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HTR-E WP 2 Recuperator Material Parameters AISI 316 L

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HTR-E WP 2 Recuperator

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Contents

List of Symbols

Symbol	Description	Unit
c_p	specific heat	[J/kg ^{o}C]
E	Young's modulus	[MPa]
T	temperature	[^{o}C]
α_i	instantaneous coefficient of thermal expansion	[1/^{o}C]
α_m	mean coefficient of thermal expansion	[1/^{o}C]
λ	coefficient of thermal conductivity	[W/m ^{o}C]
ν	Poisson ratio	[-]
ρ	density	[kg/m^3]
σ_u	ultimate tensile stress	[MPa]
σ_y	yield stress	[MPa]

1 Introduction

In this report the material parameters of AISI 316 L are summarized for use during the evaluation of the thermal and structural behaviour of the HTR-E Recuperator. The following material parameters are summarized as a function of temperature where available:

1. density
2. thermal conductivity
3. specific heat
4. Young's modulus
5. Poisson ratio
6. coefficient of thermal expansion
7. yield stress
8. ultimate tensile stress

2 General Information

The low-carbon molybdenum austenitic stainless steel has the following designations:

AISI 316 L
UNS 31603
ISO 16Cr-12Ni-2Mo
Z6 CND 17.12

Note: *The composition for Z6 CND 17.12 is slightly different from the composition for UNS 31603.*

2.1 Composition

Source: *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-1100)*

The chemical composition of stainless steel 316 L is shown in the following table.

Element	Chemical Composition [weight percent]
Fe	balance
Cr	16.00 - 18.00
Ni	10.00 - 14.00
Mo	2.00 - 3.00
Mn	2.00 max
C	0.03 max
N	0.10 max
Si	0.75 max
S	0.030 max
P	0.045 max

2.2 Solidus/Liquidus Temperature

Source: *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-3103)*

The melting point of stainles steel 316 L ranges between 1370 °C and 1400 °C.

3 Density

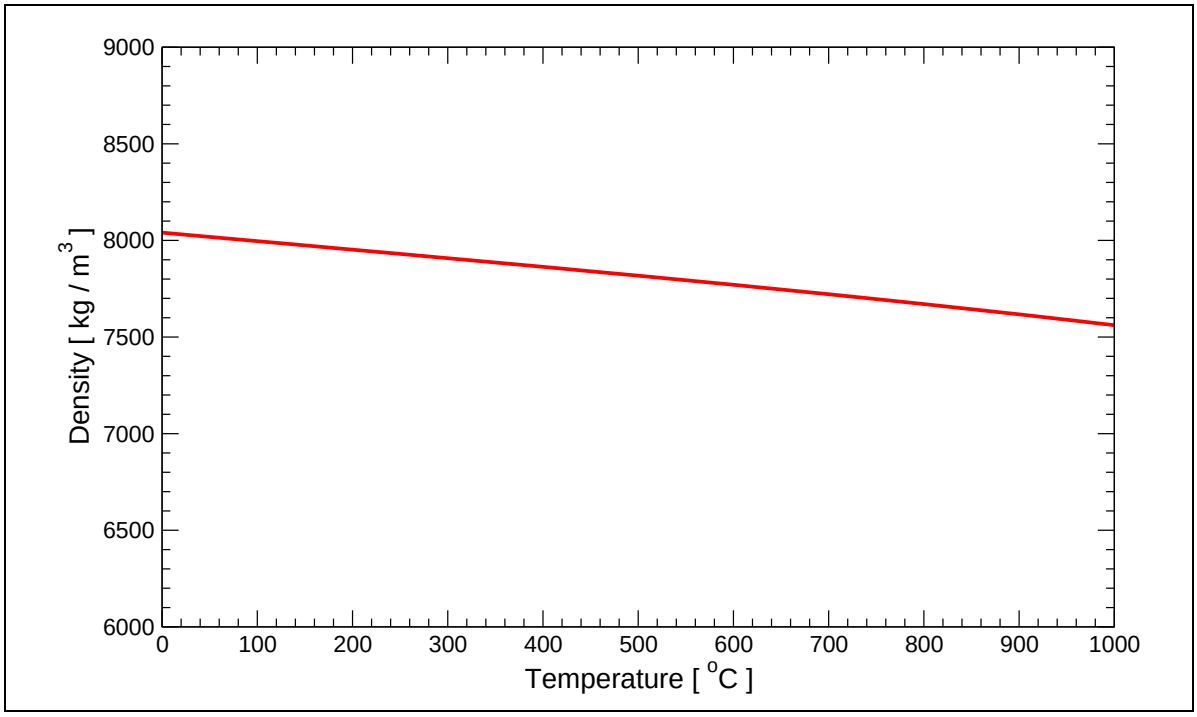
Source: *ITER Materials Properties Handbook, ITER Document No. S 74 RE 1, (file code ITER-AA02-3304)*

