IDM UID
RBFN56
VERSION CREATED ON / VERSION / STATUS
05 Jul 2018 / 1.1 / Approved
EXTERNAL REFERENCE / VERSION

Memorandum / Note

VVPSS Materials Data Summary For Structural Analysis

This document summarizes the recommended data to be used for the structural analysis of the several subsystems included in the VVPSS made of austenitic steel type 304/304L, and other materials as indicated in this document. The proposed main reference material is dual marked steel 304/304L. Other materials are bolting, piping TP304L, carbon steel G70 [G 485], Vespel insulation SP1, calcium silicate, Superwool and silicon elastomer.

Approval Process			
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Document Security: Internal Use *RO: Sarkar Biswanath*			
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Change Log			
VVPSS Materials Data Summary For Structural Analysis (RBFN56)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	Approved	02 Jun 2015	
v1.1	Approved	05 Jul 2018	Properties of austenitic steel up to 500C were added, Properties of additional bolting material type 630 (UNS S17400) were added. Some editorial corrections were made.

Table of Contents

1 Purpose

To provide materials' data for structural analysis of the ITER VVPSS.

2 Scope

This document summarizes the recommended data to be used for the structural analysis of the several subsystems included in the VVPSS made of austenitic steel type 304/304L, and other materials as indicated in this document. The proposed main reference structural material is dual marked steel 304/304L.

3 Definitions

For a complete list of ITER abbreviations see: ITER_D_2MU6W5 - ITER Abbreviations

4 General information

This document summarizes the recommended data of the materials properties needed for the structural analysis of the different subsystems of the of the ITER Vacuum Vessel Pressure Suppression System (VVPSS).

Applicable design and manufacturing Codes for VVPSS subsystems are the following:

- **For the Oblong Pipe and the VVPSS Tank:**
  ASME Section VIII Division 2, Edition 2010.

- **For the VVPSS Relief Line:**
  ASME B31.3 Category M fluid Service, Edition 2016.

These Codes do not include requirements for Category III and IV events (as defined in Codes and Standards for ITER Mechanical Components, ITER IDM 25EW4K). Special requirements for Category III and IV events are included in the document "Allowable values and limits in service level C and D for ITER mechanical components, ITER_D_3G3SYJ.

Note: It is permitted to use latest versions of codes and standards provided the equivalency of those codes and standards is demonstrated. It is recommended to use latest version of codes and standards for the new contracts.

4.1 List of materials

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

Table 1. List of Materials for VVPSS

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
Steel 304/304L*	18Cr-8Ni	-	Plate	ASME SA-240 ASTM A240/240M
Steel F304/F304L*	18Cr-8Ni	-	Forging	ASME SA-182, ASME SA-965 ASTM A182/182M ASTM A965/965M
Grade 70 [Grade 485]	Carbon steel	K02700	Plate	ASME SA-516 ASTM A516/A516M
Steel grade TP 304/304L*	18Cr-8Ni	S30400	Pipe	ASME SA-312 ASTM A312
Type B8, Class 1/ Solution treatment	18Cr-8Ni	S30400	Bolting	ASME SA-193 ASTM A-193
Type B7 Chromium-Molybdenum (1Cr-1/5Mo)	1Cr-1/5Mo	G41400	Bolting	ASME SA-193 ASTM A193
Type 630, H1100 and H1150	17Cr-4Ni-4Cu	S17400	Bolting	ASME SA-564 ASTM A564
Vespel SP1	n/a	n/a	Insulation	tbd
Calcium Silicate Insulation	n/a	n/a	Block and Pipe	ASTM C533
Superwool® Blankets	n/a	n/a	Sheets	n/a
Silicon elastomer	n/a	n/a	tbd	tbd

*Dual marked 304/304L steel

In accordance with ASME Section VIII Division 2 Edition 2010 and ASME B31.3:

- 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.

Other properties for design assessment are taken from the ITER Materials Properties Handbook (https://user.iter.org/?uid=29DDCW) or in open literature.

