INL/MIS-22-68050-Revision-0

Tensile Test Using Standard Capsule

July 2022

Changing the World's Energy Future

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Outline

- Motivation
- Challenges and Opportunities
- TTUSC

Motivation

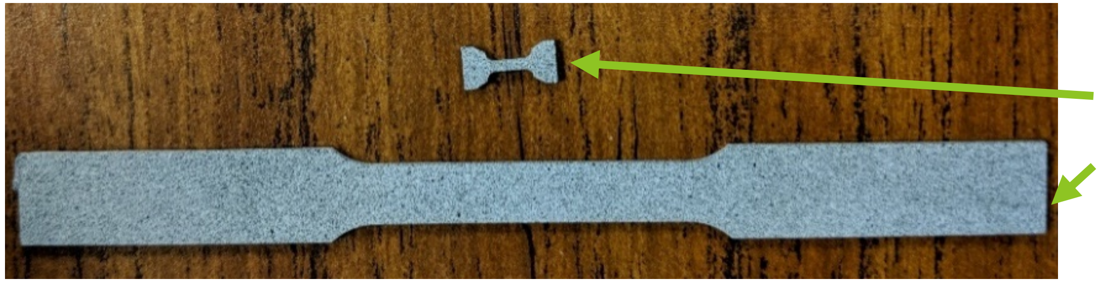
- Need for structural materials for advanced reactor systems[1, 2, 3]:
  - Higher Energy Neutron Spectrum
  - Higher Temperatures
  - Corrosive Environments
- Research on new materials is being conducted, including on Multi-Principle-Element-Alloys (MPEA's, aka High-Entropy-Alloys, aka Complex-Concentrated-Alloys)
  - In a 2021 review paper[4], ~4000 papers published on MPEA
  - Of those, only ~100 were focused on nuclear applications and were topical on fabrication, modeling, ion irradiation, and corrosion.
  - Very limited neutron irradiation data on MPEAs
  - Nearly limitless composition space for MPEAs

1 – https://doi.org/10.1016/j.matre.2021.01.002
2 – https://doi.org/10.1016/j.cossms.2016.10.004
3 – https://doi.org/10.1038/ncomms13564
4 – https://doi.org/10.3390/e23010098

Challenges and Opportunities

- How to reduce time and cost to perform neutron irradiation of structural materials?
  - Develop ”Standard Capsule” with analysis basis to perform irradiations in ATR “A” positions. Reduces cost and time to get new experiments into ATR using highly available “A” positions.
  - Allows for large numbers of specimens to be irradiated.
- How to deal with large composition space of new materials?
  - Utilize “combinatorial” approach
    - rapid specimen fabrication such as through Spark Plasma Sintering,
    - “fast-to-fail”, Computational Materials Engineering Tools
    - reduce specimen size to accommodate greater number of specimens in reactor
      - Validation of smaller specimen size for mechanical testing[1]

1 – Karnati, Isanaka, Zhang, Liou, Schulthess, “A Comparative Study on Representativeness and Stochastic Efficacy of Miniature Tensile Specimen Testing”, Accepted.

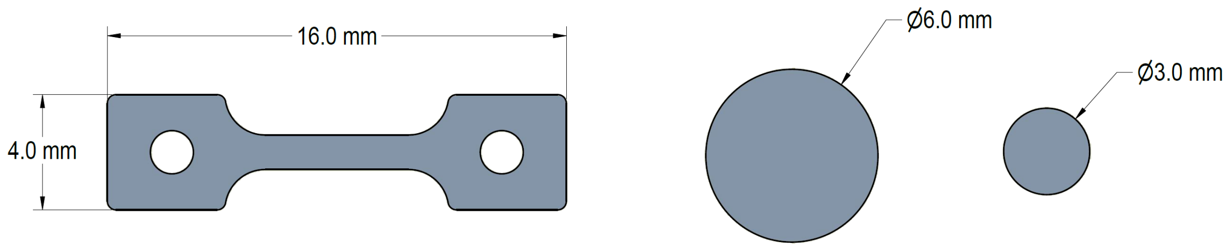


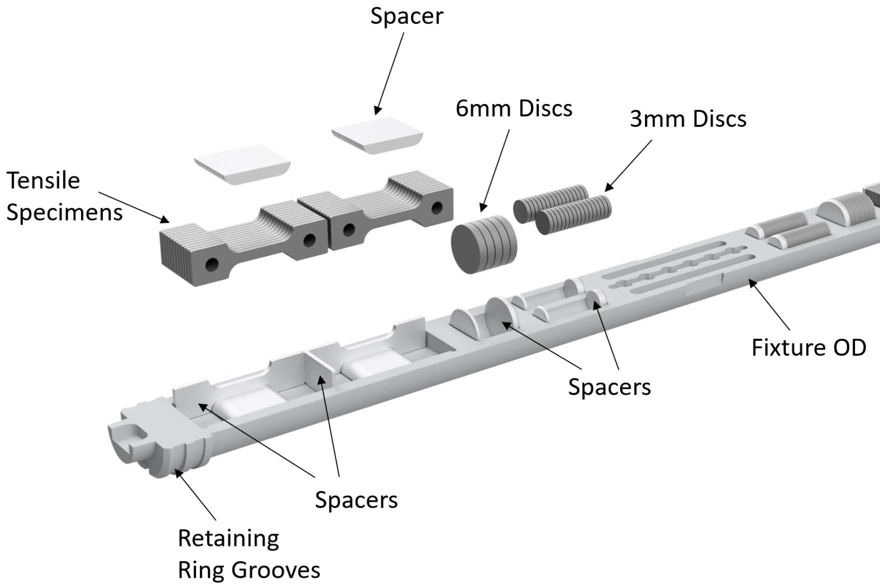
Miniature “MT2” Tensile Specimen
ASTM E8 Standard ”Sub-sized Specimen”

