Tensile Tests for High Pressure Gas Safety Regulations

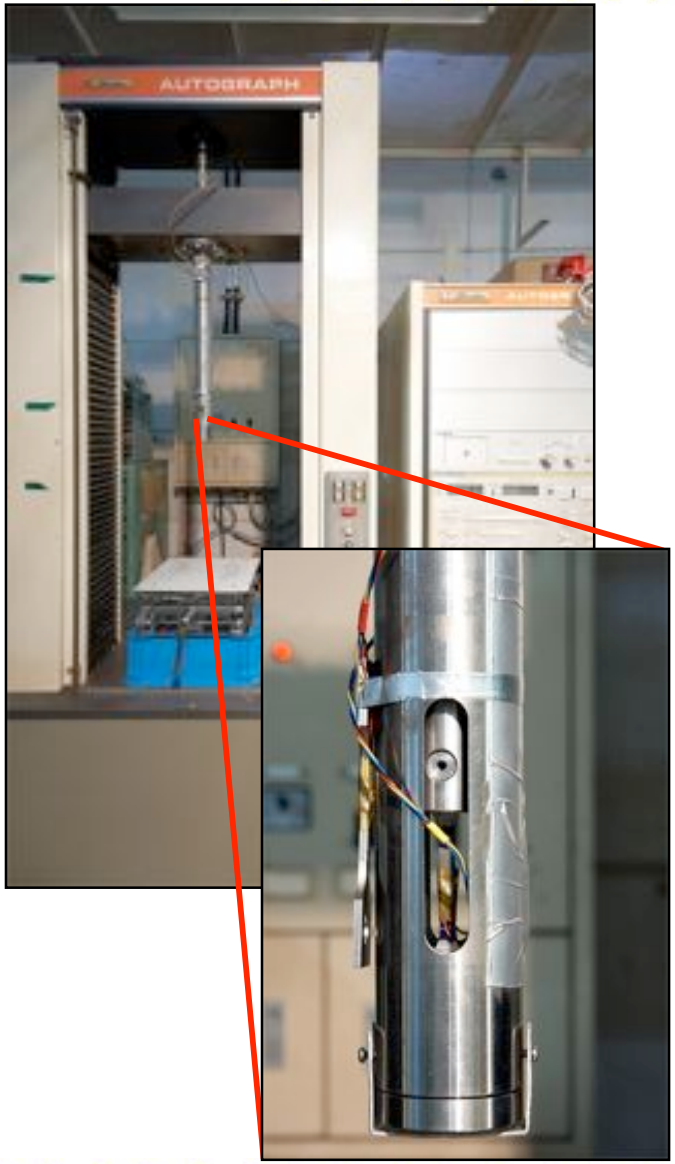
NAKAI Hirotaka
TERASHIMA Akio
(KEK)

20090601

Tensile Tests

- Acquired data
  - **Tensile strength**
  - **0.2% proof stress (if possible)**
  - **Modulus of elasticity**
  - **Elongation**
- Test temperatures
  - **Room temperature (300 K)**
  - **Liquid nitrogen temperature (77 K)**
  - **Liquid helium temperature (4.2 K)**
- Three (3) samples at least at each test temperature

Tests at Low Temperature



Cryostat for LHe

LN_2 Vessel

Tested Materials (1)

1. Nb – 2 specimen types
   - **JIS Type 7 (old standard)**
   - **JIS Type 13B (current standard)**
2. Ti – 2 companies
   - **Nippon Steel**
   - **Mitsubishi**
3. NbTi alloy

Tested Materials (2)

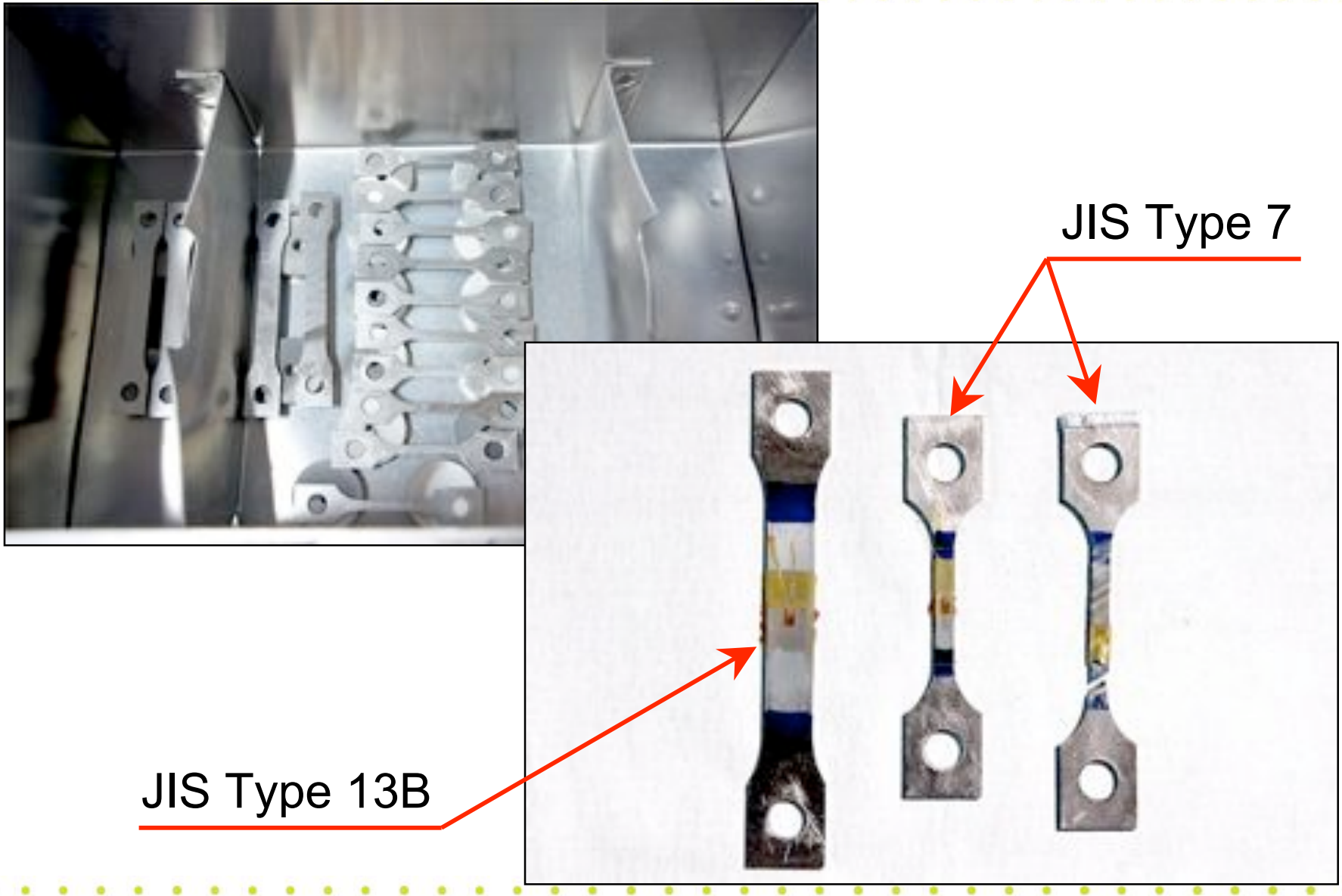
4. Nb-Nb joint (EBW)
5. Nb-Ti joint (EBW)
6. Ti-Ti joint (TIG welding) – 2 companies
   - **A company**
   - **Mitsubishi**
7. NbTi-Ti joint (TIG welding)
8. Nb-SS316L joint (HIP) – 2 companies
   - **Kuroki Composites**
   - **Kinzokugiken**

Test Samples (1)

- Sample shape: JIS Type 7 (old standard)
- Smallest sample shape of current standard: JIS Type 13B
  - **Type 13B bigger than Type 7**
  - **Test executable only at room temperature**

- See comparison of measured data of Nb

Test Samples (2)



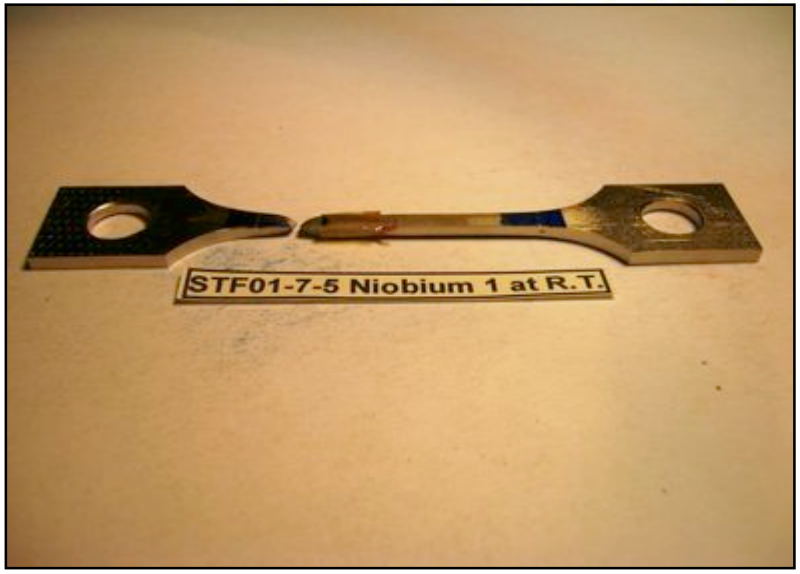
Annealing

- All samples containing niobium were annealed at 750 °C for 3 hours
  - **Nb**
  - **Nb-Nb joint**
  - **Nb-Ti joint**
  - **Nb-SS316L joint**

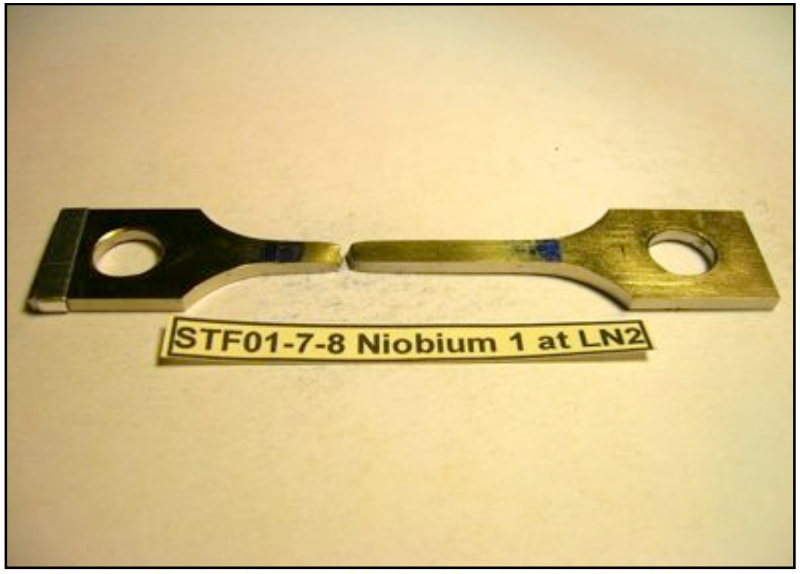
Notes

1. Ti-Ti joint samples welded by a company has pits at welded zone (both tensile test samples and impact test samples).
2. Nb-Nb joint and NbTi-Ti joint samples for tensile test were not uniform in their thickness.

Nb (1)

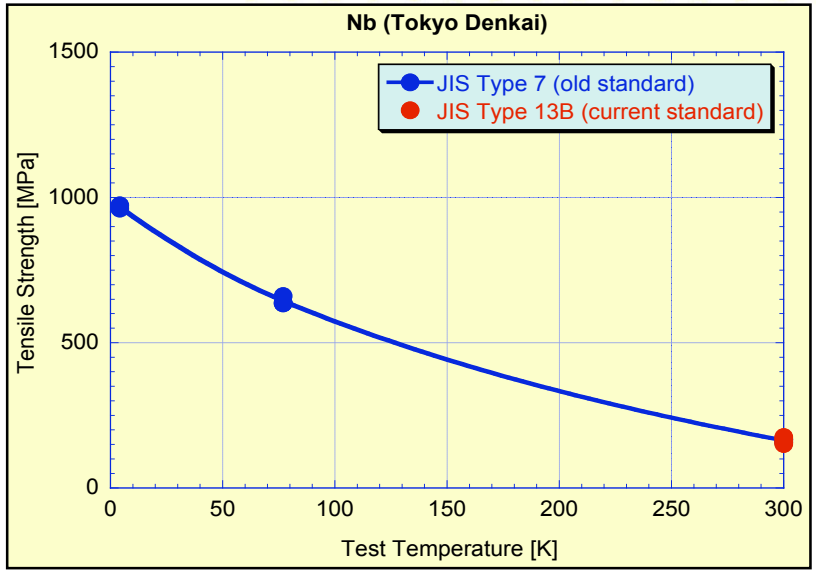

STF01-7-5 Niobium 1 at R.T.

