Material Property Study for High Pressure Code in KEK

NAKAI Hirotaka (KEK)

Outline

- Background of material testing for High Pressure Gas Safety Act (HPGSA)
- Results of material tests at KEK
  - Tensile test of pure niobium
  - Tensile test of pure titanium
- Planned material tests

Relevant Laws & Technical Standards

- High Pressure Gas Safety Act; HPGSA
- Designated Equipment Inspection Regulations; DEIR
- Note "On Implementation of Functional Standards regarding Designated Equipment Inspection Regulations" (Exemplified Technical Standards); ETS

SC Cavities & Cryomodules

- Niobium not specified in DEIR and ETS as materials for designated equipments
  - Special technical approval (STA) is required before manufacturing
- Titanium specified in DEIR and ETS as materials for designated equipments
  - No specifications given at temperatures lower than liquid nitrogen temperature
  - Special technical approval (STA) is required before manufacturing

Allowable Tensile Stress in ETS

規格名称	種類	記号	最小引張強さ （N／mm²）	注	各温度における許容引張応力（N／mm²）																											
					温度 -269	-196	-100	-80	-60	-45	-30	-10	0	40	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
チタン板及び条 JIS H 4600 (1993)	1種	TP270H TR270H TP270C TR270C	270（厚さ0.5mm以上15mm以下）	–	–	68	68	68	68	68	68	68	68	68	55	50	45	40	37	33	31	28	27	25	24	24	–	–	–	–	–	–
	2種	TP340H TR340H TP340C TR340C	340（厚さ0.5mm以上15mm以下）	–	–	85	85	85	85	85	85	85	85	85	80	74	68	62	58	54	51	47	44	41	30	29	–	–	–	–	–	–
	3種	TP480H TR480H TP480C TR480C	480（厚さ0.5mm以上15mm以下）	–	–	121	121	121	121	121	121	121	121	121	118	111	104	98	92	87	83	80	77	76	–	–	–	–	–	–	–	–
配管用チタン管 JIS H 4630 (1994)	1種	TTP270H TTP270C	270（外径10mm以上80mm以下 肉厚1mm以上10mm以下）	–	–	68	68	68	68	68	68	68	68	68	55	50	45	40	37	33	31	28	27	25	24	24	–	–	–	–	–	–
		TTP270W TTP270WC	270（外径10mm以上150mm以下 肉厚1mm以上10mm以下）	–	–	58	58	58	58	58	58	58	58	58	47	42	38	34	31	28	26	25	24	22	21	20	–	–	–	–	–	–
	2種	TTP340H TTP340C	340（外径10mm以上80mm以下 肉厚1mm以上10mm以下）	–	–	85	85	85	85	85	85	85	85	85	80	74	68	62	58	54	51	47	44	41	30	29	–	–	–	–	–	–
		TTP340W TTP340WC	340（外径10mm以上150mm以下 肉厚1mm以上10mm以下）	–	–	72	72	72	72	72	72	72	72	72	69	63	58	53	49	46	43	40	37	35	25	25	–	–	–	–	–	–
	3種	TTP480H TTP480C	480（外径10mm以上80mm以下 肉厚1mm以上10mm以下）	–	–	121	121	121	121	121	121	121	121	121	118	111	104	98	92	87	83	80	77	76	–	–	–	–	–	–	–	–
		TTP480W TTP480WC	480（外径10mm以上150mm以下 肉厚1mm以上10mm以下）	–	–	103	103	103	103	103	103	103	103	103	100	94	89	83	79	74	71	68	66	64	–	–	–	–	–	–	–	–
熱交換器用チタン管 JIS H 4631 (1994)	1種	TTH270C	270（外径10mm以上60mm以下 肉厚1mm以上5mm以下）	–	–	64	64	64	64	64	64	64	64	64	55	50	45	40	37	33	31	28	27	25	24	24	–	–	–	–	–	–
		TTH270W TTH270WC	270（外径10mm以上60mm以下 肉厚0.5mm以上3mm以下）	–	–	54	54	54	54	54	54	54	54	54	47	42	38	34	31	28	26	25	24	22	21	20	–	–	–	–	–	–
	2種	TTH340C	340（外径10mm以上60mm以下 肉厚1mm以上5mm以下）	–	–	85	85	85	85	85	85	85	85	85	80	74	68	62	58	54	51	47	44	41	30	29	–	–	–	–	–	–
		TTH340W TTH340WC	340（外径10mm以上60mm以下 肉厚0.5mm以上3mm以下）	–	–	72	72	72	72	72	72	72	72	72	69	63	58	53	49	46	43	40	37	35	25	25	–	–	–	–	–	–
	3種	TTH480C	480（外径10mm以上60mm以下 肉厚1mm以上5mm以下）	–	–	121	121	121	121	121	121	121	121	121	118	111	104	98	92	87	83	80	77	76	–	–	–	–	–	–	–	–
		TTH480W TTH480WC	480（外径10mm以上60mm以下 肉厚0.5mm以上3mm以下）	–	–	103	103	103	103	103	103	103	103	103	100	94	89	83	79	74	71	68	66	64	–	–	–	–	–	–	–	–
チタン棒 JIS H 4650 (1993)	1種	TB270H TB270C	270（径8mm以上100mm以下）	–	–	64	64	64	64	64	64	64	64	64	55	50	45	40	37	33	31	28	27	25	24	24	–	–	–	–	–	–

Assurance of Tenacity at Low Temp.

- Charpy test for assuring tenacity at low temperature
- DEIR Art. 40 (Mechanical Test Standard)
  - Impact test standard for welded part
  - In case of tensile strength of parent material is 450 MPa or smaller, mean absorbed energy of 3 samples shall be 18 J or larger, and the minimum shall be 14 J or larger (for sample cross section: 10 mm x 10 mm)

Published References

- Nb Tensile strength
  - Aerospace Structure Metal Handbook Code 5201
- Nb 0.2% proof stress
  - Proc. Roy. Soc. A281 (1964) 223
- Nb Coefficient of linear expansion
  - Handbook on Material for Superconducting Machinery, Metals and Ceramic Information Center, MCIC-HB-04, January 1977
  - Computer code “CRYOCOMP”

Published References (Cont'd)

- Walsh R. P. *et al.*, Proc. 9th Annual Workshop on RF Superconductivity 1 (2000) 195 (cited as "Ref.1" in this presentation)
- Niobium data from ATI Wah Chang web page: www.wahchang.com/pages/products/products.htm
- Titanium data from Kobelco web page: www.kobelco.co.jp/english/titan/index.html

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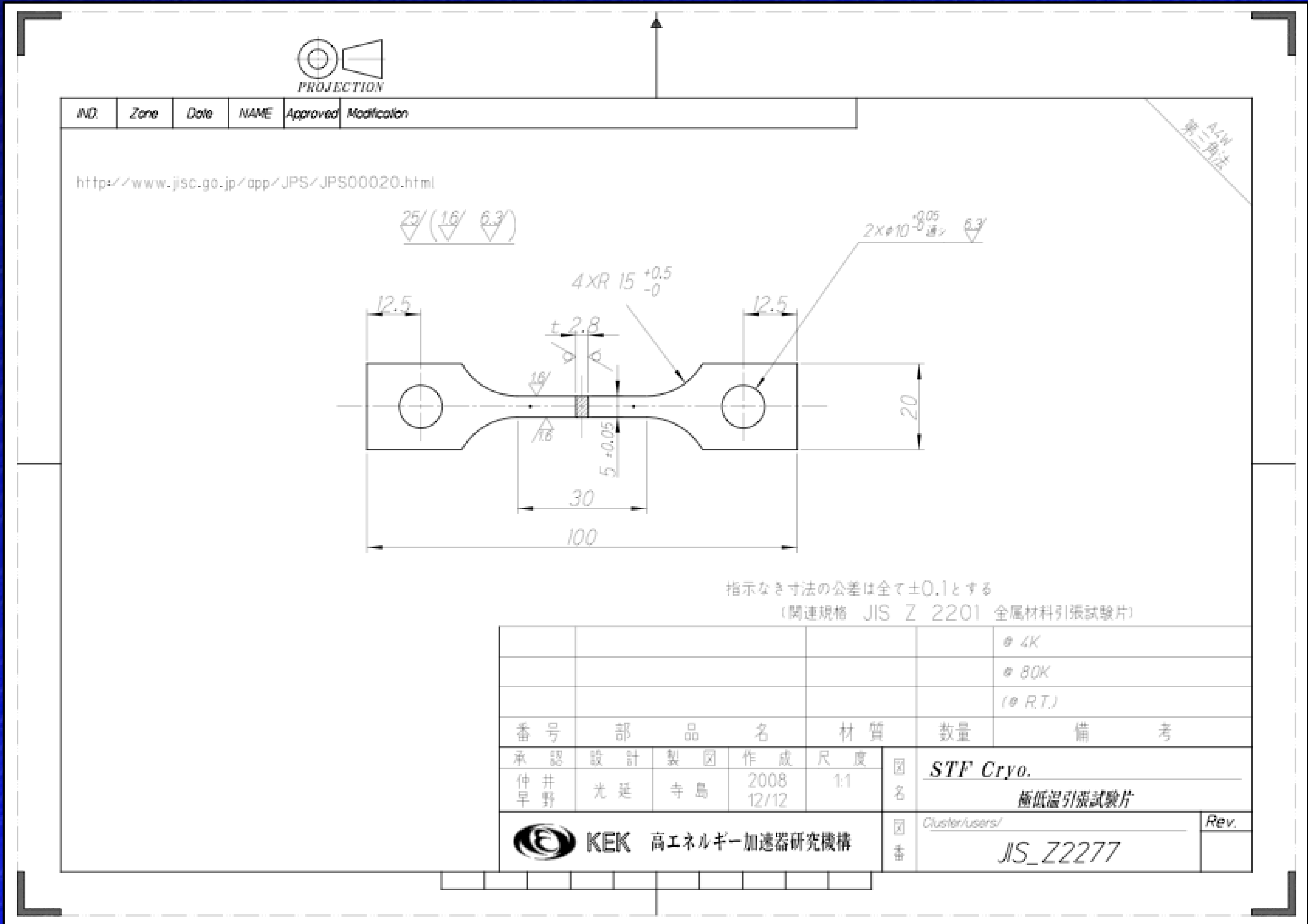
Test Specimen (Ex JIS 7)



