Ni plating technology for RPV cladding repair

Seong S. Hwang, Min S. Kim, Eun H. Lee, Dong J. Kim
Korea Atomic Energy Research Institute

2018 KEPIC week

KEPIC/ASME/KAERI Joint Seminar

Busan, Korea

Aug. 28~31, 2018

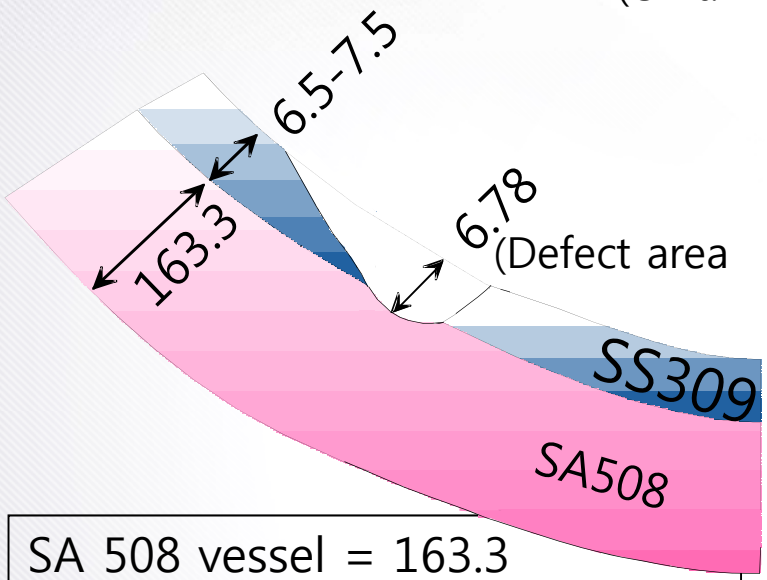
KAERI
Korea Atomic Energy
Research Institute

CONTENTS

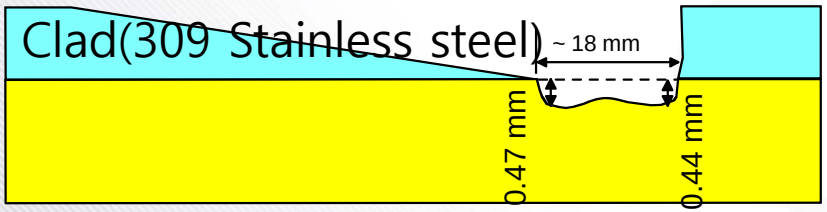
1. Background

❖ Defect morphology and corrosion trend

(Unit:mm)

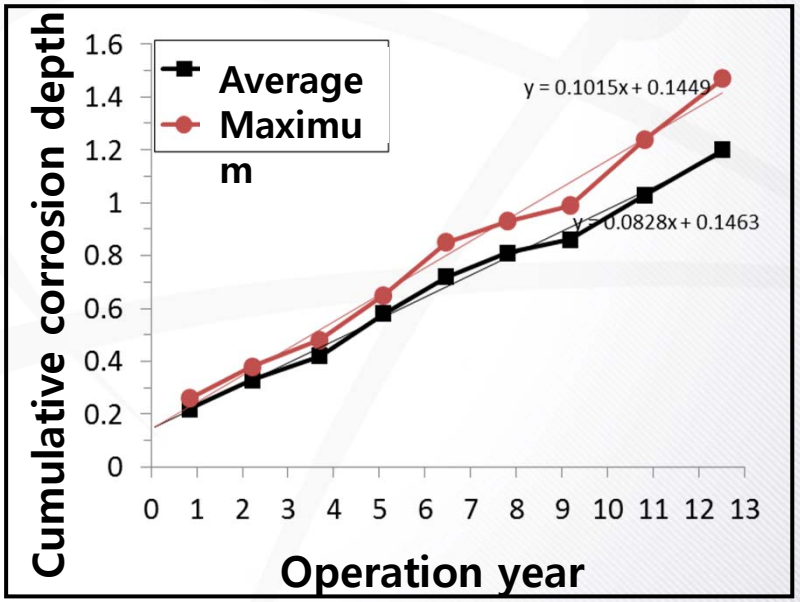


SA 508 vessel = 163.3
Minimum safety margin =103.5
Tolerance = 59.8



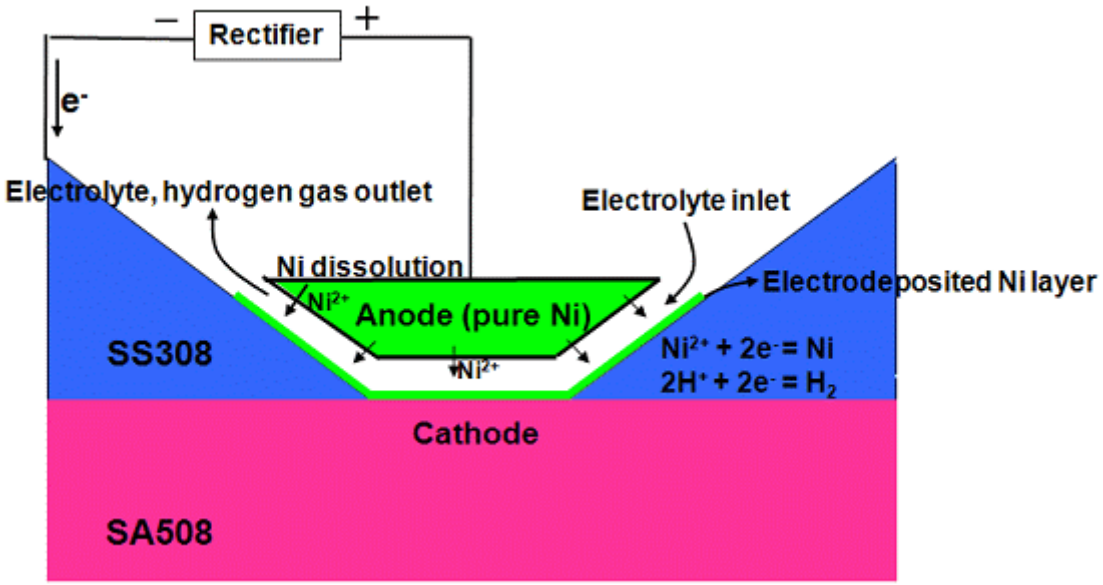
Ferritic base metal (SA 508 vessel steel)

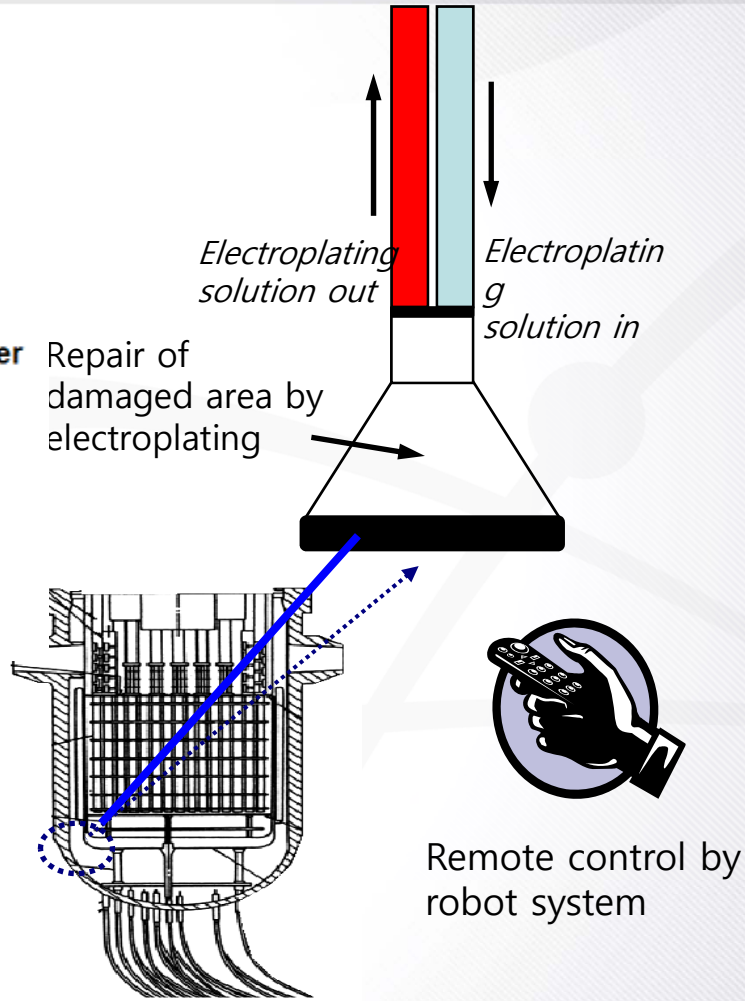
- Max depth in 2002 : 0.22mm
- Replica evaluation depth in 2012: 0.99 mm
- Corrosion rate: ~0.1mm/year



Corrosion trend of the damaged area

2.Ni electroplating technology for cladding repair





Repair using Ni electroplating technique
: repair of damaged SA508 including SS308/309
: **low temperature (~60°C) process (no further thermal budget), removable layer**
: well sealed process
(only damaged area is exposed electroplating solution)

Schematic diagram for repair of damaged area in reactor vessel

2.Ni electroplating technology for cladding repair

- ✓ Low temperature process : no further thermal budget to carbon steel and SS
- ✓ Not welded or mechanically bonded to matrix materials

  : low internal stress, no matrix structure modification, no heat treatment
- ✓ Continuously bonded to matrix materials

  : no crevice between electrodeposit and matrix
- ✓ Removable layer by chemical treatment
- ✓ Compatible with PWR water chemistry

  : electrosleeving had been applied to Callaway plant (1999)
- ✓ Excellent corrosion resistant
- ✓ Highly structural integrity by minor element

→ **Electroplating is a promising method to repair a damaged layer**

3. Code case development

- Discussion on Inquiry and committee's response to KAERI
- Inquiry #1
  - May the IWA-4640 'Cladding' rules be applied to repair of cladding if the ferritic material is exposed to coolant directly, provided adequate base material thickness exists in the location where cladding will be repaired?
  - Proposed Reply #1 : Yes.
- Inquiry #2
  - Can the IWA-4640 'Cladding' rules be applied to repair of cladding in the under water condition?
  - Recommend staff secretary send this response: ASME Section XI does not address this issue, but has initiated an action to address underwater cladding repair.

