Current status of round-robin tests for hydrogen material compatibility

Transmitted by Japan

6th Meeting of the informal working group on GTR No.13 (Phase 2)
18-20 June 2019 @ CATARC, Tianjin, China

Participant institutes, material, and remaining bars

Started in 2015

Japan

HYDROGENIUS

Sandia National Laboratories — MPA Materialprüfungsanstalt Universität Stuttgart

USA **Germany**

Participation

KRISS

浙江大学 ZHEJIANG UNIVERSITY

Korea **China**

in 2019

φ25 mm × L500 mm × 12 bars

SUS316L (MPA)

Supplied numbers of bars

SNL	3 bars
MPA	2 bars
HYDROGENIUS	7 bars

Chemical composition and mechanical properties

Chemical composition（mass%）

Heat	C	Si	Mn	P	S	Ni	Cr	Mo	N
MPA	0.019	0.49	1.41	0.029	0.024	12.19	17.13	2.05	—
Require ment[1)]	≤0.03	≤1.00	≤2.00	≤0.045	≤0.030	12.00 ~ 15.00	16.00 ~ 18.00	2.00~ 3.00	—

1) JIS G 4303 (1981), "Stainless steel bars"

$Ni_{eq} = Ni + 12.6C + 0.35Si + 1.05Mn + 0.65Cr + 0.98Mo = 27.2$ mass%

Mechanical properties

Heat	$\sigma_{0.2}$ [MPa]	σ_B [MPa]	Elongation [%]	RA [%]	*HBW*
MPA	245	551	60	78	141
Requirement[1)]	≥175	≥480	≥40	≥60	≤167

1) JIS G 4303 (1981), "Stainless steel bars"

Test procedures of round-robin test

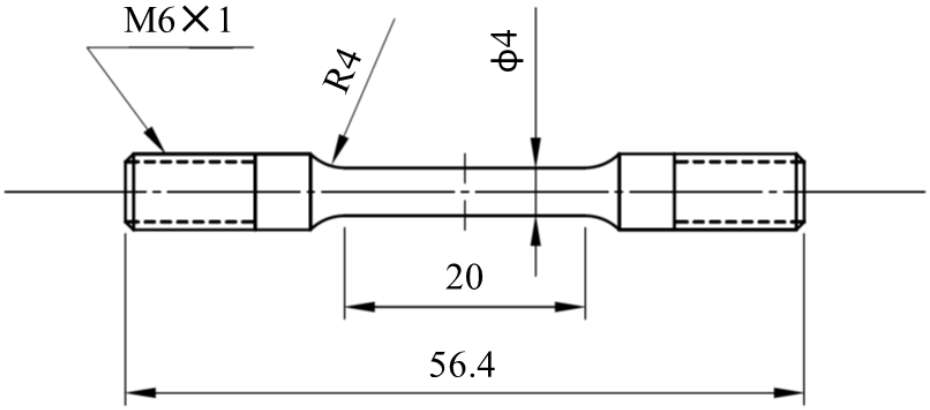
Test condition and required numbers of specimens for each test

Test	Environment	Condition	Number of specimens
SSRT at -40°C	0.1-MPa N_2 gas	5×10^{-5} /s	3
	90-MPa H_2 gas		3
Notch fatigue at R = 0.1 at -40°C	0.1-MPa N_2 gas	1Hz, σ_a=200 MPa σ_{max}=444 MPa, σ_{min}= 44 MPa	3
	90-MPa H_2 gas		3
Smooth fatigue at R = -1 at -40°C	0.1-MPa N_2 gas	1Hz, σ_a=320 MPa σ_{max}=320 MPa, σ_{min}= -320 MPa	3
	90-MPa H_2 gas		3