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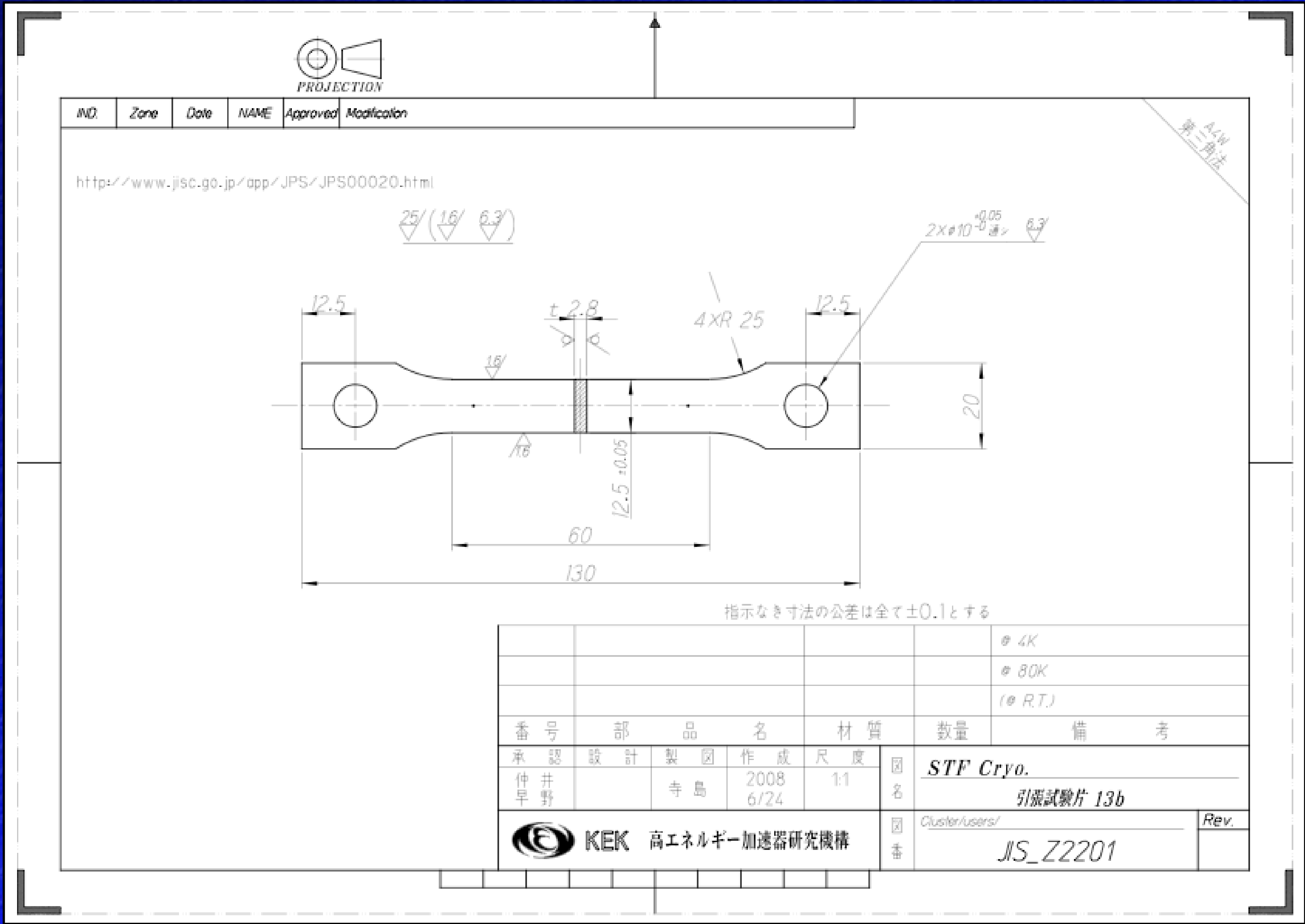
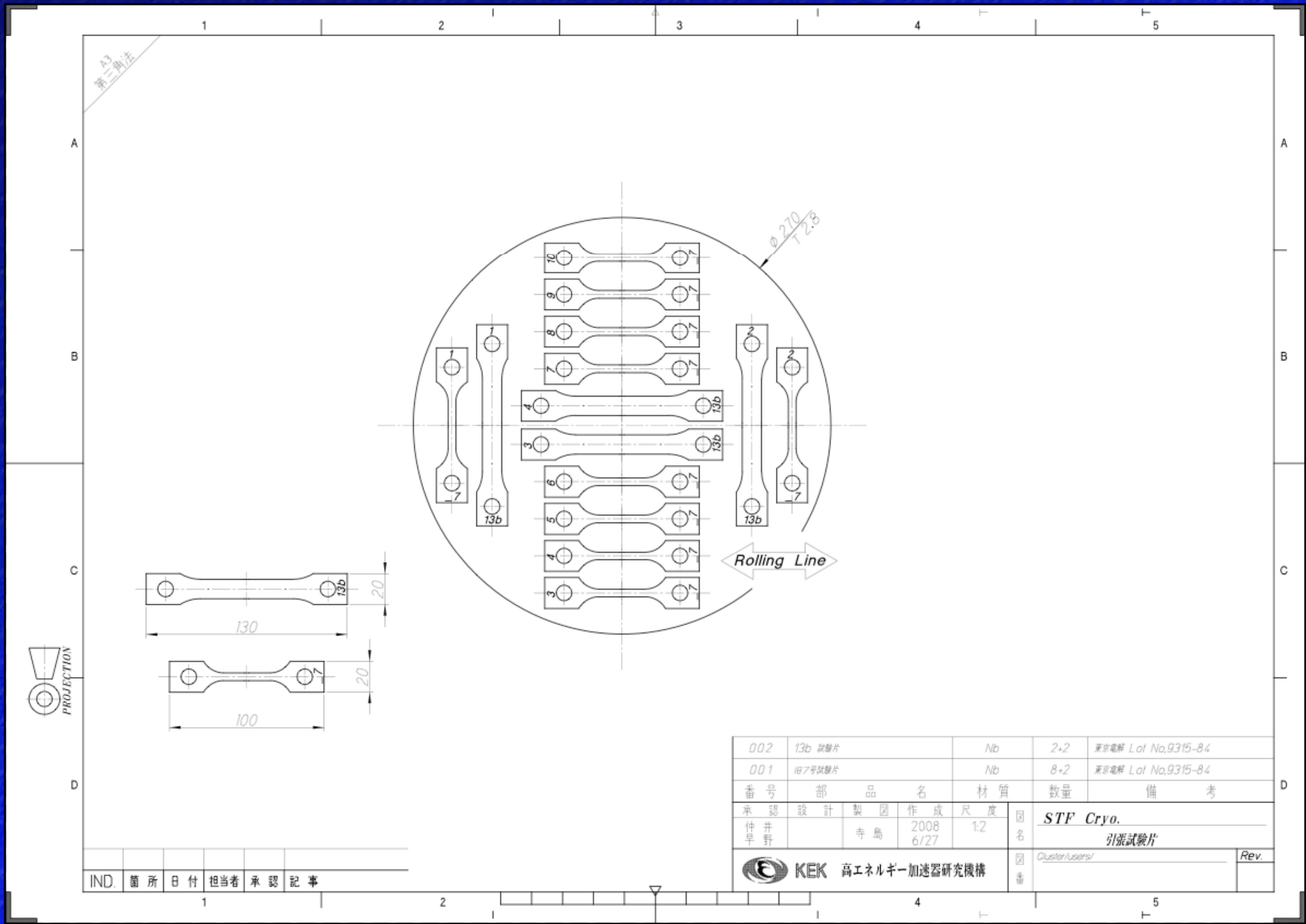
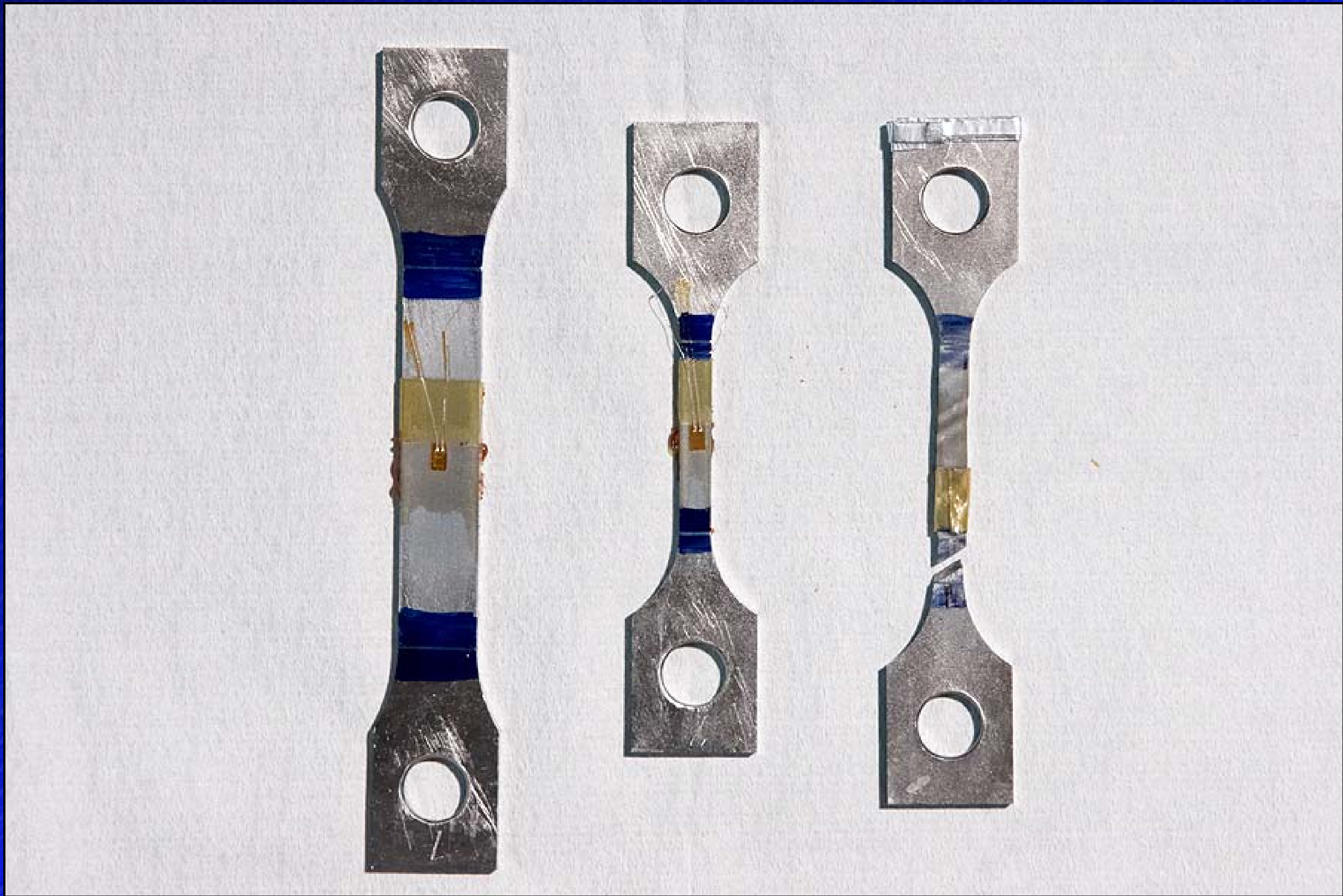
Test Specimen (JIS 13b)



