Formation of Nanoporous Oxide Layer for SCC Protection on TIG Welded Type 304 Stainless Steel Used in Nuclear Spent Fuel Dry Storage Container

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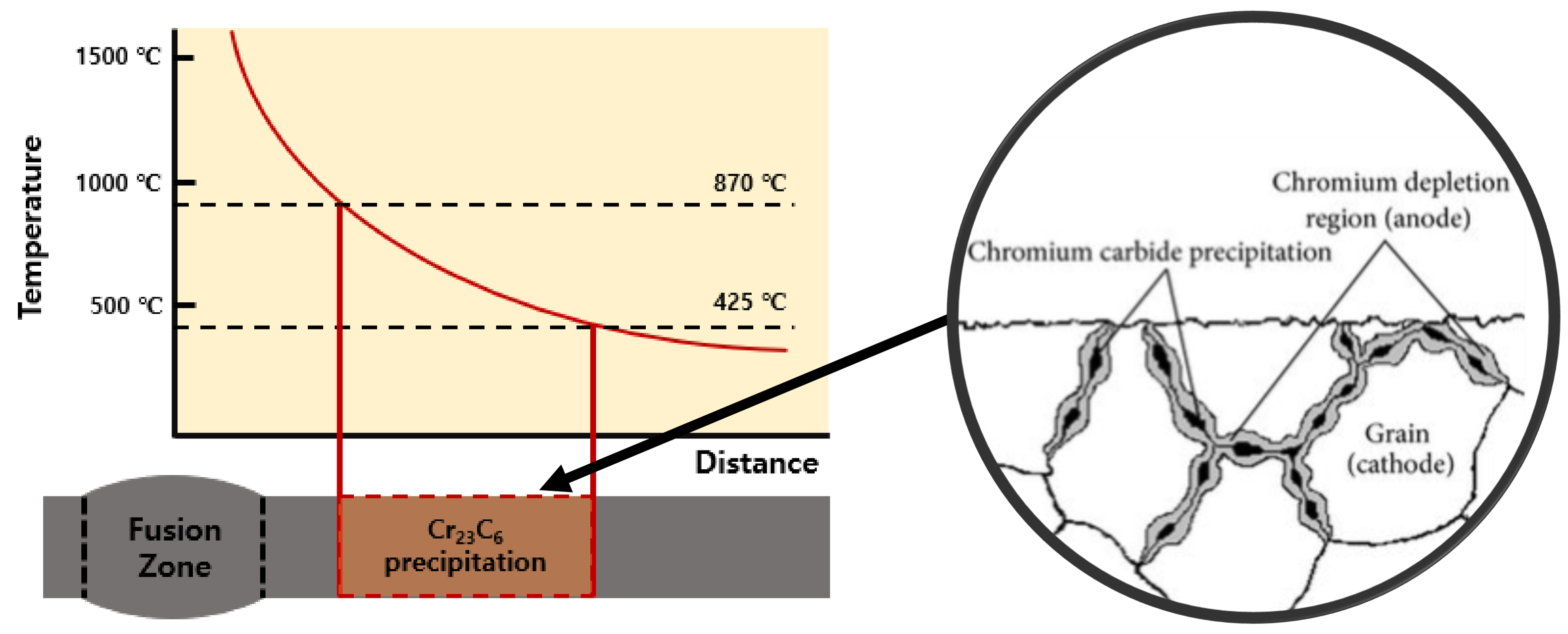
Introduction

Sensitization of Austenitic stainless steel after welding

- ❖ In specific temperature range (425 ~ 870 ℃) chromium carbide precipitates at Heat Affected Zone (HAZ) grain boundary (sensitization)
- ❖ Formation of chromium depleted zone
  - → Absence of chromium oriented protective passive film
  - → HAZ becomes susceptible of corrosion attack

