Corrosion Performance of Coating for Venturi Fouling Mitigation at Nuclear Power Plant

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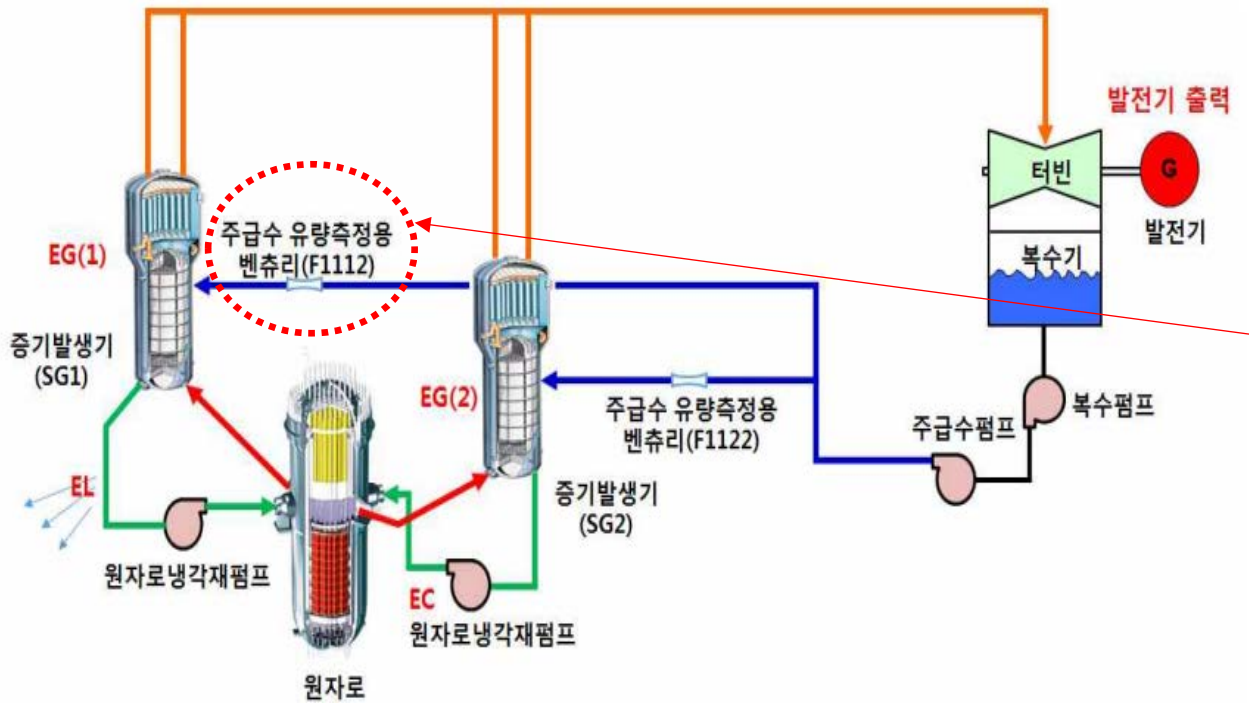
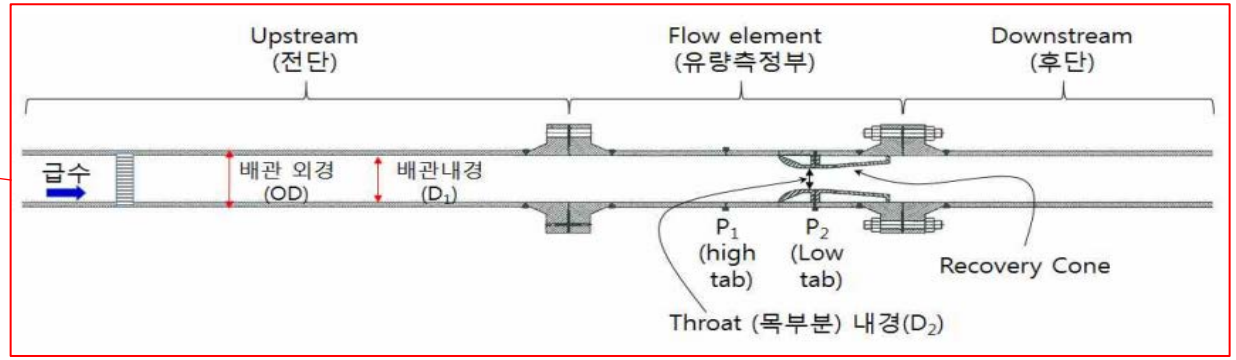
Motivation





KINS. 원전사건등급평가위원회 (2017)

[발전소 출력 산출식]

발전소 출력 = EG(1) + EG(2) + EL – EC

- EG(i) = i번째 증기발생기로 전달된 출력

= 출구증기 엔탈피 X 출구 유량 + 취출수 엔탈피 X 취출수 유량 – 급수엔탈피 X

급수 유량

- EL = 측정된 RCS 전체 에너지 손실항의 합

- EC = 측정된 RCS 전체 에너지 입력항의 합 (RCP 등)

$$W = CE\epsilon d^2\sqrt{(\rho \Delta p)}$$

W : 급수유량

E : $1/\sqrt{(1-\beta^4)}$ (접근속도계수)

β : 벤추리 튜브직경(d)/주급수유료배관직경(D)

C : discharge 계수

ϵ : 확장계수(비압축성 유체에 대해서는 1)

Δp : 차압

ρ : 주급수 압력에서의 밀도

Venturi Fouling

- **A phenomenon in which microparticle suspension such as iron oxide (Fe_3O_4, magnetite) are deposited on pipe walls and near venturi holes.**
  - Changing surface roughness, and causes an error in the measurements of the venturi flowmeter.
  - The pressure loss value of the flow rate has increased by 0.3 % every year, which has led to the problem of reducing the power generation of nuclear reactors.
  - Economic losses are incurred through the cleaning or replacement of the venturi flowmeter during the regular planned preventive maintenance.

