Electricore, Inc.

FINAL PRESENTATION

DECEMBER 5, 2012

"Determine New Design and Construction Techniques for Transportation of Ethanol and Ethanol/Gasoline Blends in New Pipelines" (WP #394)

DTPH56-09-T-000003

Electricore Proprietary: Not for Distribution

Summary of Contents

- Project Overview
- Phase 1
  - Task 1.1: Evaluation of Steel Microstructure Effect on Ethanol SCC Resistance
  - Task 1.2: Effects of Welding and Residual Stress
  - Task 1.3: Evaluation of Surface Treatment Effects
  - Task 1.4: Evaluate Effects of Pipe Manufacturing Process
  - Task 1.5: Specification of Polymeric Materials for New Construction
- Phase 2
  - Task 2.1: Control and Monitoring of Oxygen Uptake
  - Task 2.2: Internal Corrosion Monitoring
  - Task 2.3a: Standardization of SCC Test Method
  - Task 2.3b: Roadmap for Industry Guidelines for Safe and Reliable Pipeline Handling of FGE
- Recommendations for Further Research
- Conclusions

Project Overview

- Team Members
  - Electricore (Prime Contractor)
  - Honeywell (Technical Lead)
  - EWI
  - Colonial Pipeline
  - Dr. Russell Kane (iCorrosion - Consultant)
- Three year program (extended by 6 months)
- Project completed within original PHMSA budget
- PRCI provided approximately 50% cost sharing

Background

- Honeywell & iCorrosion under contract from API (2003-2012), conducted an industry survey
  - The findings concluded that FGE was a potent causative agent in the SCC of steel equipment in fuel grade ethanol
  - This resulted in over 30 cases of ethanol SCC that now include 2 failures in pipeline segments
- Previous research focused on
  - Relevant factors involved in ethanol SCC failures in steel equipment handling FGE, and
  - Assessment of the potential for SCC in existing pipelines being converted to transport FGE
- This project focused on information required to design and construct <u>new pipelines</u> handling the increased demand for fuel ethanol

ELECTRICORE
POWERING THE FUTURE

Project Overview

- Scope of Present Study:
  - Phase I - Evaluation of modern steel microstructures on ethanol SCC resistance, weld procedure alternatives, surface treatments and pipe manufacturing process on ethanol SCC, and identification of new polymeric materials.
  - Phase II – Evaluation of the use of oxygen uptake control and monitoring, specification of internal corrosion monitoring, and standardization of an ethanol SCC test method and initial development of standard guidelines for safe and reliable transport/storage of FGE including ethanol SCC guidelines per the USDOT/PHMSA Ethanol Roadmap.
- Objectives:
  - Develop supporting data, related analyses and recommendations for design and construction methods for reducing the effects of ethanol SCC in new pipeline systems
  - Evaluate design aspects for control and monitoring of oxygen uptake and internal corrosion for pipelines handling ethanolic media
  - Recommend directions for expanded and improved pipeline guidelines and testing standards to promote ethanol SCC resistance.

Phase 1

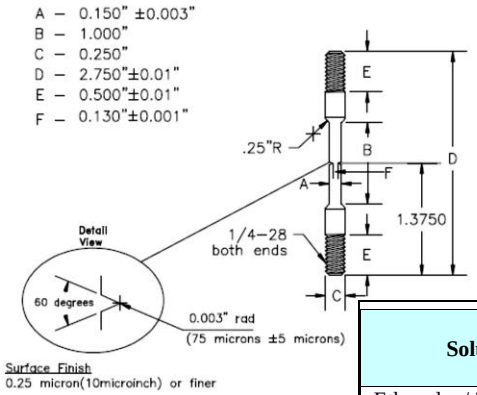
- Task 1.1: Evaluation of Steel Microstructure Effect on Ethanol SCC Resistance
- Task 1.2: Effects of Welding and Residual Stress
- Task 1.3: Evaluation of Surface Treatment Effects
- Task 1.4: Evaluate Effects of Pipe Manufacturing Process
- Task 1.5: Specification of Polymeric Materials for New Construction

Task 1.1: Evaluation of Steel Microstructure Effect on Ethanol SCC Resistance

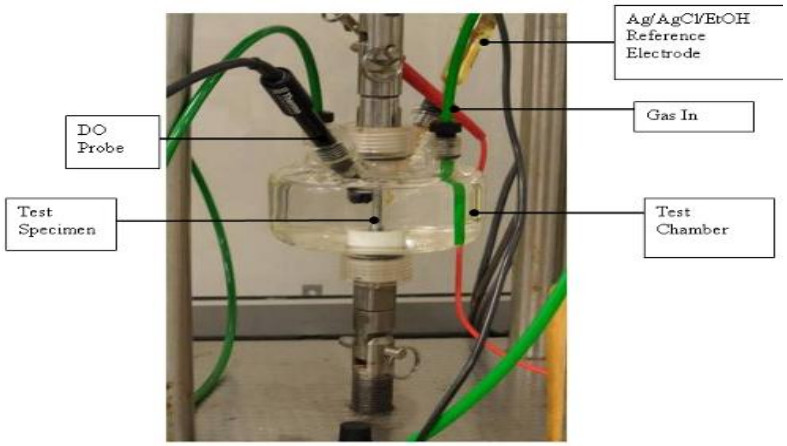
- Approach:
  - Evaluation of steels for resistance to ethanol SCC has historically been performed on older steel grades characteristic of existing pipelines and equipment.
  - Prior to this study, it was suggested that modern lower carbon pipeline steels/microstructures may have a higher resistance to ethanol SCC over conventional steels.
  - The material grades targeted in this task were mainly ferritic and bainitic versions of X-70 steel and X-80 steel made to low carbon levels combined with TMCP processing and accelerated cooling resulting in fine grained structures and high strength.

Task 1.1: Evaluation of Steel Microstructure Effect on Ethanol SCC Resistance - 2

- Methodology:
  - Included assessment of microstructures and tensile properties for pipe steels used in entire program, and evaluation of selected higher strength steels versus steels from prior studies.
  - SSR tests were performed using smooth and notched tensile tests in synthetic FGE
    - 4×10^{-7} inch/sec for N-SSR tests and 1×10^{-6} inch/sec for smooth & cyclic SSR tests in this and other tasks.
  - Data analysis:
    - Ratios of UTS, elongation, RA & composite ratios versus air tests
    - CGR measurements & fracture analysis using K_{ISCC} ratios versus air tests.
    - Fracture ductile area vs. total area



Solution	Property	Unit Spec
Ethanol w/ impurities per ASTM D4806	Reagent Ethanol	94.75%v
	Distilled Water	1%v
	Methanol (Reagent Grade)	0.5%v
	Denaturant (Pentane)	3.75%v
	Acetic acid	56mg/L
	Chloride content	10mg/kg



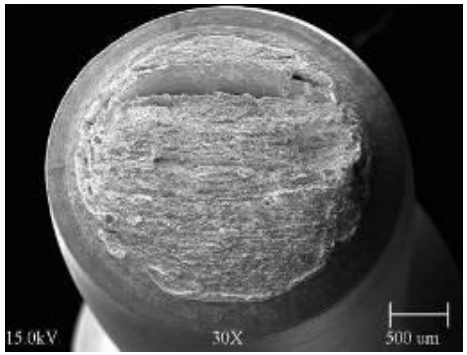
Task 1.1: Evaluation of Steel Microstructure Effect on Ethanol SCC Resistance - 3

Pipe	Length (feet)	Description	Heat #	Grade	Yield Str. (ksi)	Microstructure
A1	40	36" OD x 0.375" Wall API 5L Grade X65/X70 PSL2 Manufacturer: Tenaris Confab Double Submerged Arc Welded, UOE-SAWL (Expanded)	540887	X-65/70	79.6	Primarily ferritic/pearlitic microstructure. Mixture of small and medium-to-large ferritic grains, with some texture in the rolling direction, may indicate that this is a TMCP steel.
A2	40	36" OD x .686" Wall API 5L Grade X70 Manufacturer: Durabond Double Submerged Arc Welded; SAWL (Expanded)	712P04560	X-70	78.1	Microstructure consistent with accelerated cooled steel with bainite or tempered martensite.
A3	40	36" OD x .464" Wall API5L Grade X80, Manufacturer: Napa Pipe Double Submerged Arc Welded	MT8757	X-80	92.0	Microstructure consistent with accelerated cooled steel likely consists of acicular ferrite and bainite.
DNV	--	API 5L Grade X60 Manufacturer: Not provided (NP) – Sample provided from DNV stock	NP	X-60	75.5	Banded ferrite and pearlite

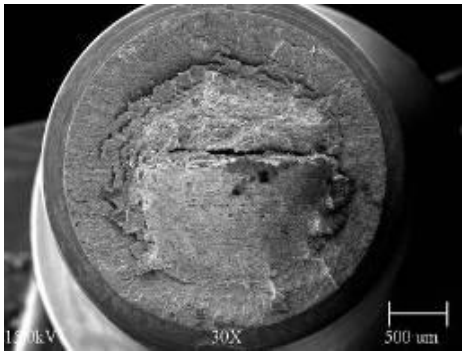
- Key Findings:
  - A-series steels tested for ethanol SCC versus X-60 steel from DNV.
  - A1-3 and X-60 had intermediate SCC susceptibility
    - SSR composite ratios yielded values grouped in the range 0.60 to 0.80 versus air tests.
    - Fracture ductile area for A1-3 less than X-60
    - CGR for all steels: 3-6x10^{-6} mm/s
    - K_{ISCC} ratio for A1-3 0.54 to 0.61 versus 0.68 for X-60 steel
  - A3 steel selected for Task 1.2 welding study.

