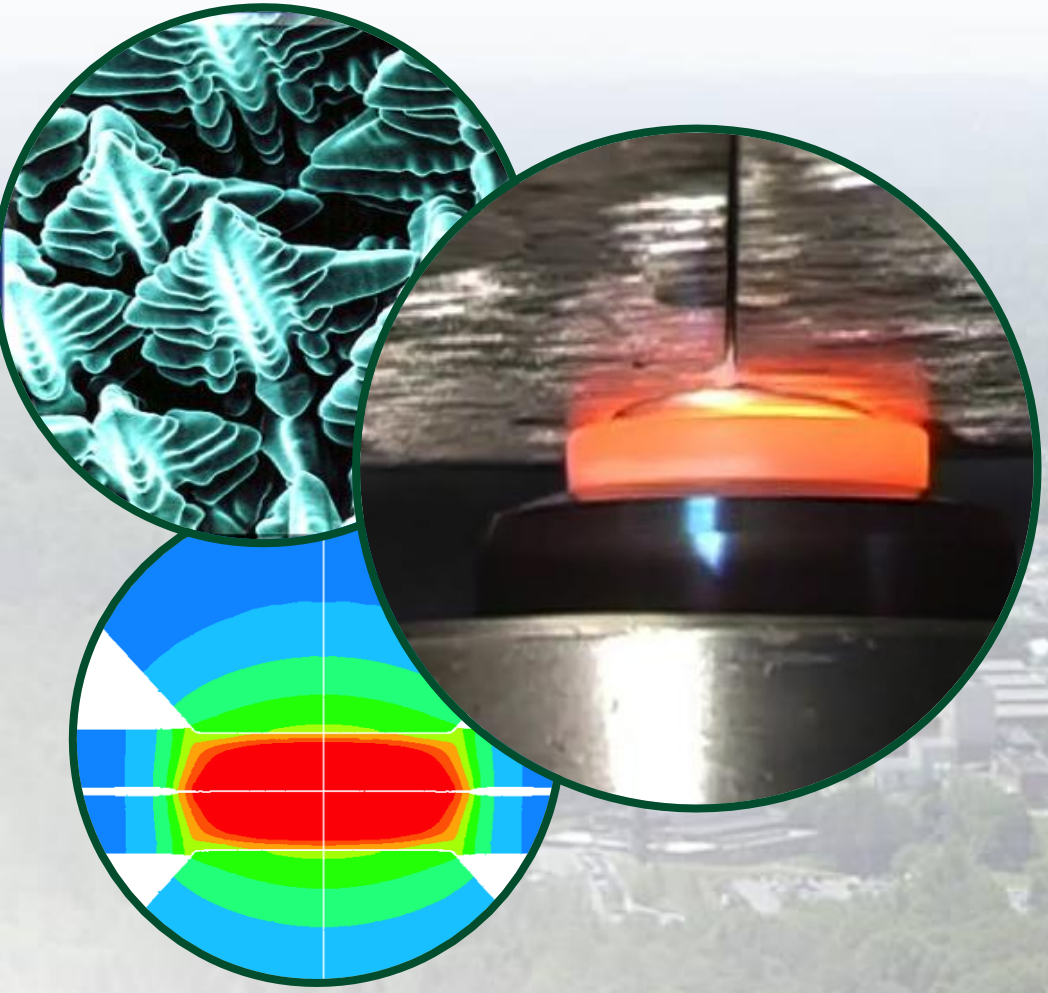
Multi-Material Joining: Challenges and Opportunities



