Dissimilar Metal Weld Pipe Fracture Testing – Analysis of Results and their Implications

by

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Introductory Note

- This paper is a follow-on effort to last year's paper PVP2011-57535
- This paper is a companion paper to PVP2012-78353

Background

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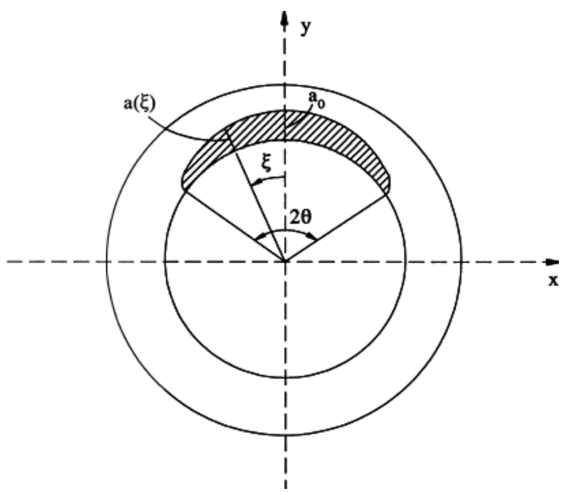
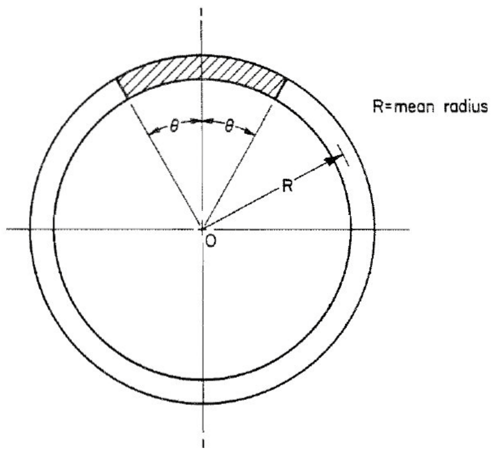
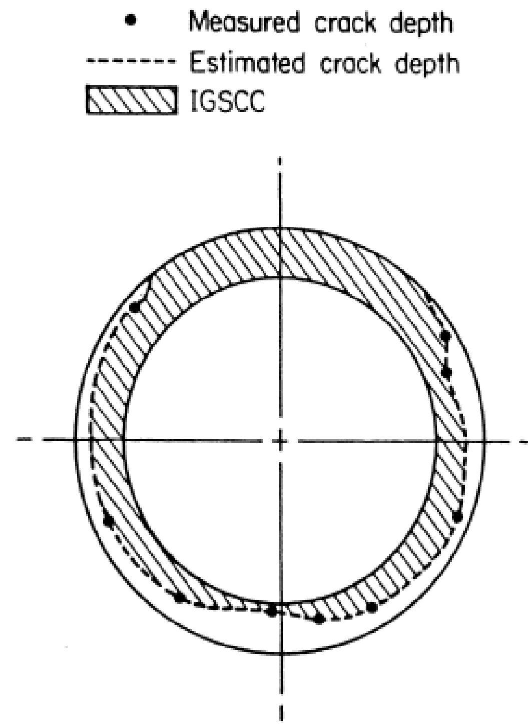
- In standard flaw evaluation procedures, per ASME Section XI IWB3600, and in determination of Leak-Before-Break (LBB), per Standard Review Plan (SRP) 3.6.3 and NUREG-1061, flaw shapes are assumed to be idealized
- But for Stress Corrosion Cracking (SCC) the flaws may not grow idealized



Elliptical Surface crack



Through-wall crack



Actual SCC

Background

- Complex crack behavior is a challenge when predicting the maximum load-carrying capacity

- In PWRs, dissimilar metal (DM) (Alloy 82/182 joining carbon steel nozzle to stainless pipe) welds are susceptible to PWSCC

- PVP2007- 26733 discusses which material properties should be used in predicting maximum load for these DM welds with idealized cracks – Behavior of complex cracks in DM welds not investigated
  - For TWC in center of weld – 60%SS, 40%CS tensile properties within J-estimation gave good crack-driving force predictions