Task 1.1: Evaluation of Steel Microstructure Effect on Ethanol SCC Resistance - 4

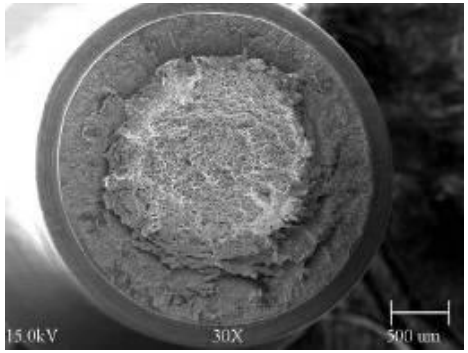
- Key Findings:
  - All steels showed similar eSCC fracture appearance:
    - SSR tests in air - all ductile
    - Brittle outer rim - mostly TG SCC; ductile central failure.
  - Some differences but generally similar ethanol SCC resistance between the older X-60 (DNV) and newer and higher strength X-70 and X-80 steels, with all steels showing moderate (intermediate) resistance to ethanol SCC.
  - Pipe generally more resistant than constructional steels (ASTM A36/A53) used in API studies.



X-70 DSAW-Air Test



X-70 DSAW-SFGE Test



X-80 DSAW-SFGE Test

X-60 DSAW-SFGE Test

Task 1.1: Evaluation of Steel Microstructure Effect on Ethanol SCC Resistance - 5

- Metallography and mechanical properties:
  - Characterized B-series steels that were used in Task 1.4 ethanol SCC studies (Manufacturing process)
- Steels included:
  - Grades X-65/70 thru X-80
  - Expanded and non-expanded pipe
  - Longitudinal & helical welding
  - DSAW and ERW seam welding
  - Varying microstructures: F/P, acicular ferrite & bainite

Pipe	Length (feet)	Description	Heat #	Grade	Yield Str. (ksi)	Microstructure
B1	40	36" OD x .375" Wall API 5L Grade X65/70 Manufacturer: Dura-Bond Double Submerged Arc Welded (Expanded)	803A64680	X-65/70	78.0	Ferritic/pearlitic microstructure. Mixture of small and medium-sized ferritic grains, possibly controlled-rolled TMCP steel. Banding (elongation) of the pearlite is visible.
B2	6	30" OD x 0.688" Wall API 5L Grade X60 Manufacturer: Berg Europipe Double Submerged Arc Welded (Non-Expanded)	648045	X-60	68.0	Mixed ferritic/pearlitic microstructure.
B3	10	42" OD x 0.541" Wall API 5L Grade X70 Manufacturer: Welspun Double Submerged Arc Welded (Expanded)	K10026926	X-70	79.5	Microstructure consistent with acicular ferrite with some carbides.
B4	40	12-3/4" OD x .375" Wall API 5L Grade X70 Manufacturer: US Steel Electric Resistance Welded (Not Expanded)	T64672	X-70	72.5	Microstructure is consistent with accelerated cooled steel with bainite.
B5	6	36" OD x .500" Wall API 5L Grade X70 Manufacturer: Durabond Double Submerged Arc Welded; SAWL (Likely Not Expanded)	A0E818	X-70	84.0	Microstructure consistent with acicular ferrite with some carbides.
B6	40	36" OD x .375" Wall API 5L Grade X70 Manufacturer: Berg Double Submerged Arc Welded Not Expanded	W5I595	X-70	73.8	Ferritic/pearlitic microstructure. Mixture of small and medium-sized ferritic grains, possibly a control-rolled or TMCP steel.
B7	40	36" OD x .464" Wall API 5L Grade X70 Manufacturer: Ipsco Double Submerged Arc Helically Welded (Not Expanded)	461883	X-70	77.0	Microstructure is consistent with accelerated cooled steel with bainite.
B8	40	20" OD x .500" Wall API 5L Grade X80 Manufacturer: Tenaris-Confab Electric Resistance Welded (Not Expanded)	420978U	X-80	98.9	Mostly ferritic microstructure with few carbides present

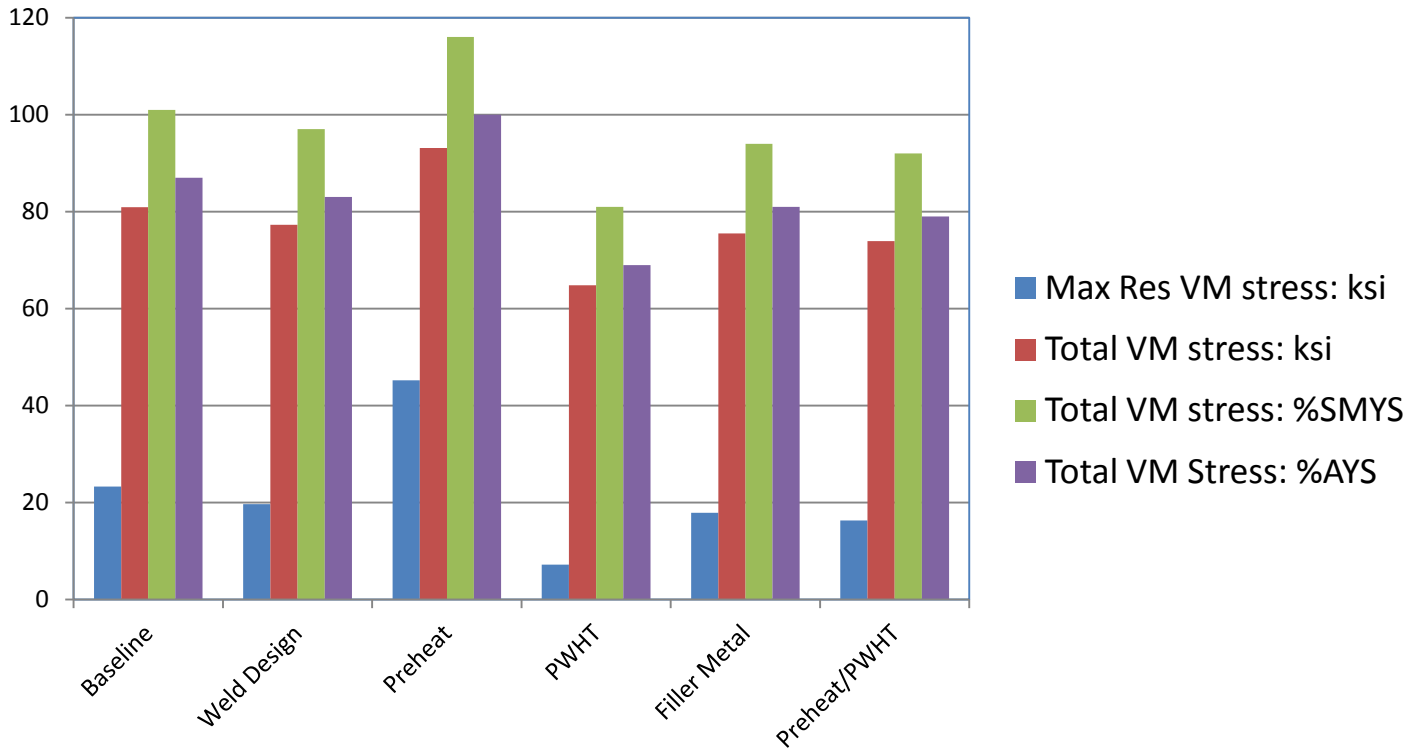
Task 1.2: Effects of Welding and Residual Stress

- Task Overview
  - This task was originally designed to investigate the effects of residual stress from welding using six different weld procedures. Plans were to measure ID residual stresses using ASTM E837, combined with allowable operating stress using Von Mises equivalent stress ($\sqrt{\frac{(\sigma_{11}-\sigma_{22})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{11}-\sigma_{33})^2}{2}}$), and evaluate their effects on initiation of ethanol SCC using cyclic SSR tests. Some variations from field welding and scatter were observed and described in report.
  - The measured residual stresses were to be simulated with applied stress in cyclic SSR specimen machined from base metal taken adjacent to the welds and exposed to SFGE at R=0.8.

Task 1.2: Effects of Welding and Residual Stress

- Task Overview (cont.)
  - Surveys found two ethanol SCC leaks/failures in pipelines, both subjected to field bending. The approach for Tasks 1.2/1.4 was then changed to simulate stress at 60% of strain to UTS in the cyclic SSR tests.
  - Cycle rates in cyclic SSR and fatigue tests in SFGE were evaluated versus steel re-passivation behavior in SFGE from other labs. Loading conditions were changed to R=0.5 with cycle rates 1×10^{-6} inch/sec.

