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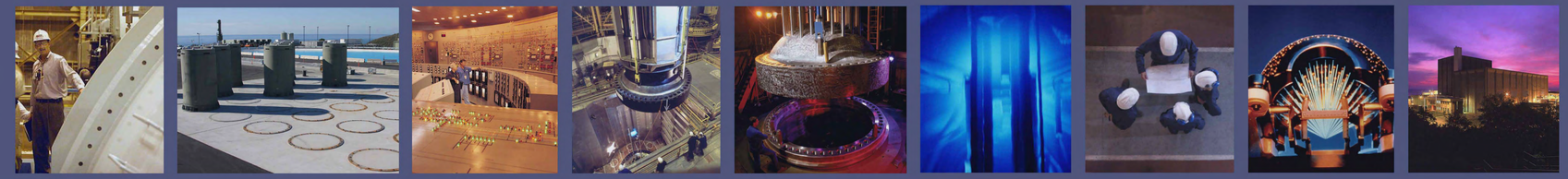


OFFICE OF NUCLEAR REGULATORY RESEARCH

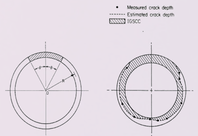
Fracture Behavior of Dissimilar Metal Welds: Validation of xLPR Stability Module

Introduction

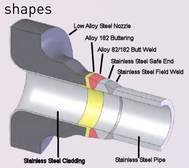
In the 1980s and 1990s, the the U.S. Nuclear Regulatory Commission (NRC) staff conducted extensive research on the stability of flaws in nuclear piping. However, with the occurrence of primary water stress-corrosion cracking (PWSCC) in dissimilar metal (DM) welds, the flaw stability characteristics are unknown. In addition, PWSCC flaws shapes are irregular and may be complex in shape, for which the assumption of an idealized flaw does not hold. To determine if and how the current methodology can be used to account for the unique situation of PWSCC in DM welds, the NRC staff has conducted experiments to confirm flaw stability assessments of complex flaws in DM welds. the NRC will use the data to enhance the joint NRC/EPRI probabilistic fracture mechanics code, xLPR.

Motivation

- A Typical flaw evaluation per American Society of Mechanical Engineers Section XI IWB3600, and in determination of leak-before-break, per Standard Review Plan section 3.6.3 and NUREG-1061, flaw shapes are assumed to be idealized.
- Flaw evaluation procedures have only been developed for similar metal welds and base metals.
- PWSCC in DM welds can produce complex-shaped cracks.
- Uncertainty in estimation schemes, material properties, crack-driving force, and toughness need to be quantified for probabilistic fracture mechanics calculations (xLPR).



Idealized and natural crack shapes



Surge nozzle geometry

Objectives of NRC-Sponsored Research

- Conduct experiments on DM welded pipe fractures to determine load-carrying capacity.
- Investigate currently available estimation scheme in predicting load-carrying capacity.
- Modify or develop a way to estimate the load-carrying capacity of idealized and complex cracks in the xLPR code the load carrying capacity of idealized and complex cracks for use in xLPR code.
- Develop a level of model uncertainty for use in the xLPR code.
- Provide regulatory insight to the stability of PWSCC in DM welds and allow the uncertainties in such data to be further quantified for use in probabilistic fracture mechanics applications.

Dissimilar Metal Weld Fracture Program

Materials

8-inch nominal diameter, schedule 160, Type 316, stainless steel pipe

- A106 Grade C pipe material — heat with tensile properties similar to A508 Grade 2 forgings
- Alloy 182, shielded metal arc welding process for butter (postweld heat treated after butter)
- Alloy 82, gas tungsten arc welding process

Pipe Test Details

Pipes tested in four-point bending at 600 F with no pressure. Measurements include:

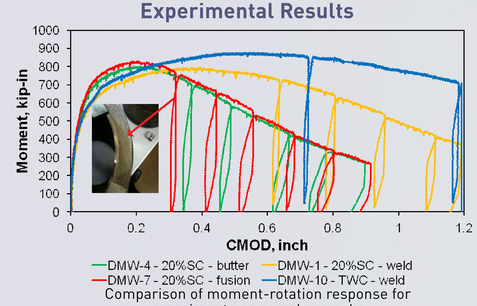
- loads (moments)
- pipe rotation
- crack mouth opening displacements
- Direct current electric potential data for crack-initiation and crack-growth assessments

