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EXTERNAL REFERENCE

Memorandum / Note

Summary of Material Data For Structural Analysis of the ITER Cryostat

This document summarizes the recommended data to be used for the structural analysis of Cryostat made of austenitic steel type 304, 304L and material properties data for cryostat toroidal skirt support material. The proposed main reference material is dual marked 304/304L.

Approval Process			
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Change Log				
Title (Uid)	***Version***	***Latest Status***	***Issue Date***	***Description of Change***
Summary of Material Data For Structural Analysis of the ITER Cryostat (3F863L_v1_6)	v1.6	Approved	06 Aug 2013	Reference page numbers were updated and format of tables was modified. Data for support materials added. Data for bolting 8.8 added.
Summary of Material Data For Structural Analysis of the ITER Cryostat (3F863L_v1_5)	v1.5	Approved	12 Mar 2013	Applicable codes and standards issue dates were updated. Reference page numbers were updated and errata and format of tables were modified.
Summary of Material Data For Structural Analysis of the ITER Cryostat (3F863L_v1_4)	v1.4	Approved	23 Jan 2013	Chapter 6 added: Tensile properties and allowable stress values for materials for bellows up to 200ºC. Data for bolts 660 added.
Summary of Material Data For Structural Analysis of the ITER Cryostat (3F863L_v1_3)	v1.3	Signed	23 Jan 2013	Chapter 6 added: Tensile properties and allowable stress values for materials for bellows up to 200ºC. Data for bolts 660 added.
Summary of Material Data For Structural Analysis of the ITER Cryostat (3F863L_v1_2)	v1.2	Approved	19 Oct 2011	Misprints corrected Stress stain curve for forgings with thickness > 125 mm added Stress strain curve for plate at RT corrected Data for tensile properties and stress strain curves for 304L removed Sm values for temperature 100C changed to conservative
Summary of Material Data For Structural Analysis of the ITER Cryostat (3F863L_v1_1)	v1.1	Approved	11 Nov 2010	Recommended reference materials is dual marked austenitic steel 304/304L; Properties of bolting material B8 included; Properties for material for cryostat toroidal skirt support added; Requirements for permeability of steel 304/304L added.
Summary of Material Data For Structural Analysis of the ITER Cryostat (3F863L_v1_0)	v1.0	Signed	20 Aug 2010	

Summary of Material Data

For Structural Analysis of the ITER Cryostat

Abstract

This document summarizes the recommended data to be used for the structural analysis of Cryostat made of austenitic steel type 304, 304L and material properties data for cryostat toroidal skirt support material.

The proposed main reference material is dual marked 304/304L.

	IDM Number:	ITER_D_3F863L v1.6	Date 31.07.2013
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Revision History

Rev. No	Date	Changes
1.0	20 August 2010	First issue
1.1	11 November 2010	Recommended reference material is dual marked austenitic steel 304/304L; Properties of bolting material B8 included; Properties for material for cryostat toroidal skirt support added; Requirements for permeability of steel 304/304L added.
1.2	19 October 2011	Misprints corrected Stress stain curve for forgings with thickness > 125 mm added Stress strain curve for plate at RT corrected Data for tensile properties and stress strain curves for 304L removed S_m values for temperature 100ºC changed to conservative.
1.3	23 January 2013	Misprint corrected
1.4	23 January 2013	Chapter 6 added: Tensile properties and allowable stress values for materials for bellows up to 200ºC. Data for bolts steel grade 660 added.
1.5	12 March 2013	Applicable codes and standards issue dates were updated. Reference page numbers were updated and errata and format of tables were modified.
1.6	06 August 2013	Reference page numbers were updated and format of tables was modified. Data for support materials added. Data for bolting 8.8 added.

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1 General information

This document summarizes the recommended data of the materials needed for the structural analysis of the ITER Cryostat.

Applicable Code - ASME Section VIII Division 2 Edition 2010.

The list of materials used in the design of ITER vacuum vessel is shown in Table 1.

Table 1. List of Materials for Cryostat

Common designation (AISI, ASTM, etc.)	Nominal composition	UNS No.	Form	Standards
Steel type 304L	18Cr-8Ni	S30403	Plate	ASME SA-240 ASTM A240/240M
Steel type 304	18Cr-8Ni	S30400	Plate	ASME SA-240 ASTM A240/240M
Steel grade F304L	18Cr-8Ni	S30403	Forging	ASME SA-182, ASME SA-965 ASTM A182/182M ASTM A965/965M
Steel grade F304	18Cr-8Ni	S30400	Forging	ASME SA-182, ASME SA-965 ASTM A182/182M ASTM A965/965M
Type B8, Class 1/ Solution treatment	18Cr-8Ni	S30400	Bolting	ASME SA-193 ASME SA-320 ASTM A-193 ASTM A320
Grade 660	25Ni-15Cr-2T	S66286	Bolting	ASME SA-453
SA-533, Type D, Class 2	Mn– ½Mo– ¼Ni	K12529	Plate for support	ASME SA-533
SA-508 Grade 3, Class. 2	¾Ni-½Mo-Cr-V	K12042	Forging for support	ASME SA-508
ISO 898-1 Class 8.8			Bolting	EN ISO 898-1

In accordance with ASME Section VIII Division 2 Edition 2010:

- physical properties are in Section II, Part D
- tensile properties are in Table Y-1 and Table U
- allowable design stresses S_m for these steels are in ASME Section II, Part D, Table 5a.
- design stress intensity values S_m for bolting materials (use with Part 5 and Annex 5.F of Section VIII, Division 2) are in ASME Section II, Part D, Table 4.