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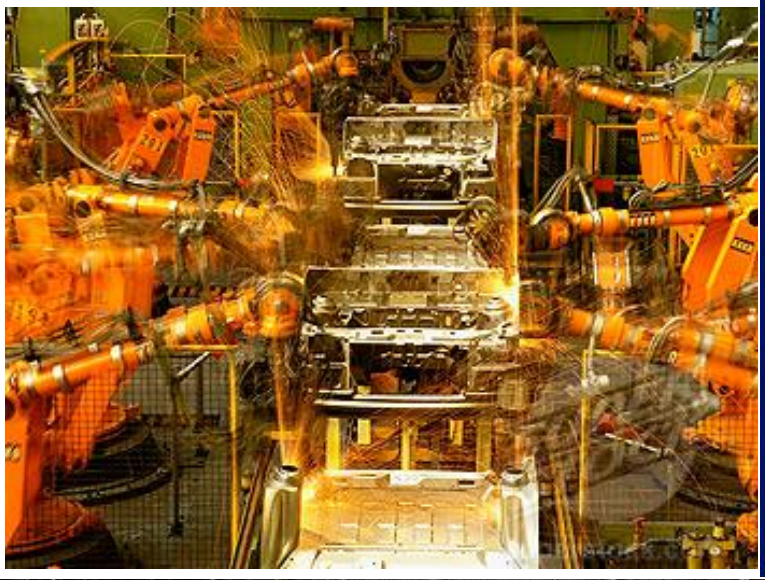
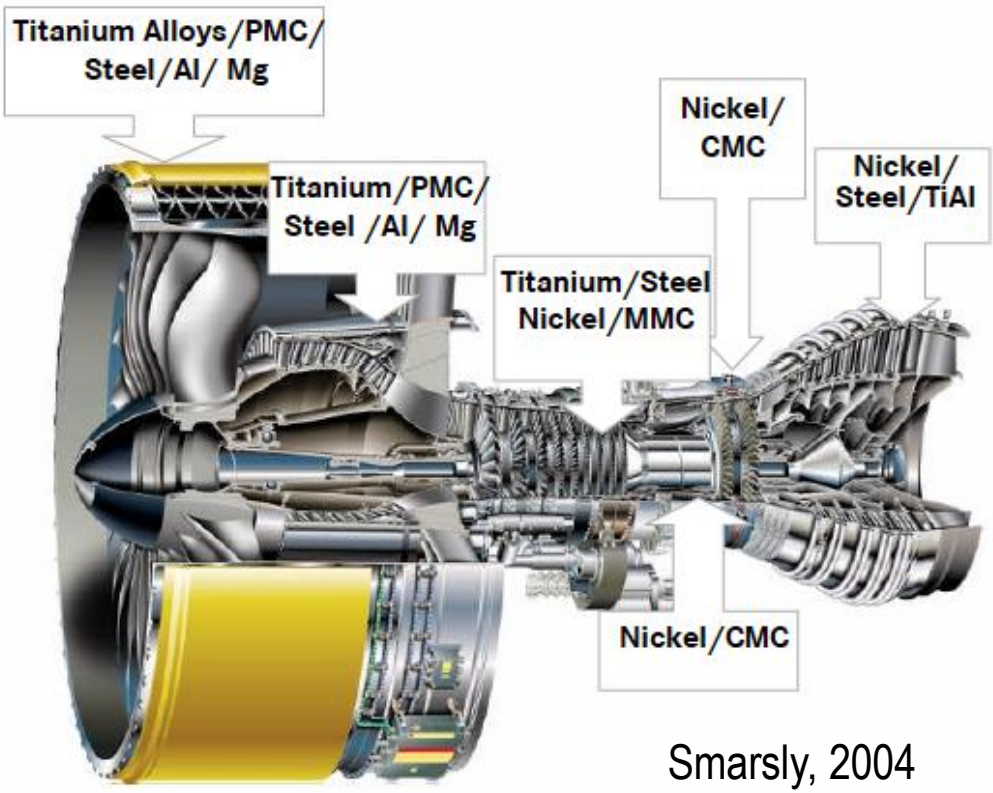
Materials Joining is a Critical Enabling Manufacturing Technology

- Nuclear Energy
- Fusion Energy
- Fossil Energy
- Oil & gas
- Solar, wind
- Battery, fuel cell
- Automotive
- Aerospace
- Computer
- Defense
- Medical
- Space Power



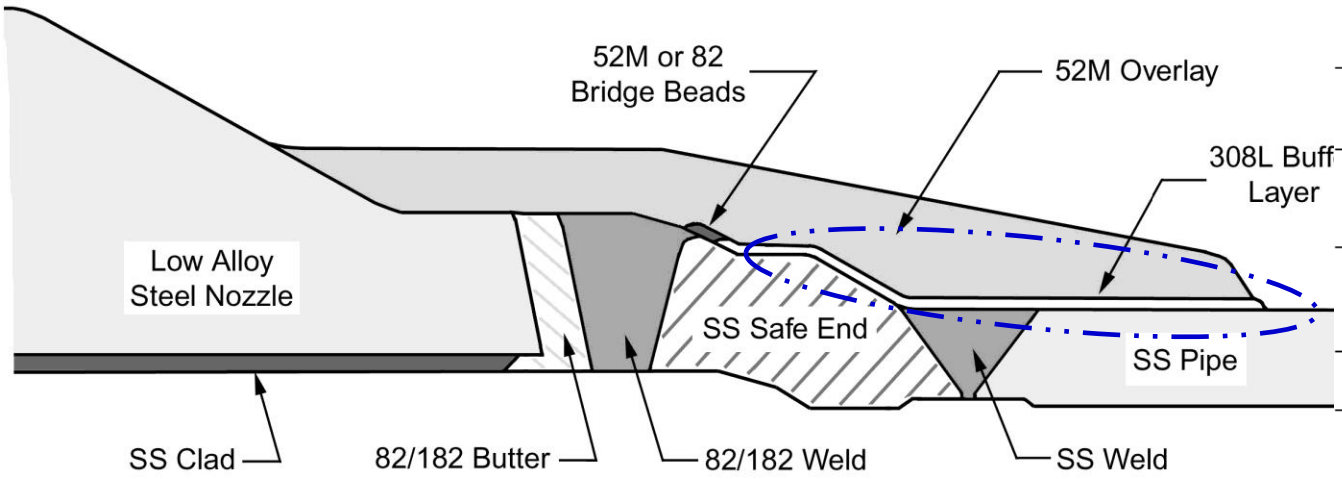
Multi-material joining in aircraft engines