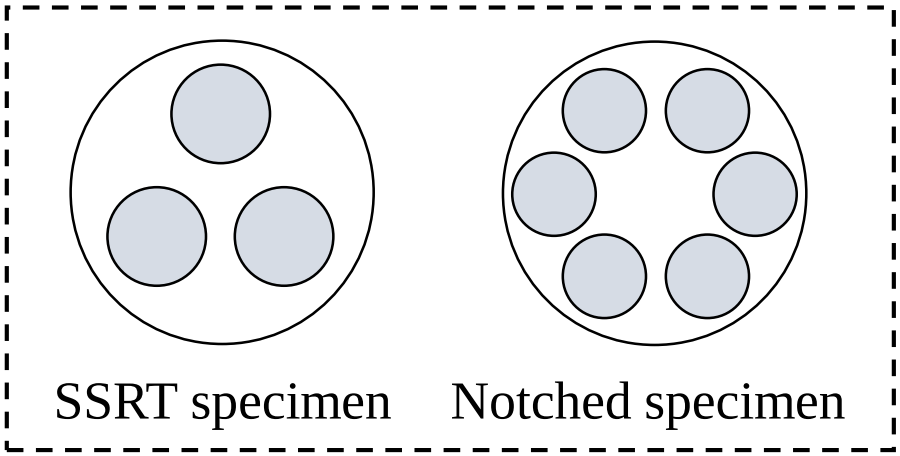
Manufacture of specimens

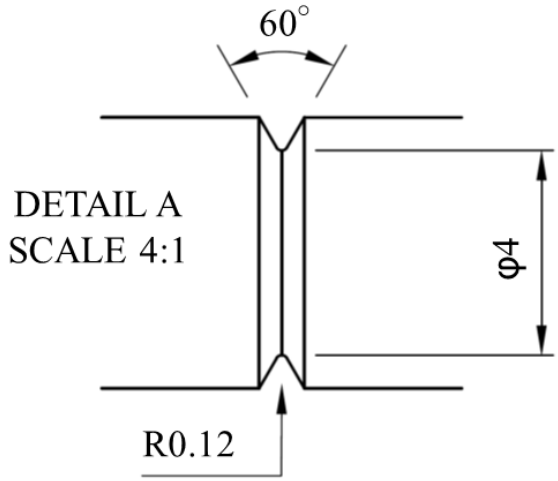
- The SSRT specimen was manufactured by MPA.
- The circumferentially-notched specimen was manufactured by SNL.
- The smooth, round-bar specimen was manufacture by HYDROGENIUS.

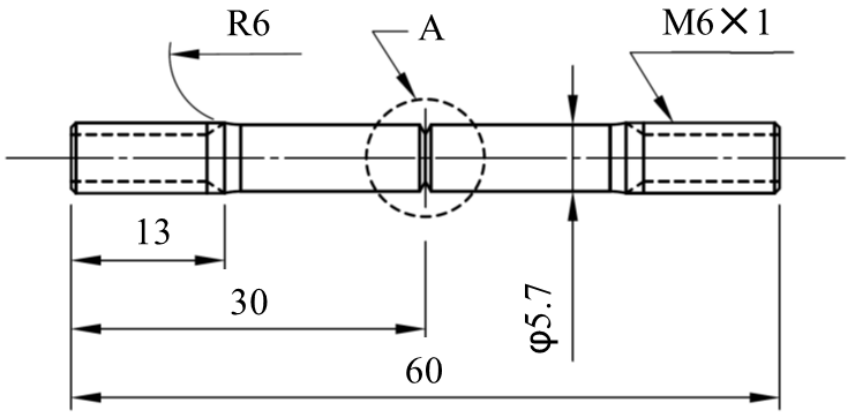
Specimen geometries（SSRT and notched specimens)



SSRT specimen
(MPA, ASTM E8 Specimen 4)



