Assessing Hydrogen Embrittlement

- Advanced Material Testing Methods -

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KOBE MATERIAL TESTING LABORATORY GROUP

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Aiming for realizing a hydrogen-based energy society

Hydrogen energy Production → Transport Storage → Utilization

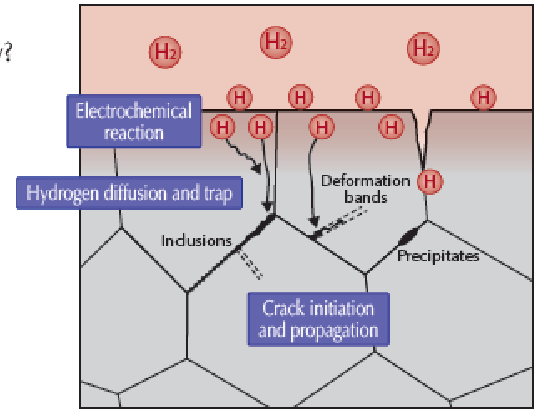
Design-related issue

- Is it appropriate to apply conventional design criteria?
- Is design consideration for hydrogen impact necessary?

Concern in structural design

Hydrogen embrittlement

Solute hydrogen diffuses into metallic materials, leading to a decrease in various strength properties.



- Delayed fracture
- Ductility loss
- Degradation of fatigue life and fatigue limit
- Acceleration of fatigue crack growth
- Decrease in fracture toughness

To evaluate the hydrogen compatibility of metallic materials, material testing in hydrogen environments is essential and indispensable.

Technical obstacles

- Handling hydrogen gas, which is flammable, requires knowledge and strict adherence to scientific safety measures.
- Material testing in hydrogen gas environments necessitates extensive explosion-proof facilities, resulting in significant costs.
- High expenses for outsourcing material testing services also pose obstacles to the development of a hydrogen energy society.

Hydrogen-gas sealed hollow type specimen

- Conventional material test in hydrogen-gas-environments

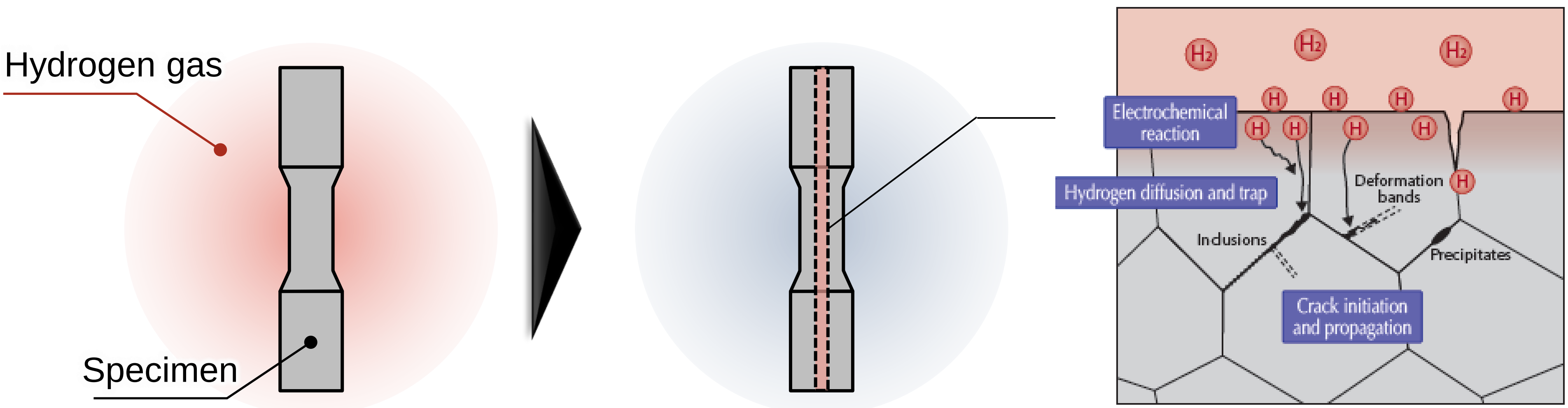
  ⇒ Testing conducted using a testing machine equipped with a large-capacity pressure vessel

  Safety/cost issues

- Principle of conventional basic testing

  ⇒ Creating hydrogen environment surrounding a solid specimen.