Criteria for allowable stress for Table 5a and Table 4 are shown below.

ASME, Section II, Part D (metric)
MANDATORY APPENDIX 10, BASIS FOR ESTABLISHING MAXIMUM ALLOWABLE STRESS VALUES FOR TABLES 5A AND 5B:

TABLE 10-100
CRITERIA FOR ESTABLISHING ALLOWABLE STRESS VALUES FOR TABLES 5A AND 5B

	Below Room Temperature		Room Temperature and Above			
Product/Material	Tensile Strength	Yield Strength	Tensile Strength	Yield Strength	Stress Rupture	Creep Rate
All wrought or cast ferrous and nonferrous product forms except bolting	$\frac{S_T}{2.4}$	$\frac{S_y}{1.5}$	$\frac{S_T}{2.4}$	$\frac{R_y S_y}{1.5}$	Min. $\left(F_{avg} S_{R\,avg}\,,\ 0.8 S_{R\,min}\right)$	$1.0 S_{C\,avg}$
All wrought or cast austenitic and similar nonferrous product forms except bolting [Note (1)]	$\frac{S_T}{2.4}$	$\frac{S_y}{1.5}$	$\frac{S_T}{2.4}$	Min. $\left(\frac{S_y}{1.5}, \frac{0.9 S_y R_y}{1.0}\right)$	Min. $\left(F_{avg} S_{R\,avg}\,,\ 0.8 S_{R\,min}\right)$	$1.0 S_{C\,avg}$

GENERAL NOTE: When using this stress basis criterion to determine the allowable stresses for a specific material as a function of temperature, the derived allowable stress at a higher temperature can never be greater than the derived allowable stress at a lower temperature.

NOTE:

(1) Two sets of allowble stress values are provided in Table 5A for austenitic materials and in Table 5B for specific nonferrous alloys. The lower values are not specifically identified by a footnote. These lower values do not exceed two-thirds of the minimum yield strength at temperature. The higher alternative allowable stresses are identified by a footnote. These higher stresses may exceed two-thirds but do not exceed 90% of the minimum yield strength at temperature. The higher values should be used only where slightly higher deformation is not in itself objectionable. These higher stresses are not recommended for the design of flanges or other strain-sensitive applications.

ASME, Section II, Part D (metric)
MANDATORY APPENDIX 2 BASIS FOR ESTABLISHING DESIGN STRESS INTENSITY VALUES FOR TABLES 2A, 2B, AND 4, AND ALLOWABLE STRESS VALUES FOR TABLE 3:

TABLE 2-100(c)
CRITERIA FOR ESTABLISHING DESIGN STRESS INTENSITY VALUES FOR TABLE 4

Product/Material	Tensile Strength		Yield Strength	
Bolting, with strength enhanced by heat treatment or strain hardening	NA	NA	$\frac{1}{3} S_Y$	$\frac{1}{3} S_Y R_Y$

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2 Material properties for cryostat structures

Grade 304L and grade 304 austenitic steels were considered for application.
Low carbon (max - 0.030 %) grade 304L has excellent welding characteristics and performance of the welded joints, but lower strength properties in comparison with steel 304.

Grade 304 has higher tensile properties than steel 304L, but due to high carbon content (max - 0.08%) the welds can be subject to enhanced corrosion and intergranular corrosion attack.

It is propose to use material with dual marking, as described in ASME 2010, Sec II, Part D, Mandatory Appendix 7, Guideline for multiple marking of materials:

> **7-210 ACCEPTABILITY OF MULTIPLE MARKING**
> Dual or multiple marking is acceptable, as long as the material so marked meets all of the requirements of all the specifications, grades, classes, and types with which it is marked…
> Many specifications or grades have significant overlap of chemistry ranges or properties. It is common for material manufacturers to produce materials that satisfy more than one specification, grade, class, or type. Examples are SA-53 and SA-106 (some grades and classes), SA-213 TP304L and TP304, SA-213 TP304 and TP304H, and SA-106 B and C.
>
> **7-240 MARKING SELECTION**
> If a material is marked with specifications, grades, classes, or types, it may be used with the allowable stresses, design stress intensities, or ratings appropriate for any of the markings on the material, as long as the material specification, grade, class, and type is permitted by the code of construction governing the boiler, vessel, or component in which the material is to be used. However, once the designer has selected which marking applies (specification, grade, class, type, etc.), the designer must use all the design values appropriate for that selection and may not mix and match values from any other specifications, grades, classes, types, etc., with which the material may be marked.