The density as a function of temperature is given by the following relation:

$$\rho = 8040.3 - 4.4165 \cdot 10^{-1} \cdot T + 2.0710 \cdot 10^{-5} \cdot T^{2} - 5.8048 \cdot 10^{-8} \cdot T^{3} \qquad [\ \mathrm{kg/m^3}\ ]$$

where:

$$0 \leq T \leq 1000\ ^{\circ}\mathrm{C}$$



T [°C]	ρ [kg/m^3]	T [°C]	ρ [kg/m^3]
0	8040.30	550	7794.00
50	8018.26	600	7770.23
100	7996.28	650	7746.04
150	7974.32	700	7721.38
200	7952.33	750	7696.22
250	7930.27	800	7670.51
300	7908.10	850	7644.21
350	7885.77	900	7617.27
400	7863.24	950	7589.65
450	7840.46	1000	7561.31
500	7817.40		

4 Thermal Conductivity

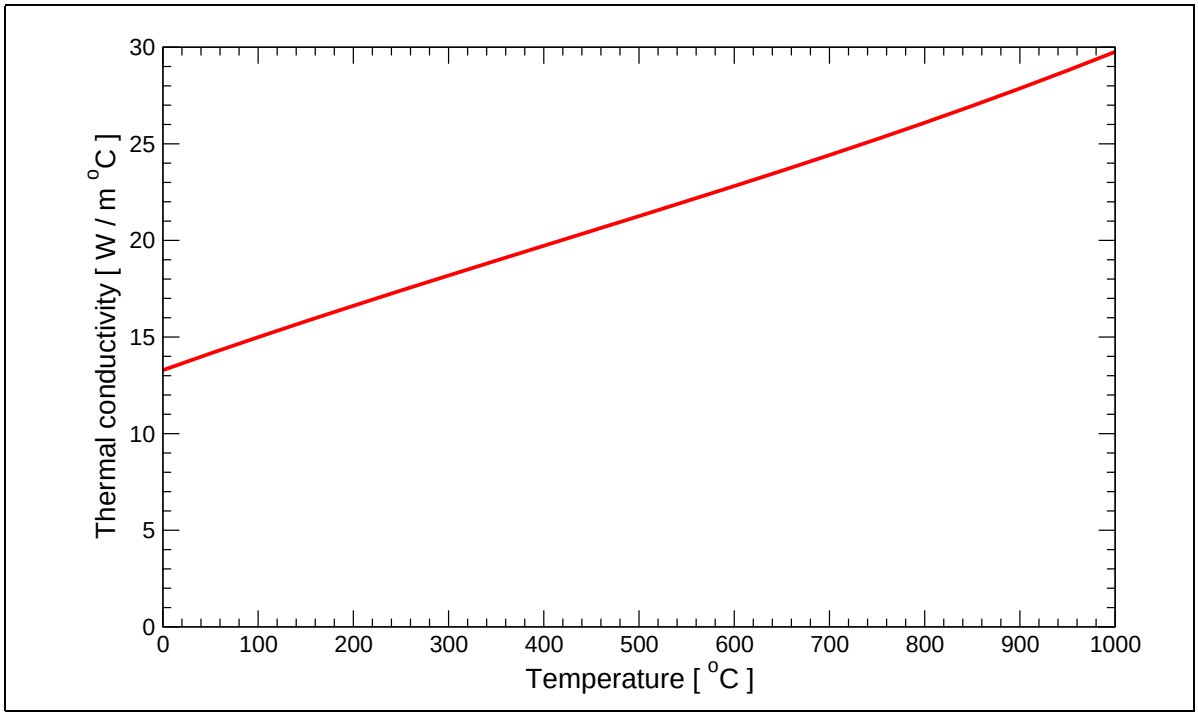
Source: *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-3112)*