  Testing with a hollow type specimen enables the creation of a testing environment with a small amount of hydrogen.



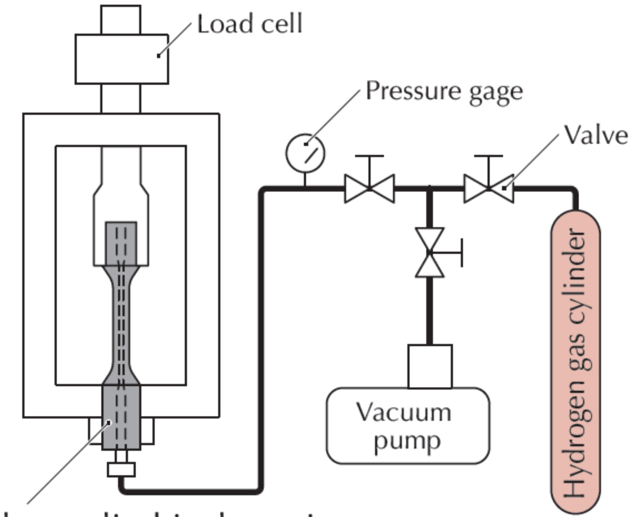
Solid sepcimen **Hollow type specimen** Surface condition of specimen exposed to hydrogen gas

Strength testing using hydrogen-gas sealed hollow specimen

Benefits 1 — Strength testing while exposing the material's surface to hydrogen gas.

Benefits 2 — Minimal amount of hydrogen gas, ensuring safety even if gas diffuses outside the test specimen.

Benefits 3 — Budget-friendly solutions integrated with KMTL's core testing technology for various testing needs.

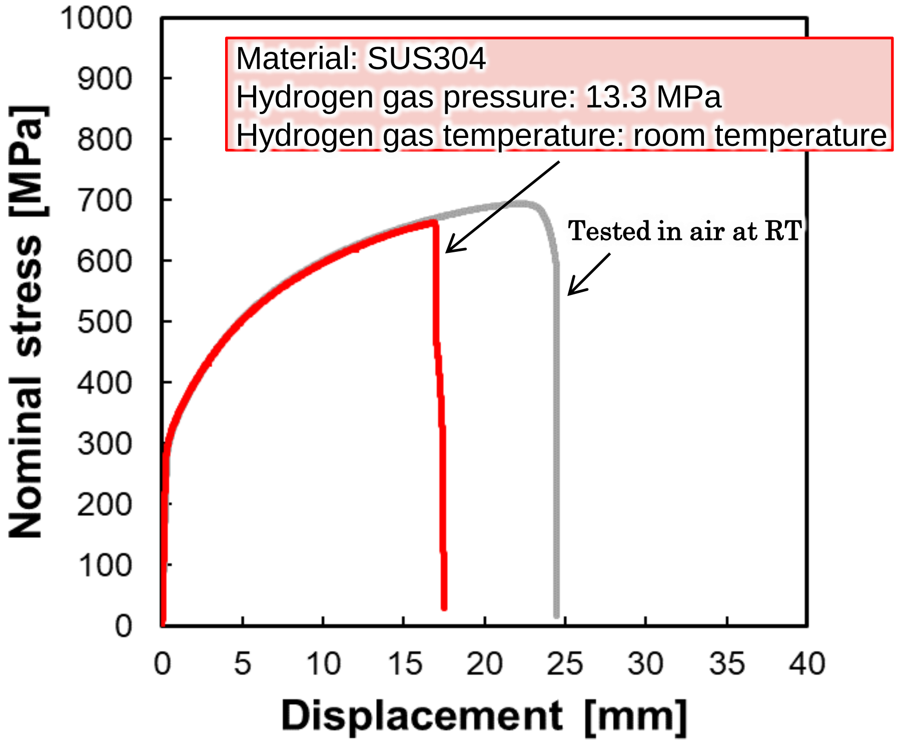


Our lineup for hydrogen material testing services

Specimen	Test	Pressure (MPa)		Temperature (℃)	
		Min.	Max.	Min.	Max.
Hollow	SSRT (Slow strain-rate test)	0.1	13.5	23	200
	Creep	0.1	13.5	23	200
	LCF (Low-cycle fatigue)	0.1	13.5	23	500
	HCF (High-cycle fatigue)	0.1	13.5	23	500

