690 Working Group on SCC Growth Rate Testing

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NRC Meeting ***June 2011***

Misconceptions Resolved

- *Alloy 690 is immune to SCC.*
- *Most Alloy 690 is very homogeneous.*
- *Only plate forms are inhomogeneous.*
- *Only extruded material is used for CRDM.*
- *1-D cold rolling is uniquely bad.*
- *Forged or tensile strained materials will show only low CGRs.*
- *CRDM forms, esp. if homogeneous, show only low CGRs.*
- *GB carbides are beneficial, and the more the better.*
- *EBSD is measuring artificial characteristics.*
- *Residual strains are always <10%.*
- *One or two "relevant" specimens (e.g., from mockups) provide clear evidence that there are no SCC concerns.*

Considerations

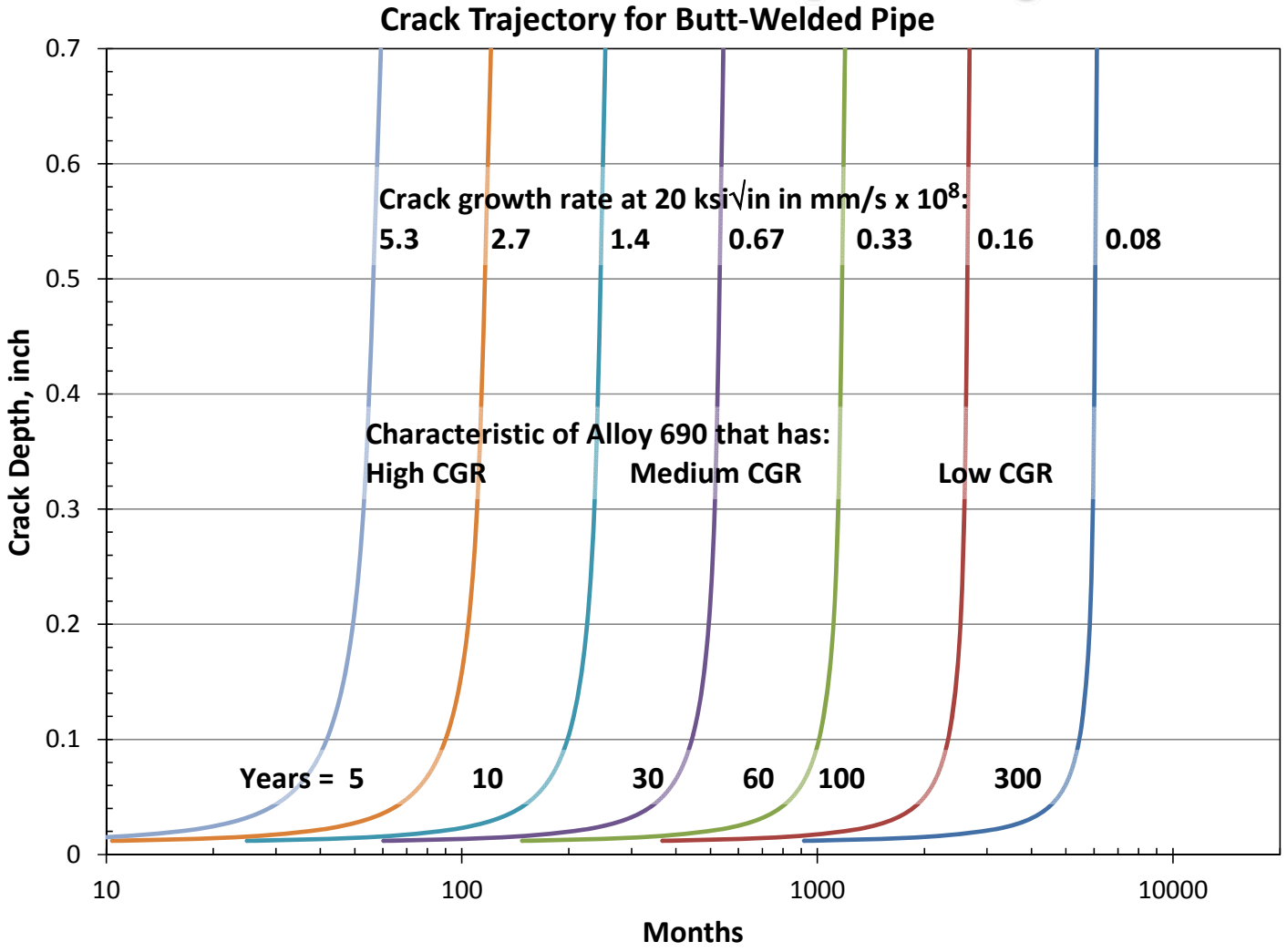
- *Growth rates in base metal often evolve over >1000 hours – perhaps this is associated with finding banded paths.*
- *Even in the banded ANL material, ~1 in 3 specimens exhibit growth rates that are 5 – 10X lower than the other specimens.*
- *Almost all weld metals to date exhibit low growth rates, and tend to decay – not accelerate – with time.*
- *Good CGR agreement with other labs when materials have been tested in common.*
- *Must recognize that in the history of SCC in plants, perhaps only 0.1 – 1% of the susceptible areas exhibit cracking. Statistically, to capture those problems, >100 tests are needed.*

What CGR Is Adequately Low?

