WE START WITH YES.

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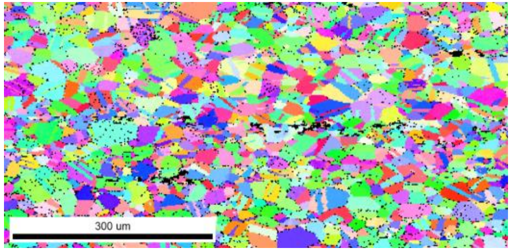
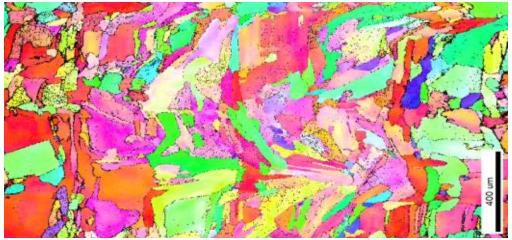
CHALLENGES IN QUALIFYING ADVANCED MANUFACTURING TECHNOLOGIES FOR HIGH TEMPERATURE NUCLEAR SERVICE



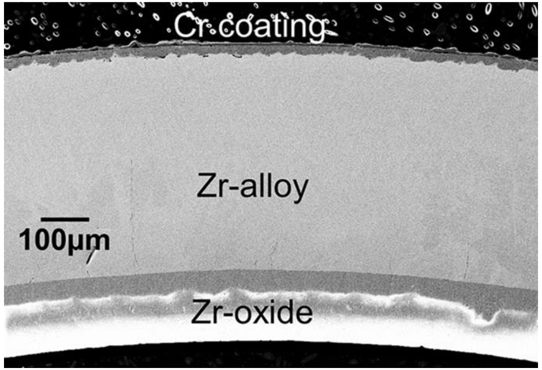


MARK MESSNER

NRC Advanced Non-Light Water Reactors – Materials and Component Integrity Workshop
10 December 2019

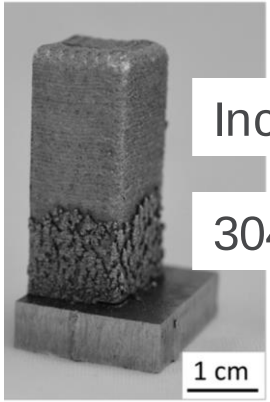
WHY WOULD YOU WANT TO USE AM TECHNOLOGIES IN ADVANCED REACTORS?

- Complicated, small, difficult to conventionally manufacture parts:
  - Pump impellers and casings
  - Core internals
  - Compact heat exchangers
- Bimaterial cladded components
- Replacement parts
- High performance, functionally graded components
- Unique, difficult to manufacture materials



Maier et al. 2018

Westinghouse

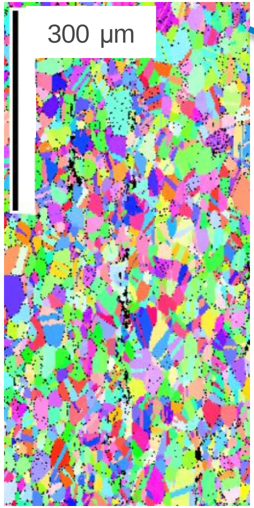


Carroll et al. 2016

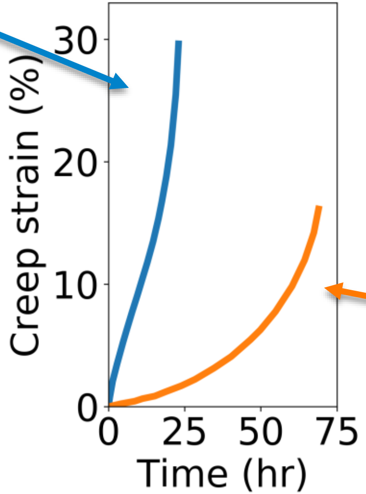
WHAT ARE THE CHALLENGES QUALIFYING AM MATERIALS IN GENERAL?

- *Variability in AM material properties is much greater than for conventional wrought/cast material – more akin to welds*
  - Less understood processes
  - Many processing parameters controllable by users
  - Wide variety of technologies
  - Manufacturing likely to occur at a number of smaller sites, rather than at large, central production facilities
- *AM methods often result in significant material property variations within a single build*
- *We want a process that can take advantage of the flexibility of AM processes – not trying to simply 3D print conventional material*

Wrought 316L



Creep at same conditions



AM 316L

AM material good, bad, or just different?

AM creep specimens courtesy UW Madison

WHAT ARE THE CHALLENGES QUALIFYING MATERIALS FOR HIGH TEMPERATURE SERVICE?

