

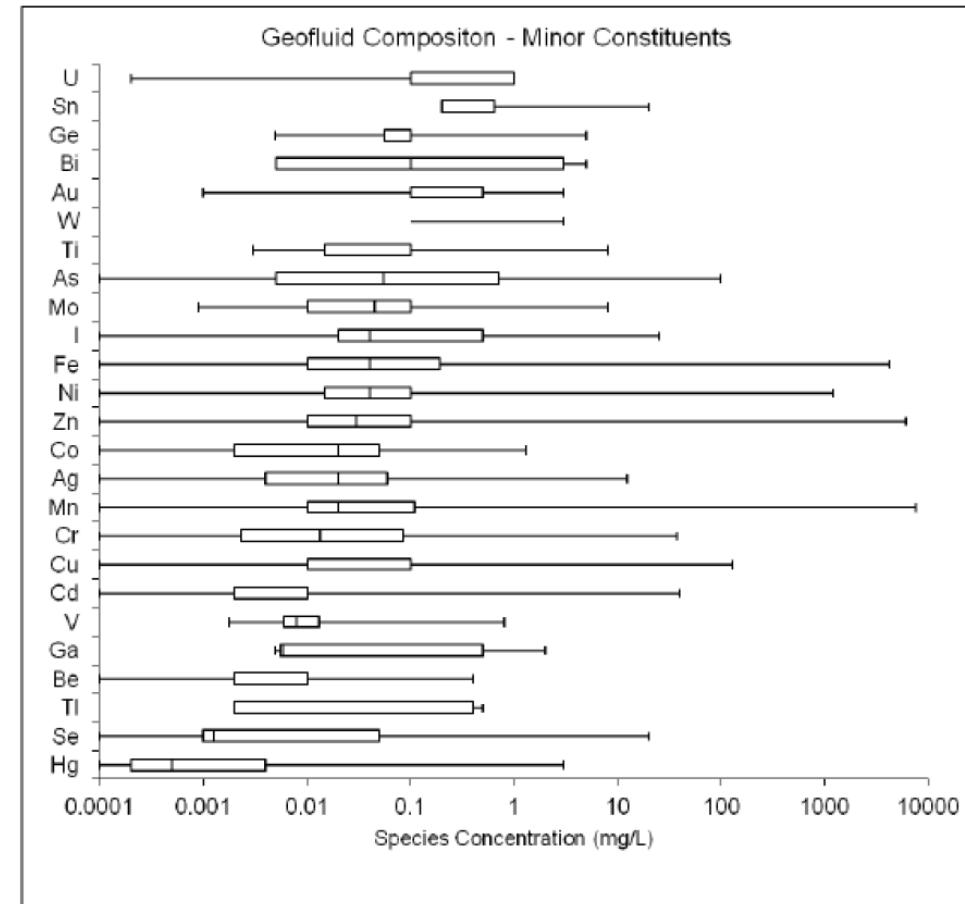
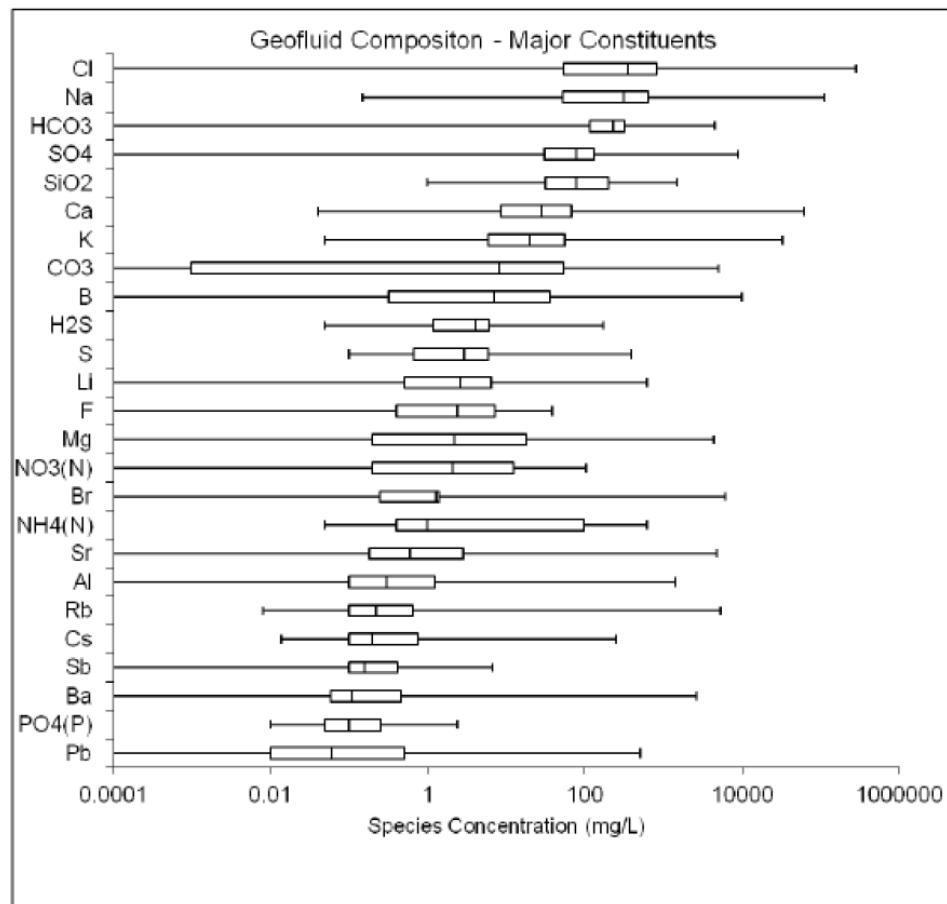
Turbomachinery in Enhanced Geothermal Systems (EGS)

