Research and Development Toward Saving Energy for Direct Air Capture With Available Cold Energy

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Implementing organizations : Nagoya University, Toho Gas Co., Ltd., Tokyo University of Science

Objectives & Development items

【Research and development item 2】

Development of bench scale machine and pilot machine
2－1（2） Soundness assessment based on material analysis

【Objectives ①】

Selection of **economical** and **reliable**
Steel material / fracture resistance
structural materials suitable for the frame of heat exchangers (sublimation tanks)

【Objectives ②】

Development of a **health monitoring** system
In-situ / operand strain sensors, mounting components
for heat exchangers (sublimation tanks)

【Pathways ①】（～March 2024）

【Pathways ②】（～March 2024）

Reliability evaluation (①) / system design (②) for use under
- **Cold-Heat shock：-162℃（-196℃）⇔ room temp.**
- **Pressure impact：10 Pa（@ dry ice）⇔ 4 MPa（@ CO_2 gas）**
- **Corrosive atmosphere: CO_2, H_2O, absorbent, etc.**

Cold-heat shock/Pressure impact test
➡ structural / mechanical property evaluation
Computer simulation

Mounting components development
Output / responsiveness evaluation

Steel material candidates

Steel type	Applicable temperature /℃	Availability (Economical)	Allowable tensile stress @-196℃~40℃ /N・mm^{-2}	Component %	Crystal System	Remarks
SL9N	-196	x	163-220	9Ni	BCC	Used for LNG tanks Expensive (without general distribution) Plate material (without pipe material) Low corrosion resistance
Invar alloy	-196	x	240	36Ni	FCC	
SUS304	-196	○	110-129	18Cr-8Ni	FCC	
SUS304L	-196	○		18Cr-8Ni Low C	FCC	
SUS316	-196	○	97-130	16Cr-12Ni-2Mo	FCC	
SUS316L	-196	○		16Cr-12Ni-2Mo Low C	FCC	

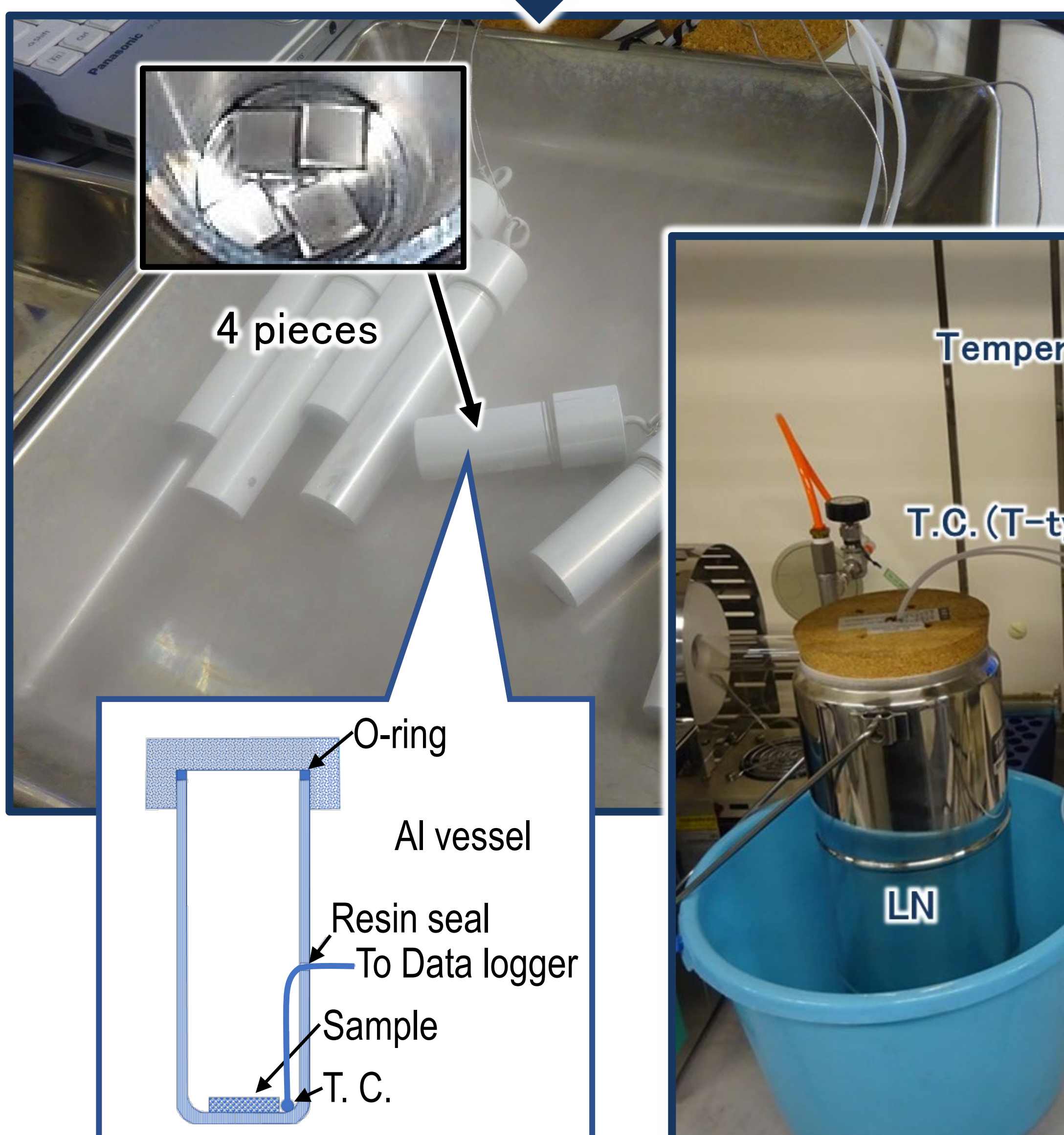
Steel type	Detailed component %(m/m)								
	C	Si	Mn	P	Mo	S	Ni	Cr	Fe
SUS304	0.07	0.49	1.19	0.030	-	0.004	8.09	18.13	residual
SUS304L	0.008	0.38	0.91	0.035	-	0.007	9.09	18.32	residual
SUS316	0.05	0.65	0.91	0.035	2.08	0.002	10.18	16.84	residual
SUS316L	0.011	0.66	0.92	0.033	2.06	0.001	12.10	17.28	residual

