SPALLATION NEUTRON SOURCE PROJECT
OAK RIDGE NATIONAL LABORATORY

SNS PROJECT TRANSMITTAL
OR NOTICE OF AVAILABILITY

Issue Date	Project 99-E-334 Subproject	Sequence no.
June 3, 1999	Target Systems	TG-0025
	WBS No.(s) 1.1.5.2	

TITLE OR DESCRIPTION "Initial Structural Design Allowables for the Spallation Neutron Source Target Module"
This report documents the completion of milestone Nos. TG01050456, TG01050458, TG01050460. This report is attached to this transmittal in a PDF format.
Comments are requested by June 12, 1999

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1.6.1 TARGET		
1.6.2 MODERATORS		
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1.1.4 Neutron Source Sys. Dev.		
1.1.5 Mercury Target Sys. Dev.		
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1.1.6 Materials Qualification		
1.1.7 Cold Moderator Sys. Dev.		
1.1.10 Robotics and Remote Handling Development		

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SNS/TSR-0086
Rev. 1

INITIAL STRUCTURAL DESIGN ALLOWABLES FOR THE SPALLATION NEUTRON SOURCE TARGET MODULE

Spallation Neutron Source Target Systems Report
SNS/TSR-0086

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April 1999

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INITIAL STRUCTURAL DESIGN ALLOWABLES FOR THE SPALLATION NEUTRON SOURCE TARGET MODULE

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ABSTRACT

Preliminary design allowable stress values are presented for type 316LN stainless steel, Inconel 718, and 6061-T6 aluminum for use in the design of the mercury target system for the Spallation Neutron Source (SNS). These preliminary design allowable stress values are based on the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, which provides the basis for the design of Class 1 nuclear power plant components. Thermal and elastic properties of the three materials are provided for convenience and to assure uniformity within the SNS project.

The SNS target vessel is of particular interest. It will be subjected to thermal transients, neutron bombardment, and pressure pulses and will be in contact with mercury. The temperature is expected to be less than 200°C.

It is expected that the effects of irradiation and the effects of contact with liquid mercury will be addressed in a later version of the design criteria for the SNS mercury target system. These preliminary criteria can be applied to the design of the SNS mercury target system in the interim.

1. INTRODUCTION

This document provides preliminary design allowable stress values for use in the design of the mercury target system for the Spallation Neutron Source (SNS). The materials are type 316LN stainless steel, Inconel 718, and 6061-T6 aluminum which meet the requirements of one or more of the American Society for Testing and Materials (ASTM) specifications listed in Tables 1, 2, and 3 respectively. The compositions of type 316LN stainless steel, Inconel 718, and 6061-T6 aluminum are given in Tables 4, 5, and 6, respectively.

Table 1. ASTM specification for Type 316LN stainless steel

Specification No.	Product Form
A-182	Forging
A-336	Forging
A-182	Forging
A-213	Seamless tube
A-240	Plate
A-249	Welded tube
A-312	Welded and seamless pipe
A-358	Welded pipe
A-376	Seamless pipe
A-403	Fittings
A-479	Bar
A-688	Welded tube
A-813	Welded pipe
A-814	Welded pipe

Table 2. ASTM specifications for Inconel 718

Specification No.	Product Form
B-670	Plate, sheet, and strip

Table 3. ASTM specifications for 6061-T6 aluminum

Specification No.	Product Form
B-209	Sheet and Plate
B-210	Drawn Seamless Tube
B-221	Extruded Bar, Rod, and Shape
B-241/SB-241M	Seamless Pipe and Seamless Extruded Tube
B-247	Die and Hand Forgings

Table 4. Chemical composition, %, of Type 316LN stainless steel (ASTM A-240)

Element	Percentage
Carbon	0.030 maximum
Manganese	2.00 maximum
Phosphorus	0.045 maximum
Sulfur	0.030 maximum
Silicon	0.75 maximum
Chromium	16.00 - 18.00
Nickel	10.00 - 14.00
Molybdenum	2.00 - 3.00
Nitrogen	0.10 - 0.16

Table 5. Chemical composition, %, of Inconel 718 (ASTM B-670)

Element	Percentage
Carbon	0.08 max
Manganese	0.35 max
Silicon	0.35 max
Phosphorus	0.015 max
Sulfur	0.015 max
Colbalt	1.0 max
Molybdenum	2.80 to 3.30
Columbium (Nb) + tantsium	4.75 to 5.50
Titanium	0.65 to 1.15
Aluminum	0.20 to 0.80
Iron	remainder
Copper	0.30 max
Nickel	50.0 to 55.0
Boron	0.006 max

Table 6. Chemical Composition, %, of 6061-T6 aluminum (Notes 1, 2, and 3)

Element	Percentage
Silicon	0.40–0.80
Iron	0.70
Copper	0.15–0.40
Manganese	0.15
Magnesium	0.80–1.20
Chromium	0.04–0.35
Zinc	0.25
Titanium	0.15
Other elements each	0.05
Other elements, total	0.15
Aluminum	remainder

NOTES

(1) Where single units are shown, these indicate the maximum amounts permitted.

(2) Analysis shall regularly be made only for the elements specified in this table. If, however, the presence of other elements is suspected or indicated in the course of routine analysis, further analysis shall be made to determine that these elements are not in excess of the amounts specific.

(3) For purposes of determining conformance to these limits, an observed value or a calculated value obtained from analysis shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the specified limit, in accordance with the rounding method of Recommended Practice E 29.

(4) Other Elements—Total shall be the sum of unspecified metallic elements 0.010% or more, rounded to the second decimal before determining the sum.

These preliminary design criteria are based on the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, Ref. 1 (ASME Code) which provides the basis for the design of Class 1 nuclear power plant components. These criteria address the following modes of failure:

1. Excessive elastic deformation including elastic instability.
2. Excessive plastic deformation.
3. Brittle fracture.
4. Stress rupture/creep deformation (inelastic).
5. Plastic instability—incremental collapse.
6. Fatigue.

The ITER Structural Design Criteria[2], was also considered for use as the basis for these preliminary design criteria for the SNS mercury target system. The International Thermonuclear Experimental Reactor (ITER) Structural Design Criteria is largely based on the ASME Code, but it goes beyond the ASME Code to address the effects of irradiation including embrittlement, swelling and irradiation induced creep. It is expected that the effects of irradiation and the effects of contact with liquid mercury will be addressed in a later version of the design criteria for the SNS mercury target system. These preliminary criteria can be applied to the design of the SNS mercury target system in the interim.

The SNS target vessel is of particular interest. It will be subjected to an extremely high number of thermal transients, neutron bombardment, and pressure pulses and will be in contact with mercury. The temperature is expected to be less than 200°C. There will be pressure shock waves and thermal transients that occur on a time scale of 100 microseconds but will occur 20-1000 times per second.

It is assumed that preliminary design analysis will primarily be elastic finite-element analysis.

2. THERMAL AND ELASTIC PROPERTIES FOR USE IN DESIGN

It is convenient to have a consistent set of thermal and elastic properties. Values of coefficient of thermal expansion, thermal conductivity, thermal diffusivity, and elastic modulus derived from the ASME Code are given in Tables 7, 8, and 9 for type 316LN stainless steel, Inconel 718, and 6061-T6 aluminum, respectively. This data is presented graphically in Figs. 1–12. The ASME code gives values of 0.29, 0.31, and 0.33 for Poisson's ratio for 316LN stainless steel, Inconel 718 and 6061-T6 aluminum, respectively.

