INL/CON-22-66309-Revision-0

TECHNICAL BACKGROUND FOR THE UPDATE AND EXTENSION OF THE TIME-DEPENDENT ALLOWABLE STRESSES OF TYPE 304H AND 316H STAINLESS STEELS

Changing the World's Energy Future

Ting-Leung Sham, Michael D McMurtrey

Idaho National Laboratory

INL/CON-22-66309-Revision-0

TECHNICAL BACKGROUND FOR THE UPDATE AND EXTENSION OF THE TIME-DEPENDENT ALLOWABLE STRESSES OF TYPE 304H AND 316H STAINLESS STEELS

Ting-Leung Sham, Michael D McMurtrey

July 2022

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

**Proceedings of the ASME 2022
Pressure Vessels & Piping Conference
PVP2022
July 17-22, 2022, Las Vegas, Nevada, USA**

DRAFT PVP2022-83840

Technical Background For The Update And Extension Of The Time-Dependent Allowable Stresses Of Type 304h And 316h Stainless Steels

Ting-Leung Sham
Idaho National Laboratory
Idaho Falls, Idaho, USA

Michael McMurtrey
Idaho National Laboratory
Idaho Falls, Idaho, USA

ABSTRACT

Type 304H and 316H stainless steels are codified in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for Section III, Division 5, Class A construction for up to 1500°F (816°C) and 300,000 hours. The extension of design lifetimes to 500,000 hours has been undertaken by various research projects and by the ASME Section III, Division 5 Code Committees. Due to a long-standing issue related to non-classical creep behavior on the use of the time to the onset of tertiary creep as one of the time-dependent allowable stress criteria, little progress was made in the extension of the time-dependent allowable stresses for Type 304H and 316H stainless steels. A recent effort by Dabrow and Nestell (Impact of Tertiary Creep on Time Dependent Allowable Stresses for Type 304H and 316H Stainless Steels, Report 0300-0003-RPT-001, MPR Associates, Alexandria, VA, 2020) has provided a rational method for the treatment of the highly variable data for the time to onset of tertiary creep. This paper presents the background formulas for determining the time-dependent allowable stress values of Type 304H and 316H stainless steels, as assembled from relevant project work. These updates and extensions are being recommended to the ASME Section III Code committees for approval and are subject to change upon feedback from those committees.

Keywords: ASME Section III, Division 5, Allowable Stresses, Type 304H and 316H Stainless Steels

1. INTRODUCTION

In the late 2000s, the Department of Energy (DOE) Office of Nuclear Energy sponsored American Society of Mechanical Engineers (ASME) Codes and Standards research and development activities to identify and address gaps in high-temperature design methods and mechanical properties data as part of the Next Generation Nuclear Plant (NGNP) Project to deploy a high-temperature gas-cooled reactor to support hydrogen production through a private-public partnership. These ASME Codes and Standards research and development activities have become known as the DOE-ASME Gen IV Materials Project.

Task 6 of the Gen IV Materials Project was undertaken by Swindeman [1] to review the allowable stresses for the ASME Boiler and Pressure Vessel Code (BPVC) Section III, Division 5, Class A components (then Section III, Division 1, Subsection NH Class 1 components) under elevated temperature cyclic service. That research assembled expanded databases on allowable stress data for the Class A materials and assessed the use of the expanded databases to extend the allowable stresses from 300,000 to 500,000 hours to support 60-year design lifetimes. The databases were deemed adequate for the extension.

A new Task 14A within the DOE-ASME Gen IV Materials Project was then commissioned to extend the allowable stresses of Type 304H and 316H stainless steels, which are Section III, Division 5 Code qualified materials, from 300,000 to 500,000 hr. Sengupta and Nestell [2,3] documented the results of Task 14A research. Based on the expanded dataset, with rupture data censored according to reference [2], and the allowable stress criteria of Section III, Division 5, Sengupta and Nestell found that the new allowable stresses are significantly lower than the current values in Division 5, particularly for the highest use temperatures and long design lifetimes.