Recommended reference material is dual marked 304/304L steel with the following main requirements:

- **low carbon as for grade 304L**
- **tensile properties as for grade 304**

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2.1 Chemical composition requirements, wt. %.

Maximum, unless range or minimum is indicated.

	304L plate	F304L forging	304 plate	F304 forging
Element	**[Ref. 1]**	**[Ref. 2]**	**[Ref. 1]**	**[Ref. 2]**
C	0.030	0.030	0.08	0.08
Mn	2.00	2.00	2.00	2.00
Si	0.75	1.00	0.75	1.00
Cr	18.0 - 20.0	18.0 – 20.0	18.0 - 20.0	18.0 – 20.0
Ni	8.0 – 12.0	8.0 – 12.0 [8.0 – 13.0]#	8.0 – 10.5	8.0 – 11.0
P	0.045*	0.045*	0.045*	0.045*
S	0.030*	0.030*	0.030*	0.030*
N	0.10	-	0.10	-

In ASME SA-182.

*** More stringent requirements are established in PA [2.4.P1A.IN.01 Cryostat Annex B (ITER_D_45N2WS v4.1)]:**

Element	Max wt. %
P	0.030
S	0.015
Nb	0.10
B	0.0018

- Requirements for Co content **(Co ≤ 0.10%)**

Ref. 1 SPECIFICATION FOR CHROMIUM AND CHROMIUMNICKEL STAINLESS STEEL PLATE, SHEET, AND STRIP FOR PRESSURE VESSELS AND FOR GENERAL APPLICATIONS, SA-240/SA-240M, (Identical with ASTM Specification A 240/A 240M-04)

Ref. 2 SPECIFICATION FOR STEEL FORGINGS, AUSTENITIC,FOR PRESSURE AND HIGH TEMPERATURE PARTS, SA-965/SA-965M, (Identical with ASTM Specification A 965/A 965M-06a)

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2.2 Physical properties

The same properties are recommended by ASME for 304 and 304L grades steels.

Temperature	Density	Young's Modulus	Poisson's Ratio	Mean Thermal Expansion	Thermal Conductivity	Specific Heat
°C	kg/m^3	GPa		10^{-6}, 1/K	W/m K	J/kg K
20	8030	195*	0.31	15.3	14.8	482
100		189		16.2	16.2	509

* at 25ºC.

References:	ASME 2010, Sec II, Part D (metric) Table PRD, page 744.	ASME 2010, Sec II, Part D (metric), Table TM-1, Group G, page 738.	ASME 2010, Sec II, Part D (metric) Table PRD, page 744.	ASME 2010 Sec. II, Materials, Part D (metric), Table TE-1, page 711.	ASME 2010, Sec II, Part D (metric), Table TCD, Group J page 727.	ITER MPH file AB01-3108 Spec Heat.doc

Electrical resistivity at RT: 72 μOhms*cm, [See ITER MPH, ITER-IDM_ZD_**29DDT7]**

Magnetic permeability at room temperature – max 1.03,
see Project Requirements (PR)_27ZRW8_v4_6.

Physical properties at cryogenic temperature:

Temperature	Density	Young's Modulus	Poisson's Ratio	Mean Thermal Expansion	Thermal Conductivity	Specific Heat
°C	kg/m^3	GPa		10^{-6}, 1/K	W/m K	J/kg K
(see in brackets below number)	As at RT	209 (73K)	As at RT	12.89 (77K)	7.98 (70K)	178 (70K)

References:		ASME 2010, Sec II, Part D (metric), Table TM-1, Group G, page 738.		ITER MPH	ITER MPH	ITER MPH

Electrical resistivity at 70K: 49.5 μOhms*cm, [see ITER MPH,]

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2.3 Tensile properties and allowable stress values

a) Plates and forgings for structures

Material	Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Maximum allowable stress values, S_m, MPa
Plate# 304	-30 to 40	**517** *(515*)*	**207** *(205*)*	**138**
	100	**485**	**170**	**113 (See Note below)**
Forging F304	-30 to 40	(t > 125 mm)** **483** *(485*)* (t ≤ 125 mm) **517** *(515*)*	**207** *(205*)*	**138**
	100	(t > 125 mm) **453** (t ≤ 125 mm) **485**	**170**	**113 (See Note below)**
Reference		ASME 2010, Sec II, Part D (metric), Table U.	ASME 2010, Sec II, Part D (metric), Table Y-1.	ASME 2010, Sec II, Part D (metric), Table 5A.

t – thickness.

ASME Code does not define the limit for plate thickness. However, thickness of plates of austenitic steels typically limited to maximum of ~120 – 150 mm. It is proposed to consider the limit for maximum thickness of plates as 125 mm (the same value is used to transition for properties change between thick and thin forgings).