Past Complex Crack Experiments

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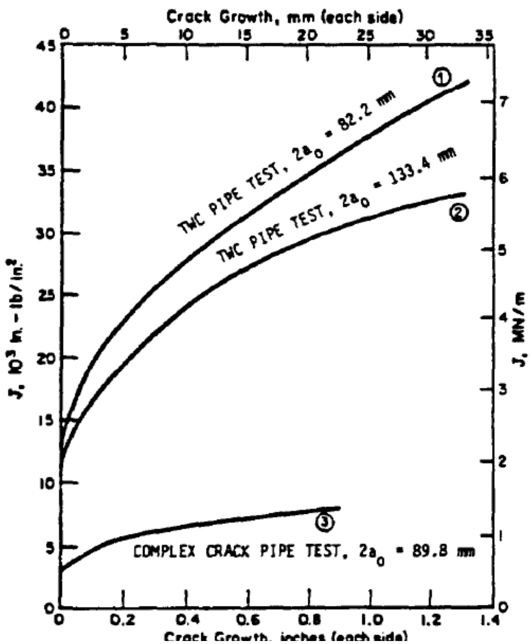
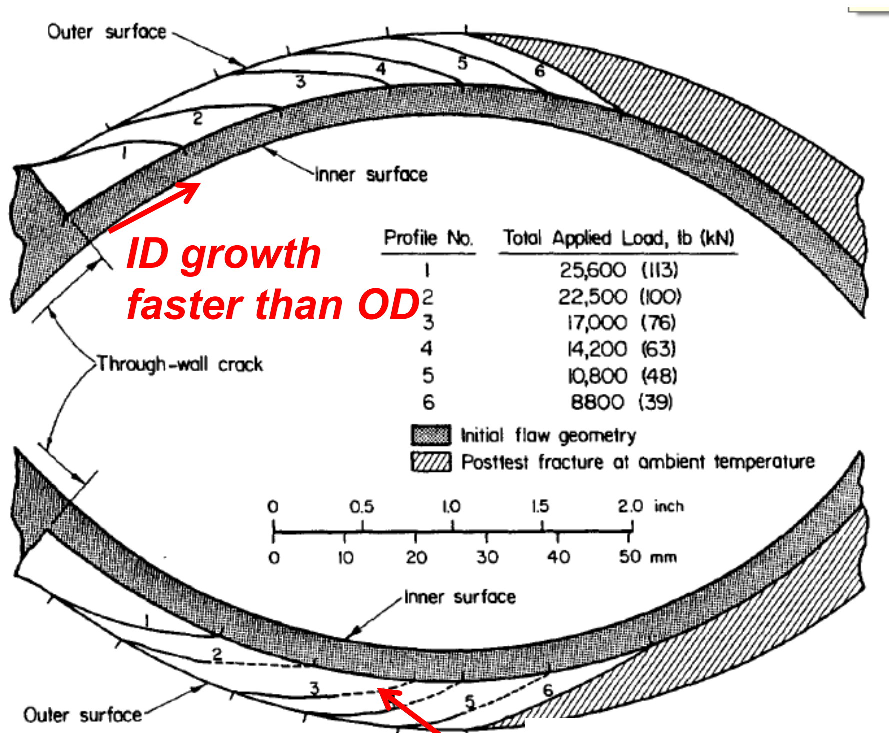
- NUREG/CR-4687 describes a series of complex crack 4-point bend experiments on A106GB, Alloy 600, and TP304 SS pipe



Analyses assumed TWC with reduced wall thickness for reasonable maximum load predictions