Niobium Test Specimens



Niobium Test Specimens



Niobium Tested

- Same material as KEK Base-Line cavities
- Annealed at 750 °C
- Difference in roll and cross directions
- Difference in specimen dimensions
  - Ex JIS 7 - specimen for low temp. testing
  - JIS 13b - current minimum-size specimen

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Niobium Test Results (Ex JIS 7)

Tensile Test Results (Form 2) No. STF-01-2

Lot No. : Tokyo Denkai 9315-84 φ270 t2.8		Material : Niobium
Test Date : July 24 (Thu), 25 (Fri), 26 (Sat) and Oct. 4 (Tue)		
Testers : NAKAI Hirotaka and YATABE Eiichi	Testing Place : PF-AR East	
Testing Machine : Shimadzu Autograph AG-5000C	Test Specimen : Ex JIS 7 and JIS 13b	
Strain Gauge : Kyowa Elect. Instr. KFL-1-C1-11 (Y010-007)	Gauge Factor : 2.02	Gauge Adhesive : PC-6

Specimen No.	Cross Section [mm^2]	Test Temp. [K]	Tensile strength [MPa]	0.2% Proof Stress [MPa]	Mod. Elasticity [MPa]	Elongation [%]	Remarks
7-2	12.7	LN2	638	577	122180	23.0	
7-6	12.6	LN2	636	626	122007	21.0	
7-10	12.6	LN2	661	640	118223	20.1	
7-8	12.9	LN2	636	-	-	21.7	Data logger check
7-1	12.5	?	581	-	-	-	Cool-down failed
7-3	12.5	LHe	973	589*	118618	19.0*	*slip included
7-9	12.7	LHe	962	640*	119465	14.1*	*slip included
7-4	12.7	302	168	55	97744	48.1	
7-5	12.6	302	166	55	98520	33.7	
7-7	12.7	302	158	55	110776	50.4	

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Niobium Test Results (JIS 13b)

Tensile Test Results (Form 2) No. STF-01-2

Lot No. : Tokyo Denkai 9315-84 !270 t2.8	Material : Niobium
Test Date : July 24 (Thu), 25 (Fri), 26 (Sat) and Oct. 4 (Tue)	
Testers : NAKAI Hirotaka and YATABE Eiichi	Testing Place : PF-AR East
Testing Machine : Shimadzu Autograph AG-5000C	Test Specimen : Ex JIS 7 and JIS 13b
Strain Gauge : Kyowa Elect. Instr. KFL-1-C1-11 (Y010-007)	Gauge Factor : 2.02 / Gauge Adhesive : PC-6

Specimen No.	Cross Section $[mm^2]$	Test Temp. [K]	Tensile strength [MPa]	0.2% Proof Stress [MPa]	Mod. Elasticity [MPa]	Elongation [%]	Remarks
13b-1	32.7	302	176	49	111354	47.0	
13b-2	33.5	302	168	49	108695	39.2	
13b-3	32.9	302	158	46	110677	40.9	
13b-4	33.3	302	152	46	109348	45.5	

Niobium Data (ATI Wah Chang)

ATI Wah Chang
Allegheny Technologies

TECHNICAL DATA SHEET

MECHANICAL PROPERTIES

Tensile strength, (psi) sheet, annealed Grade I	30,000
Yield strength, (psi) 0.2% offset, sheet, annealed	15,000
Elongation, %, annealed	30
Young's Modulus, (psi)	15.2×10^6
Hardness, (500 kg) Brinell, arc cast	60 to 75
electron beam cast	45 to 65