* The values in brackets are minimum values used in ASME/ASTM standards for acceptance of materials during procurement.
** In ASME SA-965 there are no limit for thickness for forgings.

Note:

S_m value at 100ºC was calculated in accordance with ASME, Section II, Part D (metric), Note in Table 10-100 of MANDATORY APPENDIX 10, BASIS FOR ESTABLISHING MAXIMUM ALLOWABLE STRESS VALUES FOR TABLES 5A AND 5B (see page 5 of this document):

$$S_m = S_y \text{ (100ºC) } /1.5$$

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b) Sheet/Plates for bellows (ASME standard SA-240) up to 200 ºC

Dual marked 304/304L type austenitic steel sheets are proposed for bellows.

Temperature, ºC	Elastic modulus, GPa	Mean Thermal Expansion, 10^{-6}, 1/K	Tensile strength S_u, MPa	Yield strength S_y, MPa	Allowable stress values, S_m, MPa
20	195	15.3	515	205	138
100	189	16.2	485	170	138
200	183	17.0	442	144	129
Reference	ASME 2010, Sec II, Part D (metric), Table TM-1, Group G, page 738	ASME 2010, Sec II, Part D (metric), Table TE-1, Group 3, page 711	ASME 2010, Sec II, Part D (metric), Table U	ASME 2010, Sec II, Part D (metric), Table Y-1	ASME B31.3, 2010 Table A-1 See Note 2 and 3 below

Note:

1. **Values of tensile strength Su and yield strength S_y have been taken from ASME Sec II, Part D (metric)**

2. **Value of S_m for materials for bellows defined in ASME B31.3:**
   302.3 Allowable Stresses and Other Stress Limits
   302.3.2 Bases for Design Stresses

   …(d) Other Materials. Basic allowable stress values at temperature for materials other than bolting materials, cast iron, and malleable iron shall not exceed the lowest of the following:

   …(3) for austenitic stainless steels and nickel alloys having similar stress–strain behaviour, the lower of **two thirds of S_Y (yield strength at room temperature) and 90% of yield strength at temperature** [see (e) below].

3. **ASME B31.3, Table A-1 gives value of allowable stresses in Customary units. The data were recalculated SI.**

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2.4 Stress strain curves

Stress strain curves for AISI steel 304 were prepared based on ASME Boiler & Pressure Vessel Code, Edition 2010, Section VIII, Division 2, Annex 3.D – Strength parameters, pages 3-100-3-104.

	Steel AISI 304 Plates, forgings, t ≤ 125 mm	**Steel AISI 304 Forgings, t > 125 mm**
	S_y min (RT) = 207 MPa	S_y min (RT) = 207 MPa
	S_u min (RT) = 517 MPa	S_u min (RT) = 483 MPa
	E (RT) = 195 GPa	E (RT) = 195 GPa
Stress, MPa	**Strain**	**Strain**
0	0.00000E+00	0.00000E+00
10	5.12826E-05	5.12822E-05
20	1.02581E-04	1.02571E-04
30	1.53970E-04	1.53903E-04
40	2.05650E-04	2.05398E-04
50	2.58008E-04	2.57313E-04
60	3.11679E-04	3.10115E-04
70	3.67619E-04	3.64562E-04
80	4.27164E-04	4.21786E-04
90	4.92112E-04	4.83395E-04
100	5.64792E-04	5.51578E-04
110	6.48160E-04	6.29229E-04
120	7.45902E-04	7.20097E-04
130	8.62577E-04	8.28968E-04
140	1.00381E-03	9.61909E-04
150	1.17657E-03	1.12662E-03
160	1.38960E-03	1.33293E-03
170	1.65412E-03	1.59365E-03
180	1.98485E-03	1.92578E-03
190	2.40175E-03	2.35259E-03
200	2.93264E-03	2.90684E-03
210	3.61728E-03	3.63579E-03
220	4.51313E-03	4.60855E-03
230	5.70321E-03	5.92590E-03
240	7.30456E-03	7.73096E-03
250	9.47371E-03	1.02147E-02
260	1.24002E-02	1.36029E-02
270	1.62747E-02	1.81061E-02
280	2.12208E-02	2.38229E-02
290	2.72078E-02	3.06333E-02
300	3.39982E-02	3.81718E-02
350	6.77714E-02	7.36255E-02
400	9.51772E-02	1.03397E-01
450	1.23789E-01	1.35971E-01
500	1.56151E-01	1.73484E-01
550	1.92663E-01	2.16305E-01
600	2.33445E-01	2.64617E-01
650	2.78579E-01	3.18580E-01