Sengupta and Nestell noted that lower allowable stress values were mainly driven by the time to onset of tertiary creep criterion, which, together with the criteria of time to 1% total strain and time to creep rupture, govern the allowable stress values. They also noted that the amount of data for the time to onset of tertiary creep was much less than that for the time to creep rupture, and there was a significantly larger data scatter. That could be due to the fact that some creep curves showed behavior that deviates from the classical creep deformation of primary, secondary and tertiary creep. For example, some creep curves show multiple "tertiary creep" onset points. This causes issues in determining the time of onset. Thus, Sengupta and Nestell recommended the cognizant Division 5 Code committee further study the issue and reconsider the technical basis for including the time to onset of tertiary creep as one of the criteria in setting the allowable stresses for use in the primary load design.

Due to a change in priority, the NGNP Project was put on hold in the early 2010s, thus removing a stakeholder driver for the Division 5 Code committees to address this issue, and they moved on to addressing other Code priorities. Starting around the mid-2010s, there was a groundswell of advanced reactor developers coming onto the scene, as captured by the Third Way Advanced Nuclear Map [4]. This arrival was partly motivated by the opinion that advanced nuclear is a very significant part of the clean energy portfolio in the all-of-the-above strategy to combating climate change.

In pursuing a first-to-market business strategy, many of these advanced reactor developers have called out construction materials for coolant boundary structural components that have a more robust supply chain and are ASME Code qualified. Type 316H stainless steel fits into such an envelope and has been selected as the reference construction material for a number of different advanced reactor designs. The resolution of the issues revolving around the allowable stresses of Type 304H and 316H stainless steels has become more urgent. MPR Associates Inc. was commissioned by Argonne National Laboratory to conduct a follow-on study of the allowable stresses for Type 304H and 316H stainless steels. Dabrow and Nestell documented the results of this study in a project report [5].

Dabrow and Nestell pointed out that, due to the significant data scatter on time to onset of tertiary creep for Type 304H and 316H stainless steels, the application of a strict regression analysis using the Larson-Miller (LM) time-temperature parameter would not be pertinent for the reasons discussed by Sengupta and Nestell [2,3]. But Dabrow and Nestell noted that the time to onset of tertiary creep can be correlated to the time to creep rupture, as shown by Leyda and Rowe [6] and other subsequent studies for a number of materials. Thus, Dabrow and Nestell proposed to develop the average Leyda-Rowe correlation between time to onset of tertiary creep and time to creep rupture for Type 304H and 316H stainless steels. Using this average Leyda-Rowe correlation, the LM regression results for the more robust time to creep rupture database can be leveraged to describe the temperature and stress dependence of the time to onset of tertiary creep and its associated variability. Based on such an approach, Dabrow and Nestell recommended the sets of allowable stresses for Type 304H and Type 316H stainless steels in Leyda and Rowe's work [6].

In this paper, the details of the results that are used to determine the allowable stresses are assembled from Sengupta and Nestell [2,3] and Dabrow and Nestell [5] and are presented to provide a technical background for the draft allowable stress values for Type 304H and 316H stainless steels that will be proposed to ASME Code committees for approval. Some differences from the results in References [2,3,5] are noted in this paper. The first difference was related to a corruption of the Excel spreadsheet used in Reference [2] for the LM analysis of the rupture stress dataset for Type 304H stainless steel. The second difference was related to the use of a larger Leyda-Rowe dataset for Type 304H stainless steel as compared with Reference [5], leading to a small change in the Leyda-Rowe coefficient.