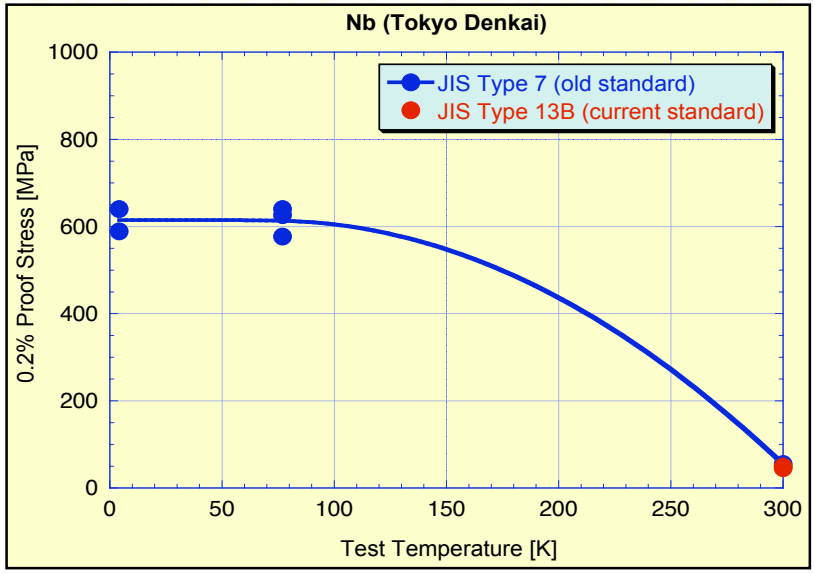

STF01-13b-2 Niobium 1 at R.T.

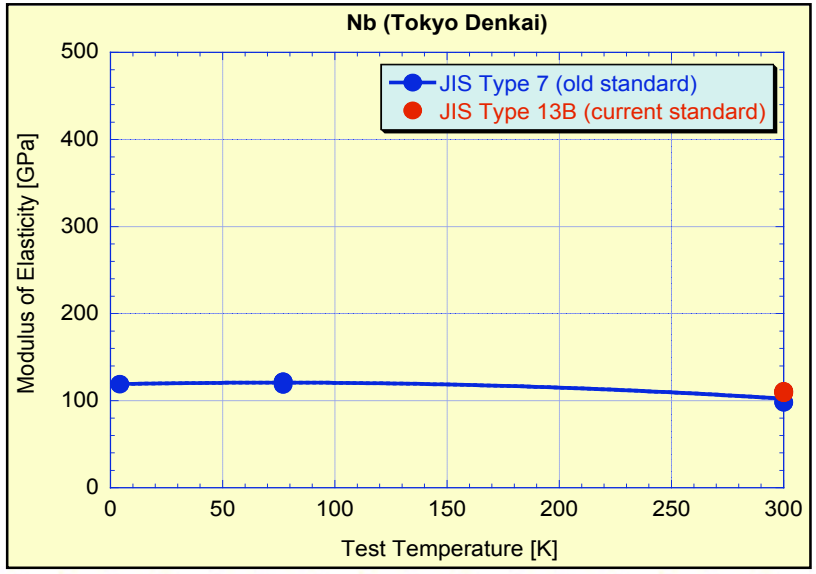

STF01-7-8 Niobium 1 at LN2

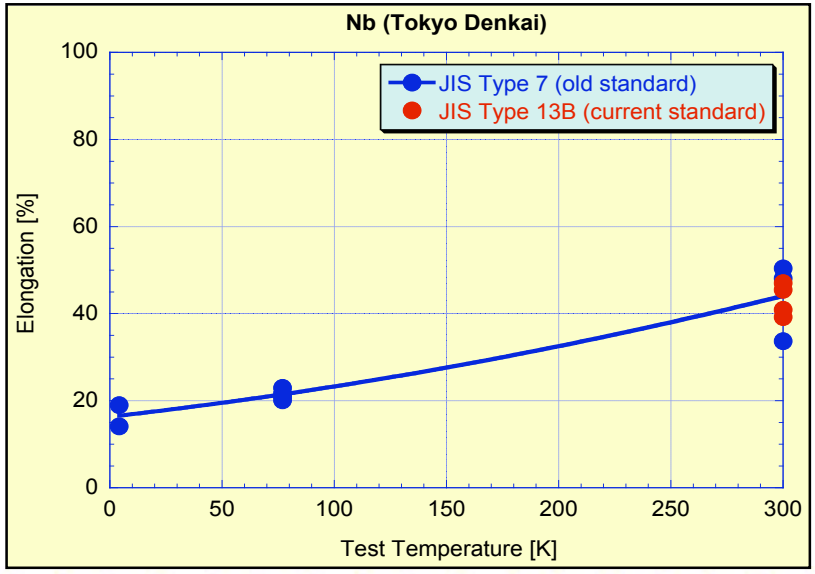

STF01-7-3 Niobium 1 at LHe

Nb (2)


Nb (Tokyo Denkai)
JIS Type 7 (old standard)
JIS Type 13B (current standard)
Tensile Strength [MPa]
Test Temperature [K]
0
500
1000
1500
0
50
100
150
200
250
300


Nb (Tokyo Denkai)
JIS Type 7 (old standard)
JIS Type 13B (current standard)
0.2% Proof Stress [MPa]
Test Temperature [K]
0
200
400
600
800
1000
0
50
100
150
200
250
300


Nb (Tokyo Denkai)
JIS Type 7 (old standard)
JIS Type 13B (current standard)
Modulus of Elasticity [GPa]
Test Temperature [K]
0
100
200
300
400
500
0
50
100
150
200
250
300


Nb (Tokyo Denkai)
JIS Type 7 (old standard)
JIS Type 13B (current standard)
Elongation [%]
Test Temperature [K]
0
20
40
60
80
100
0
50
100
150
200
250
300

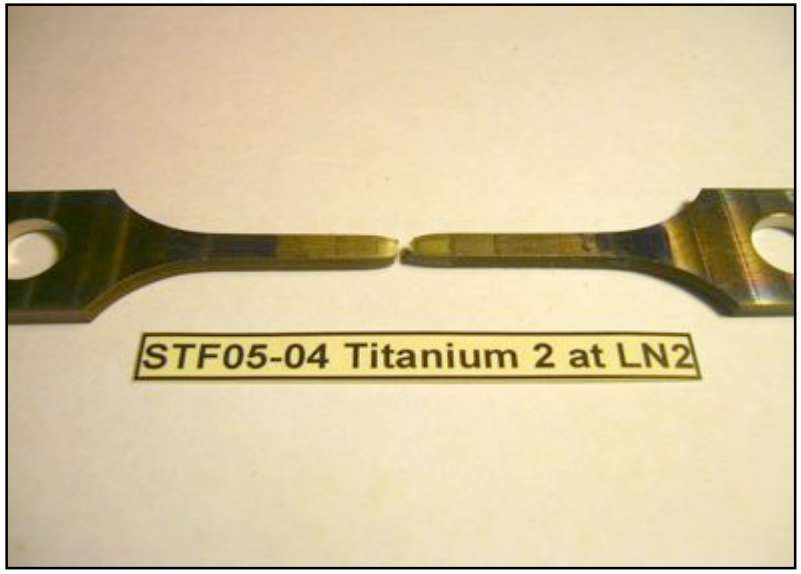
Nb (3)

- No clear difference of mechanical properties by sample shapes JIS Type 7 and JIS Type 13B, at least at room temperature
- Tests executable at low temperatures only with old standard JIS Type 7

Ti (1)

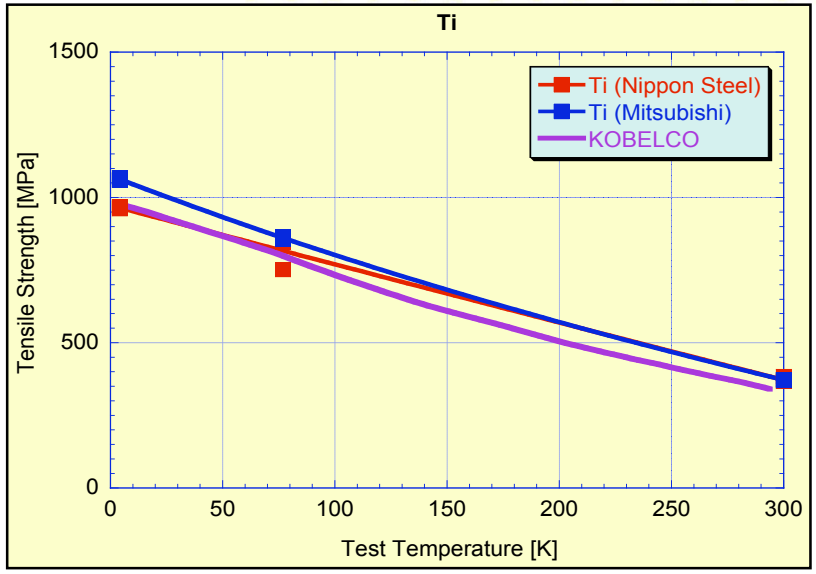
Titanium: supplied from Nippon Steel

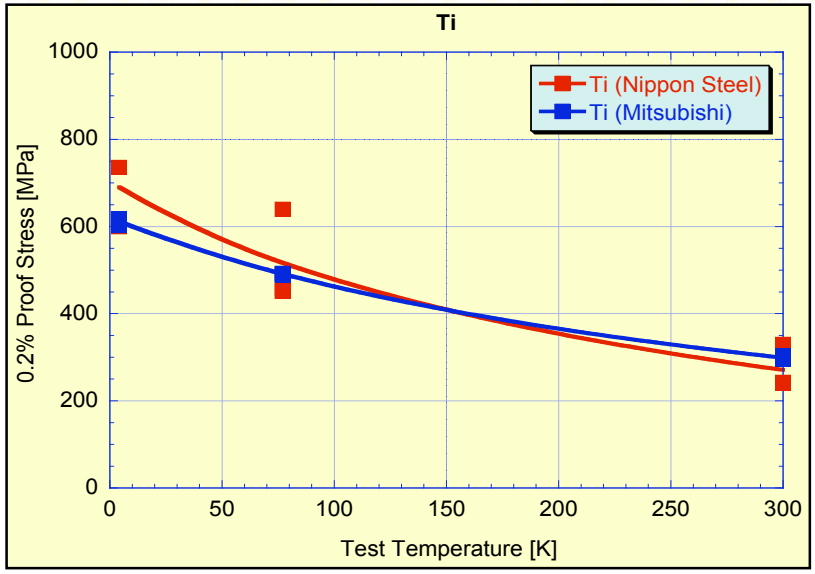
Ti (2)