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700	3.28144E-01	3.78345E-01

	Steel AISI 304 Plates, forgings, t ≤ 125 mm	**Steel AISI 304 Forgings, t > 125 mm**
	S_y min (100ºC) = 170 MPa	S_y min (100ºC) = 170 MPa
	S_u min (100ºC) = 485 MPa	S_u min (100ºC) = 453 MPa
	E (100ºC) = 189 GPa	E (100ºC) = 189 GPa
Stress, MPa	**Strain**	**Strain**
0	0.00000E+00	0.00000E+00
10	5.29184E-05	5.29136E-05
20	1.05989E-04	1.05909E-04
30	1.59726E-04	1.59318E-04
40	2.15151E-04	2.13901E-04
50	2.73887E-04	2.70983E-04
60	3.38237E-04	3.32590E-04
70	4.11258E-04	4.01573E-04
80	4.96841E-04	4.81747E-04
90	5.99819E-04	5.78041E-04
100	7.26101E-04	6.96698E-04
110	8.82909E-04	8.45560E-04
120	1.07915E-03	1.03451E-03
130	1.32606E-03	1.27622E-03
140	1.63837E-03	1.58742E-03
150	2.03624E-03	1.99118E-03
160	2.54865E-03	2.52073E-03
170	3.21906E-03	3.22602E-03
180	4.11432E-03	4.18425E-03
190	5.33768E-03	5.51527E-03
200	7.04447E-03	7.40008E-03
210	9.45291E-03	1.00923E-02
220	1.28305E-02	1.38970E-02
230	1.74247E-02	1.90769E-02
240	2.33248E-02	2.56803E-02
250	3.03222E-02	3.33931E-02
260	3.79151E-02	4.16004E-02
270	4.55189E-02	4.96728E-02
280	5.27187E-02	5.72331E-02
290	5.93659E-02	6.42033E-02
300	6.55114E-02	7.06924E-02
350	9.33232E-02	1.01068E-01
400	1.22755E-01	1.34276E-01
450	1.56039E-01	1.72322E-01
500	1.93408E-01	2.15438E-01
550	2.34899E-01	2.63705E-01
600	2.80535E-01	3.17189E-01
650	3.30334E-01	3.75952E-01
700	3.84313E-01	4.40051E-01

Note:

The development of the stress strain curve should be limited to a value of true ultimate tensile stress at true ultimate tensile strain. The stress strain curve beyond this point should be perfectly plastic.

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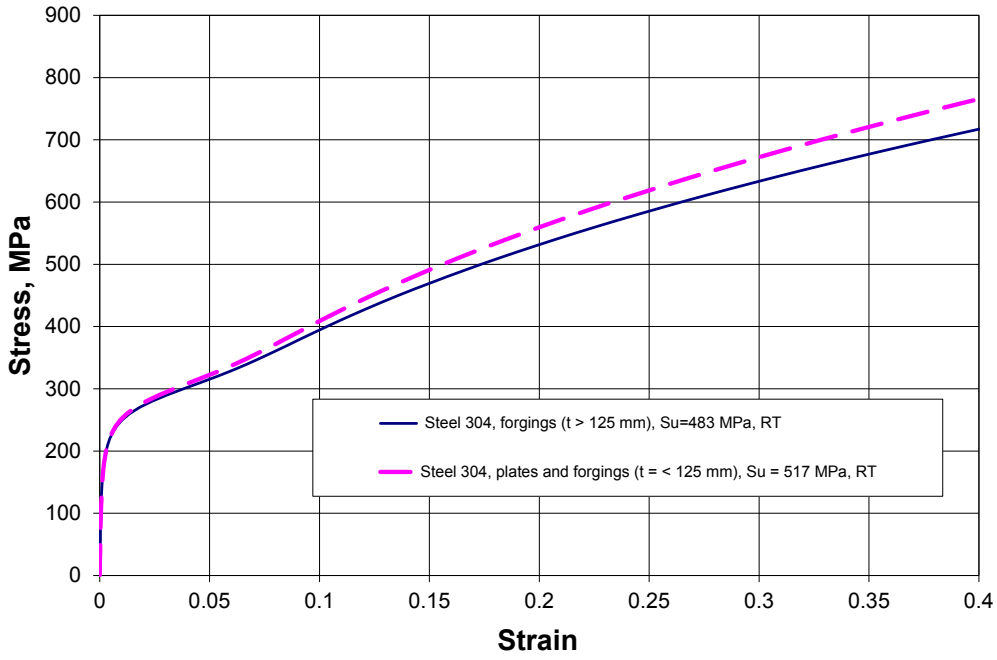
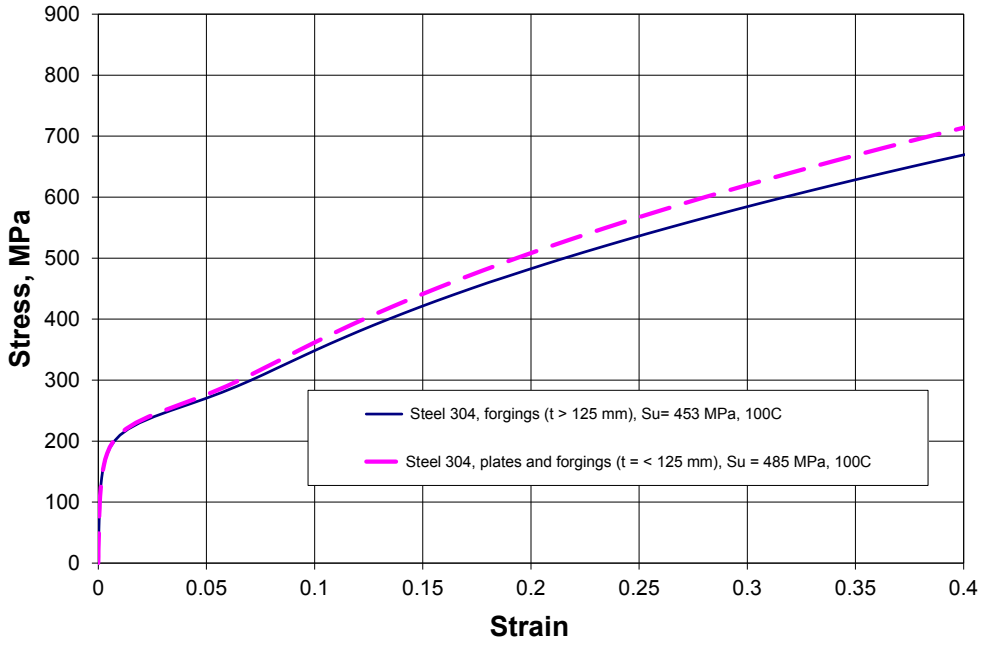
Stress Strain Curves of AISI steel 304, Room temperature



