Robust Canisters with a Nanoporous Oxide Layer for Spent Nuclear Fuel Storage

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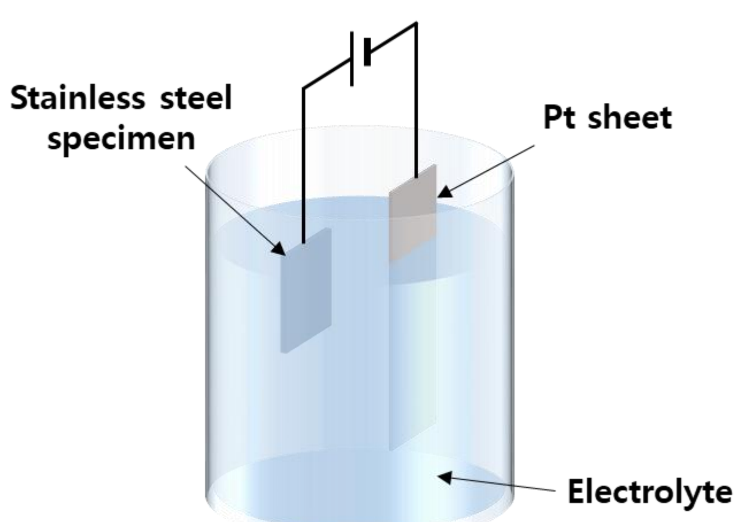
Introduction

- **Spent nuclear fuel (SNF) canisters in dry storage**
  - ✓ Switch to dry storage due to saturation of wet storage facilities
  - ✓ Mainly made of austenitic stainless steel
  - ✓ Easy to be exposed to saline environments
  - → Nuclear power plant located mainly on the coast
  - ✓ Very vulnerable to chloride-induced stress corrosion cracking (CISCC)[1,2]
- **Methods to protect stainless steel from CISCC**
  - ✓ Currently the use of coatings and alloying
  - → A limit to the use of another materials
  - ✓ Need for a facile route to protecting stainless steel
  - → Electrochemical anodization
- **Anodization**
  - ✓ Fabrication of a self-organized protective oxide layer
  - ✓ Nanopores on nanoporous oxide layer
  - → Alleviate the stress during oxide formation
  - → Higher mechanical properties

Materials & Methods

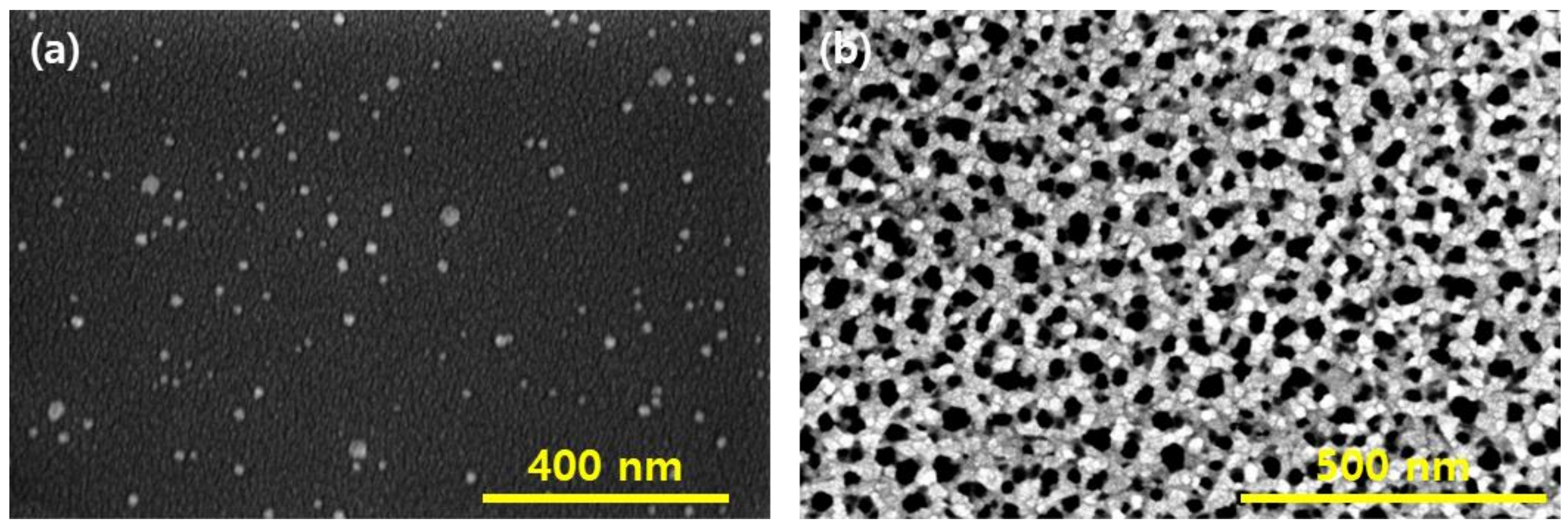
- **Materials**
  - ✓ Working electrode: Type 304 stainless steel sheet (1 mm in thickness)
  - ✓ Counter electrode: Pt sheet (10 mm × 40 mm × 0.5 mm)
  - ✓ Electrolyte: Ethylene glycol solution containing NH_4F (0.1 wt.%) and water (0.1 wt.%)
- **Sample preparation**
  - ✓ Sonication: Removing any type of impurities (using ethanol and deionized water for 5 min each)
  - ✓ Anodization: Constant voltage (60 V), room temperature, fixed electrode distance (20 mm)
  - ✓ Rinsing: Using ethanol carefully
  - ✓ Drying: 50℃ oven
- **Sample characterizations**
  - ✓ FESEM: Surface morphology
  - ✓ EDX: Element distribution
  - ✓ XRD: Crystal structure
  - ✓ VDI 3198: Adhesion
  - ✓ Vickers: Hardness