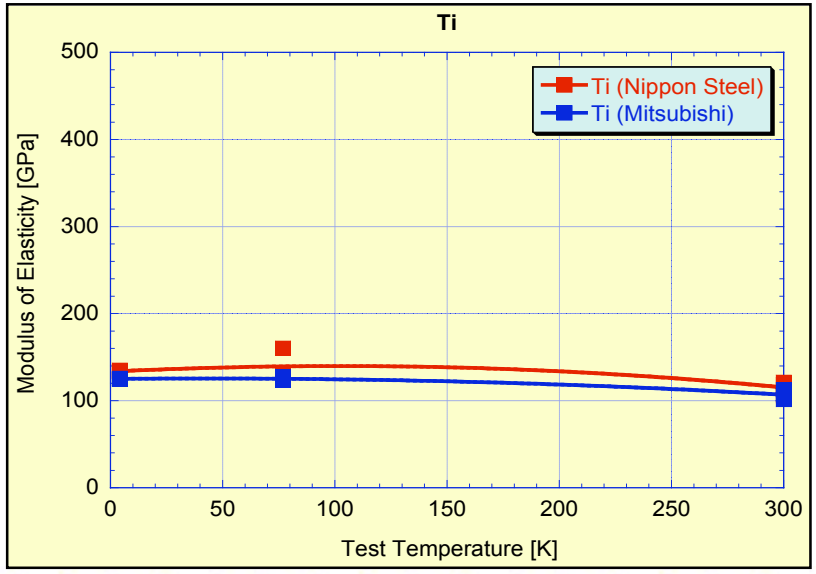


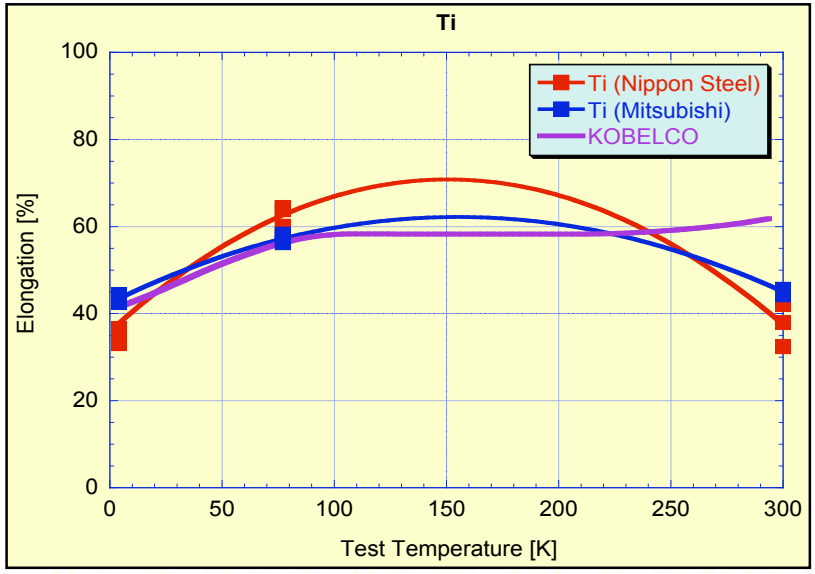
Titanium: supplied from Mitsubishi

Ti (3)


Ti
Tensile Strength [MPa]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
KOBELCO
0
500
1000
1500
0
50
100
150
200
250
300


Ti
0.2% Proof Stress [MPa]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
0
200
400
600
800
1000
0
50
100
150
200
250
300

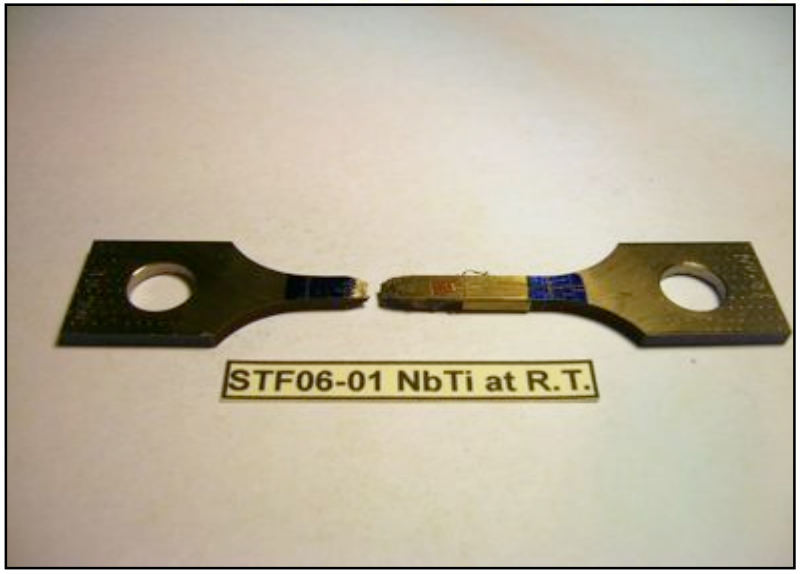

Ti
Modulus of Elasticity [GPa]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
0
100
200
300
400
500
0
50
100
150
200
250
300


Ti
Elongation [%]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
KOBELCO
0
20
40
60
80
100
0
50
100
150
200
250
300

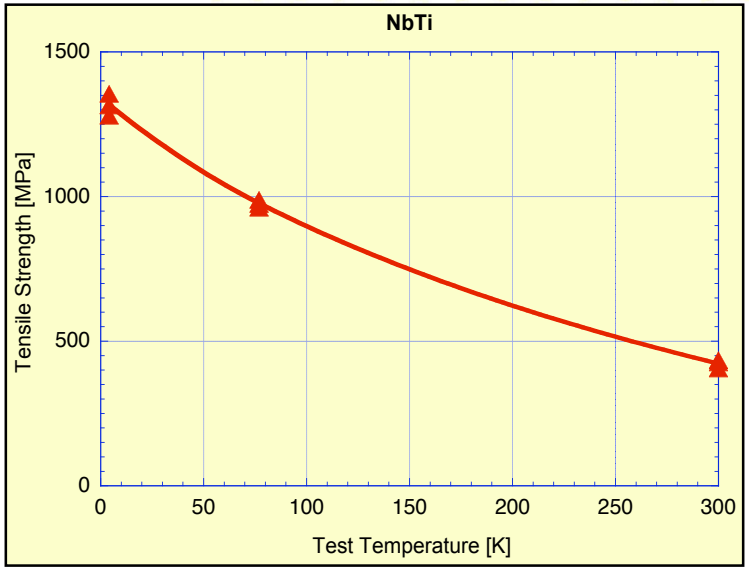
Ti (4)

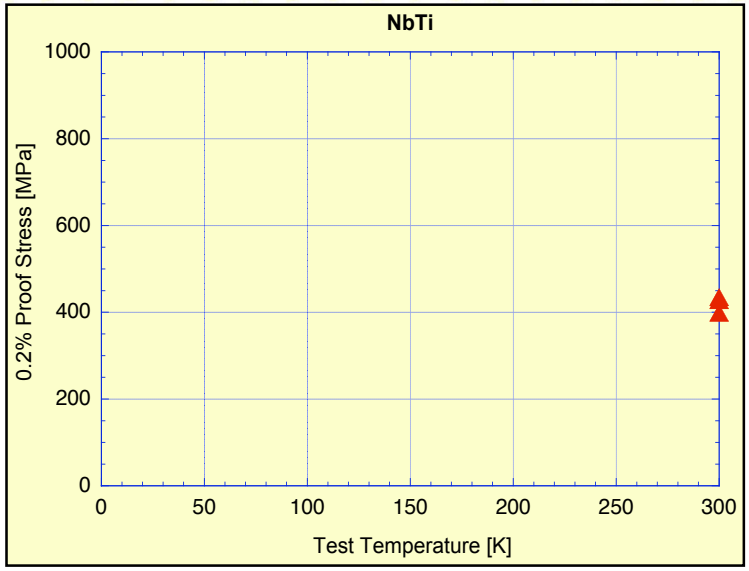
- No clear difference of mechanical properties of sample supplied by different companies
- Measured properties consistent with data supplied by KOBELCO, except elongation at room temperature

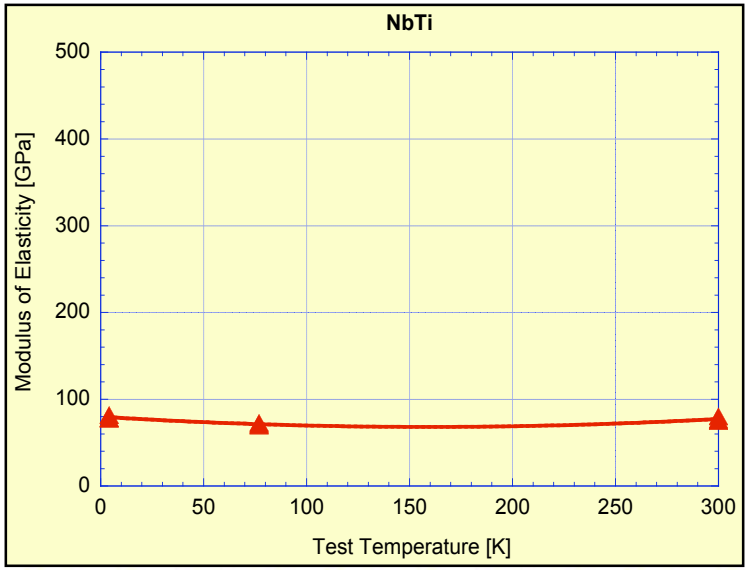
NbTi (1)

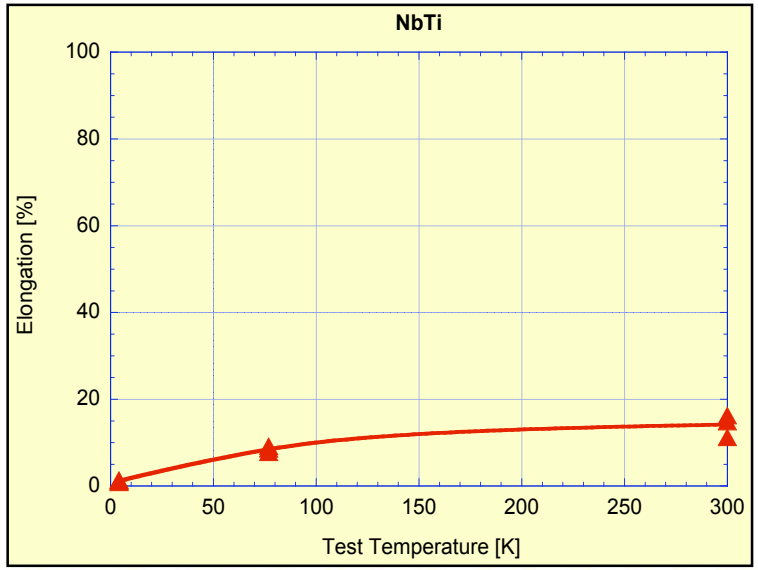


NbTi (2)


NbTi
Tensile Strength [MPa]
1500
1000
500
0
0
50
100
150
200
250
300
Test Temperature [K]


NbTi
0.2% Proof Stress [MPa]
1000
800
600
400
200
0
0
50
100
150
200
250
300
Test Temperature [K]

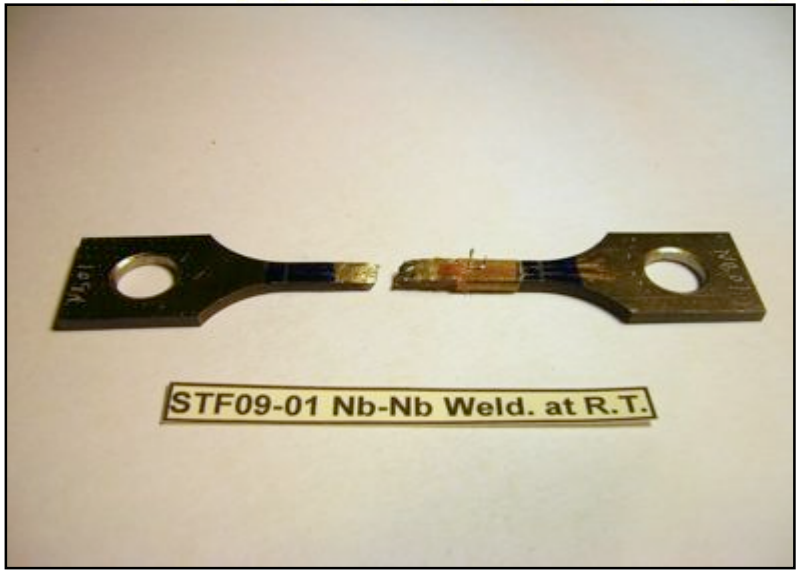

NbTi
Modulus of Elasticity [GPa]
500
400
300
200
100
0
0
50
100
150
200
250
300
Test Temperature [K]


NbTi
Elongation [%]
100
80
60
40
20
0
0
50
100
150
200
250
300
Test Temperature [K]

NbTi (3)

- Because of less elongation at low temperatures, 0.2% proof stress could not be measured at low temperatures

Nb-Nb Joint (1)

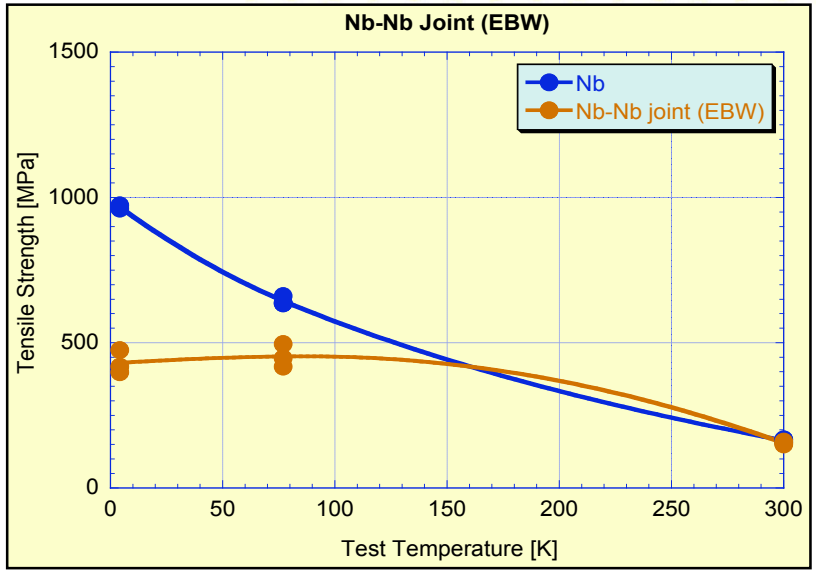

STF09-01 Nb-Nb Weld. at R.T.