Record Number 10-1901

Scope : ASME Code section XI, IWA 4640 'Cladding'
Background : The exposed SA 508 alloy steel is under PWR primary coolant. Considering any repair process on that area, it may not be easy to drain all coolant, because the area will be highly radioactive without the coolant. When the ferritic material is within 1/8 in. (3mm) of being exposed, the clad can be repaired according to IWA-4640 'Cladding'.

Inquiry #1

May the IWA-4640 'Cladding' rules be applied to repair of cladding if the ferritic material is exposed to coolant directly, provided adequate base material thickness exists in the location where cladding will be repaired?

Proposed Reply #1 : Yes.

Inquiry #2

Can the IWA-4640 'Cladding' rules be applied to repair of cladding in the under water condition?

Recommend staff secretary send this response: ASME Section XI does not address this issue, but has initiated an action to address underwater cladding repair.

Bruce Newton
2-2-11

3. Code case development

Inquiry Record No. 10-1901(Nov. 2010)

Discussion and reply in Feb. 2011 Seattle

Recommend staff secretary send this response: ASME Section XI does not address this issue, but has initiated an action to address underwater cladding repair.

RRA 11-01(Record No. 11-417)

Repair by electroplating
(Suggested by KAMC May, Las Vegas, May 2011)

Issued 8 questions from Task Group on Underwater Cladding Repair by Ni Plating (Feb. 2012 Houston)

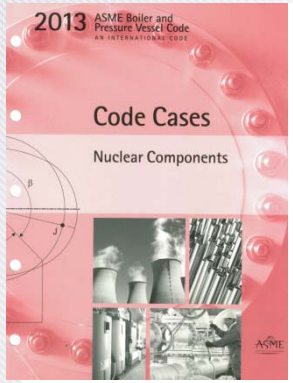
Effort for Issue resolving for two years
(May 2012, Nashville)

- Nov. 2012: WG Welding and Special repair processes, passed 14-0-1
- Feb. 2013 : Dr. Hwang motioned to approve and send to SG-RRA. Passed 14-0-1
- Aug. 2013: Dr. Hwang motioned to approve at Section XI STD committee, Motion passed to letter ballot.
- Sept. 2013 Ballot No.13-1979: Disapproved with some negatives
- Oct. 2013 : Recirculation ballot

Final presentation at Section XI STD(2013.8.15)

Approved at BNCS(Dec. 11,2013

3. Code case development



CASES OF ASME BOILER AND PRESSURE VESSEL CODE

CASE
N-840

Approval Date: January 23, 2014

Code Cases will remain available for use until annulled by the applicable Standards Committee.

Case N-840
Cladding Repair by Underwater Electrochemical Deposition in Class 1 and 2 Applications
Section XI, Division 1

Inquiry: As an alternative to Article IWA-4000 under what conditions may cladding be repaired by the application of material using underwater electrochemical deposition?

(f) Underwater electrochemical deposition uses chemicals that are introduced into an enclosure that is in direct contact with Reactor Coolant System (RCS) water. Prior to the electrochemical deposition process, an assessment shall be performed to address the following:

(1) the electrochemical constituents to be used

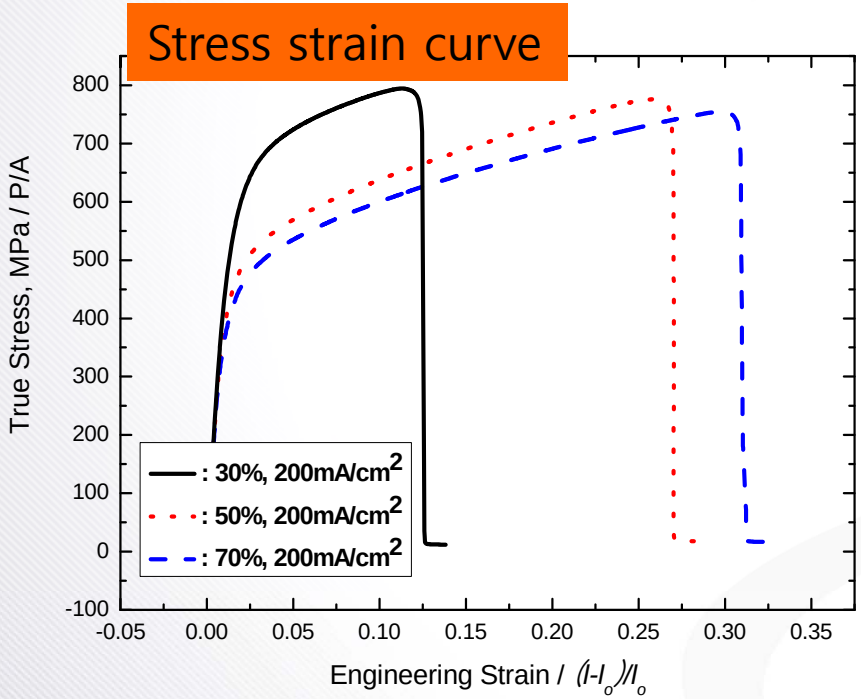
(2) the maximum volume of these chemicals that could be released into the RCS during electrodeposition, and the resulting effect on RCS chemistry

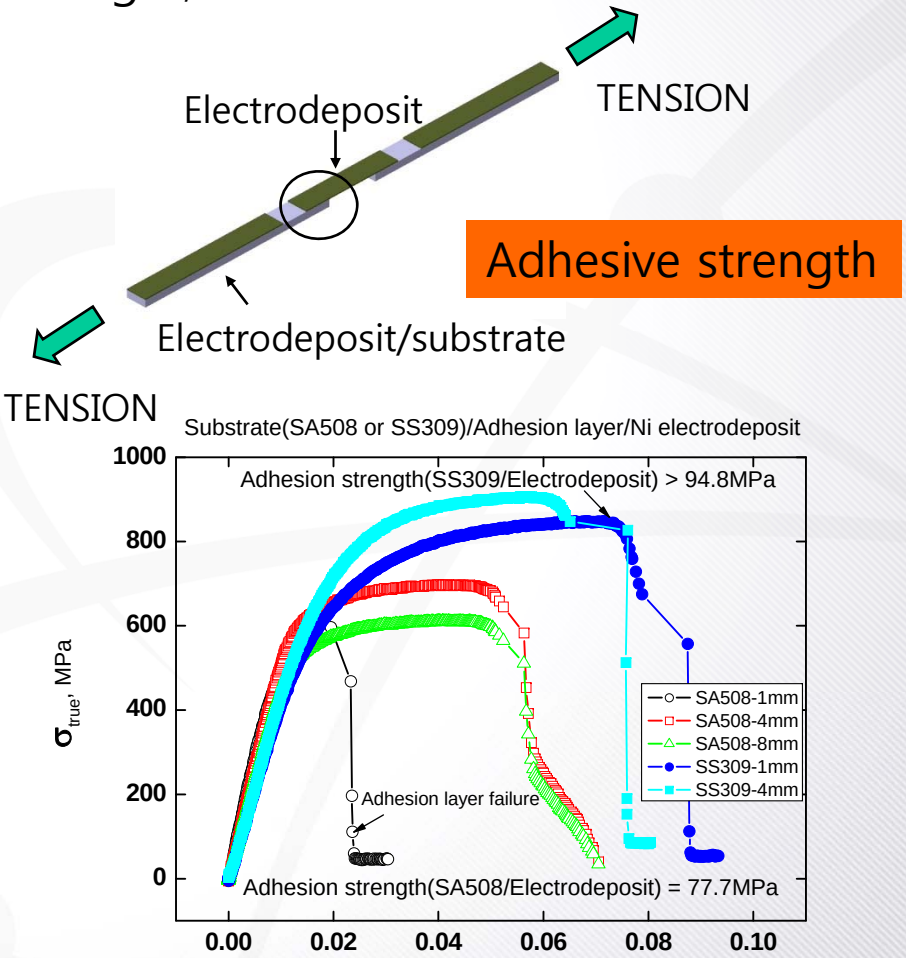
(g) Consideration shall be given to the effects of irradia-

4. Variables for Ni plating

2. Mechanical property

: stress-strain curve, hardness, adhesive strength, thermal stress evaluation





4. Variables for Ni plating

1. Set up of electroplating conditions

: temperature, pH, current density, duty cycle, additive, chemical composition, anode type, strike layer formation condition, reproducibility, etc.