The thermal conductivity as a function of temperature is given by the following relation:

$$\lambda = 13.28571 + 1.756205 \cdot 10^{-2} \cdot T - 5.378788 \cdot 10^{-6} \cdot T^{2} + 4.292929 \cdot 10^{-9} \cdot T^{3} \quad [\ \mathrm{W/m\ ^{o}C}\ ]$$

where:

$$0 \leq T \leq 1000\ ^{o}\mathrm{C}$$



T [°C]	λ [W/m °C]	T [°C]	λ [W/m °C]
0	13.286	550	22.032
50	14.151	600	22.814
100	14.992	650	23.607
150	15.813	700	24.416
200	16.617	750	25.243
250	17.407	800	26.091
300	18.186	850	26.964
350	18.958	900	27.864
400	19.725	950	28.796
450	20.491	1000	29.762
500	21.259		

5 Specific Heat

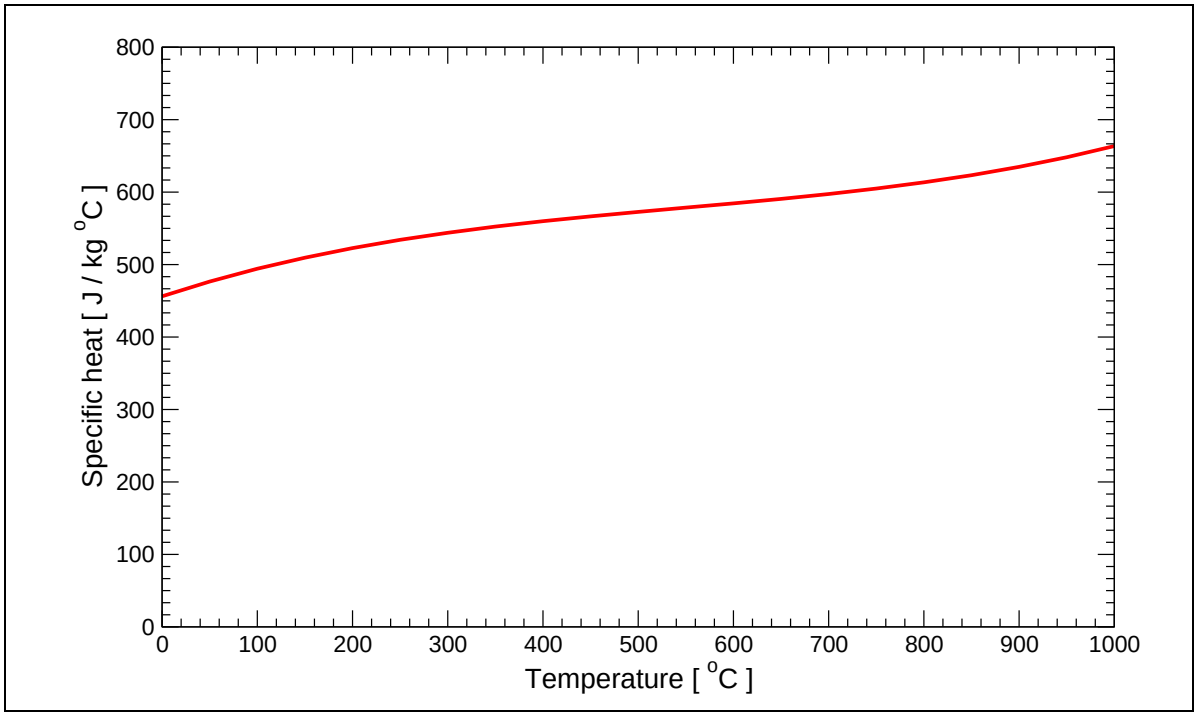
Source: *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-3108)*

The specific heat as a function of temperature is given by the following relation:

$$c_p = 456.2817 + 4.337{\cdot}10^{-1}{\cdot}T - 5.7714{\cdot}10^{-4}{\cdot}T^{2} + 3.5074{\cdot}10^{-7}{\cdot}T^{3} \qquad [\ \mathrm{J/kg\ ^oC}\ ]$$

where:

$$0 \leq T \leq 1000\ ^{o}\mathrm{C}$$



T [°C]	c_p [J/kg °C]	T [°C]	c_p [J/kg °C]
0	456.282	550	578.586
50	476.568	600	584.491
100	494.231	650	590.667
150	509.535	700	597.377
200	522.742	750	604.884
250	534.116	800	613.451
300	543.919	850	623.341
350	552.415	900	634.818
400	559.867	950	648.144
450	566.537	1000	663.582
500	572.689		