Table 7. Type 316LN stainless steel thermal and elastic properties

Temp. (°C)	Instantaneous CTE (E-6/°C)	Mean CTE (E-6/°C)	Thermal Conductivity (W/mk)	Thermal Diffusivity (E-6 m^2/s)	Elastic Modulus (GPa)
20	15.16		13.3	3.46	195.1
50	15.66	15.46	13.91	3.53	193.2
75	16.08	15.61	14.30	3.59	191.5
100	16.48	15.81	14.65	3.65	189.8
125	16.85	16.00	15.18	3.70	188
150	17.22	16.16	15.61	3.74	186.1
175	17.55	16.39	15.89	3.82	184.5
200	17.85	16.54	16.30	3.90	183

Table 8. Inconel 718 thermal and elastic properties

Temp. (°C)	Instantaneous CTE (E-6/°C)	Mean CTE (E-6/°C)	Thermal Conductivity (W/mk)	Thermal Diffusivity (E-6 m^2/s)	Elastic Modulus (GPa)
20	12.69		11.09	3.10	199.9
50	12.93	12.80	11.59	3.18	198.0.
75	13.15	12.91	11.98	3.26	196.3
100	13.35	13.05	12.42	3.35	194.7
125	13;55	13.11	12.87	3.42	193.1
150	13.73	13.19	13.31	3.48	191.6
175	13.92	13.29	13.68	3.56	191.0
200	14.08	13.39	14.10	3.64	190.4

Table 9. 6061-T6 aluminum thermal and elastic properties

Temp. (°C)	Instantaneous CTE (E-6/°C)	Mean CTE (E-6/°C)	Thermal Conductivity (W/mk)	Thermal Diffusivity (E-6 m^2/s)	Elastic Modulus (GPa)
20	22.53		166.86	68.7	68.9
50	23.12	22.82	169.20	68.6	67.9
75	23.61	23.07	170.88	68.4	67.0
100	24.10	23.32	172.33	68.3	65.9
125	24.60	23.57	173.58	68.1	64.7
150	25.09	23.82	174.83	67.8	63.4
175	25.59	24.06	175.93	67.7	61.9
200	26.08	24.31	176.89	67.6	60.3

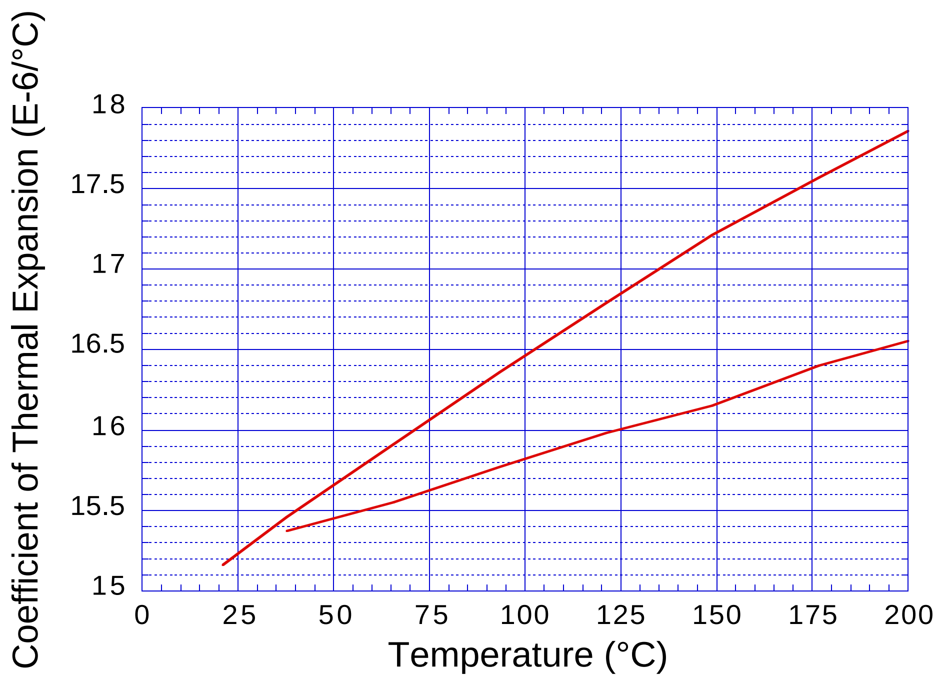


Fig. 1. Coefficient of thermal expansion of 316LN stainless steel.

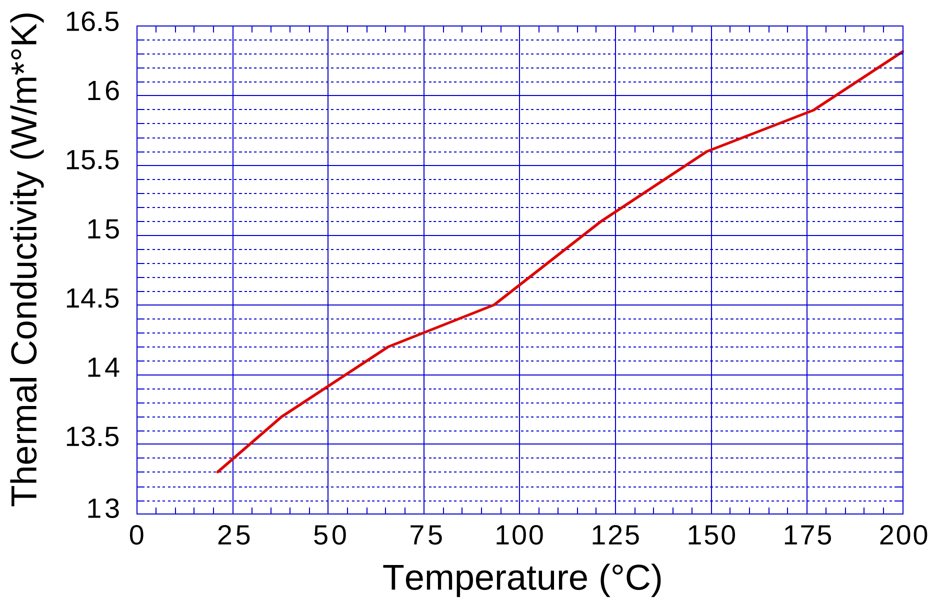


Fig. 2. Thermal conductivity of 316LN stainless steel.