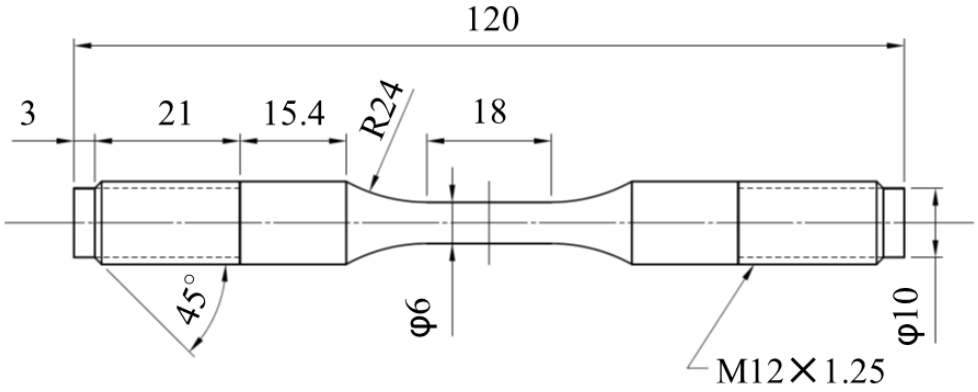




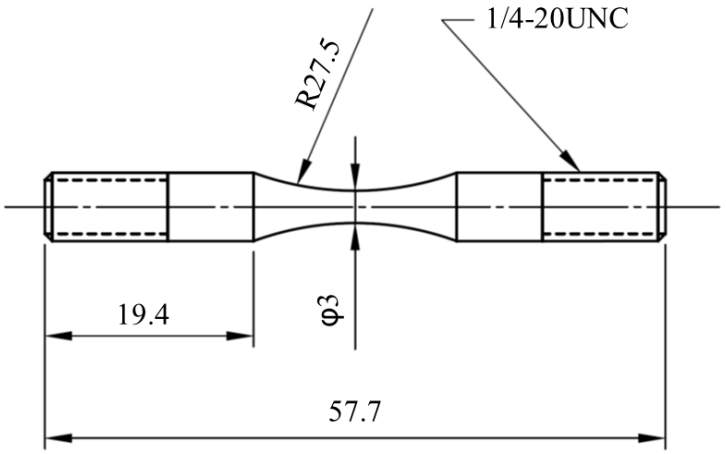
Circumferentially-notched specimen
(SNL, K_t=4.1)

Specimen geometries（smooth, round-bar specimens)