Stress Strain Curves of AISI steel 304, 100ºC



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3 Material Properties for bolting

3.1 Chemical composition requirements, wt. %.

Maximum, unless range or minimum is indicated.

	B8, Type 304 Bolting	Grade 660 Bolting
Element	**[Ref. 3]**	**[Ref. 4]**
C	0.08	0.08
Mn	2.00	2.00
Si	1.00	1.00
Cr	18.0 – 20.0	13.5–16.0
Ni	8.0 – 11.0	24.0–27.0
P	0.045	0.040
S	0.030	0.030
Mo	-	1.00–1.50
V	-	0.10–0.50
B	-	0.001–0.010
Ti	-	1.90–2.35
Al	-	0.35

Limits for Co and Nb shall be established before starting of procurements.

Ref. 3 SPECIFICATION FOR ALLOY-STEEL AND STAINLESS STEEL BOLTING MATERIALS FOR HIGHTEMPERATURE SERVICE, SA-193/SA-193M, (Identical with ASTM Specification A 193/A 193M-07.)

Ref. 4 SPECIFICATION FOR HIGH-TEMPERATURE BOLTING MATERIALS WITH EXPANSION COEFFICIENTS COMPARABLE TO AUSTENITIC STEELS ASME SA-453/ SA-453M, (Identical with ASTM Specification A 453/ A 453M -09.)

3.2 Tensile properties and allowable stress values

Type B8, Class 1/ Solution treated & Grade 660 (UNS S66286)

Material	Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Design stress intensity values, S_m, MPa, bolting
B8, bolting	-30 to 40	**517**	**207**	**68.9**
	100	**485**	**169**	**56.3**
Grade 660	-30 to 40	**896**	**586**	**195**
	100	**896**	**573**	**191**
Reference		ASME 2010, Sec II, Part D (metric), Table U.	ASME 2010, Sec II, Part D (metric), Table Y-1.	ASME 2010, Sec II, Part D (metric), Table 4.

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4 Material properties for cryostat toroidal skirt support

4.1 Chemical composition requirements, wt. %.

Maximum, unless range or minimum is indicated.

Element	SA-533,Type D, Class 2 Plates		SA-508 Grade 3, Class 2, Forgings
	[Ref. 5]		[Ref. 6]
C	0.25		0.25
Mn	Heat analysis	1.15 – 1.50	1.20–1.50
	Product analysis	1.07–1.62	
Si	Heat analysis	0.15–0.40	0.40
	Product analysis	0.13–0.45	
Mo	Heat analysis	0.45–0.60	0.45–0.60
	Product analysis	0.41–0.64	
Ni	Heat analysis	0.20–0.40	0.40–1.00
	Product analysis	0.17–0.43	
P	0.035		0.025
S	0.035		0.025
Cr	-		0.40–1.00
V	-		0.05
Nb	-		0.01
Cu	-		0.20
Ca	-		0.015
B	-		0.003
Ti	-		0.015
Al	-		0.025

Limits for Co and Nb shall be established before starting of procurements.

Ref. 5 SPECIFICATION FOR PRESSURE VESSEL PLATES, ALLOY STEEL, QUENCHED AND TEMPERED, MANGANESE-MOLYBDENUM AND MANGANESE-MOLYBDENUM-NICKEL, SA-533/SA-533M, (Identical with ASTM Specification A 533/A 533M-93.)