Adam Neil and Derrick Bauer, Elliott Group
Geothermal Energy Machinery and Systems (GEMS)
November 29-30, 2023

Material Challenges in Geothermal

- Temperature
 - Conventional Geothermal
 - $T < 300^{\circ}\text{C}$ (572°F)
 - Not very hot for a steam turbine
 - Future – Ultra High Temperature
 - $T < 600^{\circ}\text{C}$ (1112°F)
 - With the range of Elliott's Hot Gas Expanders
- Corrosion?????
 - Varies by location
 - Depends on the system design
- Erosion?????
 - Varies by location
 - Depends on the system design

Possible Constituents in Geothermal Fluids



47 of 118 (40%) of the elements on the periodic table are listed

Material Properties with Temperature and Environment

- Tensile tests
 - Yield Strength
 - Tensile Strength
 - Elastic Modulus
 - Poisson's Ratio
 - Reduction of Area
 - Percent Elongation
- Stress Based Fatigue
 - Endurance limit
 - Goodman Factor Values
- Stress Relaxation
 - 100,000 hr Rupture
 - Larson Miller curve
- Fatigue Crack Growth
 - Paris Law Constants
 - K_{th}
- Fracture Toughness
 - K_{IC}
- Strain Based Fatigue
 - Cyclic Stress-Strain
 - Strain Life Curve

Step 1. Corrosion Test Conditions;

Material: **Next Page** (Surface finish: $1\mu\text{m}$ diamond paste)