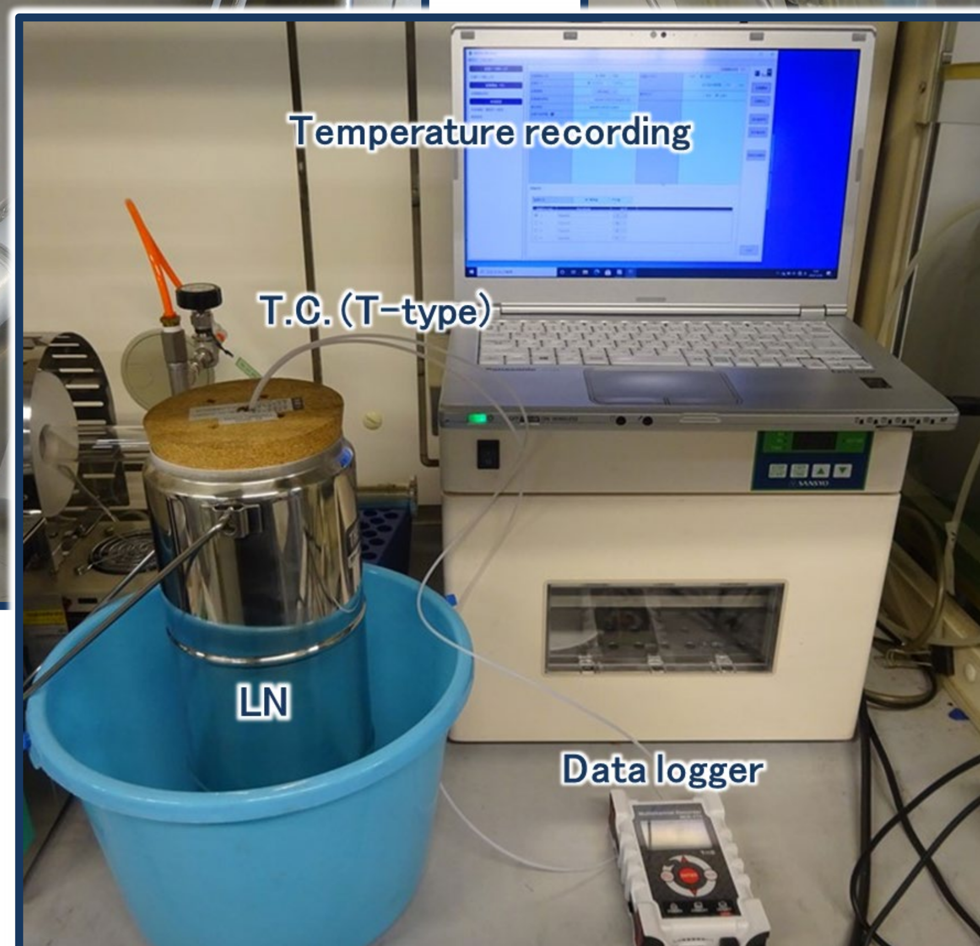
SUS304、SUS304L、SUS316、SUS316L

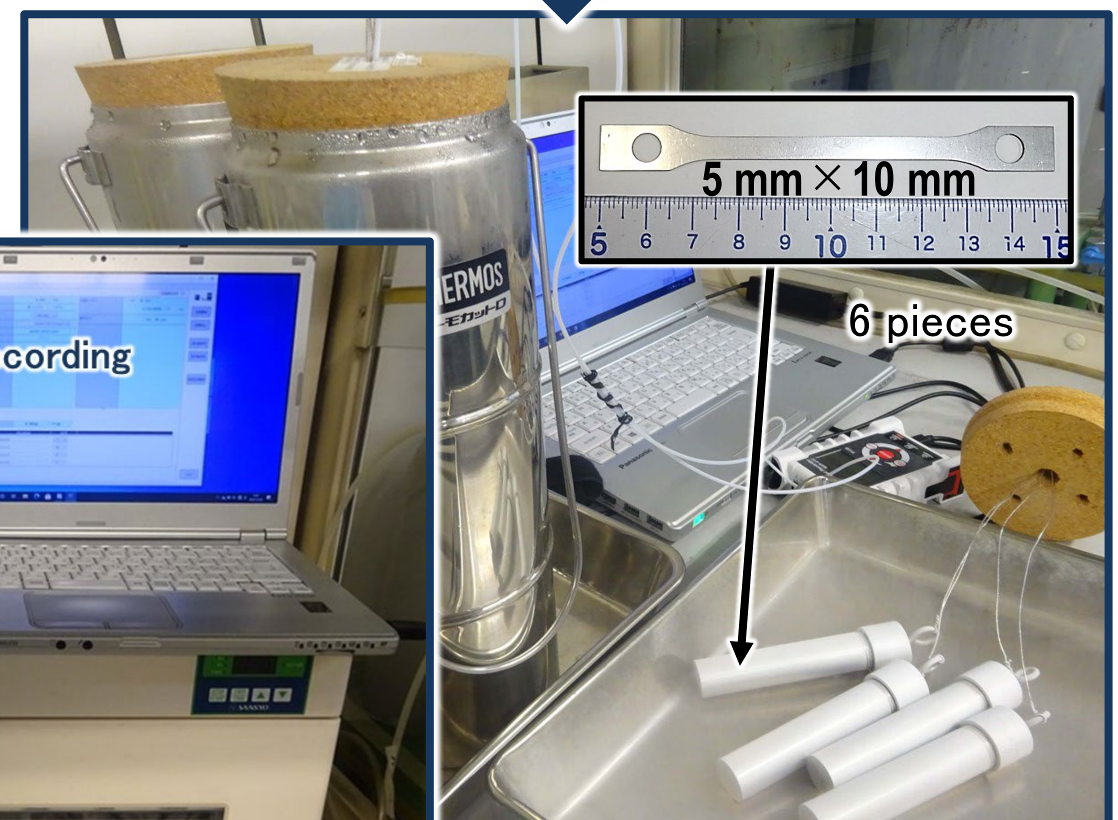
5 mm-square test piece
for structure observation and surface hardness evaluation