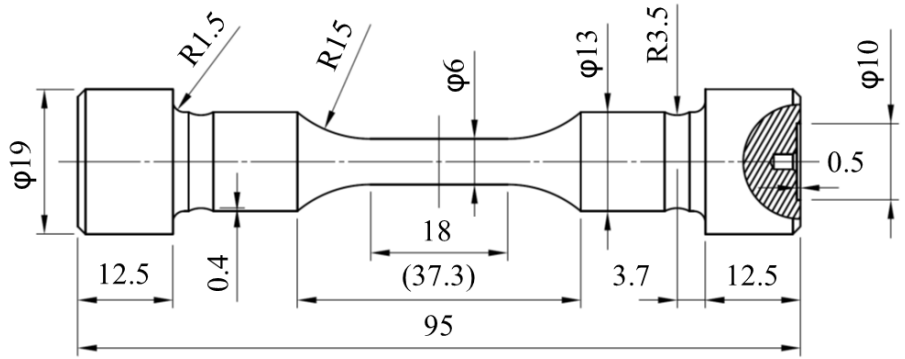
MPA

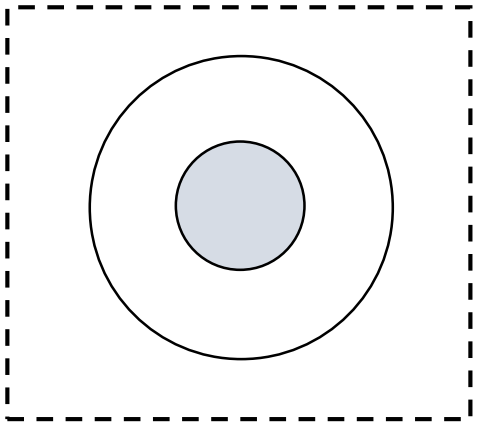


SNL



HYDROGENIUS

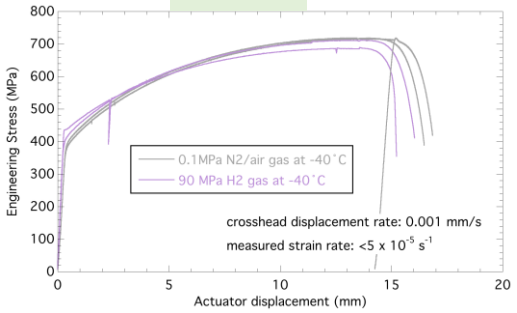




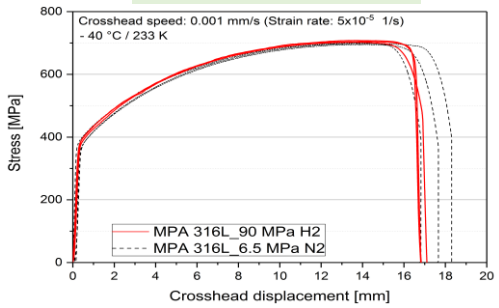
Smooth, round-bar specimens (manufactured by HYDROGENIUS)

Results of SSRT test (comparison SNL, MPA Stuttgart and HYDROGENIUS)