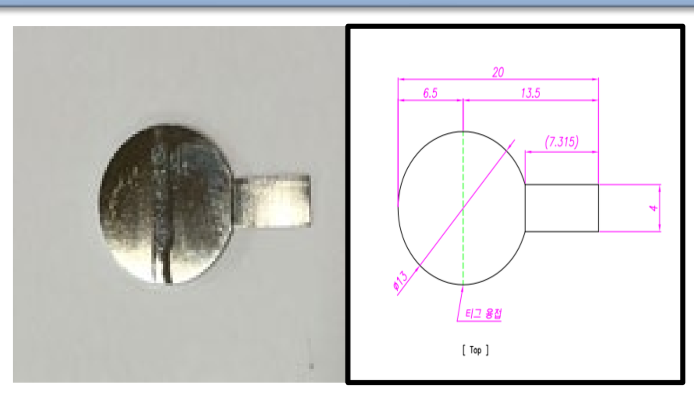


Chloride rich environments & Pitting corrosion

- ❖ Abundant chloride contents at nuclear spent fuel dry storage system which is located near sea coast line
- ❖ Breakdown of protective passive film and chloride rich environments can lead to **pitting corrosion** → **Stress Corrosion Cracking (SCC)** with residual stress of welding

Experimental

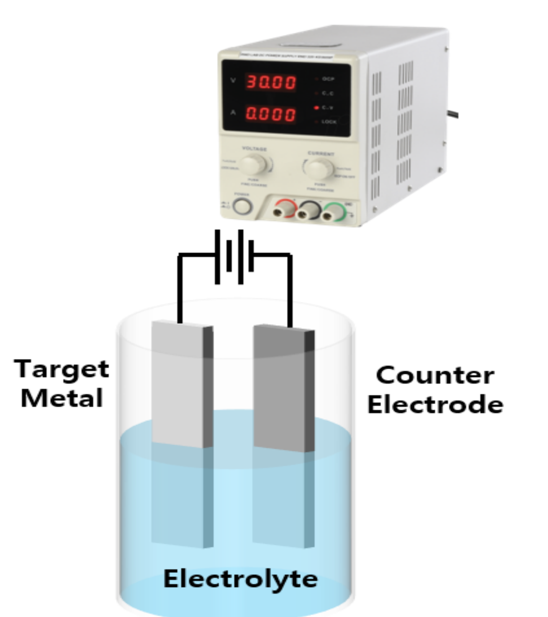
Sample Preparation



[Electropolished weld 304 SS specimen]

- ❖ Samples were sonicated in acetone followed by deionized water rinsing
- ❖ Dried in oven of 60 ℃

Anodization

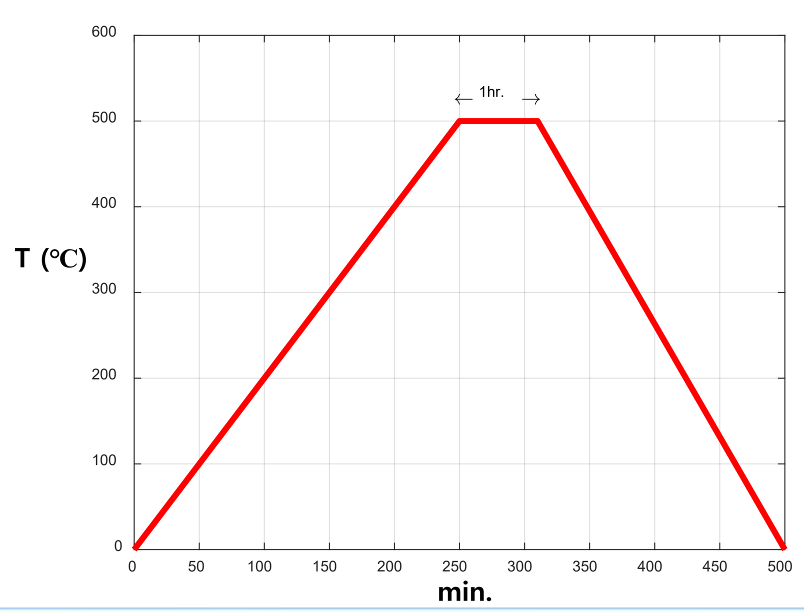


Anodizing condition

- ❖ Cooling bath was used at temperature of 25 ℃
- ❖ Target metal: 304 weld SS
- ❖ Counter electrode: Platinum sheet
- ❖ Electrolyte: 0.1 M H_2O + 0.1 M NH_4F in E.G
- ❖ Applied voltage: 50 ~ 60 V
- ❖ Duration: 10 min. ~ 15 min.