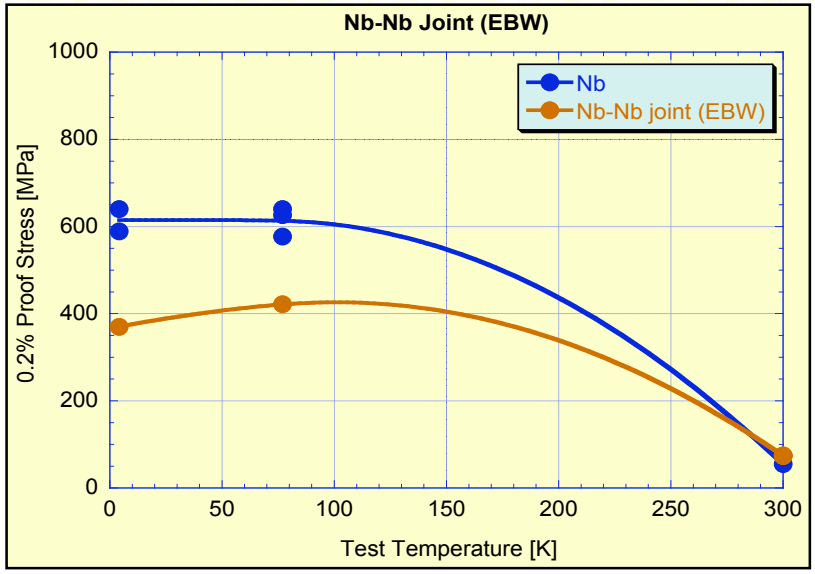

STF09-05 Nb-Nb Weld. at LN2

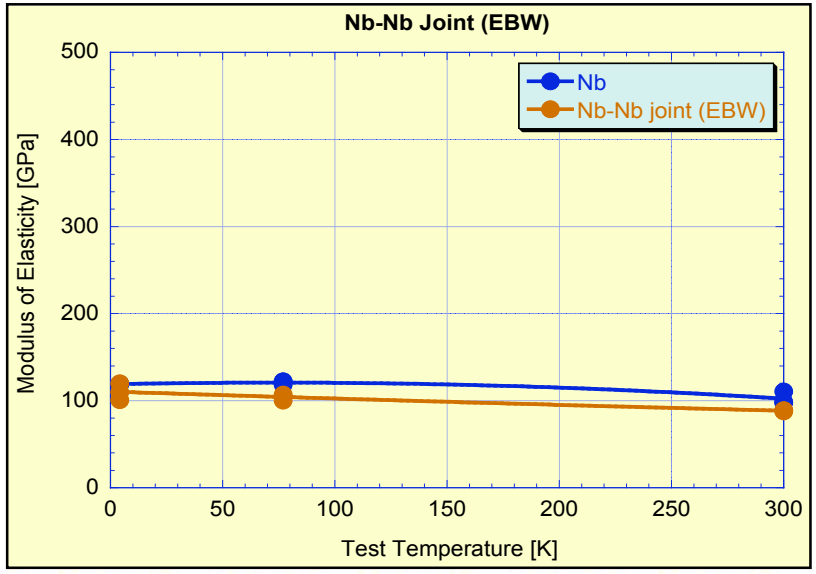

STF09-08 Nb-Nb Weld. at LHe

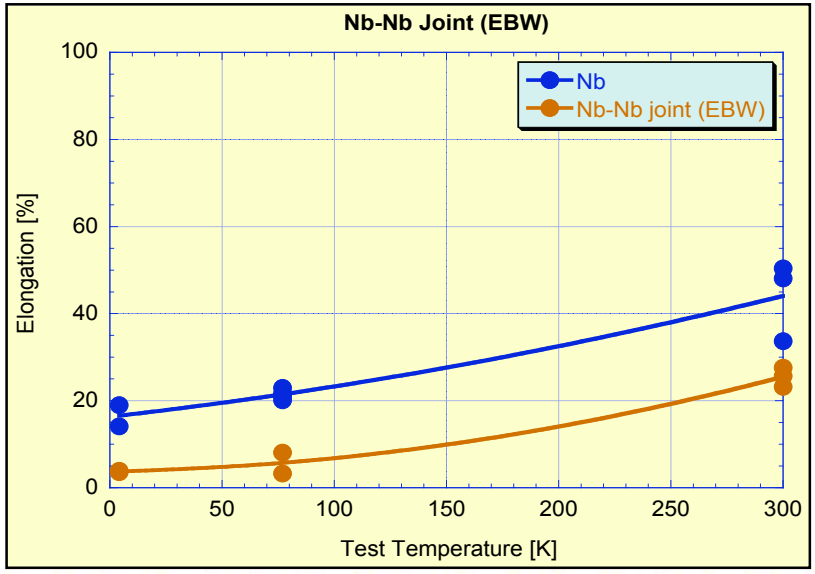

STF09-10 Nb-Nb Weld. at LHe

Nb-Nb Joint (2)


Nb-Nb Joint (EBW)
Tensile Strength [MPa]
Test Temperature [K]
Nb
Nb-Nb joint (EBW)
0
500
1000
1500
0
50
100
150
200
250
300


Nb-Nb Joint (EBW)
0.2% Proof Stress [MPa]
Test Temperature [K]
Nb
Nb-Nb joint (EBW)
0
200
400
600
800
1000
0
50
100
150
200
250
300

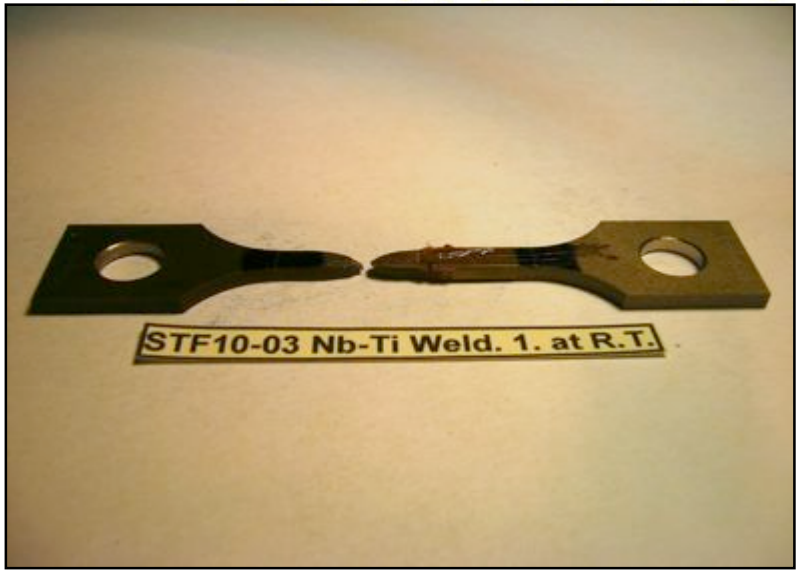

Nb-Nb Joint (EBW)
Modulus of Elasticity [GPa]
Test Temperature [K]
Nb
Nb-Nb joint (EBW)
0
100
200
300
400
500
0
50
100
150
200
250
300


Nb-Nb Joint (EBW)
Elongation [%]
Test Temperature [K]
Nb
Nb-Nb joint (EBW)
0
20
40
60
80
100
0
50
100
150
200
250
300

Nb-Nb Joint (3)

- Absolute values of mechanical properties smaller than those of Nb, especially at low temperatures
- Some samples fractured at welded zone, while other at base material
- Some samples fractured at two places

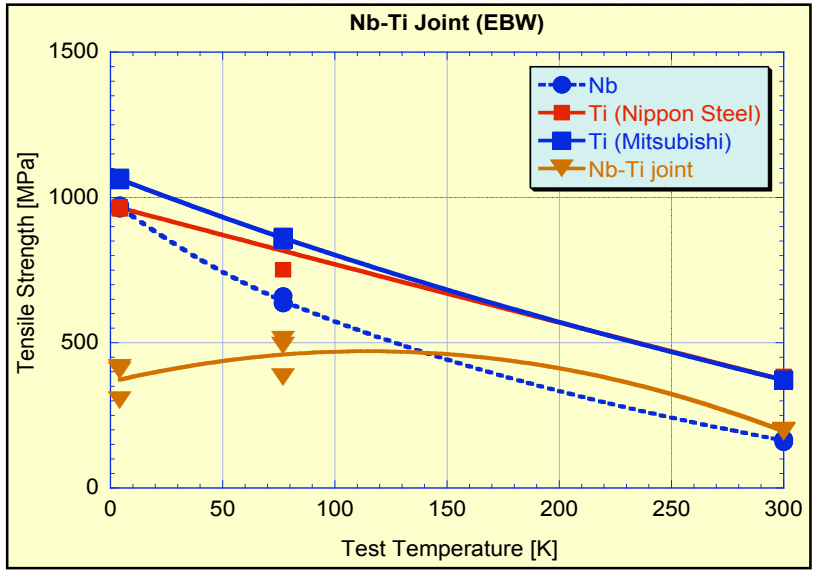
Nb-Ti Joint (1)

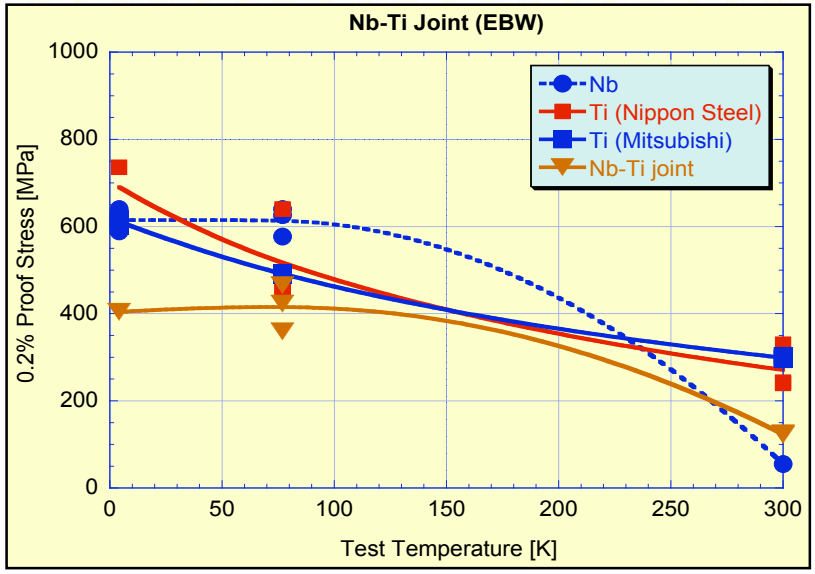

STF10-03 Nb-Ti Weld. 1. at R.T.