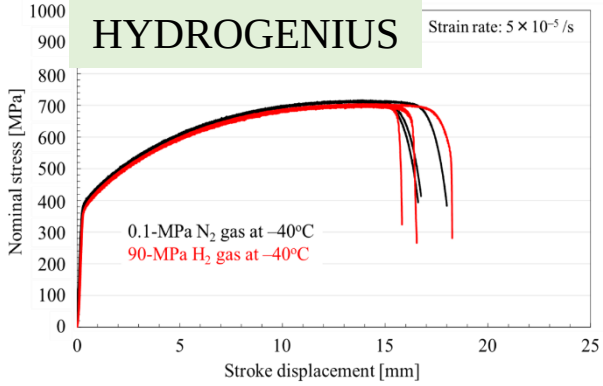
SNL



MPA Stuttgart



HYDROGENIUS

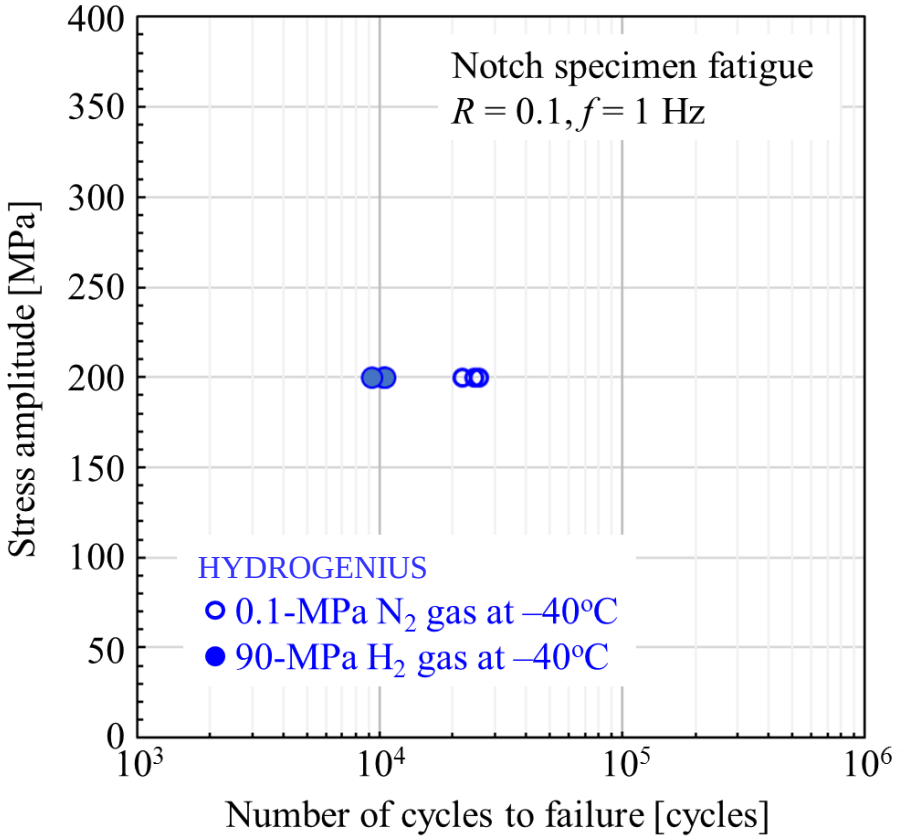


Test environment	Tensile strength [MPa]			Elongation [%]			Reduction in area [%]		
	SNL	MPA Stuttgart	HYDRO GENIUS	SNL	MPA Stuttgart	HYDRO GENIUS	SNL	MPA Stuttgart	HYDRO GENIUS
0.1 MPa N_2 at -40° C (MPA:6.5MPa)	717	699	716	77	81.99	81	82	83.52	84
	719	696	716	77	87.95	84	83	85.6	83
	–	698	716	–	88.98	90	–	83.46	85
Average	718	698	716	77	86.3	85	83	84.19	84
90 MPa H_2 at -40° C	712※1	727	704	80※1	82.84	94	84※1	62.52	76
	689※2	729	703	76※2	79.95	79	69※2	60.77	66
	–	–	699	–	–	75	–	–	58
Average	701	728	702	78	81.40	83	77	61.65	67

(SNL) ※1 Pressure > 90 MPa
※2 Slightly overloaded prior to testing

◆ The experimental results from SNL. MPA Stuttgart and HYDROGENIUS were nicely consistent.

Results of notched specimen fatigue test (HYDROGENIUS)



