Improvement of Corrosion Resistance of Austenitic Stainless Steel Used in Cooling Water Components by Cathodic Plasma Electrolytic Oxidation

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Introduction

Use of Stainless Steel in Cooling Water Components

- Excellent properties of stainless steel: Corrosion resistance / Ductility / Formability / Mechanical Strength / Weldability / High temp. performance
- Cooling water components:

Component	Materials
Turbine (blade)	12 Cr steel, Stainless steel (303, 630)
Condenser (tube)	Titanium alloy, Super stainless steel
Seawater Lift Pump (SLP)	Stainless steel (316, 316L)
Circulating Water Pump (CWP)	Stainless steel (316, 316L)
Pipes	Carbon steel (SA 106B, SA 155), Stainless steel (304, 316)
Feed-water heater	Stainless steel (304, 304L)

- The secondary and tertiary loop of the nuclear power plant involves corrosive and abrasive environments

  → Variety of corrosion and wear attacks:

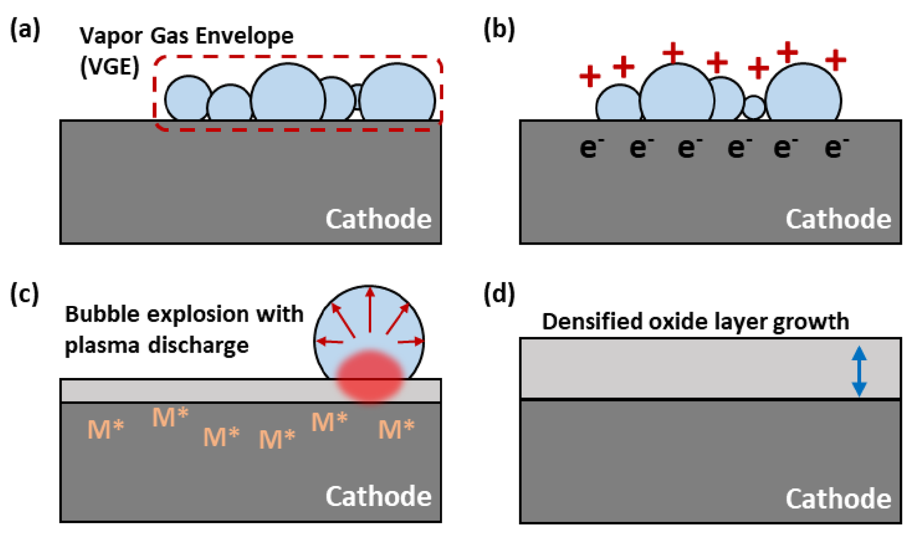
Turbine (blade) Condenser (tube) Circulating Water Pump (CWP)

Feedwater heater Feedwater pipe Seawater Lift Pump (SLP)

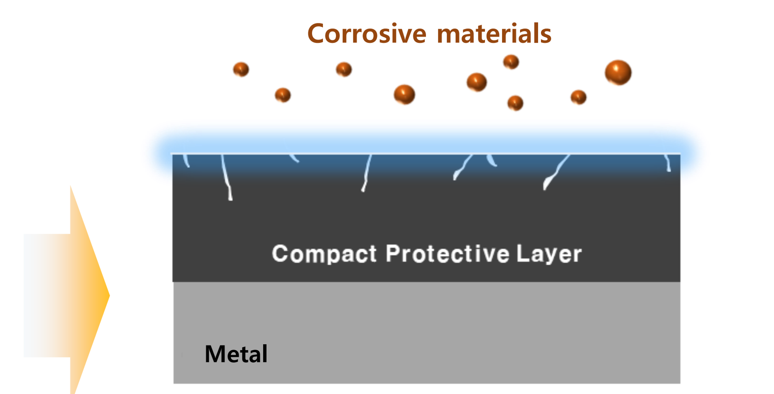
→ Surface treatment for improvement of corrosion resistance

Surface Treatment for Corrosion Resistance

Cathodic Plasma Electrolytic Oxidation (CPEO)