Task 1.2: Effects of Welding and Residual Stress - 2

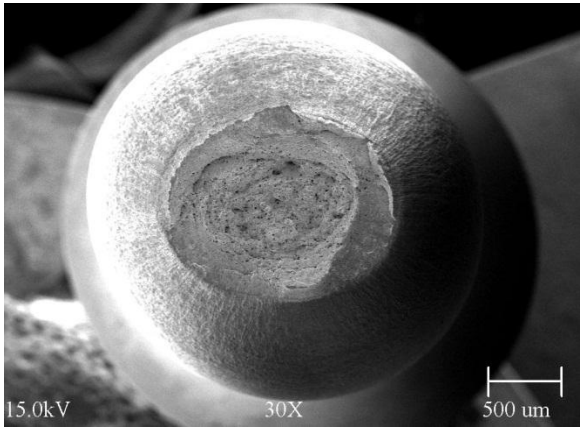


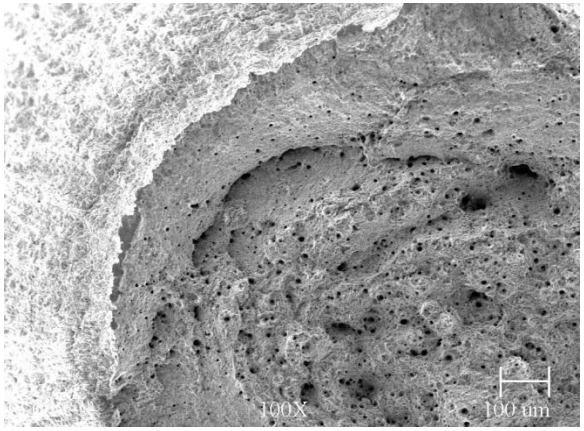
- Weld #4 (PWHT) had lowest ID tensile residual stresses followed by Weld #5 (Filler metal strength reduction), Weld #6 (Preheat/PWHT) and Weld #2 (weld design).
- However, when combined with allowable operating stresses, all except Weld #4 were at >90%SMYS (Weld #4 at 81%).

Task 1.2: Effects of Welding and Residual Stress - 3

Residual Properties after Cyclic SSR Testing in SFGE/air

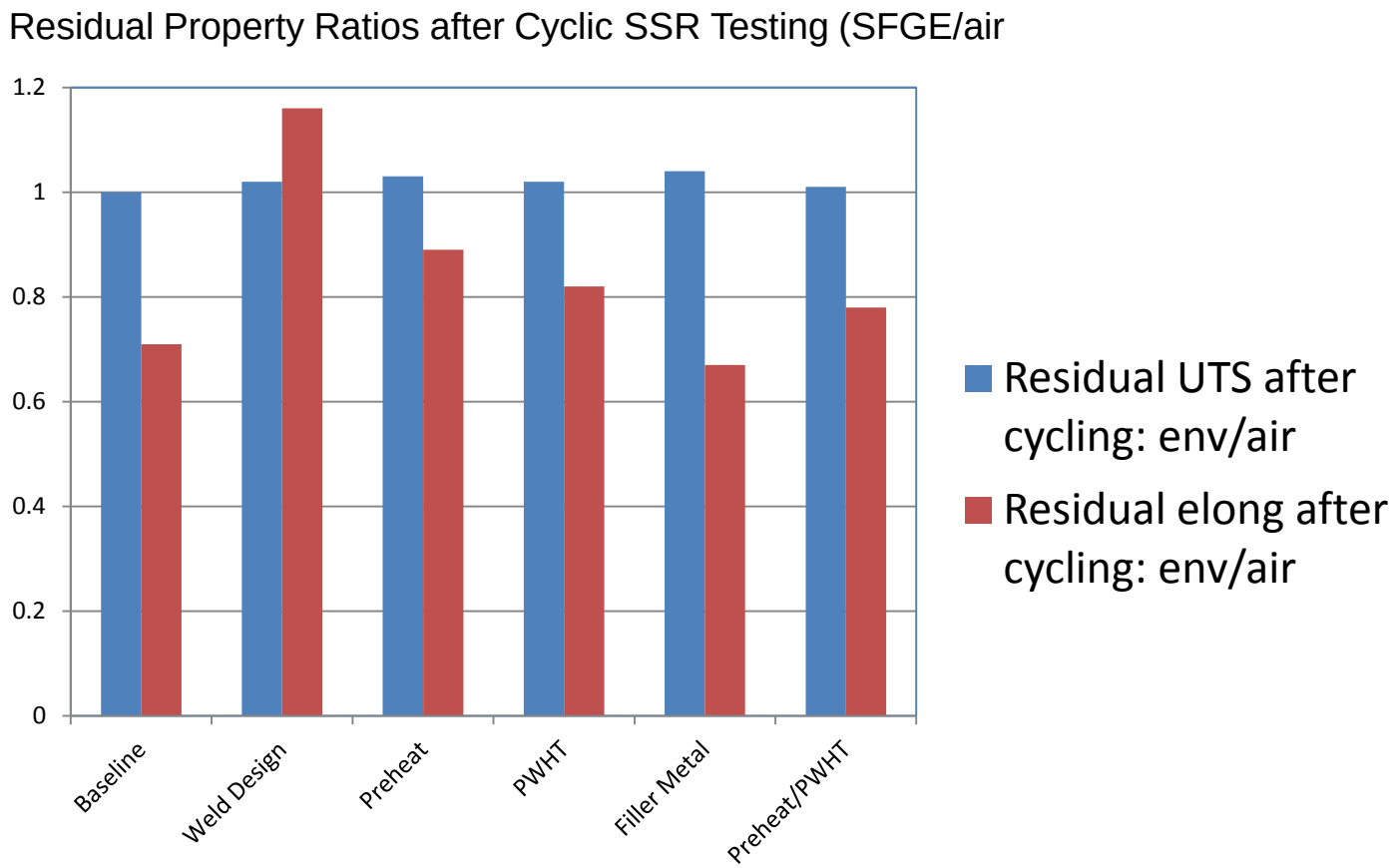
- No ethanol SCC after 64 cycles (~14 days) in SFGE. Comparison of post cycling residual properties (SGFE/air) showed:
  - No reduction in UTS for SFGE versus air cycled specimens
  - All but one steel showed reduction in residual elongation following cycling in SFGE. Suggests nascent (pre-crack) deterioration from cycling in SFGE; more cycles or test variation may support ethanol SCC.





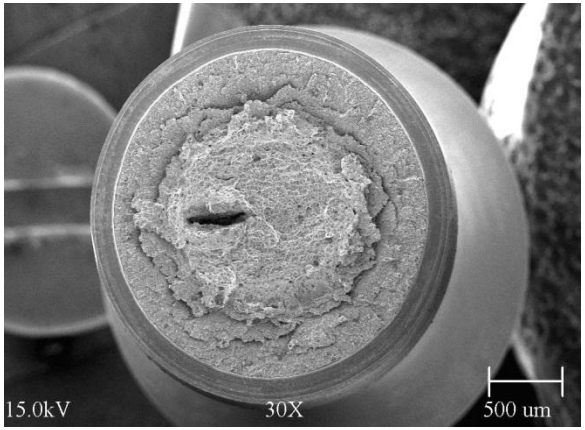
SSR specimen plastically deformed, cycled in SFGE, pulled to failure in air

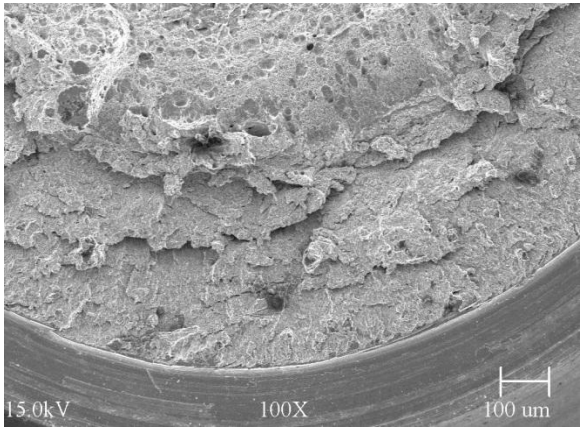
Task 1.2: Effects of Welding and Residual Stress - 3



Note: For no effect of cycling in SFGE on residual UTS versus cycling in air
Cycling in SFGE reduced residual elongation versus cycling in air (all but one case