SSRT Test using hydrogen-gas sealed hollow type specimen

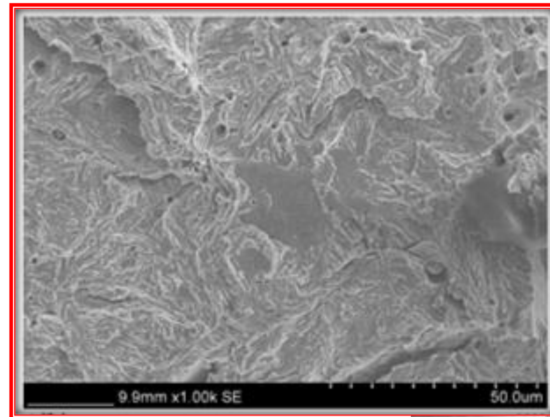
G.L. = 24 mm
Inner diameter = 2 mm
Outer diameter = 6 mm
CHS: 0.002 mm/sec



	Tensile strength (MPa)	RTS	Elongation (%)	REL	Reduction of area (%)	RRA
Air	695	0.95	78	0.62	71	0.65
Gaseous hydrogen	663		48		46	

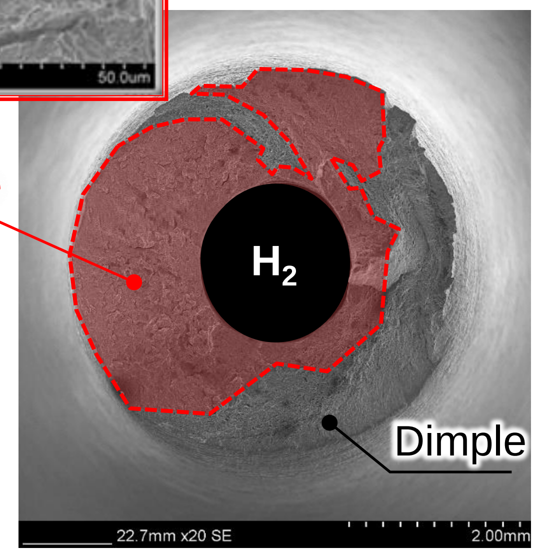
- Test result

SUS304 exhibited reduced tensile strength, elongation at fracture, and reduction of area due to hydrogen effect.



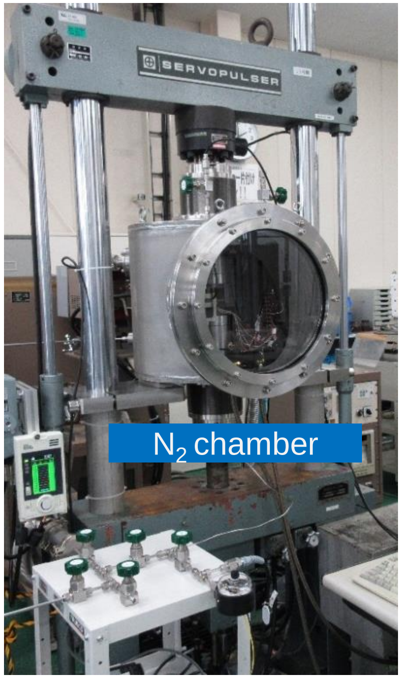
Quasi-Cleavage

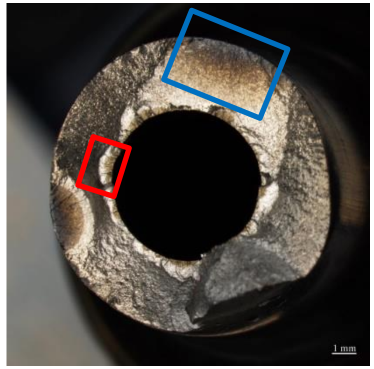
Fracture surface resulted from crack initiation at the hydrogen-exposed specimen inner surface and subsequent propagation