Properties for non-metallic materials are defined in:

- Vespel polyamide: - See reference in text
- Carbon Silicate Insulation: - See reference in text
- Superwool® Blankets - See reference in text
- Silicon elastomer - See reference in text

4.2 Criteria for allowable stresses for metallic materials

Criteria for allowable stress values of metallic materials from ASME Section 2 Part D, 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	$\frac{1}{3}\ S_Y$	$\frac{1}{3}\ S_Y R_Y$

4.3 Main structural material – dual marked 304/304L steel

Grade 304L and grade 304 austenitic steels were considered for application.
Low carbon (max - 0.030 %) grade 304L has excellent welding characteristics and corrosion 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 austenitic steel grade 304L**
- **tensile properties as for austenitic steel grade 304**

5 Materials properties data

5.1 Dual marked steel 304/304L

5.1.1 Chemical composition requirements

Chemical composition requirements for 304 and 304L plates and forgings are shown in Table 2. Maximum, unless range or maximum is indicated, wt. %, see Table 2.

Table 2. Chemical composition requirements

	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 – 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	-

Ref. 1 SPECIFICATION FOR CHROMIUM AND CHROMIUM NICKEL STAINLESS STEEL PLATE, SHEET, AND STRIP FOR PRESSURE VESSELS AND FOR GENERAL APPLICATIONS, SA-240/SA-240M

Ref. 2 SPECIFICATION FOR STEEL FORGINGS, AUSTENITIC,FOR PRESSURE AND HIGH TEMPERATURE PARTS, SA-965/SA-965M

Table 3. Chemical composition requirements for dual marked steel 304/304L.

	Dual marked 304/304L plates	Dual marked F304/304L forgings
Element	[Common for 304 and 304L]	[Common for F304 and F304L]
C	0.030	0.030
Mn	2.00	2.00
Si	0.75	1.00
Cr	18.0 - 20.0	18.0 – 20.0
Ni	8.0 – 10.5	8.0 – 11.0
P	0.045	0.045
S	0.030	0.030
N	0.10	-

SPECIAL REQUIREMENTS:

Content of other impurities (Co, Ta, Nb, B) will be defined (if needed) during preparation of the product procurement specifications. These impurities are not affecting mechanical properties of materials.

5.1.2 Physical properties

The same properties are recommended by ASME for 304 and 304L grades steels (applicable for dual marked 304/304L steel plates and forgings and pipes).

Table 4: Physical properties

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
200		183		17.0	17.9	537
250		179		17.4	18.6	548
300		176		17.7	19.4	558
350		172		17.9	20.1	567
400		169		18.1	20.8	574
450		165		18.3	21.5	584
500		160		18.4	22.2	588

* 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 Room temperature: 72 μOhms*cm, [See ITER MPH, ITER-IDM_ZD_29DDT7]

5.1.3 Tensile properties and allowable stress values

Table 5. Tensile properties and Sm values

# Dual marked 304/304L plates:			
Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Maximum allowable stress values, S_m, MPa
-30 to 40	**517** *(515*)*	**207** *(205*)*	**138**
100	**485**	**170**	**113**
150	**456**	**154**	**103**
200	**442**	**144**	**96**
250	**437**	**135**	**90**
300	**437**	**129**	**86**
350	**437**	**123**	**82**
400	**436**	**118**	**79**
450	**429**	**114**	**76**
500	**413**	**110**	**73**
Reference:	ASME 2010, Sec II, Part D (metric), Table U.	ASME 2010, Sec II, Part D (metric), Table Y-1.	**See Note 1.**

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).

Table 6:

Dual marked 304/304L forgings:			
Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Maximum allowable stress values, S_m, MPa
-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**
150	**456**	**154**	**103**
200	**442**	**144**	**96**
250	**437**	**135**	**90**
300	**437**	**129**	**86**
350	**437**	**123**	**82**
400	**436**	**118**	**79**
450	**429**	**114**	**76**
500	**413**	**110**	**73**
Reference:	ASME 2010, Sec II, Part D (metric), Table U.	ASME 2010, Sec II, Part D (metric), Table Y-1.	**See Note 1.**

t – thickness.

* 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 1:

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

2. **In accordance with MANDATORY APPENDIX 10 BASIS FOR ESTABLISHING MAXIMUM ALLOWABLE STRESS VALUES FOR TABLES 5A AND 5B, ASME SECTION II, PART D (METRIC):**

Two sets of allowable 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.***

For VVPSS application it is proposed to use Sm values based on which do not exceed two-thirds of the minimum yield strength at temperature (Sm (T) = Sy (T)/1.5) due to features of VVPSS (considered as strain-sensitive application).

5.1.4 Stress strain curves

Trues stress strain curves for steel 304/304L 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.