Ref. 6 SPECIFICATION FOR QUENCHED AND TEMPERED VACUUM-TREATED CARBON AND ALLOY STEEL FORGINGS FOR PRESSURE VESSELS, SA-508/SA-508M, (Identical with ASTM Specification A 508/A 508M-05b)

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4.2 Physical properties:

Materials	Temperature, C	Young's modulus, GPa	Poisson's ratio
SA-533,Type D, Class 2	25	200	0.3
	100	196	
SA-508 Grade 3, Class 2	25	191	0.30
	100	187	
Reference		ASME 2010 Sec II, Part D (metric), Table TM-1, page 738-739.	ASME 2010. Sec II, Part D (metric) Table PRD, page 744.

4.3 Tensile properties

a) SA-533,Type D, Class 2, K12529, Mn– 1⁄2Mo– 1⁄4Ni, Plates, Max. thickness limit 300mm:

Temperature, C	Tensile strength, S_u, MPa	Yield strength, S_y, MPa	S_m, * MPa
20	620	485 (483)	259
100	620 (621)	452	259
Reference	ASME 2010 Sec II, Part D (metric), Table U page 480-481.	ASME 2010 Sec II, Part D (metric), Table Y-1, page 584.	ASME 2010. Sec II, Part D (metric) Table 5A, page 398.

* S_m is defined based on material use for pressure vessel. For use as support the value may be revised.

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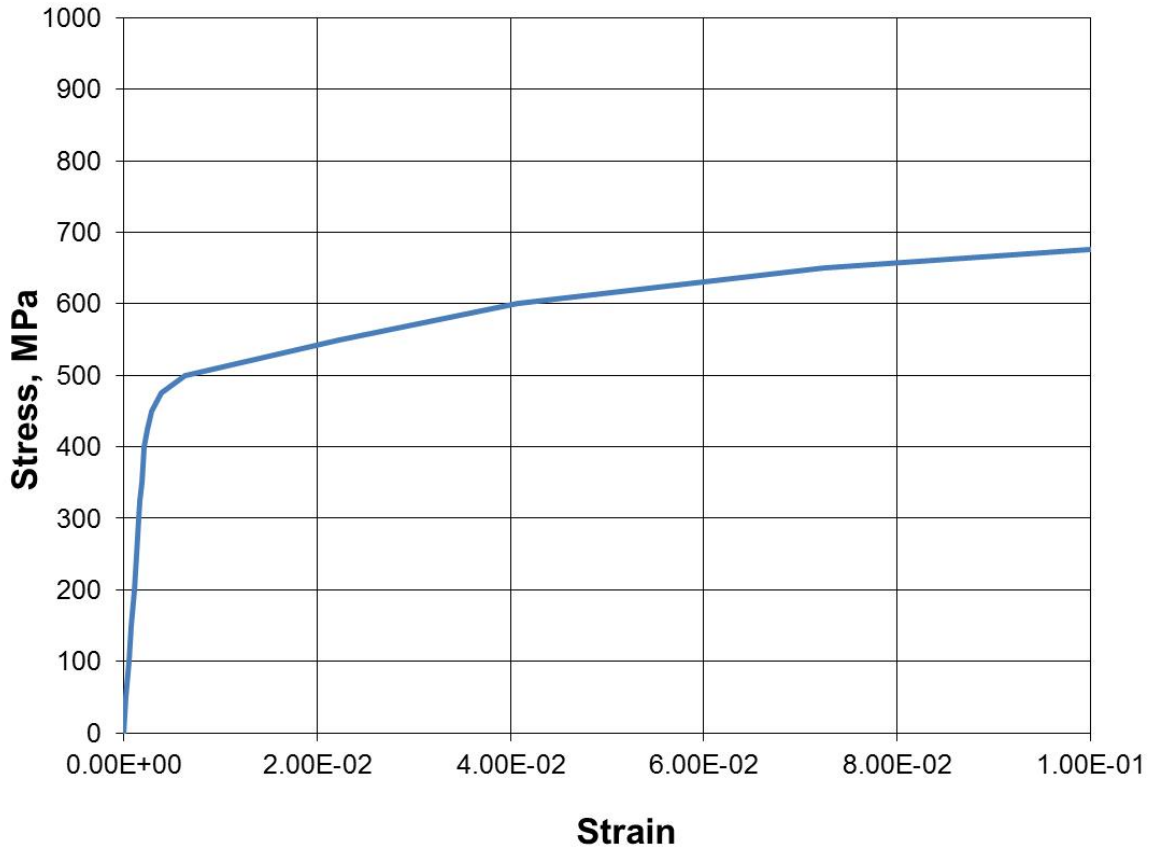
b) SA-508 Grade 3, Class 2, K12042, ¾Ni-½Mo-Cr-V, Forgings

Temperature, C	Tensile strength, S_u, MPa	Yield strength, S_y, MPa	S_m, * MPa
-30 - +40	620 (621)	450 (448)	259
100	621	420	259
Reference	ASME 2010 Sec II, Part D (metric), Table U page 482-483.	ASME 2010 Sec II, Part D (metric), Table Y-1, page 589.	ASME 2010. Sec II, Part D (metric) Table 5A, page 398.