(a) Gaseous envelope (H_2O / H_2 / Organics)
(b) Partial anode generated forming high electric field
(c) Bubbles explode with discharges generating high heat (active species)
(d) Decomposed active species react together to form oxide layer

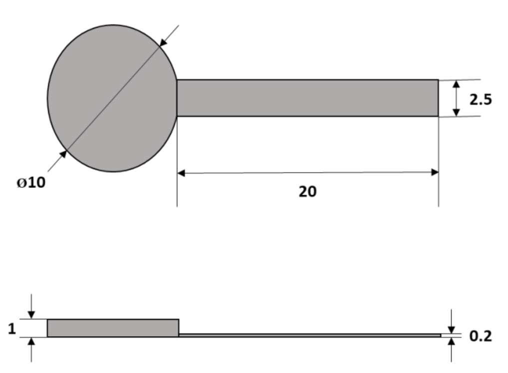


Stable compact oxide layer without ordered nanopores

1. Simple and fast process
2. No limit of geometry
3. Compact and remarkable hardness
4. Economical and environmental friendly
5. Various metal application

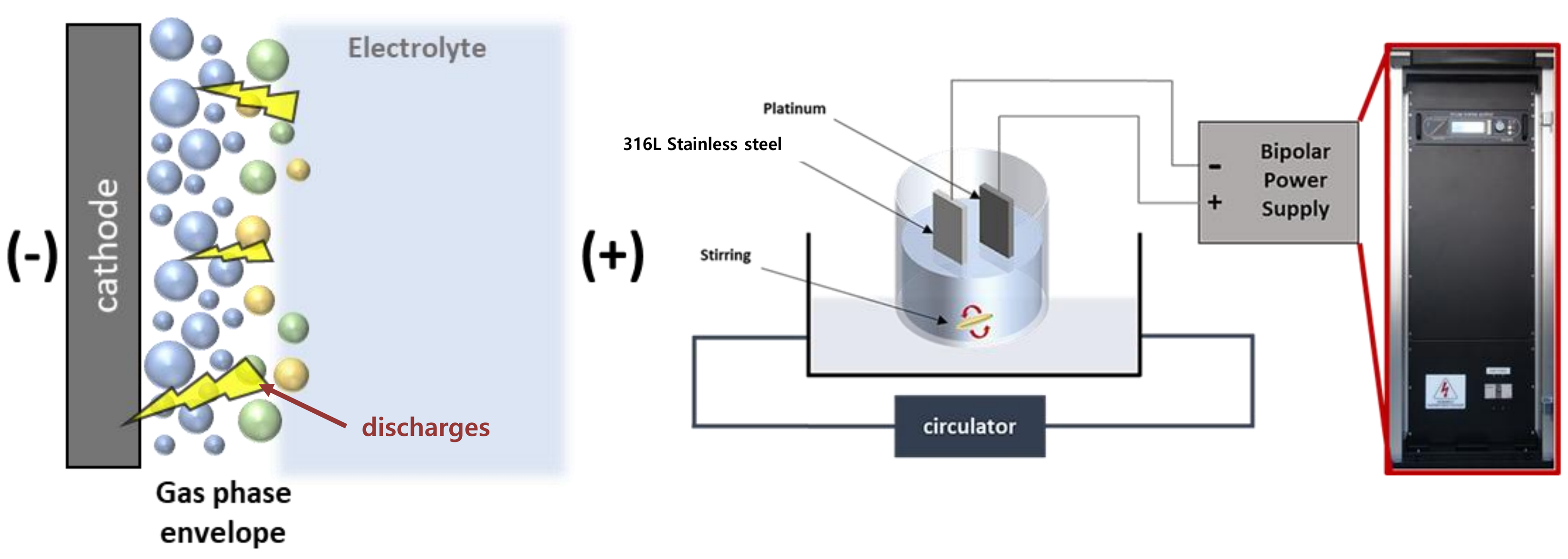
Experimental

Sample Preparation



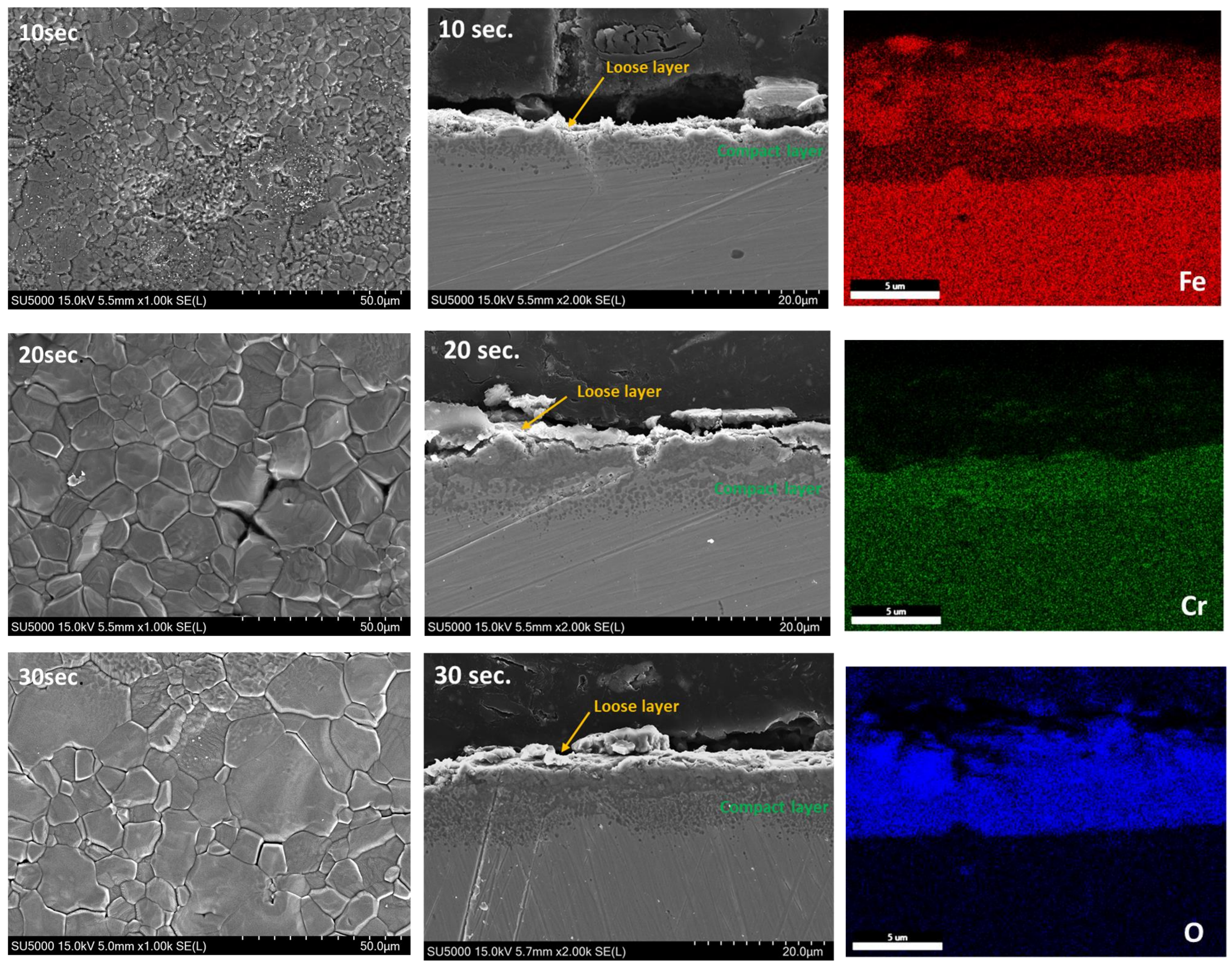
- Type 304 Stainless steel
- Pretreatment: Sonication in acetone & DI water for 10 min.
- Posttreatment: Rinsed with DI water & dried in oven

