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Recent progress on surface modified Zr-alloy claddings

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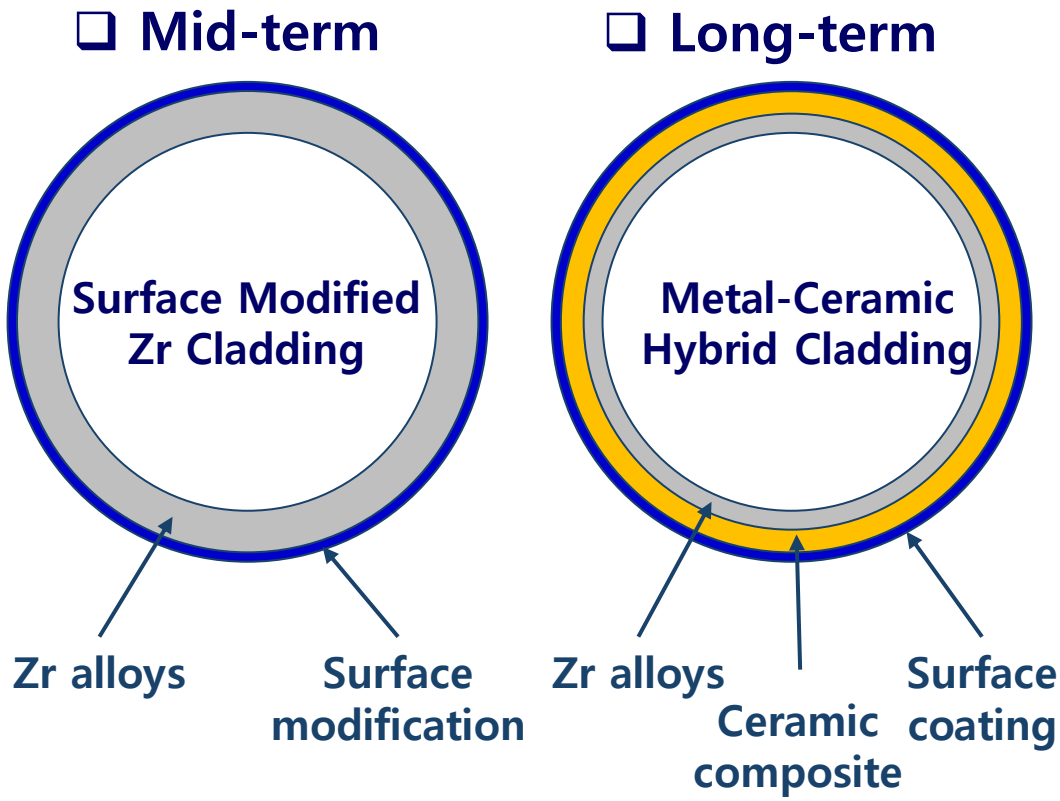
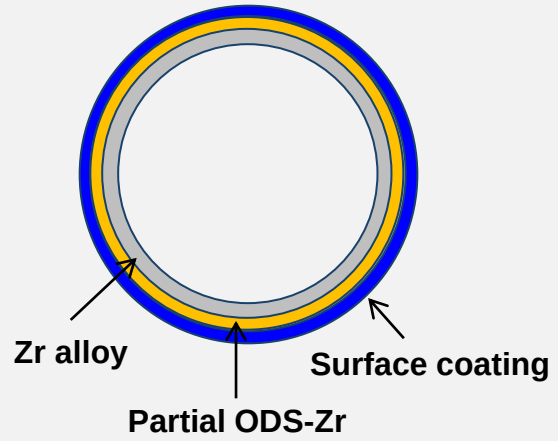
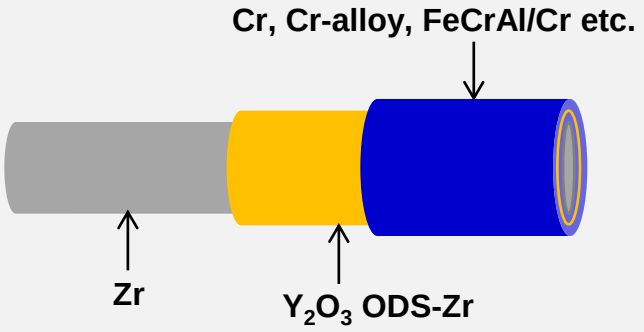
ATF Cladding Program in KAERI