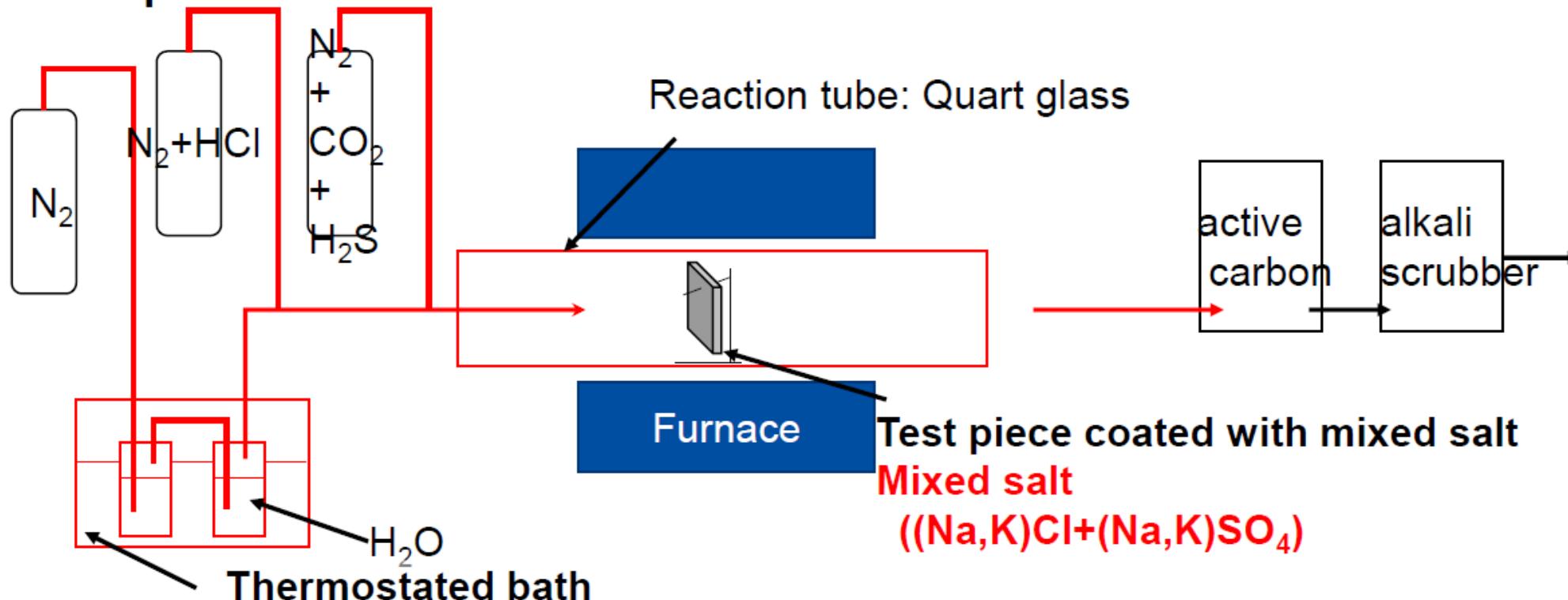
Temperature : **350°C**

Test condition : $\text{N}_2+10\%\text{H}_2\text{O}+10\%\text{CO}_2+200\text{ppm H}_2\text{S}+100\text{ppm HCl}$

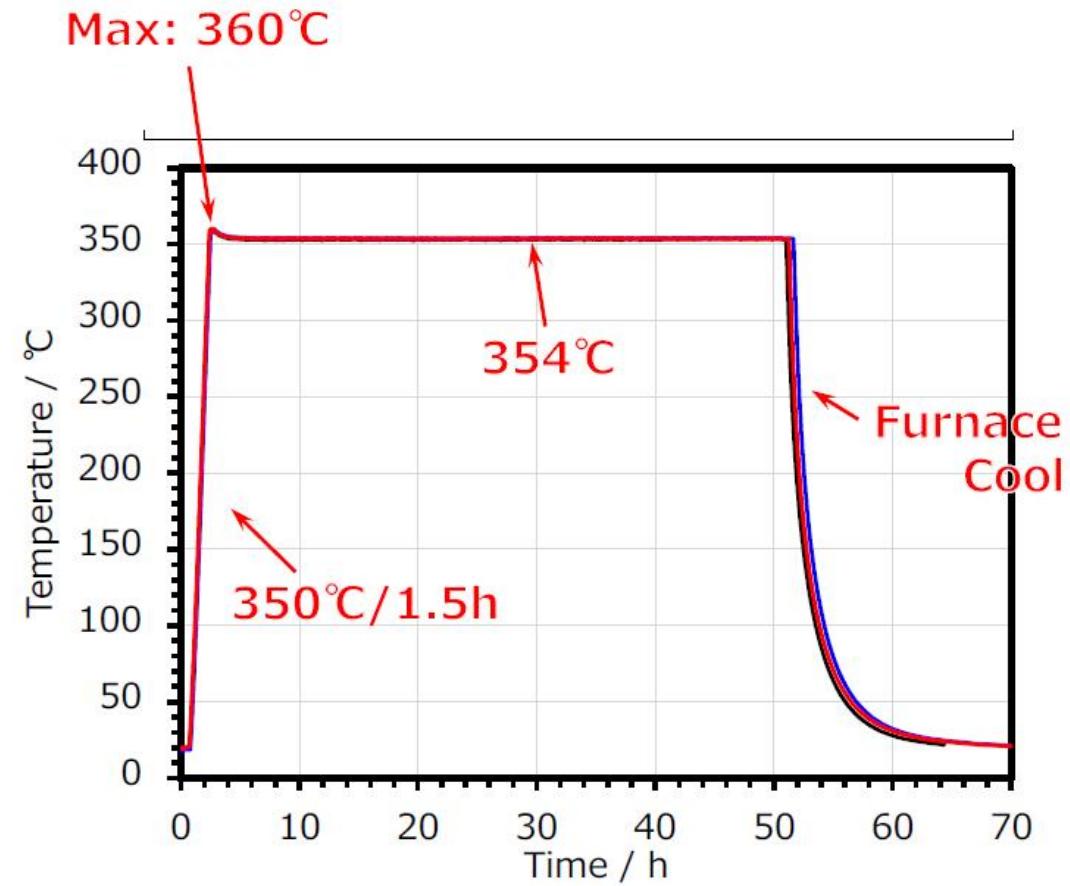
