Surface Remediation for Mitigation of PWSCC in Nickel-Based Materials

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May 30, 2007

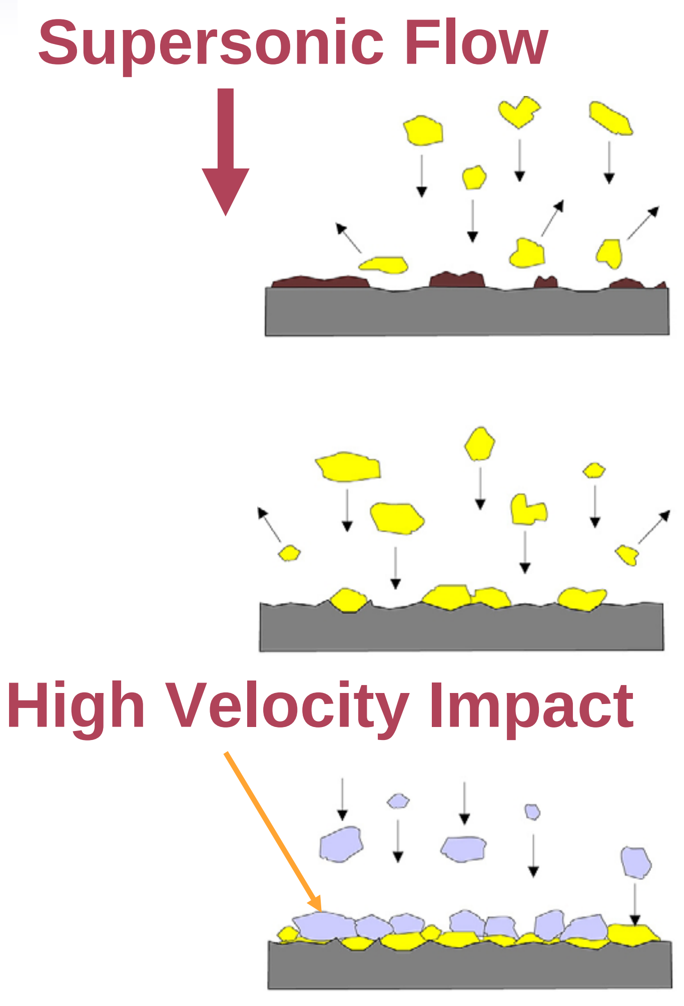
MRP/PWROG Briefing to NRC RES

Surface Remediation Technologies

- Currently under review by EPRI/MRP:
  - SIMAT process from Westinghouse
  - *ReNew*™ process from GE
  - Surface treatment from AREVA
  - SCrP process (developed by EPRI)
- The information presented is mostly vendor-supplied and is being investigated by EPRI/MRP

Supersonically Induced Mechanical Alloying Technology (SIMAT)

SIMAT Process



- Metal powder placed in an air jet
- Particles 40 microns in diameter
- Jet accelerates particles at 1-1/2 times the speed of sound
- Particles kinetically weld to the surface

Critical Parameters Finalized

- Gas Pressure
- Gas Temperature
- Gas Composition
- Powder Morphology and Composition
- Nozzle Geometry
- Surface Preparation
- Deposition Rate

Corrosion Test Results

- Doped steam at 750 F
- At least 500 hrs with no observed cracking
  - Inconel typically cracks in 50 to 100 hours
- 50 ksi preload
- Coated over pre existing cracks
- Tested different powders and parameters
- With manual process, SIMAT was proven to mitigate cracking

Moving from Manual to Automated

- Converting the process from manual to robot
- All information presented previously was from the manual process
- Recently made additional samples for NDE and corrosion testing using robotic delivery
- Visual examination looks promising
  - Visual results look similar to results from manual process
- Deposition on stainless steel and Inconel planned at Westinghouse laboratories

Next Steps

- Complete NDE compatibility
  - Transparency for UT
  - Penetration for ET
- Met samples
  - Porosity/density
  - Delamination
- Bond strength
- Corrosion testing

SIMAT Applications

- Applications
  - CRDM and J Groove Weld
  - Safe End Welds
  - RPV Internals
  - Flanges
  - Heat Exchanger Tube Sheet Welds
  - Divider Plates
  - Other

ReNew^{TM} Process

ReNew™ Surface Improvement

Technology:

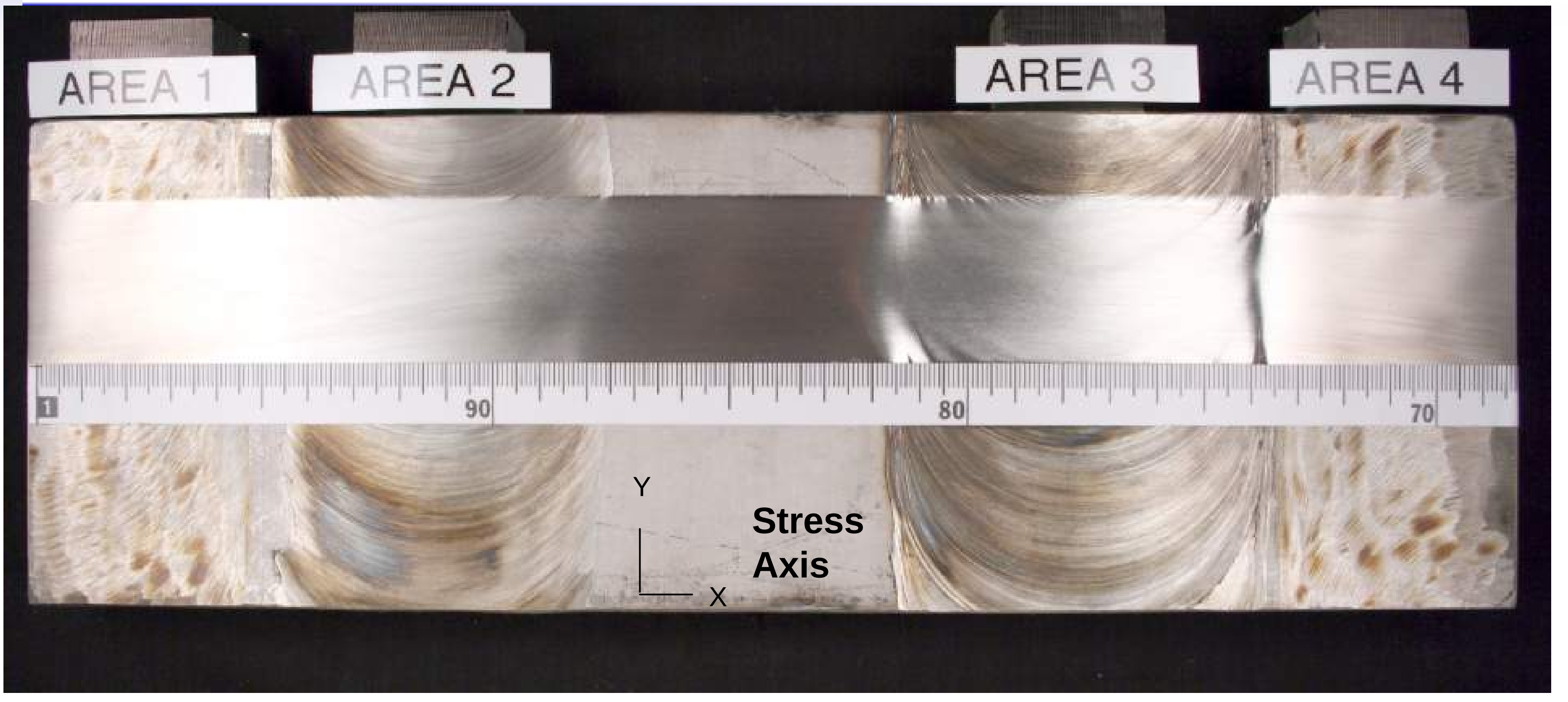
•Based on use of highly flexible, abrasive-filled, motorized bristle brushes, similar to those designed for conventional cleaning and de-burring of metals.

•Method tailored for application underwater or, in some cases, to continuously wetted surfaces.

Benefit … both BWR & PWR plants

- A surface residual stress improvement process to **change *any* surface tension to high compression,** plus
- A surface material removal method to **remove existing environmentally degraded layer(s) and small defects,** and
- A surface polishing step to **smooth the finish of surfaces** having rough machining, grinding, etc. (reduce surface strain-intensity)

ReNew™ Surface Improvement



Inconel 600 Plate

Inconel 600 Plate test after *ReNew* Surface Improvement over aggressively ground surface Areas 1 & 4, and aggressively machined surface Areas 2 & 3.