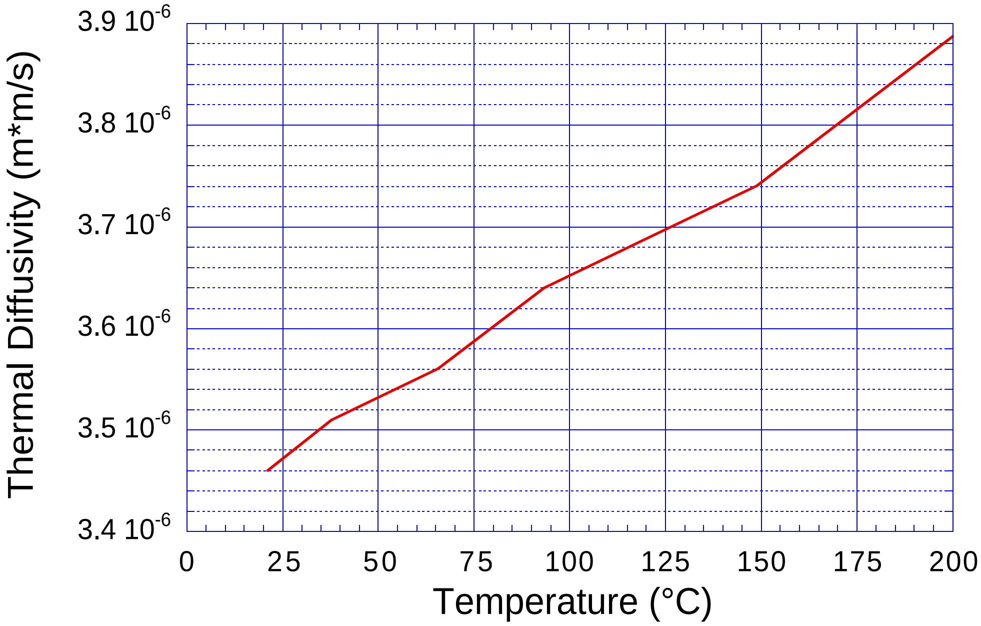


Fig. 3. Thermal diffusivity of 316LN stainless steel.

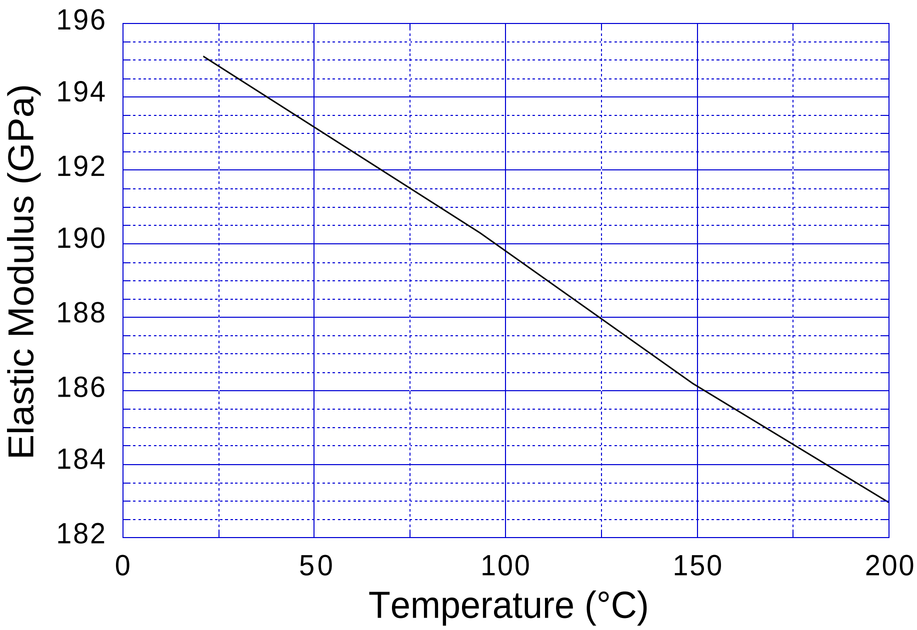


Fig. 4. Modulus of elasticity of 316LN stainless steel.

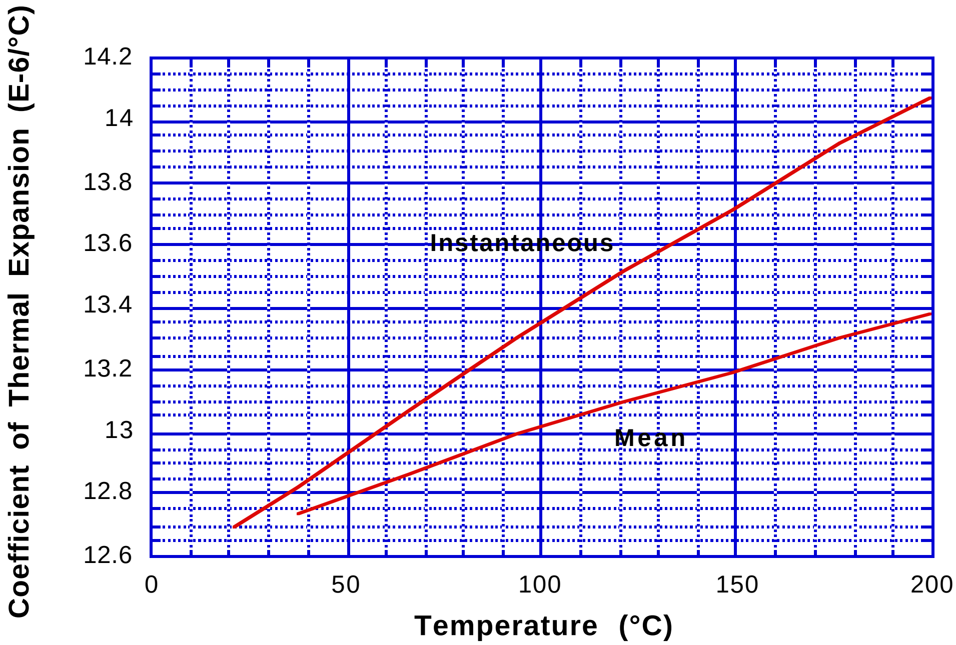


Fig. 5. Coefficient of thermal expansion of Inconel 718.

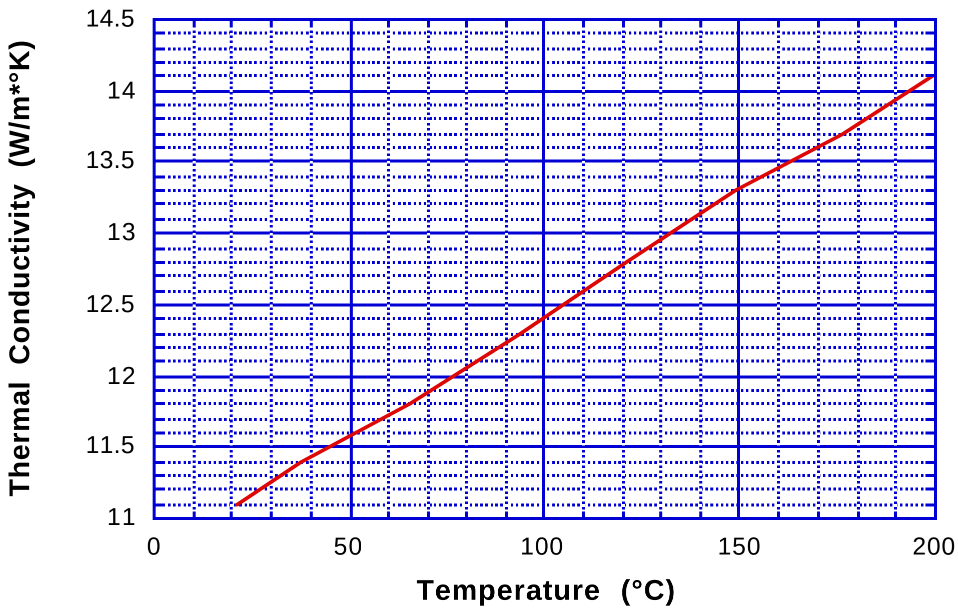


Fig. 6. Thermal conductivity of Inconel 718.