- **Objective**
  - √ Enhanced performances during accidents than current Zr cladding
  - √ Increased/Maintained performances under normal condition
- **Approach**
  - √ **Surface modification (1)**
  - √ Metal-ceramic hybrid (2)
- **Considered issues**
  - √ Oxidation/corrosion resistance
  - √ Mechanical strength
  - √ Thermal conductivity
  - √ Thermal expansion coefficient
  - √ Phase stability
  - √ Adhesion to the matrix
  - √ Neutron economy
  - √ Irradiation susceptibility
  - √ Tube fabricability
  - √ Unknowns…



1. Surface Modification Technology ?

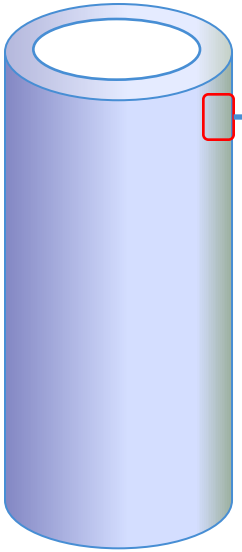




To increase high temperature strength
To increase corrosion/oxidation resistance

- **Objective**
  - √ Surface coating
    - Increase of oxidation/corrosion resistance in both accident and normal condition
  - √ Partial ODS-Zr
    - Increase of strength at high-temperature without severe decrease of ductility under normal condition
- **Approach**
  - √ Surface coating (~50 micron)
    - Coating technology development
      - → Cold spray + Laser beam scanning
      - → Arc ion plating + Laser beam scanning
      - → 3D laser coating
    - Coating material development
      - → Cr, Cr-alloy, FeCrAl/Cr…
  - √ Partial ODS-Zr (~100 micron)
    - ODS technology development
      - → Laser beam scanning with oxide powder

1-1. Coating Technology Development for ATFC



1. Coating of corrosion resistance material on cladding surface

2. Diffusion bonding between coating layer and cladding

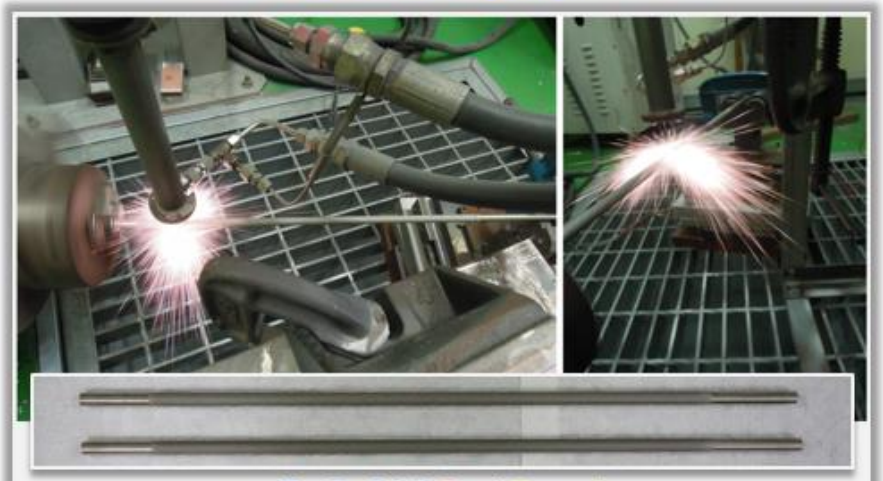
- **Coating Tech.**
  - Plasma spray
  - Cold spray
  - Ion plating
- **Diffusion Bonding Tech.**
  - Laser beam scanning
  - Ion implantation
  - Annealing
- 3D laser coating supplying with powder

- **Performance evaluation**
  - Corrosion test: up to 1200°C (normal operation and LOCA-simulated conditions)
  - Adhesion test: thermal cycle (thermal expansion), mechanical deformation
  - Micro-structural analysis