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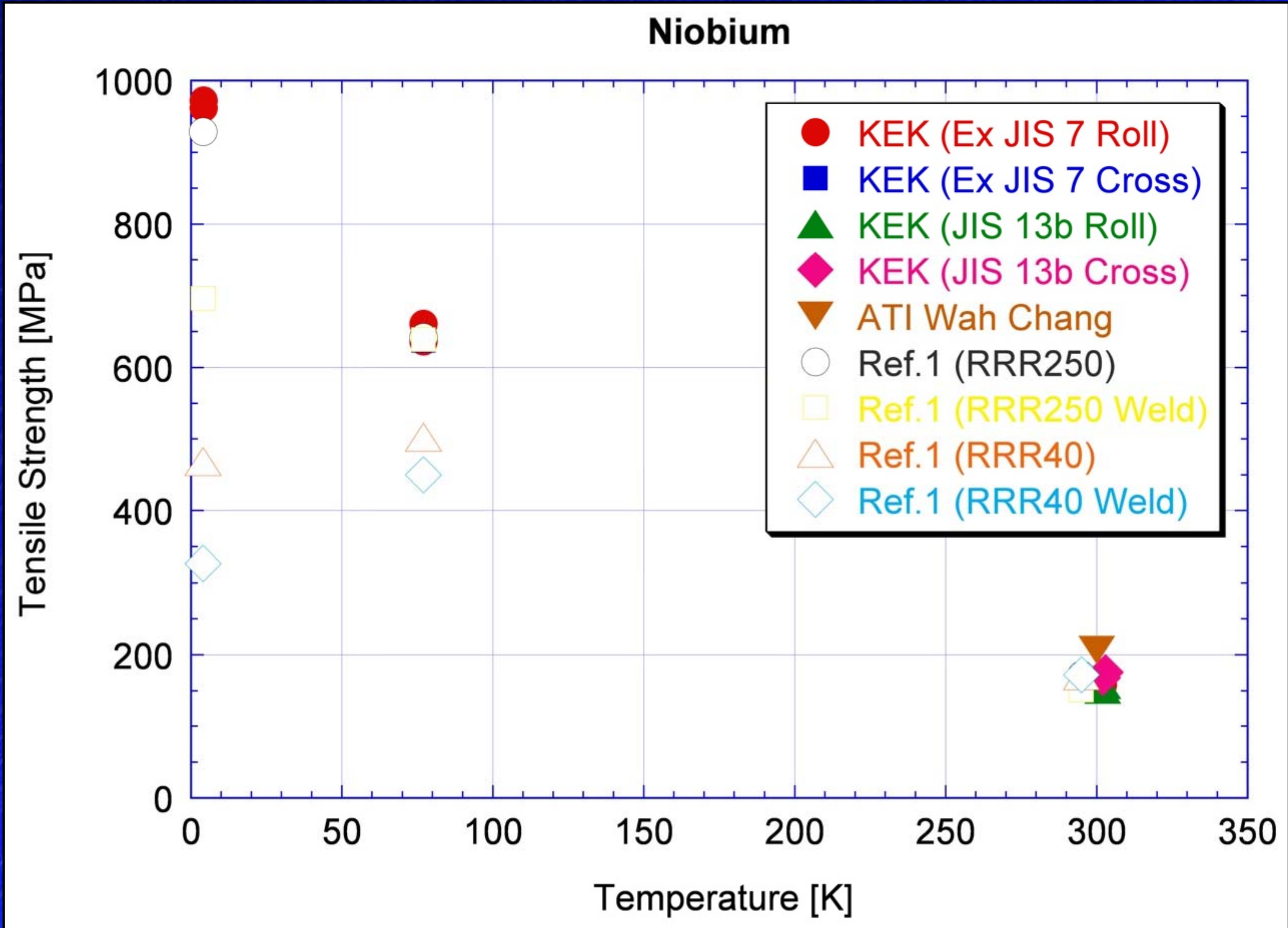
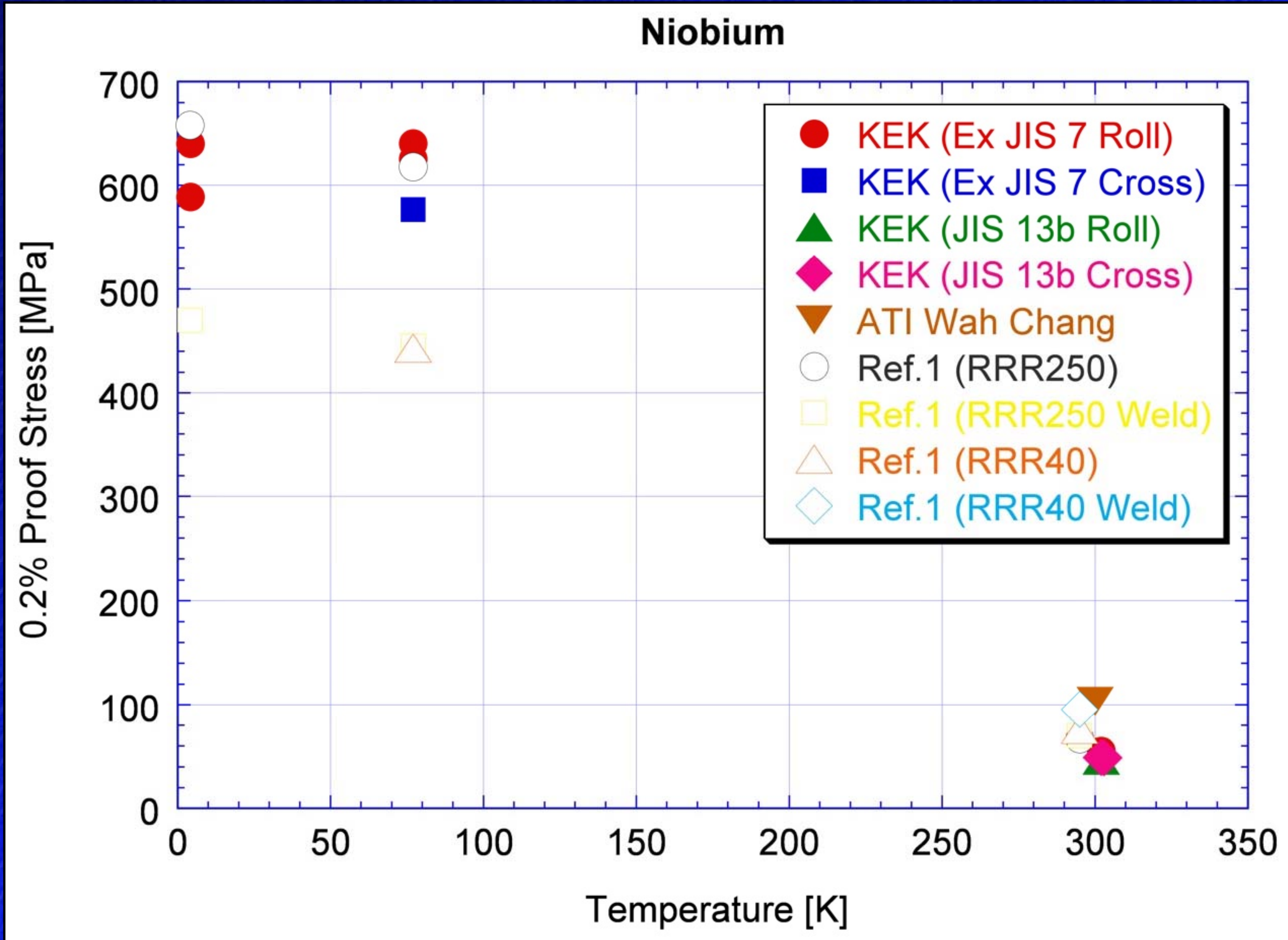
Tensile Strength (Nb)



0.2% Proof Stress (Nb)



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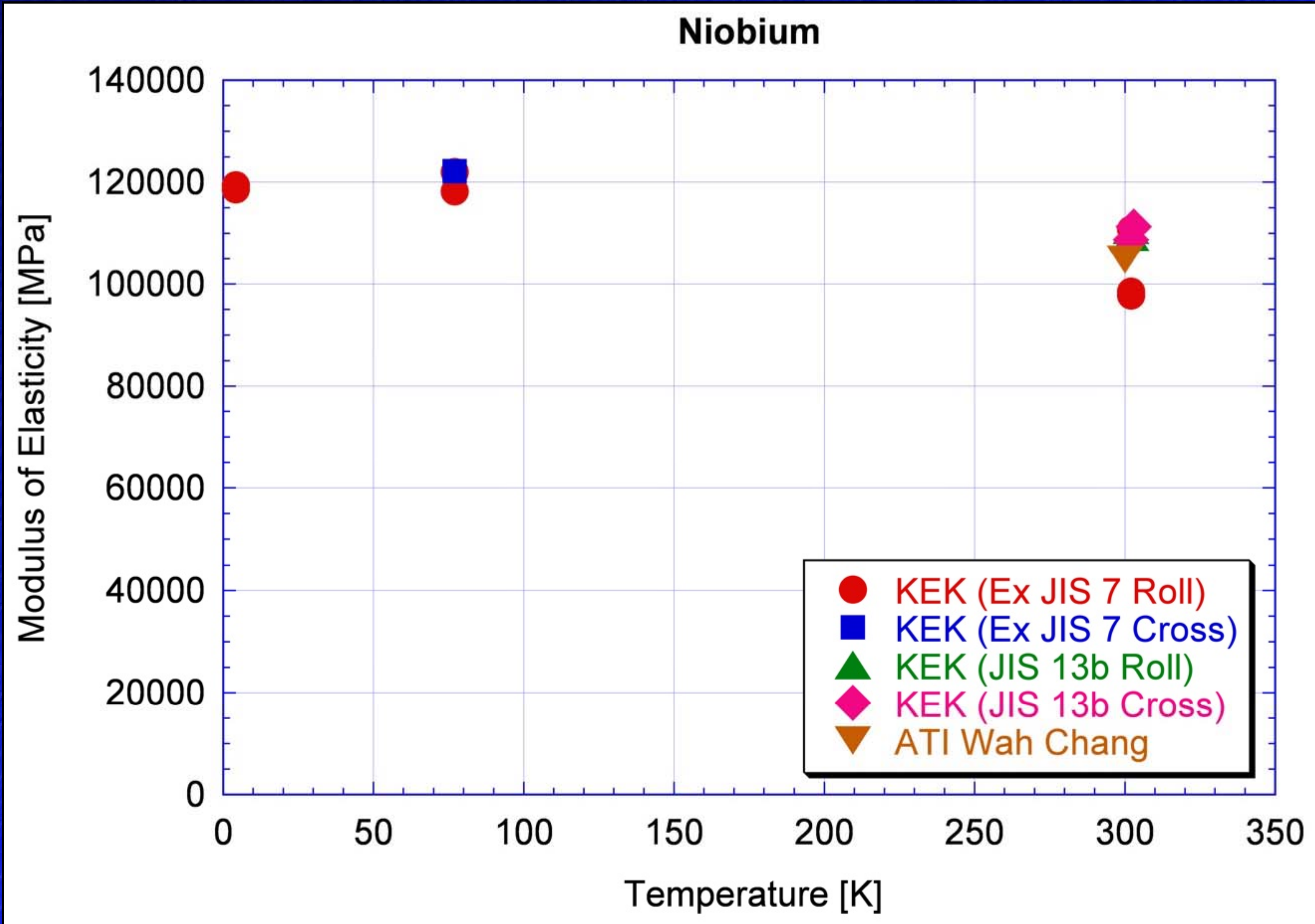
Modulus of Elasticity (Nb)