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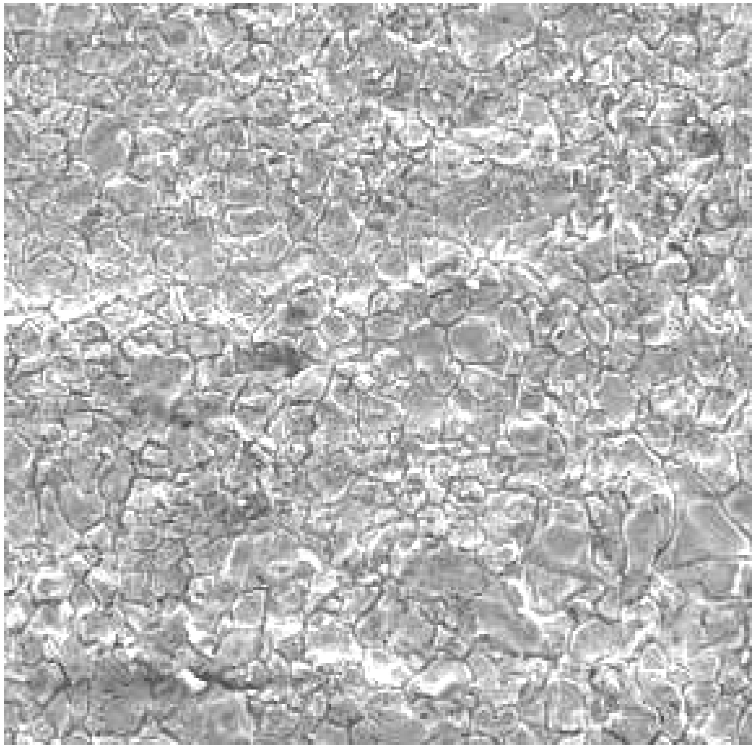
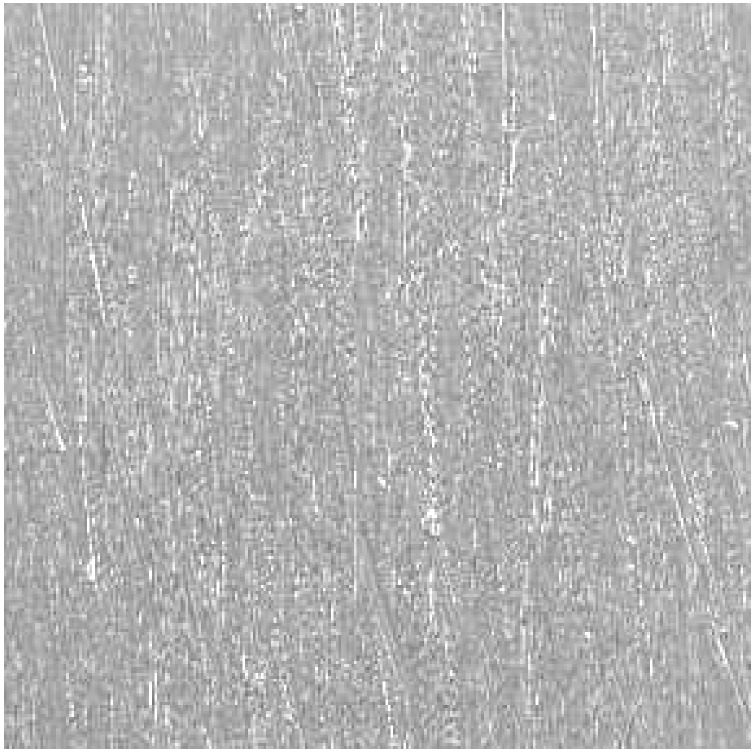
ReNew Surface Improvements





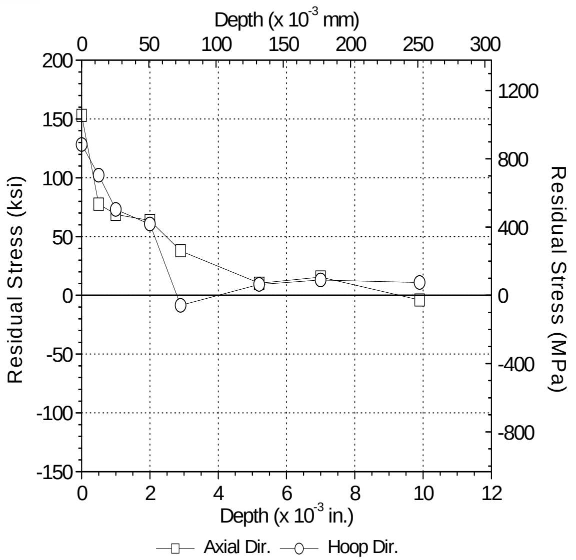
Scanning Electron Microscopy (SEM) of the Surface of Type 316L Stainless Steel Plate in Original Condition (Annealed and Pickled) (left), and After ***ReNew*** Application (right). Grain Boundary Ditching (Inter-Granular Attack) Has Been Removed.