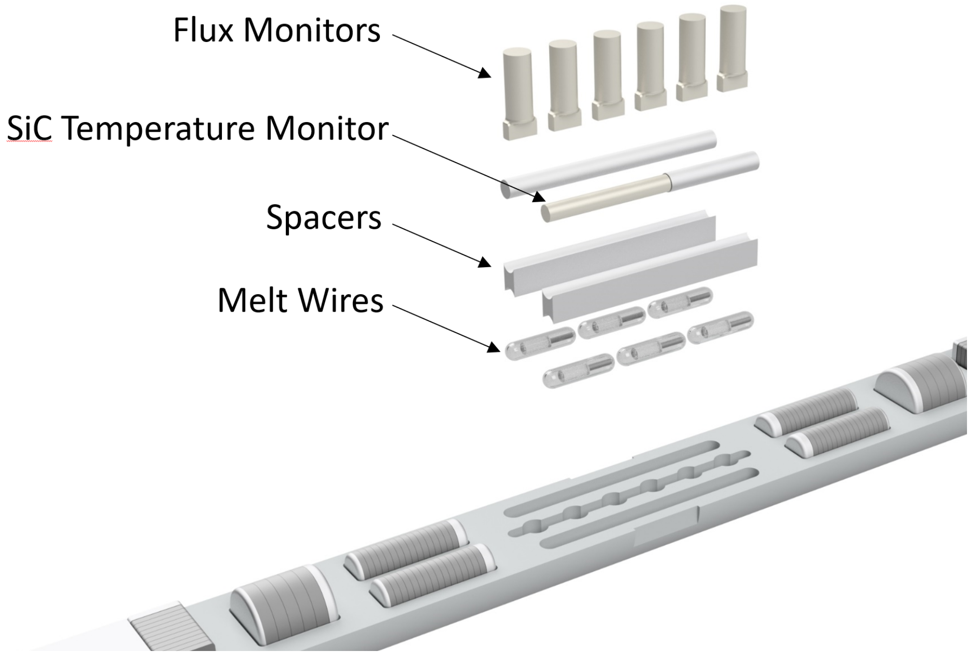
TTUSC – Tensile Test Using Standard Capsule

- Capsule design driven by three objectives:
  - Capsule should fit into a 15.9 mm diameter or larger position
    - Opens virtually every irradiation position in ATR (availability) and allows selection of test position based on flux values without limitation of the vehicle
  - Capsule should accommodate and maximize the amount of standard specimen sizes used for structural materials irradiation testing
    - Basketless design with interlocking endcaps increases inner diameter (more room for specimens) and makes reconfiguration between cycles possible.
  - Capsule analysis should be enveloping in nature so future tests can leverage the analysis to decrease deployment time
    - Parametric analysis model developed using COMSOL to allow rapid analysis for future tests.

TTUSC - Design







TTUSC - Materials

Composition Code	Composition	Total Specimens Fabricated	Specimen Identification Marking
B16-Co	Fe33.73Cr32.42Mn33.27Co0.58	20	T001-T020
A9/B23	Fe21.73Cr20.23Ni22.83Al10.5Cu24.72	23	T021-T043
B14-Co	Fe25.05Cr23.67Ni26.06Mn24.72Co0.5	24	T044-T067
B19-Co	Fe27.83Cr26.31Ni28.96Al16.4Co0.5	26	T068-T093
B18/A6	Fe24.33Cr22.65Ni25.56Mn23.93Al3.53	25	T094-T118
A7/B20	Fe23.45Cr21.83Ni24.64Al3.4Cu26.68	23	T119-T141
D4	Cr9.63Al5.0Zr16.89Mo17.77Nb17.2Ta33.51	23	T142-T164
D5	Cr14.48Al7.51Zr25.41Mo26.72Nb25.88	22	T165-T186
D6	Cr13.94Al7.23Zr24.45Mo25.72Nb24.90C3.75	20	T187-T206
D8	Ti12.63Zr24.08V13.44Mo25.32Nb24.52	26	T207-T232
D19	Cr12.31Ti11.33Zr21.59Mo11.36Nb21.99Ta21.42	23	T233-T255
D20	Ti20.22Mo40.53Nb39.25	23	T256-T278
D21	Al10.23Ti18.15Mo36.39Nb35.23	8	T279-T286
D22	Cr16.47Al8.55Ti15.16Mo30.39Nb29.43	9	T287-T295
D23	Ti14.60Zr27.82Mo29.26Nb28.33	25	T296-T320
D18	Cr15.31Ti14.09V15.00Mo28.25Nb27.35	23	T321-T343
304 L SST, XY Plane	Fe64.9Cr20.0Ni12.0Mn2.0Si1.0P0.045C0.03S0.03	12	T344-T355
304 L SST, Z Plane	Fe64.9Cr20.0Ni12.0Mn2.0Si1.0P0.045C0.03S0.03	12	T356-T367