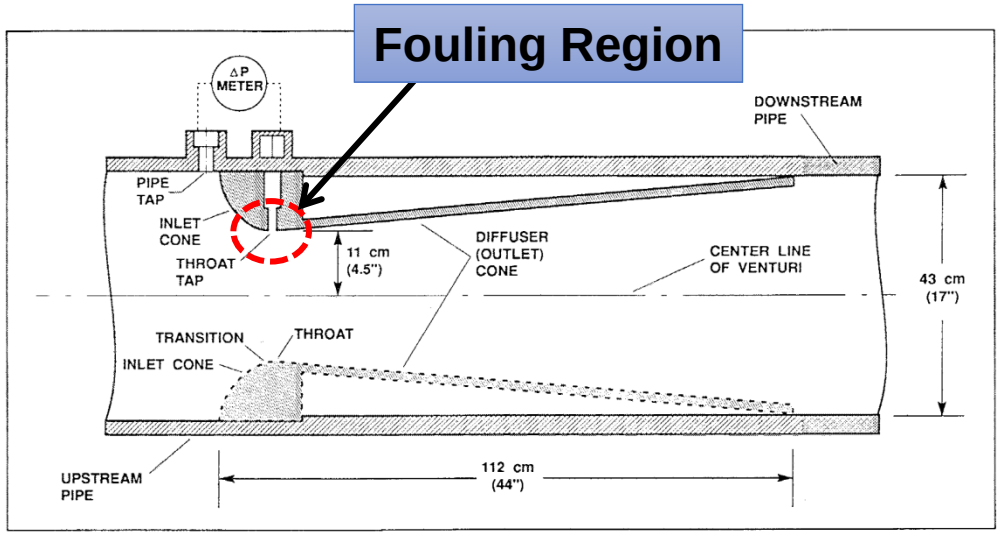
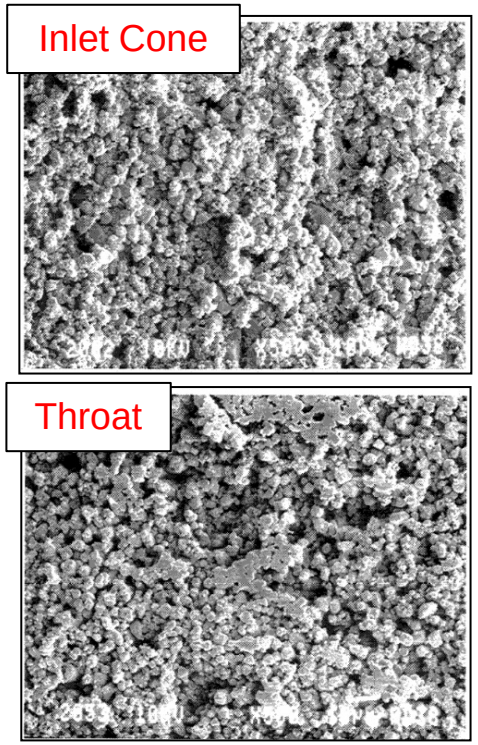


Figure 2-6. General Areas Sampled on the TMI-1 Feedwater Venturis

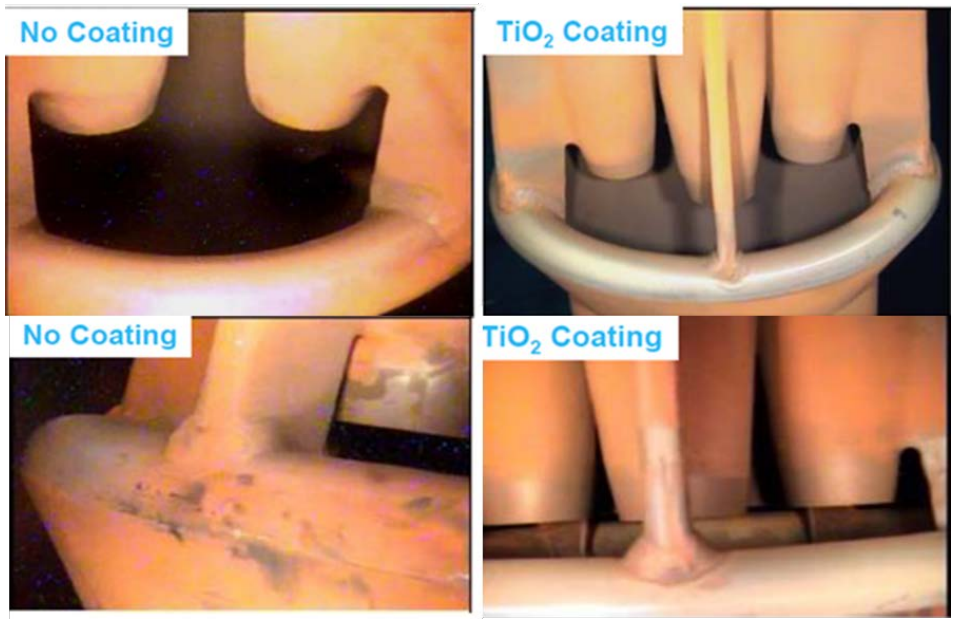
Survey and Characterization of Feedwater Venturi Fouling at Nuclear Power Plants (Volume 1: EPRI TR-100514, May 1992)



Literature Review

- **Domestic research**
  - So far, only the structure of Venturi has been modified.
  - By changing operation methods have been performed.