Preliminary Conclusions for ReNew CBB Testing

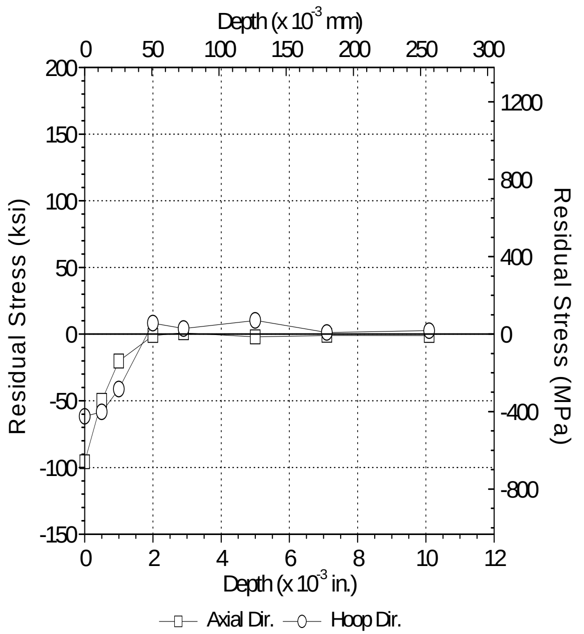
- No IGSCC detected on ReNewed face of Creviced Bent Beam (CBB) Specimens during initial optical microscope examinations*
- Factor of Improvement found to be greater than 12.4 in Autoclave Testing for 2252 hours

- ReNew CBB Samples Performed as Expected, Providing Significantly Increased Resistance to IGSCC Relative to Heavily-Ground or Finely-Sanded Surfaces.
- This Improvement was Obtained Even with Surface Cold Work, 1% Plastic Strain, and Very Aggressive Water Chemistry.

BWR SCC Mitigation - ICMH



304L SS HOUSING MOCKUP SHAFT
Specimen Ground Adjacent To The Fusion Line Location
Figure 1

