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

<table>
<thead>
<tr>
<th>System</th>
<th>BIW &amp; Cab</th>
<th>Propulsion</th>
<th>Chassis</th>
<th>Closures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joining of Multi-materials</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Optimized Performance (including mats for rotating parts, lower cost, improved strength etc)</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Predictive Models</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Optimized Manufacturing (including lower cost and larger parts)</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Design Tools</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cost and availability of Materials</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
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

Charpy V Notch

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

- 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
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

Improving Weld Residual Stress Prediction is Critically Needed

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

- **Weld region is ranked critically**

T.M. Osman, JOM 2008 No. 1
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.