We will first capture the relevant Division 5 criteria for determining the allowable stresses and then present a generic description of the formulas for obtaining average or lower bound quantities. The regression parameter values for the relevant quantities used in the determination of the allowable stresses are tabulated in the appendix for both U.S. Customary and SI units. For the former, stress is in ksi, temperature in Fahrenheit, absolute temperature in Rankine, and time in hours; and for the latter, stress is in MPa, temperature in Celsius, absolute temperature in Kelvin, and time in hours. The conversion factors between the two systems of units are also given in the appendix. The use of the formulas and their associated numerical parameters presented in this paper is limited to the temperatures of 800–1500°F, or 427–816°C.

2. ALLOWABLE STRESS CRITERIA

The allowable stresses used to evaluate primary load designs are defined for Division 5 Class A base materials as follows.

The primary load-time-dependent allowable stress S_{mt} for service loadings is defined as the lesser of:

a) S_m, time-independent allowable stress
b) S_t, time-dependent allowable stress.

The criteria for the time-independent allowable stress S_m are defined in BPVC Section II, Part D, Mandatory Appendix 2 in terms of the room temperature specification minimum yield and tensile strength, the yield strength at temperature, S_y, and the tensile strength at temperature, S_u. A factor of two-thirds is applied on the yield strengths and one-third on the tensile strengths in determining S_m. For some austenitic steels, such as Type 304H and 316H stainless steels and Alloy 800H, the two-thirds factor on the yield strength at temperature is replaced by 0.9.

As described in Division 5, it may be necessary to adjust the S_m values to account for the effects of longtime service at elevated temperature on S_y and S_u through the yield and tensile strength reduction factors. They are based on the ratio of the average strength after exposure to elevated temperature to the tabulated yield or tensile strengths, as applicable. There is no credit for strength increase, so the maximum factor is 1.0.

The yield and tensile strength reduction factors given in Section III, Division 5 are for thermal exposure at uniform temperature. Division 5 HBB-2160 (d) provides guidance on how to use these thermal aging factors to adjust the S_m values for service conditions involving variable temperatures. The values of the time-dependent allowable stress S_{mt} for service loadings given in Table HBB-I-14.3x of Division 5 are based on values of S_m that are not adjusted for the effect of thermal aging. This convention was used for the tabulated values of S_{mt} presented in later sections.

The S_t time-dependent allowable stress is temperature- and time-dependent; the data considered in establishing these allowable stresses are obtained from long-term, constant-load, uniaxial tests. For each specific time, t, the S_t value is the lesser of:

a) 100% of the average stress required to obtain a total (elastic, plastic, primary, and secondary creep) strain of 1%
b) 80% of the minimum stress to cause the onset of tertiary creep
c) 67% of the minimum stress to cause creep rupture, S_r.

2.1. Formulas for Representing Larson-Miller Regression Results

Let the stress be denoted as σ, the temperature as T, with T_a as the temperature in the absolute scale, the time to 1% total strain as $t_{1\%}$, the time to the onset of tertiary creep as t_3, and the time to creep rupture as t_r. For the following representation, we will denote $t_{1\%}$, t_3 and t_r symbolically as t. The regression model using the time-temperature LM parameter is

$$T_a(log_{10}t + C) = \sum_{p=0}^{n} a_p \Sigma^p$$

where $\Sigma \equiv log_{10}\sigma$, and C, and a_p are regression parameters. This equation can be recast as

$$log_{10}t = \left(\frac{1}{T_a}\sum_{p=0}^{n} a_p \Sigma^p\right) - C$$

To incorporate data variability in the above representation, we can write

$$log_{10}t = \left(\frac{1}{T_a}\sum_{p=0}^{n} a_p \Sigma^p\right) - C - h \times SEE$$

where $h = 0$ for determining the average value of t and $h = 1.65$ for its lower bound value. The quantity SEE is the standard error of estimate from the regression analysis.

Often, when the above LM representations for time to creep rupture and time to onset of tertiary creep data are extrapolated to very short times, the resulting stresses could be higher than the ultimate tensile strength. This is not a real physical representation, as one cannot perform a creep test at stress levels above the ultimate tensile strength. To remove such an artifact for short time extrapolations, the tabulated value of $S_u/1.1$ is used to "cap" these extrapolated stress quantities.