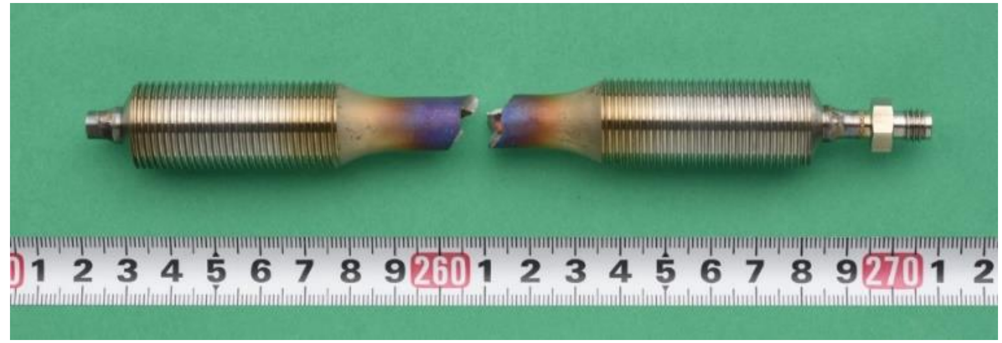


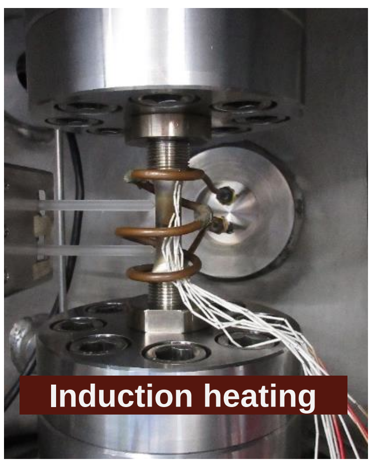
Fracture surface obtained in 13.3 MPa hydrogen gas

Low-cycle fatigue (LCF) test in 9.3 MPa hydrogen gas at 500℃









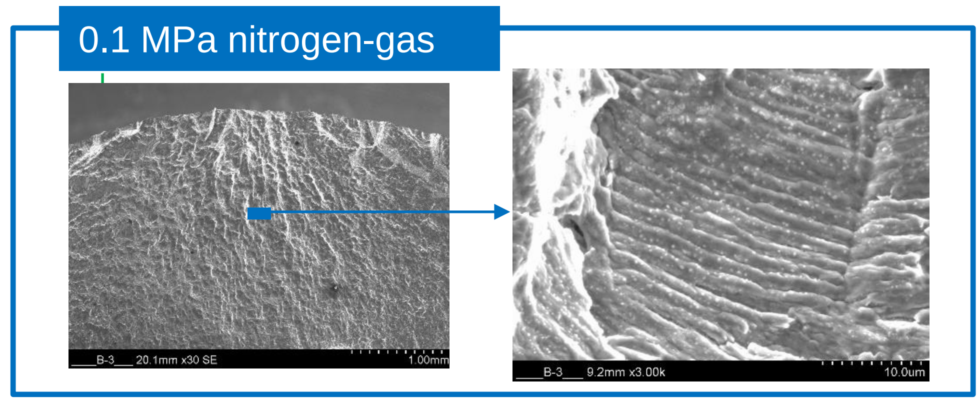
- Type 304 stainless steel
  Outer diameter 12 mm
  Inner diameter 6 mm