Table 7:

	Steel 304 Plates, forgings, t ≤ 125 mm	**Steel 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
True Stress, MPa	**True Strain (relative unit)**	**True Strain (relative unit)**
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
700	3.28144E-01	3.78345E-01

Table 8:

	Steel 304 Plates, forgings, t ≤ 125 mm	**Steel 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
True Stress, MPa	**True Strain (relative unit)**	**True Strain** (relative unit)
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

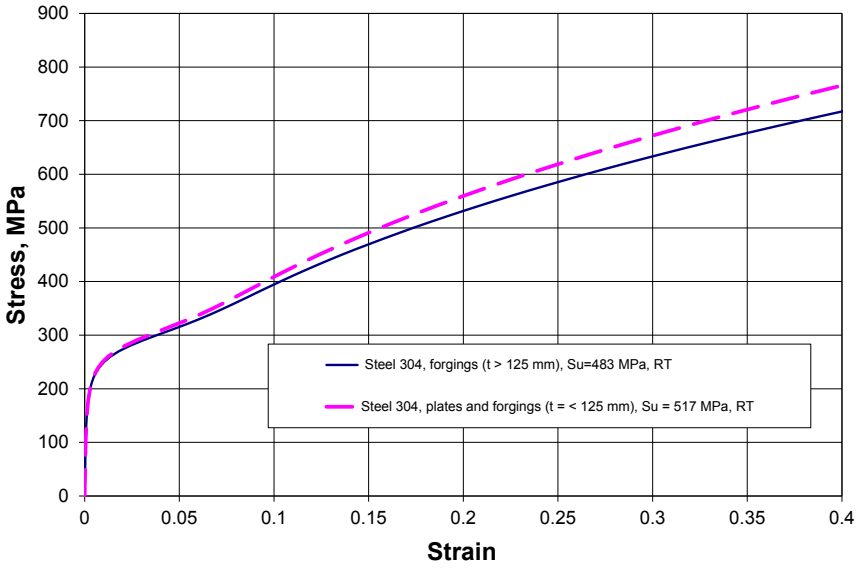
Table 9: 304/304L

Trues Stress, MPa	Total trues Strain (relative unit)
S_y min (200ºC) = 144 MPa	
S_u min (200ºC) = 442 MPa	
E (200ºC) = 183 GPa	
0	0.000E+00
25	1.381E-04
75	5.484E-04
100	1.004E-03
125	1.878E-03
150	3.660E-03
175	7.933E-03
200	1.893E-02
225	3.842E-02
250	5.758E-02
275	7.318E-02
300	8.781E-02
350	1.192E-01
400	1.549E-01
450	1.952E-01
500	2.401E-01
550	2.896E-01
600	3.437E-01
650	4.024E-01
700	4.656E-01

