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Sub-sized specimen testing and its relationship with Gen IV Materials Qualification

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Changing the World's Energy Future

Idaho National Laboratory

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Sub-sized specimen testing and its relationship with Gen IV Materials Qualification

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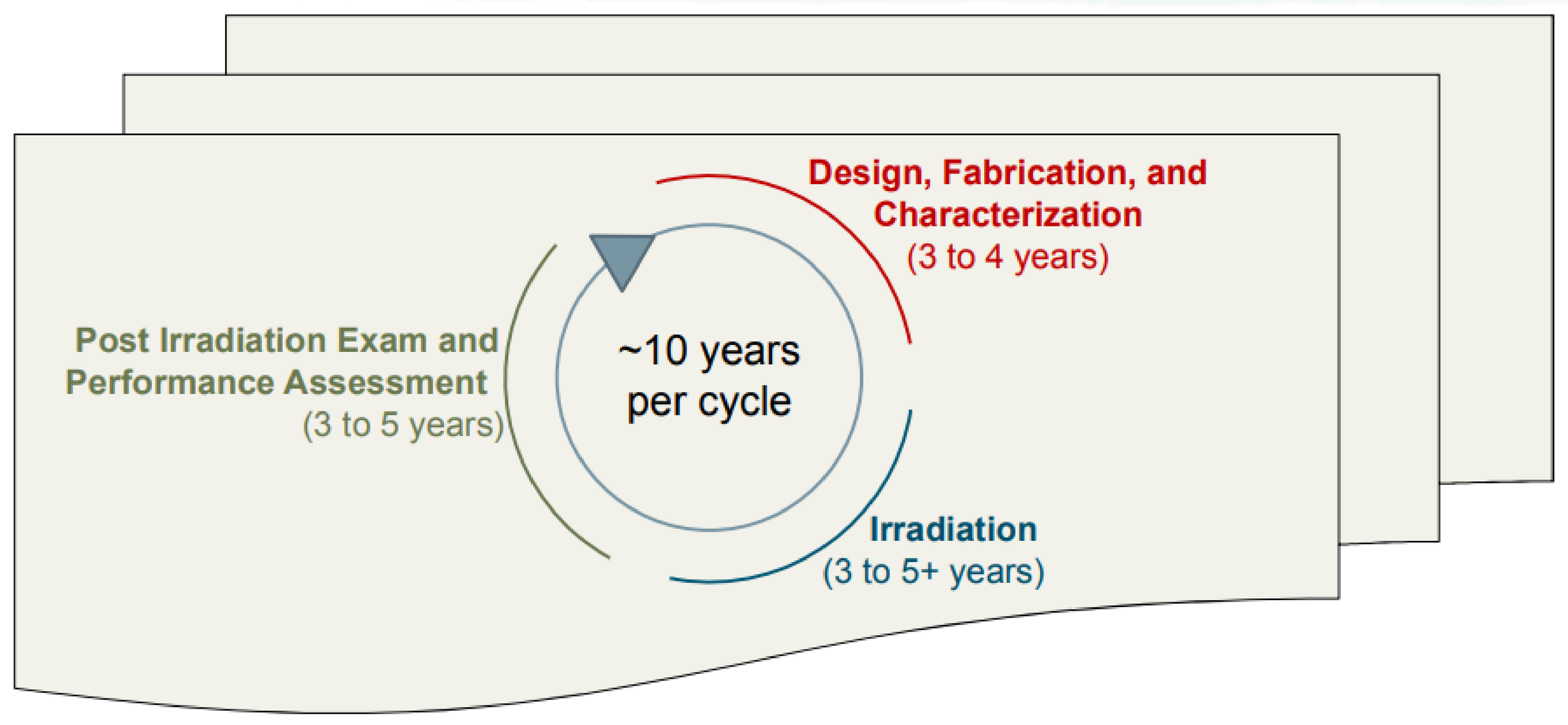
Background

- Qualification of new nuclear structural materials, currently a 20-30 year process, is critical to designing safe, reliable, more efficient Gen IV nuclear reactors that can help the US achieve our clean energy goals.



- INL's Nuclear Materials Discovery and Qualification Initiative (NMDQi) is a program designed to accelerate nuclear materials qualification and reduce that timeline to 3-5 years.
- To achieve this time frame goal, accelerated tests of materials must be performed within test/fast reactors, which are limited in number and have small testing volumes
- This leads to a need to deviate from American Society for Testing and Materials (ASTM)/ American Society of Mechanical Engineers (ASME) standard sized specimens and use sub-sized or miniature specimens.
- The goal of this project was to determine the extent to which sub-sized tensile, creep, and fatigue mechanical testing had been performed on materials applicable to the nuclear industry and the factors necessary to accurately replicate bulk material behavior

References

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Historical Sub-Sized Testing

Tensile testing of sub-sized specimens

- Applying the same loading mode (force application methods, loading direction, testing temp. strain rate, etc.) on sub-sized specimens as ASTM standard sized samples leads to observing yield strengths, ultimate tensile strengths, and elongations within +/- 2% of the standard size sample measurement.
- Sub-sized tensile specimens with a minimum width of 6-20 grains within the gauge section were observed to replicate the bulk yield strength, ultimate tensile strength, and elongation within +/- 2%.