Task 1.2: Effects of Welding and Residual Stress - 4



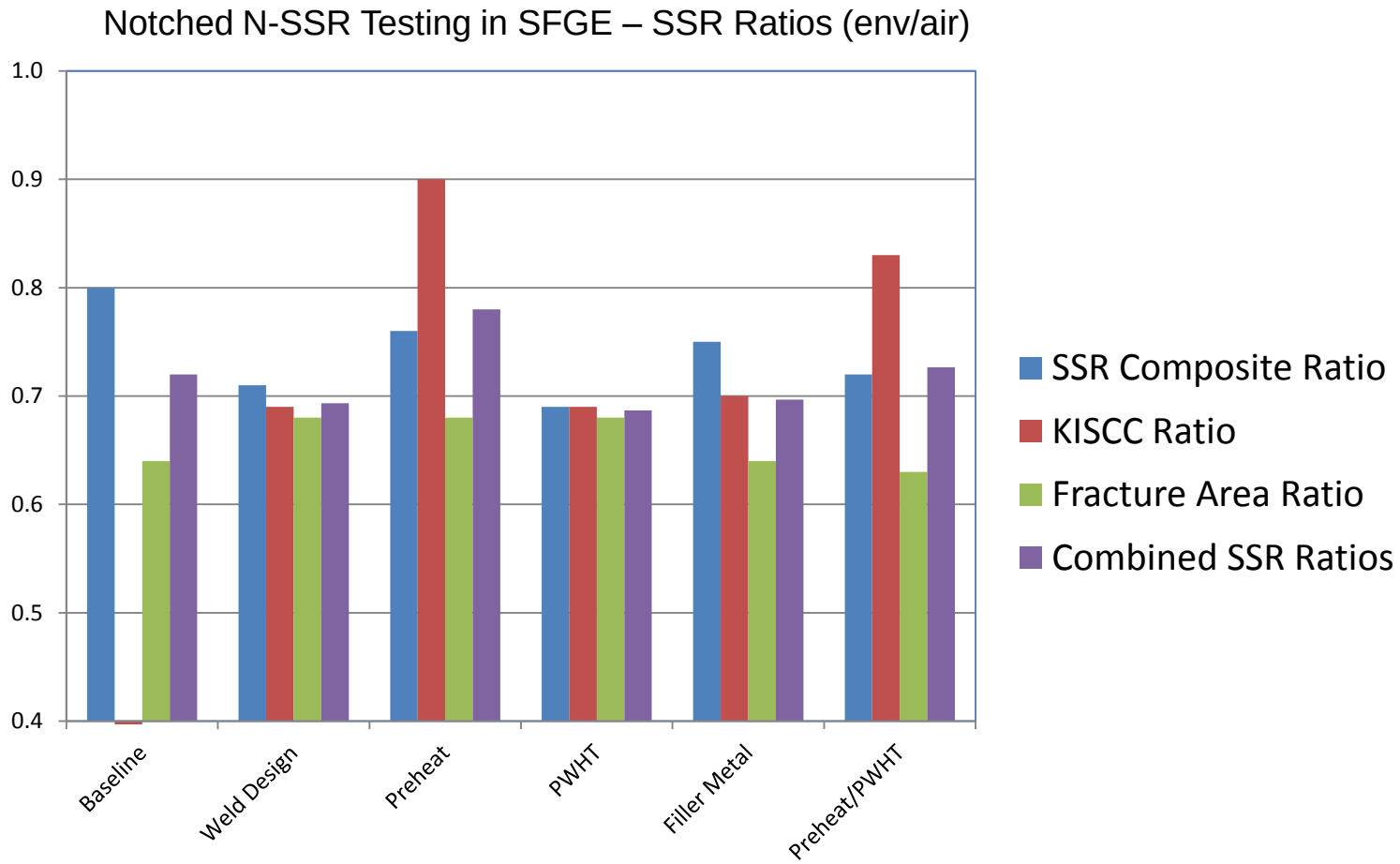


SSR specimen pulled to failure in SFGE

Notched N-SSR Testing in SFGE

- Additional notched SSR tests were performed and ethanol SCC found in all tests in SFGE.
- Ethanol SCC confirmed in all cases.
- No consistent differences in SSR composite, K_{ISCC} ratios (SFGE/air) and ductile fracture area among Welds #1-6
- Similar CGR rates in SFGE: $5\text{-}7 \times 10^{-6}$ mm/sec
- No influence of welding technique on ethanol SCC resistance of adjacent base metal.

Task 1.2: Effects of Welding and Residual Stress - 4



Notes: SSR ratios 1.0 for no ethanol SCC
All CGRs were between 5-7x10-6 mm/s
Combined SSR ratios between 0.68 and 0.78 – moderate ethanol SCC susceptibility

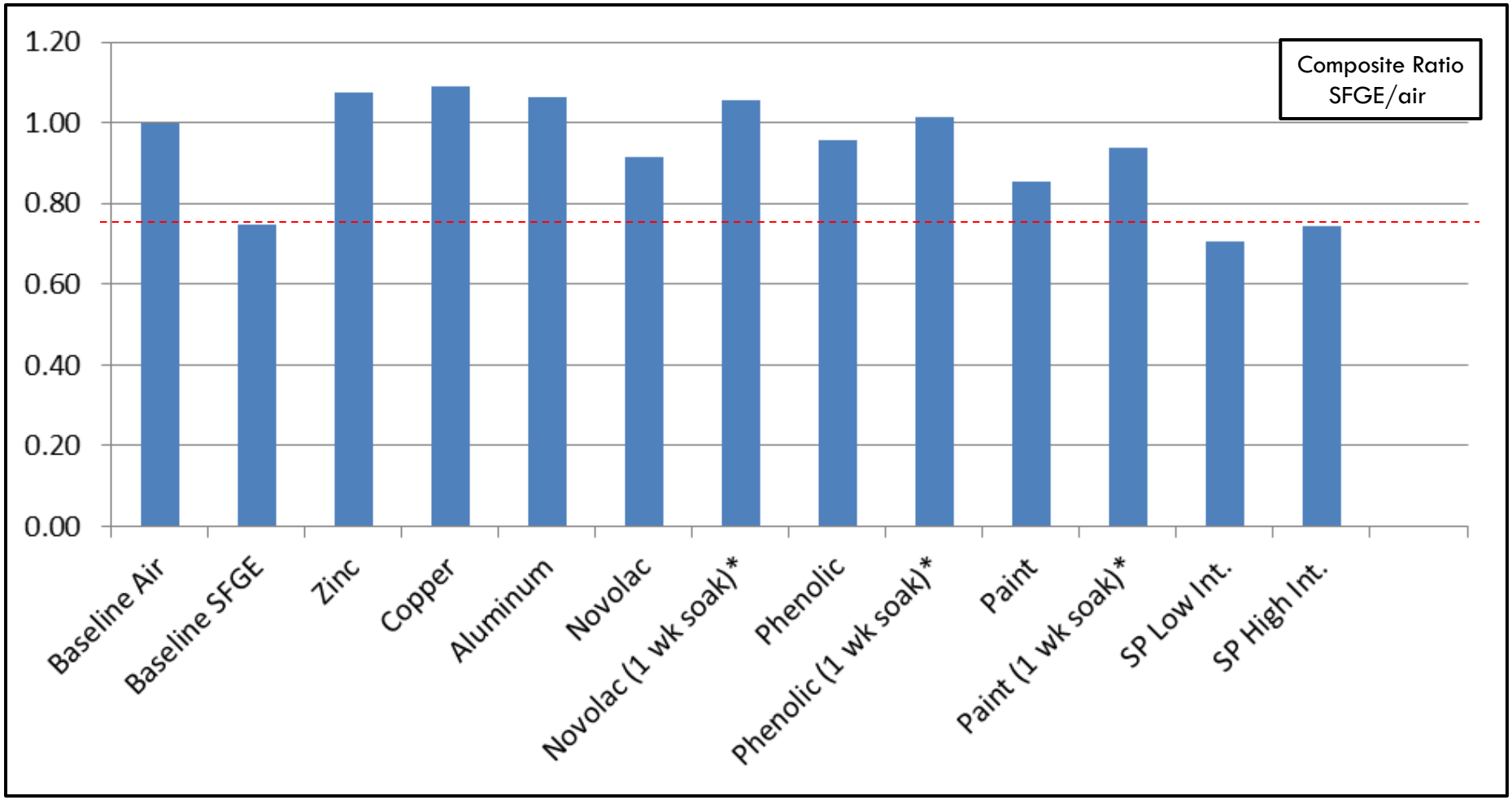
Task 1.3: Evaluation of Surface Treatment Effects

- Task Overview:
  - This Task evaluated several surface modification techniques that could be applied in the field to change the ethanol SCC characteristics of the internal pipe surface, including areas of peak stresses in the system. Surface techniques examined included:
    - Baseline (no treatment)
    - Shot peening (low and high intensity)
    - Polymeric coatings (Phenolic and Novolac Epoxies; specimens soaked for 24 hours and 1 week in SFGE prior to testing)
    - Painted (field applied pipeline coating)
    - Metallic coatings (zinc and copper)
    - Aluminum coupled
  - A combination of smooth and notched SSR tests in SFGE were utilized.
    - Similar techniques for evaluation as described in Task 1.1.