Cathodic Plasma Electrolytic Oxidation

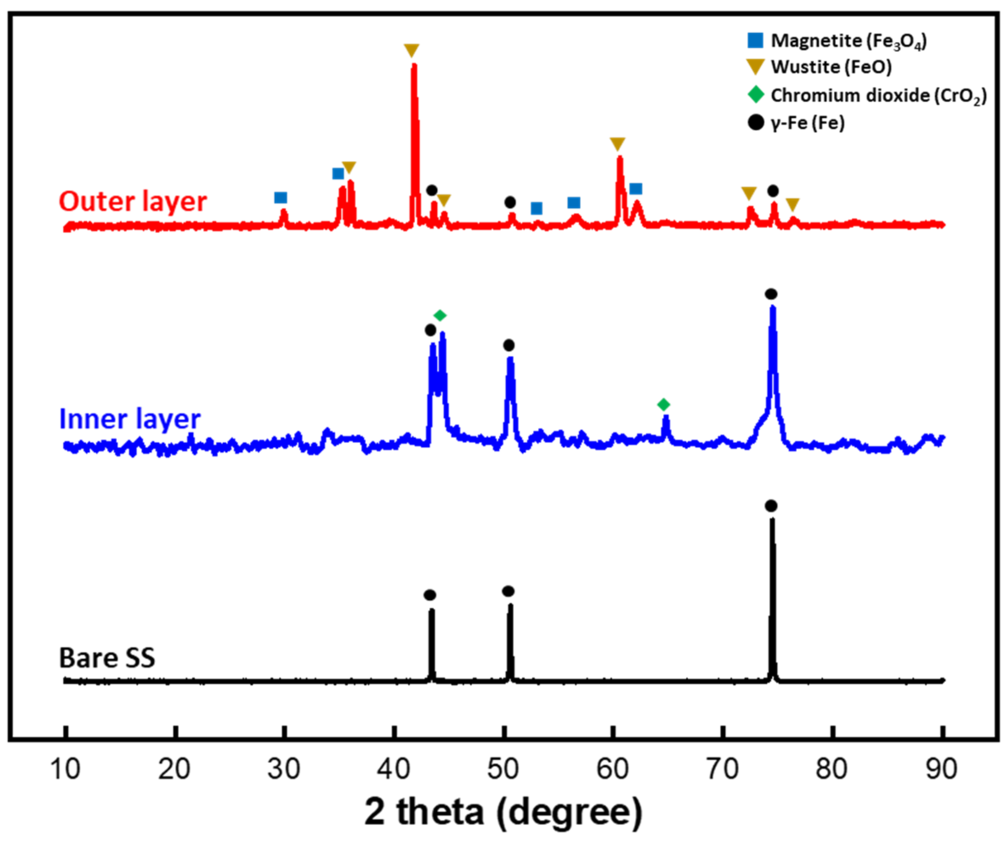


- Electrolyte: Glycerol (80 %) + Deionized water (20 %) + KCl (0.5 M)
- Working Electrode: Type 316L Stainless steel / Counter Electrode: Platinum sheet
- Applied Voltage: (+) 600 V & / Frequency: 100 Hz
- Duty cycle: (+) 10 %
- Duration: 10 / 20 / 30 s