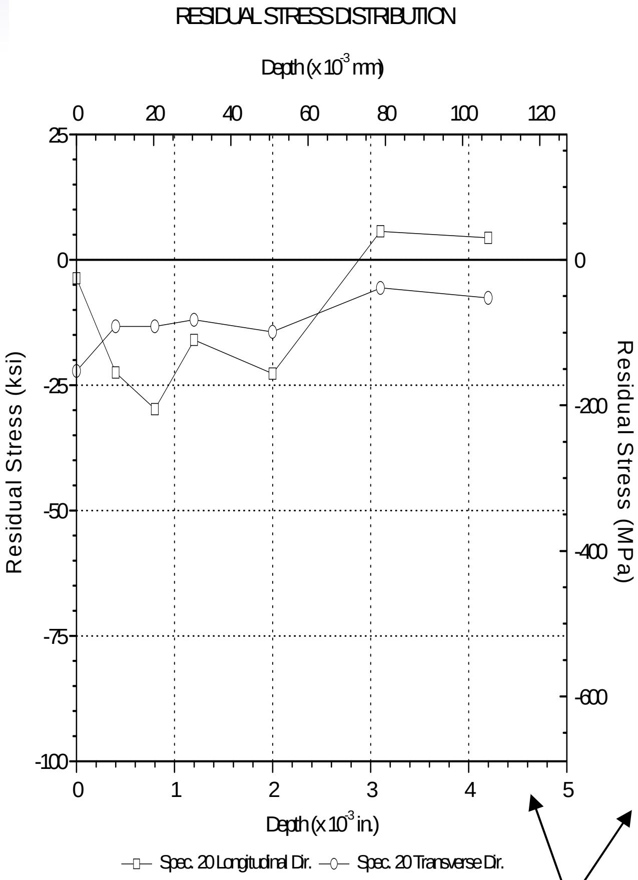


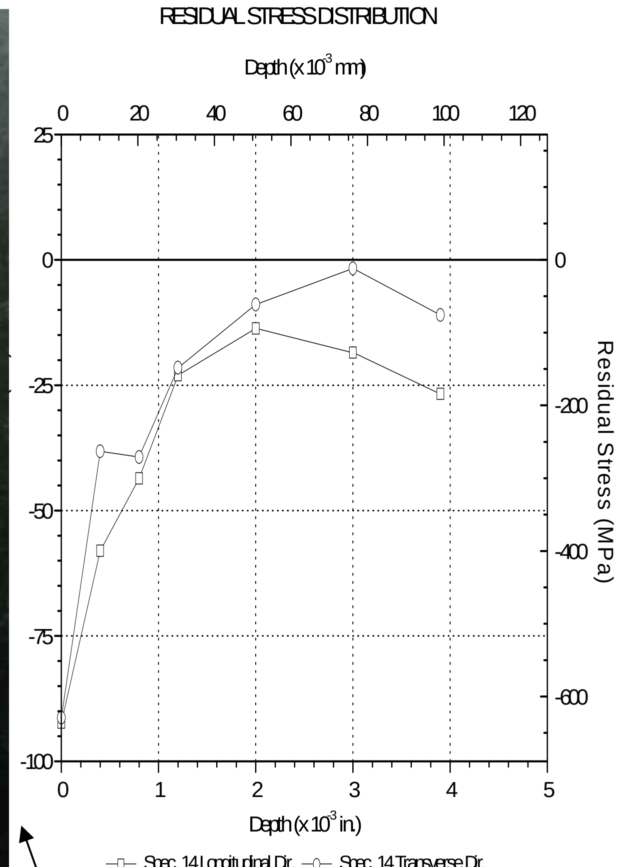
304L SS HOUSING MOCKUP SHAFT
Specimen Polished Adjacent To The Fusion Line Location
Figure 2

Residual Stress measurement areas

ICMH Weld Mockup, after ReNew and after sectioning for residual stress measurements in Housing and Weld