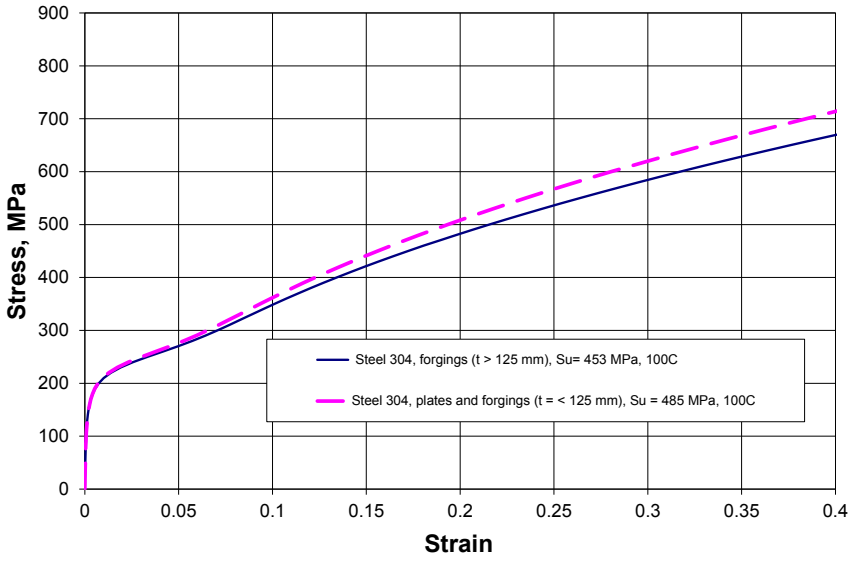
Table 10: 304/304L

Trues Stress, MPa	Total trues Strain (relative unit)
S_y min (300ºC) = 129 MPa	
S_u min (300ºC) = 437 MPa	
E (300ºC) = 176 GPa	
0	0.000E+00
25	1.462E-04
75	6.870E-04
100	1.360E-03
125	2.701E-03
150	5.811E-03
175	1.452E-02
200	3.298E-02
225	5.255E-02
250	6.802E-02
275	8.231E-02
300	9.711E-02
350	1.298E-01
400	1.668E-01
450	2.081E-01
500	2.537E-01
550	3.036E-01
600	3.576E-01
650	4.158E-01
700	4.781E-01

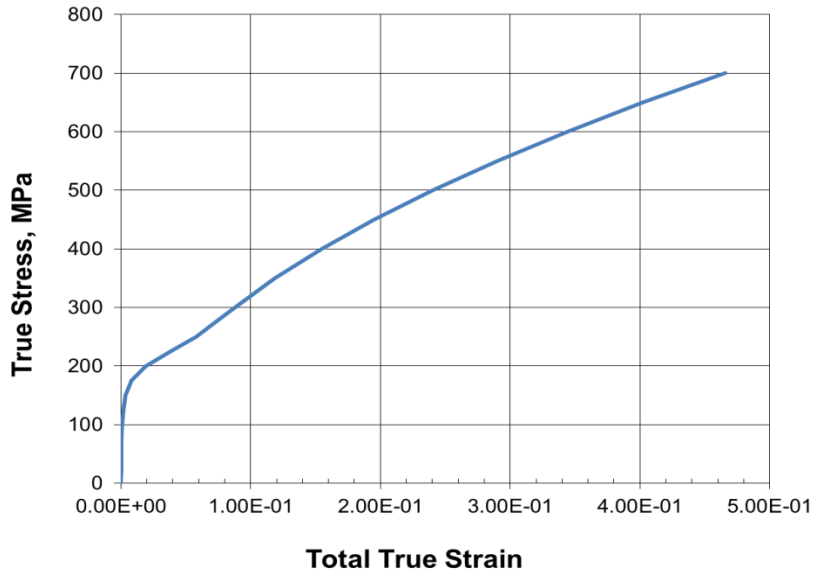
Note:
The development of the stress strain curve should be limited to a value of true ultimate tensile stress at true ultimate tensile strain. For the purposes of analysis the stress strain curve beyond this point should be considered to be perfectly plastic.



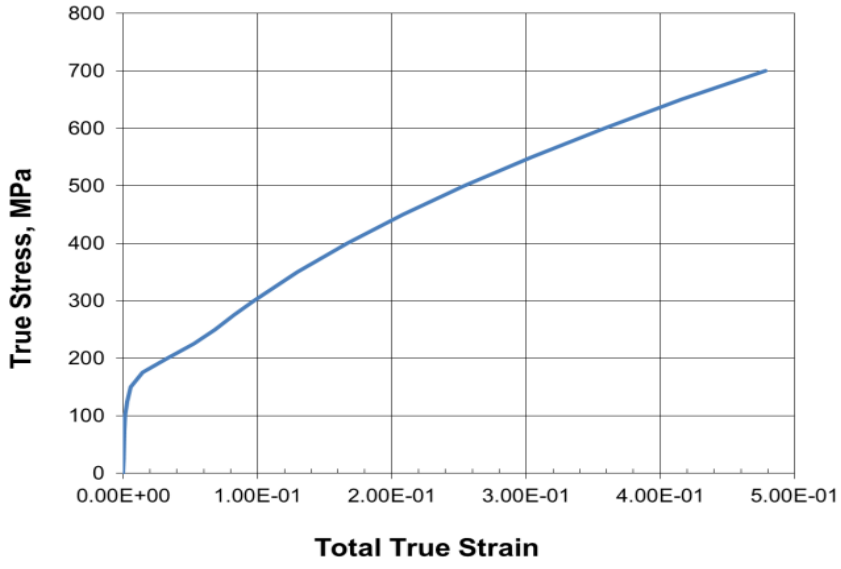
Stress Strain Curves of steel 304/304L, Room temperature (true stress strain)



Stress Strain Curves of steel 304/304L, 100ºC (true stress strain)