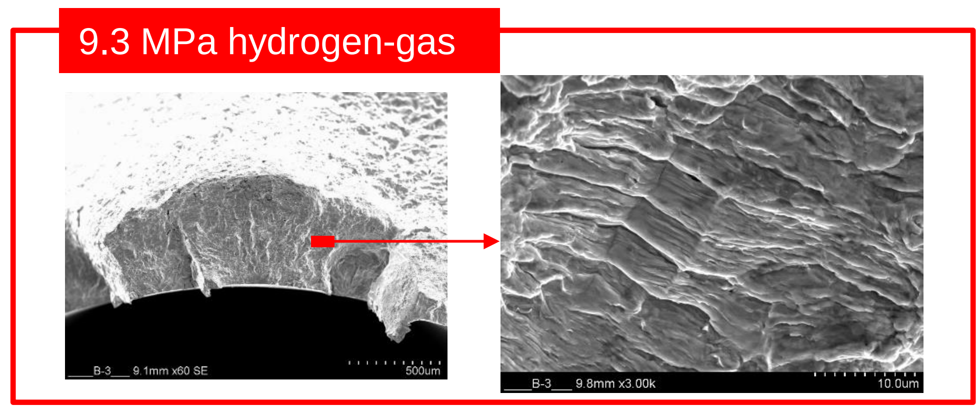
- Temperature 500℃

- Internal atmosphere 9.3 MPa H_2
- External atmosphere 0.1 MPa N_2

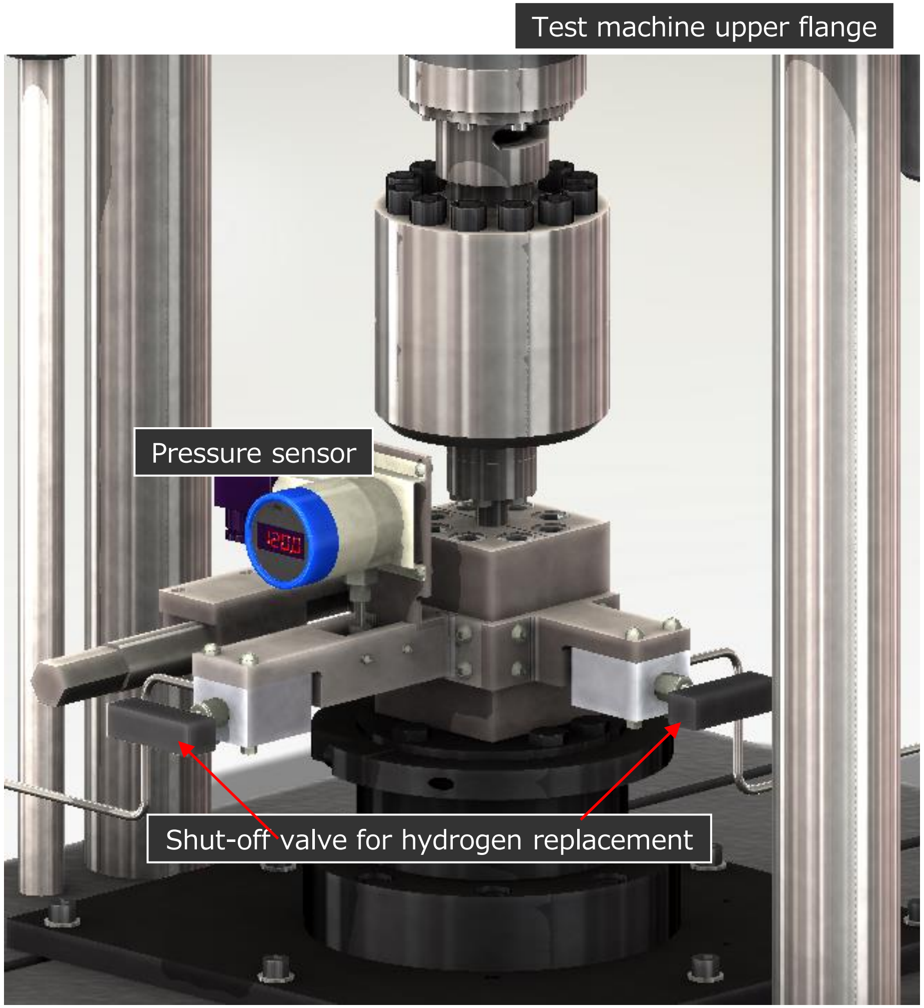
- Stress ratio R =−1
- Waveform Triangle
- Total strain $\Delta\varepsilon_t$ = 1.0 %
- Test speed 0.1%/sec