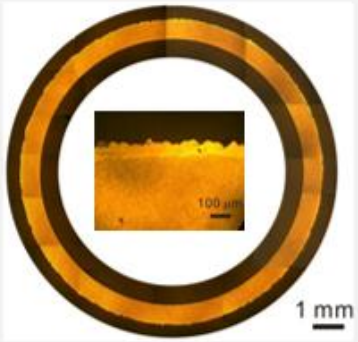
→ Increased adhesion property between coating layer and Zr alloy cladding

1-1. Coating Technology Development for ATFC

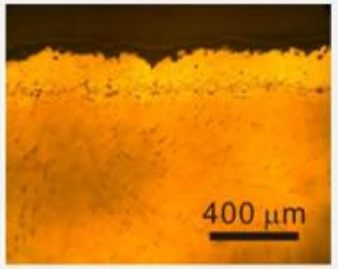
❖ Cold Spray



FeCrAl / Cr / Zr tube



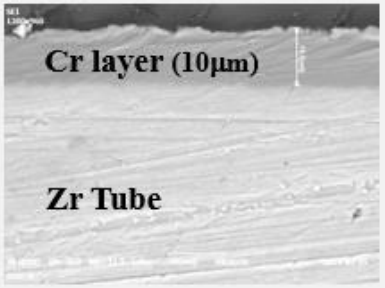
As-coated



After HT oxidation test at 1200°C for 2000s

❖ Arc Ion Plating

Cr / Zr tube



As-coated

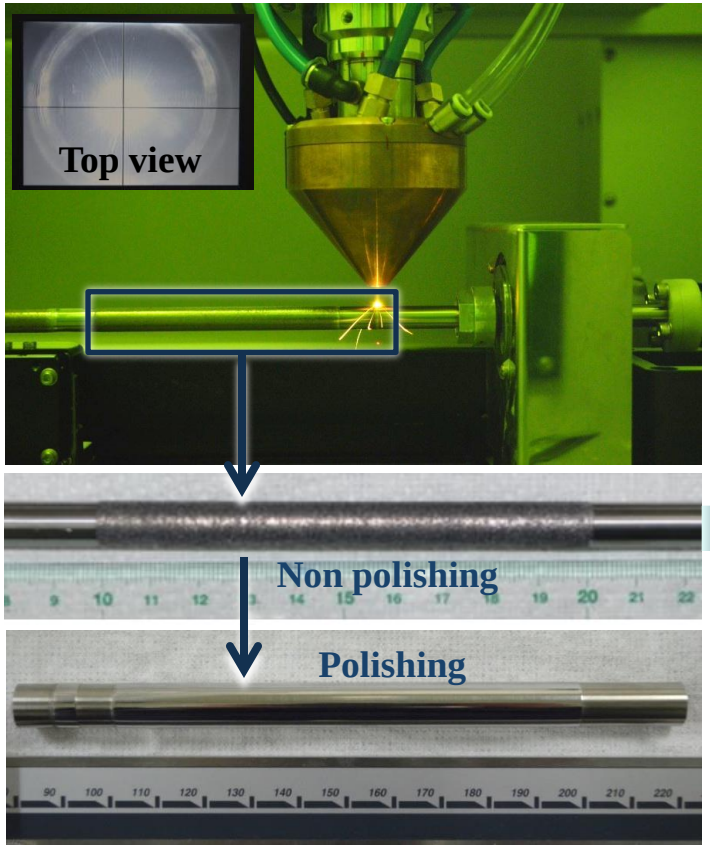
After HT oxidation test at 1200°C for 2000s

→ Increased coating efficiency and coating layer properties

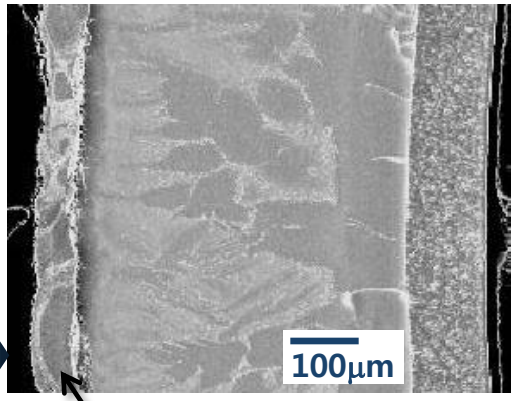
1-1. Coating Technology Development for ATFC