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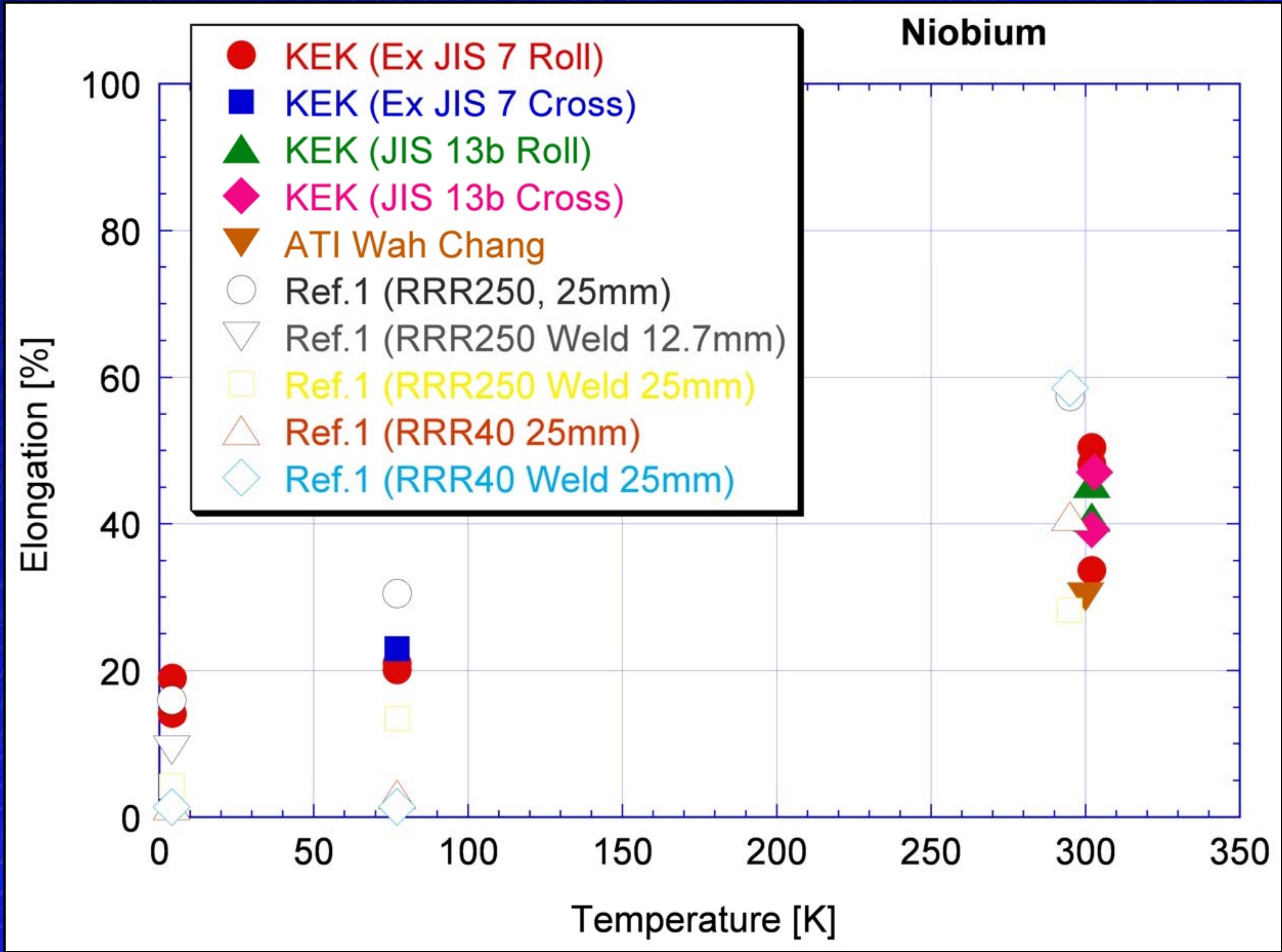
Elongation (Nb)



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Titanium Test Results (Ex JIS 7)

Tensile Test Results (Form 2) No. STF-02

Lot No. : Nippon Steel Corporation TC60575	Material : Titanium (TP340C)
Test Date : Oct. 4 (Sat), 6 (Mon) and 9 (Thu), 2008	
Testers : NAKAI Hirotaka and YATABE Eiichi	Testing Place : PF-AR East
Testing Machine : Shimadzu Autograph AG-5000C	Test Specimen : Ex JIS 7
Strain Gauge : Kyowa Elect. Instr. KFL-1-C1-11 (Y010-007)	Gauge Factor : 2.02; Gauge Adhesive : PC-6

Specimen No.	Cross Section [mm^2]	Test Temp. [K]	Tensile strength [MPa]	0.2% Proof Stress [MPa]	Mod. Elasticity [MPa]	Elongation [%]	Remarks
3	9.30	LHe	961	599*	133141	43.8*	*slip included
6	9.42	LHe	964	736*	133321	33.1*	*slip included
9	9.42	LHe	968	670*	135200	36.5*	*slip included
2	9.35	LN2	846	457	125810	64.4	
5	9.28	LN2	852	451	132096	63.9	
8	9.40	LN2	751	640	160702	60.1	
1	9.41	Room Temp.	366	243	118425	38.0	
4	9.37	Room Temp.	366	240	105716	42.1	
7	9.39	Room Temp.	384	330	121318	32.4	
10	9.46	-	-	-	-	-	for temp. comp.

Inspection Certificate (Ti)

製品検査証明書 INSPECTION CERTIFICATE

新日本製鐵株式會社
Nippon Steel Corporation

本社 HEAD OFFICE : 〒100-8071 東京都千代田区大手町二丁目6番3号 6-3,OTEMACHI2-CHOME,CHIYODA-KU,TOKYO,100-8071,JAPAN
チタン事業部光チタングループ : 〒743-8510 山口県光市大字島田3434番地 HIKARI TITANIUM DEPT.,TITANIUM DIVISION : 3434,SHIMATA,HIKARI-SHI,YAMAGUCHI,743-8510,JAPAN

注文者 SHIPPER : NITTETSU SHOJI
注文者照合番号 REFERENCE No. : 152 -060111
契約番号 CONTRACT No. : 6-972-RR-1-4-4107
商品名 COMMODITY : TITANIUM SHEET
規格 SPECIFICATION : JIS H4600 TP340C
仕上 FINISH : ANNEALED & PICKLED

需要家 CUSTOMER : UEX
需要家管理番号 CUSTOMER'S CONTROL No. :
特記 NOTE :