Stress Strain Curves of steel 304/304L, 200ºC



Stress Strain Curves of steel 304/304L, 300ºC

5.2 Carbon steel Grade 70 [Grade 485]

5.2.1 Chemical composition requirements

CHEMICAL REQUIREMENTS

Elements	Composition, % Grade 70 [Grade 485]
Carbon, max[A, B]:	
½ in. [12.5 mm] and under	0.27
Over ½ in. to 2 in. [12.5 to 50 mm], incl	0.28
Over 2 in. to 4 in. [50 to 100 mm], incl	0.30
Over 4 to 8 in. [100 to 200 mm], incl	0.31
Over 8 in. [200 mm]	0.31
Manganese[B]:	
½ in. [12.5] and under:	
Heat analysis	0.85–1.20
Product analysis	0.79–1.30
Over ½ in. [12.5 mm]:	
Heat analysis	0.85–1.20
Product analysis	0.79–1.30
Phosphorus, max[A]	0.035
Sulfur, max[A]	0.035
Silicon:	
Heat analysis	0.15–0.40
Product analysis	0.13–0.45

NOTES:
(A) Applies to both heat and product analyses.
(B) For each reduction of 0.01 percentage point below the specified maximum for carton, an increase of 0.06 percentage point above the specified maximum for manganess is permitted, up to a maximum of 1.50% by heat analysis and 1.60% by product analysis.
(C) Grade 60 plates ½ in. [12.5 mm] and under in thickness may have 0.85–1.20% manganese on heat analysis, and 0.79–1.30% manganese on product analysis.

Ref. 3 SPECIFICATION FOR PRESSURE VESSEL PLATES, CARBON STEEL, FOR MODERATE- AND LOWERTEMPERATURE SERVICE, SA-516/SA-516M (Identical with ASTM Specification A 516/A 516 M-06).

5.2.2 Physical properties

Table 11:

Temperature	**Density**	**Young's Modulus**	**Poisson's Ratio**	**Mean Thermal Expansion**	**Thermal Conducti-vity**	**Thermal diffusivity**
°C	**kg/m^3**	**GPa**		**10^{-6}, 1/K**	**W/m K**	**10^{-6} m^2/sec**
20	7750	202*	0.30	11.5	60.4	18.10
100		198		12.1	58.0	15.60
200		192		12.7	53.6	13.40
250		189		13.0	51.4	12.42
300		185		13.3	49.2	11.48

* at 25°C.

References:	ASME 2010, Sec II, Part D (metric) Table PRD,	ASME 2010, Sec II, Part D (metric), Table TM-1,	ASME 2010, Sec II, Part D (metric) Table PRD,	ASME 2010 Sec. II, Materials, Part D (metric), Table TE-1,	ASME 2010, Sec II, Part D (metric), Table TCD,	ASME 2010, Sec II, Part D (metric), Table TCD

5.2.3 Tensile properties and allowable stress values for Grade 70 [Grade 485]

Table 12:

Grade 70			
Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Maximum allowable stress values, S_m, MPa
-30 to 40	485 - 620	260 (262)	175
100	483	239	159
150	483	232	154
200	483	225	150
250	483	216	144
300	483	204	136
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.

5.3 Dual marked steel 304/304L pipe

5.3.1 Chemical composition requirements

Chemical composition requirements for 304 and 304L pipes are shown in Table 13. Maximum, unless range or maximum is indicated, wt. %, see Table 13.

Table 13. Chemical composition requirements

	TP304L pipe	**TP304 pipe**
Element	**[Ref. 3]**	**[Ref. 3]**
C	0.035	0.08
Mn	2.00	2.00
Si	1.00	1.00
Cr	18.0 - 20.0	18.0 - 20.0
Ni	8.0 – 13.0	8.0 – 11.0
P	0.045	0.045
S	0.030	0.030

Ref. 3 SPECIFICATION FOR SEAMLESS AND WELDED AUSTENITIC STAINLESS STEEL PIPES, SA-312/SA-312M (Identical with ASTM Specification A 312/A 312M-01a).

Table 14. Chemical composition requirements for dual marked steel TP 304/304L pipe.