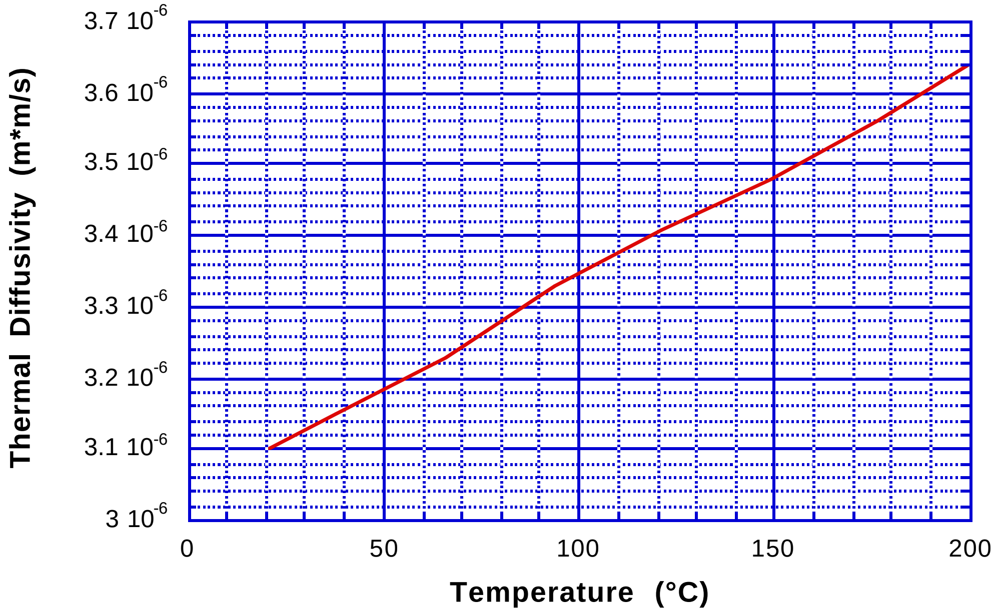


Fig. 7. Thermal diffusivity of Inconel 718.

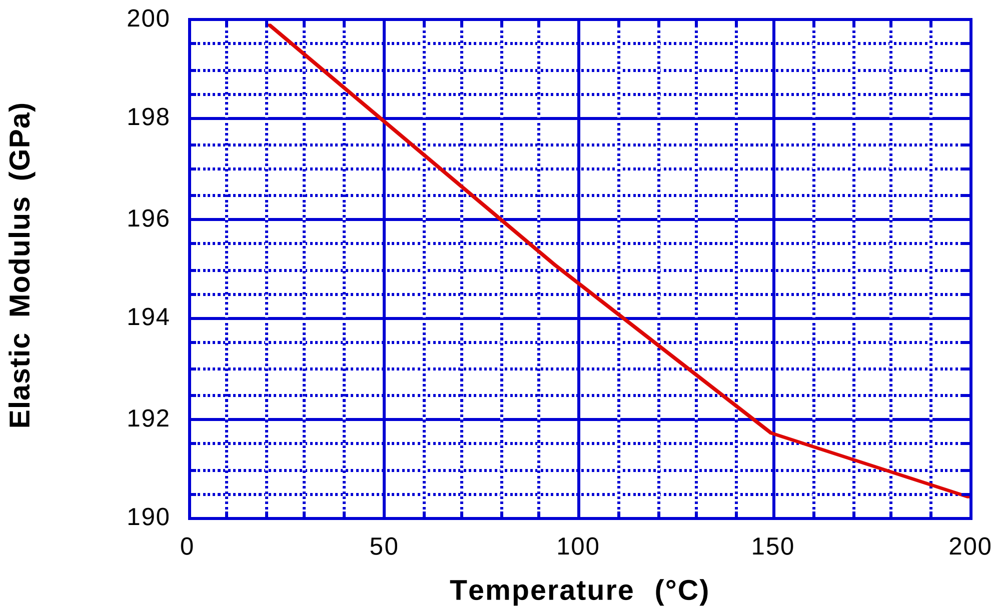


Fig. 8. Modulus of elasticity of Inconel 718.

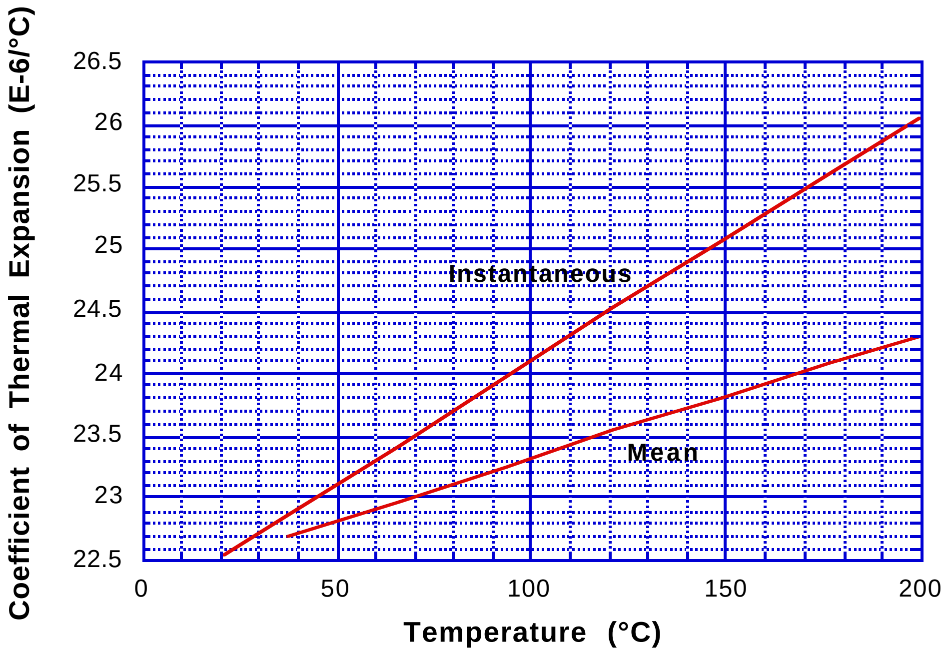


Fig. 9. Coefficient of thermal expansion of 6061-T6 aluminum.