証明書番号 CERTIFICATE No. : TC60575
頁 PAGE : 1E
発行年月日 DATE OF ISSUE : 2006-05-11

行番 ITEM No.	寸法 SIZE MM	員数 QUANTITY	質量 MASS NET KG	管理番号 CONTROL No. 検査番号 INSPECTION No.	溶解番号 HEAT No.	コイル番号 COIL No.	*1	*2	*3	引張試験 TENSILE TEST (GL: 50MM) 耐力 YS N/MM2	引張強さ TS N/MM2	伸び EL %	降伏比 YR %	硬さ HARDNESS	曲げ BEND TEST	結晶粒度 GSN	エリクセン ER	*4	化学成分 CHEMICAL COMPOSITION % H ×1000	O ×100	N ×100	Fe ×100	C ×100	×100 ×1000	×100 ×1000	×100 ×1000	Ti
					SPEC.	MIN.				215	340	23															
						MAX.					510								13	20	3	25	8				
01	2.0X1219X4050																										
		13		65-AT009	N64130	90-1027	T	T	5	346	445	39			G			I	1	9	1	4	1				BAL.
																		P	2								
		6			N64265	90-0933	T	T	5	322	433	38			G			I	1	9	1	4	1				BAL.
																		P	1								
	TOTAL	19	846																								
		20	891	65-AT010	N64130	90-1027	T	T	5	346	445	39			G			I	1	9	1	4	1				BAL.
																		P	2								
		20	891	65-AT011	N64130	90-1027	T	T	5	346	445	39			G			I	1	9	1	4	1				BAL.
																		P	2								
		20	891	65-AT012	N64130	90-1027	T	T	5	346	445	39			G			I	1	9	1	4	1				BAL.
																		P	2								
		10	445	65-AT013	N64130	90-1027	T	T	5	346	445	39			G			I	1	9	1	4	1				BAL.
																		P	2								

その他試験 DESCRIPTION OF TEST	寸法検査 DIMENSIONAL INSPECTION	表面検査 SURFACE INSPECTION
	G	G

注釈 NOTES: GL:標点距離 Gauge Length (D: 4√So, E: 5.65√So), YR: Yield Ratio, GSN: Grain Size Number, ER: Erichsen, G:合格 Good, *1 T:頂部 Top, M:中央部 Middle, B:底部 Bottom, *2 L:圧延方向 Longitudinal, T:直角方向 Transverse, *3 JIS (5: No.5, B: No.13B), ASTM (A: 1/2"), *4 I:インゴット分析 Ingot Analysis, P:製品分析 Product Analysis

E04

上記注文品は、御指定の規格または仕様に従って製造され、その要求事項を満足していることを証明します。

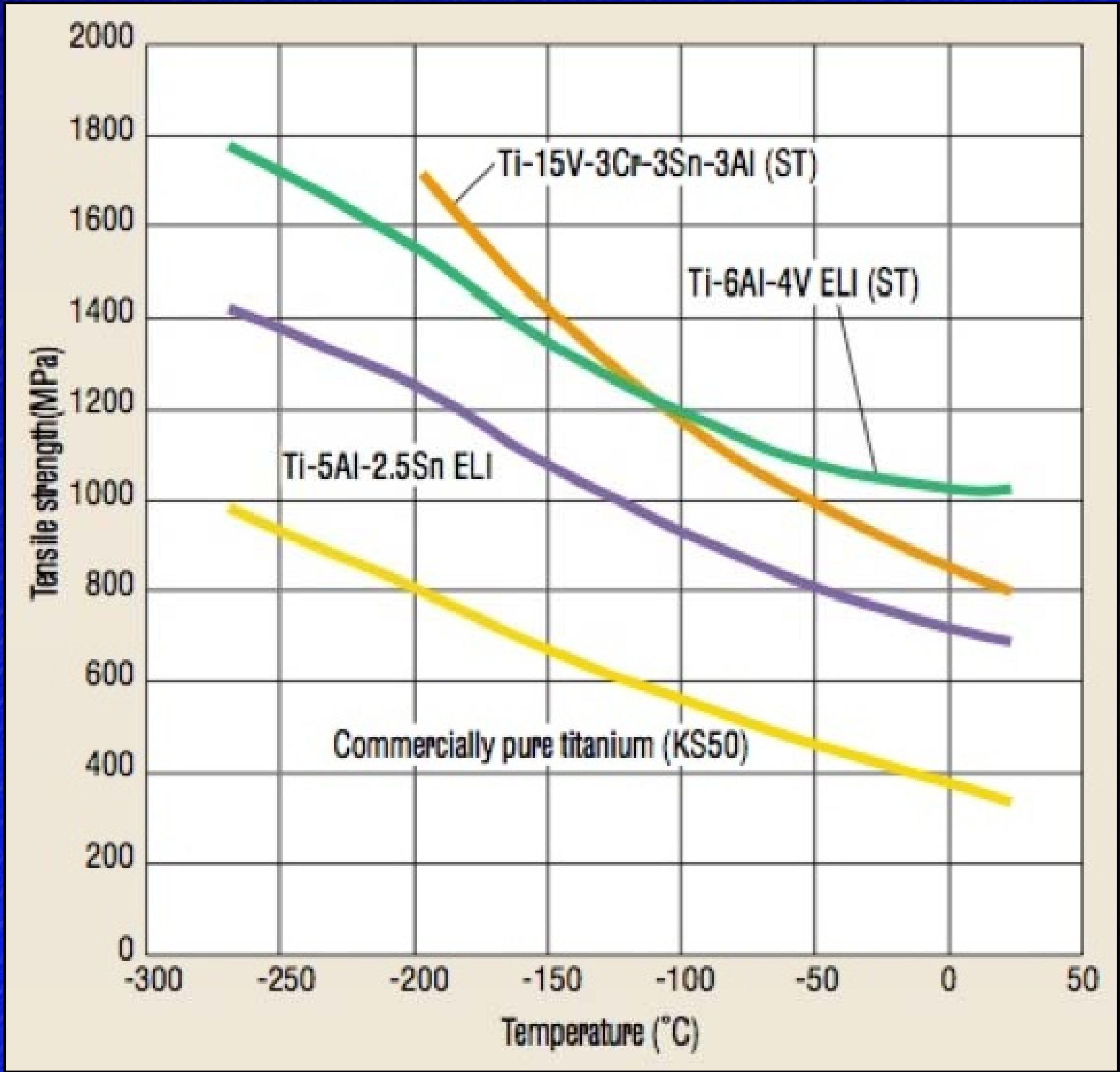
WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HEREIN HAS BEEN MADE IN ACCORDANCE WITH THE RULES OF THE CONTRACT.