Similarly, the stress for 1% total strain, $S_{1\%}$, as obtained from an average hot tensile curve, is used to "cap" the stress from the LM representation of the time to 1% total strain data.

It is noted that the factor of 1.1 on S_u is to render an approximate minimum tensile strength value to cap the minimum stress to rupture and the minimum stress to the onset of tertiary creep.

We will denote the values of S_y, S_u and $S_{1\%}$ symbolically with α and represent the temperature dependence by a polynomial:

$$\alpha = \sum_{q=0}^{m} b_q T^q$$

where b_q are best-fit coefficients.

We can now restate the criteria for the time-dependent allowable stress S_t as the lesser of

a) 100% of the lesser of (i) the average stress required to obtain a total (elastic, plastic, primary, and secondary creep) strain of 1% and (ii) the stress $S_{1\%}$ required to obtain 1% total strain from the average tensile curve
b) 80% of the lesser of (i) the minimum stress to cause the onset of tertiary creep and (ii) the tabulated value of $S_u/1.1$
c) 67% of the lesser of (i) the minimum stress to cause rupture, S_r, and (ii) the tabulated value of $S_u/1.1$.

Dabrow and Nestell employed a different treatment of the onset of tertiary creep data of Type 304H and 316H stainless steels [5]. Instead of conducting a direct LM regression of the onset of tertiary creep data, the Leyda-Rowe correlation was used to represent t_3 as

$$t_3 = At_r$$

where A is a fitting parameter.

Using the LM representation of t_r, we can express t_3 in the form of

$$log_{10}t_3 = \left(\frac{1}{T_a}\sum_{p=0}^{n} a_p \Sigma^p\right) - (C - log_{10}A) - h \times SEE$$

where it is understood that the values of a_p, C, and SEE are those for t_r.

The preceding formulas for $t_{1\%}$, t_3, and t_r can be used to determine their values quite straightforwardly for given temperature, stress, and regression parameter values. However, the determination of the corresponding stresses for the given temperature and value of $t_{1\%}$, t_3, and t_r is more involved, particularly for higher order stress polynomials. For stress polynomials up to cubic, Prager et al. [7] provided direct formulas to determine the stress.

3. RESULTS

The allowable stress intensity values of S_{mt} and S_t and the values of the expected minimum stress to rupture, S_r, for Type 304H and 316H stainless steels in both U.S. Customary and SI units are shown below. These values are valid from 800 to 1500°F. Values tabulated for 425 and 825°C are only for the purpose of interpolation.

Type 304H SS, S_{mt}—Allowable Stress Intensity Values (ksi), U.S. Customary Units												
Temp., °F	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
800	15.23	15.23	15.23	15.23	15.23	15.23	15.23	15.23	15.23	15.23	15.23	15.23
850	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90
900	14.58	14.58	14.58	14.58	14.58	14.58	14.58	14.58	14.58	14.58	14.58	14.58
950	14.27	14.27	14.27	14.27	14.27	14.27	14.27	14.27	14.27	14.27	13.02	12.19
1000	13.95	13.95	13.95	13.95	13.95	13.95	13.95	13.95	13.95	11.92	10.27	9.57
1050	13.64	13.64	13.64	13.64	13.64	13.64	13.64	13.01	11.18	9.43	8.05	7.46
1100	13.34	13.34	13.34	13.34	13.34	13.34	12.41	10.43	8.88	7.40	6.25	5.77
1150	13.01	13.01	13.01	13.01	13.01	11.77	9.99	8.31	6.99	5.76	4.81	4.41
1200	12.66	12.66	12.66	12.66	11.47	9.51	7.99	6.57	5.47	4.45	3.66	3.34
1250	12.27	12.27	12.27	11.11	9.31	7.64	6.35	5.16	4.24	3.40	2.75	2.49
1300	11.80	11.80	11.06	9.07	7.52	6.10	5.01	4.01	3.25	2.56	2.04	1.84
1350	11.09	10.93	9.07	7.35	6.04	4.83	3.92	3.09	2.47	1.91	1.49	1.33
1400	9.64	9.01	7.40	5.92	4.81	3.79	3.04	2.35	1.84	1.40	1.07	0.94
1450	8.23	7.40	6.00	4.74	3.80	2.95	2.32	1.77	1.36	1.01	0.75	0.66
1500	6.94	6.03	4.84	3.77	2.97	2.27	1.76	1.31	0.98	0.71	0.52	0.44