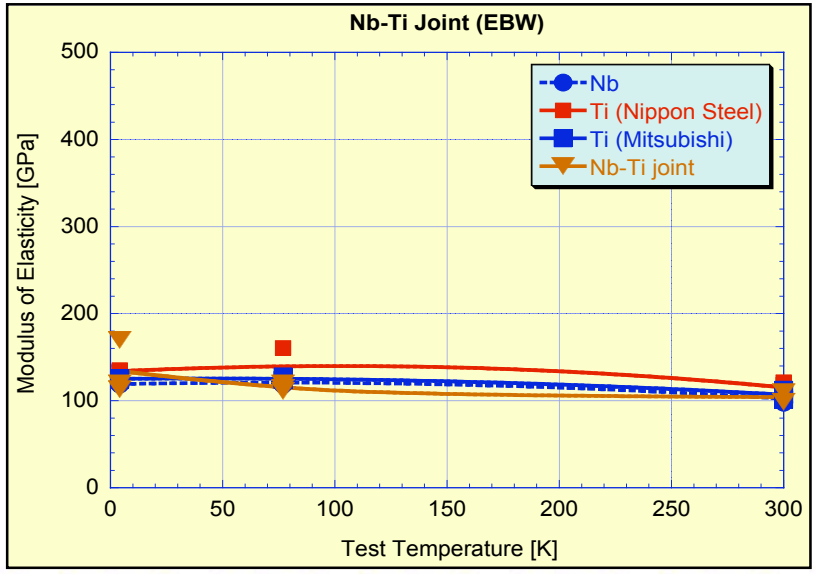

STF10-02 Nb-Ti Weld. 1. at LN2

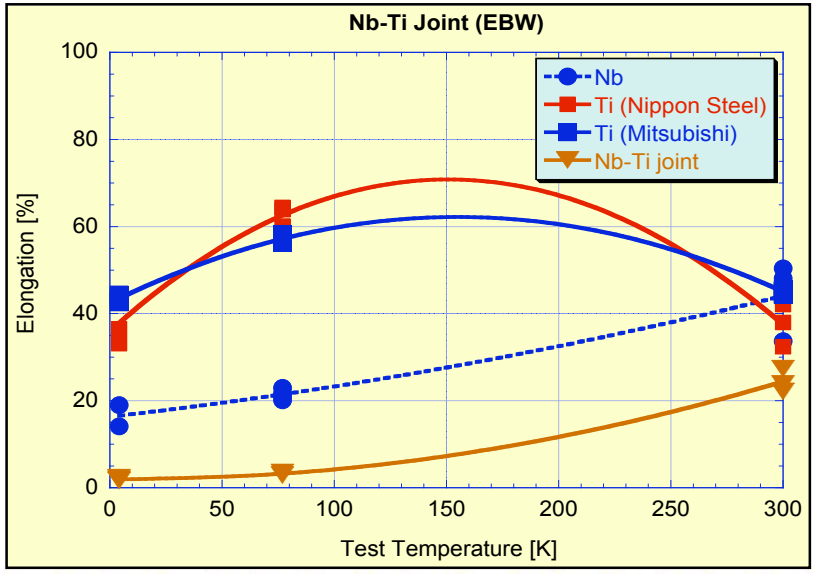

STF10-09 Nb-Ti Weld. 1. at LHe

Nb-Ti Joint (2)


Nb-Ti Joint (EBW)
Tensile Strength [MPa]
Test Temperature [K]
Nb
Ti (Nippon Steel)
Ti (Mitsubishi)
Nb-Ti joint


Nb-Ti Joint (EBW)
0.2% Proof Stress [MPa]
Test Temperature [K]
Nb
Ti (Nippon Steel)
Ti (Mitsubishi)
Nb-Ti joint

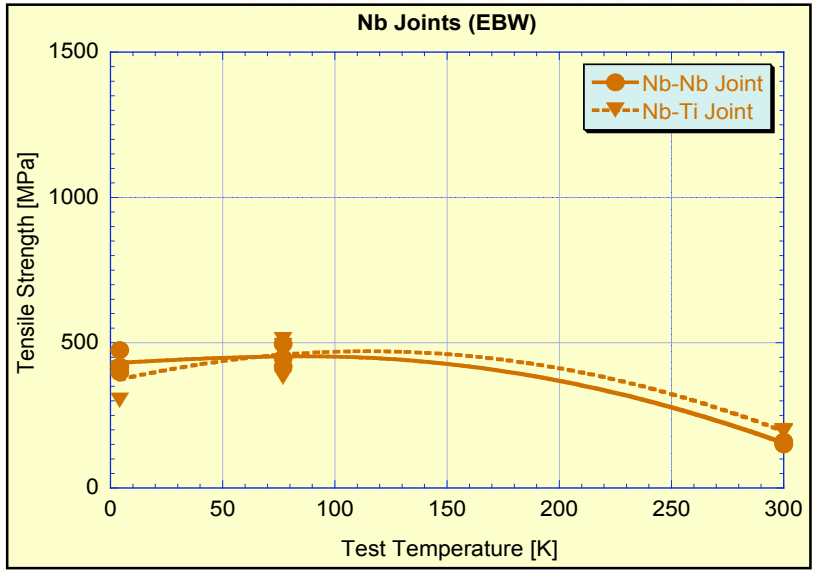

Nb-Ti Joint (EBW)
Modulus of Elasticity [GPa]
Test Temperature [K]
Nb
Ti (Nippon Steel)
Ti (Mitsubishi)
Nb-Ti joint

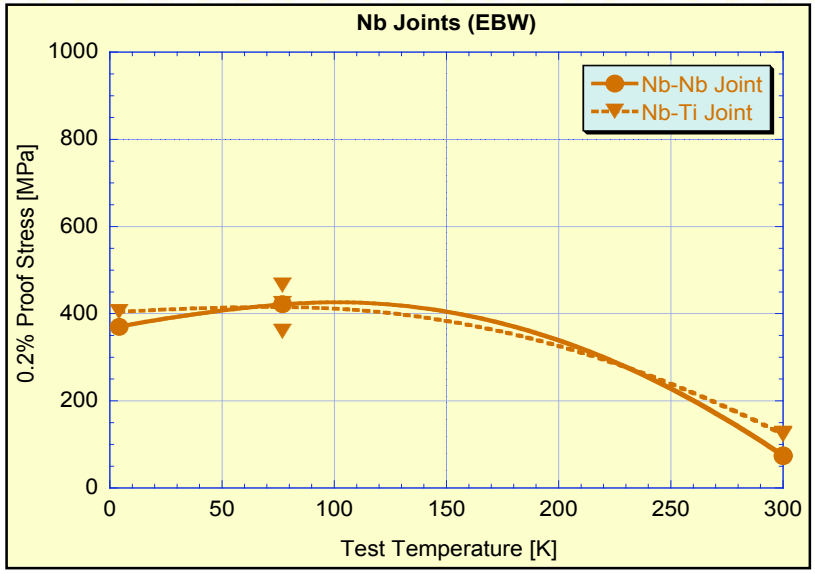

Nb-Ti Joint (EBW)
Elongation [%]
Test Temperature [K]
Nb
Ti (Nippon Steel)
Ti (Mitsubishi)
Nb-Ti joint

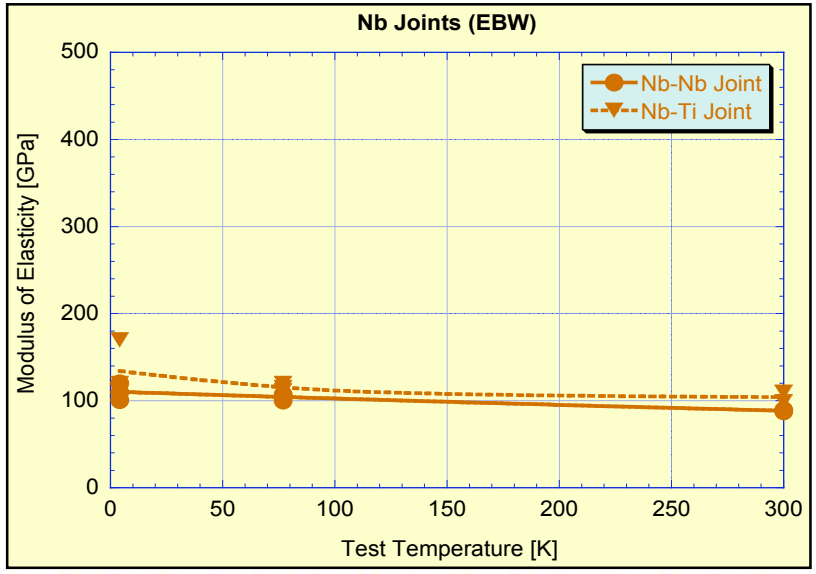
Nb-Ti Joint (3)

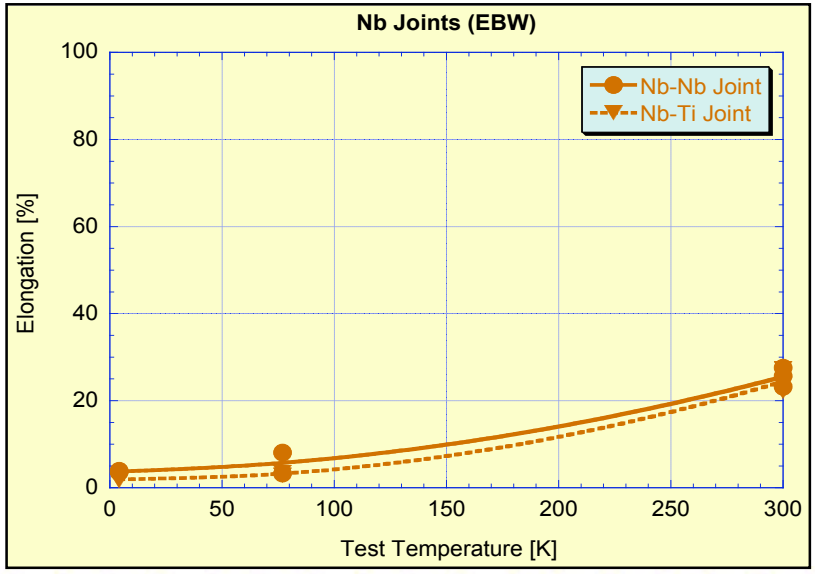
- All samples fractured in Nb part
- Temperature variation of properties similar to those of Nb, except tensile strength
- Absolute values smaller than those of Nb, especially at low temperatures

Nb Joints (1)


Nb Joints (EBW)
Tensile Strength [MPa]
Test Temperature [K]
Nb-Nb Joint
Nb-Ti Joint
0
500
1000
1500
0
50
100
150
200
250
300


Nb Joints (EBW)
0.2% Proof Stress [MPa]
Test Temperature [K]
Nb-Nb Joint
Nb-Ti Joint
0
200
400
600
800
1000
0
50
100
150
200
250
300

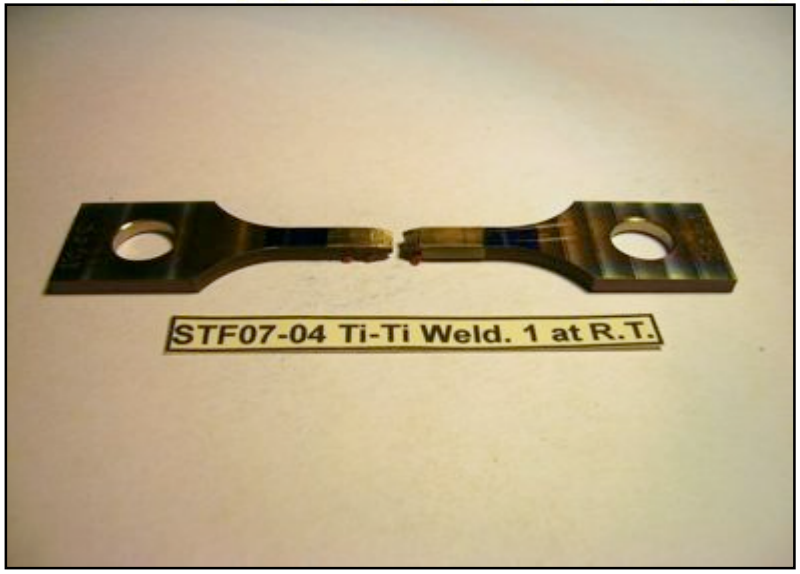

Nb Joints (EBW)
Modulus of Elasticity [GPa]
Test Temperature [K]
Nb-Nb Joint
Nb-Ti Joint
0
100
200
300
400
500
0
50
100
150
200
250
300