▲ Schematic view of anodization system

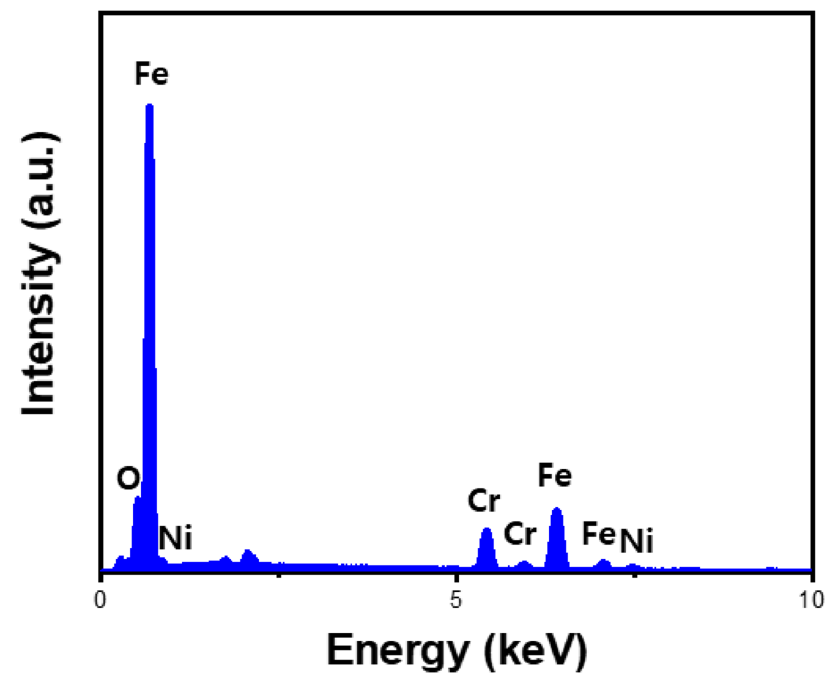
Results & Discussion

- **Fabrication of nanoporous oxide layer**

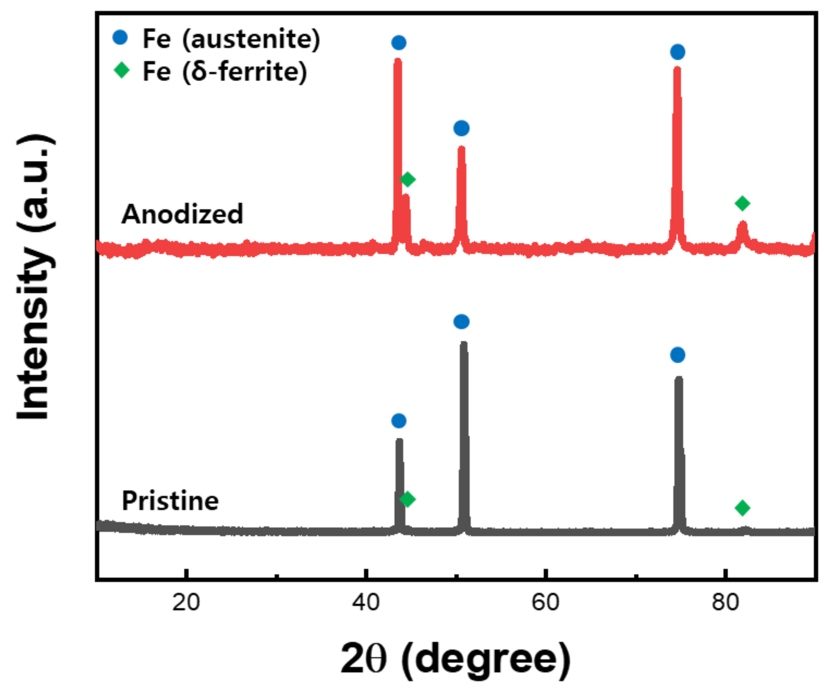


▲ FESEM images of (a) the pristine stainless steel and (b) anodized stainless steel surface

  - ✓ Many nanopores on the surface for anodized stainless steel
  - → Average pore size: ~50 nm
  - ✓ Observation of oxygen peak
  - → Oxidation of the surface

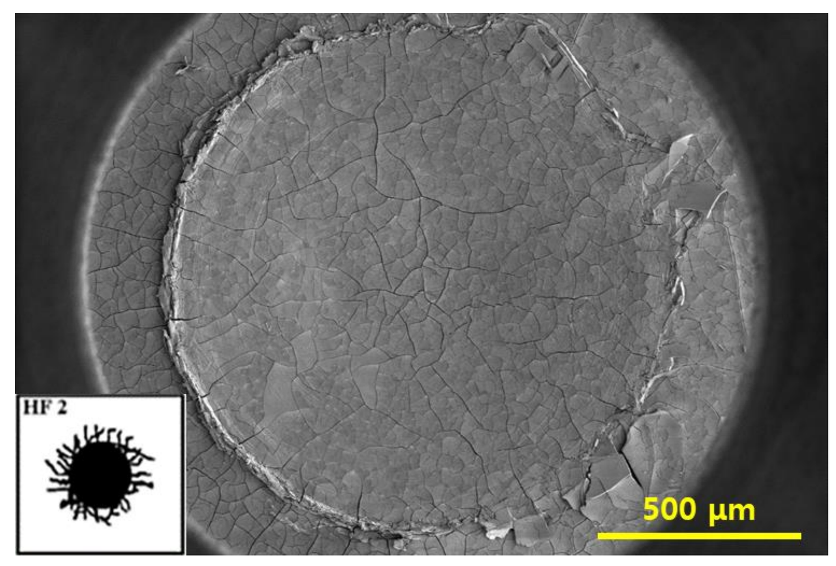


▲ EDX spectrum of the anodized stainless steel



▲ XRD patterns of the pristine and anodized stainless steel

  - ✓ No clear difference in the crystal structure
  - → Amorphous iron oxide[3]
- **Mechanical properties of nanoporous oxide layer**
  - ✓ Excellent adhesion of the nanoporous oxide layer
  - → The level of HF 2[4]
  - ✓ Similar hardness to pristine stainless steel
  - → ~160.0 HV
  - → Due to the amorphous phase of the oxide layer



▲ FESEM image of the anodized stainless steel surface after VDI 3198 test (inset: an example of HF 2 mode from Daimler-Benz method[4])

Conclusions

- **Nanoporous oxide layer on the surface of type 304 stainless steel produced by anodization showed excellent adhesion to the substrate**
- **Amorphous phase of nanoporous oxide layer has the low hardness but is mechanically stable, avoiding damage to the substrate**
- **Nanopores on the stainless steel surface relieve stress acting in the material and block aggressive chlorine to prevent CISCC**

Acknowledgement

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References

[1] D. Ogg, U.S. *Nuclear Waste Technical Review Board*, Rev. 1A (2017).
[2] S. Marschman, Stainless Steel Canister Challenges, *NEET ASI Review Meeting*, Idaho National Laboratory (2014).
[3] S. K. Saha *et al.*, *Journal of Molecular Liquids*, 296, 111823 (2019).
[4] Verein-Deutscher-Ingenieure, *VDI 3198*, VDI-Verlag, p.7 (1992).