Type 304H SS, S_{mt}—Allowable Stress Intensity Values (MPa), SI Units												
Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05
450	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99
475	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95
500	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	97.55	91.49
525	97.02	97.02	97.02	97.02	97.02	97.02	97.02	97.02	97.02	91.30	79.04	73.84
550	95.11	95.11	95.11	95.11	95.11	95.11	95.11	95.11	87.41	74.18	63.66	59.23
575	93.22	93.22	93.22	93.22	93.22	93.22	93.22	83.27	71.30	59.92	50.95	47.19
600	91.32	91.32	91.32	91.32	91.32	91.32	81.26	68.15	57.83	48.11	40.49	37.32
625	89.35	89.35	89.35	89.35	89.35	78.83	66.80	55.47	46.63	38.34	31.93	29.27
650	87.22	87.22	87.22	87.22	78.43	65.06	54.63	44.88	37.33	30.34	24.96	22.75
675	84.83	84.83	84.83	77.52	65.05	53.42	44.41	36.08	29.68	23.80	19.33	17.50
700	82.01	82.01	78.65	64.57	53.69	43.62	35.89	28.80	23.40	18.50	14.80	13.31
725	78.58	78.58	65.87	53.55	44.09	35.41	28.81	22.81	18.28	14.22	11.20	9.98
750	70.05	66.66	54.95	44.19	36.01	28.56	22.95	17.90	14.14	10.81	8.35	7.38
775	61.21	55.88	45.61	36.27	29.22	22.87	18.14	13.92	10.81	8.09	6.12	5.35
800	52.82	46.64	37.68	29.59	23.56	18.17	14.20	10.70	8.16	5.96	4.40	3.80
825	45.23	38.75	30.96	24.00	18.85	14.30	10.99	8.12	6.06	4.31	3.09	2.62

Type 304H SS, S_t – Allowable Stress Intensity Values (ksi), U.S. Customary Units												
Temp., °F	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
800	25.47	25.47	25.47	25.47	25.47	25.47	25.47	25.47	25.47	25.47	25.45	24.11
850	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	24.96	23.14	20.48	19.33
900	24.45	24.45	24.45	24.45	24.45	24.45	24.45	24.37	21.48	18.66	16.37	15.40
950	23.94	23.94	23.94	23.94	23.94	23.94	22.97	19.88	17.38	14.96	13.02	12.19
1000	23.43	23.43	23.43	23.43	23.43	21.59	18.81	16.13	13.98	11.92	10.27	9.57
1050	22.92	22.92	22.92	22.92	20.74	17.73	15.32	13.01	11.18	9.43	8.05	7.46
1100	22.41	22.41	22.41	19.85	17.11	14.49	12.41	10.43	8.88	7.40	6.25	5.77
1150	21.90	21.90	19.46	16.44	14.04	11.77	9.99	8.31	6.99	5.76	4.81	4.41
1200	21.39	18.99	16.19	13.55	11.47	9.51	7.99	6.57	5.47	4.45	3.66	3.34
1250	20.88	15.87	13.41	11.11	9.31	7.64	6.35	5.16	4.24	3.40	2.75	2.49
1300	18.89	13.20	11.06	9.07	7.52	6.10	5.01	4.01	3.25	2.56	2.04	1.84
1350	15.95	10.93	9.07	7.35	6.04	4.83	3.92	3.09	2.47	1.91	1.49	1.33
1400	13.41	9.01	7.40	5.92	4.81	3.79	3.04	2.35	1.84	1.40	1.07	0.94
1450	11.23	7.40	6.00	4.74	3.80	2.95	2.32	1.77	1.36	1.01	0.75	0.66
1500	9.37	6.03	4.84	3.77	2.97	2.27	1.76	1.31	0.98	0.71	0.52	0.44