H. Harada

チタン事業部
光チタングループリーダー
GROUP MANAGER,
HIKARI TITANIUM DEPT.,
TITANIUM DIVISION

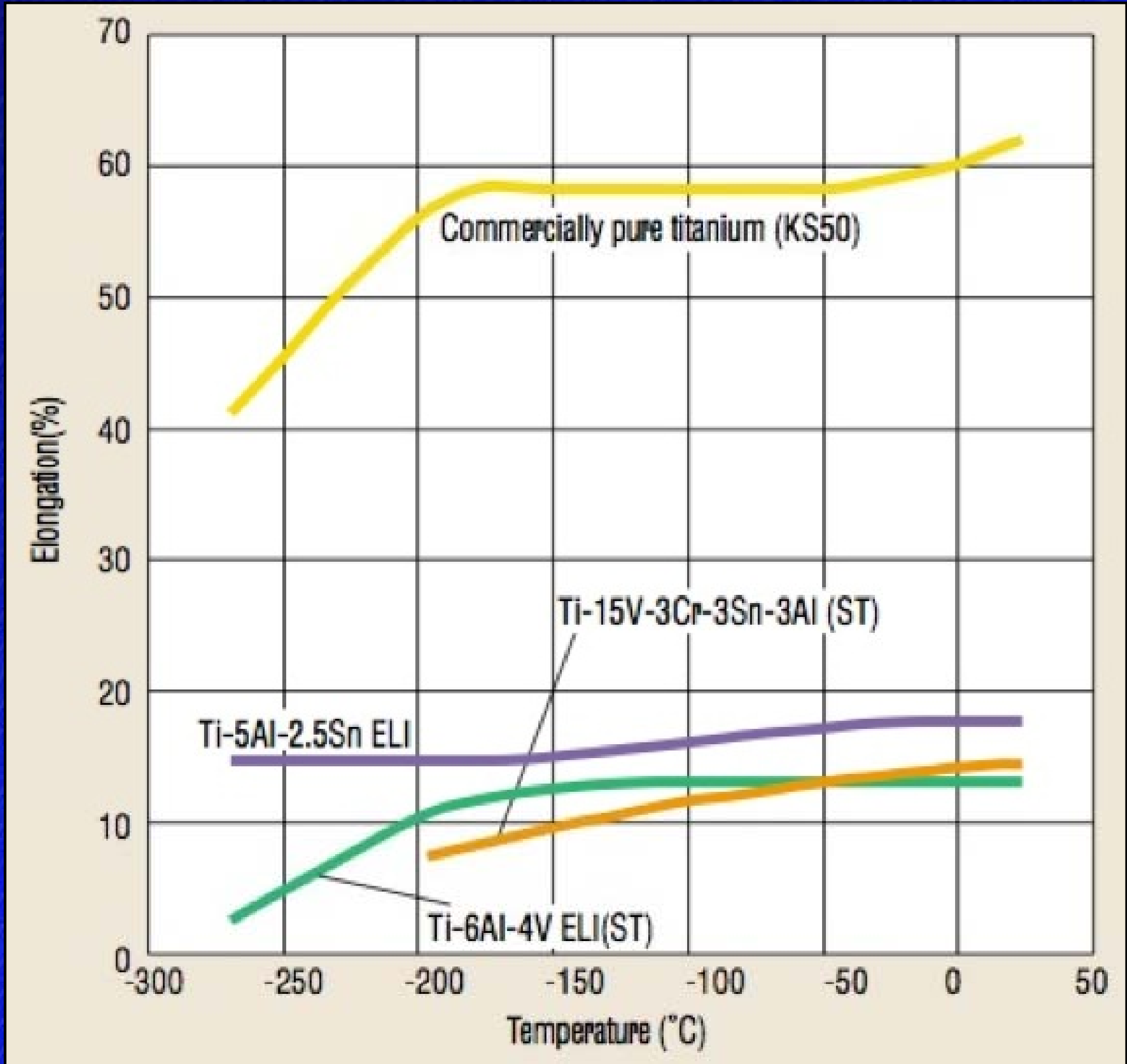
KEK

Tensile Strength Data (Kobelco)

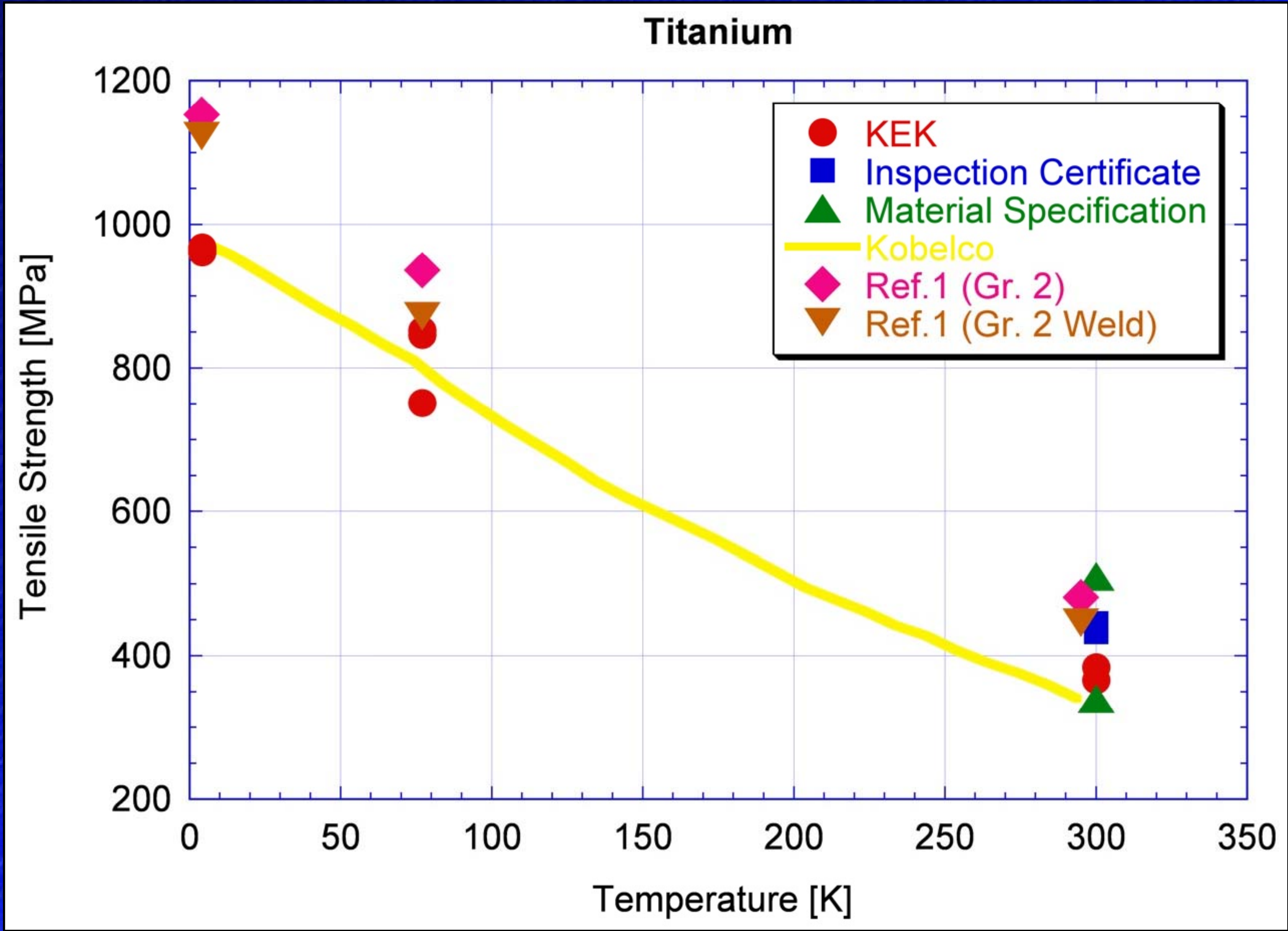


KEK

Elongation Data (Kobelco)



Tensile Strength (Ti)