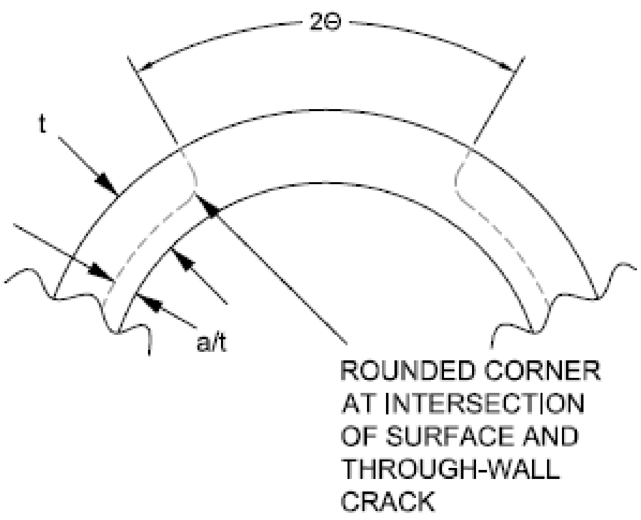
Not quite idealized

DM Weld Complex Crack Experiments

- 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, SMAW process for butter (post weld heat treated after butter)
  - Alloy 82, GTAW process
- Small scale experiments – all at 600F
  - Tensile tests for both the A106C and Type 316 base materials,
  - Tensile tests for the DM weld, and
  - Fracture toughness tests for the DM weld for the fusion line, butter, and main DM weld

Test Matrix and Results

Expt Number	Crack Location	a/t	θ/π	Max Moment kN-m (in-kips)	Initiation Moment, kN-m (in-kips)
DMW1	Weld	0.2	0.37	92.80 (821.4)	N/D
DMW2	Weld	0.4	0.37	82.86 (733.4)	78.9 (698.4)
DMW3	Weld	0.6	0.37	64.85 (574.0)	63.78 (564.5)
DMW4	Butter	0.2	0.37	94.28 (834.6)	92.7 (820.8)
DMW5	Butter	0.4	0.37	82.17 (727.2)	81.5 (721.3)
DMW6	Weld	N/A	0.20	187.3 (1658.3)	169.7 (1,502.0)
DMW7	Fusion Line	0.2	0.37	96.44 (853.6)	94.32 (834.8)
DMW8	Fusion Line	0.4	0.37	82.04 (726.2)	78.76 (697.1)
DMW9	Butter	N/A	0.37	105.1 (930.4)	102.1 (903.7)
DMW10	Weld	N/A	0.37	102.9 (911.0)	N/D
DMW11	Weld	N/A	0.37	106.8 (944.9)	100.9 (893.2)
DMW12	Weld	0.6	N/A	220.2 (1,948)	N/D
DMW13	Weld (PC)	N/A	0.37	103.3 (914.2)	97.9 (866.8)



Experimental Results

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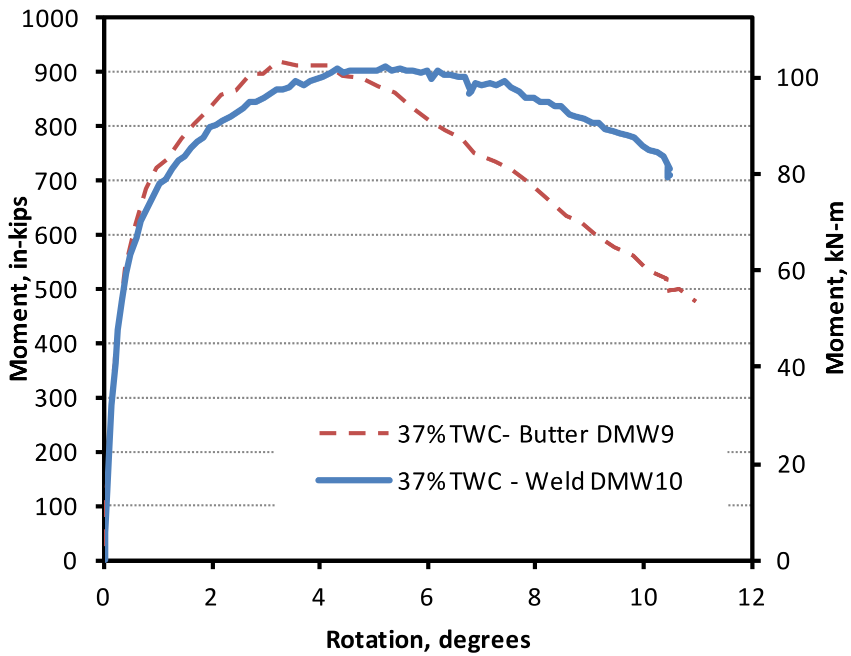