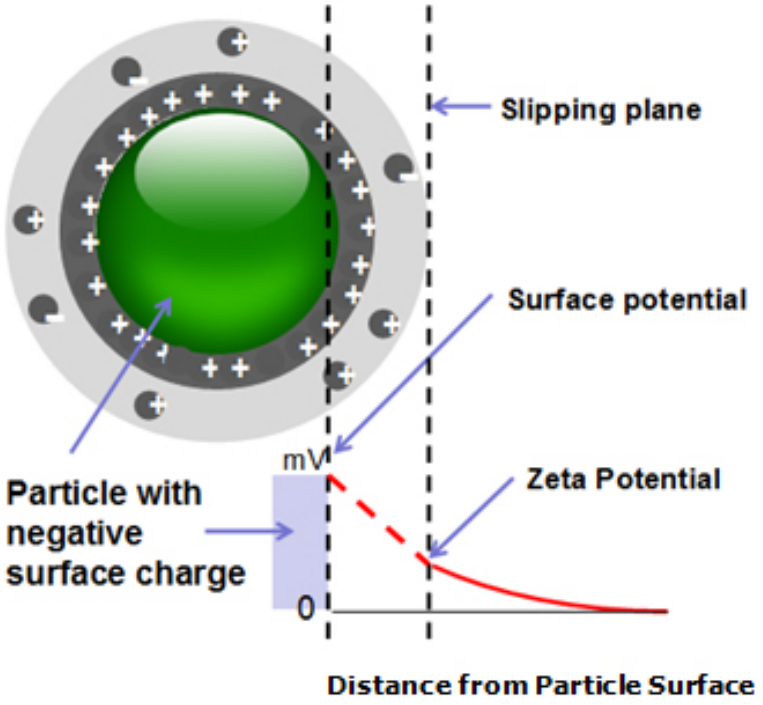
- **Oversea research**
  - General Electric company (GE) solved the fouling phenomenon in the jet pump pipe of the BWR by applying a TiO_2 coating technology.

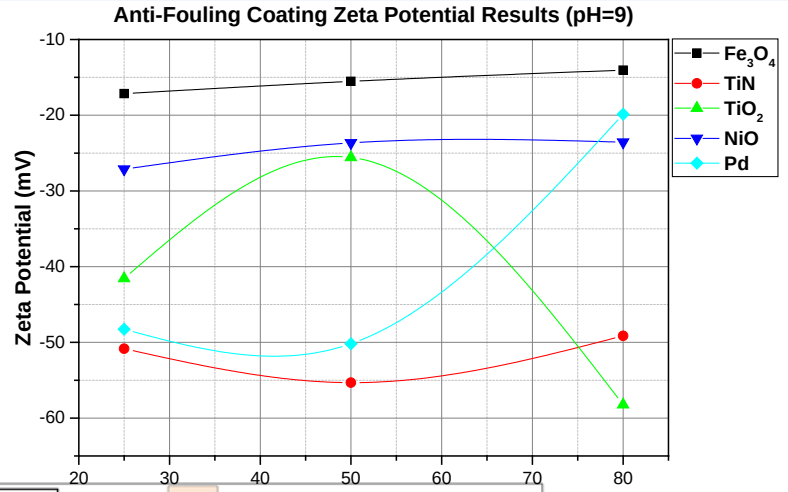


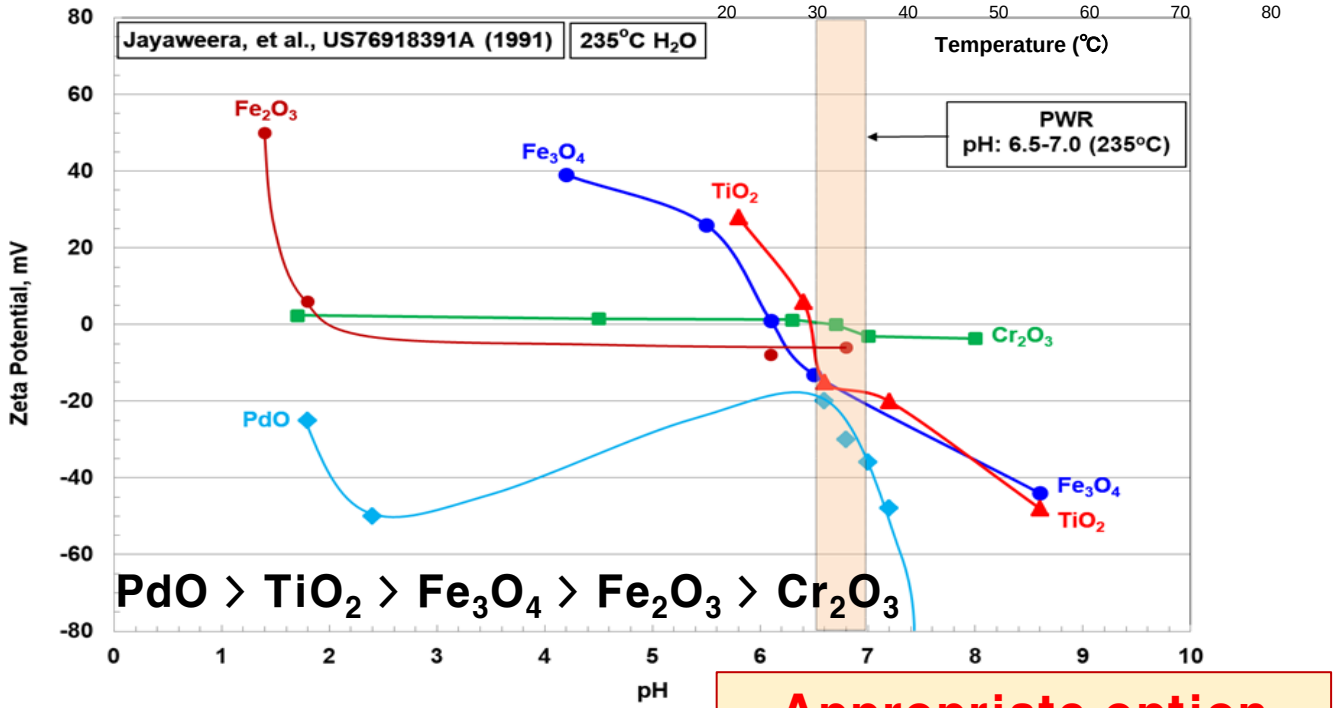
(Y-J Kim, GE, 2007)

Zeta Potential

- **The charge that develops at the interface between a solid surface and its liquid medium.**
- **A key indicator of the stability of colloidal dispersions.**







Appropriate option
Pd, Ni, CrN, Ti, TiN

Materials and Methods

Materials and Method

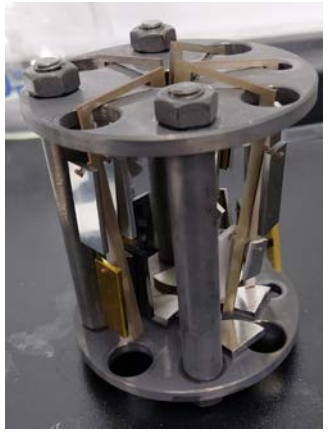
- **Specimens**
  - Commercial stainless steel (Type 304L).
  - All surfaces of each specimen were mechanically ground with silicon-carbide papers up to 800 Grit, and then ultrasonically cleaned in ethanol and deionized water for 5 min and dried.