Annealing

- ❖ Heat treatment was conducted in order to eliminate fluorine species from anodized sample
- ❖ Heat rate: 2 ℃/min.
- ❖ 500 ℃ for 1 hr.



Electrochemical test

Potentiodynamic control condition

- ❖ Working electrode: 304 SS (surface ~ 1 cm²)
- ❖ Counter Electrode: Graphite rods
- ❖ Reference electrode: Saturated calomel electrode
- ❖ Potential range: -250 ~ 1500 mV
- ❖ Electrolyte: Artificial seawater
- ❖ OCP (open circuit potential) was preconditioned

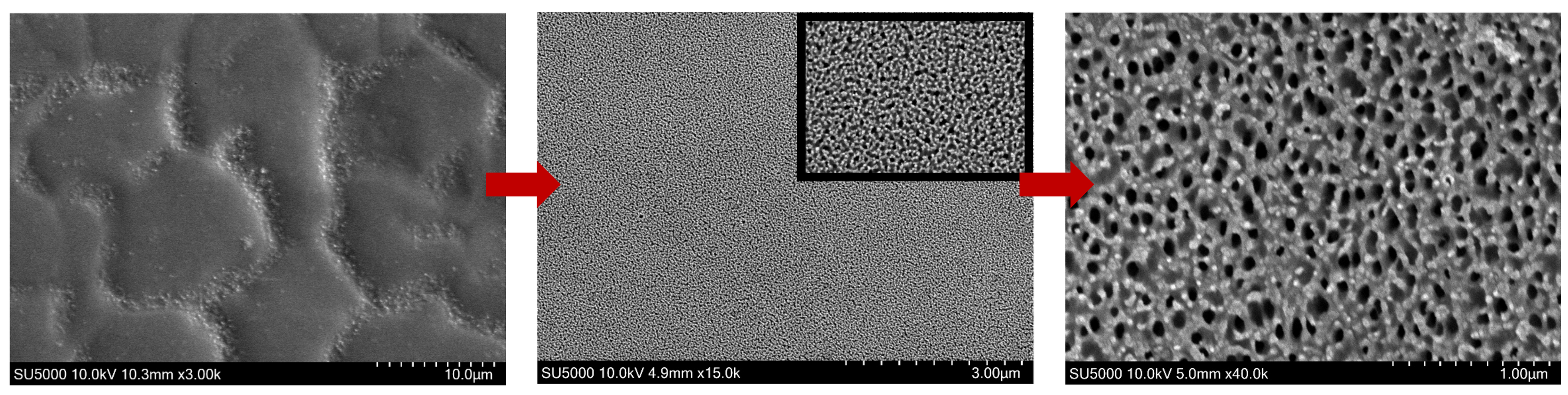
Element	Composition (g/L)
Cl	19.00
Na	9.72
Mg	1.3
S	0.81
Ca	0.40
K	0.35
Sr	0.007
B	0.004

- ❖ Using ISO_15158, samples' pitting potential was averaged through five repetition test