TTUSC – Computational Materials Engineering and Archive Characterization (Ongoing)

Alloy system	CALPHAD	XRD		Optical microscopy	Hardness [kg/mm^2]		SEM analysis
	ThermoCalc prediction	As Melt	Annealed	Microstructural features	As melt	Annealed	EDS
D8 - Ti12.63 Zr24.08 V13.44 Mo25.32 Nb24.52	BCC_B2 + C15 Laves + HCP_A3	B2/C15 and HCP A3	Amorphous + B2/C15 and HCP A3	Semi rosettes, dendrites and inter dendritic phases	Dendrite – 688 Inter – 1102 Black – 1587	Dendrite – 586 Inter – 1140 Black – 1545	Dendrite –Mo, Nb, V, Ti, Zr Inter – Mo, Zr, Nb, V, Ti Black – Zirconia
D18 - Cr15.31 Ti14.09 V15.00 Mo28.25 Nb27.35	BCC_B2 + BCC_B2	Amorphous	B2	Dendritic phase and porous middle part	767	754	Dendrite – Nb, Mo, Cr, V, Ti Black – Ti oxide
D19 - Cr12.31 Ti11.33 Zr21.59 Mo11.36 Nb21.99 Ta21.42	BCC_B2 + C15 Laves + HCP A3	B2, C15 and HCP A3	B2, C15 and HCP A3	Rosettes, dendrites and inter dendritic phases	Dendrite – 805 Inter – 1313 Black – 1700	Dendrite – 740 Inter – 1144 Black – 1263	Dendrite – Ta, Nb, Mo Inter – Zr, Cr, Ti, Nb, Ta, Mo Black – Zirconia
D20 - Ti20.22 Mo40.53 Nb39.25	BCC_B2	B2	B2	Pits in grain interiors and grain boundary phases after annealing	660	527	Matrix –Nb, Mo, Ti, O (3%) Black – Nb, Mo, Ti, O (10%)
D23 - Ti14.6 Zr27.82 Mo29.26 Nb28.33	BCC_B2 + HCP_A3	B2	B2	Dendrites and inter dendritic phases	Dendrite – 738 Inter – 990	Dendrite – 567 Inter – 983	Dendrite – Ta, Nb, Mo Inter – Zr, Ti, Nb, Mo, C, O Black – Zr, Ti, Nb, C, O
B19 - Fe22.12 Cr20.6 Ni23.25 Al10.69 Co23.34	BCC_B2 + SIGMA	B2	Amorphous + B2	Black dendrites and inter dendritic phases	Dendrite – 676 Inter – 729	Dendrite – 617 Inter – 768	Dendrite – Ni, Al, Fe, Cr, C Inter – Cr, Fe, Ni, C Black – Aluminum Nitride

TTUSC - Final Assembly

- Final loading of the capsules and final assembly of the test train (5 capsules containing 240 tensile specimens including temperature sensors and flux wires) was completed and the experiment is ready for insertion in the next ATR cycle.

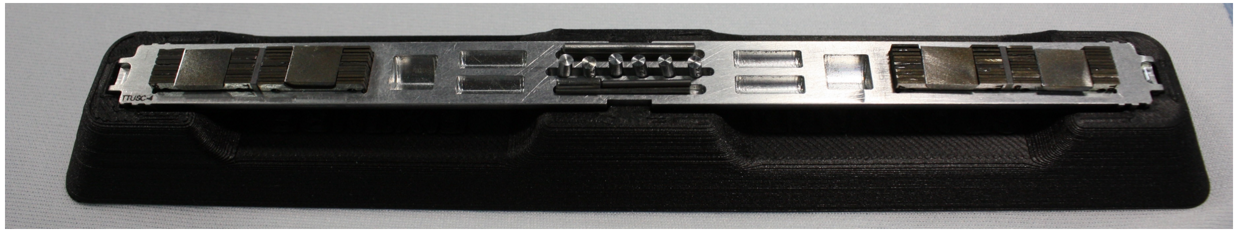


Figure 1. Capsule with all specimens loaded.

Figure 2. Capsules after final seal welding.

Figure 3. Test train after final assembly. Ready for insertion at ATR.

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