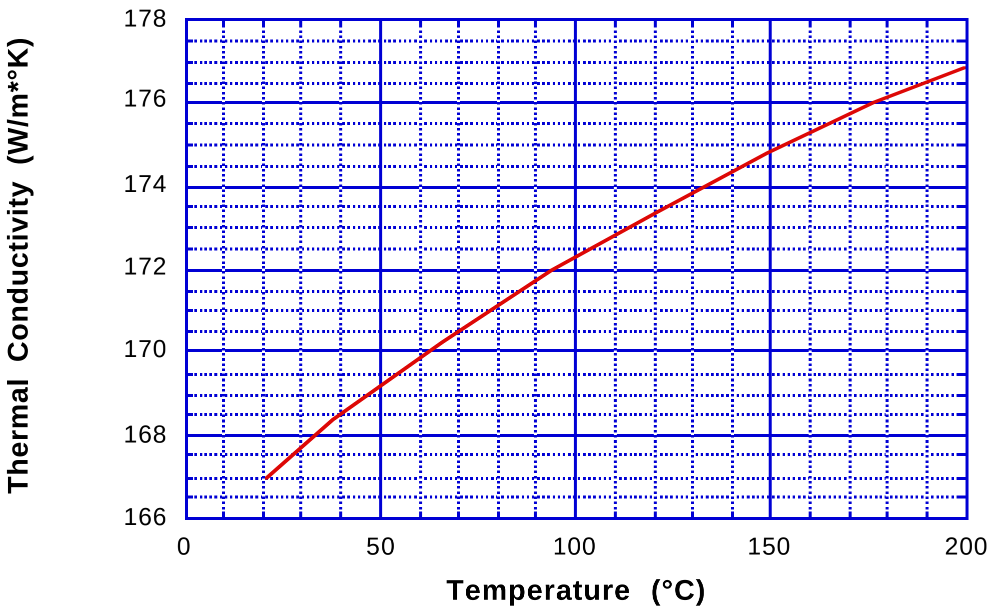


Fig. 10. Thermal conductivity of 6061-T6 aluminum.

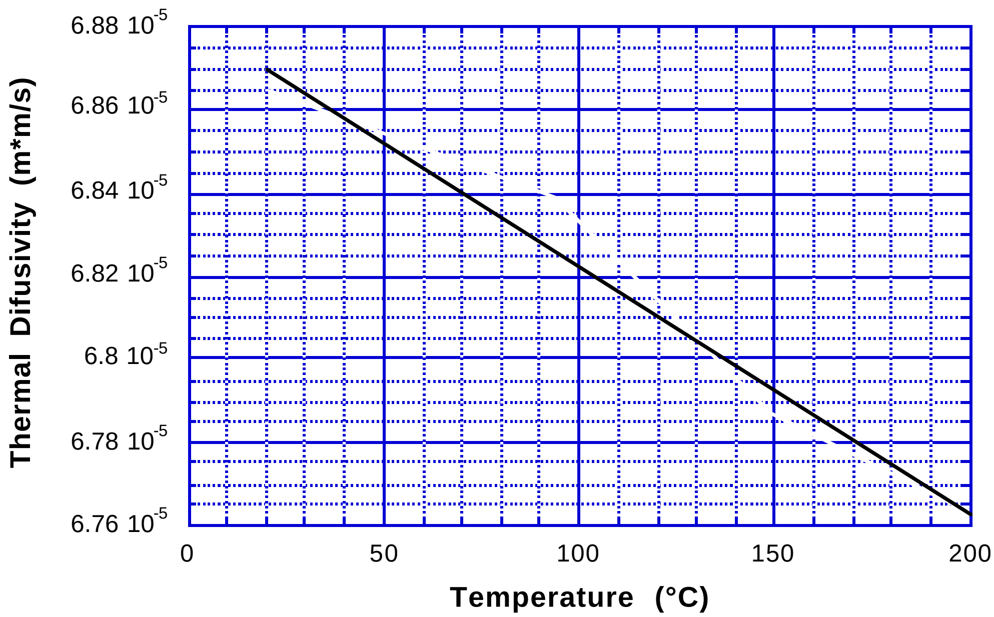


Fig. 11. Thermal diffusivity of 6061-T6 aluminum.

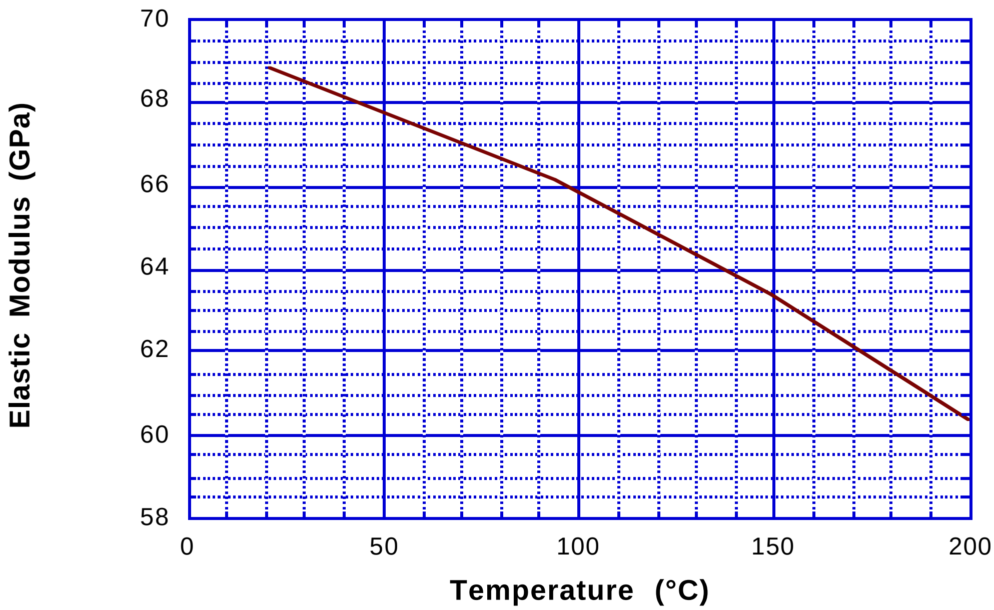


Fig. 12. Modulus of elasticity of 6061-T6 aluminum.

3. MULTIAXIAL STRENGTH CRITERION

The stress state at any point in a structure may be completely defined by giving the magnitudes and directions of the three principal stresses. When two or three of these stresses are different from zero, a strength theory is required. The most commonly used theories are the maximum stress theory, the maximum shear stress theory (Tresca), and the distortion energy theory (von Mises). The maximum shear stress theory and the distortion energy theory are both better than the maximum stress theory for predicting both yielding and fatigue failure of ductile metals. The maximum shear stress theory is used in this document.

The maximum shear stress at a point is defined as the absolute value of one-half of the algebraic difference between the largest and the smallest of the three principal stresses. Thus, if the principal stresses are σ_1, σ_2, and σ_3, and $\sigma_1 > \sigma_2 > \sigma_3$ (algebraically), the maximum shear stress is 1/2 $(\sigma_1 - \sigma_3)$. The maximum shear stress theory of failure states that yielding occurs when the maximum shear stress reaches a value equal to the maximum shear stress at the yield point in a tensile test. In the tensile test, at yield, $\sigma_1 = S_y$, $\sigma_2 = 0$, and $\sigma_3 = 0$; therefore, the maximum shear stress is $S_y/2$. Therefore, yielding in the component occurs when

$$1/2 \left| \sigma_1 - \sigma_3 \right| = 1/2\ S_y.$$

In order to avoid the unfamiliar and unnecessary operation of dividing both the calculated and the allowable stresses by two before comparing them, a new term, "stress intensity" is used. The stress intensity is defined as twice the maximum shear stress and is equal to the largest algebraic difference between any two of the three principal stresses. Thus the stress intensity is directly comparable to strength values found from tensile tests.