6 Young's Modulus

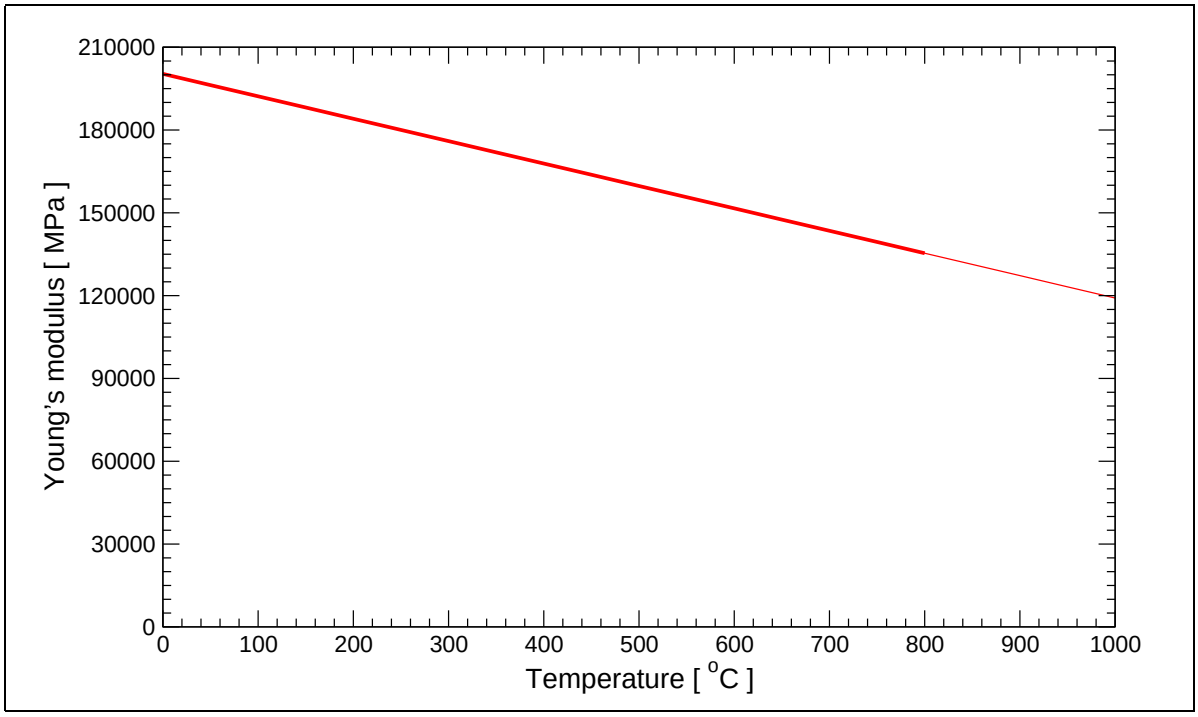
Source: *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-2111)*

The Young's modulus as a function of temperature is given by the following relation:

$$E = 200333 - 81.20 \cdot T \qquad [\text{ MPa }]$$

where:

$$0 \leq T \leq 800\ ^{o}\text{C}$$



T [°C]	E [MPa]	T [°C]	E [MPa]
0	200333	550	155673
50	196273	600	151613
100	192213	650	147553
150	188153	700	143493
200	184093	750	139433
250	180033	800	135373
300	175973	*850*	*131313*
350	171913	*900*	*127253*
400	167853	*950*	*123193*
450	163793	*1000*	*119133*
500	159733		