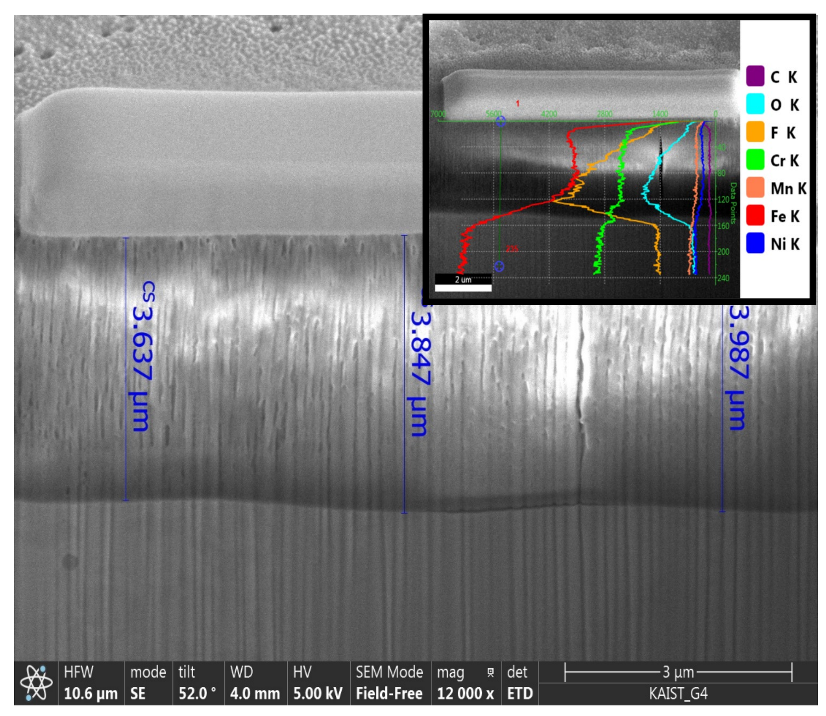
→ **Artificial seawater composition**

Results & Analysis

Protective nanoporous oxide layer fabrication



Sensitized weld SS | Anodized weld SS | Anodized weld SS + Heat treated



Cross sectional image of nanoporous oxide layer

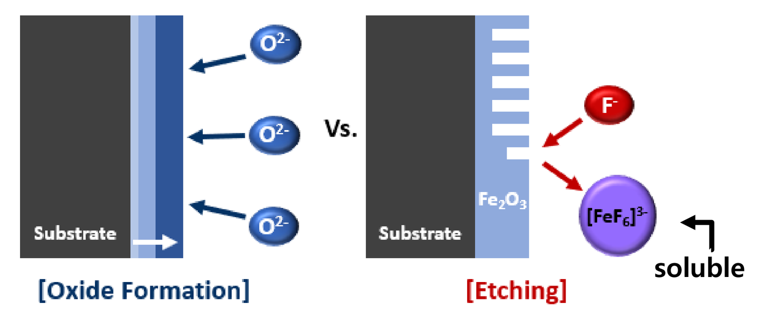
Anodized weld SS:

Element	Weight %	Atomic %
C K	1.07	2.28
O K	5.44	8.76
F K	49.72	67.43
FeL	4.80	2.21
NiL	0.03	0.01
CrK	38.94	19.29

Anodized weld SS + Heat treated:

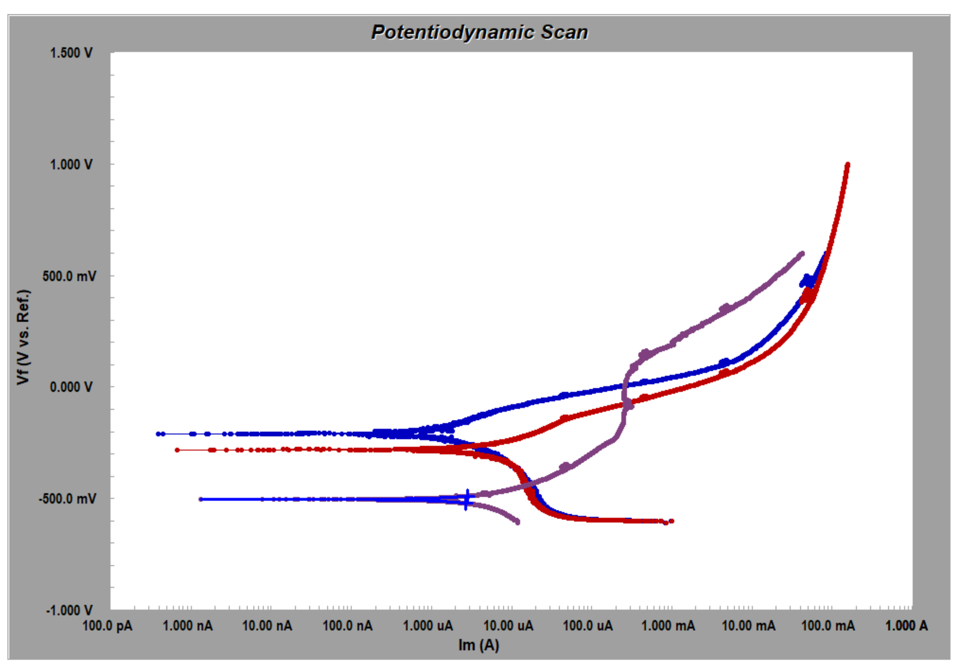
Element	Weight %	Atomic %
C K	1.86	4.45
O K	31.72	56.84
F K	3.60	5.43
FeL	28.41	14.58
NiL	4.46	2.18
CrK	29.95	16.51