4. DESIGN STRESS INTENSITY VALUE

The basic allowable stress intensity value is the design stress intensity S_m.

The design stress intensity, S_m, is the lowest of the following:

– 1/3 specified tensile strength at room temperature,

– 1/3 tensile strength at temperature,

– 2/3 specified minimum yield strength at room temperature,

– 2/3 yield strength at temperature, or

– 90% yield strength at temperature for stainless steel.

The values of S_m for 316LN stainless steel, Inconel 718, and 6061-T6 aluminum are given in Tables 10, 11, and 12, respectively. The S_m values for type 316LN stainless steel came from Ref. 3. The allowable stress values for Inconel 718 were derived using the ASME Code basis for establishing design stress intensity values for use with Subsection NB which is discussed above and the temperature dependence of tensile strength given in Ref. 4. The allowable stress values for 6061-T6 aluminum are from Code Case N-519 (Ref. 5).

Table 10. Design stress intensity values, S_m, for Type 316LN stainless steel

Temperature (°C)	S_m (MPa)
-29 to 38	137.9
93	137.9
149	137.9
204	130.3

Table 11. Design stress intensity values, S_m, for Inconel 718

Temperature (°C)	S_m (MPa)
20	413.7
50	413.7
100	413.7
150	413.5
200	405.7
250	400.9
300	398.2
350	396.6
400	395.1

Table 12. Design stress intensity values, S_m, for 6061-T6 aluminum

Spec. No.	Temper	Size or Thickness (mm)	Specified min. Tensile Strength (MPa)	Specified min. Yield Strength (MPa)	Allowable Stress Values, MPa for Metal Temperature not Exceeding, °C					
					Notes	38	66	93	121	149
Sheet and Plate										
SB-209	T6	1.30-6.32	289.6	241.3	(1)(2)	96.5	96.5	96.5	92.4	77.9
	T651	6.33 101.60	289.6	241.3	(1)(2)	96.5	96.5	96.5	92.4	77.9
	T651	101.61-152.40	275.8	241.3	(1)(2)	91.7	91.7	91.7	89.6	76.5
	T6, T651 Wld.	All	165.5	--	(1)	55.2	55.2	55.2	54.5	50.3
Rod, Bar, and Shapes										
SB-221	T6	All	262.0	241.3	(1)(2)	87.6	87.6	87.6	84.8	72.4
	T6 Wld.	All	165.5	--	(1)	55.2	55.2	55.2	54.5	50.3
Drawn Seamless Tube										
SB-210	T6	0.635-12.7	289.6	241.3	(1)(2)	96.5	96.5	96.5	92.4	77.9
	T6 Wld.	All	165.5	--	(1)	55.2	55.2	55.2	54.5	50.3
Seamless Pipe										
SB-241	T6	<25.4	289.6	241.3	(1)(2)	96.5	96.5	96.5	92.4	77.9
	T6	≥25.4	262.0	241.3	(1)(2)	87.6	87.6	87.6	84.8	72.4
	T6 Wld	All	165.5	--	(1)	55.2	55.2	55.2	54.5	50.3
Seamless Extruded Tube										
SB-241	T6	All	262.0	241.3	(1)(2)	87.6	87.6	87.6	84.8	72.4
	T6 Wld.	All	165.5	--	(1)	55.2	55.2	55.2	54.5	50.3
Die and Hand Forging										
SB-247	Die T6	Up thru 101.60	262.0	241.3	(1)(2)	87.6	87.6	87.6	83.4	72.4
	Hand T6	Up thru 101.60	255.1	227.5	(1)(2)	84.8	84.8	84.8	80.7	71.0
	Hand T6	101.61-203.20	241.3	220.6	(1)(2)	80.7	80.7	80.7	77.2	68.3
	T6 Wld.	Up thru 203.20	165.5		(1)	55.2	55.2	55.2	54.5	50.3

NOTES
(1) Design stress intensity value for 37.8°C may be used at temperatures down to -268.9°C without additional specification requirements.
(2) The stress values given for this material are not applicable when either welding or thermal cutting is employed.

5. SERVICE LEVELS

The allowable stress value is dependent on the service level assigned. The service levels are as follows:

- Service level A covers loads that are normally expected to occur regularly.

- Service level B covers loads that are expected to occur only a few times over the life of the component. Previously, this was referred to as upset loads. The allowable stress values are such that no damage requiring repair will occur.

- Service level C was previously referred to as emergency conditions. The allowable stress values for this service level permit large deformations in areas of structural discontinuity which may necessitate the removal of the component from service for inspection or repair of damage to the component or support.

- Service level D was previously referred to as faulted conditions. The allowable stress values for this service level permit gross general deformations with some consequent loss of dimensional stability and damage requiring repair, which may require removal of the component from service.

6. ALLOWABLE STRESS INTENSITY VALUES

Not all elastically calculated stresses are equally capable of causing a structure to fail. For example, if a weight is hung on a ductile steel rod it will cause failure if the stress is higher than the strength of the rod. However, if the same elastically calculated stress is applied to the same ductile steel rod by moving the opposite ends of the rod and holding them there, the rod will deform plastically but will not fail. The first case is an example of a "primary" stress and the second case is an example of a strain controlled stress. The first case would result in immediate catastrophic failure. The second case would only result in catastrophic failure if a much higher elastically calculated stress were applied repeatedly.

The different types of stress require different limits. The different types of stress are categorized as follows:

A. Primary Stress
   (1) General primary membrane stress, P_m.
   (2) Local primary membrane stress, P_L.
   (3) Primary bending stress, P_b.
B. Secondary Stress - Q.
C. Peak Stress - F.

Primary stress is a stress developed by the imposed loading which is necessary to satisfy the laws of equilibrium between external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. If a primary stress exceeds the yield strength of the material through the entire thickness, the prevention of failure is entirely dependent on the strain-hardening properties of the material.

Secondary stress is a stress developed by the self-constraint of a structure. It must satisfy an imposed strain pattern rather than being in equilibrium with an external load. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the discontinuity conditions or thermal expansions which cause the stress to occur.

Peak stress is the highest stress in the region under consideration. The basic characteristic of a peak stress is that it causes no significant distortion and is objectionable mostly as a possible source of fatigue failure or crack initiation that may lead to brittle fracture.

The need for dividing primary stress into membrane and bending components is that, limit design theory shows that the calculated value of a primary bending stress may be allowed to go higher than the calculated value of a primary membrane stress. The placing in the primary category of local membrane stress produced by mechanical loads, however, requires some explanation because this type of stress really has the basic characteristics of a secondary stress. It is self-limiting and when it exceeds yield, the external load will be resisted by other parts of the structure, but this shift may involve intolerable distortion and it was felt that it must be limited to a lower value than other secondary stresses, such as discontinuity bending stress and thermal stress.

Secondary stress could be divided into membrane and bending components, just as was done for primary stress, but after the removal of local membrane stress to the primary category, it appeared that all the remaining secondary stresses could be controlled by the same limit and this division was unnecessary.