Type 304H SS, S_t—Allowable Stress Intensity Values (MPa), SI Units												
Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	168.44
450	172.67	172.67	172.67	172.67	172.67	172.67	172.67	172.67	172.67	165.07	146.23	138.13
475	169.50	169.50	169.50	169.50	169.50	169.50	169.50	169.50	156.37	136.14	119.74	112.71
500	166.34	166.34	166.34	166.34	166.34	166.34	166.34	147.59	129.40	111.77	97.55	91.49
525	163.18	163.18	163.18	163.18	163.18	162.69	142.26	122.50	106.61	91.30	79.04	73.84
550	160.02	160.02	160.02	160.02	159.00	136.55	118.54	101.24	87.41	74.18	63.66	59.23
575	156.85	156.85	156.85	154.69	134.01	114.17	98.37	83.27	71.30	59.92	50.95	47.19
600	153.69	153.69	153.69	130.86	112.54	95.07	81.26	68.15	57.83	48.11	40.49	37.32
625	150.53	150.53	130.80	110.32	94.14	78.83	66.80	55.47	46.63	38.34	31.93	29.27
650	147.36	129.98	110.80	92.66	78.43	65.06	54.63	44.88	37.33	30.34	24.96	22.75
675	144.20	110.57	93.53	77.52	65.05	53.42	44.41	36.08	29.68	23.80	19.33	17.50
700	133.82	93.75	78.65	64.57	53.69	43.62	35.89	28.80	23.40	18.50	14.80	13.31
725	114.95	79.20	65.87	53.55	44.09	35.41	28.81	22.81	18.28	14.22	11.20	9.98
750	98.44	66.66	54.95	44.19	36.01	28.56	22.95	17.90	14.14	10.81	8.35	7.38
775	84.05	55.88	45.61	36.27	29.22	22.87	18.14	13.92	10.81	8.09	6.12	5.35
800	71.53	46.64	37.68	29.59	23.56	18.17	14.20	10.70	8.16	5.96	4.40	3.80
825	60.66	38.75	30.96	24.00	18.85	14.30	10.99	8.12	6.06	4.31	3.09	2.62

Type 304H SS, S_r—Expected Minimum Stress-To-Rupture Values (ksi), U.S. Customary Units												
Temp., °F	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
800	56.89	56.89	56.89	56.89	56.89	56.89	56.89	53.95	48.24	42.61	37.99	35.99
850	56.23	56.23	56.23	56.23	56.23	56.23	50.49	44.40	39.43	34.54	30.56	28.85
900	55.26	55.26	55.26	55.26	53.81	47.14	41.70	36.38	32.06	27.85	24.44	22.99
950	53.95	53.95	53.95	50.97	44.93	39.05	34.29	29.67	25.94	22.33	19.43	18.19
1000	52.25	52.25	49.30	42.70	37.37	32.22	28.07	24.07	20.86	17.79	15.33	14.29
1050	50.16	47.52	41.48	35.64	30.96	26.46	22.86	19.42	16.68	14.07	12.01	11.14
1100	47.67	40.14	34.77	29.63	25.53	21.62	18.52	15.57	13.25	11.05	9.33	8.61
1150	44.79	33.79	29.05	24.53	20.96	17.57	14.91	12.40	10.44	8.60	7.18	6.58
1200	39.19	28.34	24.16	20.22	17.12	14.20	11.93	9.81	8.16	6.64	5.46	4.98
1250	33.30	23.68	20.01	16.58	13.90	11.41	9.48	7.70	6.33	5.07	4.11	3.72
1300	28.20	19.70	16.50	13.53	11.23	9.10	7.48	5.98	4.85	3.82	3.05	2.74
1350	23.80	16.32	13.54	10.97	9.01	7.21	5.85	4.61	3.68	2.85	2.23	1.98
1400	20.01	13.45	11.05	8.84	7.18	5.66	4.53	3.51	2.75	2.09	1.60	1.41
1450	16.76	11.04	8.96	7.08	5.67	4.41	3.47	2.64	2.03	1.50	1.12	0.98
1500	13.98	9.00	7.22	5.63	4.44	3.39	2.63	1.95	1.47	1.06	0.77	0.66