❖ 3D Laser Coating

Development of
3D laser coating equipment



After HT oxidation test
At 1200°C for 2000s

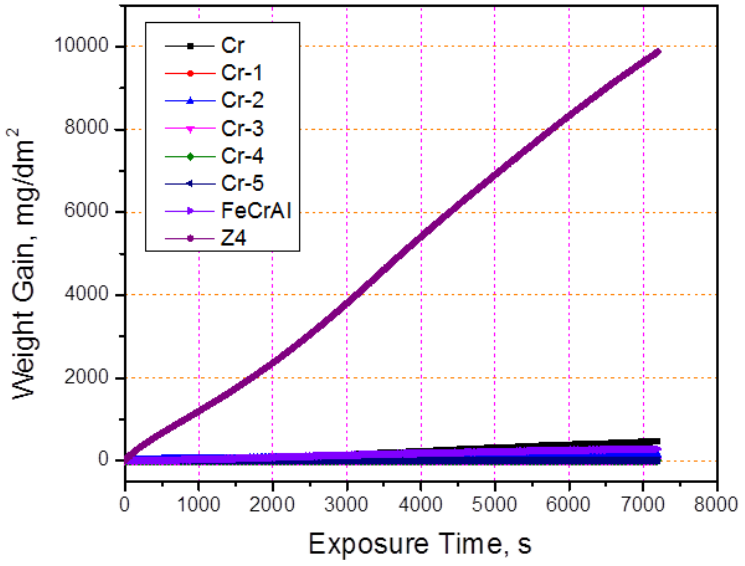


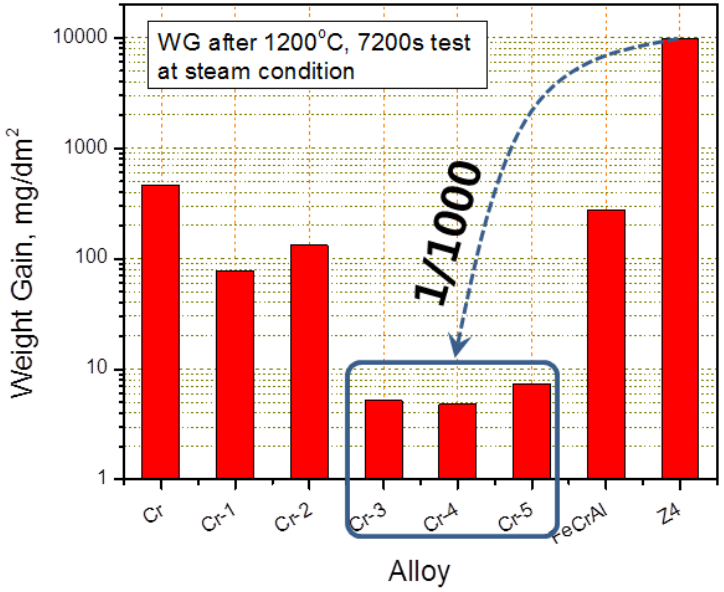
Oxide thickness	
Cr-coating	Zry-4
4 μm (1/30 of Zry-4)	113 μm

→ Increased coating efficiency, adhesion, and coating layer properties

1-2. Coating Material Development for ATFC

- **Objective of new coating material development**
  - √ more increased oxidation resistance than Cr metal in accident condition
  - √ more increased corrosion resistance than Zr alloy in normal condition
- **Approach**
  - √ model alloy design based on physical/mechanical property, neutron economy, corrosion characteristics, manufacturing process of alloying and coating…
  - √ performance evaluation of model alloy