Note: *Italic data is added for numerical reasons.*

7 Poisson Ratio

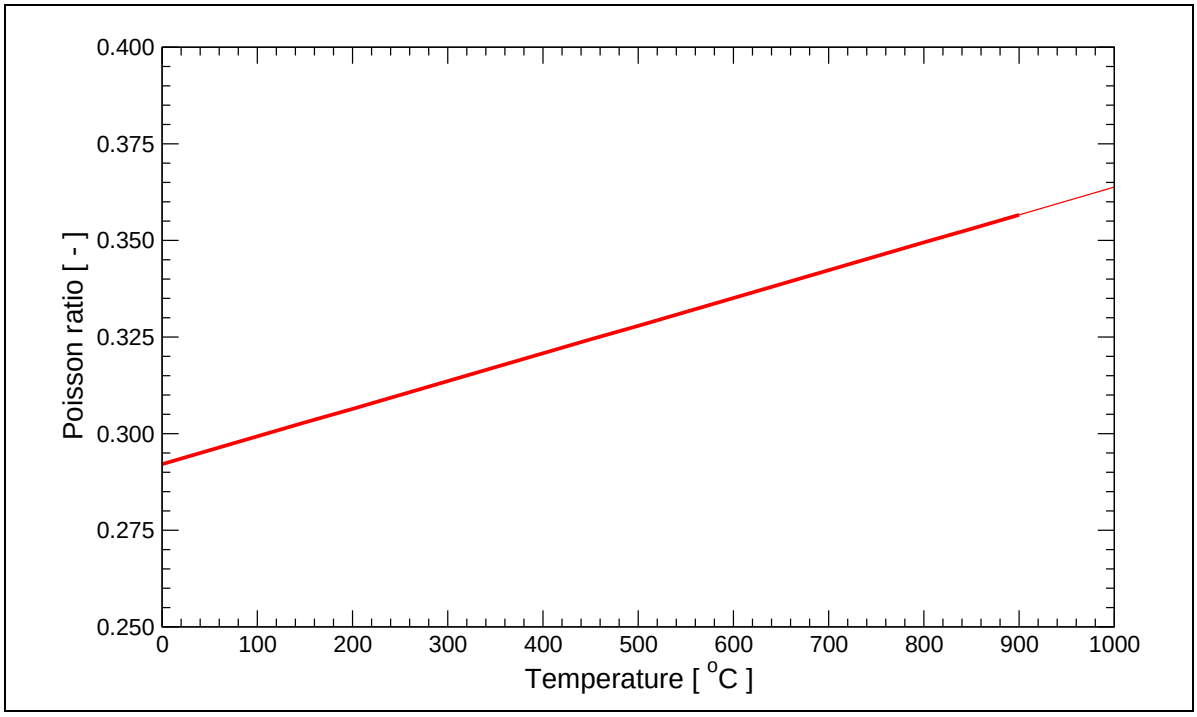
Source: *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-2110)*

The Poisson ratio as a function of temperature is given by the following relation:

$$\nu = 0.2921 - 7.169 \cdot 10^{-5} \cdot T \qquad [\ -\ ]$$

where:

$$0 \leq T \leq 900\ ^{o}\mathrm{C}$$



T [°C]	ν [-]	T [°C]	ν [-]
0	0.2921	550	0.3315
50	0.2957	600	0.3351
100	0.2993	650	0.3387
150	0.3029	700	0.3423
200	0.3064	750	0.3459
250	0.3100	800	0.3495
300	0.3136	850	0.3530
350	0.3172	900	0.3566
400	0.3208	*950*	*0.3602*
450	0.3244	*1000*	*0.3638*
500	0.3279		