Test data（HYDROGENIUS）

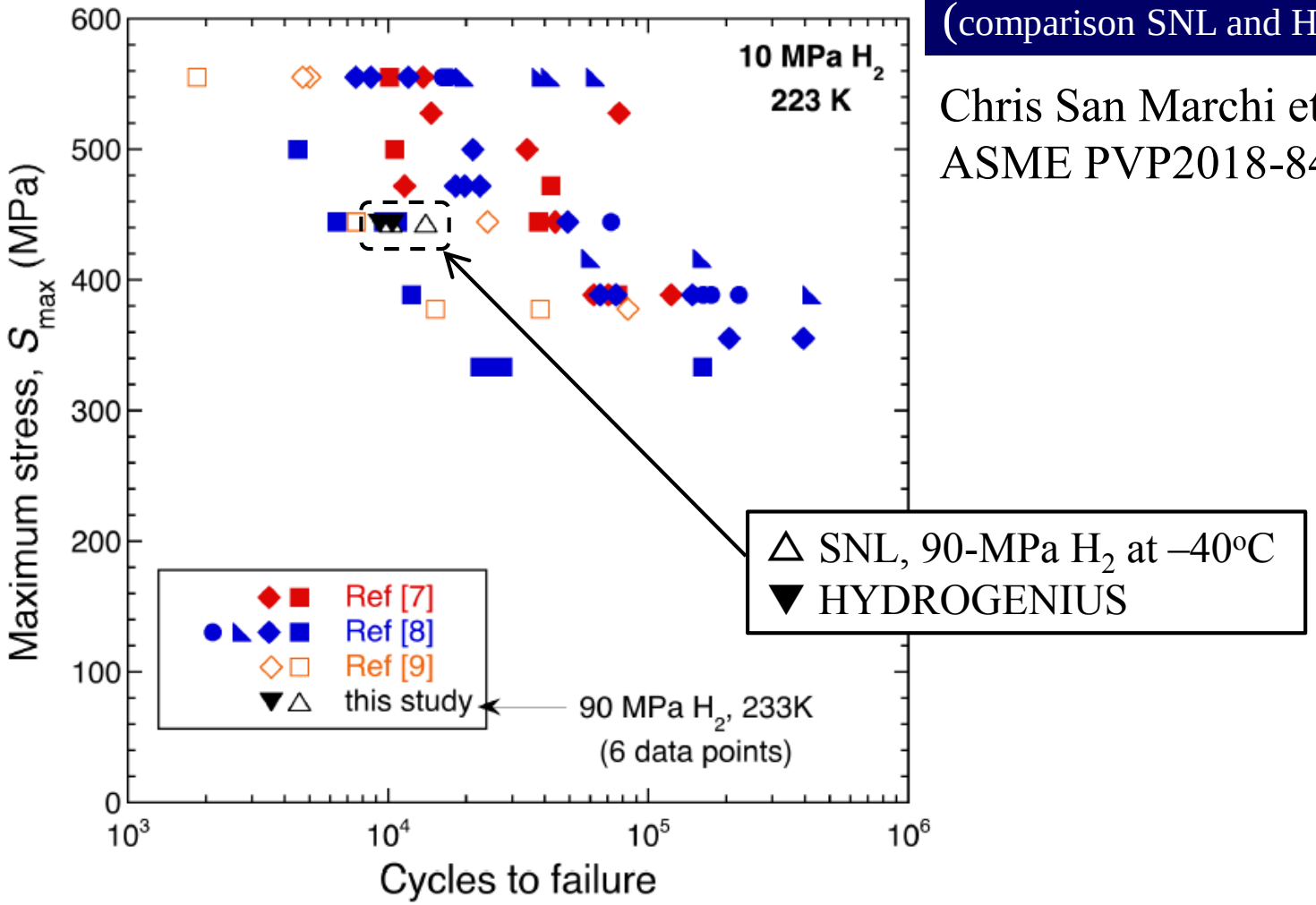
Test environment	Number of cycles to failure [cycles]
	Notch specimen fatigue : σ_a = 200 MPa, R = 0.1, f =1Hz
0.1-MPa N_2 gas at -40°C	2.20×10^4
	2.57×10^4
	2.44×10^4
90-MPa H_2 gas at -40°C	1.03×10^4
	1.04×10^4
	9.25×10^3

Notched specimen fatigue properties (HYDROGENIUS)

- In HYDROGENIS, all the tests (3 tests at each environment) were finished.
- At –40°C, the notch fatigue life was shorter in 90-MPa hydrogen gas than 0.1-MPa nitrogen gas.

Results of notched specimen fatigue test

(comparison SNL and HYDROGENIUS)