Tensile test piece
for stress / strain characterization

Cold heat shock test: LN (-196 ℃) immersion ⇔ Reheating at room temperature

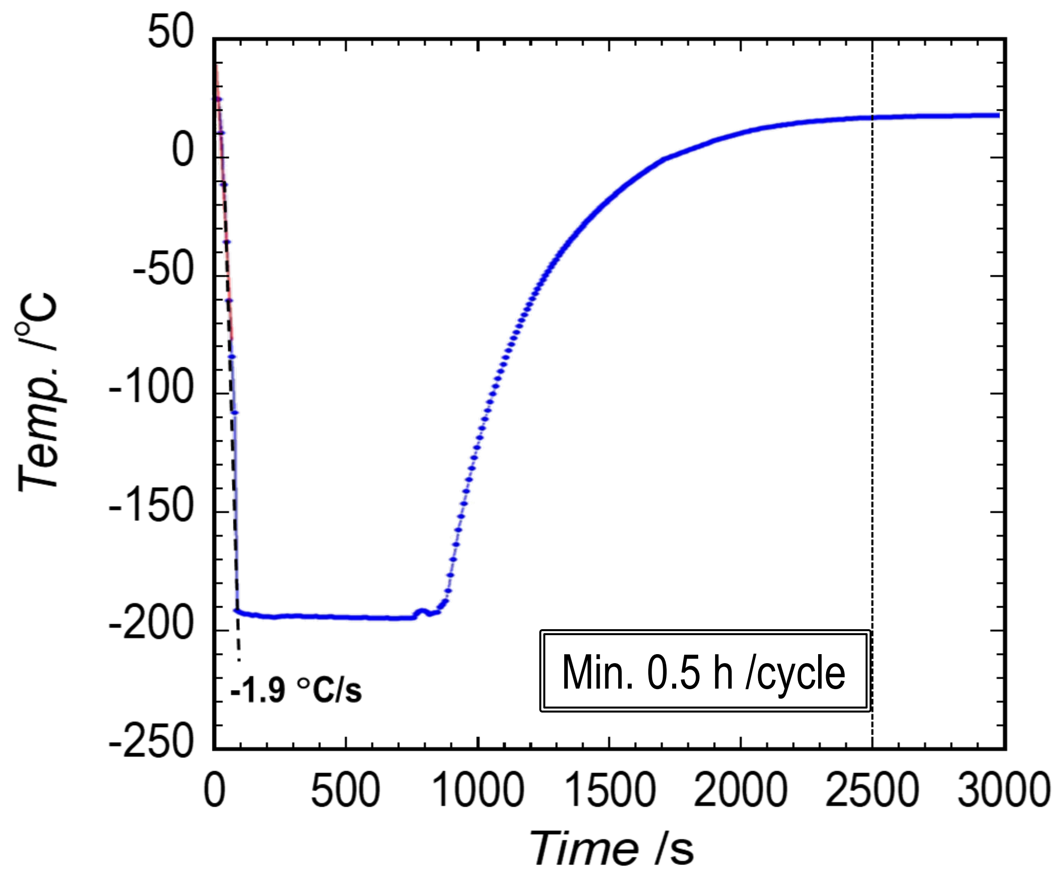






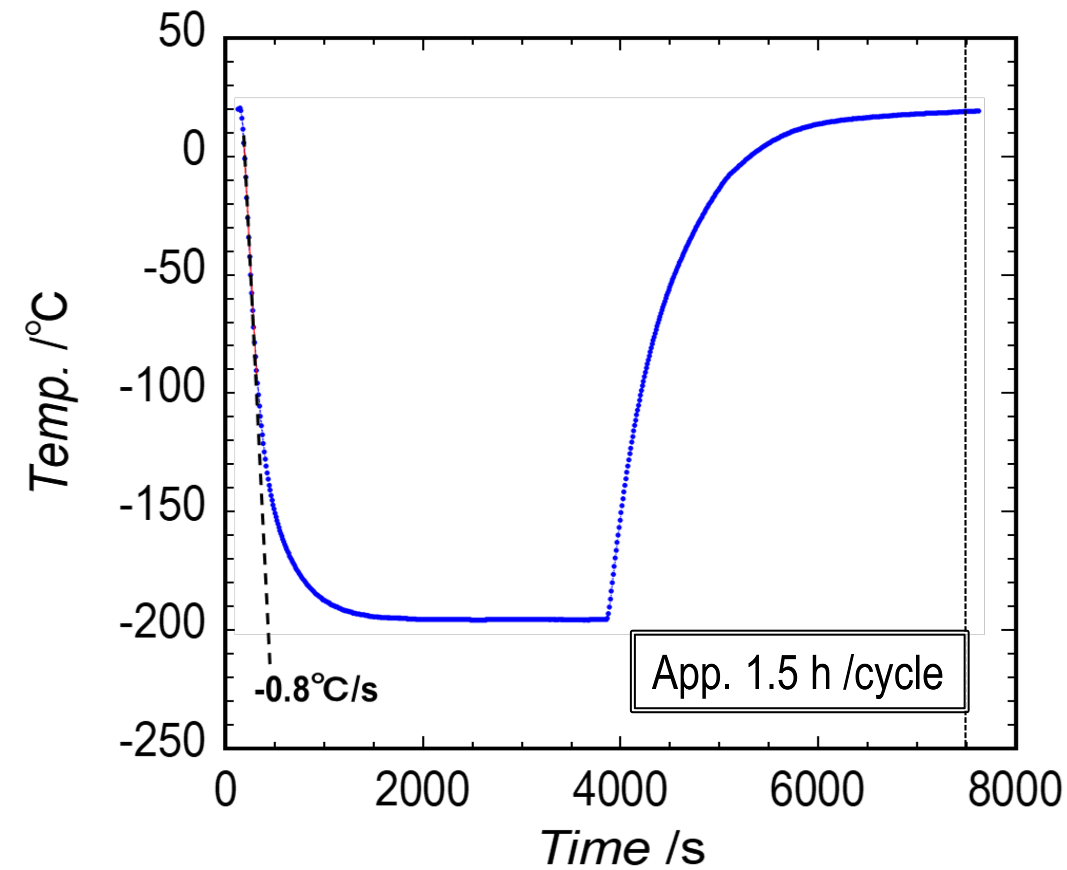
【Objectives ①】Evaluation method》Cold-heat shock test