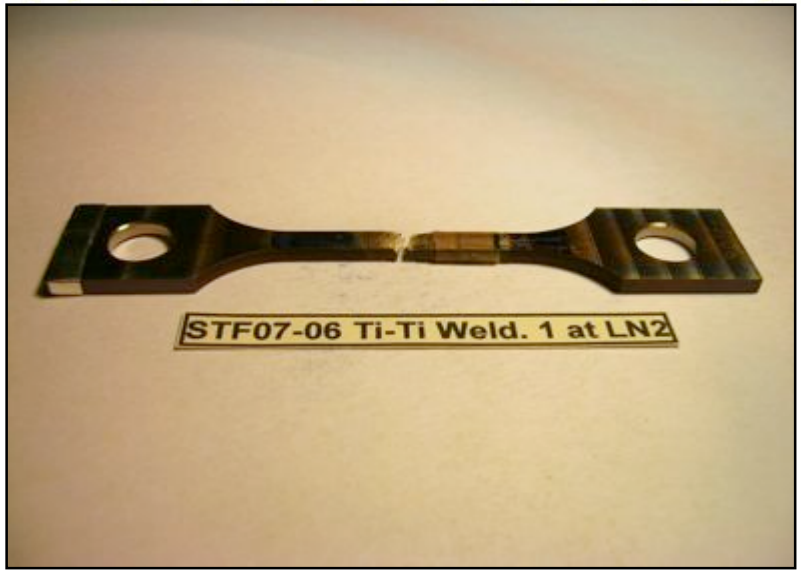

Nb Joints (EBW)
Elongation [%]
Test Temperature [K]
Nb-Nb Joint
Nb-Ti Joint
0
20
40
60
80
100
0
50
100
150
200
250
300

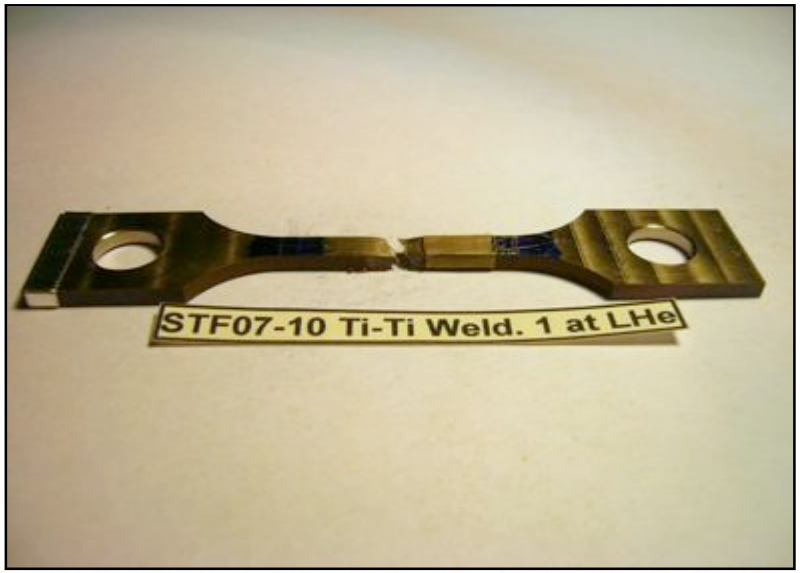
Nb Joints (2)

- Mechanical properties of Nb-Nb and Nb-Ti joints are very similar
- Since all samples of Nb-Ti joint fractured in Nb part, mechanical properties similar to those of Nb-Nb joint
- These characteristics may come from Nb affected by EBW

Ti-Ti Joint (1)

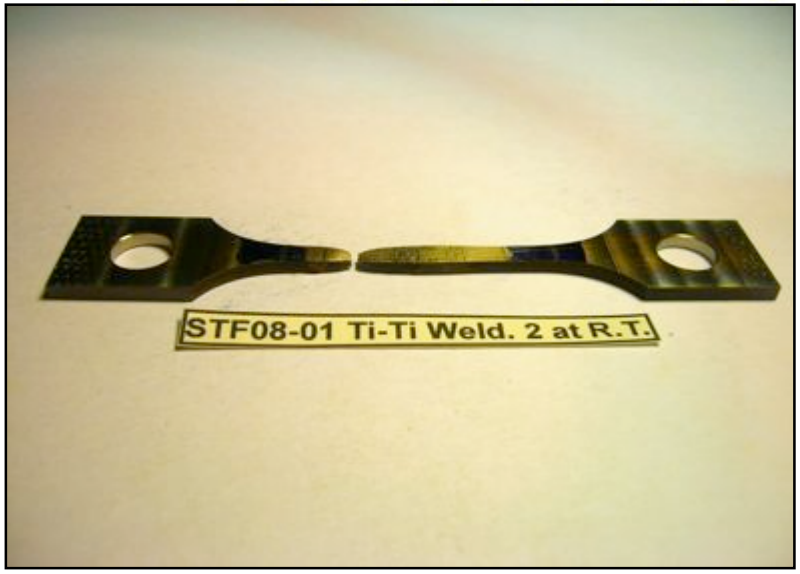






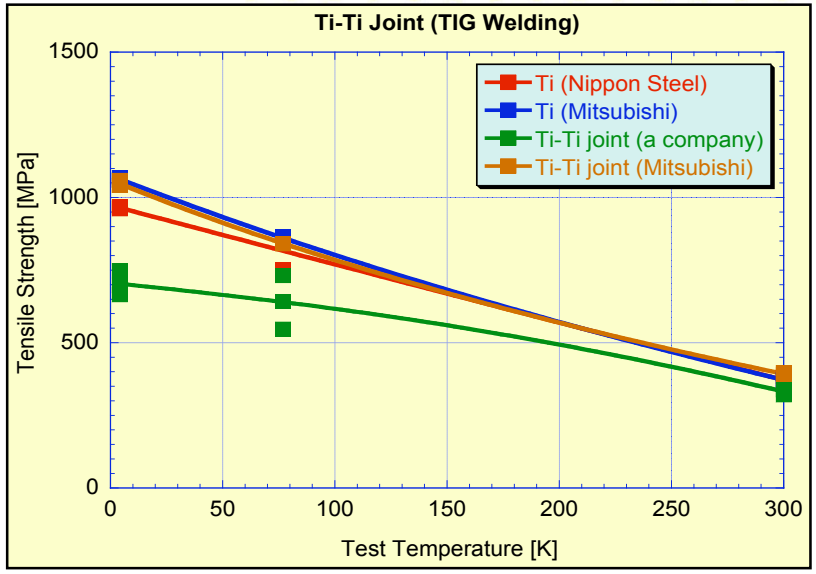
Welded by a company

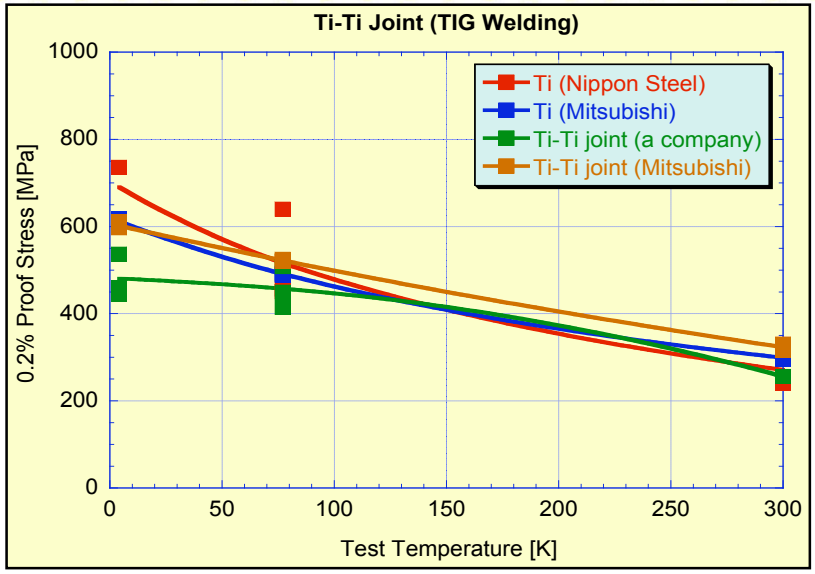
Ti-Ti Joint (2)

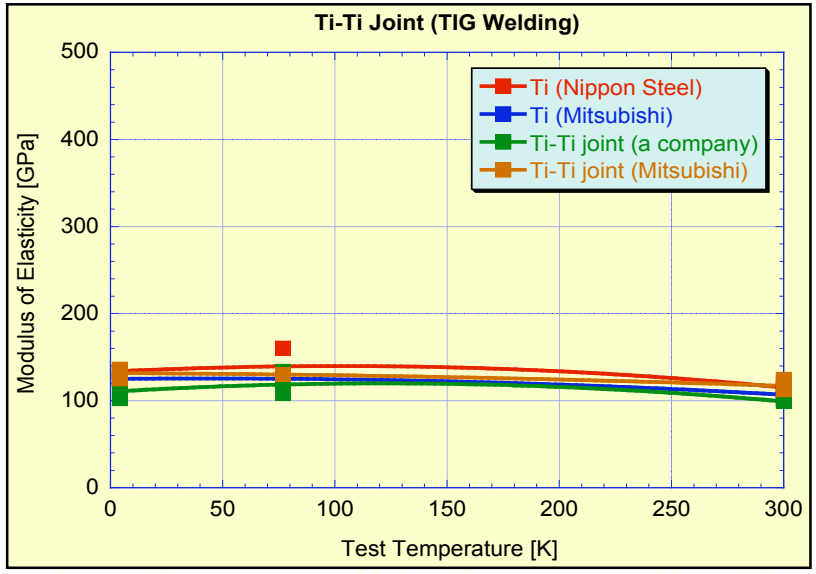


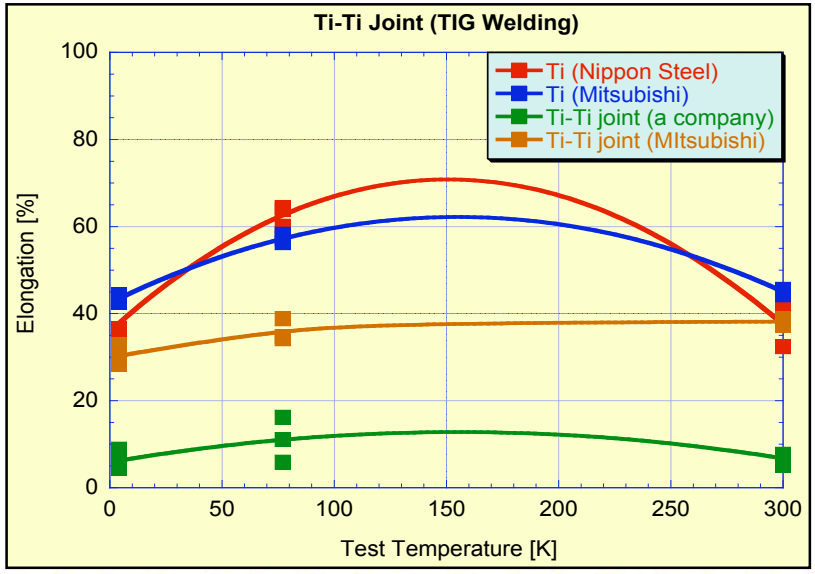
Welded by Mitsubishi

Ti-Ti Joint (3)


Ti-Ti Joint (TIG Welding)
Tensile Strength [MPa]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
Ti-Ti joint (a company)
Ti-Ti joint (Mitsubishi)