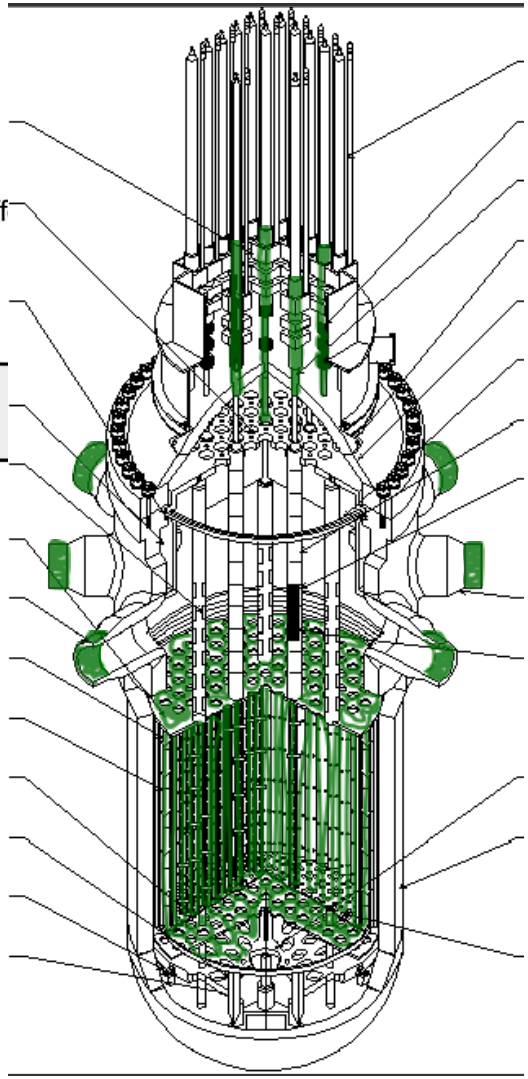
- Uses a variety of highly engineered high-performance materials
- Must meet the fit-form-function requirements
  - Microstructure and properties changes in the joint region
  - High-cost in controlling/correcting joining induced distortion of high-precision components
- R&D Needs
  - Joining process innovation and improvement
  - Application of ICME to integrate joining into the engine manufacturing chain for cost and weight reduction and performance/reliability improvement
  - Virtual manufacturing system



Smarsly, 2004

Joining of multi-materials for nuclear reactors





- Manufacturing issues: hot cracking
- Service issues: stress corrosion cracking (SCC)
- Critically impact
  - Construction of new nuclear power plants
  - Life extension of existing nuclear power plants

Joining of multi-materials is a high priority for automotive body light weighting

Technology Gaps and Priorities for both HD and LD Vehicle Systems

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

System	BIW & Cab	Propulsion	Chassis	Closures
Joining of Multi-materials	X		X	X
Optimized Performance (including matls for rotating parts, lower cost, improved strength etc)		X	X	X
Predictive Models	X			X
Optimized Manufacturing (including lower cost and larger parts)	X		X	
Design Tools	X			X
Cost and availability of Materials	X			
Corrosion				X

Vehicle Technologies Program eere.energy.gov 9

C. Schutte and W. Joost, DOE EERE Vehicle Technologies Program, 2012

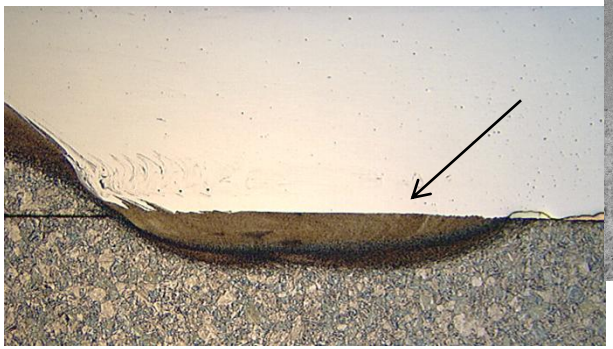
Challenges in Automotive Joining of Dissimilar Materials

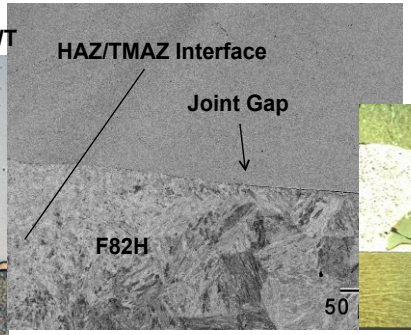
- New emphasis on light weighting through use of new, lower density or stronger materials
  - Gen II and Gen III AHSS, aluminum, magnesium, polymer composites, carbon fiber composites
    - Each material has it's unique attributes (often attained through thermal processing)
    - Many are subject to degraded performance when exposed to high temperatures (as in welding or paint bake)
- Processes MUST be fast, robust and low cost
  - Legacy facilities, equipment and skills based on "conventional" steels
  - Various joining options to choose from, but with limited application knowledge or experience in new materials
    - RSW, GMAW, laser, solid-state joining (FSW, ultrasonic), adhesive bonding, mechanical fastening
- Service and Performance Issues
  - Galvanic corrosion
  - Distortion and stress due to differing coefficients of thermal expansion
  - Limited ability to model properties and performance of joints or assemblies