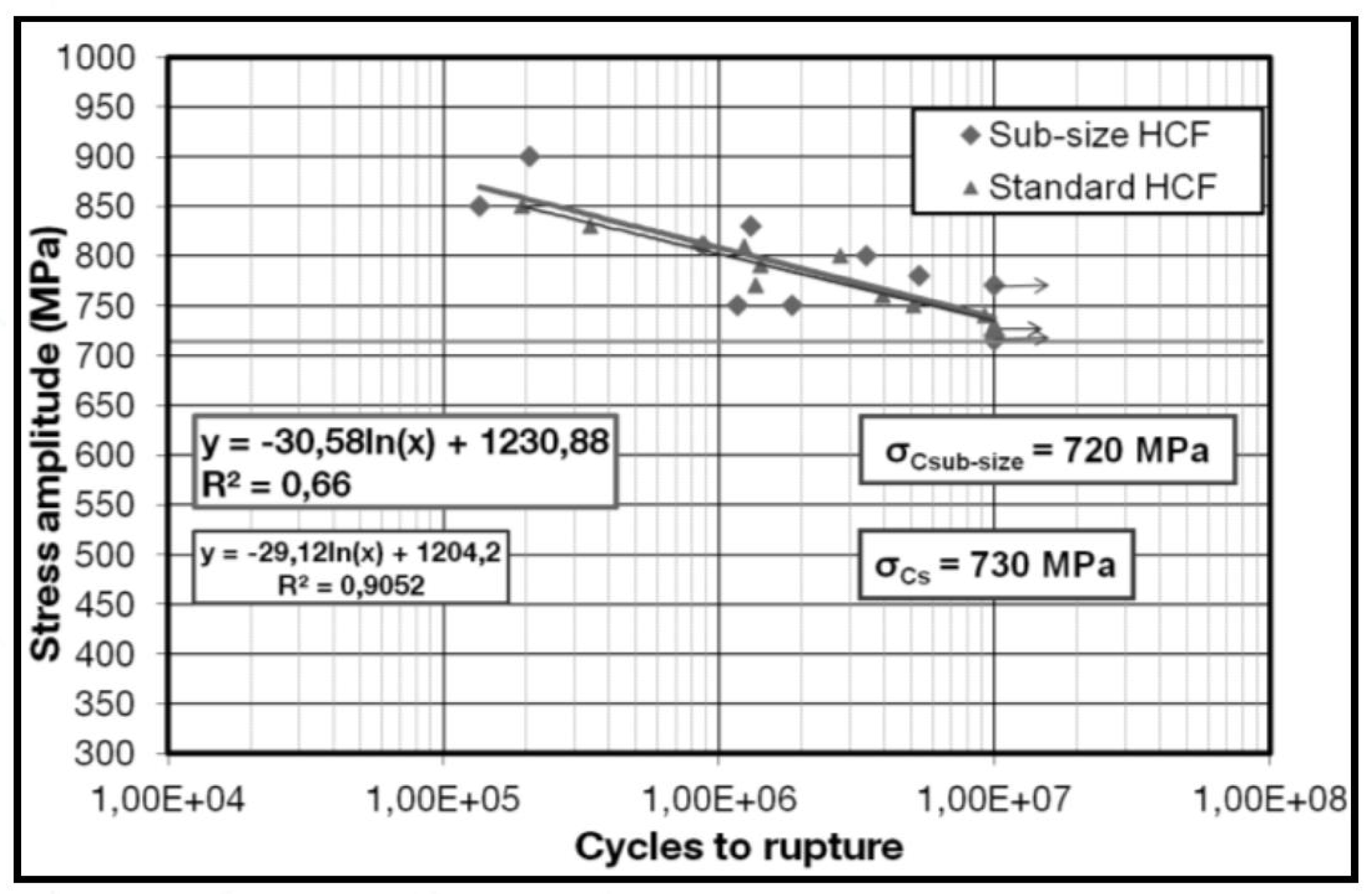
Creep Testing of sub-sized specimens

- Uniaxially loaded sub-sized specimen and small punch test (SPT) are common methods of creep testing materials with limited volumes within the nuclear industry.
- SPT however, is limited by the uniqueness of the testing environment within a given lab and the need for correlations specific to the material being tested and specific to the material property of interest, thereby leading to enormous amounts of data generation.

Fatigue Testing of sub-sized specimens

- Sub-sized fatigue specimens produce fatigue cycle values within +/- 18% and rupture stress values within +/- 7% of ASTM sized samples over the entirety of a Stress-Cycles to failure curve.
- Although scatter exists with sub-sized fatigue specimen data, the graph below shows a linear regression and approximation for the S-N curve is achievable within +/- 1.5% of the fatigue limit.