Degreasing (NaOH,100mA/cm^2)

↓ Cleaning

Activation

↓

Strike Layer Formation ($NiCl_2$ + H_3BO_3,)

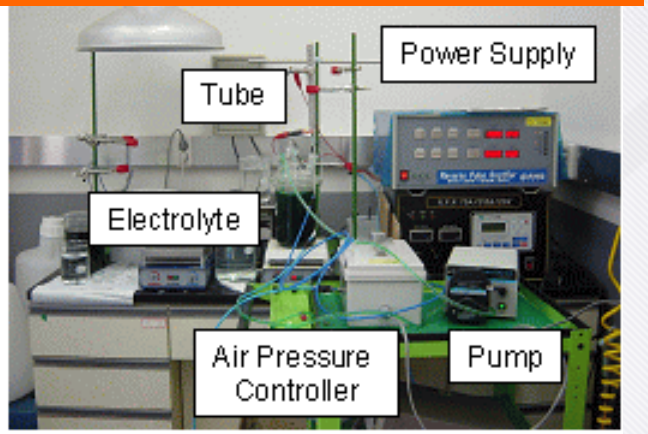
↓ Cleaning

Electroplating layer formation

<u>Electroplating conditions</u>

- $Ni(SO_3 \cdot NH_2)_2$: 1.39mol
- H_3BO_3 : 0.65mol
- H_3PO_3 : 0~0.007mol
- Additives : stress reducing agent, leveler, surfactant
- Current Density : 20~350mA/cm^2
- Duty Cycle : 0.3~1
- Temp. : 50~70°C / pH : 1~5

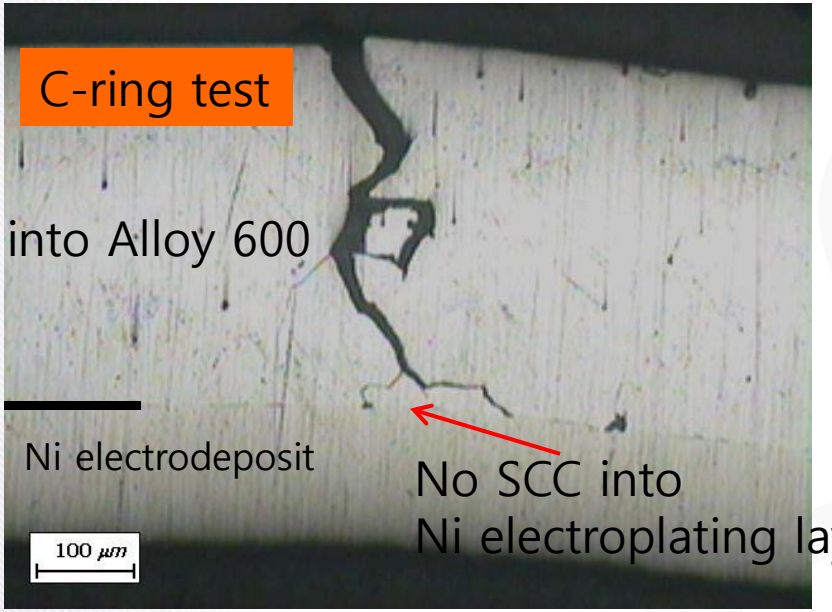
Electroplating condition set up

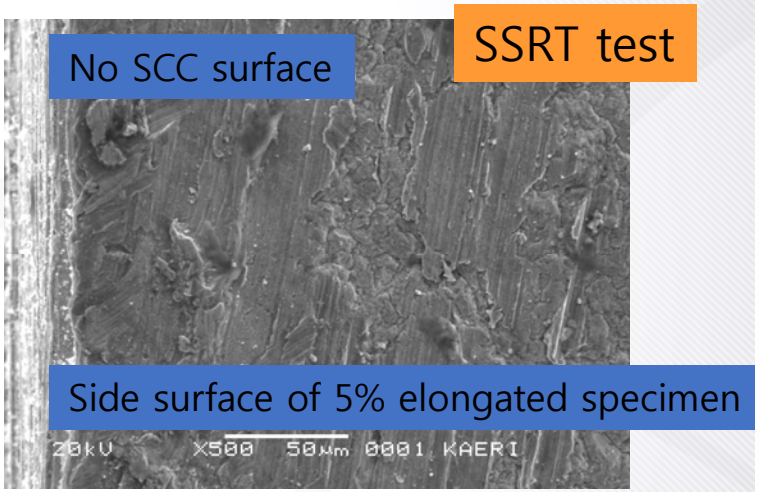


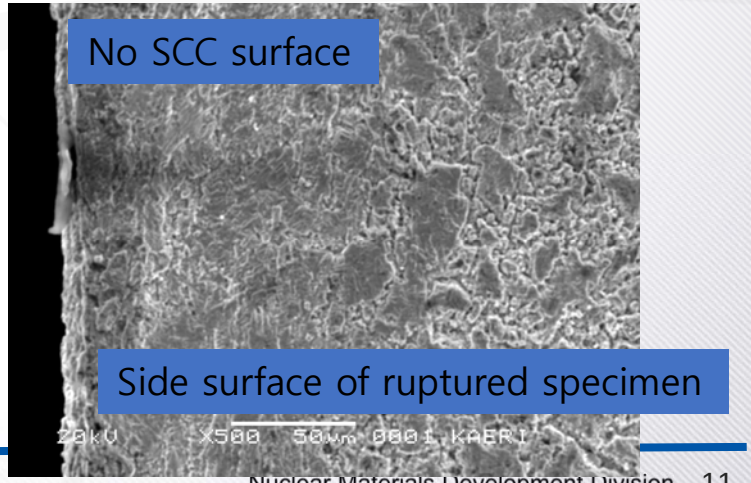
4. Variables for Ni plating

3. Corrosion property

: SCC resistance, general corrosion, Galvanic corrosion







4. Variables for Ni plating

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Surface & Coatings Technology 192 (2005) 88–93

SURFACE & COATINGS TECHNOLOGY

www.elsevier.com/locate/surfcoat

Effects of the peak current density and duty cycle on material properties of pulse-plated Ni–P–Fe electrodeposits

Dong Jin Kim, Yu Mi Roh, Moo Hong Seo*, Joung Soo Kim

Nuclear Materials Technology Development Division, Korea Atomic Energy Research Institute (KAERI), P. O. Box 105, Yuseong, Daejeon, 305-600, South Korea

Received 26 January 2004; accep
Available online

Abstract

This work investigated the effects of the peak current density (properties of the Ni–P–Fe electrodeposits obtained from a Ni sulph stress–strain curve and microstructure. Chemical compositions, th inductively coupled plasma (ICP) mass spectrometer, tension teste (TEM), respectively. From the results of the stress–strain curves a strength (YS) and the tensile strength (TS) decreased, whereas the elo depletion at the interface of the electrodeposit/solution, the fraction chemical concentration (Fe and P). As the duty cycle increased, the During the off time at a high duty cycle, the concentration depleti electrodeposit/solution, resulting in a coarse grain sized electrodepos high duty cycle due to the relatively small hydrogen reduction reactio comparison between the stress–strain curves for the pulse-plated ele an additive, the enhancement of the nucleation rate caused by the rec of the pulse plating is comparable with the effect of the additive on

Keywords: Peak current density; Duty cycle; Pulse plating; Ni–P–Fe electr

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Surface & Coatings Technology 202 (2008) 2519–2526

SURFACE & COATINGS TECHNOLOGY

www.elsevier.com/locate/surfcoat

Material characteristics of Ni–P–B electrodeposits obtained from a sulfamate solution

Dong-Jin Kim *, Myong Jin Kim, Joung Soo Kim, Hong Pyo Kim

Nuclear Materials Research Center, Korea Atomic Energy Research Institute (KAERI), 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, South Korea

Received 2 July 2007; accepted in revised form 13 September 2007
Available online 29 September 2007

MATERIAL RELIABILITY OF Ni ALLOY ELECTRODEPOSITION FOR STEAM GENERATOR TUBE REPAIR

DONG-JIN KIM*, MYONG JIN KIM, JOUNG SOO KIM and HONG PYO KIM
Division of Nuclear Material Technology Developments, Korea
Korea Atomic Energy Research Institute
150 Deokjin-dong, Yuseong-gu, Daejeon, 305-353 Korea
*Corresponding author. E-mail : djink@kaeri.re.kr

Received January 10, 2007
Accepted for Publication March 17, 2007

Due to the occasional occurrences of stress corrosion cracking (SCC) in steam generator tubing (Alloy 600), degraded tubes are removed from service by plugging or are repaired for re-use. Since electrodeposition inside a tube does not entail parent tube deformation, residual stress in the tube can be minimized. In this work, tube restoration via electrodeposition inside a steam generator tubing was performed after developing the following: an anode probe to be installed inside a tube, a degreasing condition to remove dirt and grease, an activation condition for surface oxide elimination, a tightly adhered strike layer forming condition between the electroforming layer and the Alloy 600 tube, and the condition for an electroforming layer. The reliability of the electrodeposited material, with a variation of material properties, was evaluated as a function of the electrodeposit position in the vertical direction of a tube using the developed anode. It has been noted that the variation of the material properties along the electrodeposit length was acceptable in a process margin. To improve the reliability of a material property, the causes of the variation occurrence were presumed, and an attempt to minimize the variation has been made. A Ni alloy electrodeposition process is suggested as a primary water stress corrosion cracking (PWSCC) mitigation method for various components, including steam generator tubes. The Ni alloy electrodeposit formed inside a tube by using the installed assembly shows proper material properties as well as an excellent SCC resistance.