- At high temperatures long-term, time-dependent material properties control design:
  - Creep strength and ductility
  - Creep-fatigue life
  - Thermal aging characteristics
- Short-term tests might tell you very little about important long-term properties
- Statistical variation in mechanical properties tends to be high, even for well-controlled traditional wrought material processes
- Weld resilience can be challenging
- Very little long-term mechanical test data on AM material for properties relevant to high temperature design

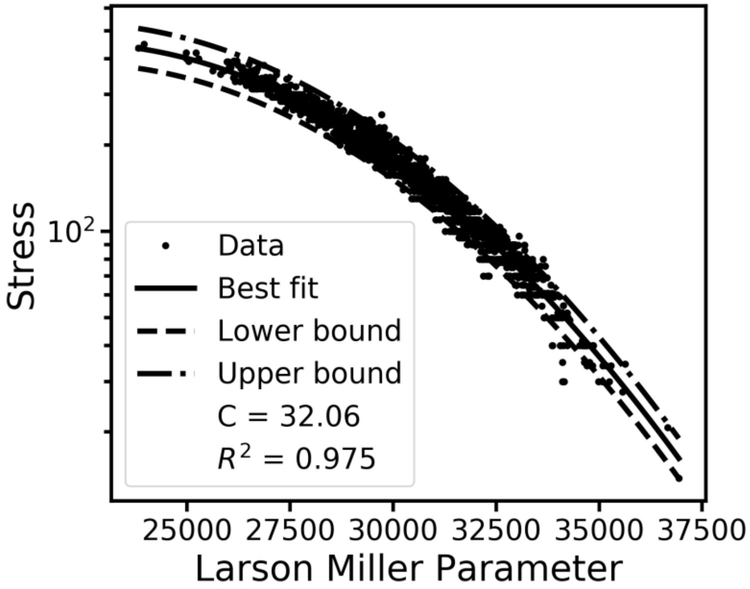
Seam pipe failure at coal power station (Viswanathan and Stringer, 2000)

Creep cavitation (INL)

HRSG tube failure (EPRI, 2005)

THE CLASSICAL QUALIFICATION PROCESS

- Get a material specification from the metallurgists – *this "ensures" repeatability*
- Procure several heats of material – *this tests material variability*
- Long term mechanical testing (including creep, creep-fatigue, and thermal aging)
- Extrapolate properties (factor of 3 typical)
- Establish time-dependent design properties out to desired/available design life



For design, qualification is a contract: "I promise you will have material properties better than xxx"

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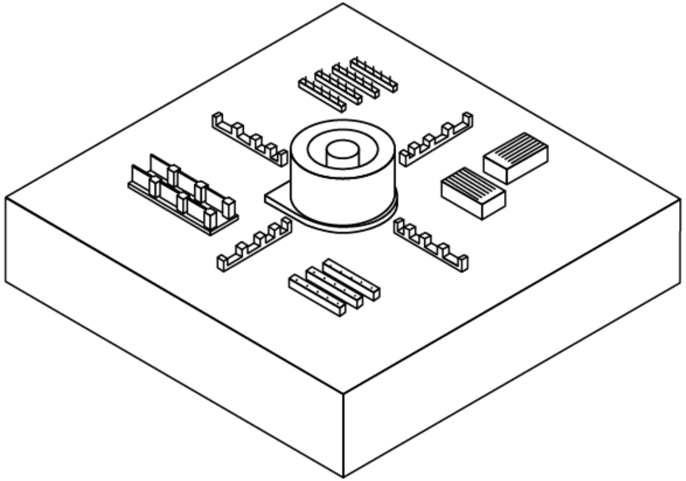
AM QUALIFICATION, BASIC STANDARD: REPEATABILITY

Process, machine, and operator qualification



ASTM-ISO/ASTM52902-19

- Don't worry about properties (yet) just make sure builds are repeatable with adequate geometric tolerances
- Example of an existing standard: ASTM-ISO/ASTM52902-19
  - Use test artifacts to assess machine capabilities and build repeatability
- Could use other properties to assess repeatability:
  - Mechanical properties
  - Microstructural measurements
  - Indirect signals from in-situ monitoring

PROPERTIES QUALIFICATION OPTION 1: WITNESS TESTING

Materials with adequate short-term properties will meet long-term property requirements (?)

Example from ASTM F42.01 Work Item WK49229

Short-term

1. Fabricate part along with witness test samples
2. Measure mechanical properties of witness samples, compare to minimum specified properties

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3. Assume long-term material properties will be comparable to reference material having the same *short term* properties – ***requires test program***