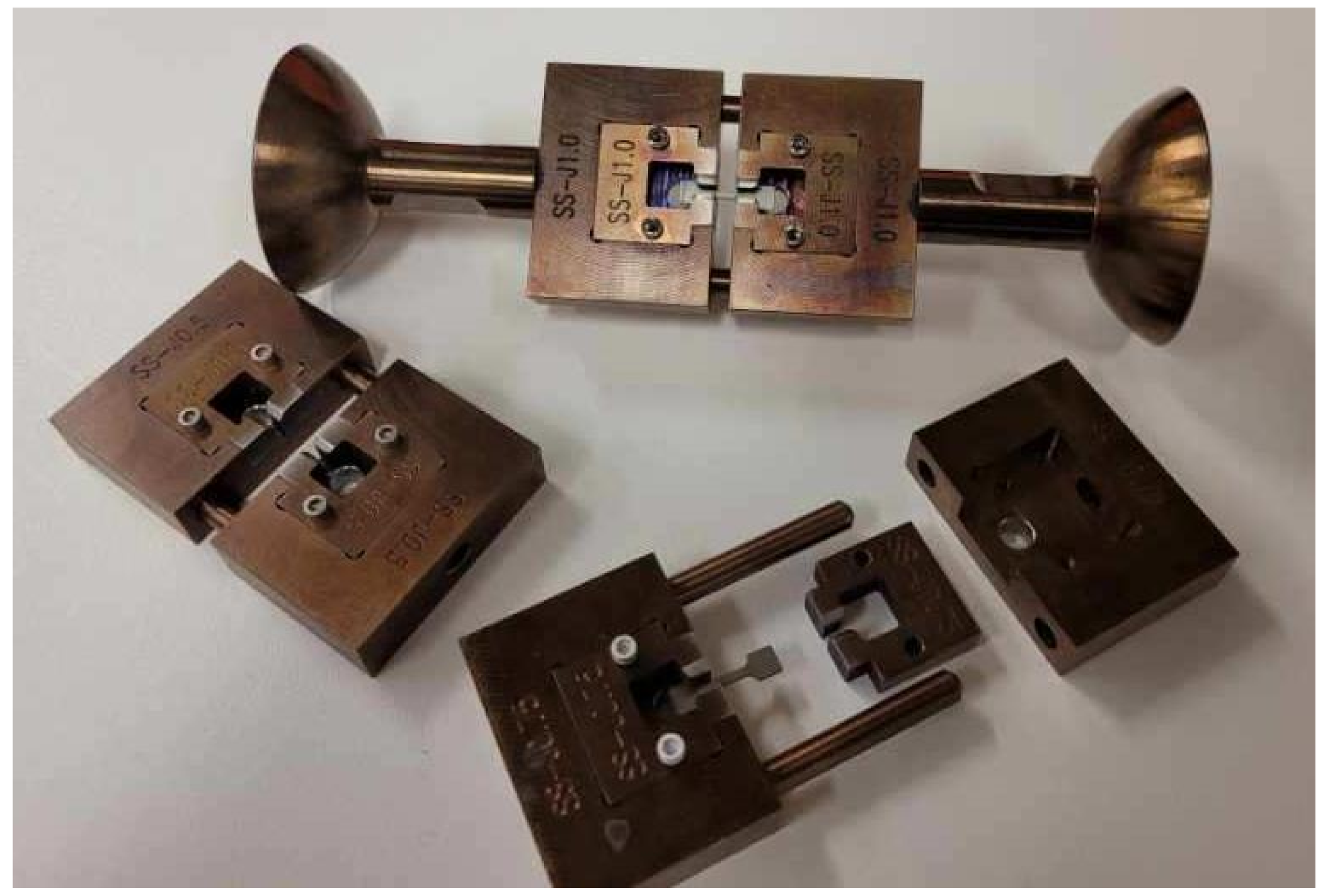
Comparison of standard size and sub-sized fatigue specimens



Results of high cycle fatigue tests performed on standard vs sub-sized specimens

Specimen	Temp	E	YS	UTS	EL
	ºC	GPa	MPa	MPa	%
Standard size	20	213.0	1592.0	1648.0	1.0
Micro-Tensile Test	20	213.3	1593.5	1645.6	1.3

Standard vs Micro-Tensile test at 20C data showing Young's modulus (E), Yield Strength (YS), Ultimate Tensile Strength (UTS), and Elongation (EL) within +/- 2%



Clevises for SS-J3 creep testing currently under design and development at INL

Current & Future Plans

- Given that the literature demonstrates governing factors in sub-sized specimen testing is geometry agnostic, SS-J3 sub-sized specimen have been identified as an ideal sample size due to their limited volume requirements and ubiquity in Nuclear Science User Facilities.
- Development of clevises and mechanical testing systems for testing of irradiated SS-J3 sub-sized specimens has commenced as part of NMDQi.
- INL plans to initially creep test irradiated Inconel 617 SSJ3 sub-sized specimens as copious material testing data of Inconel 617 ASTM standard sized samples exists within INL's previous experimental results.
- After comparing with Inconel 617 data, 709, 800H, and 316H alloys will be tested as these alloys have shown promise for future viability in high temperature/Gen IV reactor structural applications.

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