KEYWORDS : Stress Corrosion Cracking, Steam Generator Tubing, Electrodeposition, Repair, Anode Probe, Material Reliability

1. INTRODUCTION

Due to occasional occurrences of a localized corrosion, such as a stress corrosion cracking (SCC) and pitting in steam generator tubing (Alloy 600), degraded tubes are removed from service by plugging or are repaired for re-use. Typical sleeving repair techniques introduce welding and mechanical expansions that lead to residual stress in the parent tube, which should be relieved to improve the in-service life [1,2]. However, electrodeposition inside a tube does not introduce parent tube deformation and, hence, entails negligible residual stress.

Particular equipment and conditions are needed to perform an electrodeposition inside a tube successfully, including the following: an anode to be installed inside a tube, a degreasing condition to remove dirt and grease, an activation condition for surface oxide elimination, a tightly adhered strike layer forming condition between the electroforming layer and the parent tube, and the coridition for an electroforming layer. Through a combination of these various process parameters, the desired material properties can be realized. For application in a plant, the material reliability of an electrodeposit with a variation of the material properties as a function of the electrodeposit position in the vertical direction of a tube is also very important.

It is logical to select a Ni alloy electrodeposition in a proper electrodeposition system, because Alloy 600 is mainly composed of nickel and because nickel electroplating has been widely studied to improve corrosion resistance as well as mechanical and magnetic properties [3,4]. Moreover, a Ni alloy electrodeposition process can be used for primary water stress corrosion cracking (PWSCC) mitigation for various components, including steam generator tubes, because Ni alloy electrodeposit shows excellent SCC resistance [5].

This work deals with the process development for tube repair and is especially focused on anode development, a strike layer forming condition, and the material properties and the reliability of the layer formed by electrodeposition.

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Thin Solid Films 489 (2005) 122–129

thin solid films

www.elsevier.com/locate/tsf

The effects of pH and temperature on Ni–Fe–P alloy electrodeposition from a sulfamate bath and the material properties of the deposits

Moo Hong Seo[a,*], Dong Jin Kim[b], Joung Soo Kim[b]

[a]*Samsung Electro-Mechanics Co., Ltd. UTCSP Development Team, Dong-Myon, Yeongi-Gun, Chungcheongnam-Do, Korea*
[b]*Korea Atomic Energy Research Institute, Nuclear Materials Technology Development Division, Daejeon, Korea*

Received 5 September 2003; received in revised form 15 June 2004; accepted 2 May 2005
Available online 22 June 2005

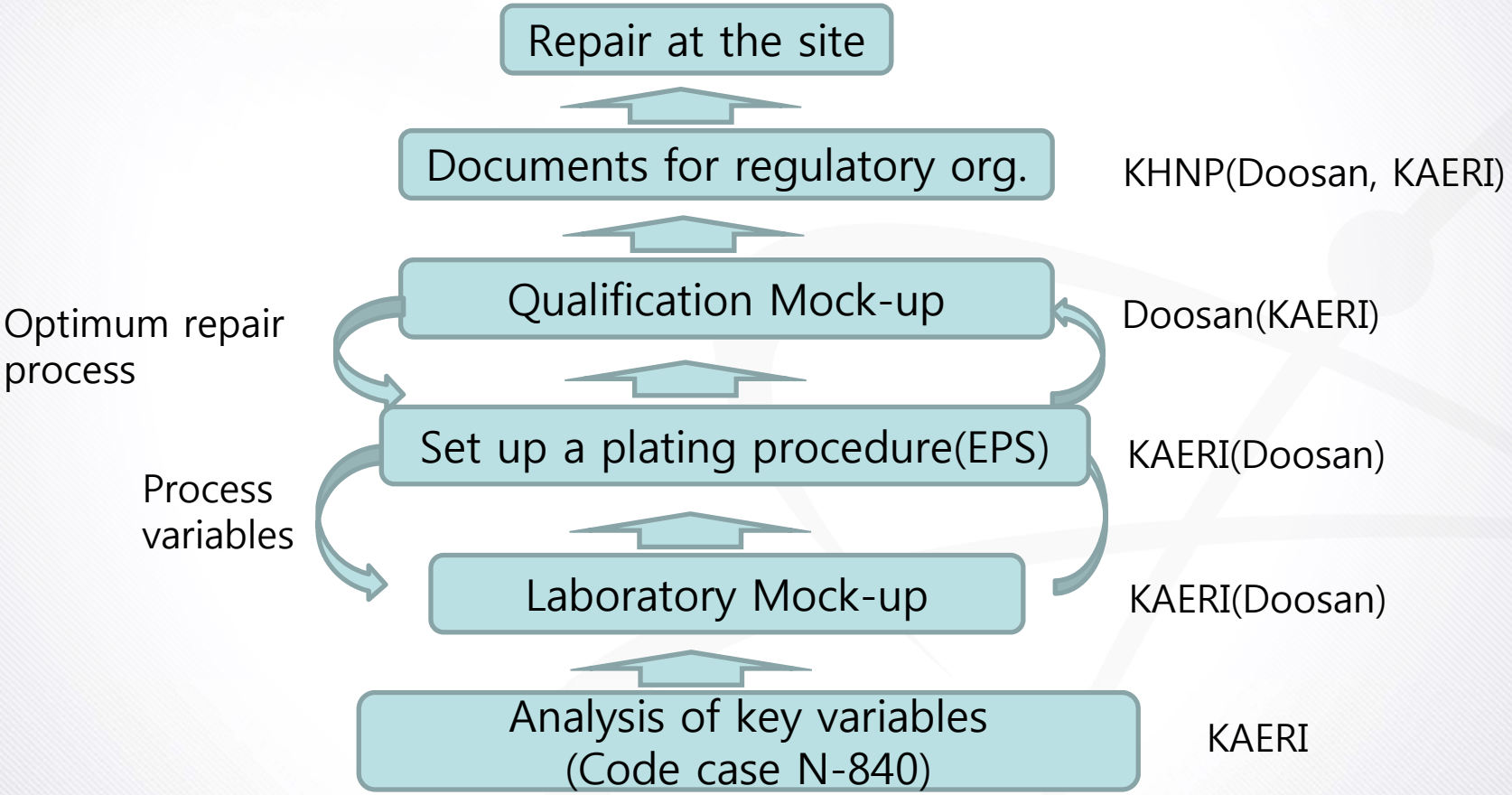
Abstract

The effects of pH and temperature on Ni–Fe–P alloy electrodeposition from a Ni sulfamate bath and the material properties of the deposits were investigated. Electrochemical behavior was evaluated by potentiostat and impedance spectroscopy and the material properties of the deposits were determined using Inductively Coupled Plasma, Scanning Electron Microscope, X-Ray Diffractometer. Nyquist plots of the impedance spectra of Ni–Fe–P deposition were characterized by a capacitive loop and an inductive loop similar to those obtained for Ni–Fe deposition, while the mechanism of Ni–Fe–P deposition was normally controlled by the introduction of P unlike abnormal Ni–Fe deposition. Sulfur content of the deposits from the Ni sulfamate bath increased with the pH of the electrolyte and decreased at an elevated temperature of electrolyte up to 60 °C. As the pH of the electrolytes increased from 1 to 3.5, current efficiency, grain size and stresses in the deposits increased. It seems to be related to the decrease of the hydrogen evolution reaction and hydrogen absorption, and the increase of NH_4 added into the bath in order to control the pH. When the temperature of the electrolyte increased from 60 to 70 °C, the increase of the value of R_a and a rapid decrease in the crystallinity appeared due to the transformation of sulfamate into impurities, fairly consistent with the results of the sulfur contents of the deposits.