- **Applied Coating Methods**
  - In a broad sense, two techniques of coating were used.
  - CrN, TiN, and Ti were deposited by Physical vapor deposition (PVD).
  - Ni and Pd were deposited using an electroless plating (EP).
  - Coating was conducted by companies who carry coating as an industry scale.

Experimental

<Adhesion Test>

Pull-Down Breaking Adhesion Test
(ROMULUS system)



<Static Corrosion Test>

Temperature : 235 ℃ (포화증기압:400psig) *300hrs*
Waterchemistry Condition : pH 9.3, (ETA, N_2H_4 60 ppb)
Dissolution Oxygen : < 5 ppb (Deaeration : Ar gas)

<Flow Accelerated Corrosion Test>

유속 : 6.0 m/s *700hrs*
pH : 9.3 (ETA, Hydrazine 60 ppb)
Pressure/Temp. : 1,200 psi / 235℃

- **Mass change : Corrosion rate**
- **Scanning electron microscopy (SEM) : Surface morphology**
- **X-ray diffraction (XRD) : Phase identification**
  - Scanned at 20–80° with a 0.02°/s.

Results and Discussion

Adhesion Test

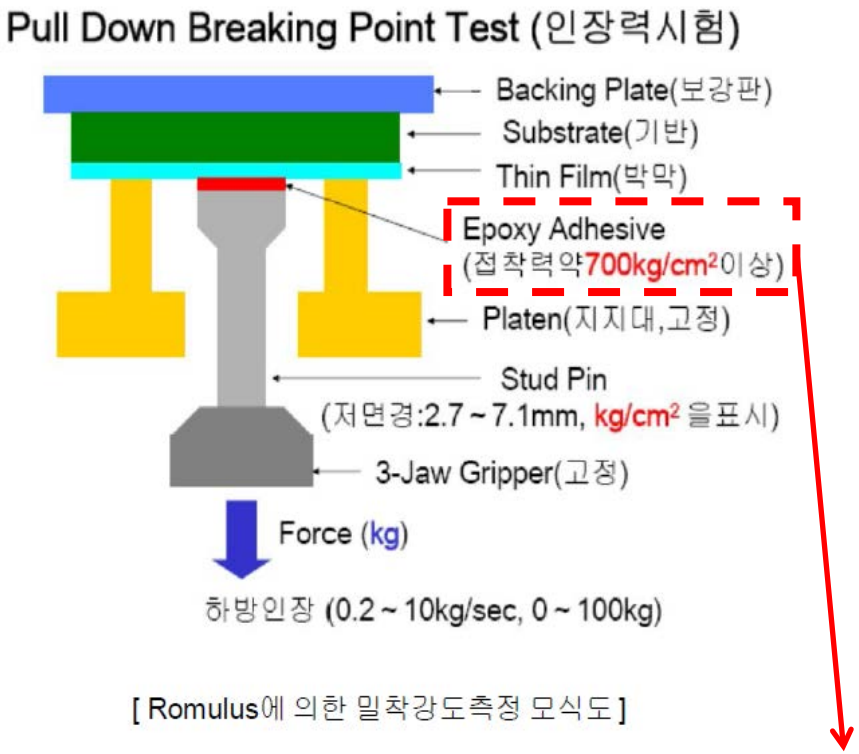
Materials in Nuclear Systems Lab
MINS

Pull-Down Breaking Adhesion Test

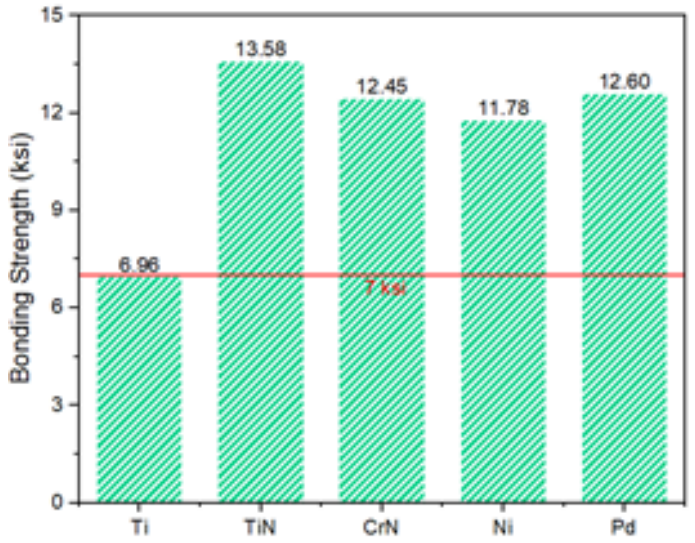
- **ASTM D4541 : 200 psi**
- **ROMULUS (Used for testing coating of gas turbine at high temperature environments)**

After test

Coating strength: 7 ksi.