Ti-Ti Joint (TIG Welding)
0.2% Proof Stress [MPa]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
Ti-Ti joint (a company)
Ti-Ti joint (Mitsubishi)

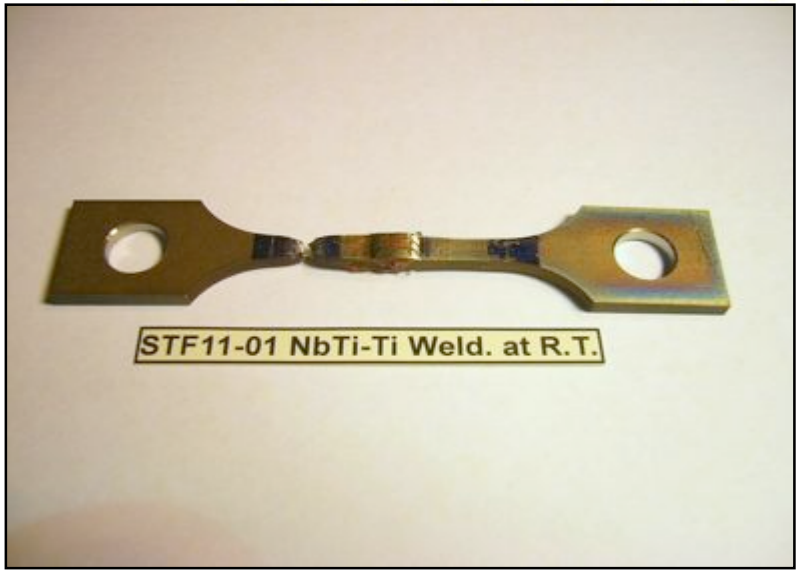

Ti-Ti Joint (TIG Welding)
Modulus of Elasticity [GPa]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
Ti-Ti joint (a company)
Ti-Ti joint (Mitsubishi)

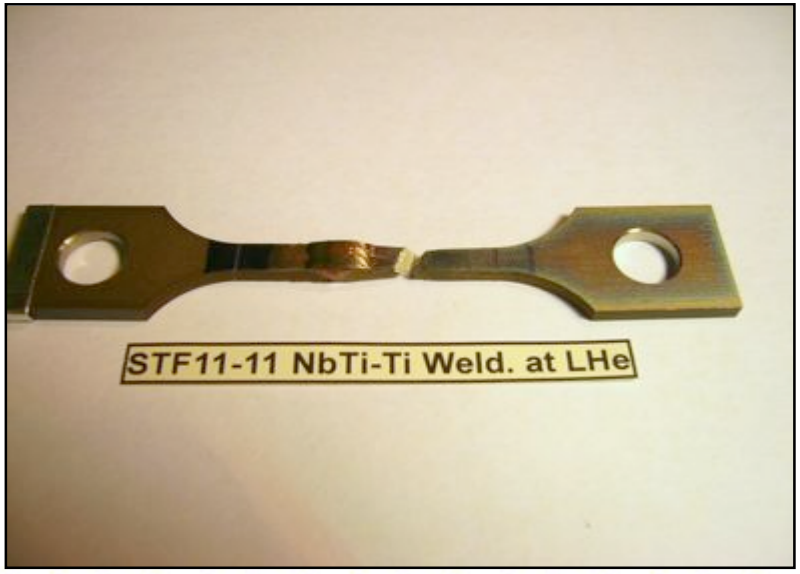

Ti-Ti Joint (TIG Welding)
Elongation [%]
Test Temperature [K]
Ti (Nippon Steel)
Ti (Mitsubishi)
Ti-Ti joint (a company)
Ti-Ti joint (MItsubishi)

Ti-Ti Joint (4)

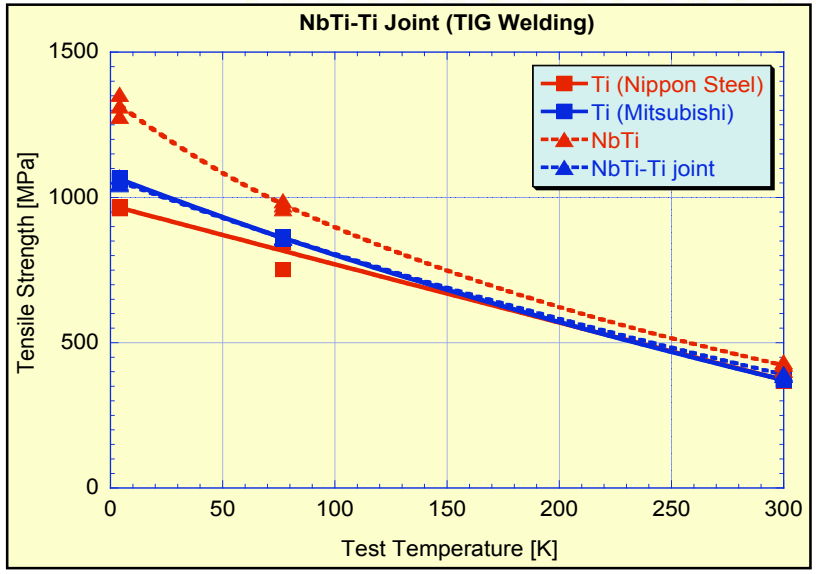
- Ti-Ti joint samples welded by Mitsubishi has almost same mechanical properties as those of Ti samples, except elongation
- Samples welded by a company show lower mechanical properties than those welded by Mitsubishi (and also than those of Ti samples)

NbTi-Ti Joint (1)

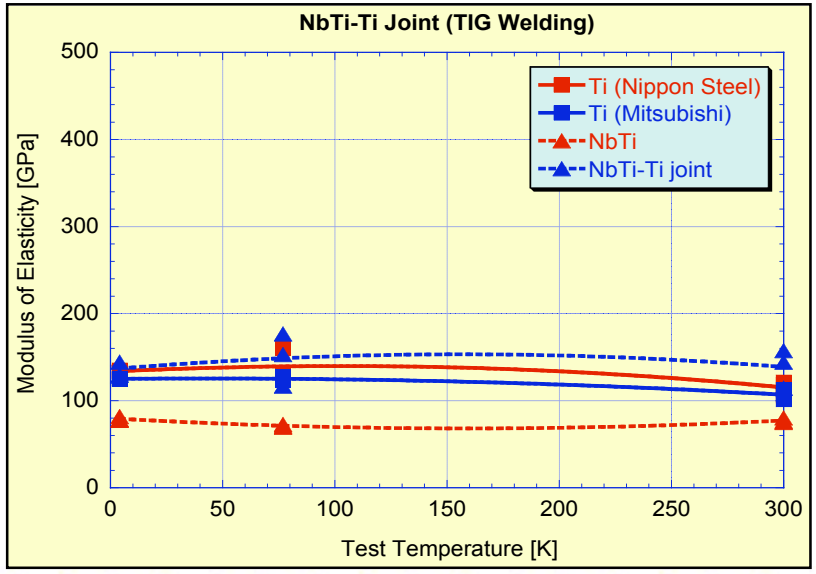


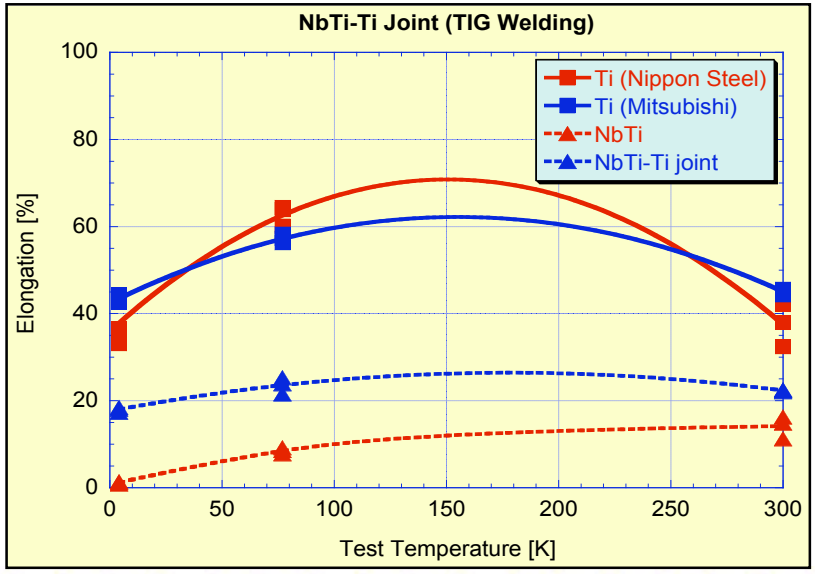


NbTi-Ti Joint (2)



No 0.2% proof stress data acquired

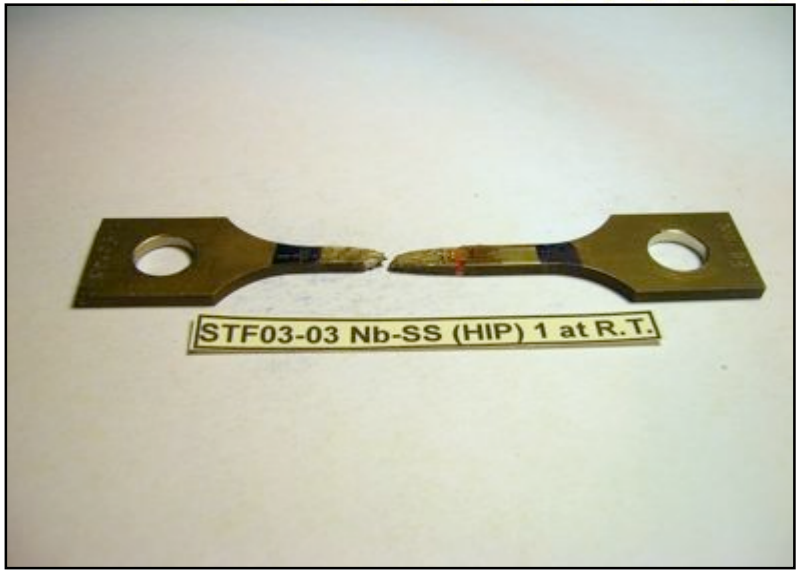




NbTi-Ti Joint (3)

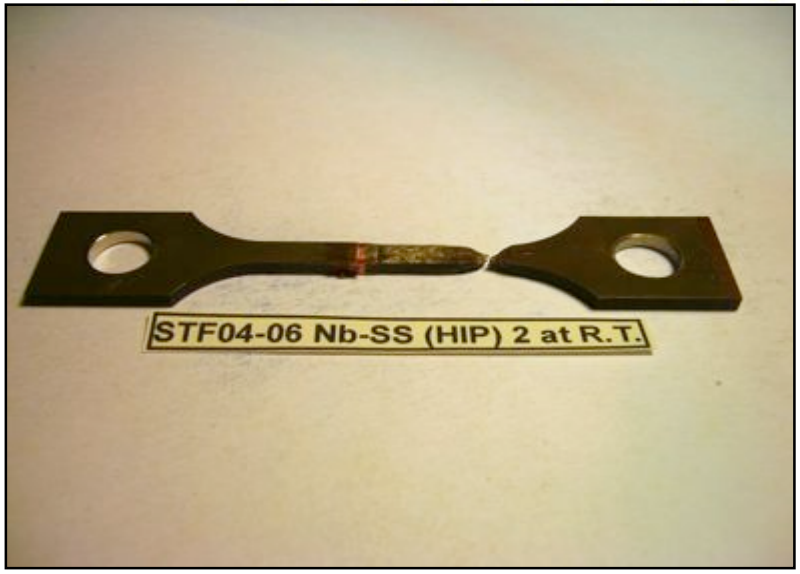
- Most samples fracured in Ti part
- Hence properties similar to those of Ti rather than those of NbTi alloy, except elongation