Note: *Italic data is added for numerical reasons.*

8 Coefficient of Thermal Expansion

Source: *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-3114)*

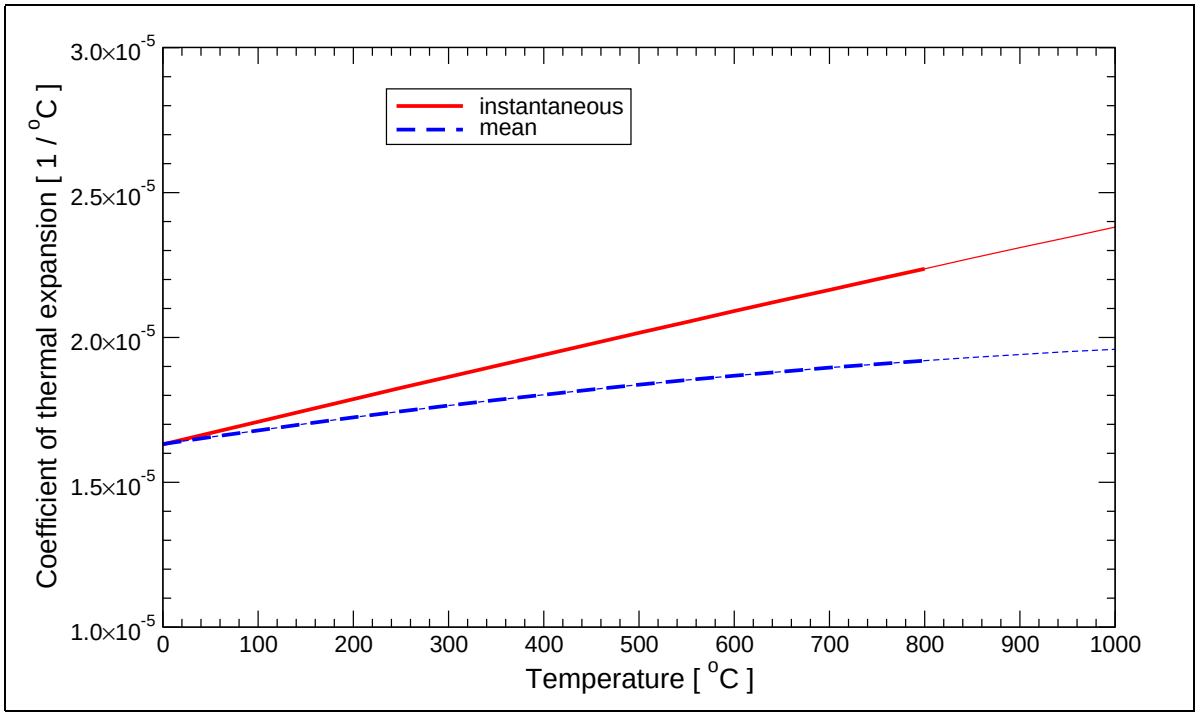
The instantaneous and mean coefficient of thermal expansion as a function of temperature are given by the following relations:

$$\alpha_{\mathrm{i}} = 1.63058{\cdot}10^{-5} + 7.9069{\cdot}10^{-9}{\cdot}T - 4.016{\cdot}10^{-13}{\cdot}T^{\,2} \qquad [\ 1/^{\mathrm{o}}\mathrm{C}\ ]$$

$$\alpha_{\mathrm{m}} = 1.63153{\cdot}10^{-5} + 4.9348{\cdot}10^{-9}{\cdot}T - 1.6585{\cdot}10^{-12}{\cdot}T^{\,2} \qquad [\ 1/^{\mathrm{o}}\mathrm{C}\ ]$$

where:

$0 \leq T \leq 800\ ^{\mathrm{o}}\mathrm{C}$



T [°C]	instantaneous α_{i} [1/°C]	mean α_{m} [1/°C]
0	1.631E-05	1.632E-05
50	1.670E-05	1.656E-05
100	1.709E-05	1.679E-05
150	1.748E-05	1.702E-05
200	1.787E-05	1.724E-05
250	1.826E-05	1.745E-05
300	1.864E-05	1.765E-05
350	1.902E-05	1.784E-05
400	1.940E-05	1.802E-05
450	1.978E-05	1.820E-05
500	2.016E-05	1.837E-05
550	2.053E-05	1.853E-05
600	2.091E-05	1.868E-05
650	2.128E-05	1.882E-05
700	2.164E-05	1.896E-05
750	2.201E-05	1.908E-05
800	2.237E-05	1.920E-05
850	*2.274E-05*	*1.931E-05*
900	*2.310E-05*	*1.941E-05*
950	*2.345E-05*	*1.951E-05*
1000	*2.381E-05*	*1.959E-05*