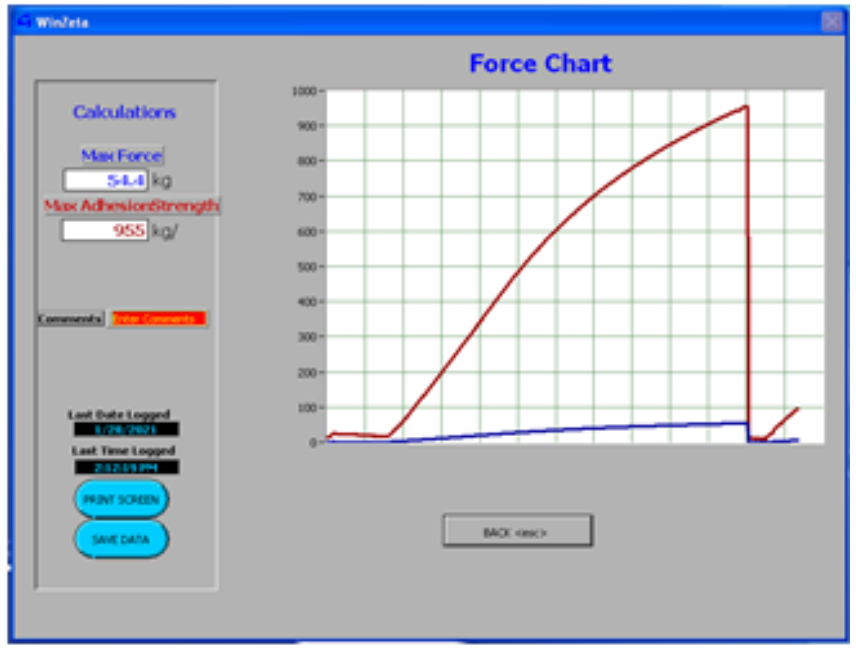


[Romulus에 의한 밀착강도측정 모식도]