PWR ID Bottom Mounted Instrumentation





As Fabricated

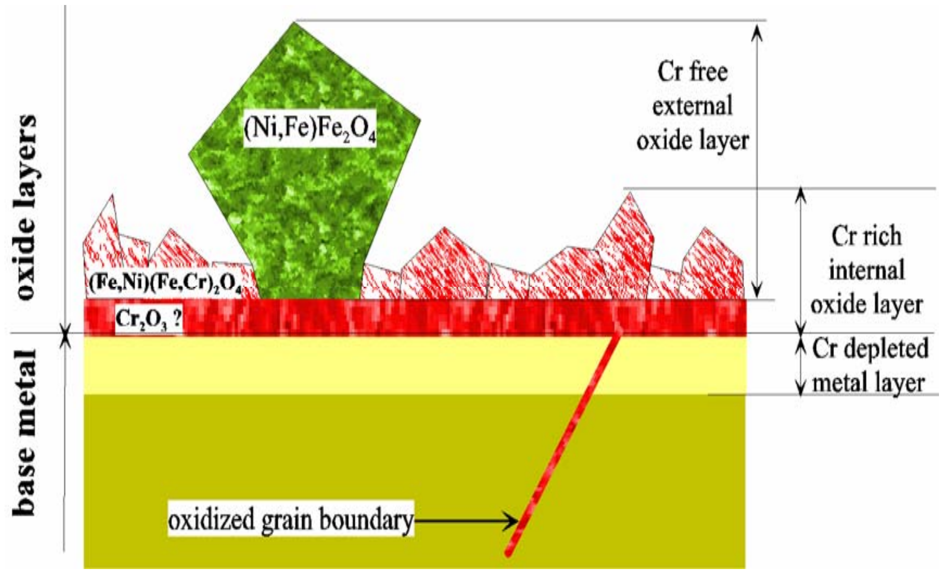
Results After ReNew

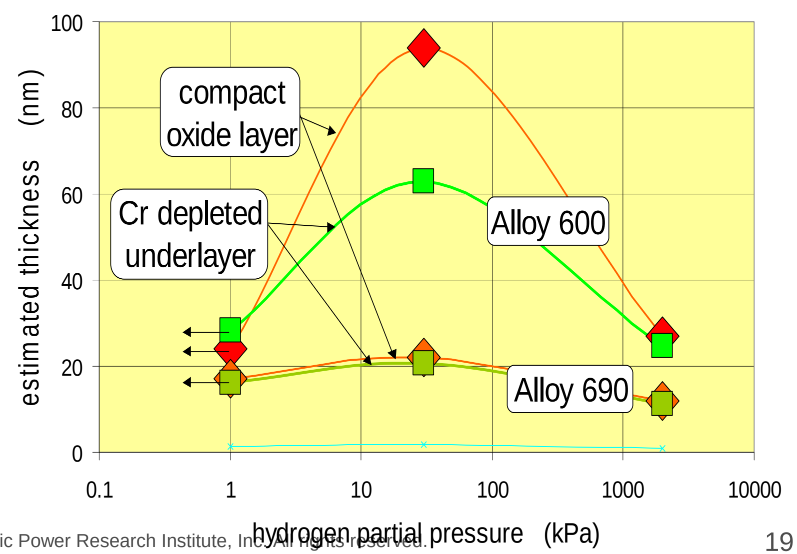
Surface Treatment

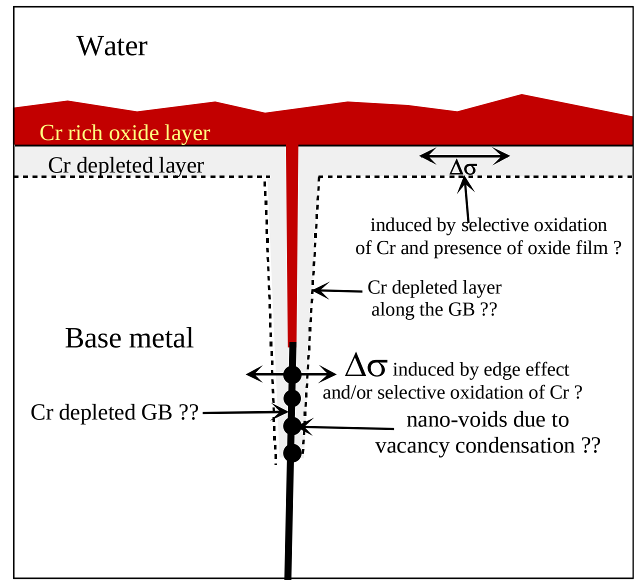
Alloy 600/182 Surface Oxidation Studies: Background

- AREVA NP (France) with internal R & D funding as well as FROG and EPRI financial support have investigated in detail surface oxidation processes of Alloy 600 and 182 in PWR primary water
- Objective is to understand what leads to long incubation times in the field to crack initiation and to investigate the feasibility of mitigating PWSCC by removing a thin surface layer of aged material prior to actual crack formation
- Surface chromium depletion is believed to be a precursor for crack initiation

Structure of oxide layers formed of Ni-base Alloys in PWR primary coolant: theoretical basis for surface remediation to delay PWSCC initiation







Initiation mechanism is assumed to involve oxide and oxygen ingress along grain/dendrite boundaries

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Investigations of PWSCC in Alloys 600 and 182

- Part I: Review of Operating and Laboratory Experience of PWSCC in Alloy 182 Weld Metal
  - Summarize relevant operating experience and laboratory results on PWSCC of Alloy 182 and similar nickel base weld metals
- Part II: Assess effects of surface finish on PWSCC of Alloy 182
- Part III: Assess applicability of surface remediation techniques to delay PWSCC Initiation in Alloy 600
  - Prepare suitable specimens from material with long-term exposure and examine for evidence of internal oxidation
  - Test ability to “reset the clock” by removing a thin surface layer
- Part IV: Plan to assess applicability of surface remediation techniques to delay initiation of PWSCC of Alloy 182

Results Summary and Plans for Further Studies

- PWSCC initiation times in Alloy 182 clearly linked to surface residual stresses induced by a combination of the grinding specification and subsequent plastic straining
- The critical surface parameter due to grinding is surface cold work, which does not correlate with surface roughness that is commonly used to categorize grinding standards
- Electro-polishing prior to PWSCC testing of previously exposed Alloy 600 has a remarkably beneficial effect on initiation times

Stabilized Chromium Process

Evaluation of SCrP for PWSCC Mitigation: Background

- The EPRI patented SCrP has been shown to dramatically lower the incorporation of Co-60 in replacement components
- It has been applied to over 100 PWR diaphragms, pump parts and many valves during the last few years
- SCrP is a three stage process that involves:
  - Intensive surface cleaning and electropolishing
  - Deposition of a very thin Cr layer by electroplating
  - Pre-oxidation in steam at ~ 600 ^{o}F for ~ 100 h
- It results in a Cr enriched layer (to > 90 weight %) from a depth of about 0.01 to 0.15 mils at the component surface
- Because Cr content plays a key role in PWSCC of Ni-base alloys, this study was carried out to evaluate the effect of treating Alloy 600 RUB specimens by SCrP