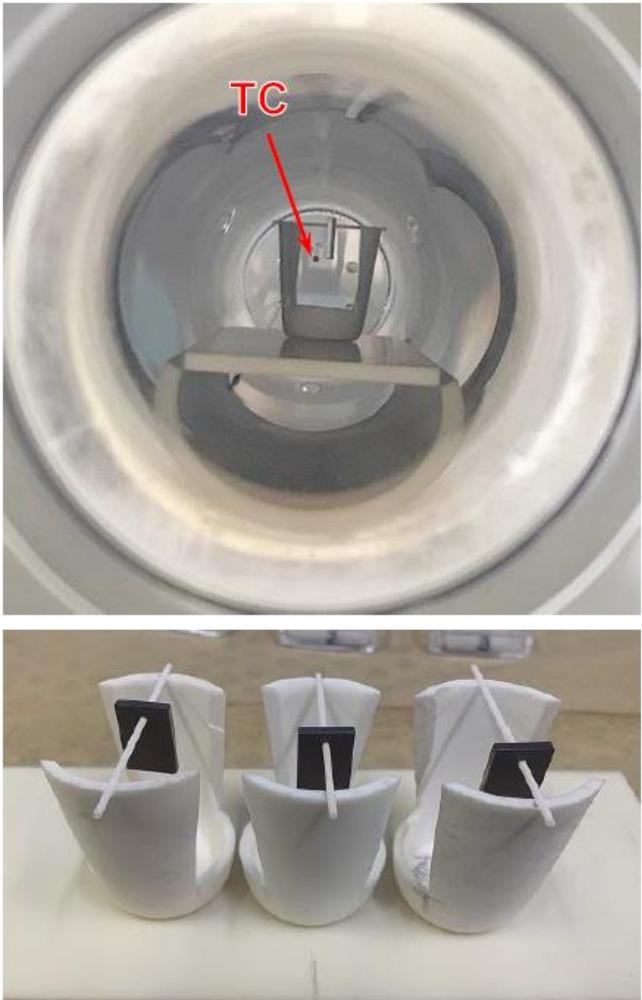
Mixed salt : $((\text{Na},\text{K})\text{Cl}+(\text{Na},\text{K})\text{SO}_4)$ ($[\text{K}^+]/[\text{Na}^+]=0.2$, $[\text{Cl}^-]/[\text{SO}_4^{2-}]=1$)