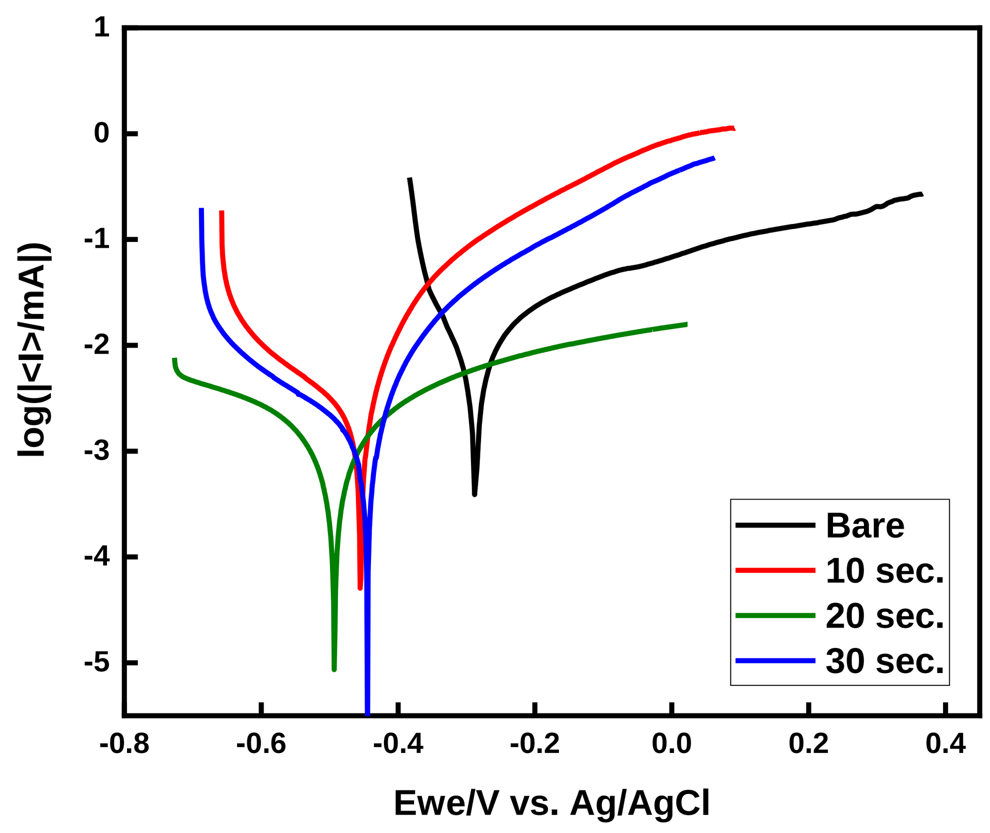
Results & Analysis



[EDS mapping]



1. Grain coarsening and smoother surface with increasing CPEO duration
2. Cross-sectional image showed Outer loose layer and Inner Compact layer
3. With EDS mapping of 30 s sample, outer layer and inner layer was composed of iron oxide and chromium oxide each
4. With XRD patterns, outer layer was characterized as mainly Magnetite (Fe_3O_4) and Wustite (FeO) and inner layer was characterized as Chromium dioxide (CrO_2)



1. CPEOed samples showed lower corrosion potential, indicating more active surface
   → negative charges were accumulated on the surface with high capacitance
2. However, corrosion current was much lower with CPEOed samples, indicating improved corrosion resistance
   → By using below equation, corrosion rate was calculated and large improvement was inspected

$$\text{Corrosion rate} = \frac{k \times i_{corr} \times M(g)}{d(gcm^{-3}) \times A(cm^2)}$$

k: constant M: mass of steel

d: density A: exposed area

	Bare	10 sec.	20 sec.	30 sec.
Corrosion potential (E_{corr}) / mV	-287.398	-455.046	-493.699	-444.568
Corrosion current (i_{corr}) / µA	4.119	1.939	1.483	1.318
Corrosion rate (mmpy)	3.735×10^{-3}	1.713×10^{-3}	1.310×10^{-3}	1.164×10^{-3}

Conclusion

- ✓ Cathodic Plasma Electrolytic Oxidation was applied to 316L stainless steel for corrosion resistance
- ✓ Oxide layers were deposited on the 316L SS with layer upon layer structure
- ✓ Magnetite (Fe_3O_4) & Wustite (FeO) for outer layer an & Chromium dioxide (CrO_2) for inner layer
- ✓ Polarization curves showed improved corrosion resistance with decreased corrosion rate
  → However, corrosion potential was lower with CPEOed samples, indicating active surface
- ✓ Deeper electrochemical studies should be conducted further with CPEOed samples
  → Optimum interpretation of corrosion resistant mechanism

References

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