Looking Forward

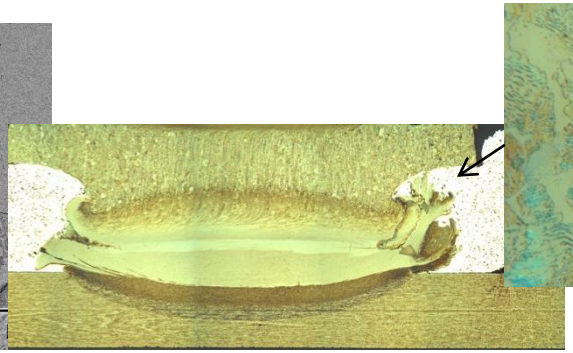
- Welding connects structural members together in economically favorable fashion, to perform adequately for the intended services and applications
- Multi-material joining would require both technology innovations in process, and improved design and engineering practices, for quality, property and performance
  - Friction stir welding and other solid-state joining processes,
  - Proactive weld residual stress control,
  - Weld microstructure/property engineering,
  - More reliable prediction the performance of welded structures
  - Integrated computational weld engineering model (ICWE) can play a critical role
- Collaborate and leverage among all interested parties

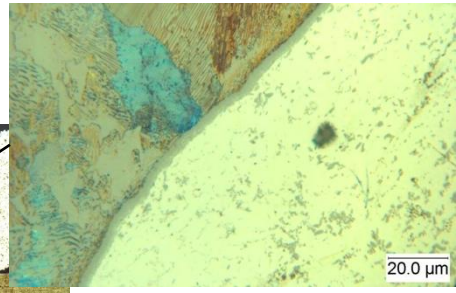
Solid-state joining technologies such as FSW for multi-material joining



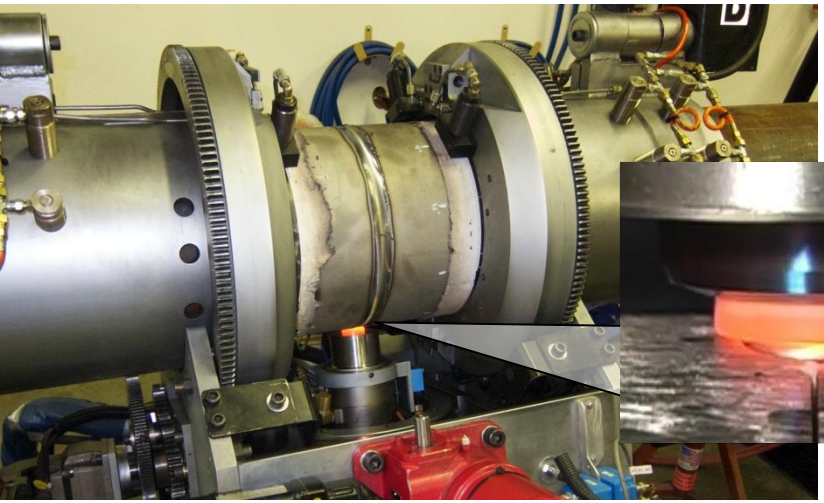


FSW of ODS to RAFM steel

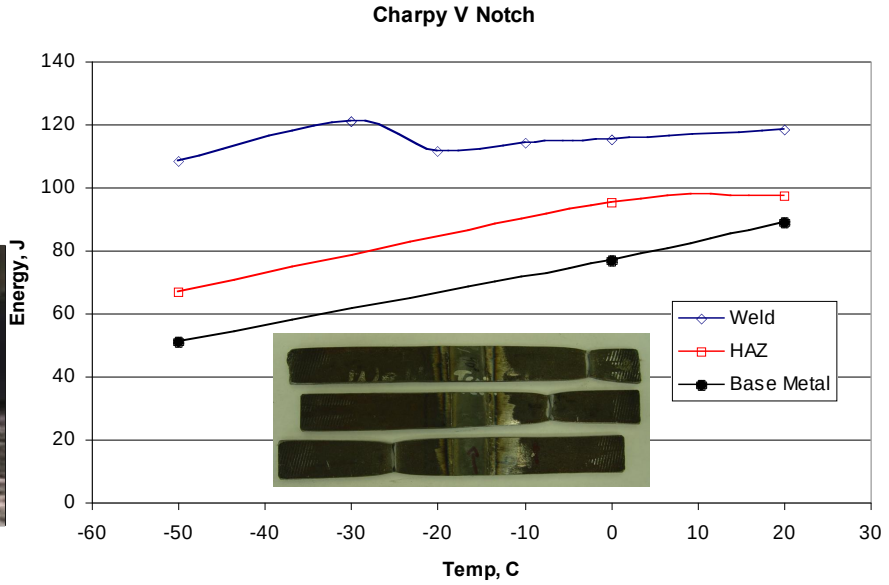




Friction bit joining of Al to AHSS



Field Deployable Orbital FSW system



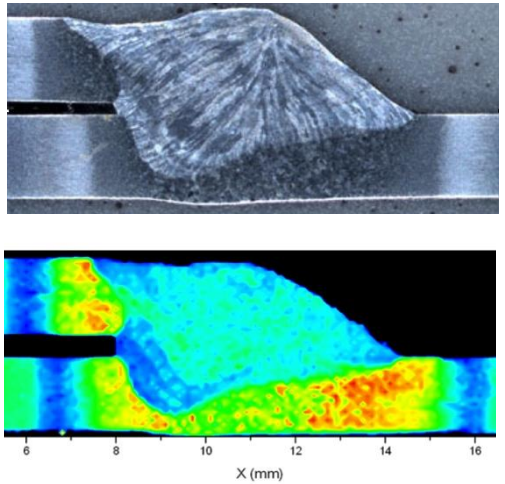
FSW of X65 steel

Backup Slides

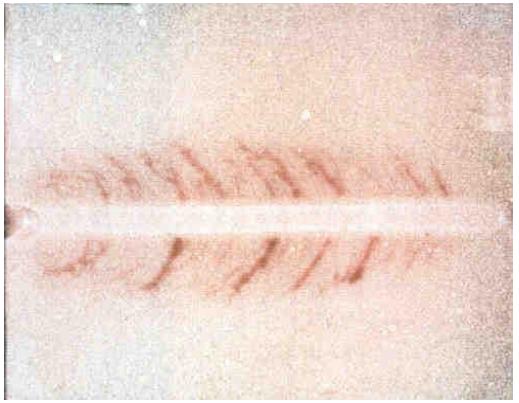
Weld region can have a profound influence on performance and reliability of welded structure