Long-term

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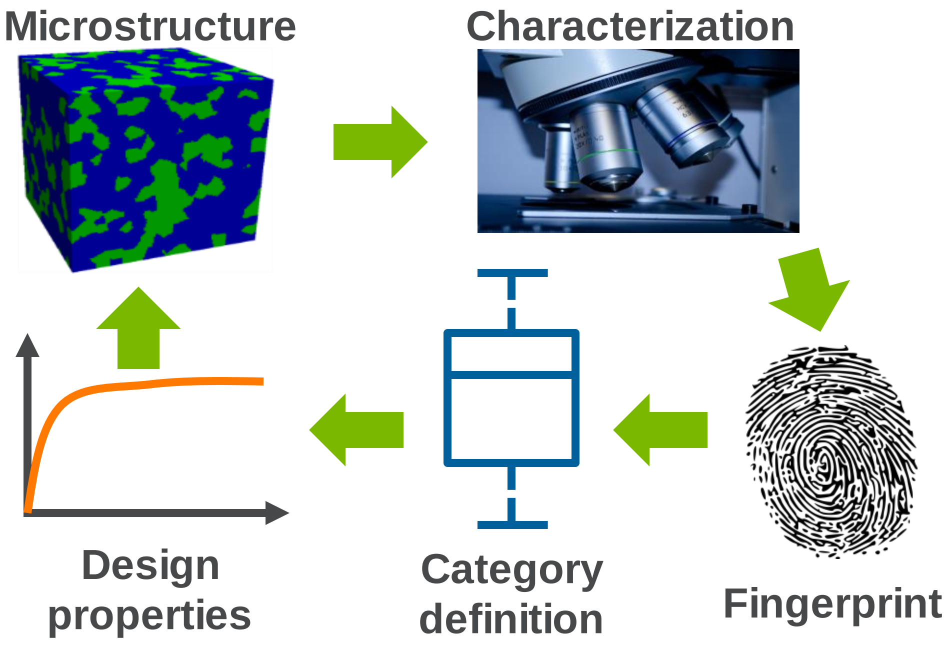
PROPERTIES QUALIFICATION OPTION 2: QUALIFY BY MICROSTRUCTURE

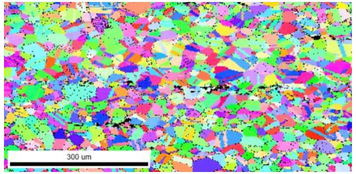
Two materials with the same microstructure will have the same long-term properties



1. Define a material class with definite microstructural characteristics (i.e. a “fingerprint”)
2. Develop qualified properties for that class via ***testing or modeling/simulation***
3. Ensure that production material falls into the material class via in-situ or ex-situ high throughput characterization

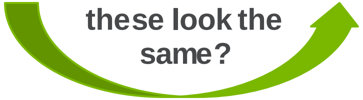
ACCELERATING QUALIFICATION

Several options to accelerate the traditional high temperature qualification process

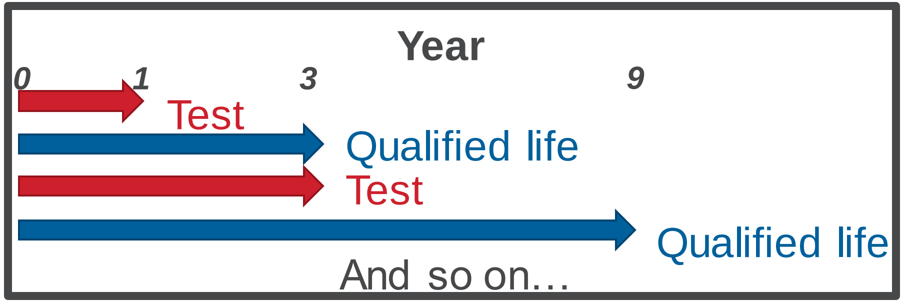


Wrought 316L

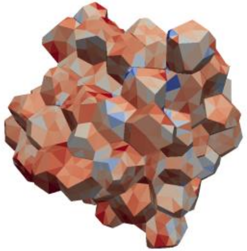
AM 316L (as printed)

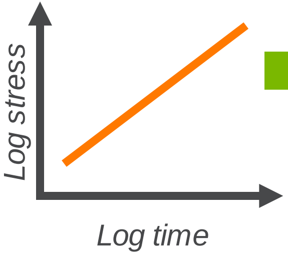


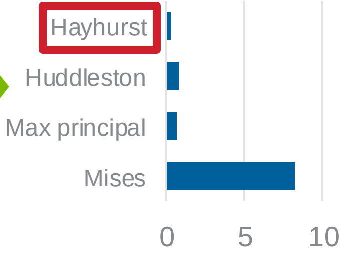
Emulate traditional wrought material



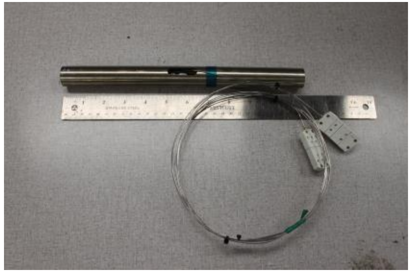
Staggered testing schedules







Use models to replace (some) tests



Partially rely on in-situ monitoring

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CONCLUSIONS AND QUESTIONS TO ANSWER

Qualifying AM materials for high temperature nuclear service will have some unique challenges, but options are available. It would be best to start now with likely technologies and materials, given the reliance of high temperature design on long-term material properties.

1. What is going to be the first use of AM material in high temperature reactors? What time frame? Replacement parts or new construction?
2. Given the answer to #1, what basic research will be required before we need to start the qualification process?
3. What properties/measurements should we use to assess components?
4. How much trust do we have in physically-based models for relevant properties? How much (if any) testing could we forgo and replace by simulation?
5. Can vendors live with the risk of a staggered testing schedule and/or in-situ monitoring?