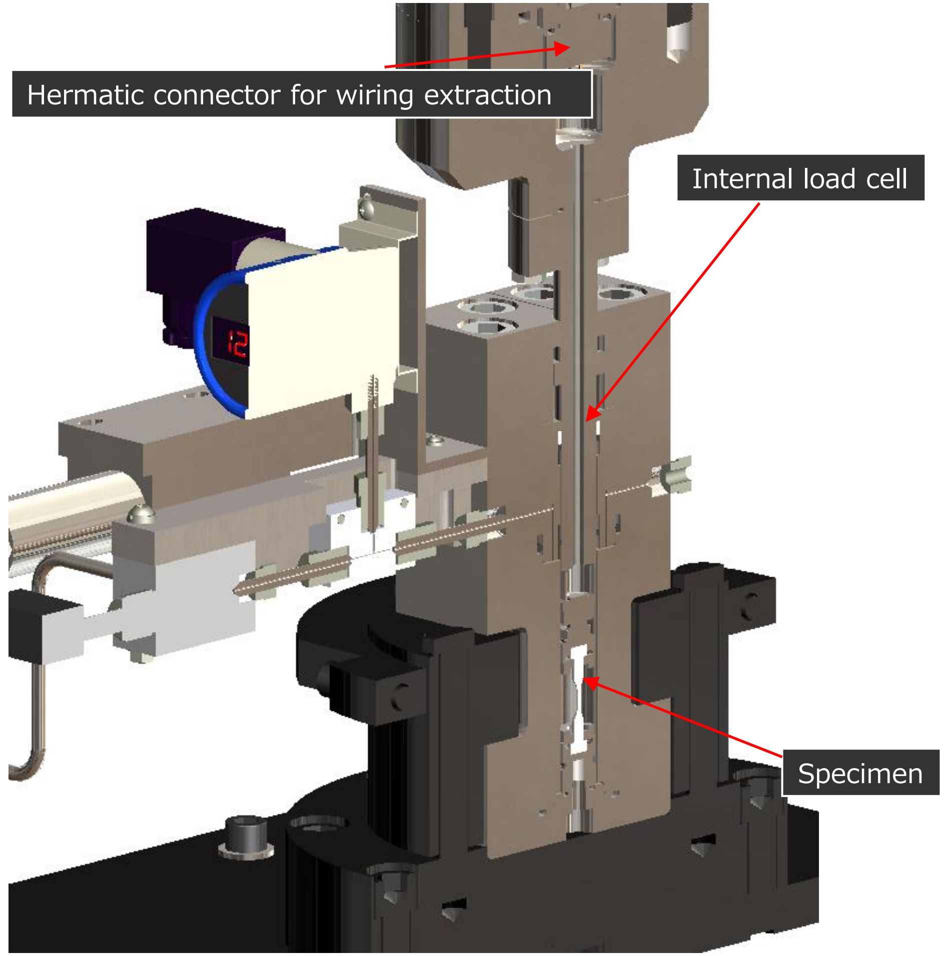
- Number of cycles to failure
  N_f = 7,289 cycles





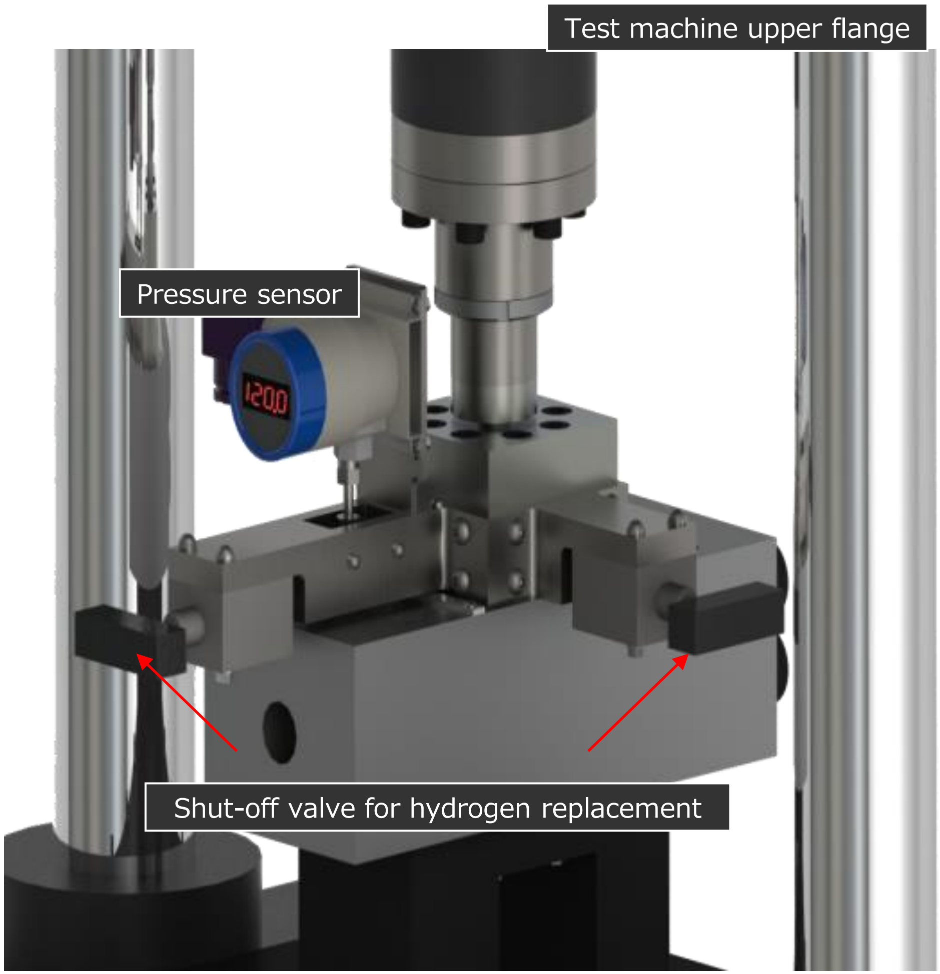
Miniature testing technique｜
120MPa-class ultra-high-pressure hydrogen gas environment testing machine