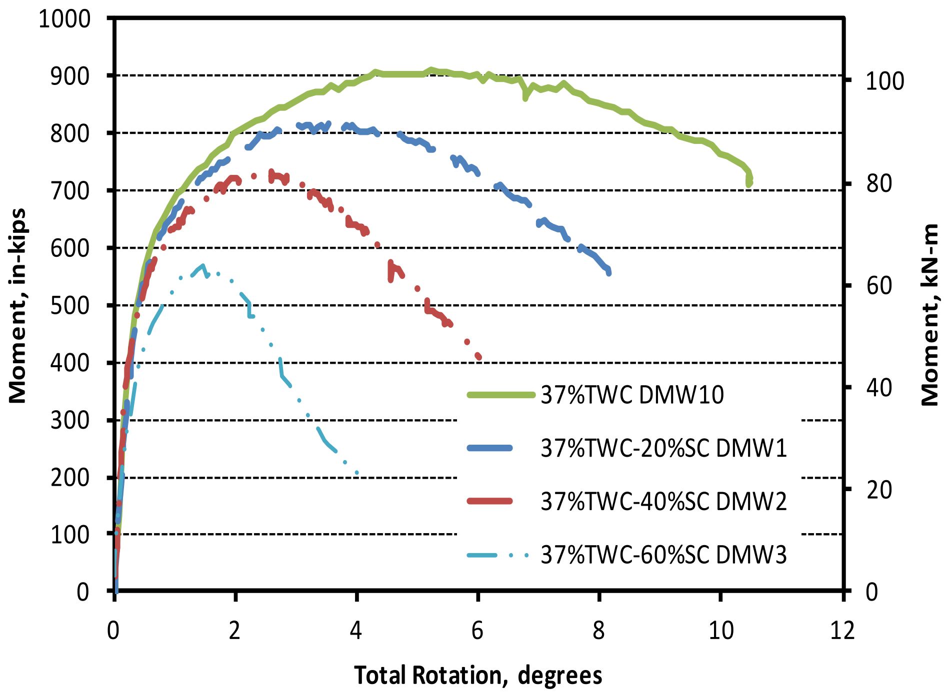

Experimental details found in PVP2012-78353

Predicting Response

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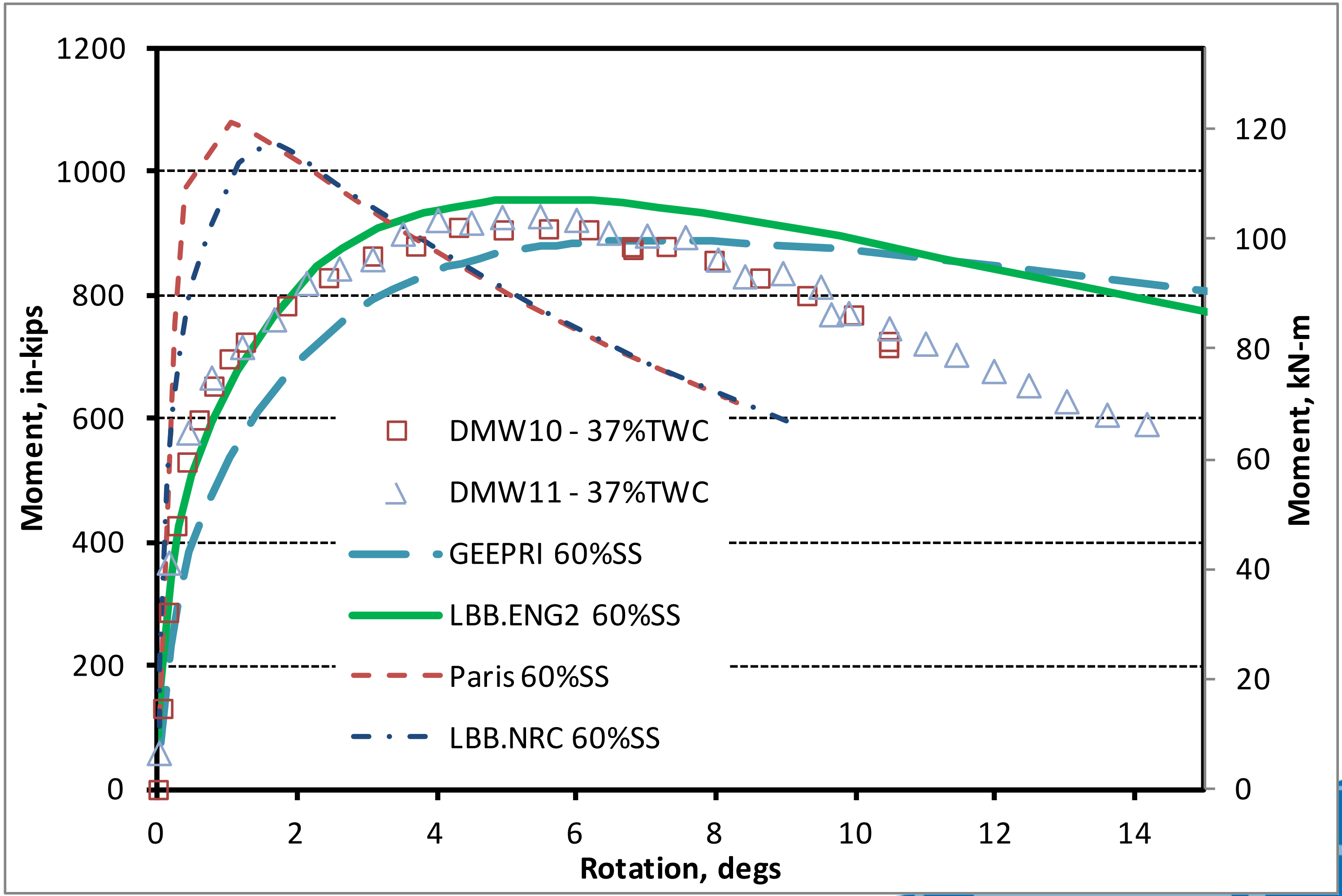
- Several J-estimation schemes were used to predict load-rotation behavior of experiments
- GE/EPRI
  - Based on a compilation of finite-element solutions for TWC pipes using deformation theory of plasticity
- Paris/Tada
  - Interpolates between elastic and rigid-plastic conditions with Irwin plastic-zone correction
- LBB.NRC
  - Similar to Paris/Tada but with correction to plastic rotation
- LBB.ENG2
  - Uses equivalence criterion incorporating a reduced thickness analogy for simulating system compliance due to the presence of a crack in pipe