5 mm-square test piece
for structure observation and surface hardness evaluation



Steel type	Number of tests /cycle	
SUS304	1000	2000
SUS304L	1000	2000
SUS316	1000	2000
SUS316L	1000	2000

Tensile test piece
for stress / strain characterization

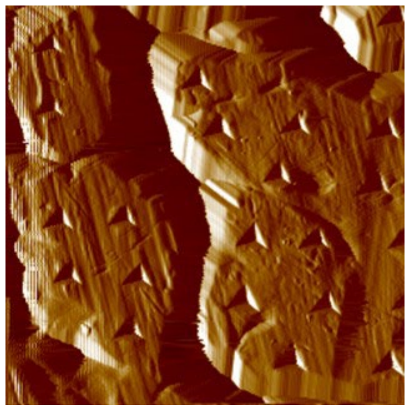


Steel type	Number of tests /cycle	
SUS304	510	1000
SUS304L	510	1000
SUS316	510	1000
SUS316L	510	1000

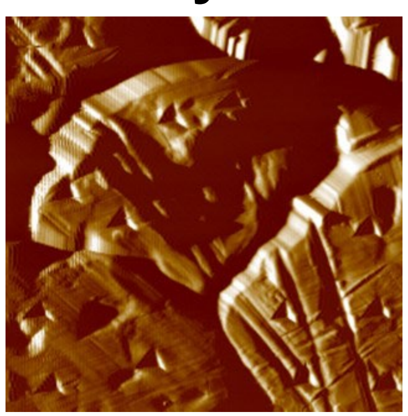
【Objectives ①】 Result of hardness measurement

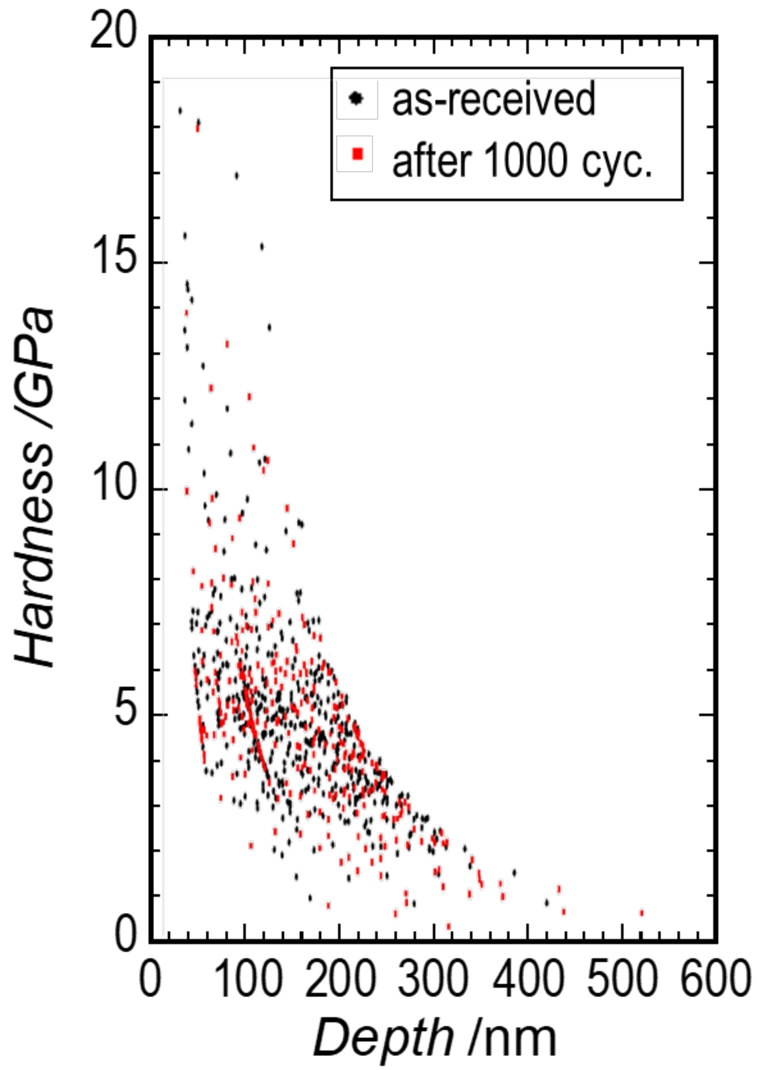
SUS304 (5 mm-square test piece)