Note: *Italic data is added for numerical reasons.*

9 Yield Stress

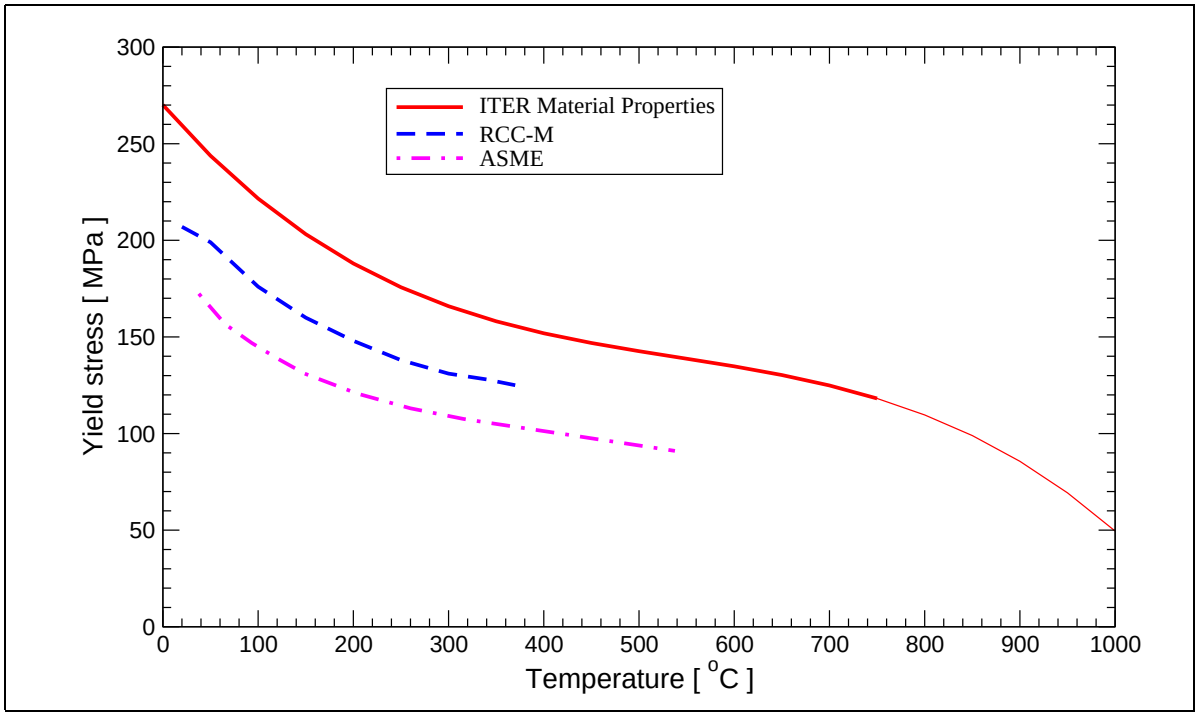
Sources: [a] *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-2102)*
[b] *RCC-M Edition 1993, Subsection Z, Technical Appendices, Table I 2.2*
[c] *ASME Boiler & Pressure Vessel Code, Section II, Material Properties, 2001 Edition, Table Y-1, Yield Stress Values S_y for Ferrous and Nonferrous Materials*

The yield stress as a function of temperature is given by the following relation [a]:

$$\sigma_y = 270.09 - 5.702 \cdot 10^{-1} \cdot T + 9.1162 \cdot 10^{-4} \cdot T^2 - 5.6198 \cdot 10^{-7} \cdot T^3 \qquad [\text{ MPa }]$$

where:

$0 \leq T \leq 750$ °C



ITER		RCC-M		ASME	
T [°C]	σ_y [MPa]	T [°C]	σ_y [MPa]	T [°C]	σ_y [MPa]
0	270.09	20	207.00	37.78	172.37
50	243.79	50	199.00	65.56	172.37
100	221.62	100	176.00	93.33	146.86
150	203.17	150	160.00	204.44	120.66
200	188.02	200	148.00	260.00	113.07
250	175.74	250	138.00	315.56	107.56
300	165.90	300	131.00	343.33	105.49
350	158.10	340	128.00	371.11	103.42
400	151.90	350	127.00	398.89	101.35
450	146.89	360	126.00	426.67	99.28
500	142.65	370	125.00	454.44	97.22
550	138.75			482.22	95.15
600	134.77			510.00	93.08
650	130.29			537.78	91.01
700	124.88				
750	118.14				
800	*109.63*				
850	*98.94*				
900	*85.64*				
950	*69.31*				
1000	*49.53*				