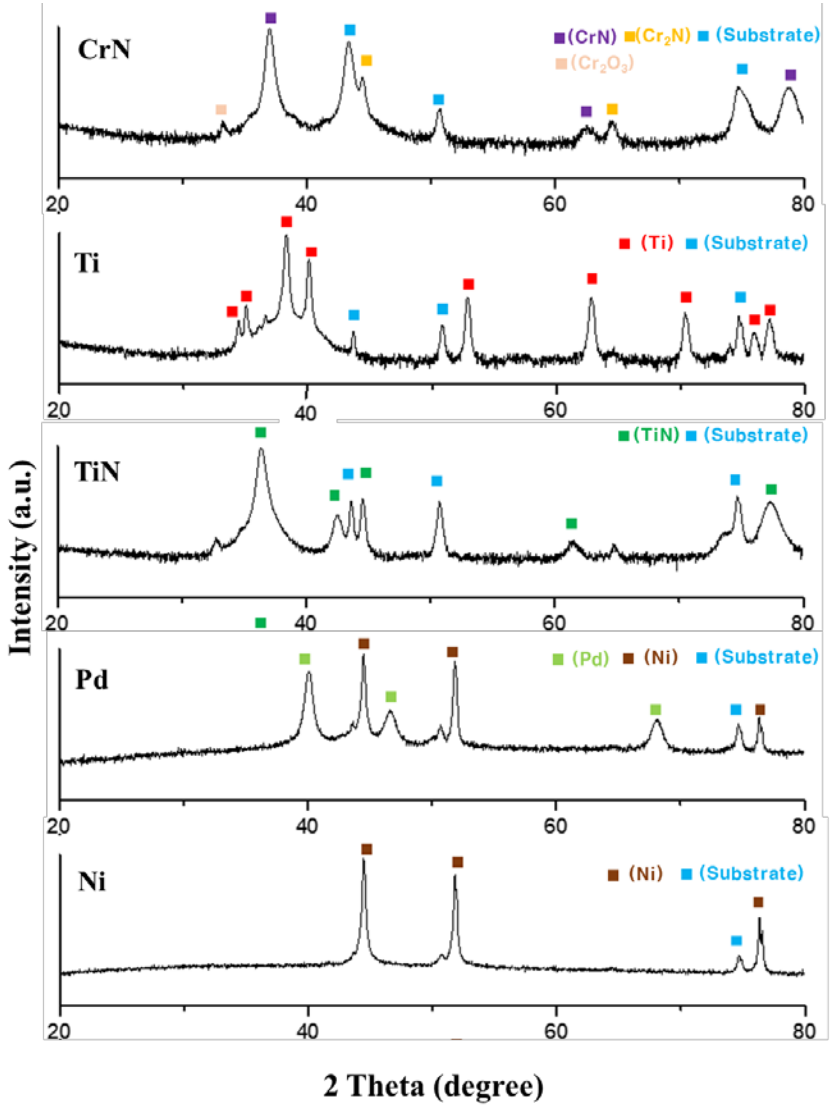


<TP304L>

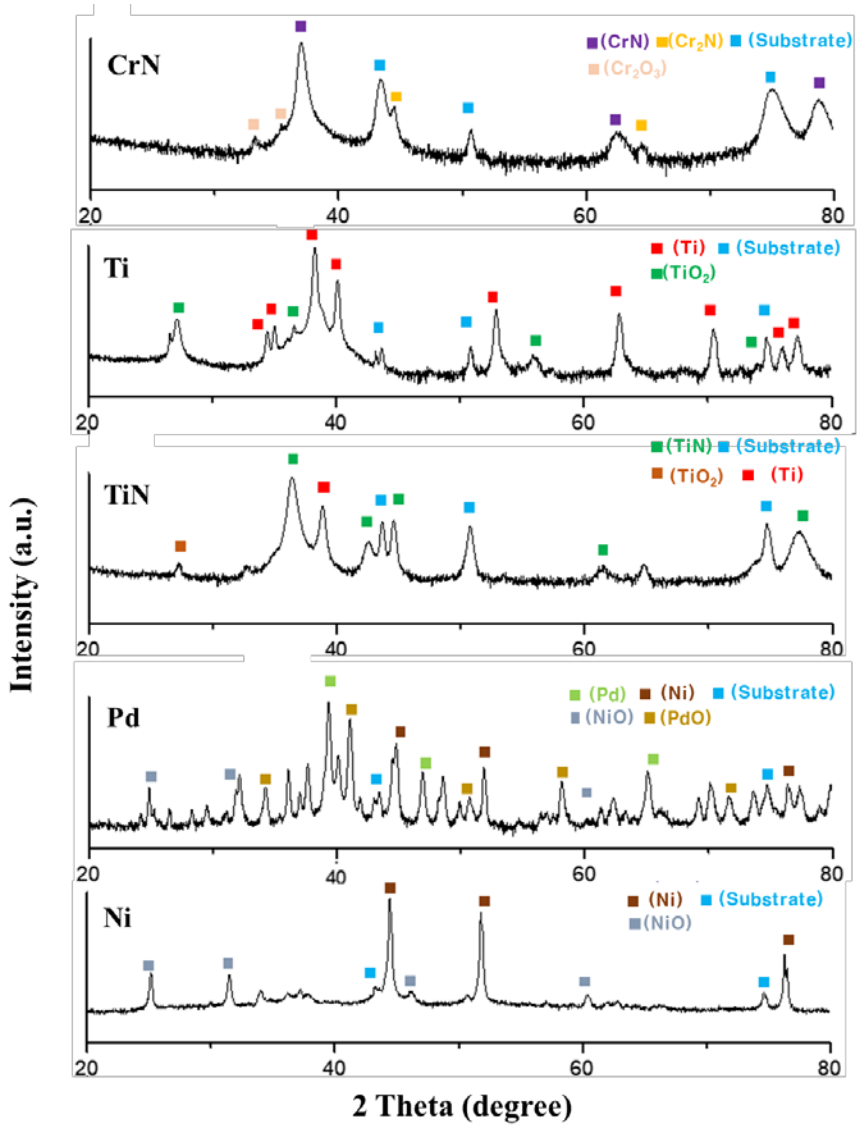
※ 약 10 ksi Epoxy Bonding Strenth



XRD Analysis : Phase Identification

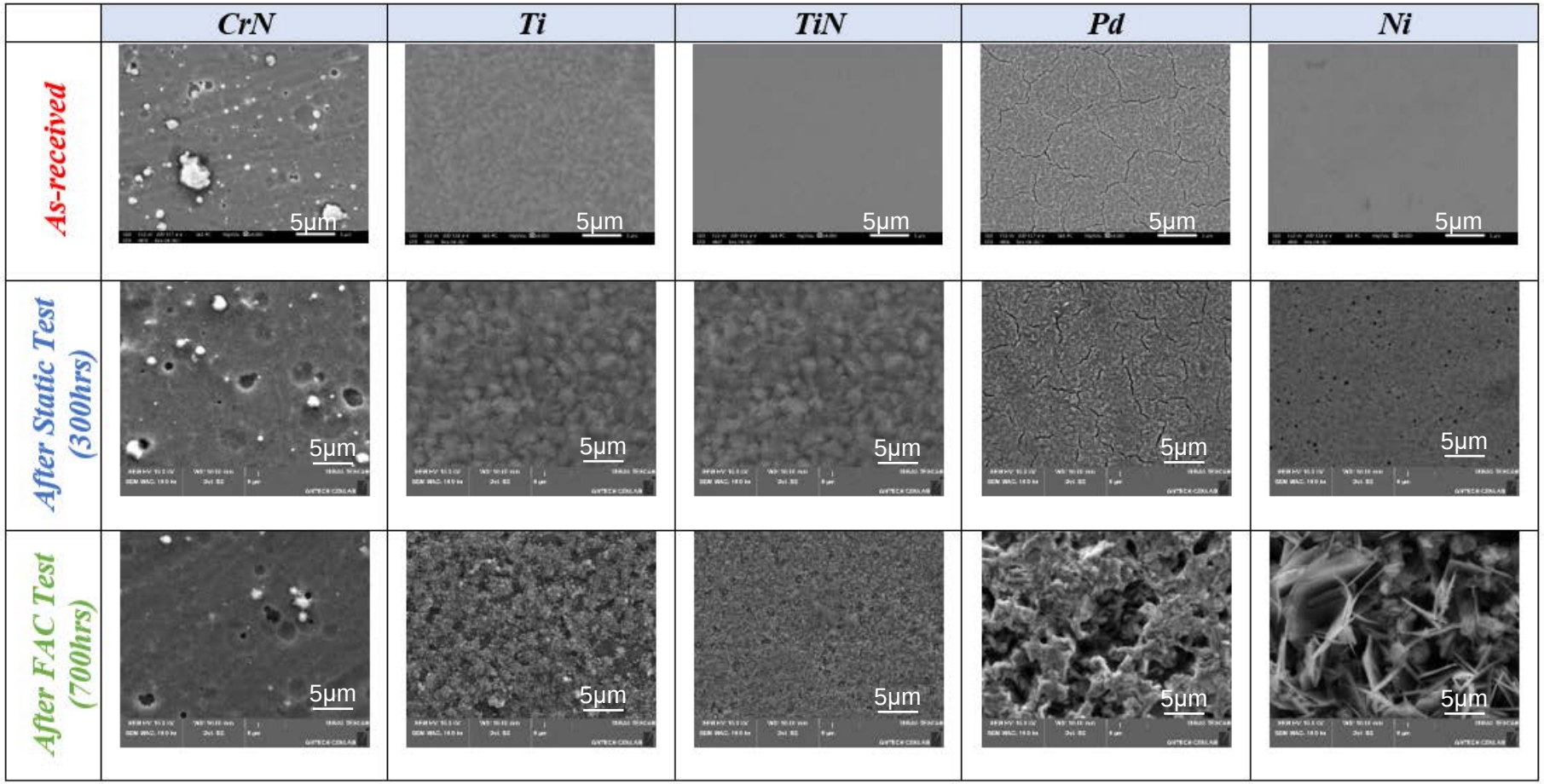


Static test at 235℃ during 300 hrs.