- Fundamental causes
  - Localized heating resulting in different thermo-mechanical cycles at different locations
  - Inhomogeneity of the weld region (property gradient)
    - "Composite" nature of inhomogeneity
    - Different from base metal
  - Residual stress and distortion (dimensional change)

- These effects are amplified in multi-material joining
  - Compatibility of materials.
  - Difficulties to join them
  - Subsequent service performance issues

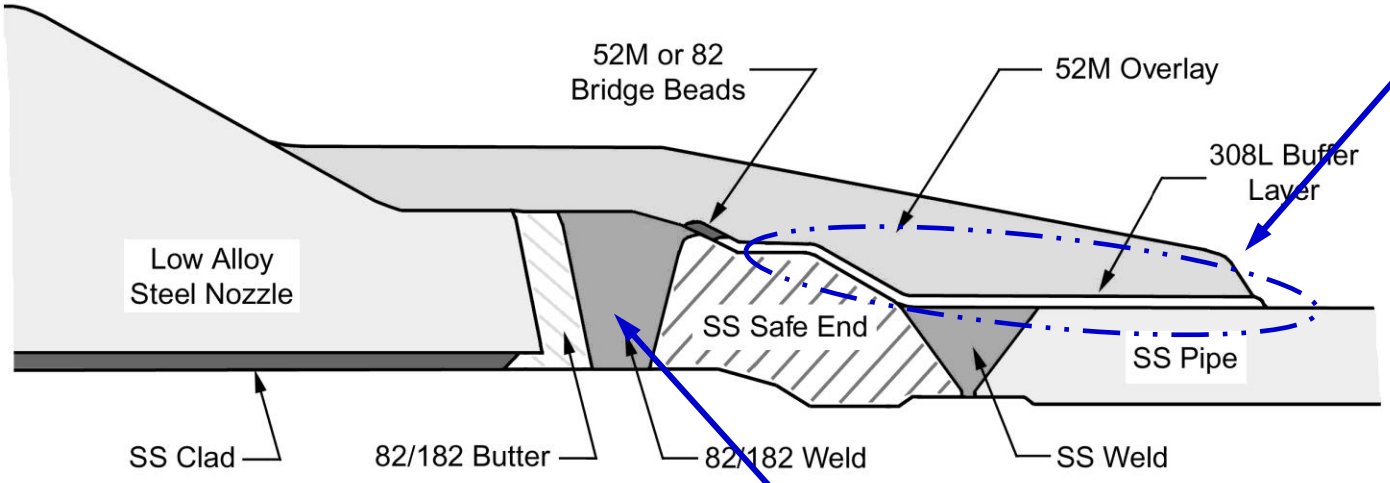


Microhardness mapping of a AHSS weld

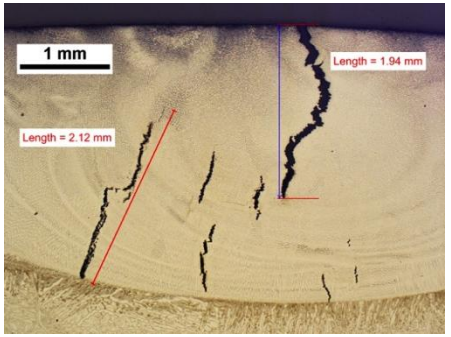


SCC in HAZ of SS304 Weld

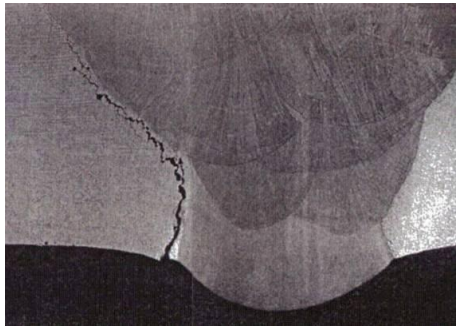
Joining of multi-materials for nuclear reactors