Amount of salts : **3~4 mg/cm²**

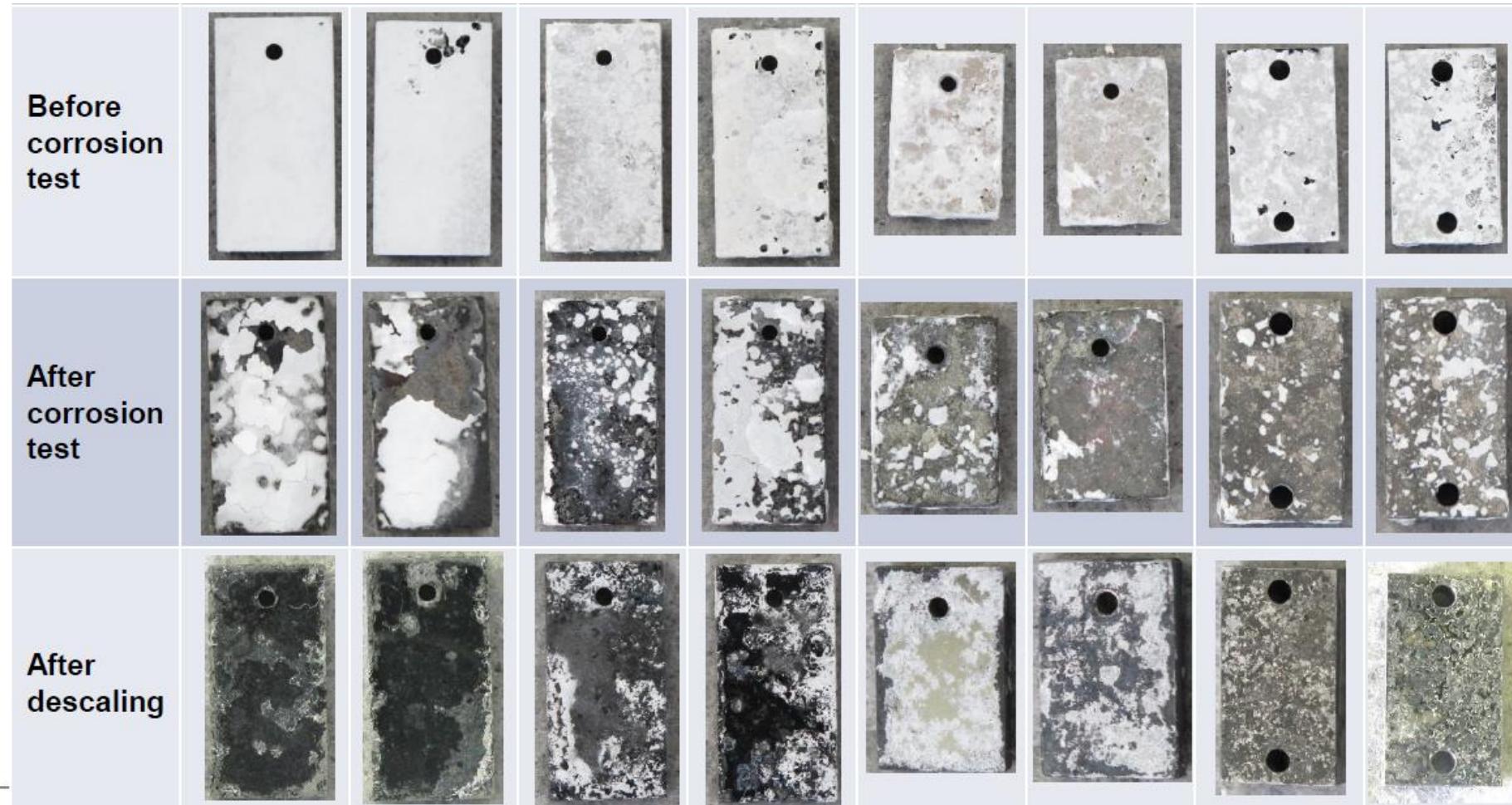
Exposure time : **48h**



Corrosion Testing Setup

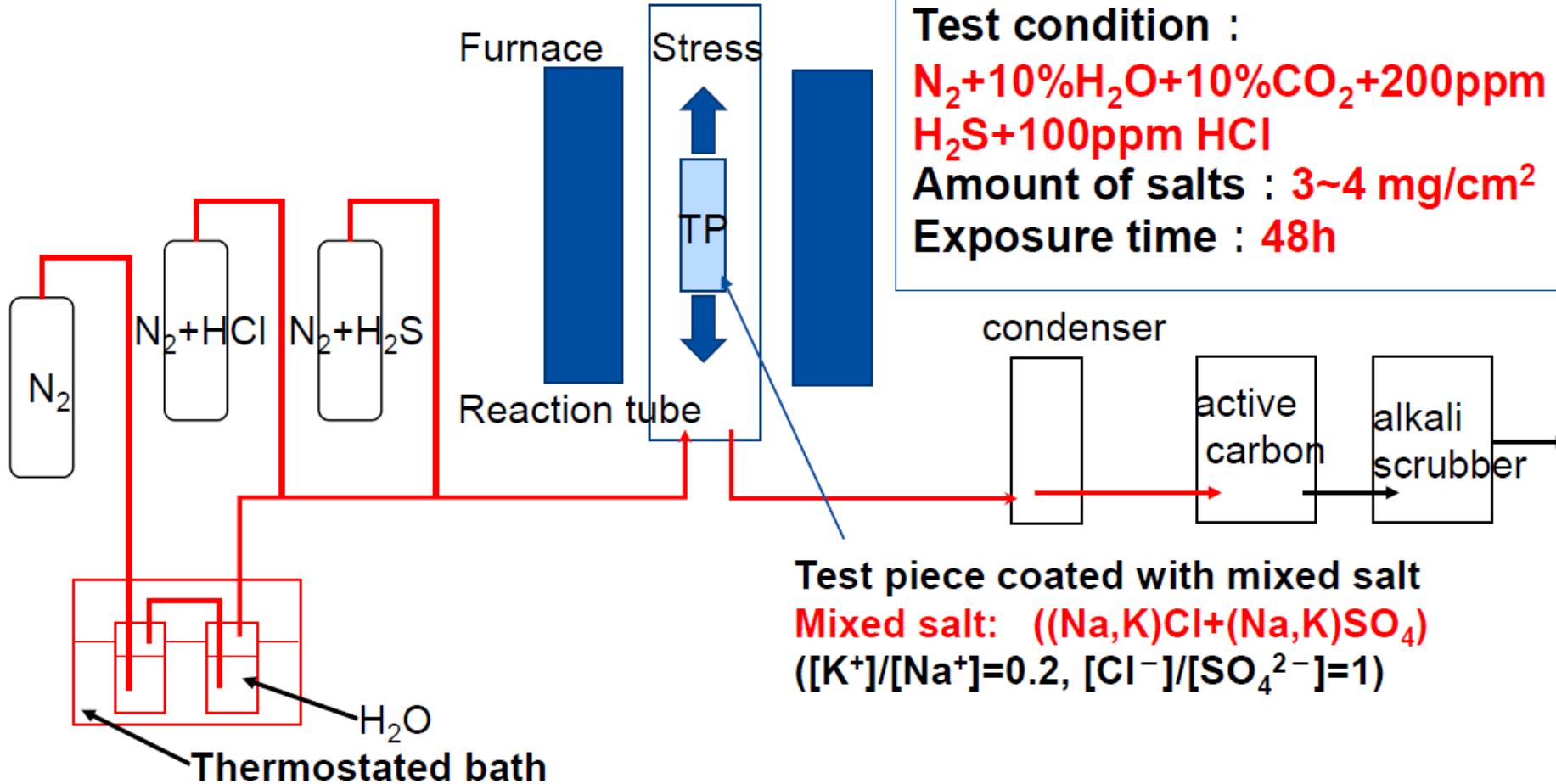


Appearance of Test Pieces after 48 Hour Exposure



Environment Testing

- Static Load -



TPNo.	Applied stress	Testing environment	Salt deposit	remark