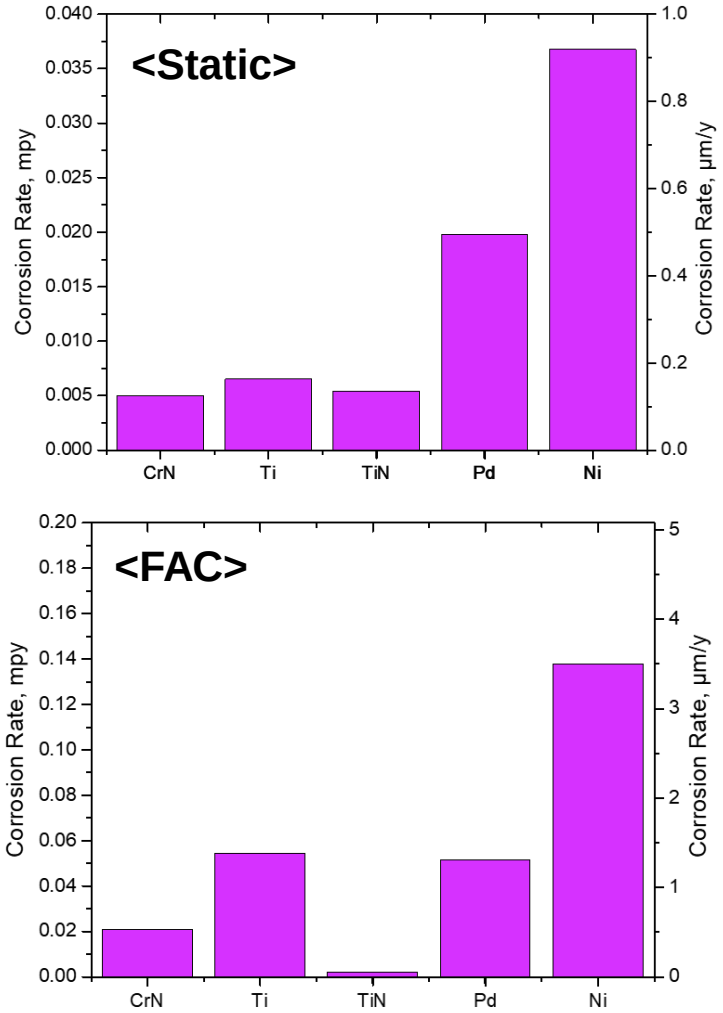


FAC test at 235℃ during 700 hrs.

Surface Morphology and Corrosion rate



SEM images of the surface

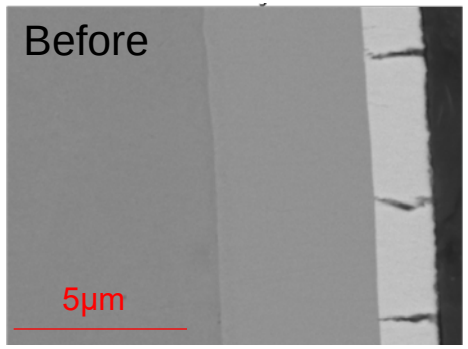


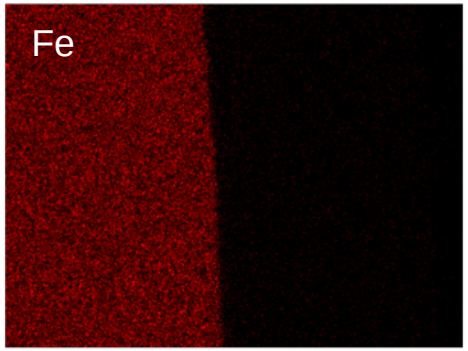
Corrosion rate from mass change

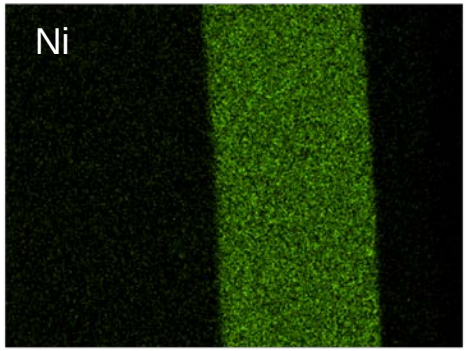
Discussion

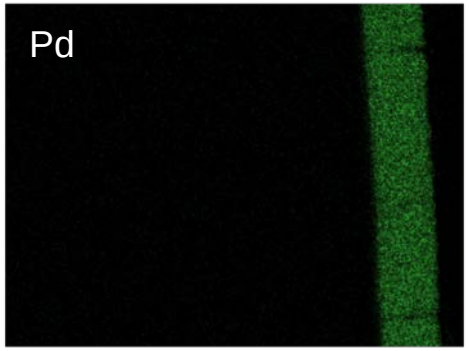
EP-Pd : Crack

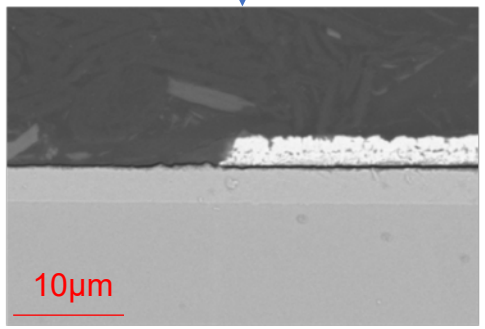
- **The Pd coating was deposited as a double layer with Ni.**
- **Assumed to be caused by the Ni inner layer under the Pd layer.**
- **To remove the cracking issue, additional Pd plating without the Ni inner layer is also planned.**