as-received



After 1000 cyc. test



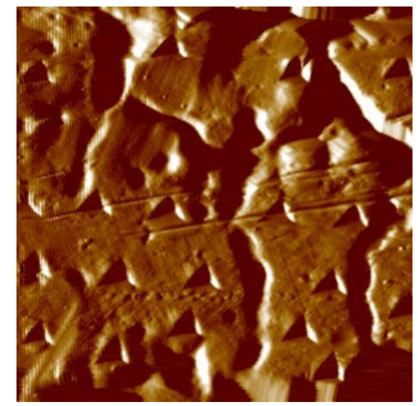


Steel type	Ave. hardness /GPa	Standard deviation
as-received	5.0	2.3
after 1000 cyc.	4.8	2.2

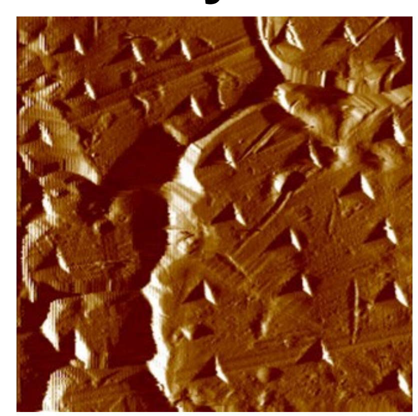
No significant difference in surface hardness

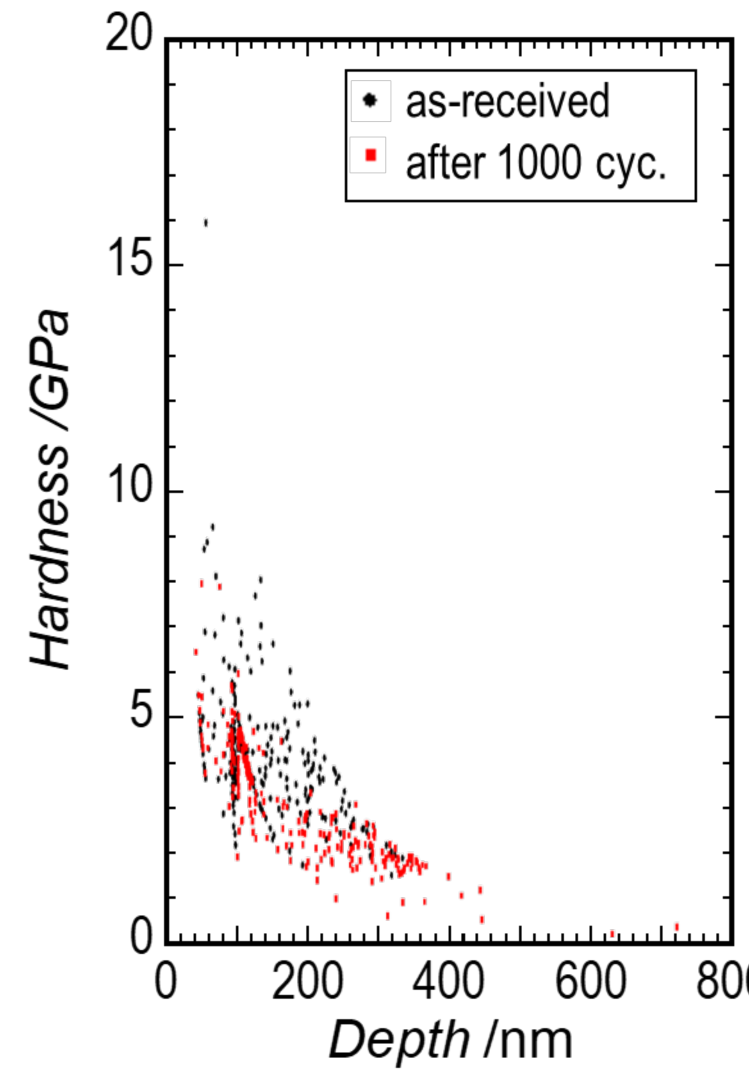
SUS316L (Tensile test piece)