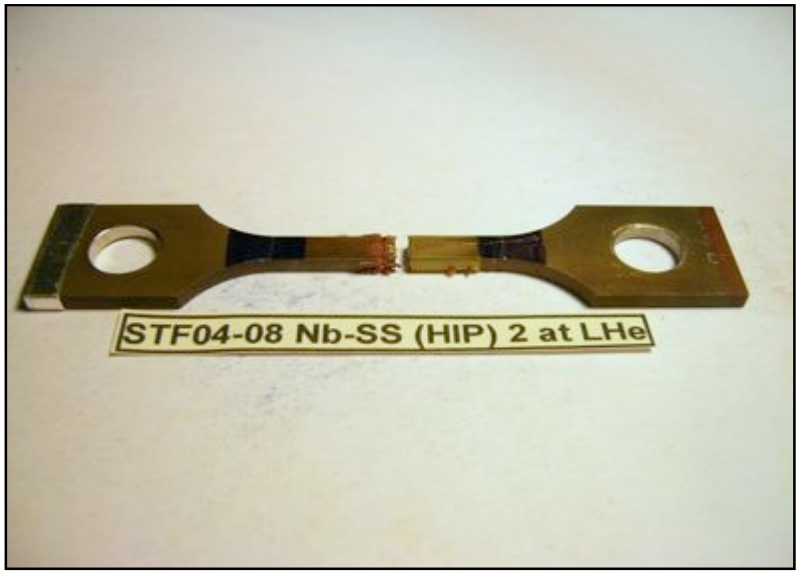
Nb-SS Joint (1)



HIP'ed by Kuroki Composites

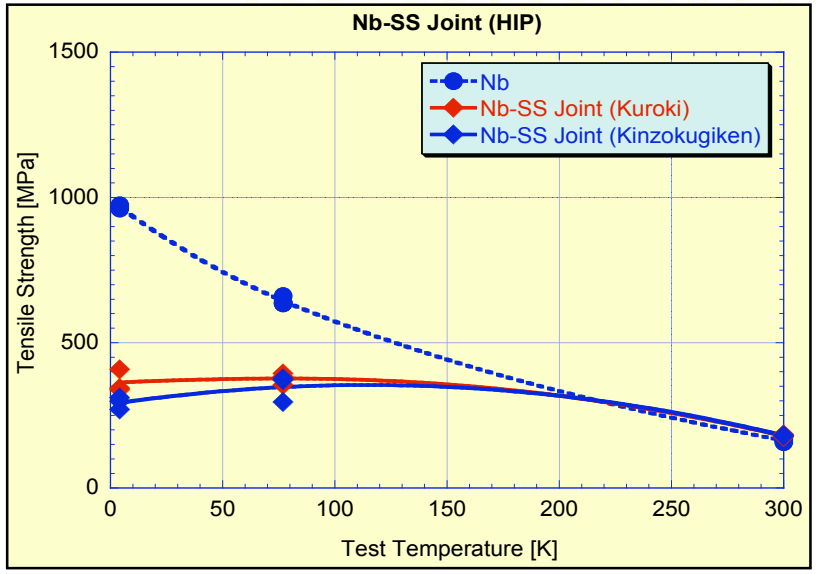
Nb-SS Joint (2)

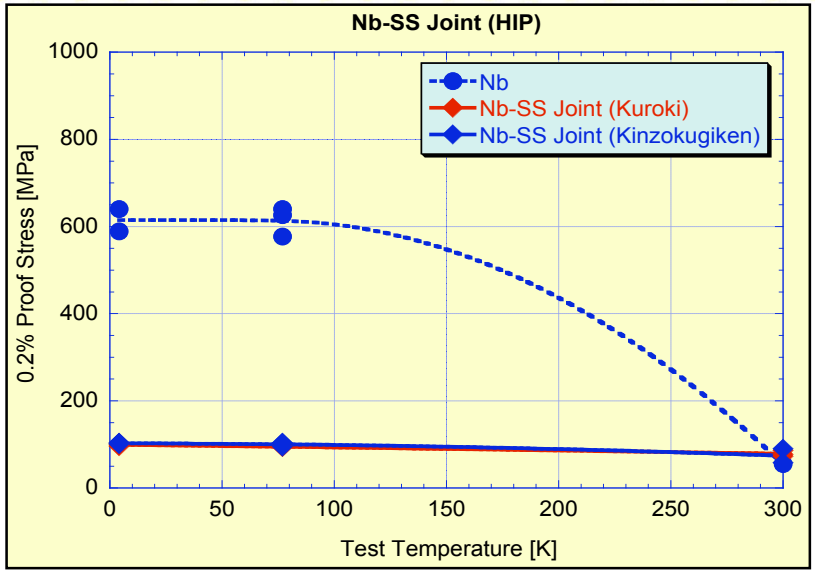


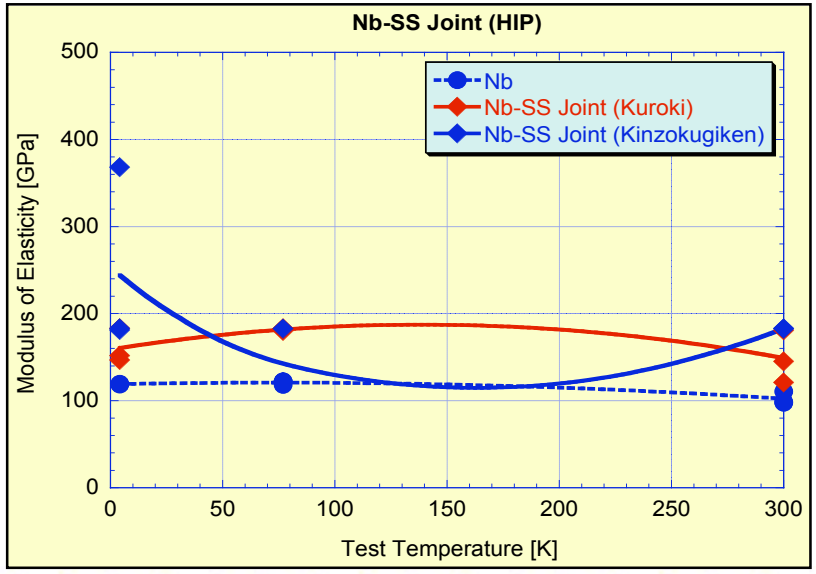


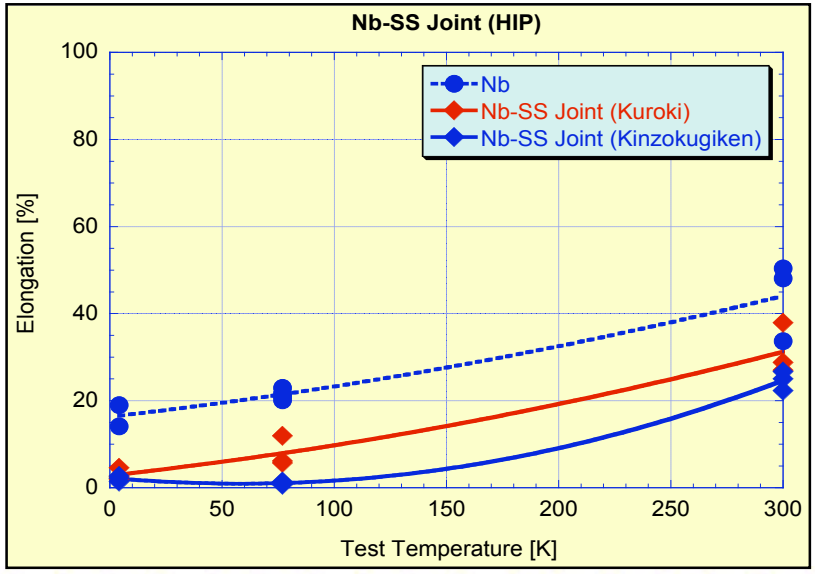
HIP'ed by Kinzokugiken

Nb-SS Joint (3)

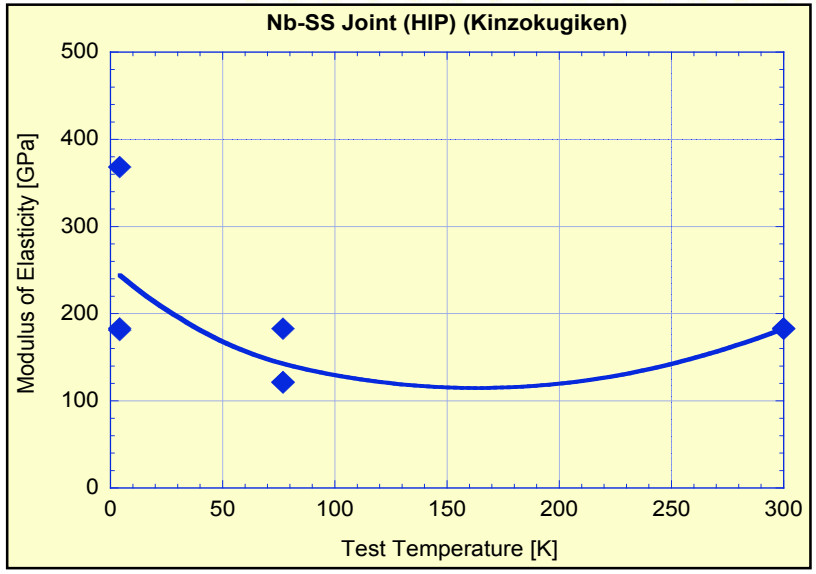

Nb-SS Joint (HIP)
Tensile Strength [MPa]
Test Temperature [K]
Nb
Nb-SS Joint (Kuroki)
Nb-SS Joint (Kinzokugiken)
0
500
1000
1500
0
50
100
150
200
250
300

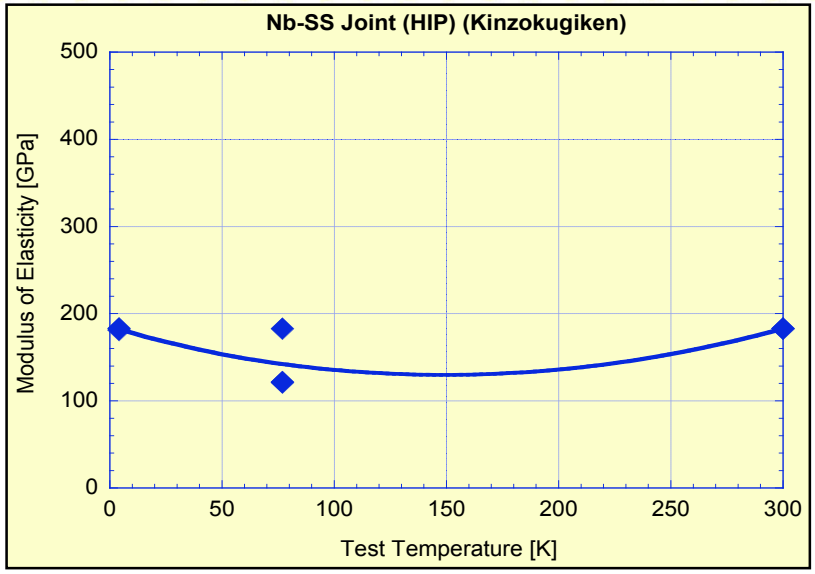

Nb-SS Joint (HIP)
0.2% Proof Stress [MPa]
Test Temperature [K]
Nb
Nb-SS Joint (Kuroki)
Nb-SS Joint (Kinzokugiken)
0
200
400
600
800
1000
0
50
100
150
200
250
300


Nb-SS Joint (HIP)
Modulus of Elasticity [GPa]
Test Temperature [K]
Nb
Nb-SS Joint (Kuroki)
Nb-SS Joint (Kinzokugiken)
0
100
200
300
400
500
0
50
100
150
200
250
300


Nb-SS Joint (HIP)
Elongation [%]
Test Temperature [K]
Nb
Nb-SS Joint (Kuroki)
Nb-SS Joint (Kinzokugiken)
0
20
40
60
80
100
0
50
100
150
200
250
300

Nb-SS Joint (4)





- Erroneous data point in modulus of elasticity
- Even by exclusion of doubtful data, smoothened temperature variation of modulus does not change so much

Nb-SS Joint (5)

- All samples fractured in Nb part
- Absolute values smaller than those of Nb at low temperatures, except modulus of elasticity
- Almost same properties of samples prepared by two different companies

Summary

- A series of tensile tests have been carried out at KEK with metal materials and welded materials for application of special approval in accordance with high pressure safety regulations in Japan
- Some additional tests may be required, because number of acquired data not enough for special approval