.
- Highlights of some of these development were discussed, as well as direction for future work.
- Leveraging existing experience and capabilities, new work are being initiated to fuel development applied to advanced fuels, particularly for SMR's.



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Thank You.

Pleased to answer any questions.

Ike.Dimayuga@cnl.ca



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