as-received



After 1000 cyc. test





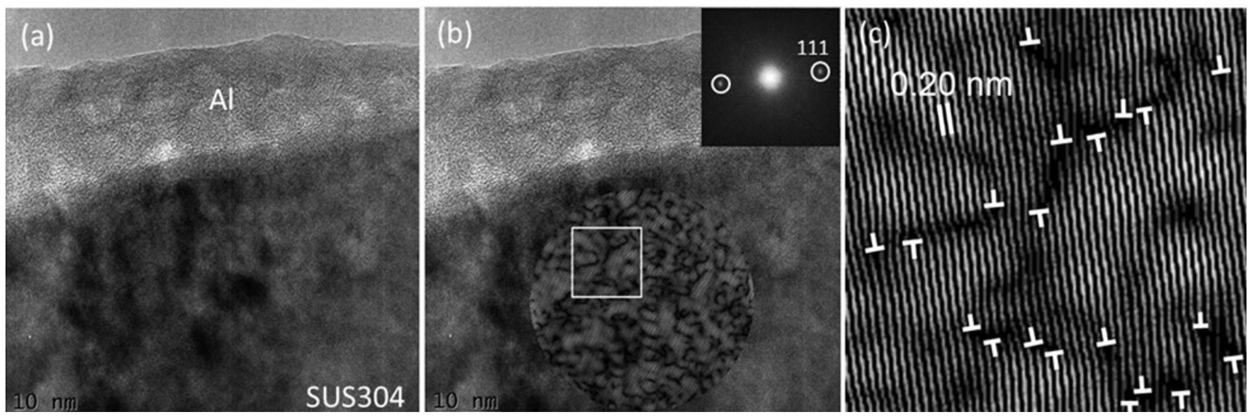
Steel type	Ave. hardness /GPa	Standard deviation
as-received	4.1	1.4
after 1000 cyc.	3.2	1.3

Significant reduction in surface hardness

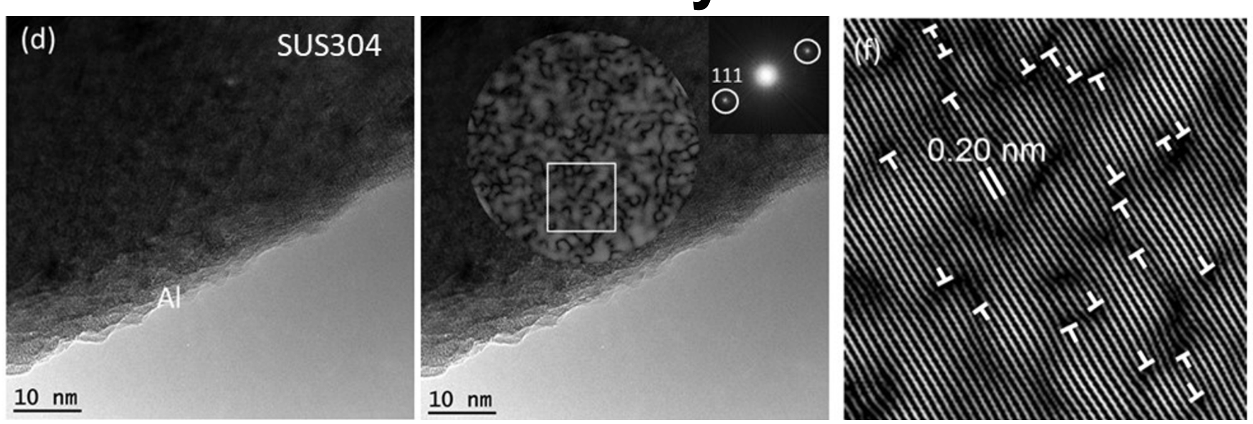
【Objectives ①】 Observation of cross section TEM