* S_m is defined based on material use for pressure vessel. For use as support the value may be revised.

Stress strain curve at room temperature:
Stress strain curve was prepared based on ASME Boiler & Pressure Vessel Code, Edition 2010, Section VIII, Division 2, Annex 3.D – Strength parameters, pages 3-100-3-104.
Coefficients for ferritic steels have been used.



X	Y
Strain	Stress, MPa
0.000E+00	0
2.618E-04	50
5.236E-04	100
7.853E-04	150
1.047E-03	200
1.309E-03	250
1.571E-03	300
1.703E-03	325
1.837E-03	350
1.979E-03	375
2.148E-03	400
2.390E-03	425
2.837E-03	450
3.832E-03	475
6.377E-03	500
2.222E-02	550
4.071E-02	600
7.242E-02	650
1.253E-01	700
2.103E-01	750
3.423E-01	800
5.423E-01	850
8.377E-01	900

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5 Material properties for bolting 8.8 in accordance with ISO 898-1

5.1 Chemical composition requirements

Property class	Material and heat treatment	Chemical composition limit (cast analysis, %)[a]					Tempering temperature
		C		P	S	B[b]	°C
		min.	max.	max.	max.	max.	min.
8.8[f]	Carbon steel with additives (e.g. Boron or Mn or Cr) quenched and tempered	0,15[e]	0,40	0,025	0,025	0,003	425
	or Carbon steel quenched and tempered	0,25	0,55	0,025	0,025		
	or Alloy steel quenched and tempered[g]	0,20	0,55	0,025	0,025		

Limits for Co and Nb shall be established before starting of procurements.

5.2 Physical properties:

Material, property class	Temperature, C	Young's modulus, GPa	Poisson's ratio
8.8	**20**	**202**	**0.3**

5.3 Tensile properties:

Temperature, C	Tensile strength, Rm, min MPa	Yield strength, Rp0.2, min, MPa
20	830	660
Reference	EN ISO 898-1	EN ISO 898-1

Stress strain curve at room temperature for 8.8 material:
Stress strain curve was prepared based on ASME Boiler & Pressure Vessel Code, Edition 2010, Section VIII, Division 2, Annex 3.D – Strength parameters, pages 3-100-3-104.
Coefficients for ferritic steels have been used.

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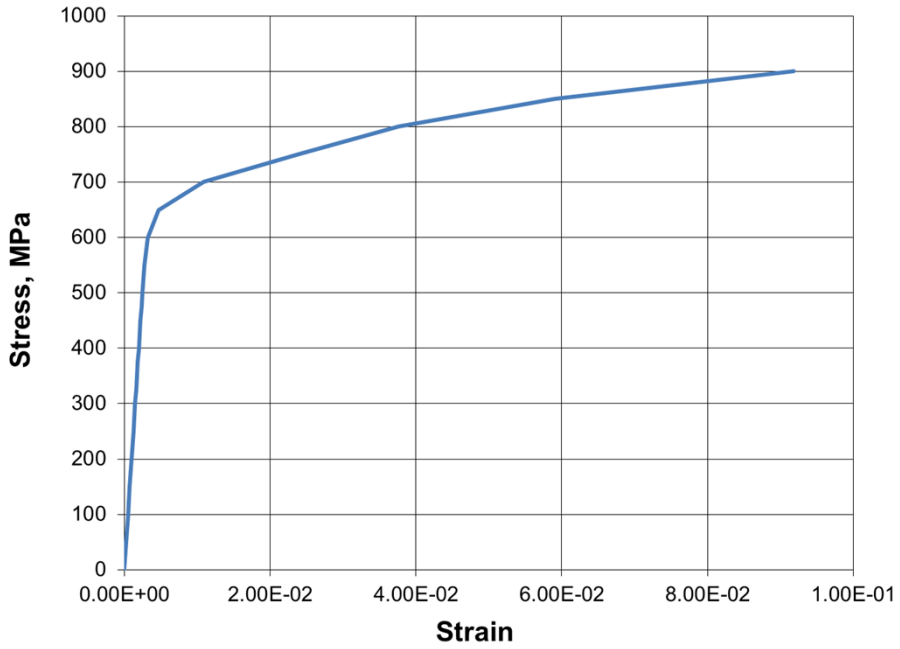

X	Y
Strain	Stress, MPa
0.000E+00	0
2.475E-04	50
4.950E-04	100
7.426E-04	150
9.901E-04	200
1.238E-03	250
1.485E-03	300
1.609E-03	325
1.733E-03	350
1.856E-03	375
1.980E-03	400
2.104E-03	425
2.229E-03	450
2.354E-03	475
2.483E-03	500
2.774E-03	550
3.259E-03	600
4.677E-03	650
1.087E-02	700
2.394E-02	750
3.762E-02	800
5.910E-02	850
9.183E-02	900