Pipe fracture experimental facility

Test Matrix

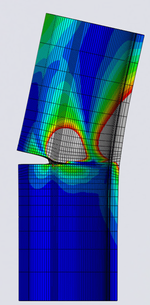
Expt No.	Type of Crack	Crack Location	Surface Crack a/t	Surface Crack Θ/n	TWC Θ/n
DMW-0	Uncracked	N/A	N/A	N/A	N/A
DMW-1	Complex Crack	Weld	0.2	1.0	0.37
DMW-2	Complex Crack	Weld	0.4	1.0	0.37
DMW-3	Complex Crack	Weld	0.6	1.0	0.37
DMW-4	Complex Crack	Butter	0.2	1.0	0.37
DMW-5	Complex Crack	Butter	0.4	1.0	0.37
DMW-6	TWC	Weld	N/A	N/A	0.20
DMW-7	Complex Crack	Fusion Line	0.2	1.0	0.37
DMW-8	Complex Crack	Fusion Line	0.4	1.0	0.37
DMW-9	TWC	Weld	N/A	N/A	0.37
DMW-10	TWC	Weld	N/A	N/A	0.37
DMW-11	TWC	Butter	N/A	N/A	0.37
DMW-12	Surface Crack	Weld	0.6	1.0	N/A
DMW-13	TBD	TBD	TBD	TBD	TBD

Experimental Results

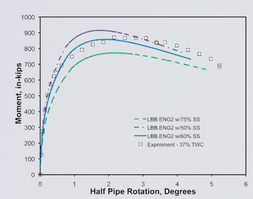


Comparison of moment-rotation response for experiments on complex cracks

Predicting Experimental Results



Finite-element results



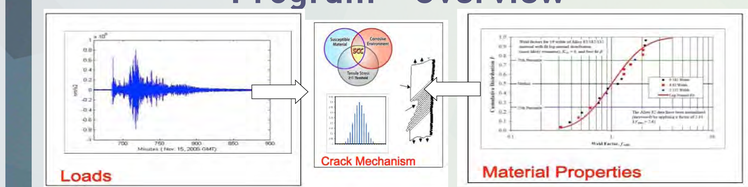
Moment-rotation predictions for 37% through-wall cracked DM welds

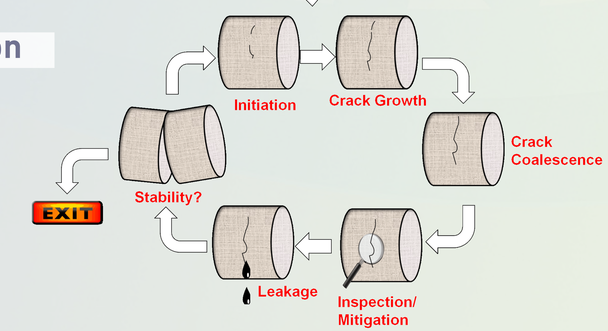
Estimation Scheme Development

- Predict pipe response using finite-element analyses and analytical solutions.
- Modify analytical solutions for DM welds using experimental results.
- Use modified analytical solutions in xLPR.

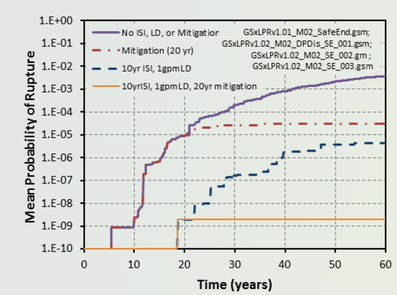
Validation

NRC/EPRI-Sponsored xLPR Program—Overview





Schematic of xLPR process



Mean probability of rupture

Current Research Efforts

- Develop a robust methodology for evaluating reactor coolant system piping rupture probabilities.
- Conduct the xLPR project under an agreement that allows cooperative research by the NRC and EPRI.
- Verify, validate, benchmark, and document the software tool to enable its use in support of design and regulatory decisions by both industry and the NRC.

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