PACS: 81.15.P
Keywords: Electrodeposition; Nickel–iron alloy; Stress; Surface morphology

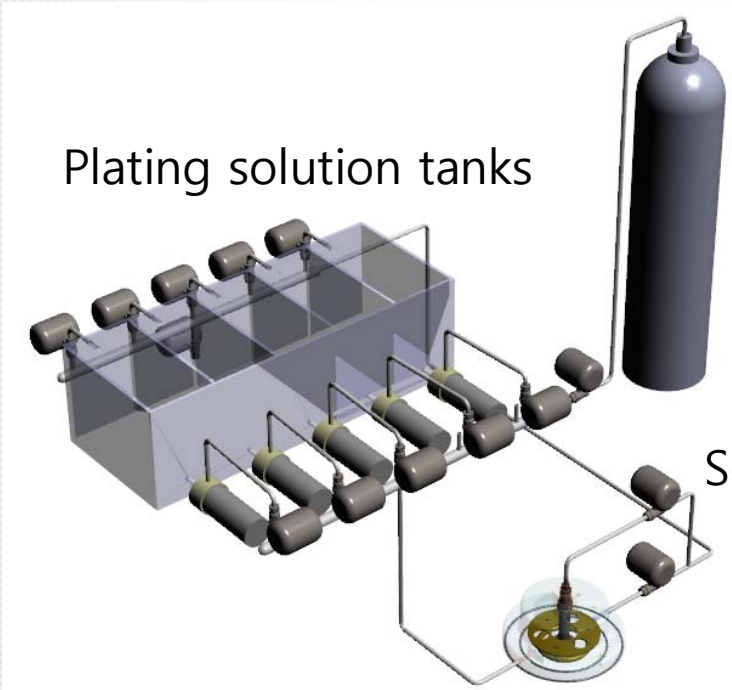
5. Ni plating process development

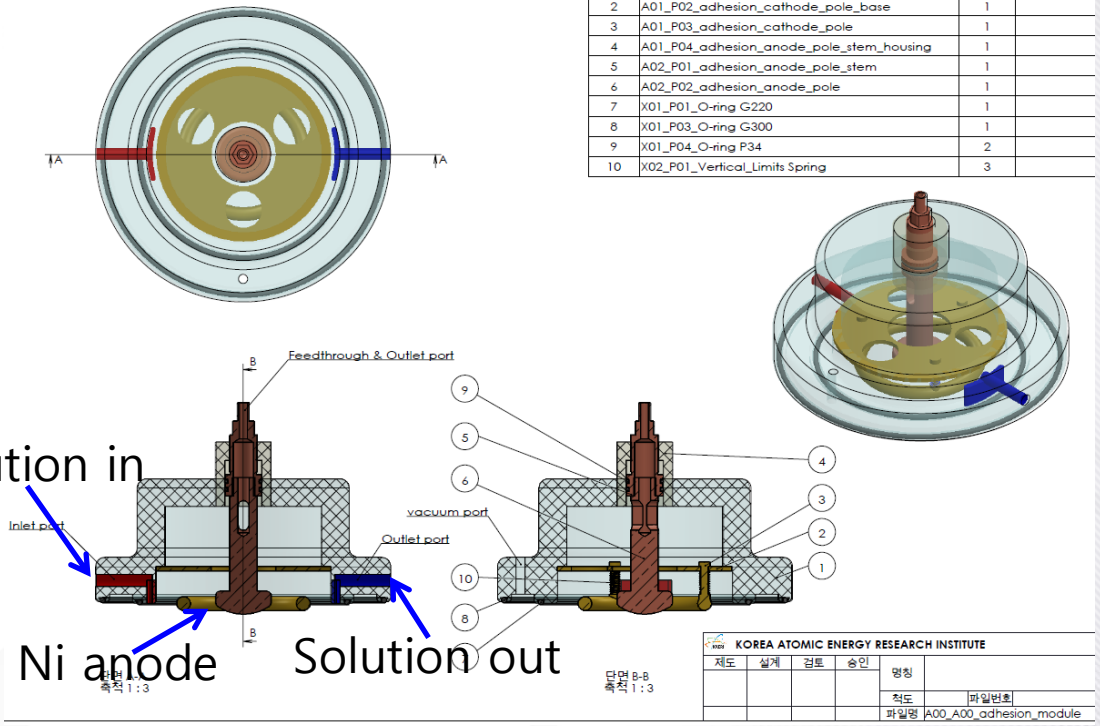
❖ General process



5. Ni plating process development

●Ni plating demonstration facility

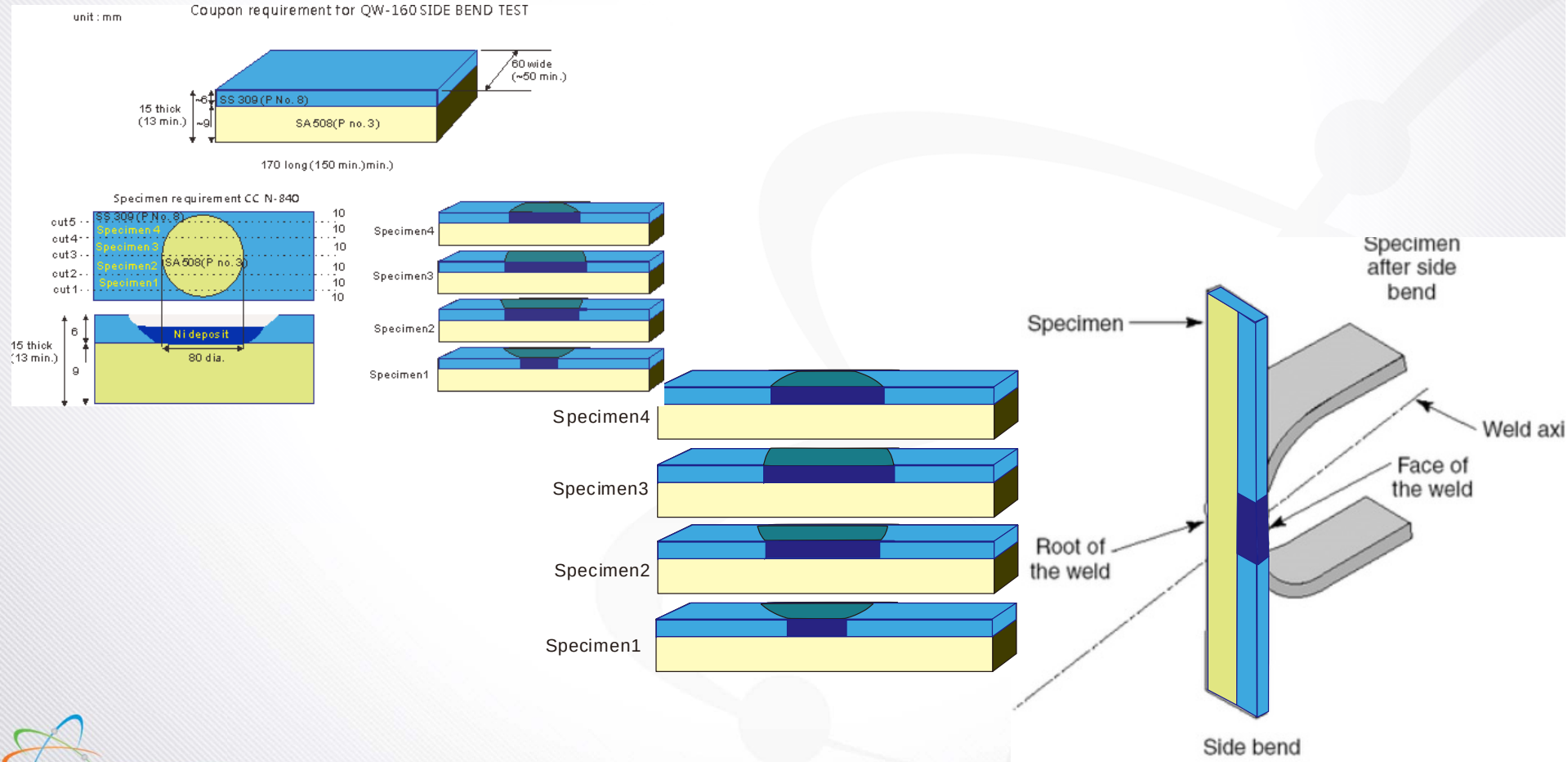




품번	품명	수량	비고
1	A01_P01_adhesion_body	1	
2	A01_P02_adhesion_cathode_pole_base	1	
3	A01_P03_adhesion_cathode_pole	1	
4	A01_P04_adhesion_anode_pole_stem_housing	1	
5	A02_P01_adhesion_anode_pole_stem	1	
6	A02_P02_adhesion_anode_pole	1	
7	X01_P01_O-ring G220	1	
8	X01_P03_O-ring G300	1	
9	X01_P04_O-ring P34	2	
10	X02_P01_Vertical_Limits Spring	3	

5. Ni plating process development

- Plating integrity evaluation: Side bend test
  - ✓ side bend test(2017 ASME boiler & pressure vessel code IX)
  - ✓ QW-160 (GUIDED-BEND TESTS)
  - ✓ QW-163 ACCEPTANCE CRITERIA - BEND TESTS



5. Ni plating process development

Flow chart

Substrate degreasing (NaOH,100mA/cm^2)

↓ Cleaning

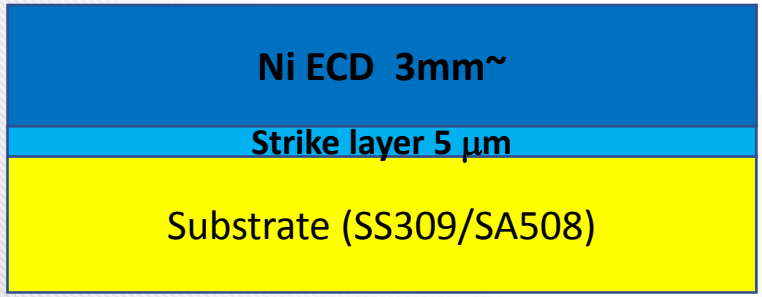
Activation (Sulfuric acid)