Hot cracking can occur in these areas



Stress corrosion cracking (SCC) during service



- Manufacturing issues: hot cracking
- Service issues: stress corrosion cracking (SCC)
- Critically impact
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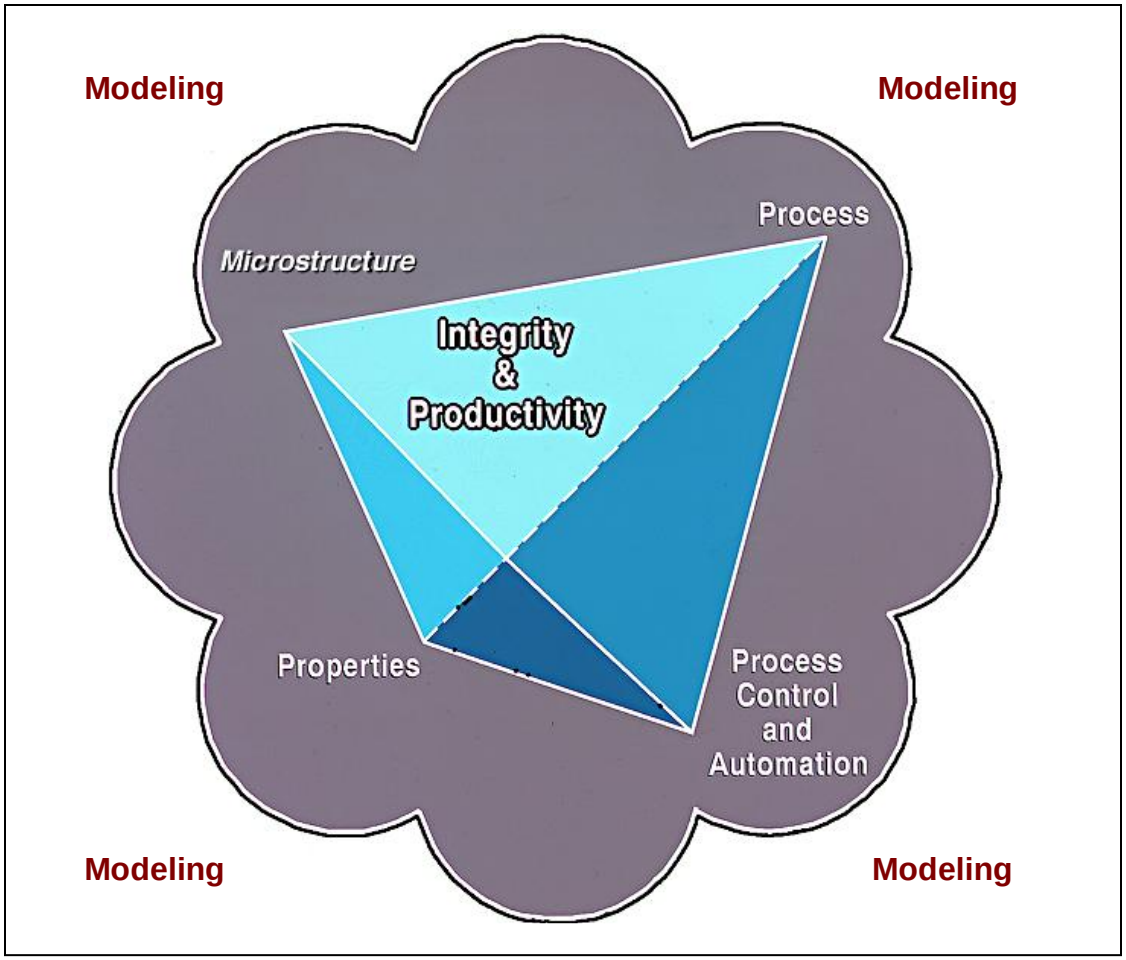
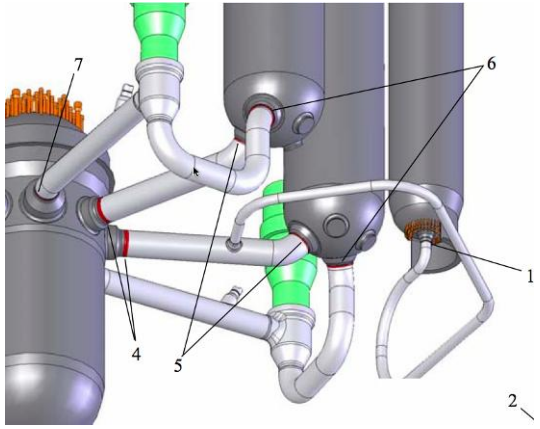
Integrated computational weld engineering model (ICWE) play a critical role in multi-material joining

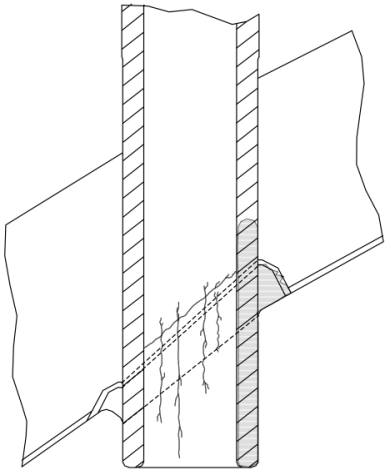
- Establish quantitative relationship between welding process variables (input) and quality/performance (output)
- Gaining insights to a welding process
- Assisting process development/design

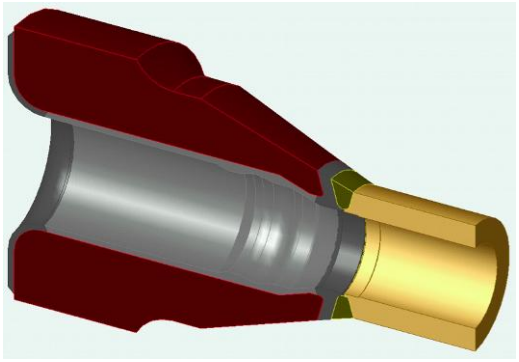


Dissimilar Metal Weld SCC is a Major Degradation Mechanism in Light Water Reactors