Predicting TWC Response

J-estimation Schemes



Using SS & CS strength property combination from PVP2007-26733

Predicting TWC Response
Material Strength and Crack Size

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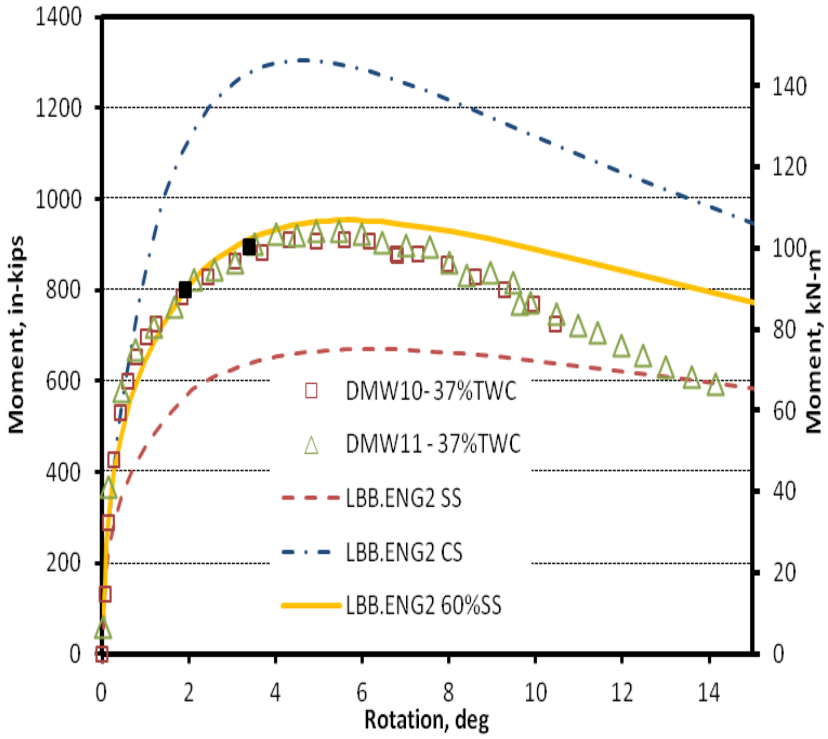
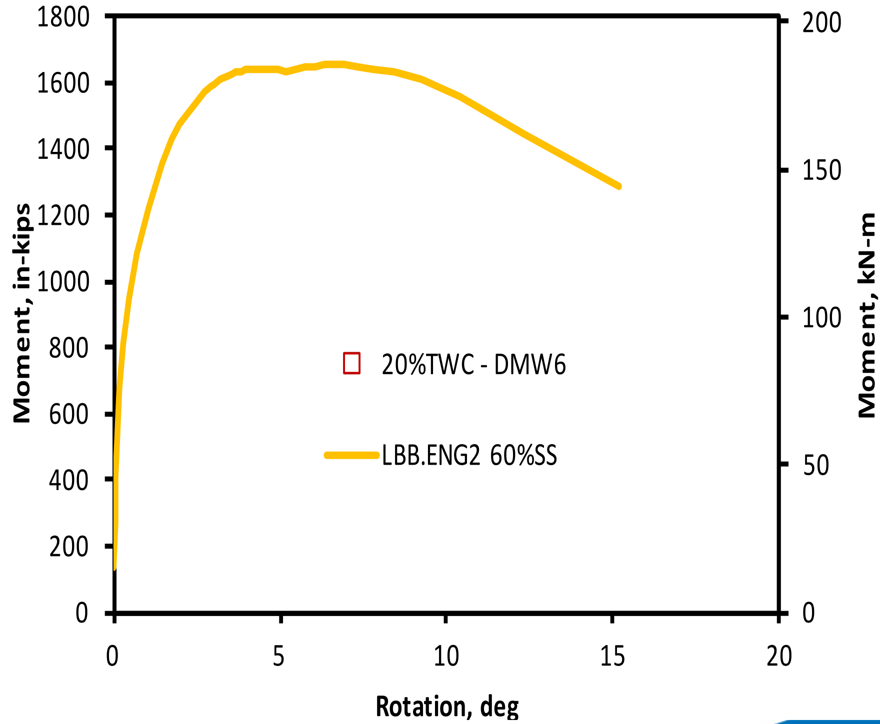