3-3	320 MPa	$N_2 + 10\%H_2O$	3 mg/cm ²	今回報告
3-4	320 MPa	$N_2 + 10\%H_2O + 10\%CO_2 + 200\text{ppm } H_2S + 100\text{ppm HCl}$	x	今回報告
3-5	320 MPa	$N_2 + 10\%H_2O + 10\%CO_2 + 200\text{ppm } H_2S + 100\text{ppm HCl}$	o	実施中

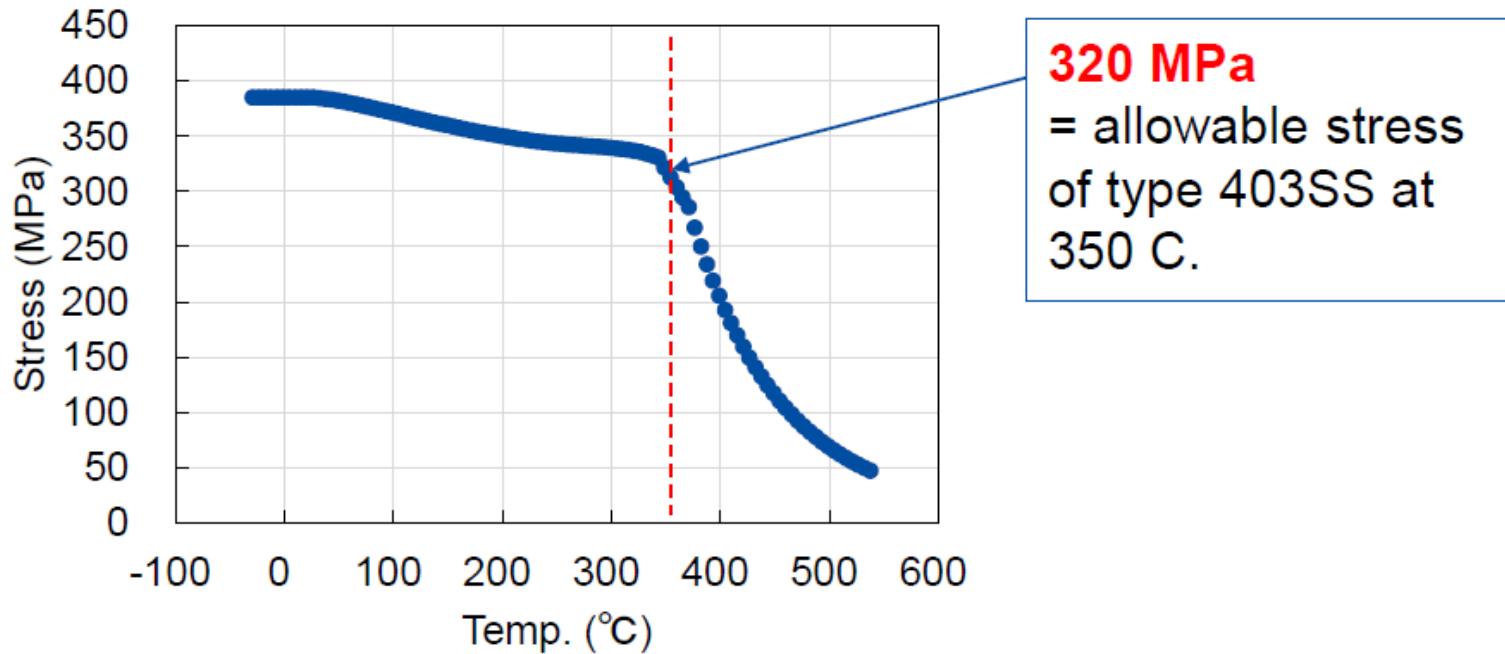


Fig. Allowable stress of type 403SS

Static stress applied cond.