Thermal stresses are never classed as primary stresses, but they appear in both of the other categories, secondary and peak. Thermal stresses which can produce distortion of the structure are placed in the secondary category and thermal stresses which result from almost complete suppression of the differential expansion, and thus cause no significant distortion, are classed as peak stresses.

The potential failure modes and various stress categories are related to the code provisions as follows:

(a) The primary stress limits are intended to prevent plastic deformation and to provide a nominal factor of safety on the ductile burst pressure.
(b) The primary plus secondary stress limits are intended to prevent excessive plastic deformation leading to incremental collapse, and to validate the application of elastic analysis when performing the fatigue evaluation.
(c) The peak stress limit is intended to prevent fatigue failure as a result of cyclic loadings.

The allowable stress intensity depends on the service level and stress category, but are all related to the basic design stress intensity values, S_m, as shown in Table 13 except for peak stresses which are limited by the fatigue design curve and service level D loads which require inelastic analysis.

Table 13. Allowable stress intensity depends on service level and stress category

	P_m	P_L	P_b	Q	F
Design	S_m	1.5 S_m	1.5 S_m		
A	S_m	1.5 S_m	1.5 S_m	3 S_m	S_a
B	1.1 S_m	1.65 S_m	1.65 S_m	3 S_m	S_a
C	1.2 S_m	1.8 S_m	1.8 S_m		
	S_y	1.5 S_y	1.5 S_y		
D	Inelastic Analysis				

7. FATIGUE DESIGN CURVE

Fatigue design curves for type 316LN stainless steel and Inconel 718 are shown in Figs. 13 and 14 for evaluating peak stresses. There is a single fatigue design curve for less than one million cycles in Fig. 13 because any initial mean stress cannot be maintained because the material yields. There are three fatigue design curves for greater than one million cycles in Fig. 14 because any initial mean stress is maintained to some extent at alternating stress intensities, S_a less than 187.6 MPa. Table 14 indicates how to determine which of the three curves should be used. Tabulated values of S_a are given in Table 15. It should be noted that the alternating stress intensity S_a is one-half the stress range. Miner's linear damage rule is used to sum the damage from different stress cycles.

$$\Sigma \frac{n}{N} \leq 1.0$$

where n is the expected number of cycles at a particular stress amplitude and N is the allowable number of cycles from the fatigue design curve at that particular stress amplitude.

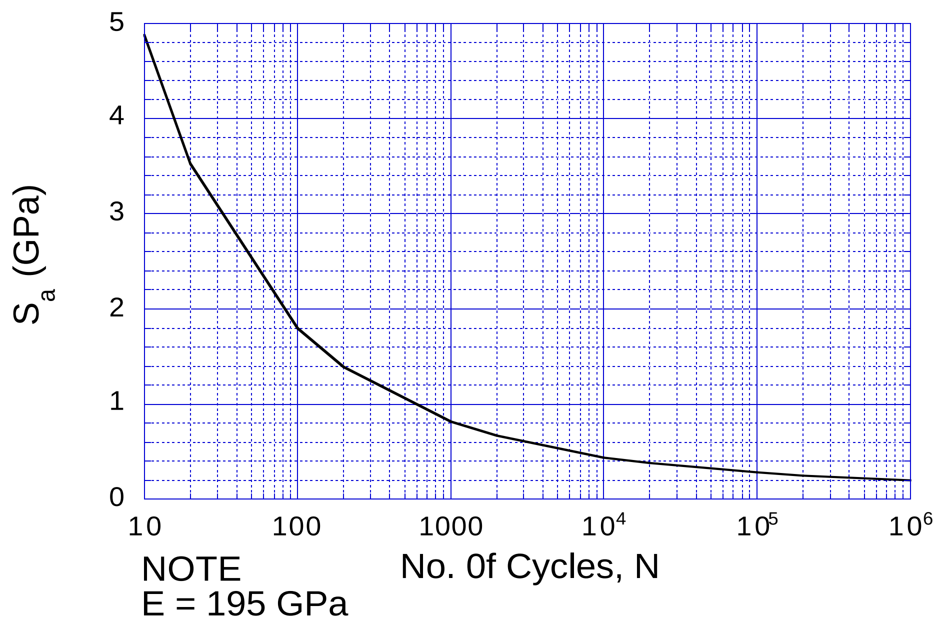
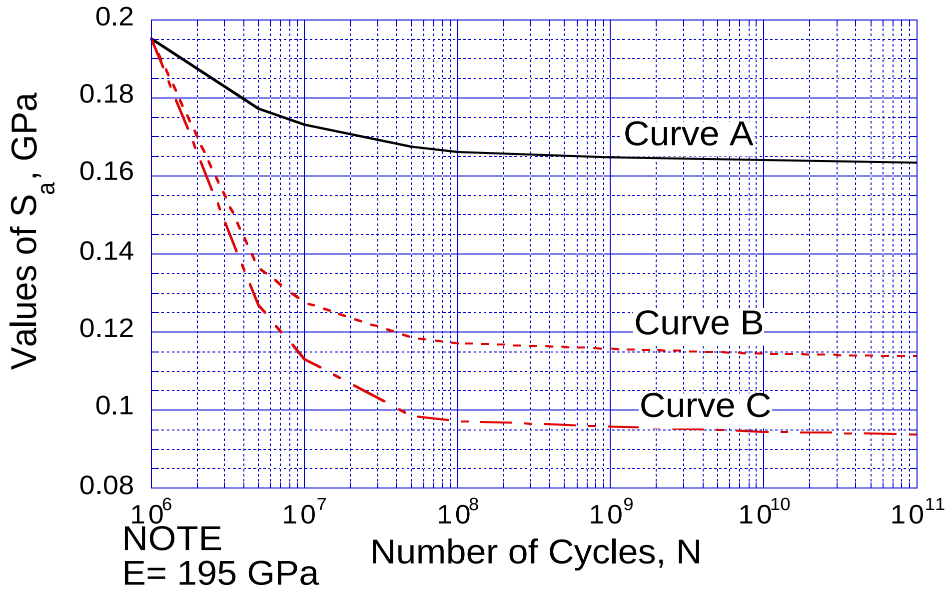


Fig. 13. Design fatigue curve for type 316LN stainless steel and Inconel 718 for less than a million cycles.



NOTE
E= 195 GPa

Fig. 14. Design fatigue curves for type 316LN stainless steel and Inconel 718 for greater than a million cycles.

Table 14. Criteria for the use of the curves in Fig. 14 [Notes (1) - (5)]

Curve	Elastic Analysis of Material Other Than Welds and Adjacent Base Metal	Elastic Analysis of Welds and Adjacent Base Metal
A	$(P_L + P_b + Q)_{Range} \leq 187.6$ MPa	…..
B	$(P_L + P_b + Q)_{Range} > 187.6$ MPa and S_a is corrected for applied mean stress	$(P_L + P_b + Q)_{Range} \leq 187.6$ MPa
C	$(P_L + P_b + Q)_{Range} > 187.6$ MPa	$(P_L + P_b + Q)_{Range} > 187.6$ MPa

NOTES:

(1) Range applies to the individual quantities P_L, P_b, and Q and applies to the set of cycles under consideration.

(2) Thermal bending stresses resulting from axial and radial gradients are excluded from Q.