Different Strength Properties



Different Crack Size

Predicting CC Response

Reduced Wall Thickness

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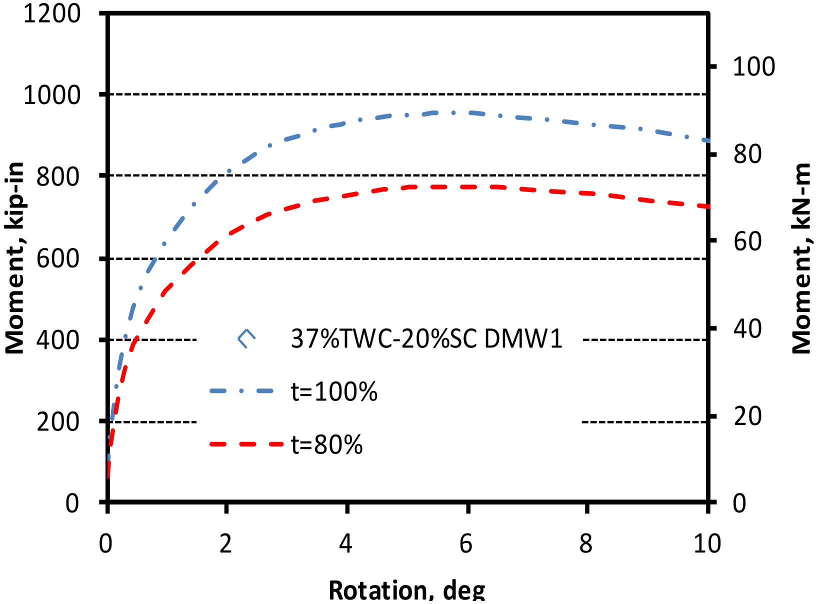
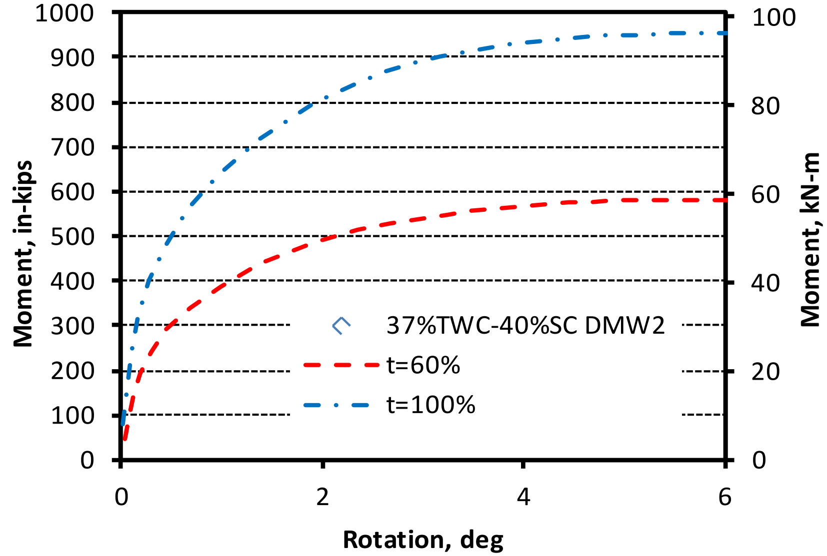
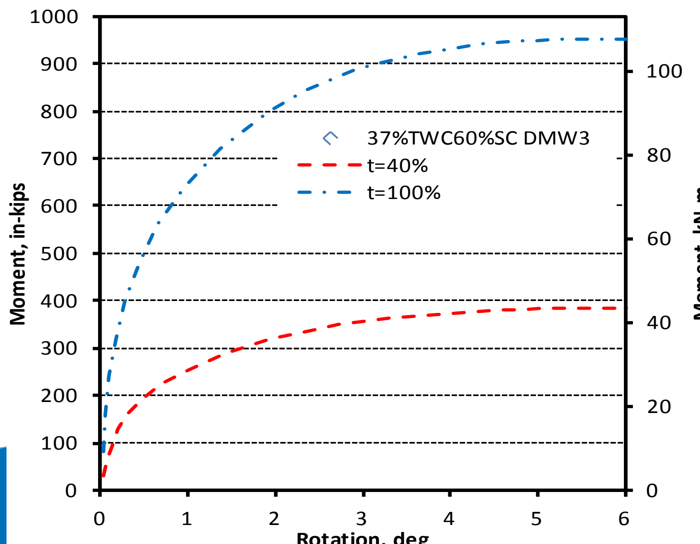
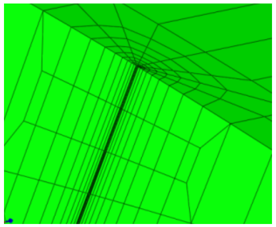


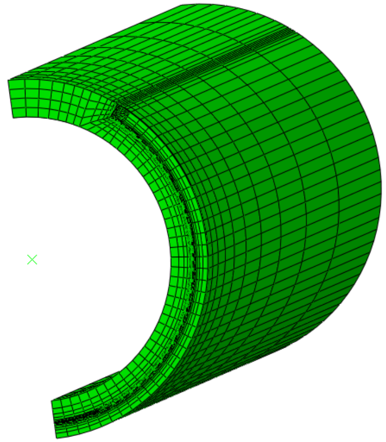


- ***Maximum load predictions are inconsistent with experiments***
- ***The deeper the SC the less accurate the prediction***
- ***Reduced wall thickness approximation is conservative***