Calculations could be performed for many different component and geometries.

1. *Assume butt welded pipe with a wall of ~20 – 25 mm*
2. *Perform the calculation to grow a small defect to about 80% of through-wall*
3. *Evaluate the growth rate when the K is ~30 ksi$\sqrt{in}$*
4. *The growth rate corresponding to 80 – 100 year life is in the vicinity of ~4 x 10^{-9} mm/s*

What CGR Is Adequately Low?



80 – 100 year life requires ~4 x 10^{-9} mm/s

Testing Ideas

- *PNNL 700C "recovery" heat treatment shows that SCC tracks the EBSD measured strains. If concern for low temperature deformation, try higher strain at higher temperature to get same EBSD strains. (fewer cracked carbides, etc.)*
- *IHI characterized four 690 plates & some remaining material.*
- *GB carbide dissolution may cause Cr enrichment, confounding these two factors.*
- *Simulated HAZ and PMZ microstructures.*
- *Blunt notch initiation testing of 690 plate, large notch radius.*
- *Expand tensile strained 690 studies (Ciemat + ANL plate).*
- *Examine 10 – 20% cold work levels.*

Young HAZ Measurements

- *Residual plastic strain in Alloy 690 HAZ: 12 – 28%*
- *Residual plastic strain in 690 HAZ: 2 – 13% (best practice)*
- *SS HAZ with 52M weld: 13 – 25%*
- *Residual strain of weld repair relative to original weld = 1X:*

  One repair: 2.1X

  Two repairs: 2.7X

  Three repairs: 3.0X

- *Excellent correlation between EBSD strains and SCC CGRs*

Some Areas of Progress in 2010/2011

1. *Comparison data across labs for several materials.*
2. *Very high growth rates evolve at long times in banded plate.*
3. *Medium to high CGRs on CRDM in the S-L orientation in 2 cases.*
4. *Similar CGRs on 1D-rolled and 2D-forged 690.*
5. *Large effect of 1100C/1h/WQ heat treatment: 10X CGR reduction.*
6. *HAZ testing with some medium CGRs reported;*
   but most specimens positioned too far into HAZ.
7. *By and large very good performance of weld metals, but some key observations for follow-up from ANL & KAPL.*
8. *Growing collection of weld metals, types & geometries evaluated.*
9. *…*

Some Areas of Emphasis in 2011/2012

1. *Expanded emphasis on HAZ testing with positioning closer to the weld fusion line, more linear welds (e-b, laser, etc.), and perhaps on some HAZ simulation (Gleeble, etc.)*
2. *Evaluate intermediate levels of cold work, e.g., 20, 15, 10%, and test more forged and/or tensile strained materials.*
3. *Expand evaluation of CRDM materials, which now show moderate to high growth rates when cold worked in the S-L orientation.*
4. *Continue evaluation of altered microstructures, such as the 1100C/1h/WQ to determine the role of grain boundary carbides.*
5. *Continue cross-lab comparisons and capabilities of new labs.*
6. *Get details of ANL & KAPL observations on weld metals.*
7. *Evaluate dilution zone effects on SS and LAS.*
8. *Emphasizes CGR > ~1 x 10^{-8} mm/s to reduce testing time.*
9. *Expand characterization of HAZ vs. CR/forging deformation.*

GE Emphasis on Alloy 690

1. Examine forging and tensile strained Alloy 690.
2. Examine cold work levels in the 10 – 20% range.
3. Examine wider range of CRDM materials, e.g., Sumitomo.
4. Examine orientation effects of microstructure vs CW vs SCC.
5. Examine “carbide modification” (sol’n annealing) effects.
6. Examine more “HAZ” and simulated “HAZ” microstructures. Consider effects of weld repairs and wash passes.
7. Examine SCC along the interface of dissimilar metal welds.

Tasks Initiated or Completed

1. *Creation of documents for guidance or testing guidelines, all available on the central site (SharePoint):*
   - *Proposed Test Matrix for SCC Evaluation.*
   - *690 Processed Materials Inventory.*
   - *SCC CGR Test Guidelines.*
   - *Recommendations for HAZ Testing.*
2. *Creation of 690 Inventory and Processed Materials Inventory.*
   - *Focus on two commercial 690 plates.*
   - *Initial availability of ~20% cold rolled and 20% cold forged 690.*
   - *Other forms (CRDM, billet…) also available.*
3. *Collaboration and interaction among labs.*
   Current & future testing summary from key labs in Nov 2010.
4. *CGR database defined.*