- May compromise functionality of the safety systems
- A recurring problem since the mid 1970s
  - Re-circulation piping cracking in BWRs
  - 2000 VC summer, Ringhals 3 & 4
  - 2002 Davis-Besse, CRDM
  - 2003 Tsuruga (Japan)
  - 2005 Calvert Cliffs
  - 2006 Wolf Creek
- SCC is driven by the high-tensile residual stress and microstructure changes in the weld region







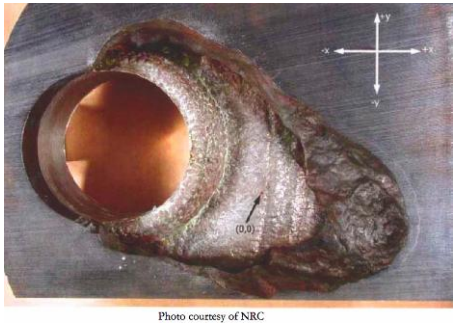
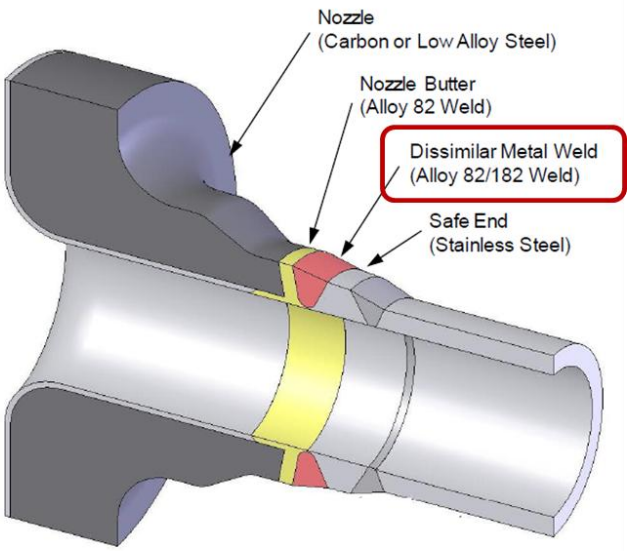
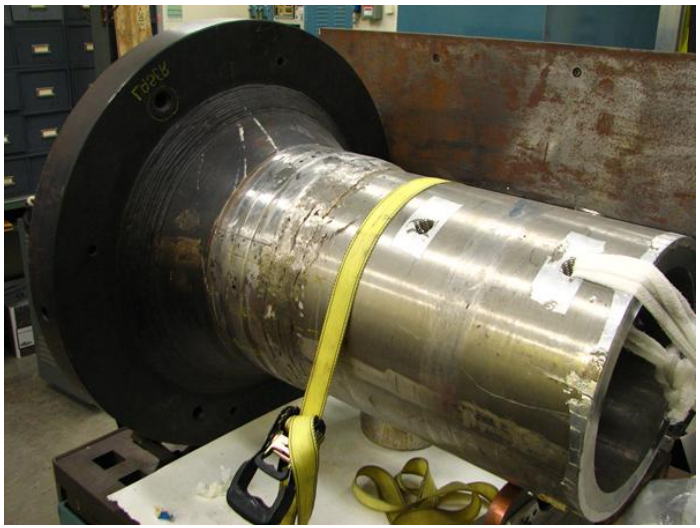


Photo courtesy of NRC

* Expert Panel Report on Proactive Materials Degradation Assessment US NRC NUREG/CR-6923, 2007

Improving Weld Residual Stress Prediction is Critically Needed





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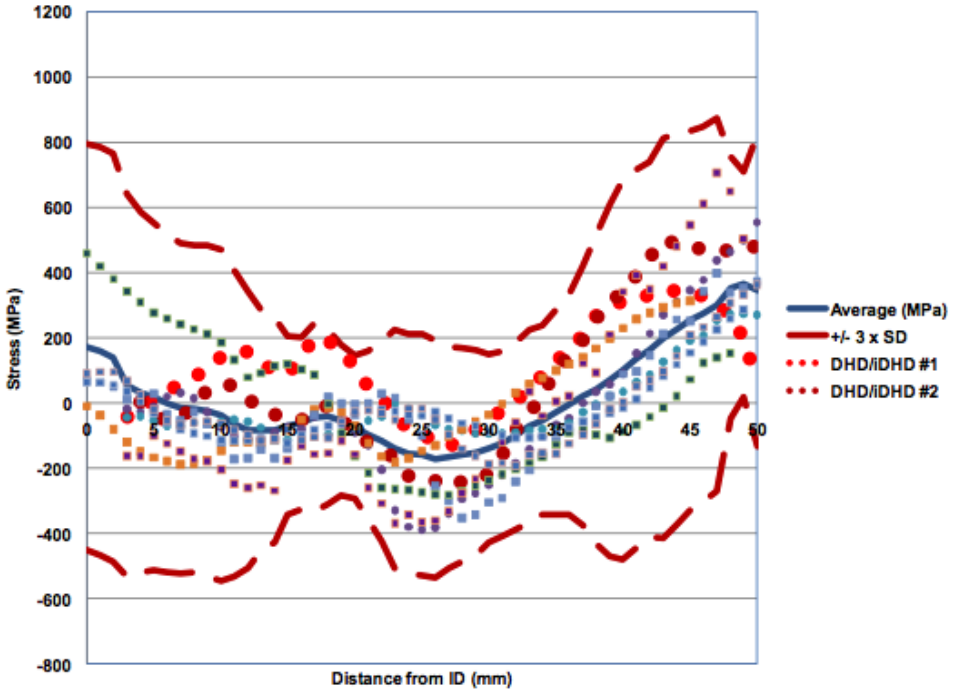
Rolls-Royce ansto Structural Integrity Associates, Inc.
Battelle OSAKA UNIVERSITY