Evaluation of SCrP for PWSCC Mitigation: Test Procedure

- 40 reverse U-bends (RUB) specimens were machined from a low temperature MA heat (M71) of Alloy 600
- 20 were then treated by SCrP (in the stressed state)
- All were tested in simulated PWR primary water (2 ppm Li, 1000 ppm B, $pH_T = 7.2$) at 608 ^oF with periodic inspections
- Times at which cracking was first detected by microscopic examination were plotted in a Weibull diagram
- Longest exposure time was just under 4000 h
- Some specimens were selected for metallographic examination at the end of testing (after coating with Ni to preserve the edge contrast)

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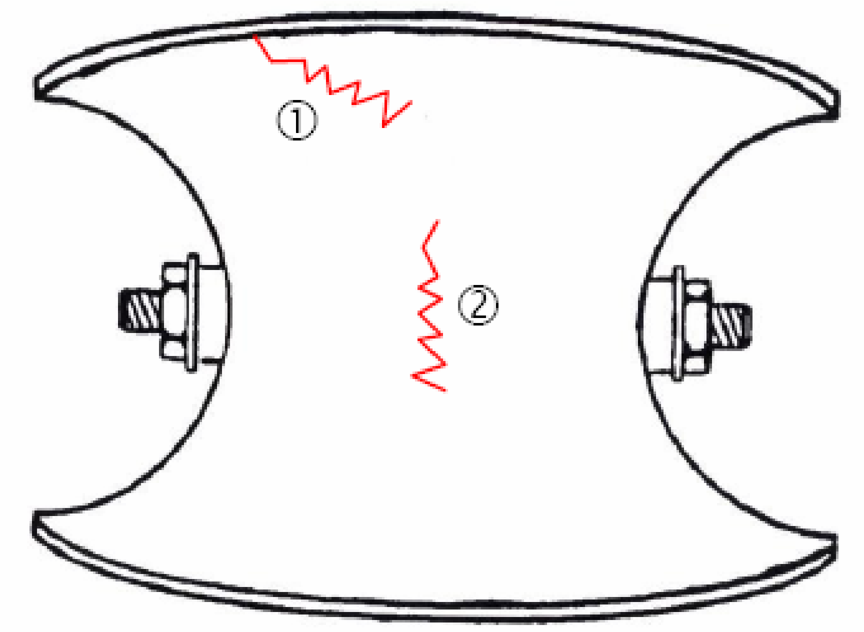
Evaluation of SCrP for PWSCC Mitigation: Results



Evaluation of SCrP for PWSCC Mitigation: Results

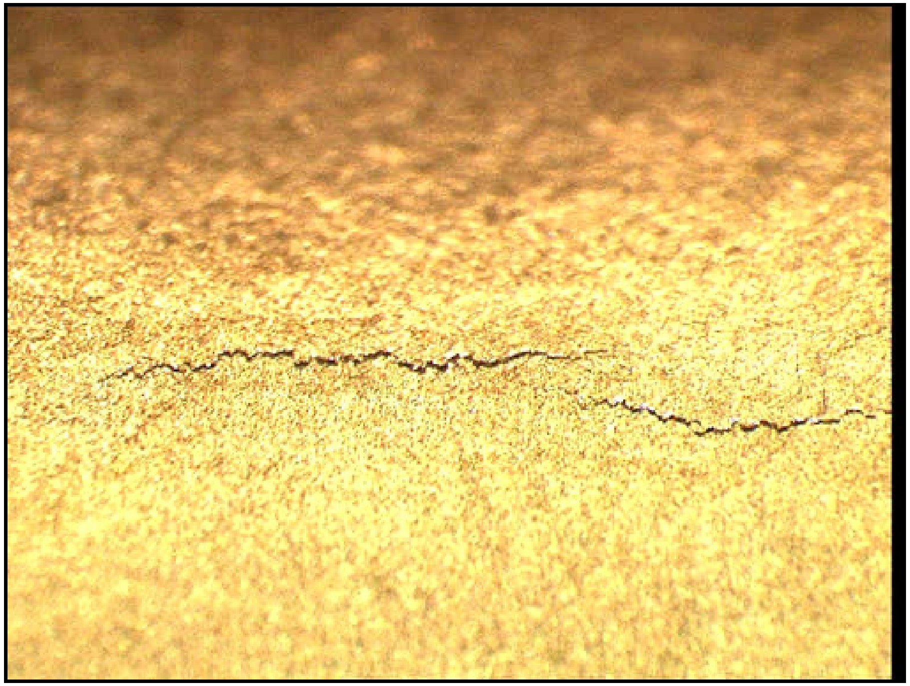


Figure 3 – Observation of cracks at the surface of as-received specimen MC/EP/03-44 (1250 h).