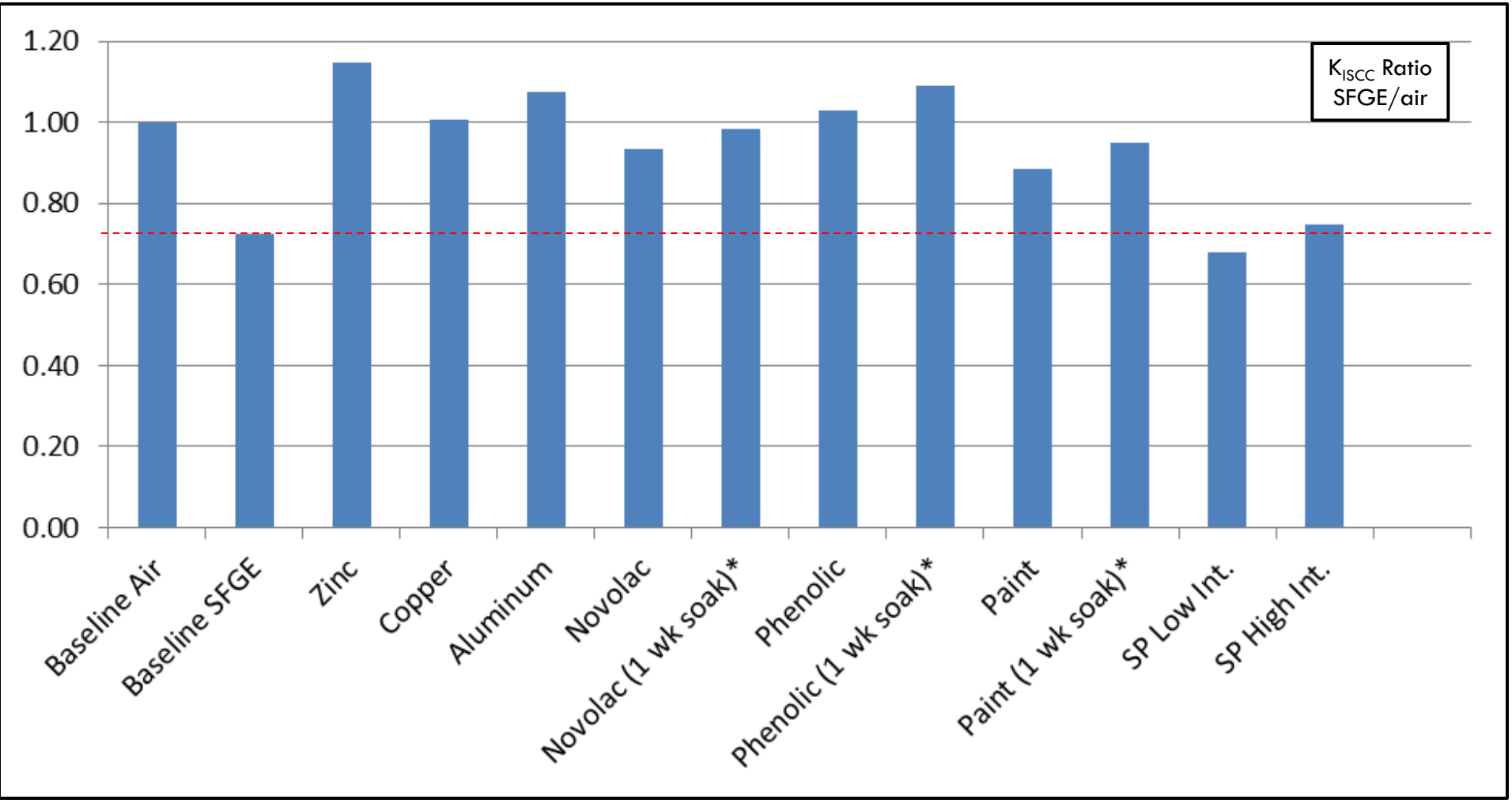
Task 1.3: Evaluation of Surface Treatment Effects - 2

- Discussion/Results
  - High or low shot peening (SP) levels did not mitigate ethanol SCC on neither smooth nor N-SSR specimens likely due to either induced plastic deformation or surface roughness.
  - Both the active metal coatings (zinc and copper) and aluminum coupling provided increased resistance to ethanol SCC.
  - Novolac and Phenolic epoxy coatings and a hand applied paint coating delayed the onset of ethanol SCC.
  - A one week soak period in SFGE provided added coating resistance likely due to increased ductility of the coating in the SSC test.

Task 1.3: Evaluation of Surface Treatment Effects - 2



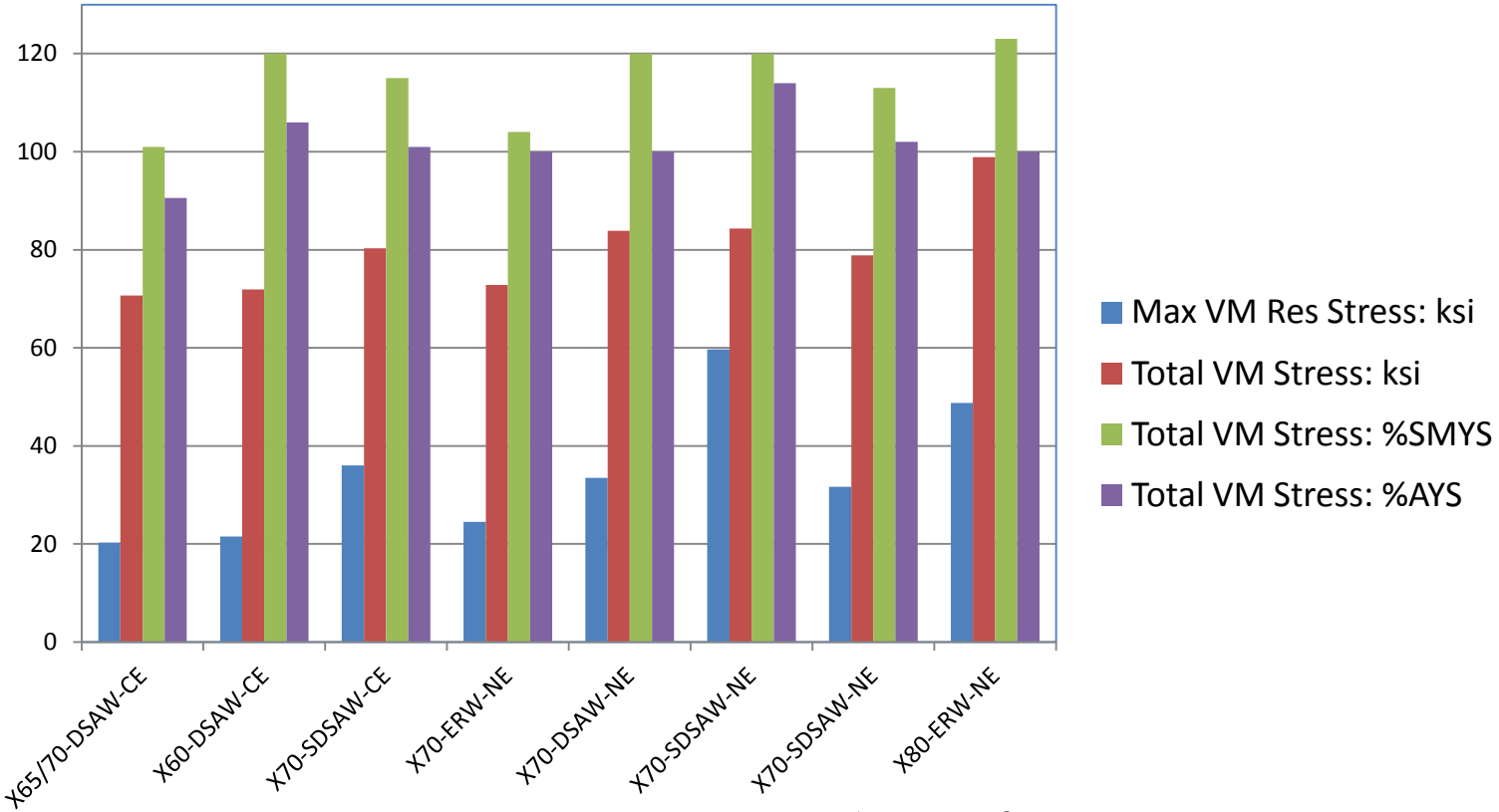
Task 1.3: Evaluation of Surface Treatment Effects - 2



Task 1.4: Evaluation of Effects of Pipe Manufacturing Process

- Task Overview
  - This Task was originally aimed to evaluate the residual stresses in the pipe material resulting from various pipe manufacturing methods.
  - Steels (B Series – B1-8) used in this task were highlighted in Slide 10. Similar methods of residual stress measurement were used (ASTM E837) and combing them with allowable operating stress using Von Mises equivalent stress.
  - As described in Task 1.2, this approach was changed due to two survey results showing leaks/failures due to ethanol SCC in pipeline segments with field bending.
  - The cycle conditions used in cyclic SSR and fatigue tests in SFGE were similar to those used in Task 1.2:
    - Simulate stress at 60% of strain to UTS in the cyclic SSR tests
    - R=0.5 with a cycle rate of 1×10^{-6} inch/sec.

Task 1.4: Evaluate Effects of Pipe Manufacturing Process - 2

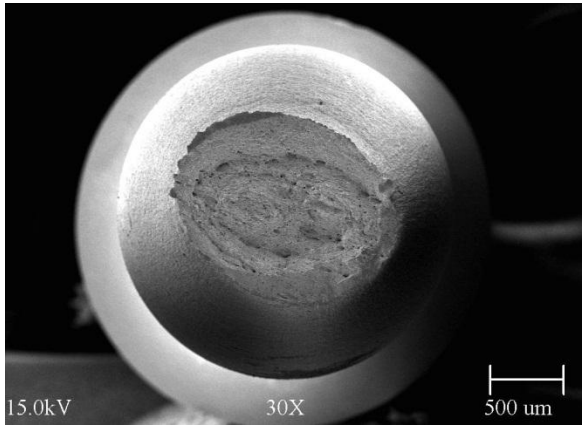


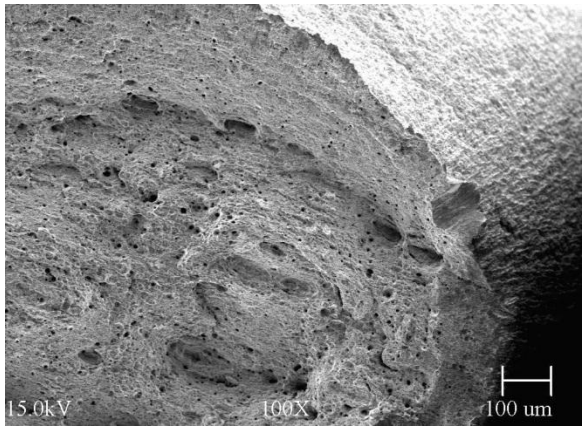
- Highest ID residual stresses were in Steels B5, B6 and B8 (all non-expanded) and B3 (Spiral welded & cold expanded).
- Lowest stresses were in B1, B2 (long seam DSAW & cold expanded) and B4 (ERW welded and non-expanded).
- There was no systematic correlation of stress with processing.