No stress applied cond.
(reference sample)



K_{ISCC} test method (based on ASTM F1624-12)

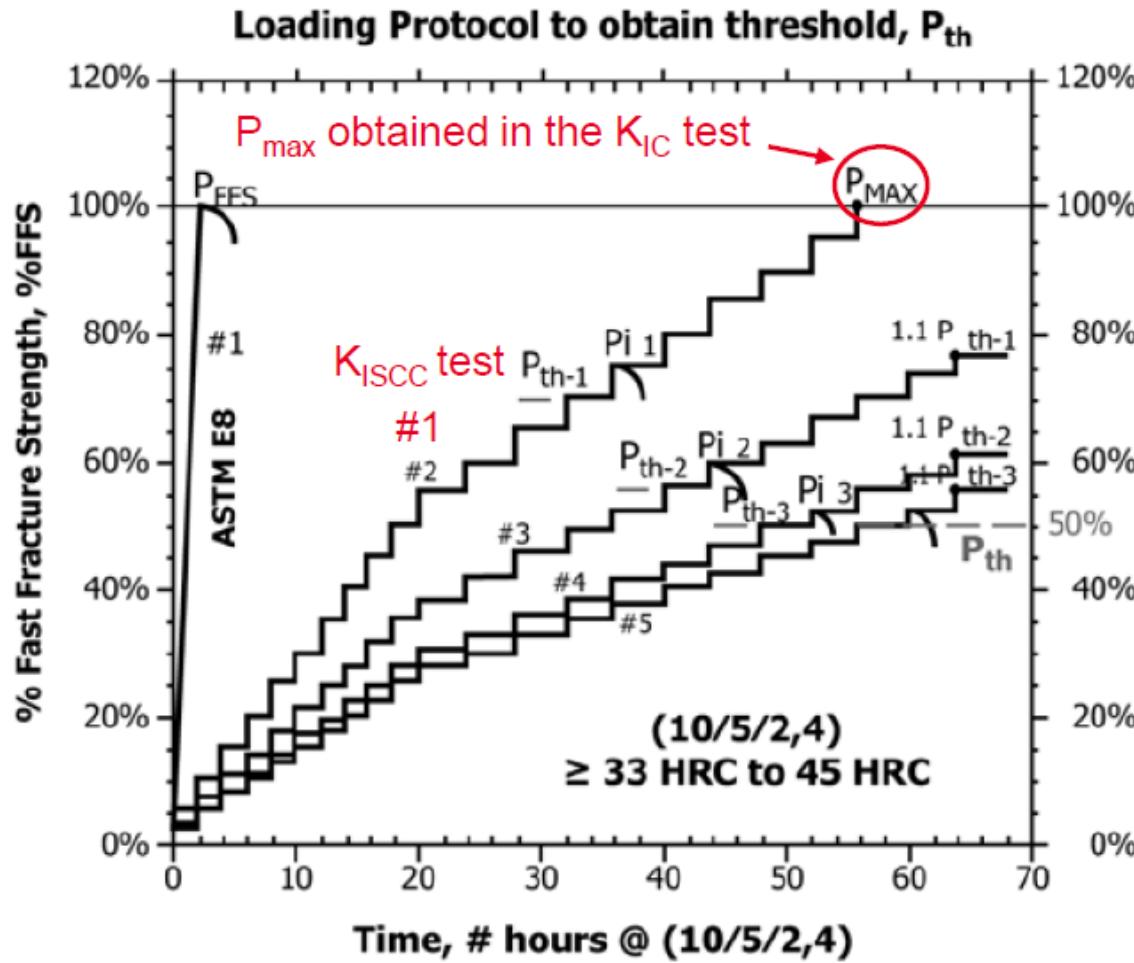


FIG. 3 Schematic of a (10/5/2,4) Step Loading Profile to Determine Threshold for the Hardness of Steel ≥ 33 HRC to 45 HRC

SN(1)-Baseline: fast fracture test of specimen after plating to measure $P_{MAX} = P_{FFS}$. (This ensures that no cracks initiated or softening occurred during the plating process)

For the hardness range of >54 HRC (see Fig. 1)

SN(2)-(20/5/1) @ $P_{MAX} = P_{FFS}$; $\rightarrow P_{th-1}$

SN(3)-(20/5/1) @ $P_{MAX} = 1.1 \times P_{th-1}$; $\rightarrow P_{th-2}$

SN(4)-(20/5/1) @ $P_{MAX} = 1.1 \times P_{th-2}$; $\rightarrow P_{th-3}$

and if necessary;

SN(5)-(20/5/1) @ $P_{MAX} = 1.1 \times P_{th-3}$; $\rightarrow P_{th-4}$

measures P_{th-EHE} , P_{th-SCC} , or P_{th-IHE} when $\Delta P_{th} \leq 5\% P_{FFS}$

or,

For the hardness range of >45 HRC to 54 HRC (see Fig. 2)

SN(2)-(10/5/1,2) @ $P_{MAX} = P_{FFS}$; $\rightarrow P_{th-1}$

SN(3)-(10/5/1,2) @ $P_{MAX} = 1.1 \times P_{th-1}$; $\rightarrow P_{th-2}$

SN(4)-(10/5/1,2) @ $P_{MAX} = 1.1 \times P_{th-2}$; $\rightarrow P_{th-3}$

and if necessary;