SUS304 (5 mm-square test piece)

as-received



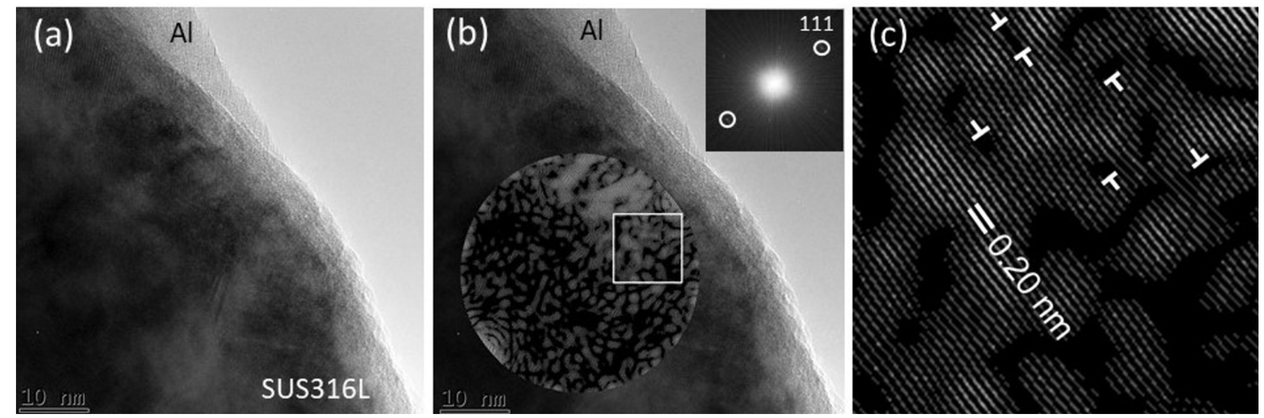
After 1000 cyc. test



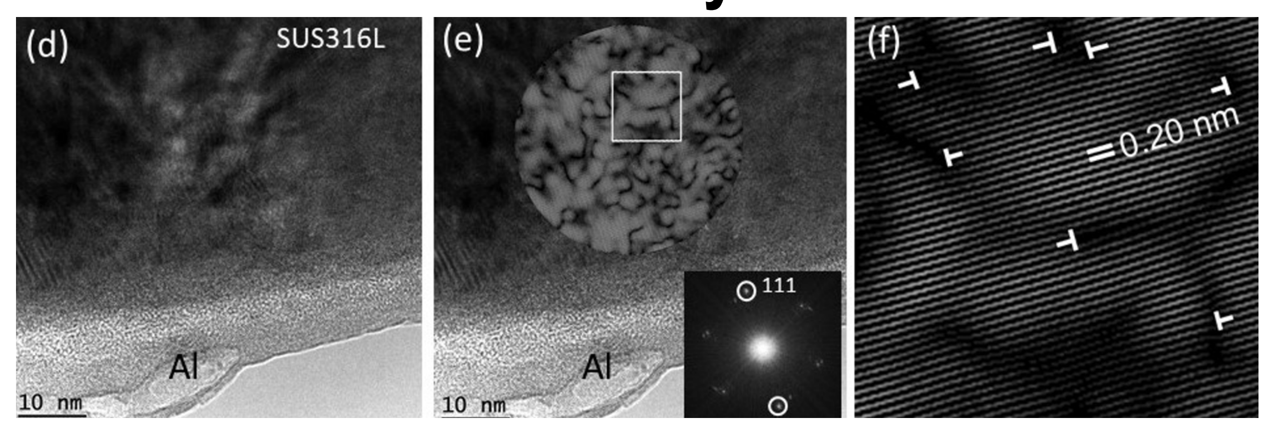
No significant difference in metallic structure

SUS316L (Tensile test piece)

as-received



After 1000 cyc. test



Significant reduction in dislocation density

Cold–heat shock resistance (~1000 cycle): SUS304 > SUS316L

Tens of thousands of cycles ⇒ Prediction of 25-year repeatability

Summary

・We have developed a screening evaluation system for materials that can withstand cold-heat shock
(-162℃⇔ room temperature)

・The surface hardness and microstructure of <u>SUS304</u>
(a versatile, low-cost steel material that can withstand -196 ℃)
did not change after 1000 cycles of cold thermal shock
⇒ Good candidate as structural materials suitable for the frame of heat exchangers (sublimation tanks)?

Development of equipment for low temperature fatigue testing under constant tensile stress

⇒ Carry out tens of thousands of low temperature fatigue tests on SUS-based steels

⇒ ⇒ Prediction of 25-year repeatability