Note: *Italic data is added for numerical reasons.*

10 Ultimate Stress

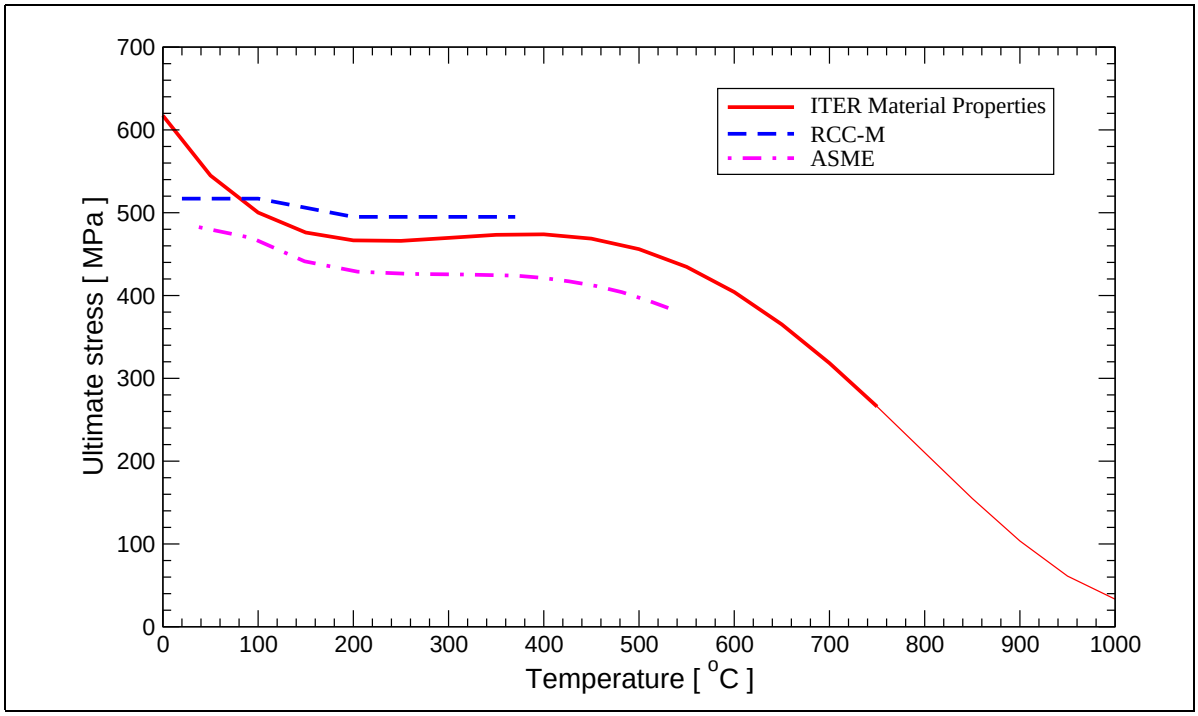
Sources: [a] *ITER Materials Properties Handbook, ITER Document No. S 74 MA 2, (file code ITER-AA02-2101)*
[b] *RCC-M Edition 1993, Subsection Z, Technical Appendices, Table I 3.2*
[c] *ASME Boiler & Pressure Vessel Code, Section II, Material Properties, 2001 Edition, Table U, Tensile Strength Values S_u for Ferrous and Nonferrous Materials*

The ultimate stress as a function of temperature is given by the following relation [a]:

$$\sigma_u = 617.275 - 1.775 \cdot T + 7.0659 \cdot 10^{-3} \cdot T^2 - 1.0769 \cdot 10^{-5} \cdot T^3 \; 4.8941 \cdot 10^{-9} \cdot T^4 \qquad [\text{ MPa }]$$

where:

$0 \leq T \leq 750$ °C



ITER		RCC-M		ASME	
T [°C]	σ_y [MPa]	T [°C]	σ_y [MPa]	T [°C]	σ_y [MPa]
0	617.27	20	517.00	37.78	482.63
50	544.87	50	517.00	93.33	469.53
100	500.15	100	517.00	148.89	441.26
150	476.14	150	506.00	315.56	425.41
200	466.59	200	495.00	343.33	424.72
250	466.00	250	495.00	371.11	424.03
300	469.59	300	495.00	398.89	421.27
350	473.32	330	495.00	426.67	417.13
400	473.89	350	495.00	454.44	411.62
450	468.73	360	495.00	482.22	404.03
500	456.01	370	495.00	510.00	393.69
600	404.17			537.78	381.97
650	365.06				
700	318.37				
750	265.95				
800	*210.35*				
850	*154.88*				
900	*103.57*				
950	*61.20*				
1000	*33.28*				

Note: *Italic data is added for numerical reasons.*