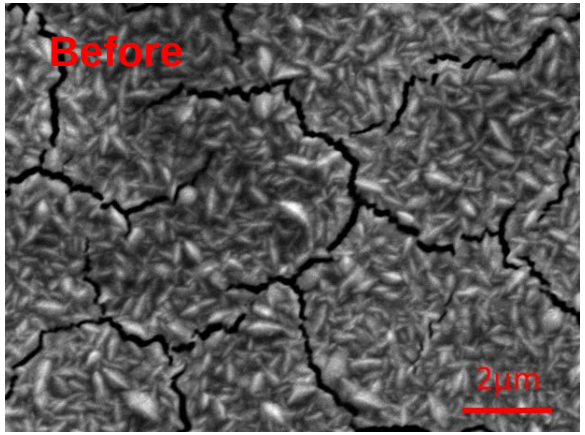


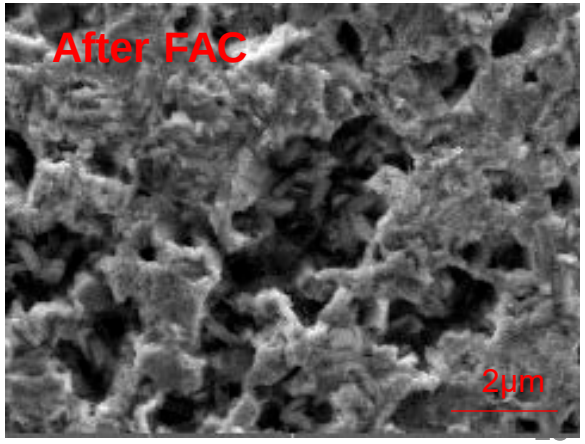




<After FAC test>

Pd layer spalling due to high flow velocity





Conclusions and Future Work

Conclusions

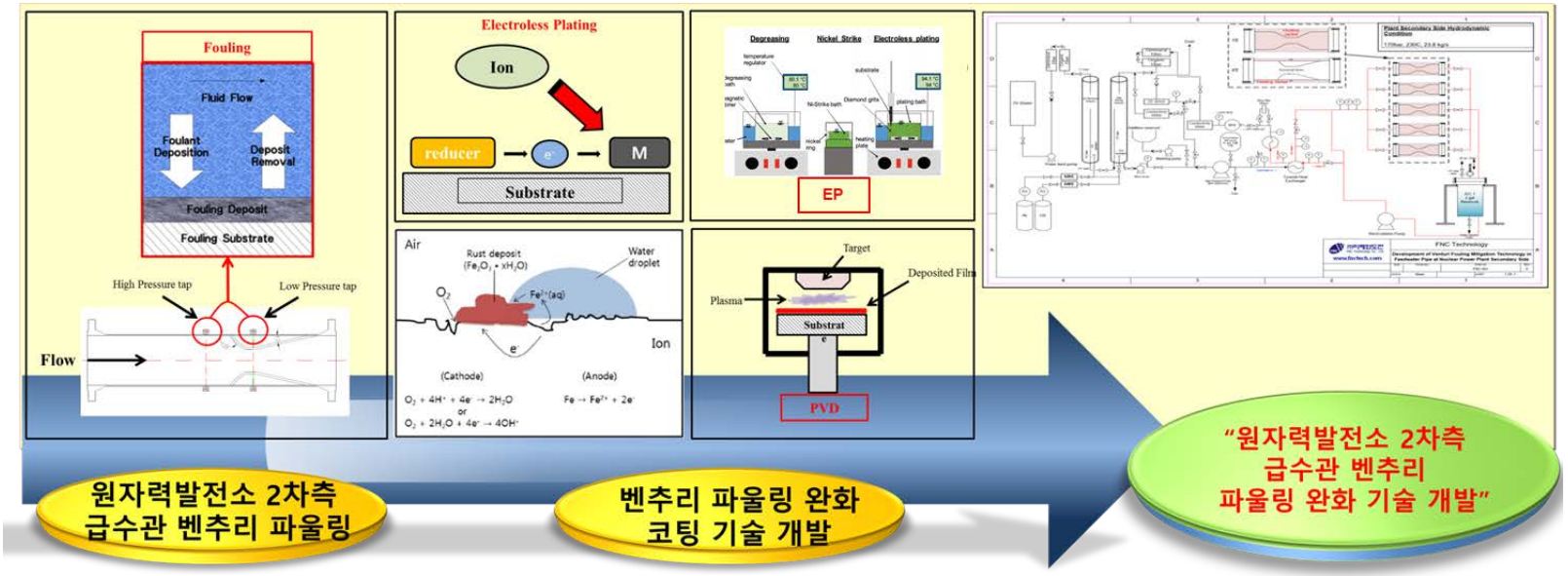
- **Various metal surface coating technologies such as physical vapor deposition (PVD) and electroless plating (EP) to reduce the deposition of Fe_3O_4 inside the venturi system, to increase the operating time of the venturi, and to minimize the error in main feedwater flow rate measurement.**
- **PVD coating has excellent material quality, but the coating process is difficult when the structure of the raw material has non-flat surface morphology.**
- **Therefore, in the case of operating nuclear power plants, we will consider applying EP, which can ensure uniform coating quality while maintaining the existing surface morphology.**

		CrN	Ti *	TiN	Pd *	Ni *
Corrosion rate (MPY)	Static (300Hr)	0.00499	0.00654	0.00545	0.01984	0.03681
	Flow Accelerated (700Hr)	0.02079	0.05451	0.00227	0.05153	0.13781
Corrosion Morphology	Static	particle * spallation	none	none	Cracking *	none
	Flow Accelerated	none	none	none	Pd spalling *	none
XRD Phase	Static	CrN, Cr_2N	Ti	TiN	Pd, Ni	Ni
	Flow Accelerated	CrN, Cr_2N,Cr_2O_3	Ti, TiO_2	Ti, TiN,TiO_2	Pd, PdO, Ni, NiO	Ni, NiO

New nuclear power plant → PVD
Operating nuclear power plant → EP

Future Work

- **Performance test with optimal coating method applied.**
  - Design and manufacture of mock-up Venturi Tube for performance test.
  - Long-term corrosion performance tests on coated specimens
- **Oxide film analysis**
  - SEM-EDS / XRD /TEM Analysis + Epoxy Mounting and Pullout Test
- **Prototype development**
  - Scale-down Venturi Flowmeter(Mock-up)



Thank you

Material in Nuclear Systems Lab

http://corrosion.pusan.ac.kr

Questions : wjchoi91@pusan.ac.kr

ACKNOWLEDGEMENT

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