Task 1.4: Evaluate Effects of Pipe Manufacturing Process - 3

Residual Properties after Cyclic SSR Testing in SFGE/air

- No ethanol SCC after 64 cycles (~14 days in SFGE.
- Post-cycling residual elongation (SGFE/air) showed a decrease in certain materials but not in others:
  - B5 (X-70 non-expanded) vs. B8 (X-80 non-expanded)

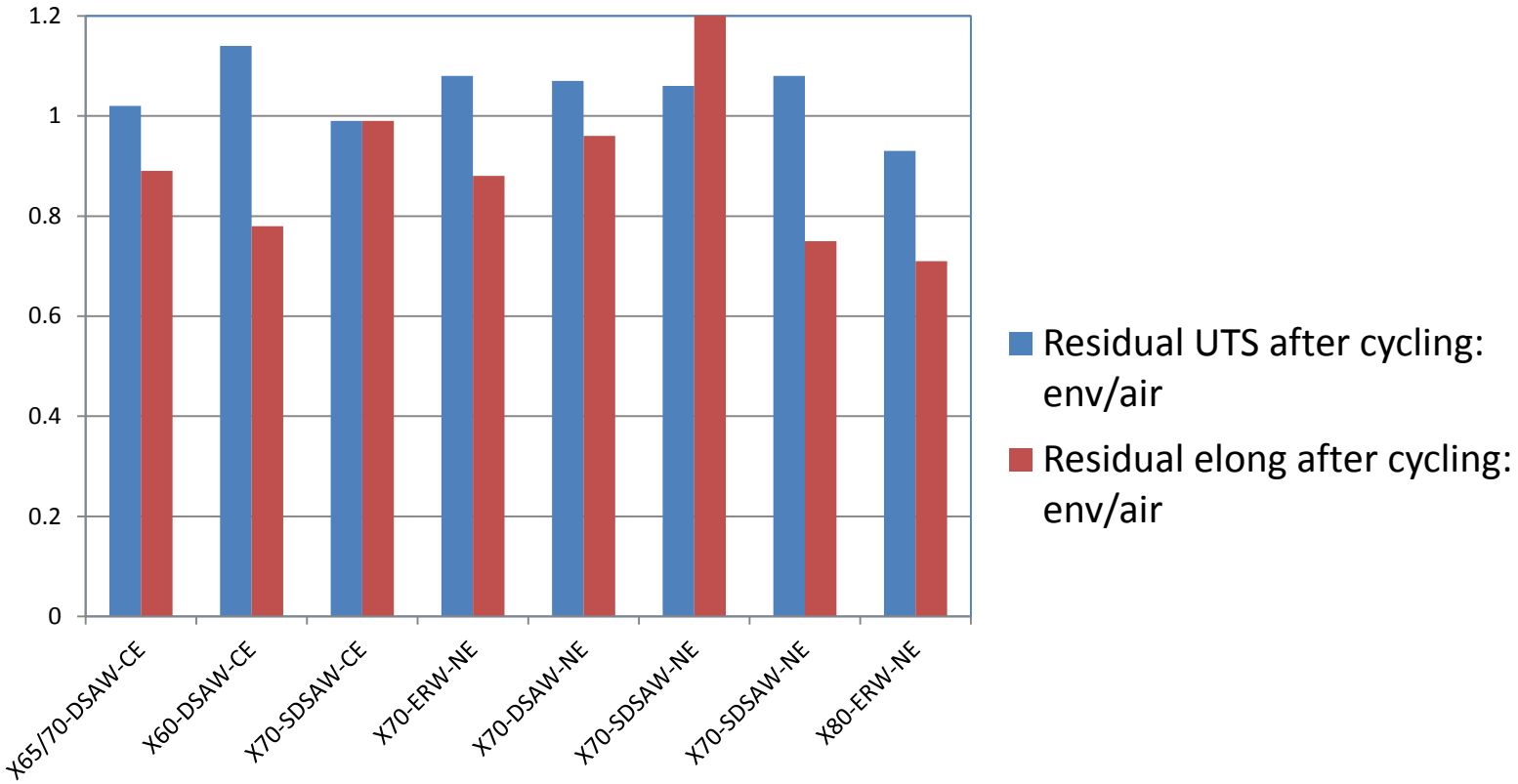




SSR specimen plastically deformed, cycled in SFGE, pulled to failure in air

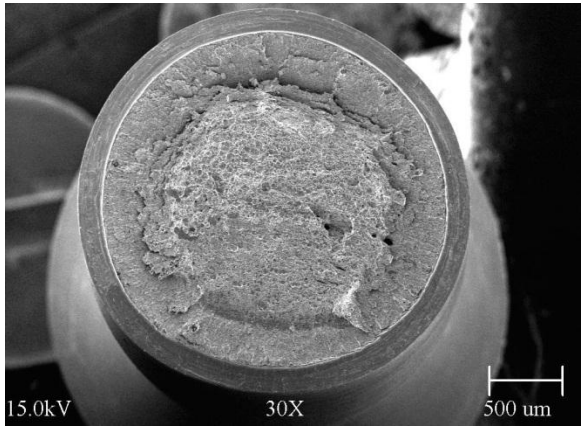
Task 1.4: Evaluate Effects of Pipe Manufacturing Process - 3

Residual Properties after Cyclic SSR Testing in SFGE/air

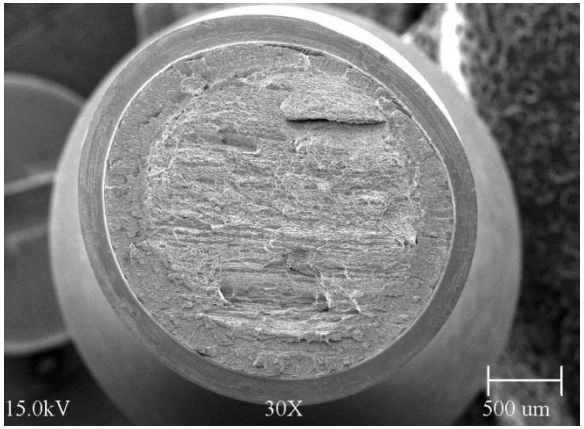


Note: No effect of cycling in SFGE on residual UTS versus cycling in air
Cycling in SFGE reduced residual elongation versus cycling in air (all but one case)