Crack Growth Rate Database

Lab	Material	Form	CONSTANT K SHEET - SEE INSTRUCTIONS IN COLUMN Y Overall Test ID	Heat	Lab Treatment	% Thickness Reduction	Processing	Crack Orientation vs. Def. Plane	Crack Orientation vs. Banding	Total Hours in Test
ANL	690		A690-WC-SL-1	ANL Plate, NX3297HK12	1DCR	26	26% 1D Cold Roll	S-L		2854
ANL	690		A690-WC-ST-1	ANL Plate, NX3297HK12	1DCR	26	26% 1D Cold Roll	S-T		
ANL	690		A690-WC-ST-1	ANL Plate, NX3297HK12	1DCR	26	26% 1D Cold Roll	S-T		5090
ANL	690		C690-CR-1	Valinox WP142			As-received	C-R		4678
ANL	690		C690-LR-2	Valinox WP142			As-received	L-R		3726

ID for CGR Segment	Hours for CGR Segment	K MPa/m	Test Temp	Dissolved H2, cc/kg	Δa, mm for Segment	Δt, hours for Segment	% IG Engaged	Post-test Correction	Correction Technique	Optional Text to Show Range in SCC CGR mm/s	Numerical SCC CGR, mm/s	Auto Generated Category	Comments
										1.46×10^{-8}	1.46E-08	Medium	
										3.3×10^{-8}	3.30E-08	Medium	
										3.7×10^{-8}	3.70E-08	Medium	
										5.4×10^{-9}	5.40E-09	Medium	
										3.7×10^{-9}	3.70E-09	Low	

Structure of database reviewed, but no formal inputs provided

Some Key Issues to Address in WG#2

1. *Effect of various types of microstructural inhomogeneities.*
2. *Effect of cold work on 690 with excellent microstructure.*
3. *Combined effect of cold work and inhomogeneity/banding.*
4. *Linkages between response of cold worked base metal and HAZ.*
   - residual stresses & strains in SS/600 vs. 690: EBSD & SCC.
   - nature of welds & coincidence of banding, stresses, strains.
   - SCC measurements on HAZs.
5. *Effect of K, temperature & dissolved H_2 on above 690 variations.*
6. *Perhaps extension to other materials, so that the synergistic. effect of banding and cold work is more fully understood.*

Alloy 690 SCC Future Options

	Available in Inventory?
Alloy 690 base metals include:	
1. *T-K VDM plate – forged vs rolled 20%*	*YES*
2. *ENSA plate – forged vs rolled 20%*	*YES*
3. *ANL plate – forged vs rolled*	*YES*
4. *Various CRDM tubes*	*YES*
5. *Various billets*	*YES*

** not all conditions of forge/roll/tensile-strain are yet available in all materials. CW CRDM tubes don't support S-L orientation with reconstitution.*

Alloy 690 welds and HAZs include:

1. *KAPL, B&W, GE Nuclear, ANL, PG&E and other*

Many new materials available in 2010 and 2011

Added (&) or emphasized for 2011

Base Metal Evaluation* (Default = S-L Orientation)

Form**	Heat #	As-rec'd	10% F	20% F	30% F	10% R	20% R	20% T
Plate	#1	X	X	X, YY	X	X	X	X, YY
T-L	#1			X	X		X	
Plate	#2	X	X	X	X	X	X	X
Plate	#3			X			X	
CRDM	#1	X	&, 15%	X	X		X	
T-L	#1			X	X		X	
CRDM	#2		&, 15%	X			X	
CRDM	#3..#10	X		X			X	
Billet	#1			X			X	
Billet	#2			X			X	

- * F = Forged, R = Rolled, T = Tensile strained
- YY listing on plate #1 represents banding oriented in the direction of deformation, e.g., along tensile or compressive axis. Crack plane remains S-L orientation relative to deformation, although some evaluation of the S-T orientation is needed.
- S-L orientation defined by relative orientation of deformation and crack plane/direction.
- ** Plates #1 and #2, and Billet #1 should be banded and/or show high growth rates
- Key tests: ***Banded 690 + Forging,*** ***Banded 690 + Tensile Strain,*** ***Billet & CRDM Behavior*** ***Crack Orientation vs. Deformation,*** ***Banding Orientation vs. Deformation (YY)***

Added (&) or emphasized for 2011

HAZ Evaluation* (Default = S-L Orientation)

Test	Heat #	V-groove	Narrow gap	Electron beam	High constraint	NG / e-beam + banded
HAZ	#1 *	X	X	X	X	X
HAZ	#2 *	X	X	X	X	X
HAZ	#3..#10		X			

** S-L orientation defined by relative orientation of deformation and crack plane*

*** Heat #1 / #2 applies to each weld type, i.e., test two heats / welds with a V-groove prep*

Last column (narrow gap or e– beam + banded) means that a banded, high growth rate plate material will be welded with S-L alignment between banding and weld residual strains

Added (&) or emphasized for 2011

Alloy 152/52 Weld Metal: Materials

1. *Compositional variations among 52, 52M, 52MS, 52MSS… are expected to affect weld cracking, not SCC.*
2. *SCC is expected to be affected by:*
   - *Cr and perhaps Fe concentration*
   - *Carbide and other particles in the grain boundary*
   - *Residual strain in the weld metal (constraint, heat input…)*

As diverse a combination of 52 and 152 welds as possible should be evaluated, and demonstrating reproducibility and identifying the origins or high CGR welds is a priority. Additional cold work can be considered – this is potentially representative of more highly constrained welds.

3. ***Examine CGR in SS & CS dilution zones***