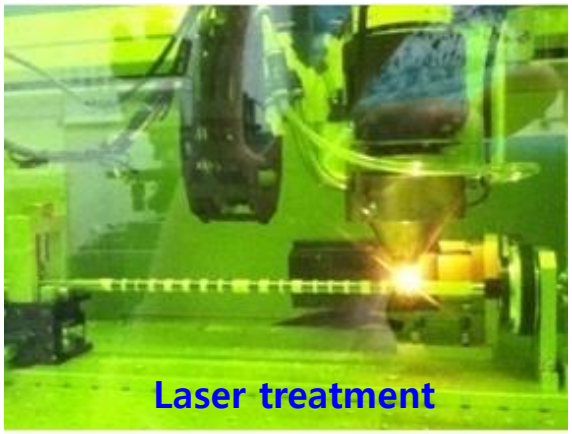


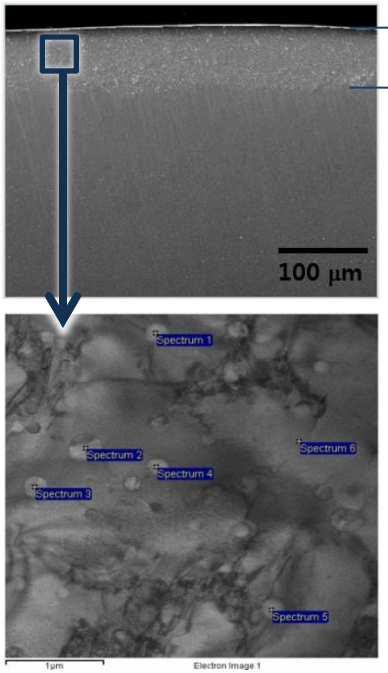


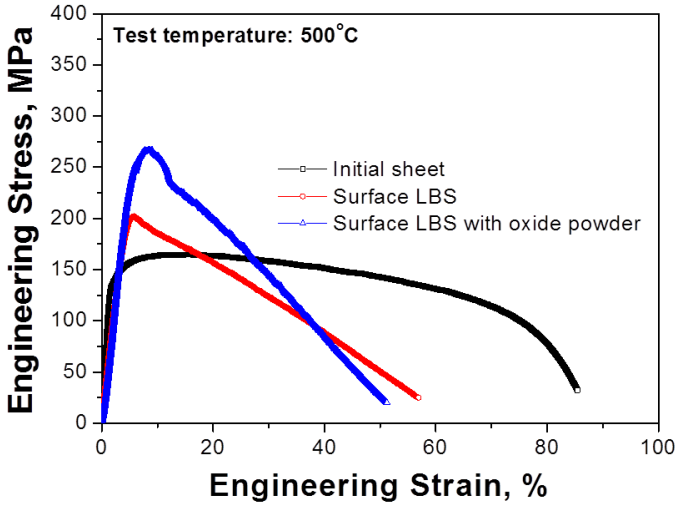
1-3. ODS Technology Development for ATFC

- **Objective of partial ODS-Zr development**
  √ more increased mechanical strength than Zr-alloy at high-temperature
  - reduce of severe ballooning/rupture deformation during accident
- **Approach**
  √ consideration of strength mechanism of Zr-alloy at high-temperature
  √ consideration of performance, easy application, and efficiency

❖ **Laser Beam Scanning with Y_2O_3 Powder**







Performance Assessment Plan

Performance	Test items of tube samples	Schedule (5 year)				
		2015	2016	2017	2018	2019
Corrosion	• PWR simulation loop					
Creep	• 300 to 450°C at various stresses					
Mechanical (adhesion)	• Bend test • Ring compression and tensile test • Wear test					
Simulated LOCA	• Oxidation up to 1300°C • Ballooning-rupture test • Ring compression for PQD					
Physical property	• Thermal cycling • Melting point • Microstructure analysis • Neutrons analysis					

Tests will be repeated for screening and optimization of technology

Irradiation Test Plan

❑ Halden reactor test: Cooperation with "THOR Energy"

- Two ATF rods with instrumentation
- **Rod 1**: Metallic microcell pellet(UO_2+5vol% Cr) + **Cr based alloy coated Zr cladding**
- **Rod 2**: Ceramic microcell pellet(UO_2+0.6wt%Si-Ti-O) + **Cr based alloy coated Zr cladding (or other)**
- Irradiation period: 2015.06 ~2017.05 (Estimated burnup: 25 GWd/MTU)

❑ Halden reactor test: Halden Reactor Project (HRP)

- **ATF Claddings** and ATF Pellets were proposed as candidates for test
- **Surface modified Zr claddings** are proposed
- Irradiation period: 2016 ~

감사합니다.

Thank you for your attention!

2. Hybrid Technology Development for ATFC

- Combination of advantages of metal and SiC material
  - → Inner Zr alloy for ductility and fission gas retention
  - → Mid SiC/SiCf for reducing H generation and increasing mechanical strength
  - → Outer coating for preventing dissolution of SiC in normal condition