Large scattering in predicted weld residual stress distribution

Rathbun et al., "NRC Welding Residual Stress Validation Program International Round Robin Program and Findings," 2011 ASME PVP.

Critical Knowledge Gaps in Materials Degradation in Nuclear Reactor Primary Components

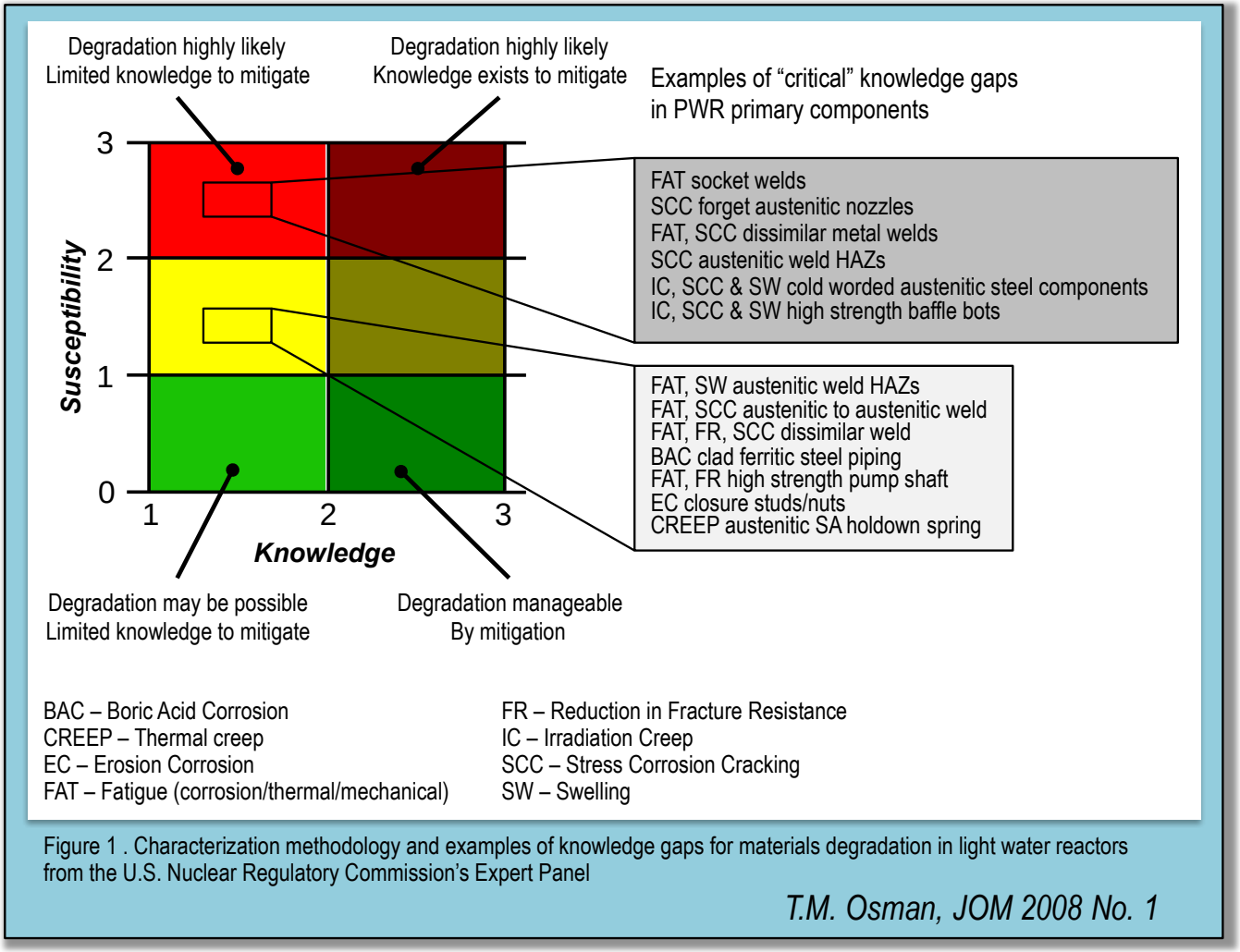


Figure 1 . Characterization methodology and examples of knowledge gaps for materials degradation in light water reactors from the U.S. Nuclear Regulatory Commission's Expert Panel

T.M. Osman, JOM 2008 No. 1

- **Weld region is ranked critically**

Advanced mitigation techniques: welding and advanced alloys

Motivation: To provide a mitigation strategy for overcoming key degradation

Issue Impact on extended service: Potentially high. Qualified welding methods may greatly improve reliability, safety, and economics