	TP304/TP304L pipe
Element	[Common for 304 and 304L]
C	0.035
Mn	2.00
Si	1.00
Cr	18.0 - 20.0
Ni	8.0 – 11.0
P	0.045
S	0.030

SPECIAL REQUIREMENTS:

Content of other impurities (Co, Ta, Nb, B, N) will be defined (if needed) during preparation of the product procurement specifications. These impurities are not affecting mechanical properties of materials.

5.3.2 Physical properties

See Table 4.

5.3.3 Tensile properties and allowable stress values for dual marked TP304/304L pipe

Table 14:

Steel dual marked TP304/304L pipe				
Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Maximum allowable stress values, S_m, MPa (Seamless pipe)	Maximum allowable stress values, S_m, MPa (welded pipe)
-30 to 40	517	207	**138**	**117**
100	485	170	138	117
150	456	154	138	117
200	442	144	129	110
250	437	135	122	103
300	437	129	116	98.5
350	437	123	111	94.4
400	436	118	107	90.7
450	429	114	103	87.4
500	413	110	99.1	84.3
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.	ASME 2010, Sec II, Part D (metric), Table 5A.

Note: data for TP304 in ASME B31.3, Appendix A, ALLOWABLE STRESSES AND QUALITY FACTORS FOR METALLIC PIPING AND BOLTING MATERIALS, are in customary unis.
The metric values are the same as in ASME, Section II, Part D.

5.4 Bolting

5.4.1 Chemical composition requirements, wt. %.

Maximum, unless range is indicated.

Table 15:

	B8, B8A S30400 (304) Bolting	**B7, B7M (see Note) Chromium-Molybdenum Bolting**	**SA-564/SA-564M, Type 630 (UNS S17400)**
Element	**[Ref. 4**	**[Ref. 4]**	**[Ref. 5]**
C	0.08	0.37 – 0.49	0.07
Mn	2.00	0.65 – 1.10	1.00
Si	1.00	0.15 – 0.35	1.00
Cr	18.0 – 20.0	0.75 – 1.20	15.00-17.50
Ni	8.0 – 11.0		3.00-5.00
P	0.045	0.035	0.040
S	0.030	0.040	0.030
Mo	-	0.12 – 0.25	-
Cu	-	-	3.00-5.00
Nb+Ta	-	-	0.15-0.45

Note: Typical steel compositions used for this grade include 4140, 4142, 4145, 4140H, 4142H, and 4145H.

SPECIAL REQUIREMENTS:

Content of other impurities (Co, Ta, Nb, B, N) will be defined (if needed) during preparation of the product procurement specifications. These impurities are not affecting mechanical properties of materials.

Ref. 4 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. 5 SPECIFICATION FOR HOT-ROLLED AND COLD FINISHED AGE-HARDENING STAINLESS STEEL BARS AND SHAPES, SA-564/SA-564M (Identical with ASTM Specification A 564/A 564M-04 (R09).)

5.4.2 Physical properties

For B8, B8A S30400 (304) see Table 4.

For B7, B7M, Chromium-Molybdenum (1Cr-1/5Mo). see be Table 16

Table 16:

Temperature	Density	Young's Modulus	Poisson's Ratio	Mean Thermal Expansion	Thermal Conductivity	TD
°C	kg/m^3	GPa		10^{-6}, 1/K	W/m K	10^{-6} m^2/sec
20	7750	204*	0.30	11.5	41.0	11.87
100		200		12.1	40.6	10.88
200		193		12.7	40.1	9.82
250		190		13.0	39.5	9.32
300		186		13.3	38.7	8.82

* 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 C.	ASME 2010, Sec II, Part D (metric) Table PRD, page 744.	ASME 2010 Sec. II, Materials, Part D (metric), Table TE-1.	ASME 2010, Sec II, Part D (metric), Table TCD, Group C.	ASME 2010, Sec II, Part D (metric), Table TCD, Group C.

Electrical resistivity at Room temperature: 22 μOhms*cm
[steel G41440; http://www.matweb.com]

For SA-564/SA-564M, Type 630 (UNS S17400). see be Table 17

Table 17:

Temperature	Density #	Young's Modulus*	Poisson's Ratio*	Mean Thermal Expansion **	Mean Thermal Expansion ***	Thermal Conductivity	TD*
°C	kg/m^3	GPa		10^{-6}, 1/K	10^{-6}, 1/K	W/m K	10^{-6} m^2/sec
20	7750	196#	0.31	11.1	11.5	17.3	4.80
100		191		11.4	11.9	18.4	4.86
200		184		11.6	12.3	20.2	4.88
250		181		11.8	12.5	21.1	4.88
300		177		11.9	12.7	21.9	4.86
350		173		12.0	12.8	22.5	4.81
400		169		12.1	12.9	23.0	4.71
450		166		12.2	13.0	23.5	4.54
475				12.3	13.1		
500						23.8	4.30

at 25ºC.