↓

Strike layer formation ($NiCl_2$ + H_3BO_3)
(Solution composition, temperature, current density and thickness)

↓ Cleaning

Electroplating layer formation



❖ Pre treatment

- **Degreasing - 5% NaOH**
- **Activation - 5% H_2SO_4**
- **Strike layer (40°C/RT.)**

  $NiCl_2$ 1.6 mol/L + Boric acid 0.6 mol/L + HCl 50mL/L, 100 mA/cm^2

❖ Ni deposition

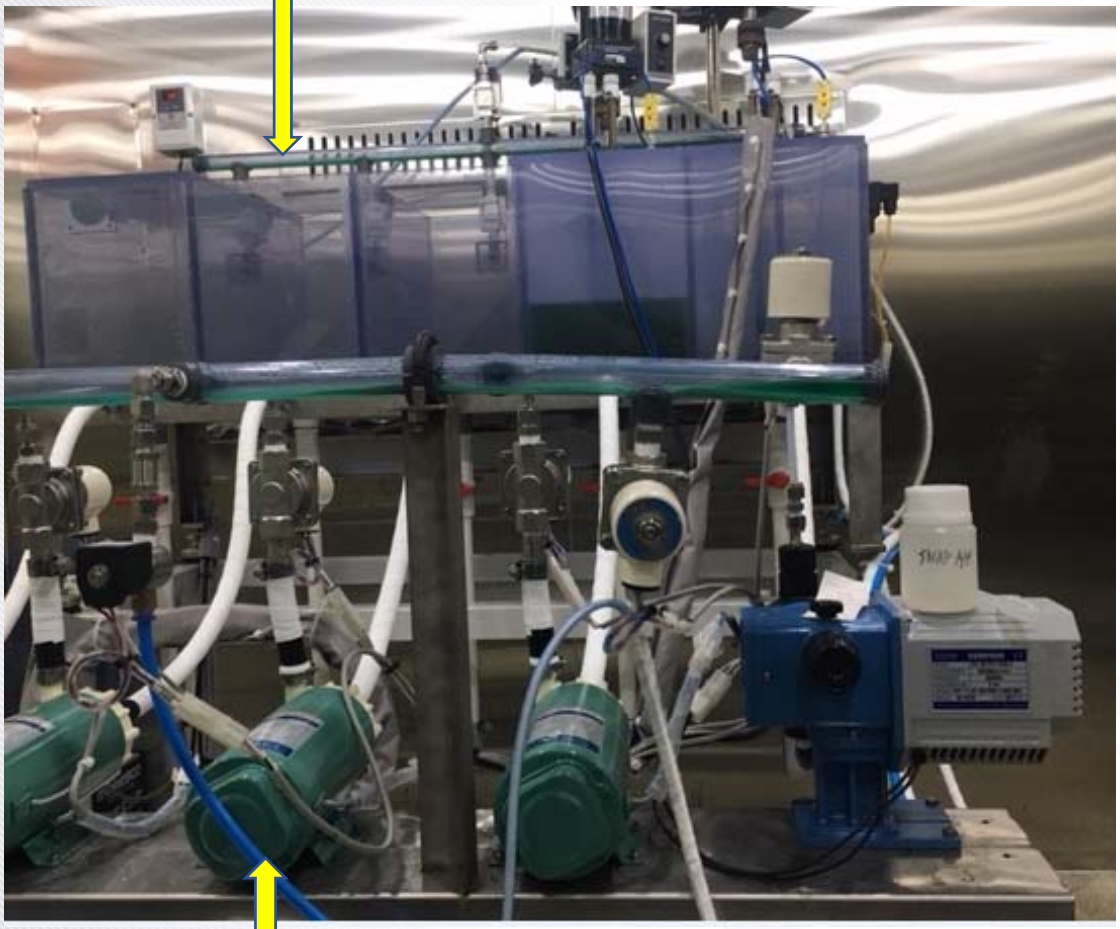
- **Nickel sulfamate($Ni(SO_3 \cdot NH_2)_2$) : 1.39 mol/L**
- **Boric acid (H_3BO_3) : 0.65 mol/L**
- **Current density : D.C. = 10 A/dm^2**
- **Bath Temperature : 60±1°C**
- **Substrate : SS309 / SA508**
- **Anode : Depolarized Nickel/S-Nickel**
- **pH : 3.0~ 3.4**