Task 1.4: Evaluate Effects of Pipe Manufacturing Process - 4



SSR fracture of Steel B1



SSR fracture of Steel B6

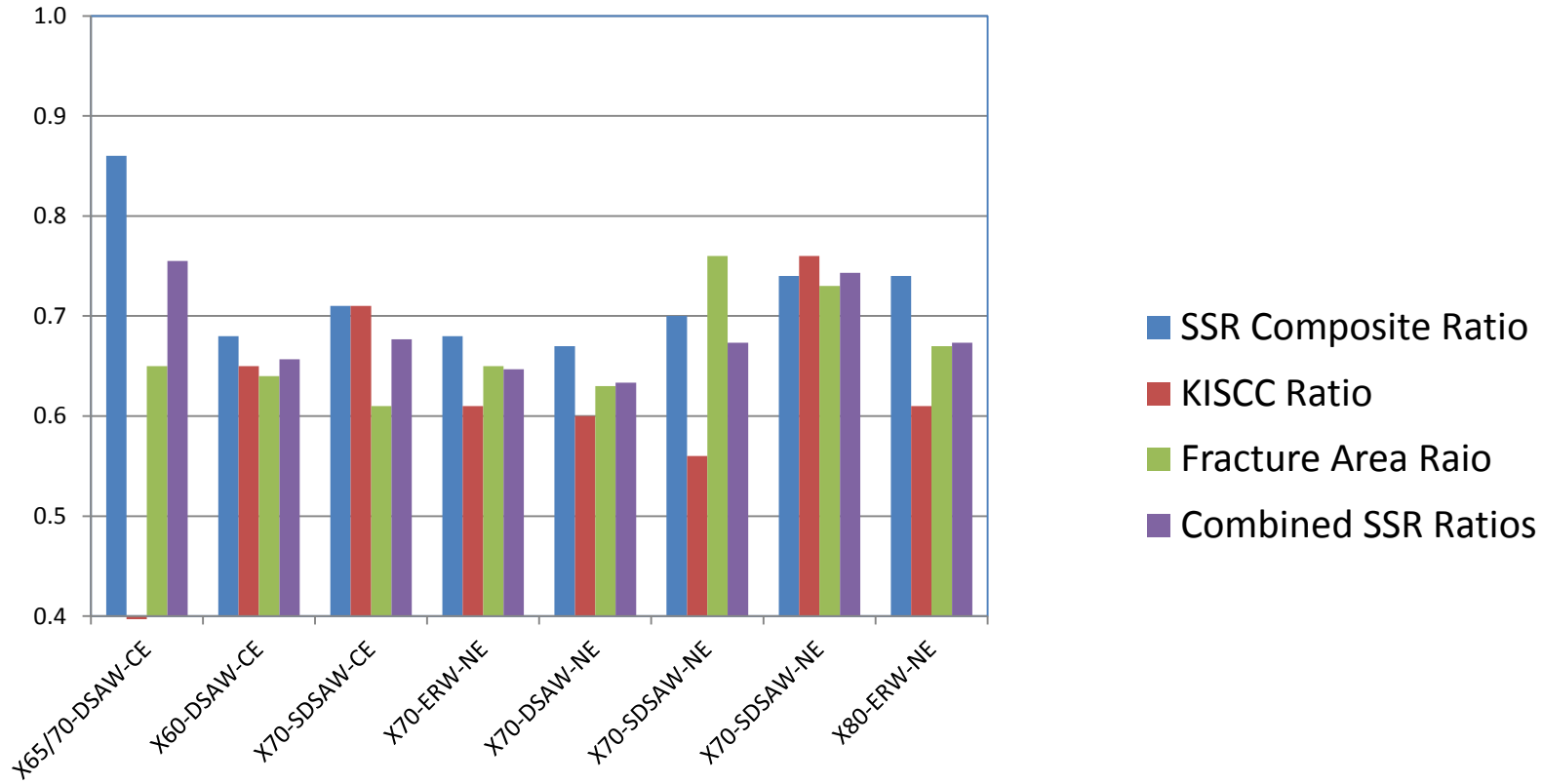
SSR specimen pulled to failure in SFGE

Notched SSR Testing in SFGE

- Ethanol SCC observed, some differences in steels but generally no consistent differences among steels in SSR composite, K_{ISCC} ratios (SFGE/air) and ductile fracture area.
- All showed moderate susceptibility to SCC.
- Similar CGRs in SFGE: $2\text{-}5 \times 10^{-6}$ mm/sec
- No systematic influence of manufacturing process on ethanol SCC for F/P, bainitic, acicular ferritic steels.

Task 1.4: Evaluate Effects of Pipe Manufacturing Process - 4

Notched N-SSR Testing in SFGE – SSR Ratios (env/air)



Notes: SSR ratios 1.0 for no ethanol SCC
All CGRs were between 2-5x10^{-6} mm/s
Combined SSR ratios between 0.63 and 0.75 – moderate ethanol SCC susceptibility

Task 1.5: Specification of Polymeric Materials for New Construction

- Task Overview:
  - This task involved a review of the technical and commercial literature for polymeric materials (elastomers and engineering plastics) that have high resistance to FGE, transmixtures with gasoline and jet fuel
  - The review also included service conditions that include regular/periodic service exposures as result from batch shipping of FGE.

Task 1.5: Specification of Polymeric Materials for New Construction

- Key Findings:
  - This review indicated there were no additional or "new" elastomeric materials inherently suitable for FGE transmission service, but different formulations and processing regimes for existing materials may be used to optimize chemical resistance.
  - Chemical compatibility testing of these materials is warranted to demonstrate performance in static and dynamic service regimes, including:
    - Swelling, shrinking cracks, tearing, cutting, and shredding
    - Deformation related to varying the compressive / shear loading / motion of mating parts
    - Lists of compatible materials and preferred test protocols are provided.
    - Key parameters are: Permeation Resistance (ASTM E96), Chemical Resistance, Change in Volume & Hardness (ASTM D47), Hardness Measurement/Durometer (ASTM D2240), Tear Resistance (ASTM D624).

Phase 2

- Task 2.1: Control and Monitoring of Oxygen Uptake
- Task 2.2: Internal Corrosion Monitoring
- Task 2.3a: Standardization of SCC Test Method
- Task 2.3b: Roadmap for Industry Guidelines for Safe and Reliable Pipeline Handling of FGE

Task 2.1: Control and Monitoring of Oxygen Uptake

- Task Overview:
  - The scope of Task 2.1 included assessing pipeline system parameters for controlling and monitoring the uptake of oxygen during the pipeline transportation process. Research has shown that, by far, the most significant environmental variable controlling susceptibility to ethanol SCC in steel is dissolved oxygen concentration for both SFGE and FGE samples.
- Approach:
  - Assessment of transport of FGE from the manufacturer to the pipeline facility, tank storage, transfer of FGE between tanks during storage (prior to and after pipeline transport), and entry and exit of FGE with the pipeline was conducted.
  - Lab testing involved aeration and deaeration of SFGE to simulate field FGE unloading and loading procedures and the long term use of oxygen monitoring probes and associated equipment.

Task 2.1: Control and Monitoring of Oxygen Uptake - 2

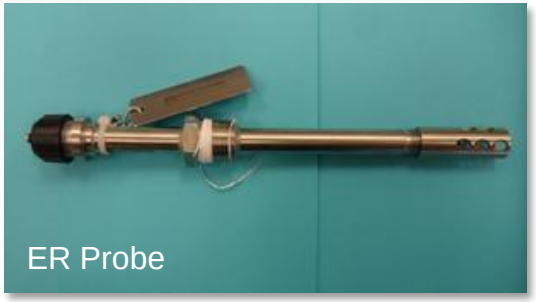
- Key Findings (field assessment)
  - Considerable opportunity exists for oxygen to enter the FGE stream during the truck, rail, and barge loading and unloading processes.
    - Once FGE enters the pipeline terminal tank very little, if any, additional oxygen enters the process during normal operations.
  - Eliminating the entry of oxygen during truck, rail, and barge loading and unloading processes, or removing the oxygen from the FGE stream as the stream enters the first pipeline terminal tank (by purging or scavenging) will provide the largest benefit to preventing oxygen and ethanol SCC in FGE/transmixes during transported by pipeline. Procedures & locations are highlighted in report.
  - Existing oxygen monitoring equipment yielded qualitative measurement that varied with aeration/deaeration. Issues of probe compatibility and calibration limited their effectiveness.
    - Further attention to instrument compatibility/calibration and measurement frequency can result in better long term monitoring performance and capabilities for field service.

Task 2.2: Internal Corrosion Monitoring

- Task Overview:
  - The requirements for internal corrosion monitoring for cases of transportation of FGE by pipelines were reviewed in this task. This review considered monitoring for common forms of corrosion attack – mass loss corrosion, pitting corrosion, and ethanol SCC. It also included evaluation of offline and online methods that are available for each of these corrosion phenomena.
- Approach:
  - Long term (>5 months) laboratory corrosion tests were performed in SFGE and in modified SFGE environments that included the effects of aeration and deaeration, and water content in excess of that defined by the ASTM D4806 for FGE.
  - During this cumulative exposure period, measurements were made with a combination of conventional corrosion probes and corrosion coupons along with stressed specimens (plastically deformed U-bends and an instrumented bolt fracture mechanics compact tension specimen).

Task 2.2: Internal Corrosion Monitoring - 2

- Key Findings:
  - **Super ER Probe**
    - Only significant increase in corrosion rate (up to 7.2 mpy) in SFGE occurred at10% water.
  - **ER Probe**
    - No corrosion was measured until the water content raised to 10% (0.18 mpy).
  - **LPR Probe**
    - No readings in SFGE at 10 ppm chloride.
      - Note: This did not appear to prevent previous field measurements (perhaps due to larger electrode size).
    - Corrosion rates from 0.1 to in excess of just over 1 mpy (at 10% water) were obtained in SFGE solutions with 40 ppm chloride.
    - Default B value of 26 mV was shown appropriate.

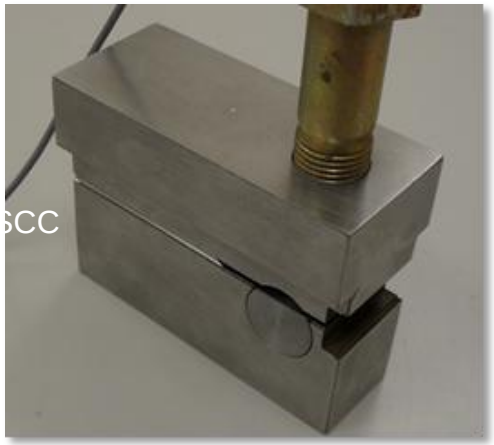


Stage	Corrosion Rate	Description of Stages
Stage 1	1.03 mpy	Reagent EtOh (Static)
Stage 2	0.63 mpy	Reagent EtOh (N_2 Purge)
Stage 3	0.13 mpy	Addition of Methanol and Acetic Acid
Stage 4	0.25 mpy	Switch gas to air purge
Stage 5	0.19 mpy	Addition of NaCl
Stage 6	0.18 mpy	Addition of 0.7% Water
Stage 7	0.52 mpy	Addition of 0.3% Water (total 1%)
Stage 8	2.13 mpy	Addition of 1% Water (total 2%)
Stage 9	7.19 mpy	Addition of 8% Water (total 10%)

Task 2.2: Internal Corrosion Monitoring - 2

- Key Findings:
  - No ethanol SCC in U-bend tests.
    - Similar to most other studies involving statically-stressed specimens.
  - Instrumented compact tension specimens exhibited deterioration of the strain gauge assembly in the SFGE solution. No SCC.