References:	ASME 2017, Sec II, Part D (metric) Table PRD, page 841.	ASME 2017, Sec II, Part D (metric), Table TM-1, page 837	ASME 2017, Sec II, Part D (metric) Table PRD, page 841.	ASME 2017 Sec. II, Materials, Part D (metric), Table TE-1, page 807.	ASME 2017 Sec. II, Materials, Part D (metric), Table TE-1, page 807.	ASME 2017, Sec II, Part D (metric), Table TCD, Group I. page 822	ASME 2017, Sec II, Part D (metric), Table TCD, Group I. page 822

* Applicable for Condition H1100 and H1150
**Applicable for Condition H1075. The conservative values of condition H1075/H1150 may be applied for condition H1100 in the design.
***Applicable for Condition H1150

5.4.3 Tensile properties and allowable stress values

Type B8, Class 1/Solution treated
Table 18:

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	**515**	**205**	**68.9**
	100	**485**	**169**	**56.3**
	150	**456**	**144**	**51.6**
	200	**442**	**144**	**47.9**
	250	**437**	**135**	**45.3**
	300	**437**	**129**	**42.7**
	350	**437**	**123**	**41.0**
	400	**436**	**118**	**39.3**
	450	**429**	**114**	**38.0**
	500	**413**	**110**	**36.7**
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.

B7, B7M, Chromium-Molybdenum (1Cr-1/5Mo).
Table 19:

Material	Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Design stress intensity values, S_m, MPa, bolting
B7, bolting, 100<t<175 mm	-30 to 40	**689**	**517**	**172**
	100	**689**	**479**	**160**
	200	**689**	**451**	**151**
	250	**689**	**438**	**146**
	300	**689**	**425**	**142**
	350	**685**	**406**	**136**
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.

Table 20:

Material	Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Design stress intensity values, S_m, MPa, bolting
B7, bolting, 64<t<100 mm	-30 to 40	**793**	**655**	**219**
	100	**793**	**606**	**202**
	200	**793**	**572**	**191**
	250	**793**	**556**	**185**
	300	**793**	**538**	**179**
	350	**785**	**514**	**171**
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.

Table 21:

Material	Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Design stress intensity values, S_m, MPa, bolting
B7, bolting, t < 64 mm	-30 to 40	**862**	**724**	**241**
	100	**862**	**671**	**223**
	200	**862**	**632**	**211**
	250	**862**	**614**	**205**
	300	**862**	**595**	**198**
	350	**852**	**568**	**190**
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.

SA-564/SA-564M, Type 630 (UNS S17400) bar
Table 22:

Material	Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Design stress intensity values, S_m, bolting, MPa#
H1150	40	**931**	**724**	**241**
	100	**931**	**666**	**222**
	150	**931**	**641**	**213**
	200	**907**	**620**	**206**
	250	**889**	**603**	**201**
	300	**877**	**588**	**196**
	350	**863**	**575**	**191**
	400	**837**	**559**	**-**
	450	**789**	**533**	**-**
	500	**708**	**483**	**-**
Reference		ASME 2017, Sec II, Part D (metric), Table U.	ASME 2017, Sec II, Part D (metric), Table Y-1.	.

Sm for bolting were calculated with formula described above.

SA-564/SA-564M, Type 630 (UNS S17400) bar
Table 23:

Material	Temperature, ºC	Tensile strength values S_u, MPa	Yield strength values S_y, MPa	Design stress intensity values*, S_m, bolting MPa
H1100	40	**965**	**793**	**264**
	100	**965**	**729**	**242**
	150	**965**	**701**	**234**
	200	**941**	**680**	**226**
	250	**922**	**660**	**220**
	300	**910**	**644**	**215**
	350	**894**	**629**	**210**
	400	**868**	**612**	**-**
	450	**818**	**584**	**-**
	500	**734**	**530**	**-**
Reference		ASME 2017, Sec II, Part D (metric), Table U.	ASME 2017, Sec II, Part D (metric), Table Y-1.	ASME 2017, Sec II, Part D (metric), Table 4.