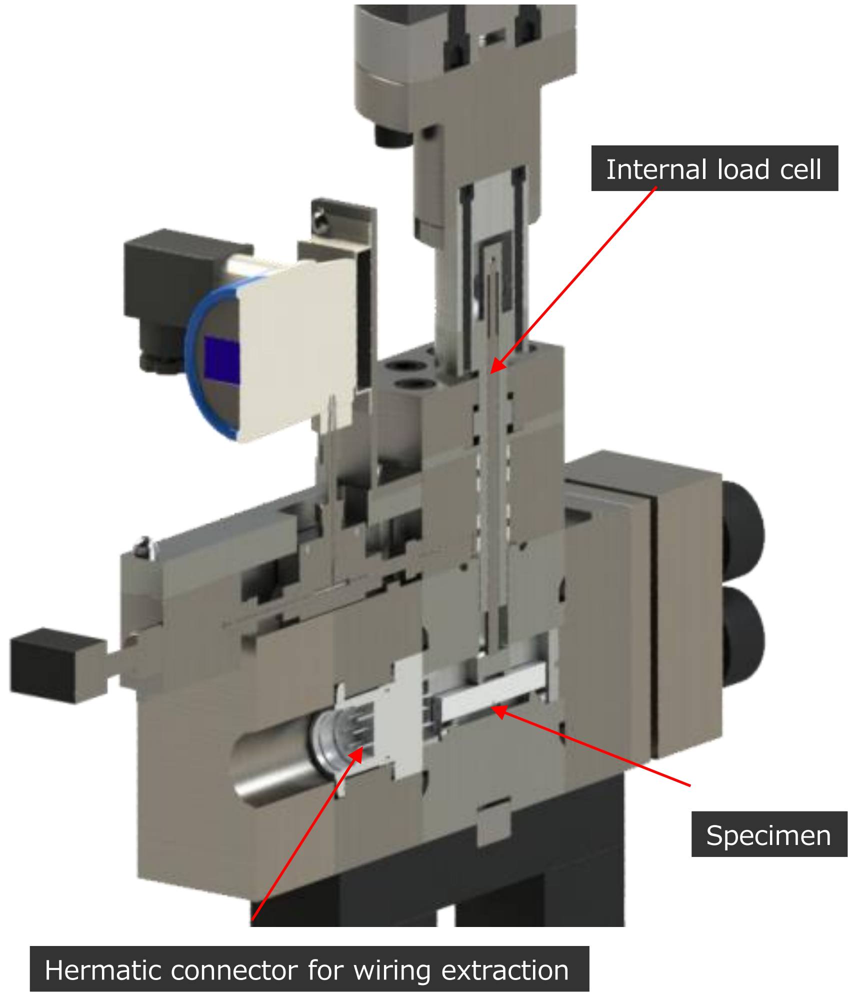




- Max. operating pressure **120MPa**
- Pressurized volume **30cc**

Miniature testing technique |
120MPa-class ultra-high-pressure hydrogen gas environment testing machine