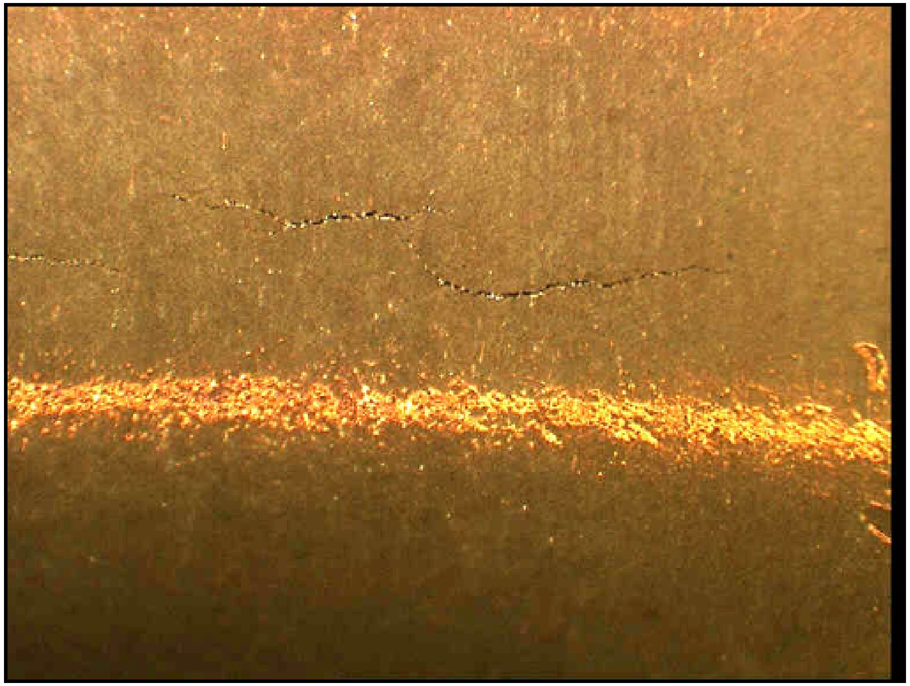


Figure 4 – Observation of cracks at the surface of SCrP specimen MC/EP/03-17 (2000 h).

Evaluation of SCrP for PWSCC Mitigation: Results

Table 3 – Weibull approach for results interpretation using Bernard's formula.

Surface state	Time to intiation (h)	Number of RUBs with initiation	Number of de RUBs without initiation	*N*	*i*	*F(t)*	Ln[Ln(1/(1-*F*)]	Ln(*t*)
As-received	250	0	20	20	-	-	-	-
As-received	500	0	20	20	-	-	-	-
As-received	750	0	20	20	-	-	-	-
As-received	1000	2	18	20	2	0.083	-2.442	6.908
As-received	1250	18	0	20	20	0.966	1.216	7.131
SCrP	500	0	20	20	-	-	-	-
SCrP	1000	0	20	20	-	-	-	-
SCrP	1500	0	20	20	-	-	-	-
SCrP	2000	7	13	20	7	0.328	-0.921	7.601
SCrP	2500	6	7	20	13	0.623	-0.026	7.824
SCrP	3000	1	6	20	14	0.672	0.107	8.006
SCrP	3470	1	5	20	15	0.721	0.243	8.152
SCrP	3970	5	0	20	20	0.966	1.216	8.287

Evaluation of SCrP for PWSCC Mitigation: Conclusions

- All specimens eventually failed by PWSCC, but crack initiation was significantly delayed by SCrP process
- Characteristic life of SCrP treated specimens was increased by a factor of ~ 2.4 with respect to control specimens
- As expected, no differences in macroscopic crack morphology were apparent
- Use of SCrP could benefit replacement components (including Alloys 690/152/52) since field history is good and radiation benefits result
- Alternative pre-oxidation procedures would probably be required