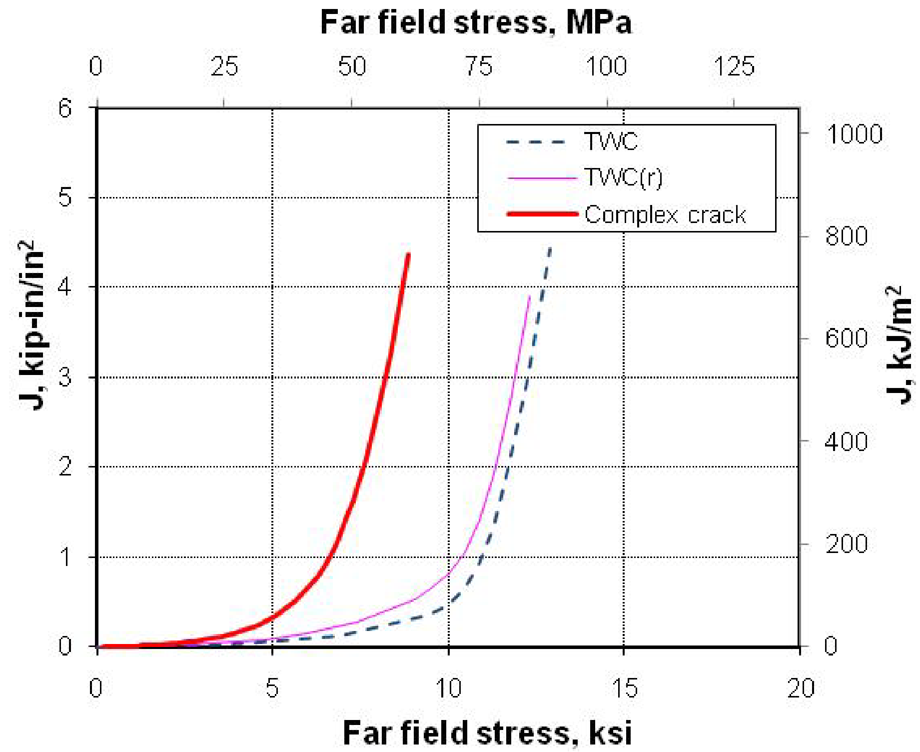


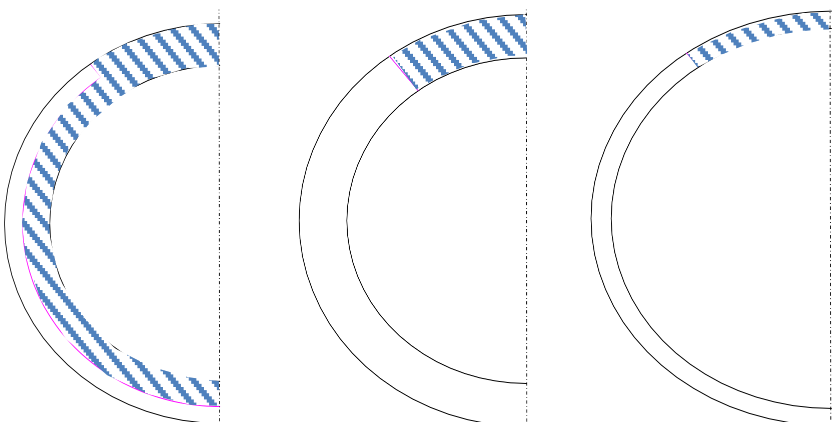
Driving Force Prediction





Quarter model with 20-noded isoparametric elements were used, with a small key-hole





Complex ***TWC*** ***TWC reduced t***

Summary

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- Using LBB.ENG2 with equivalent strength properties equal to 60% SS and 40% CS and weld center J-R curve produced the best predictions of load carrying capacity for TWC in center of DM weld
  - Using only SS properties will be conservative
- For cracks closer to the carbon steel, a different set of equivalent strength properties are needed
  - Using the 60% SS and 40% CS produce conservative load predictions
- For complex cracked pipe experiments, the load carrying capacity was overestimated
  - If the wall thickness in the analyses was reduced to equal the ligament in the experiment, predictions of load are conservative

Future Work

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- **TWC close to carbon steel**:
  - Detailed FE analyses, and appropriate J-R curves are needed to determine the equivalent properties for this case
- **Tearing resistance for complex cracks**:
  - The apparent tearing resistance from the complex crack pipe experiment is much lower than measured in a CT specimen. J-R curve from the pipe experiments will be calculated and used
  - Correlations between pipe J-R and CT J-R curve may be needed
- **Updated estimation scheme:**
  - The LBB.ENG2 estimation scheme was developed for base metals and later modified for similar metal welds
  - A modification is needed so that DM welds can be considered