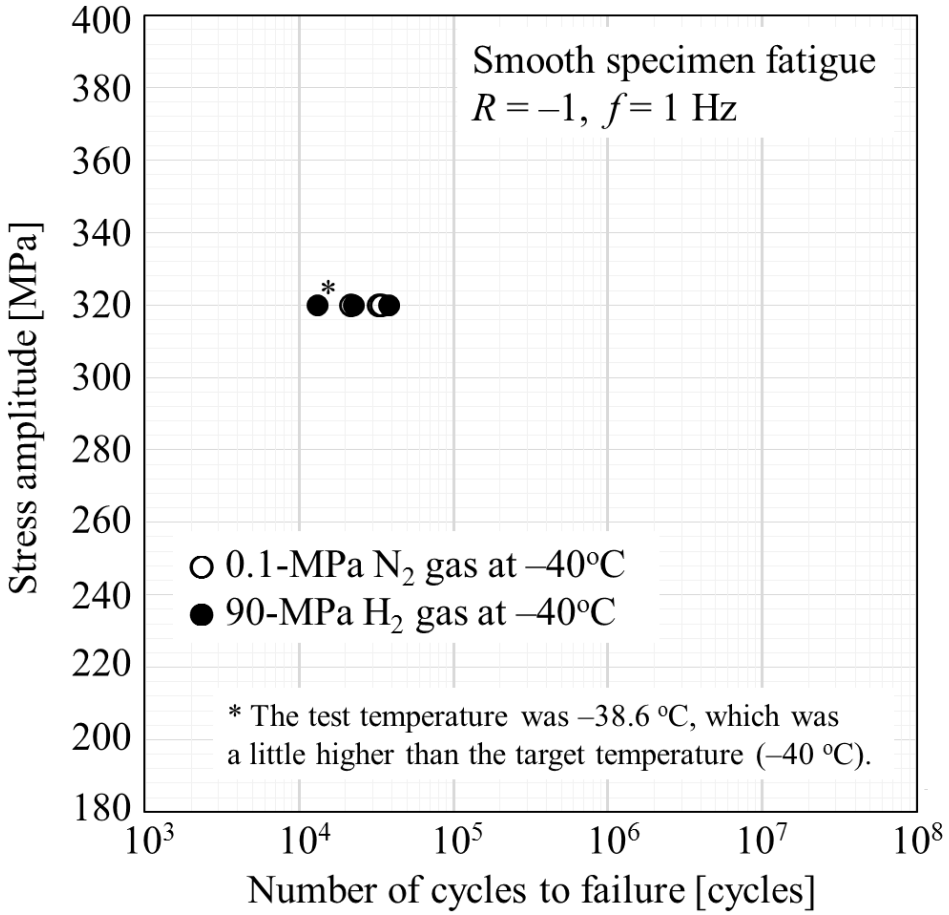


Chris San Marchi et al.,
ASME PVP2018-84898

Notched specimen fatigue properties (SNL and HYDROGENIUS)

- In SNL, 3 tests in 90-MPa hydrogen gas were finished.
- The experimental results from SNL and HYDROGENIUS were nicely consistent.

Results of smooth specimen fatigue test (HYDROGENIUS)



Smooth specimen fatigue properties (HYDROEGNIUS)

Test data (HYDROGENIUS)

Test environment	Number of cycles to failure [cycles]
	Smooth specimen fatigue : σ_a = 320 MPa, R = -1, f =1Hz
0.1-MPa N_2 gas at -40°C	3.29×10^4
	2.17×10^4
	3.41×10^4
90-MPa H_2 gas at -40°C	2.26×10^4
	1.31×10^4 *
	3.83×10^4

◆ In HYDROGENIS, all the tests (3 tests at each environment) were finished.

Summary of current status of round-robin test

Current status of round-robin test

Institute	Environment	SSRT	Notched specimen fatigue	Smooth specimen fatigue
SNL	H_2	2	3 (finished)	(declined)
	Inert	2	0	(declined)
MPA Stuttgart	H_2	2	0	0
	Inert	3 (finished)	0	0
HYDRO GENIUS	H_2	3 (finished)	3 (finished)	3 (finished)
	Inert	3 (finished)	3 (finished)	3 (finished)

Plan of round-robin tests

- At China and Korea, notched specimen fatigue in H_2 gas (3 specimens) and smooth specimen fatigue in H_2 gas (at maximum, 3 specimens) will be expected.
- Supply the specimen for SSRT from MPA Stuttgart ※ Preferentially
- Supply the notched specimen from SNL
- Supply the raw material for the smooth specimen (φ25 × L275mm) from HYDROGENIUS. The specimen geometry of the smooth specimen can be determined at each institute.

Notch fatigue at R = 0.1 at -40°C	0.1-MPa N_2 gas	1Hz, σ_a=200 MPa σ_{max}=444 MPa, σ_{min}= 44 MPa	3
	90-MPa H_2 gas		3
Smooth fatigue at R = -1 at -40°C	0.1-MPa N_2 gas	1Hz, σ_a=320 MPa σ_{max}=320 MPa, σ_{min}= -320 MPa	3
	90-MPa H_2 gas		3

Schedule to be expected

1. Supply the specimen and raw material to China and Korea
   : will be Completed soon
2. Finished of Round Robin tests in H_2 gas : September, 2019 (hopefully)

Thank you for your kind attention