***Bolting materials**

5.5 Material properties for insulations

Final materials for insulation will be defined on later stage.

There are several candidates listed below with limited number of properties which can be used for preliminary analysis.

5.5.1 Polyimide Vespel SP1

Typical End-Use Applications of grade SP1 is Mechanical and electrical parts at elevated temperatures.
Polyimide Composition: Unfilled base resin.

Features: Maximum strength and elongation: lowest modulus and thermal conductivity: optimum electrical properties.

Other grades (not only SP1) may be considered if needed.

The typical values presented below are preliminary results and are subject to revision.

Typical Properties of SP1 Vespel: :

Table 24:

Temperature	Density	Flexural Modulus	Compressive Modulus	Poisson's Ratio	Mean Thermal Expansion	Thermal Conductivity	Specific Heat
°C	kg/m^3	MPa	MPa		10^{-6}, 1/K	W/m K	J/kg K
23	1430	3102	2413	0.41	54 (23 – 260C)	0.35 (At 40C)	1130
260		1724		-	-	-	-

Temperature	Tensile Strength	Elongation, Ultimate	Flexural Strength, Ultimate	Shear Strength	Axial fatigue, Endurance limit at 10^3 cycles	Axial fatigue, Endurance limit at 10^7 cycles
°C	MPa	%	MPa	MPa	MPa	MPa
23	86.2	7.5	110.3	89.6	55.8	42.1
260	41.4	6.0	62.1	-	26.2	16.5

Note:
Data for Parts machined out of shapes material (Column M in reference below).

For parts obtained by «Direct Forming» process see Column DF in reference below.

Reference:
Vespel S-line Design Handbook (ITER_D_RB4C8W).

5.5.2 Calcium Silicate Thermal Insulation

Thermal insulation shall be of the following types as defined in ASTM C533-13:
Type I—Block for use on surfaces at temperature from 27°C to 649°C.
Type I—Pipe for use on surfaces at temperature from 27°C to 649°C.

Table 25:

Temperature	Density	Flexural Strength min	Compressive strength	Poisson's Ratio	Mean Thermal Expansion	Thermal Conductivity	Specific Heat
°C	kg/m^3	MPa	MPa		10^{-6}, 1/K	W/m K	J/kg K
23	240	0.344	0.688			0.059	
260						0.087	

Reference:

ASTM C533-13: Standard Specification for Calcium Silicate Block and Pipe Thermal Insulation.

See additional information on properties of insulating materials in the reference **02075-73783-001_WP01_D02_Rev.B - Passive Fire Protection for ITER Systems and Components (WMVZXP v1.1) (current)**

5.5.3 Superwool® Blankets

Superwool offers an alternative to traditional solutions due to its high refractoriness and excellent non-wetting characteristics with molten aluminum. Maximum temperature of use is 1100 - 1300°C.

Table 26:

Temperature	Density	Tensile strength min	Compressive strength	Poisson's Ratio	Mean Thermal Expansion	Thermal Conductivity	Specific Heat
°C	kg/m^3	MPa	MPa		10^{-6}, 1/K	W/m K	J/kg K
23	64 - 160	0.075					n/a
260						0.06	n/a

Reference: Superwool® Blanket, www.thermalceramics.com (ITER_D_R9VDAA v1.0).

See additional information on properties of insulating materials in the reference **02075-73783-001_WP01_D02_Rev.B - Passive Fire Protection for ITER Systems and Components (WMVZXP v1.1) (current)**

5.5.4 Silicon Elastomer

Silicon Elastomers are used for electrical insulation and electronic encapsulation.

Table 27:

Temperature	Density	Tensile strength typical	Yield strength typical	Elastic modules	Mean Thermal Expansion	Thermal Conductivity	Specific Heat
°C	kg/m^3	MPa	MPa	GPa	10^{-6}, 1/K	W/m K	J/kg K
Room	1.3 – 1.8	2.4 – 5.5	2.4 – 5.5	0.005 – 0.08	n/a	n/a	n/a

Reference: Materials data book Cambridge 2003 (ITER_D_R9WSQ9).

See additional information on properties of insulating materials in the reference **02075-73783-001_WP01_D02_Rev.B - Passive Fire Protection for ITER Systems and Components (WMVZXP v1.1) (current)**