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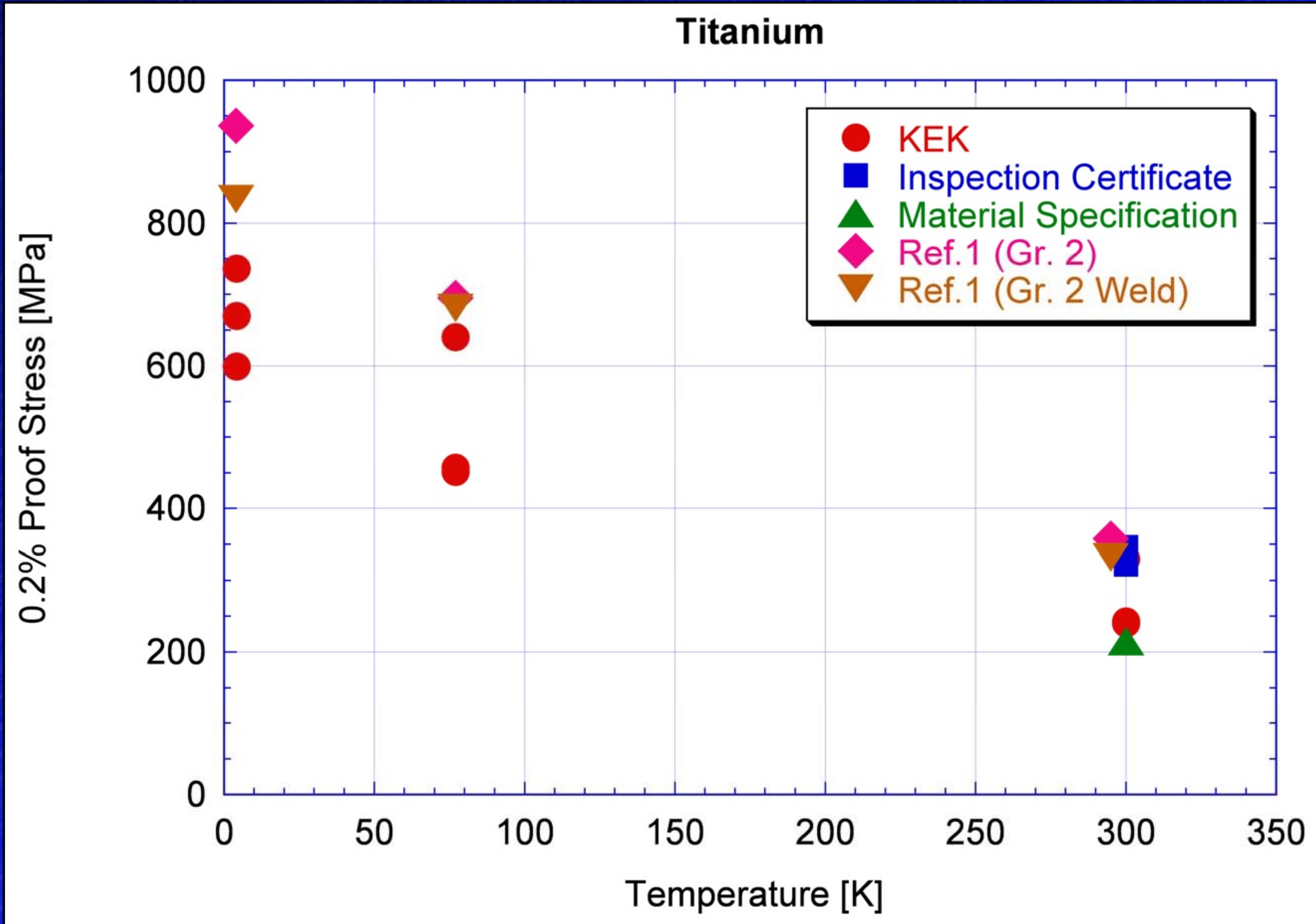
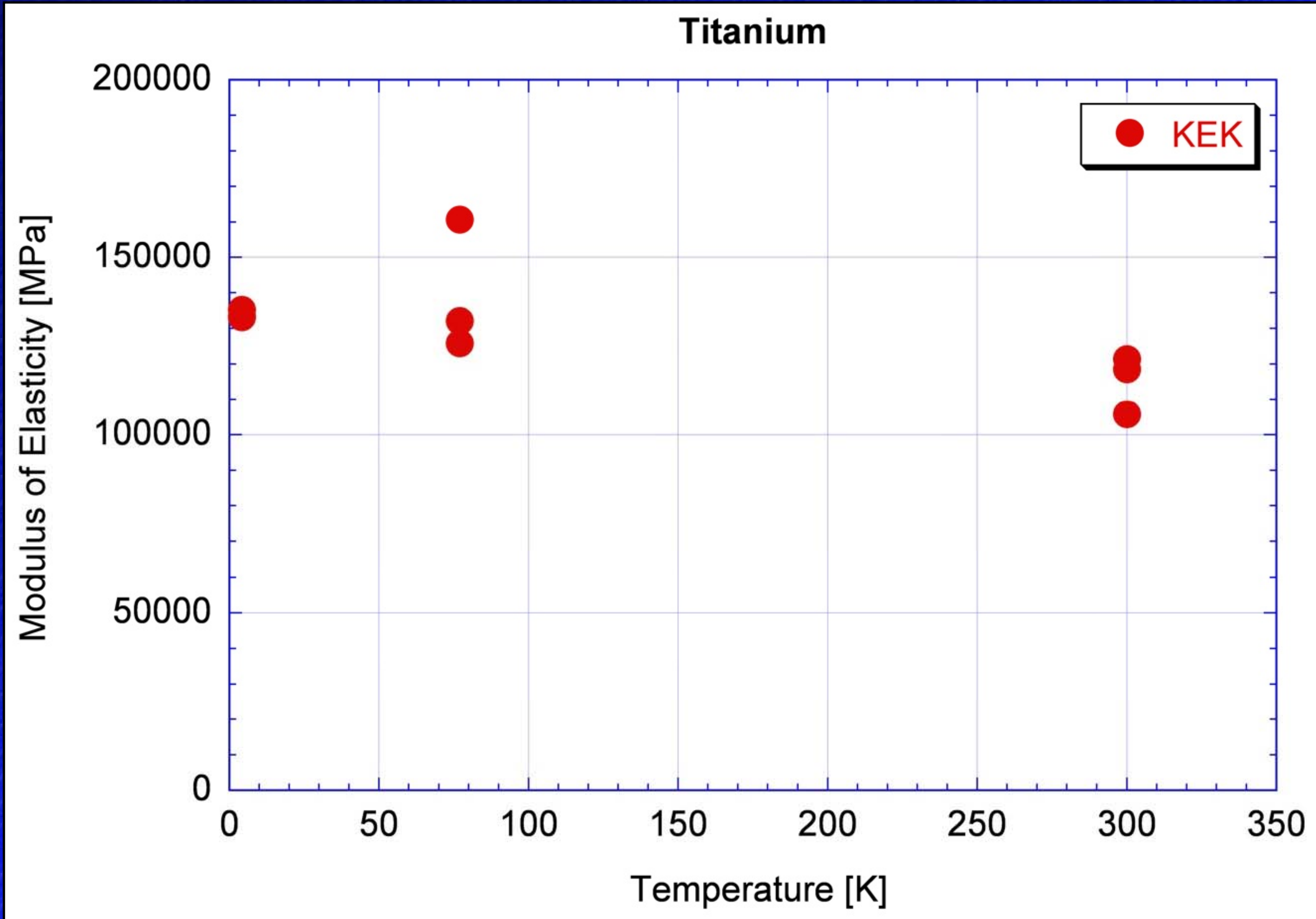
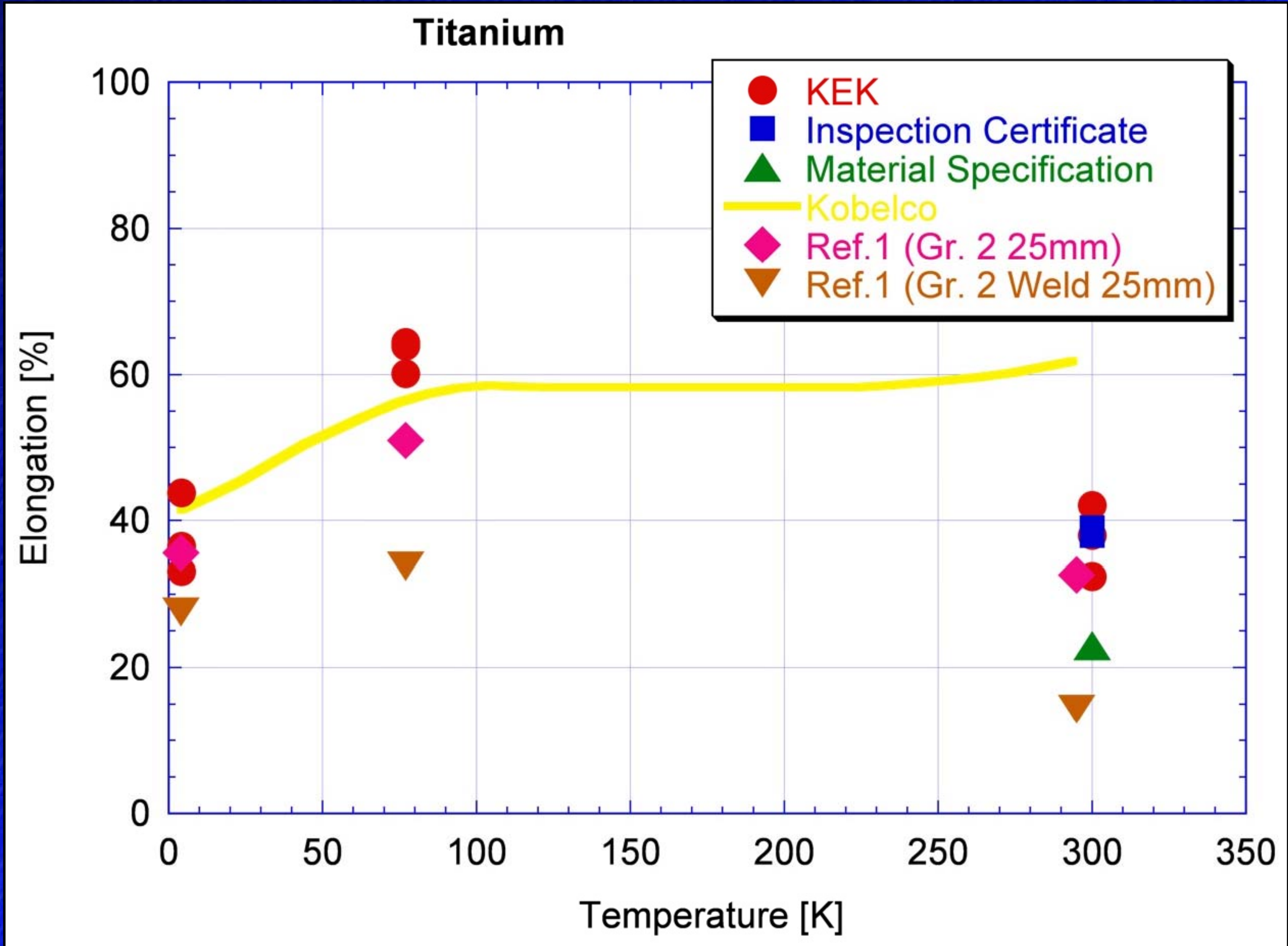
0.2% Proof Stress (Ti)



Modulus of Elasticity (Ti)



Elongation (Ti)



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Planned Material Tests

- Tensile tests at room, LN_2 and LHe temp.
  - welded part of Nb-Nb (EBW)
  - welded part of Ti-Ti (TIG)
  - welded part of Nb-Ti (EBW)
  - welded part of Nb-NbTi
- Charpy tests at room, LN_2 and LHe temp.
  - Nb-Stainless Steel (HIP with Cu)

KEK

Material Testing Machine at KEK

Specimen Set in Testing Section

KEK

Material Test at LN_2 Temp.

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Cryostat for LHe Temp. Test

Material Test at LHe Temp.