❖ Bend tests

- **Adhesion force test: Side Bend Test**

5. Ni plating process development

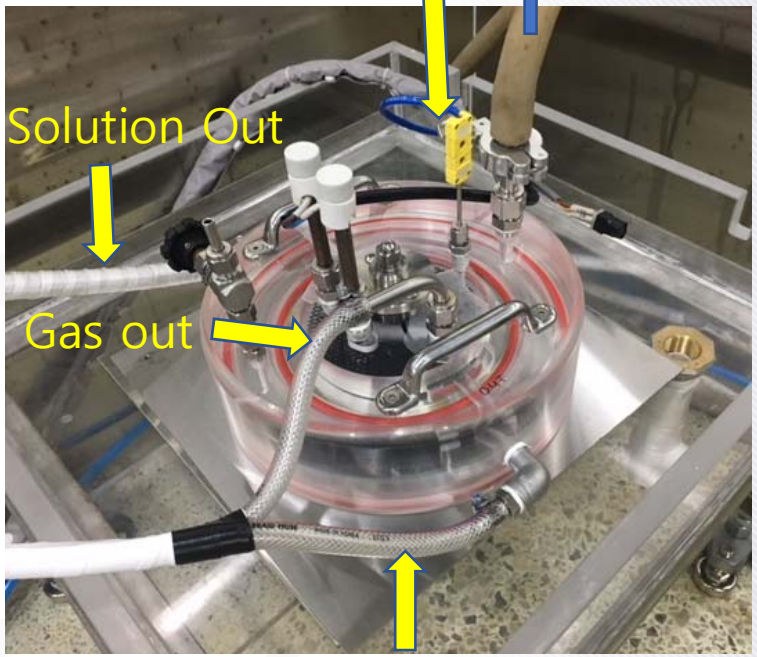
Plating Solution tanks



Circulation pumps

Thermocouple

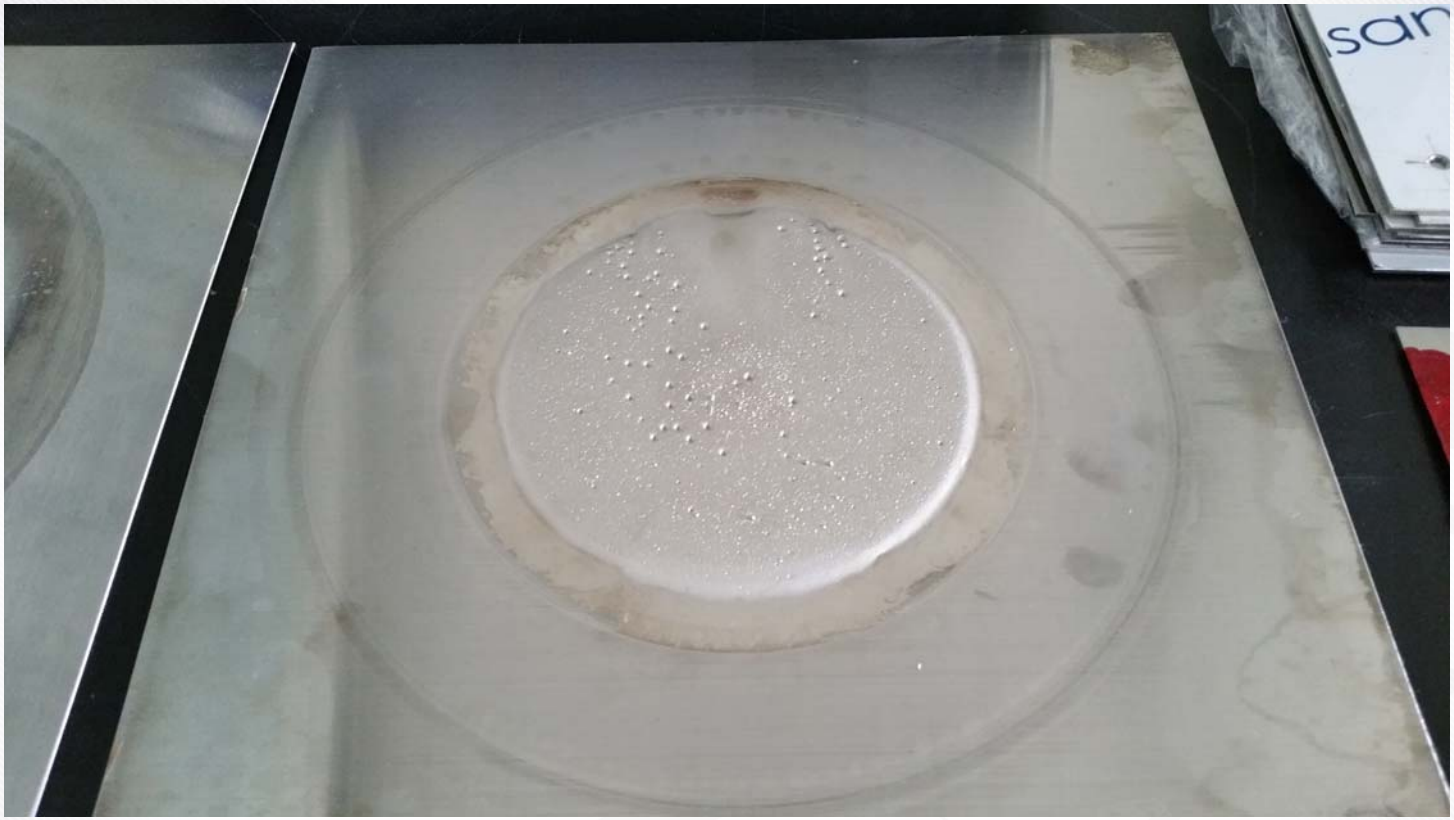
Vacuum



Solution IN

Plating chamber cell for underwater application

5. Ni plating process development

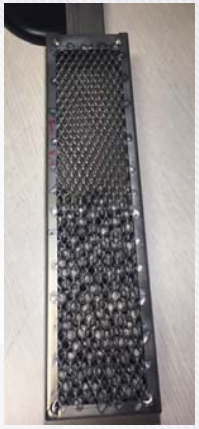


- ✓ Successful deposition of Ni on type 304 SS
- ✓ Some pits and burning on the surface due to pH decrease

5. Ni plating process development

- Ni plating condition adjustment
  - ✓ Depolarized Electrolytic Ni → S Nickel anode
  - ✓ Strike layer formation temperature
  - ✓ Set up for pH control process

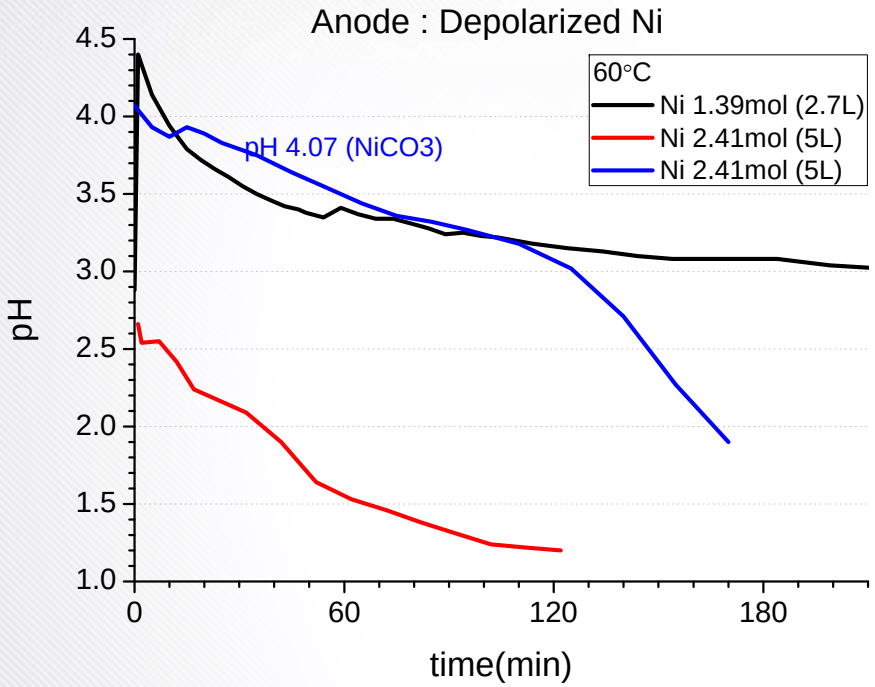
S-Nickel



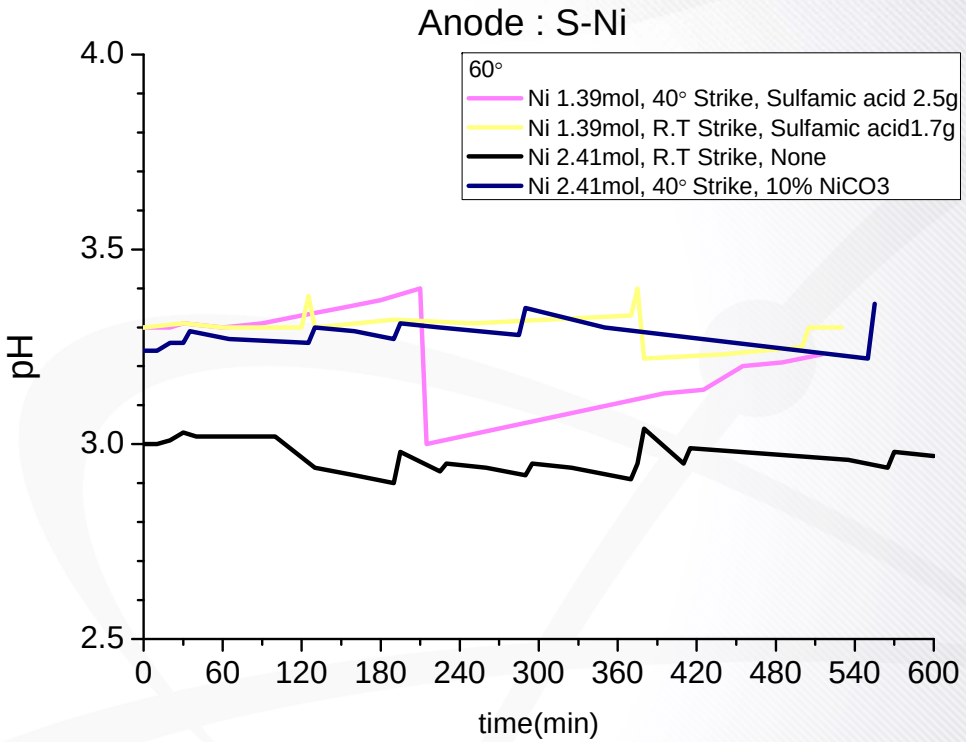
Ti Basket for S-Ni anode

5. Ni plating process development

❖ pH control



(a)



(b)

(a) Depolarized Ni : Abrupt pH decrease with time

(b) S-Ni : Constant pH with some addition of Sulfamic acid and $NiCO_3$

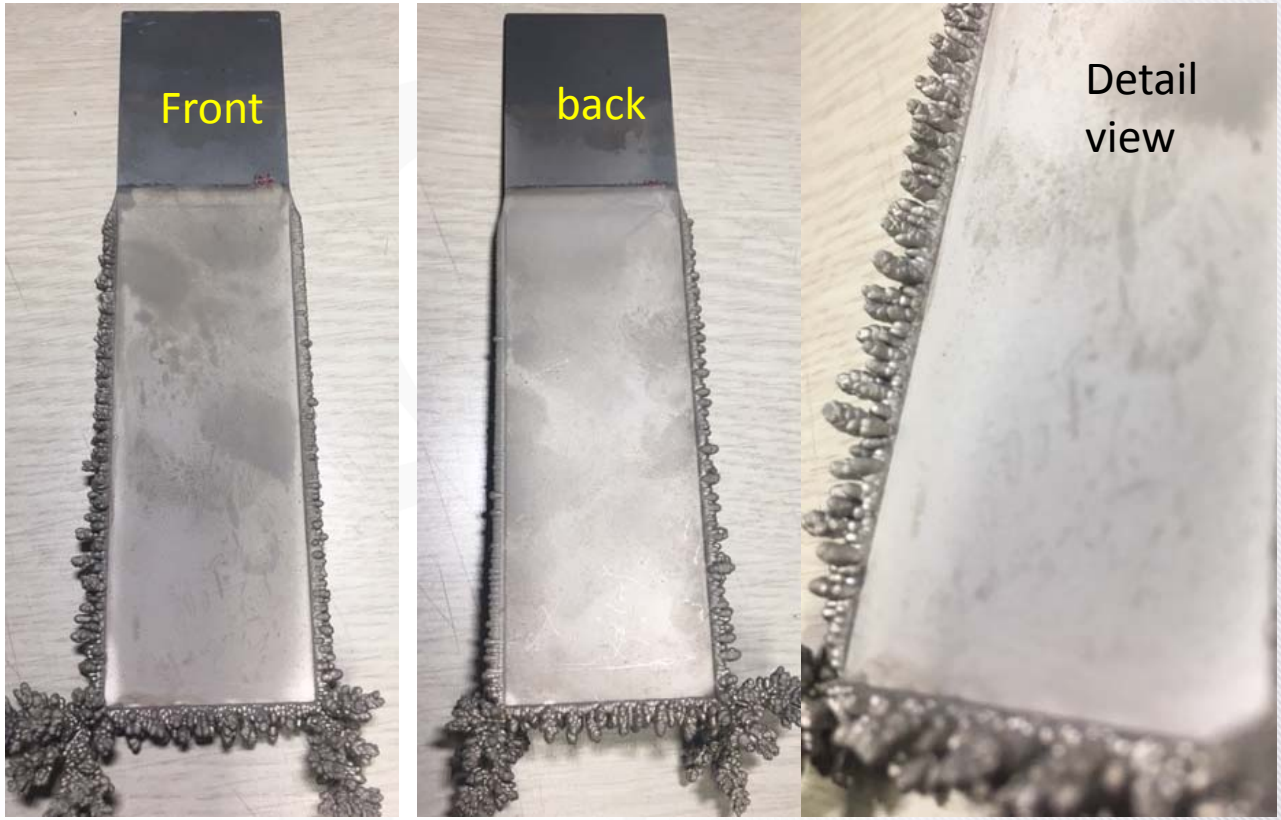
5. Ni plating process development

❖ Condition:

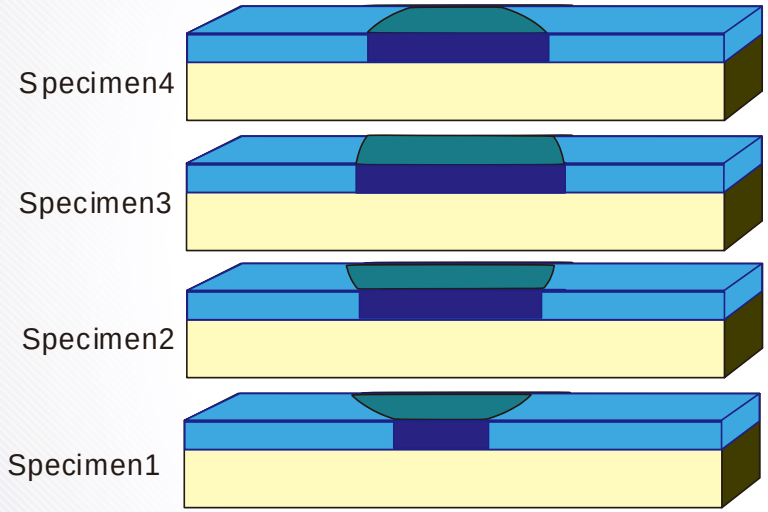
- Strike layer formation 40℃
- Ni 2.41 mol,
- Anode: S containing Ni (S-Nickel)
- Temp. 60℃
- pH : 3.06
- For 10 hours

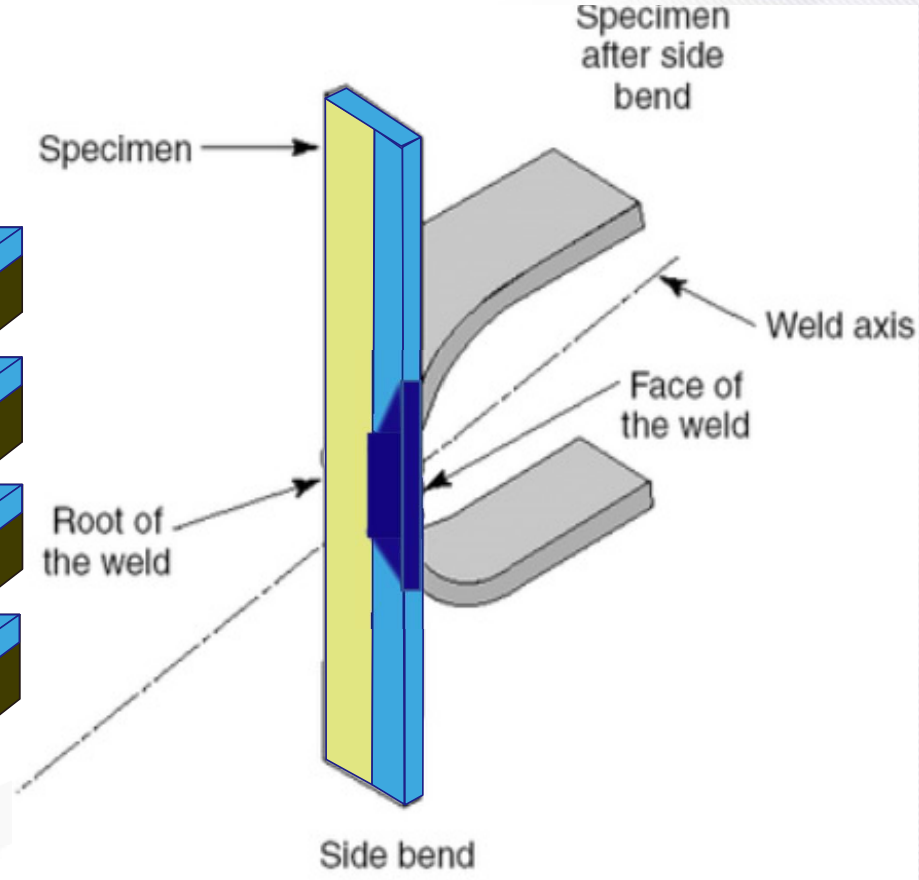
❖ Results

- Plating efficiency: 99.5%
- Pit free surface
- Reasonable result



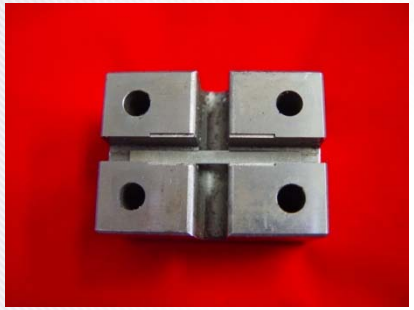
6. Side bend test





6. Side bend test

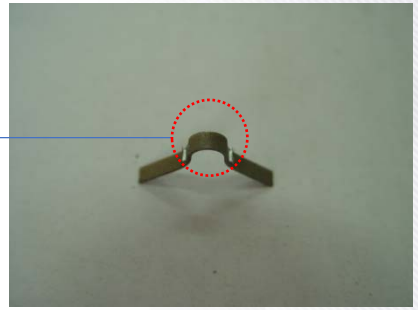
- Test process



Installation of the sample

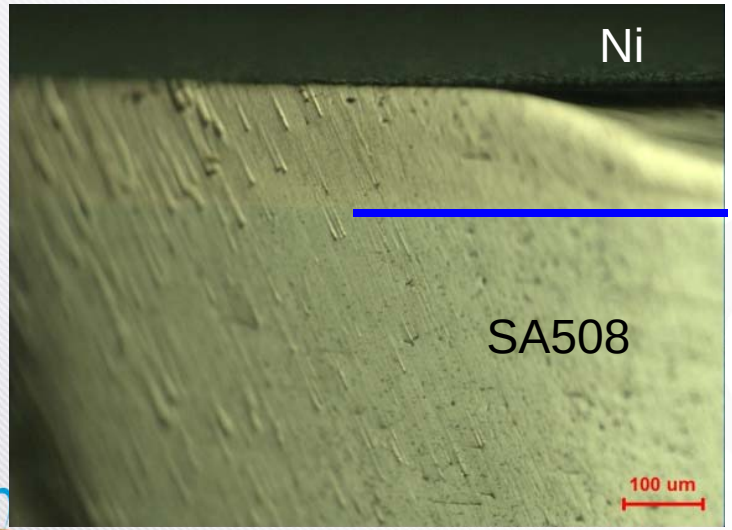
Bend with a vise

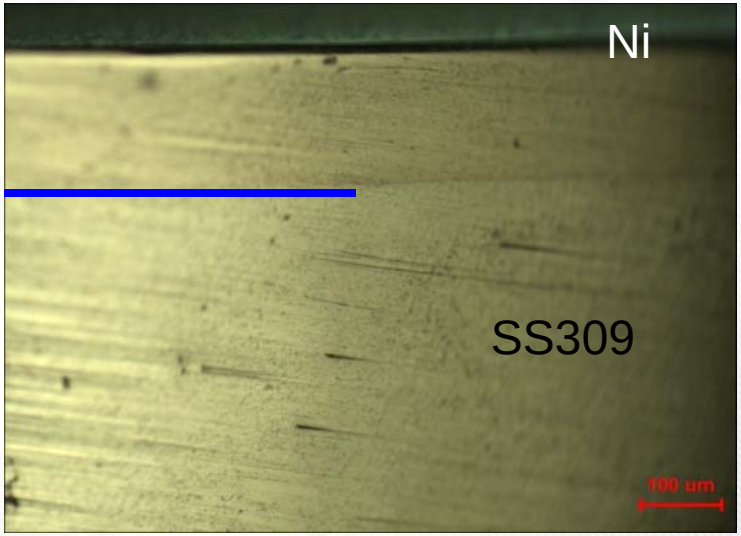
Detaching the lid



Detaching sample

- Optical microscope on convex after bend test: No de bonding





7. Summary

1. Urgent issue in Korean plant in 2010
2. Technology details (Ni electroplating)
   - Low temperature process, Neither welded or mechanically bonded to matrix materials, low internal stress, no matrix structure modification, no heat treatment
   - Compatible with PWR water chemistry
   - Promising method to repair a damaged layer
3. Standards(Code case) development
   - Led by Korea International Working Group (ASME Committee)
   - Approval in WG(Feb. 2013), SG(May 2013) and Section XI standards committee in Dec. 2013
4. Project to develop application equipment
   - Development of Ni plating system for underwater application
   - Demonstration of key variables using the Ni plating system

Thank You for Your Attention!