(3) Curve A is also to be used with inelastic analysis with $S_a = 1/2\, \Delta\, \varepsilon_t\, E$, where $\Delta\, \varepsilon_t$ is the total effective strain range.

(4) The maximum effect of retained mean stress is included in Curve C.

(5) The adjacent base metal is defined as three wall thicknesses from the center line of the weld.

Fatigue design curves for 6061-T6 aluminum are shown in Fig. 15. The upper curve is for zero mean stress, i.e., fully reversed loading. The lower curve is for maximum amount of mean stress that can be sustained. The S_a values must be reduced by a factor of 2 for welds. Tabulated values of S_a for 6061-T6 aluminum are given in Table 16.

Table 15. Tabulated Values of S_a, MPa, for type 316LN stainless steel and Inconel 718

Number of cycles	Curve A (GPa)	Curve B (GPa)	Curve C (GPa)
10	4.882	4.882	4.882
20	3.530	3.530	3.530
50	2.379	2.379	2.379
100	1.800	1.800	1.800
200	1.386	1.386	1.386
500	1.020	1.020	1.020
1000	0.821	0.821	0.821
2000	0.669	0.669	0.669
5000	0.524	0.524	0.524
10,000	0.441	0.441	0.441
20,000	0.383	0.383	0.383
50,000	0.319	0.319	0.319
1.00E+05	0.281	0.281	0.281
2.00E+05	0.248	0.248	0.248
5.00E+05	0.214	0.214	0.214
1.00E+06	0.195	0.195	0.195
5.00E+06	0.177	0.137	0.127
1.00E+07	0.173	0.128	0.113
5.00E+07	0.168	0.119	0.099
1.00E+08	0.166	0.117	0.097
1.00E+09	0.165	0.116	0.096
1.00E+10	0.164	0.115	0.095
1.00E+11	0.163	0.114	0.094

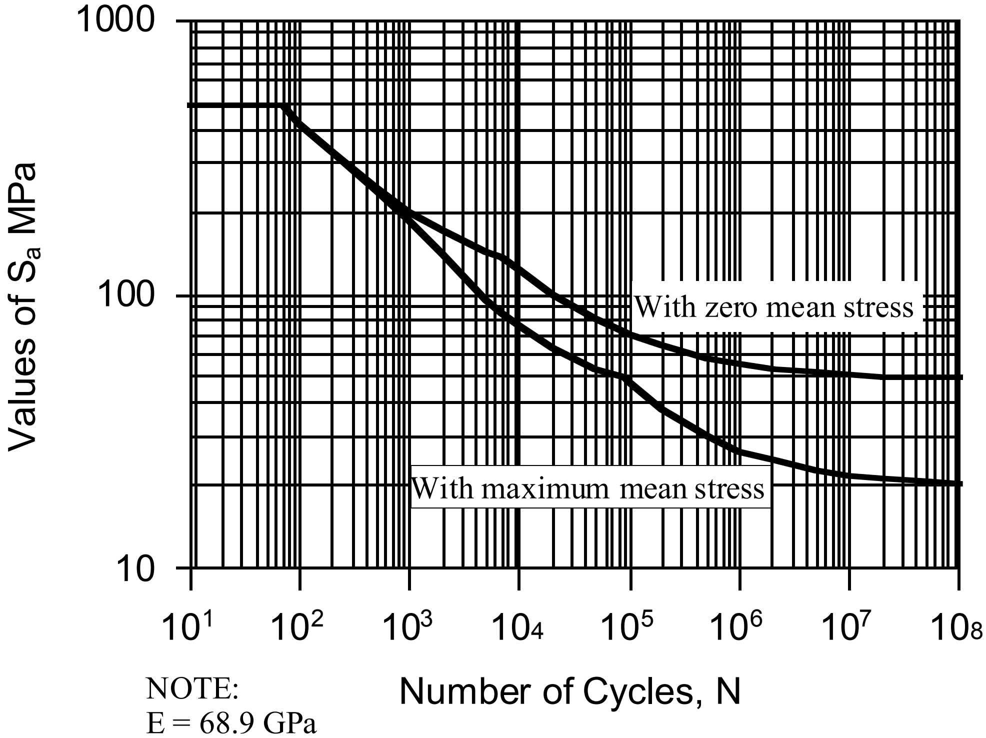


Fig. 15. Design fatigue curves for 6061-T6 aluminum.

Table 16. Tabulated values of S_a, MPa, for 6061-T6 aluminum

Number of Cycles [Note (2)]	Zero Mean Stress	Maximum Mean Stress
1.0E1	482.63	482.63
2.0E1	482.63	482.63
5.0E1	482.63	482.63
7.0E1	482.63	482.63
1.0E2	420.30	420.30
2.0E2	325.43	325.43
5.0E2	241.32	239.94
1.0E3	198.91	184.71
2.0E3	168.92	137.90
5.0E3	142.31	95.01
7.0E3	135.83	85.49
1.0E4	120.66	75.36
2.0E4	99.49	63.02
5.0E4	80.67	53.37
9.0E4	72.60	49.50
1.0E5	71.15	47.50
2.0E5	64.47	37.71
5.0E5	58.54	30.06
1.0E6	55.50	26.68
2.0E6	53.37	24.48
5.0E6	51.50	22.68
1.0E7	50.54	21.79
2.0E7	49.92	21.17
5.0E7	49.30	20.68
1.0E8	49.02	20.41
2.0E8	48.75	20.20
5.0E8	48.61	20.06
1.0E9	48.47	19.99

NOTES

(1) Interpolation between tabular values is permissible based upon data representation by straight lines on a log-log plot.

(2) The number of cycles indicated shall be read as follows:
IEJ = I X 10^j, e.g., 5E6 = 5 X 10^6 or 5,000,000

8. METHODOLOGY FOR EVALUATING THERMAL SHOCK STRESSES

For the purpose of establishing allowable stresses, there are two types of thermal stress, depending on the volume or area in which distortion takes place. The equivalent linear stress produced by the through-the-wall temperature distribution caused by the thermal shock is classified as a secondary stress, Q. The equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution. The secondary stresses plus the primary stresses are limited to 3 S_m for service levels A and B. Evaluation of the potential for the secondary stress to cause ratcheting that can produce large distortions must also be evaluated.

The difference between the actual stress and the equivalent linear stress resulting from a through-the-wall temperature distribution is classified as a peak stress, F. The peak stress plus the secondary and primary stresses is limited by the fatigue design curve. Detailed procedures are given in paragraphs NB-3222.4, Analysis for Cyclic Operation, and NB-3222.5, Thermal Stress Ratchet of Ref. 1.

REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB Class 1 Component, American Society of Mechanical Engineers, New York, New York, July 1, 1998.

2. ITER Structural Design Criteria for In-Vessel Components, S 74 MA1.

3. ASME Boiler and Pressure Vessel Code, Section II, Part D—Properties, American Society of Mechanical Engineers, New York, New York, July 1, 1998.

4. P. L. Rittenhouse, APT Materials Handbook, Rev. 0. Volume 1—Materials Data, APT-102-1998-101, Rev. 0.

5. ASME Boiler and Pressure Code, 1994, "Case N-519, Use of 6061-T6 and 6061-T651 Aluminum for Class 1 Nuclear Components," Section II, Division 1.