Fluorine elimination by heat treatment
→ To prevent dissolution



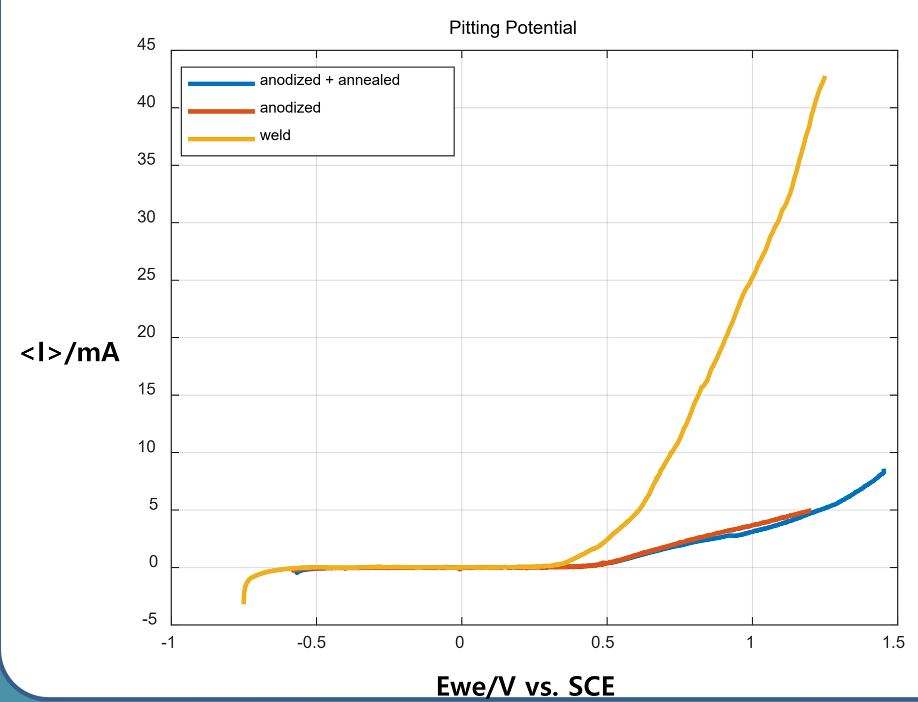
Nanoporous structure formation mechanism

Electrochemical measurements



Specimen	E_{corr} (mV/SCE)	I_{corr} (10^{-7} Acm^{-2})
Weld STS	-504	48.5
Anodized weld STS	**-281**	**8.33**
Annealed & Anodized weld STS	**-210**	**4.45**

→ Corrosion potential and current are improved with anodized and annealed STS
→ Overall corrosion resistance improved



Specimen	Average Pitting Potential (mV), V'_{c100} (V vs. SCE)
Bare STS	290.3
Weld STS	258.6
Anodized weld STS	397.2
Annealed & Anodized weld STS	373.6

→ Anodized samples' pitting potential has been increased about **53%** compared to weld SS
→ Pitting resistance improved

Conclusion

- ➢ Stainless steel becomes susceptible to corrosion after welding
- ➢ Nanoporous protective oxide layer fabrication electrochemical anodization
- ➢ Pitting corrosion resistance was improved (pitting potential 53% increased)
- ➢ Stress Corrosion Cracking resistance can be improved
- ➢ Further corrosion tests should be conducted, various applications expected

References

- ▶Sourav Kr. Saha _ Self-organized honeycomb-like nanoporous oxide layer for corrosion protection of type 304 stainless steel in an artificial seawater medium
- ▶ISO15158 _ Method of measuring the pitting potential for stainless steels by potentiodynamic control in sodium chloride solution
- ▶Yingge Wang _ Fabrication and formation mechanisms of ultra-thick porous anodic oxides film with controllable morphology on type-304 stainless steel