SN(5)-(10/5/1,2) @ $P_{MAX} = 1.1 \times P_{th-3}$; $\rightarrow P_{th-4}$

measures P_{th-EHE} , P_{th-SCC} , or P_{th-IHE} when $\Delta P_{th} \leq 5\% P_{FFS}$

or,

For the hardness range of ≥ 33 HRC to 45 HRC (see Fig. 3)

SN(2)-(10/5/2,4) @ $P_{MAX} = P_{FFS}$; $\rightarrow P_{th-1}$

SN(3)-(10/5/2,4) @ $P_{MAX} = 1.1 \times P_{th-1}$; $\rightarrow P_{th-2}$

SN(4)-(10/5/2,4) @ $P_{MAX} = 1.1 \times P_{th-2}$; $\rightarrow P_{th-3}$

and if necessary;

SN(5)-(10/5/2,4) @ $P_{MAX} = 1.1 \times P_{th-3}$; $\rightarrow P_{th-4}$

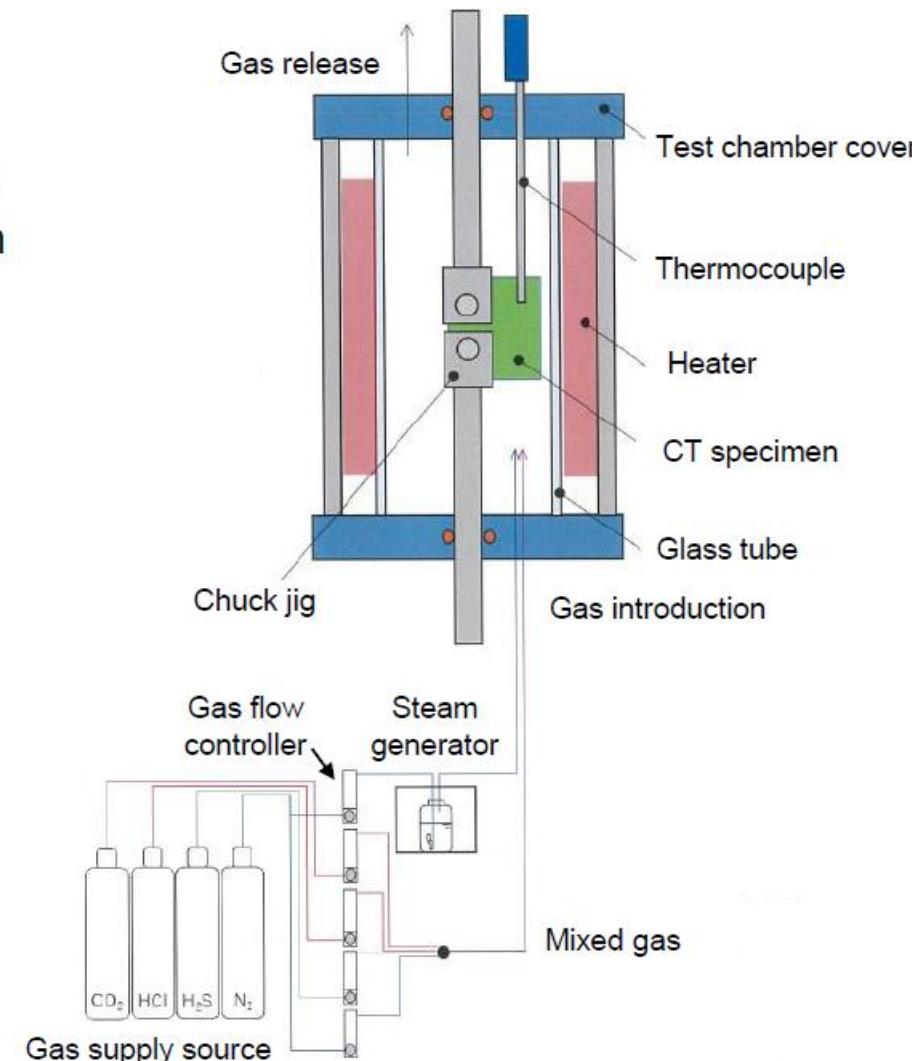
measures P_{th-EHE} , P_{th-SCC} , or P_{th-IHE} when $\Delta P_{th} \leq 5\% P_{FFS}$

K_{ISCC} test method (based on ASTM F1624-12)



Test conditions

- Test equipment:
Shimadzu Servo Pulsar EHF-EUD50KN-10L
type manufactured by Shimadzu Corporation
- Test temperature: 350°C±10°C
- Test atmosphere:
***Same conditions as the corrosion test**
 - 1st: N₂+10vol% CO₂+10vol% steam +
200ppmv H₂S+100ppmv HCl
 - 2nd: 100% N₂ gas
- Test gas flow rate: 500ml/min
- Loading speed: 0.15 kN/min



Schematic diagram of the K_{ISCC} test