Stage	Corrosion Rate	Description of Stages
Stage 1	1.03 mpy	Reagent EtOh (Static)
Stage 2	0.63 mpy	Reagent EtOh (N_2 Purge)
Stage 3	0.13 mpy	Addition of Methanol and Acetic Acid
Stage 4	0.25 mpy	Switch gas to air purge
Stage 5	0.19 mpy	Addition of NaCl
Stage 6	0.18 mpy	Addition of 0.7% Water
Stage 7	0.52 mpy	Addition of 0.3% Water (total 1%)
Stage 8	2.13 mpy	Addition of 1% Water (total 2%)
Stage 9	7.19 mpy	Addition of 8% Water (total 10%)



Task 2.3a: Standardization of SCC Test Method

- Task Overview:
  - Test methods for assessment of ethanol SCC have focused on use of a slow strain rate (SSR) test for rapid/reliable evaluation and screening FGE for ethanol SCC susceptibility.
  - This task solicited international input from academia, contract testing and research institutions and pipeline operators stakeholders to and supported the development of an industry-wide test method standardization effort through NACE International.
  - The team also
    - Documented experience of successful/unsuccessful evaluation methods for ethanol SCC,
    - Reviewed candidate testing methods for standardization,
    - Developed an industry standard test method for ethanol SCC
    - Assisted in the organization of an ethanol SCC SSR round-robin testing program.

Task 2.3a: Standardization of SCC Test Method

- Key Findings:
  - NACE TM0111[Slow Strain Rate Test Method for Evaluation of Ethanol Stress Corrosion Cracking in Carbon Steels]
    - It was successfully developed and standardized, included smooth and notched tension specimens, standard extension rates, standard synthetic ethanol solution, and data analysis and reporting procedures.
  - A round robin testing program with international participation is now in progress, slated for completion March 2013.

Task 2.3b: Roadmap for Industry Guidelines for Safe and Reliable Pipeline Handling of FGE

- Task Overview:
  - This task assessed the available information from PRCI and API on ethanol SCC and handling of alcoholic media in pipelines with the goal of pursing a roadmap for the development of guidelines for safe handling and transport of ethanol-fuels in pipelines.
  - It also involved extensive discussions with pipeline industry personnel about needs for guidelines for ethanol SCC specific to the needs of the pipeline industry.
  - Consideration was given to the possibilities for collaboration on a joint pipeline and facilities document based on the existing API 939E that would include the needs of the pipeline industry for ethanol SCC guidelines.

Task 2.3b: Roadmap for Industry Guidelines for Safe and Reliable Pipeline Handling of FGE - 2

- Key Findings:
  - API 939E document contained much of the information needed, and it was more a matter of identifying key topics for inclusion into API 939E and a path forward agreeable to members of the API Refining and Pipeline Committees.
  - Proposed 939E changes consisted of including:
    - Corrosion of non-ferrous alloys (aluminum, copper, etc.) and compatibility of polymeric materials.
    - Information on pipeline fabrication, inspection and repair
    - FGE content expanded to include ethanol-fuel blends and transmixes where available.
    - Control of SCC by deaeration, pH modifiers, use of ethanol SCC inhibitors.
    - Fracture data: Nominal K_{ISCC} and crack growth rate values for eSCC.
    - Documentation of ethanol SCC failures/leaks in pipeline segments.
    - Documentation of hydrostatic pressure testing of the pipeline segment as successfully used in a previous pipeline failure/leakage incident.
    - Information on ultrasonic testing (UT) performed by in-line inspection (ILI) to detect ethanol SCC emanating from pipeline internal surface (limitations and options).

Task 2.3b: Roadmap for Industry Guidelines for Safe and Reliable Pipeline Handling of FGE - 3

- Key Findings:
  - Development of a two-step plan for ethanol SCC guidelines within API Refining and Pipeline Committees :
    - Path 1 (short term – 1 to 2 years) - Inclusion of API Pipeline Committee representatives in the present round of updating and revision of API 939E.
    - Path 2 (longer term – 2 to 4 years) – Identification of key points for ethanol SCC for pipelines and development of a path forward for the cooperative modification and expansion of 939E to handle pipeline needs.

ELECTRICORE
POWERING THE FUTURE

Discussion of Results

- While there were some differences in ethanol SCC susceptibility among the X-70/X-80 steels tested in the program, their overall rankings were comparable to that exhibited by the older X-60 steel sample provided by DNV.
- There did not appear to be substantive differences in ethanol SCC susceptibility from the generally lower carbon content in the modern pipeline steels and their predominantly ferritic and bainitic microstructures versus the pearlitic microstructures found in the X-60 steel or steels manufactured by more conventional methods.
- Other than use of PWHT, alternative welding methods were not found to control tensile stresses, particularly when residual stress was combined with allowable operating stresses.
- Variation in pipe manufacturing method produced some variations in residual stress, however when combined with allowable operating stresses, this effect was minimal.
- Plastic deformation (at 60% elongation to UTS) followed by cyclic SSR testing did not produce ethanol SCC. However, after cycling, in most cases the residual elongation of ethanol-cycled tension specimens were substantially reduced versus similar air cycled specimens. This suggests some form of nascent pre-crack deterioration as a result of the cyclic exposure in ethanol.

Discussion of Results - 2

- No benefit in terms of ethanol SCC resistance were found for both conditions of shot peening despite confirmation of the compressive residual stresses on the steel surface by X-ray methods.
  - Possible reasons for this could be the severe conditions induced by either the SSR test or possible detrimental effects of cold work and increased surface roughness induced by the shot peening process.
- Active metal (Cu & Zn) coatings, aluminum coupling and polymeric coatings all provided reductions in ethanol SCC susceptibility that exceeded the data for the baseline (untreated) steel in SFGE.
- While "new" elastomeric materials were identified that were inherently suitable for FGE transmission service beyond the common ones currently used in other industries (listed herein), different formulations and processing regimes for existing materials may be used to optimize performance in this service.
- Substantial progress was made on test method standardization and ethanol SCC guidelines applicable to the pipeline industry.

Recommendations for Further Research

- Further work is needed to investigate strain and cycle frequency to identify conditions that promote SCC without the use of conventional SSR methods that may better explain the unexpected nature of field failures from ethanol SCC
  - This work should be focused particularly between the yield point and engineering yield stress and the post-yield region in steels.
  - This work needs to investigate R ratio, cycle frequency versus repassivation rates in various ethanolic solutions relevant to FGE, SFGE, and ethanolic transmixes and fuel blends.
- Some surface treatments were successful in mitigating ethanol SCC, but further work is necessary to examine more treatments and potential limits.
- Refinements in equipment and operating procedures are needed to improve field/in-servce monitoring of the oxygen, corrosion, and SCC monitoring in FGE and fuel blends.
- Support is needed to advance the Path 2 ethanol SCC guidelines development activities to extend API 939E to include comprehensive ethanol SCC guidelines for pipelines.

Recommendations for Further Research - 2

- Results from this study indicate that further refinements in calibration, operation and equipment modification could enhance the serviceability and quantitative nature of the oxygen monitoring in FGE and fuel blends. This work should include both lab data and field oxygen monitoring in operating systems to provide a better database from which better control of ethanol SCC may be implemented through reduction in dissolved oxygen in these environments.
- This study showed the problems associated with conventional methods for corrosion and SCC monitoring in ethanolic media that are compatible to long-term field use. Further investigation is needed of methods to improve and optimize these measurements for assessment of corrosion rate, pitting tendencies and susceptibility SCC. The lack of methods compatible for SCC assessment are most acute and necessary as early warning of conditions leading to leaks and failure.
- Support is needed to advance the Path 2 ethanol SCC guidelines development activities to extend API 939E to include guidelines for both pipelines and facilities.

ELECTRICORE
POWERING THE FUTURE

Conclusions

- API X-70 and X-80 steels made by a range of manufacturing processes exhibited moderate susceptibility to ethanol SCC.
  - This susceptibility was generally on par with that of an older vintage API X-60 steel used for benchmarking this work to previous studies, but showed better performance than conventional constructional steels (ASTM A36 and A53) evaluated in previous investigations.
  - Thus, no benefit of lower carbon content or bainitic and ferritic microstructures were found.
  - Variation in residual stress was found depending on manufacturing and welding methods, but this effect was minimal after factoring in allowable operational stresses.
  - PWHT and to a lesser degree filler metal strength reduction and use of preheat+PWHT and weld design reduced the level of peak residual stress, but this effect was minimal after factoring in allowable operational stresses for all cases except use of PWHT.

Conclusions

- Active metal coatings, aluminum coupling and polymeric coatings successfully mitigated the effects of ethanol SCC.
  - Shot peening was not effective in mitigating ethanol SCC.

- Control of oxygen in pipelines, tankage and facilities appears feasible but demonstrated improvements in oxygen monitoring are needed for long-term field use.

Conclusions - 2

- No new polymeric materials with enhanced compatibility to ethanolic environment were identified, but changes in formulation and processing appear to be paths that can improve polymeric materials for this service.
- For all conditions per ASTM D4806, corrosion rates of steel were low (<1 mpy). However, upset conditions can produce higher corrosion rates.
  - Improvements in corrosion, pitting and SCC monitoring are needed that are compatible and work effectively in FGE and ethanolic transmixes and fuel blends for long-term field use.

Conclusions - 3

- An industry standard for evaluation of steel for ethanol SCC was developed (NACE TM0111) and a round robin test is currently in progress.
- The existing ethanol SCC guidelines in API 939E handle about 60-70 percent of pipeline industry needs. A path forward consisting of two steps was developed.
  - Path 1 is already being implemented with the short term modification of this document based on input received from the pipeline industry.
  - Path 2 will follow and will involve deeper structural changes to API 939E as information is available and supported by industry.

Contact Information

- Electricore, Inc.

27943 Smyth Drive, Suite 105

Valencia, CA 91355

Tel: (661) 607-0261

Fax: (661) 607-0264

ian@electricore.org

www.electricore.org