- Max. operating pressure **120MPa**
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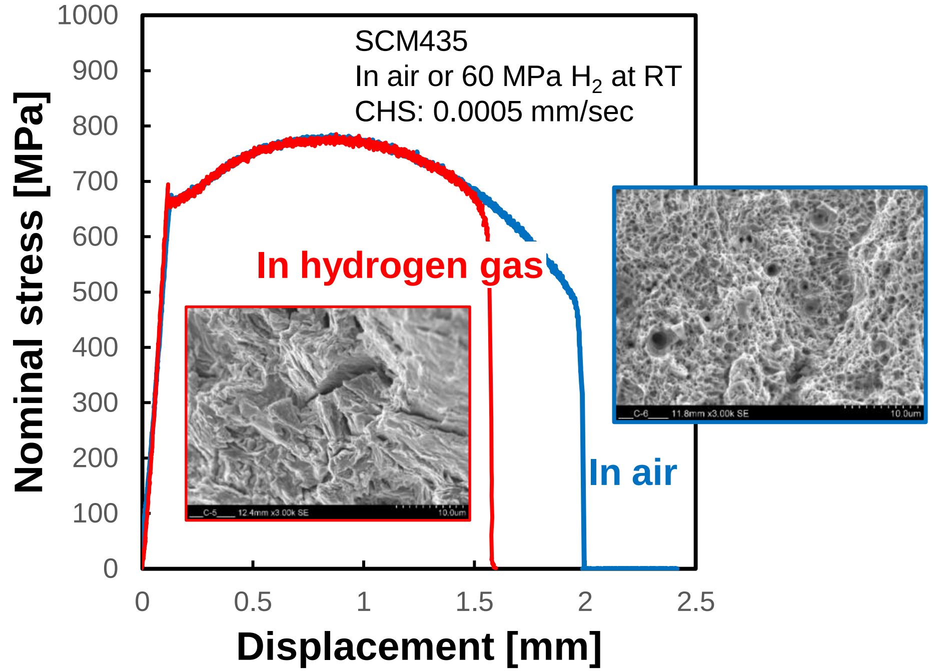
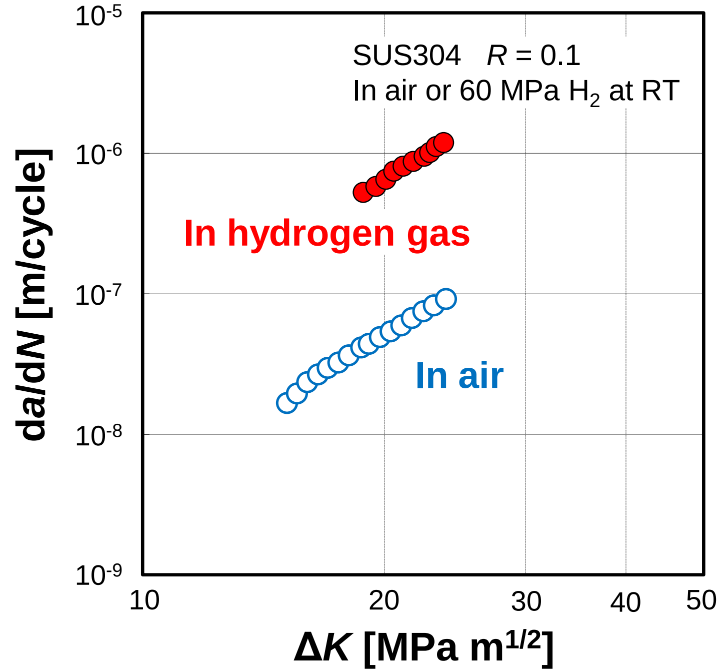
SSRT and fatigue crack growth testing using miniature specimen



Result of SSRT testing in high-pressure hydrogen gas at room temperature

	σ_B (MPa)	Elongation (%)	REL (%)	Reduction of area (%)	RRA (%)
Air	793	20	-	66	-
60 MPa H_2	786	15	0.78	46	0.70



Result of fatigue crack growth testing at room temperature

Material: SUS304

Fatigue crack growth rate increased approximately ten times in 60 MPa hydrogen gas at room temperature.

Thank you for your time

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