Type 304H SS, S_r—Expected Minimum Stress-To-Rupture Values (MPa), SI Units												
Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	392.53	392.53	392.53	392.53	392.53	392.53	392.53	376.27	336.62	297.46	265.29	251.41
450	388.55	388.55	388.55	388.55	388.55	388.55	358.78	315.93	280.84	246.38	218.25	206.16
475	382.92	382.92	382.92	382.92	382.92	341.09	302.30	264.31	233.39	203.20	178.71	168.23
500	375.39	375.39	375.39	374.19	330.72	288.28	253.82	220.28	193.14	166.82	145.59	136.55
525	365.81	365.81	365.81	319.51	280.60	242.82	212.33	182.84	159.12	136.27	117.97	110.21
550	354.05	354.05	315.15	272.02	237.31	203.80	176.93	151.10	130.47	110.72	95.02	88.40
575	340.05	309.50	269.45	230.88	200.01	170.41	146.82	124.29	106.42	89.44	76.05	70.43
600	323.83	265.63	229.71	195.32	167.97	141.90	121.28	101.72	86.32	71.80	60.43	55.70
625	305.46	227.34	195.22	164.66	140.51	117.66	99.70	82.79	69.59	57.23	47.65	43.69
650	268.51	194.00	165.37	138.30	117.06	97.10	81.53	66.99	55.72	45.28	37.25	33.96
675	231.88	165.03	139.59	115.70	97.09	79.73	66.29	53.85	44.30	35.52	28.85	26.12
700	199.73	139.92	117.39	96.38	80.14	65.11	53.57	42.98	34.93	27.61	22.09	19.86
725	171.56	118.21	98.32	79.92	65.81	52.85	43.00	34.04	27.29	21.23	16.71	14.90
750	146.93	99.49	82.01	65.95	53.74	42.63	34.26	26.72	21.11	16.13	12.47	11.01
775	125.45	83.40	68.08	54.13	43.61	34.13	27.07	20.77	16.14	12.08	9.14	7.99
800	106.76	69.61	56.24	44.17	35.16	27.12	21.19	15.97	12.18	8.90	6.57	5.67
825	90.54	57.83	46.21	35.82	28.14	21.35	16.41	12.12	9.05	6.44	4.61	3.92

Type 316H SS, S_{mt}—Allowable Stress Intensity Values (ksi), U.S. Customary Units												
Temp., °F	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
800	15.96	15.96	15.96	15.96	15.96	15.96	15.96	15.96	15.96	15.96	15.96	15.96
850	15.80	15.80	15.80	15.80	15.80	15.80	15.80	15.80	15.80	15.80	15.80	15.80
900	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67
950	15.53	15.53	15.53	15.53	15.53	15.53	15.53	15.53	15.53	15.53	15.53	15.53
1000	15.36	15.36	15.36	15.36	15.36	15.36	15.36	15.36	15.36	15.36	13.71	12.75
1050	15.17	15.17	15.17	15.17	15.17	15.17	15.17	15.17	14.97	12.54	10.63	9.84
1100	14.95	14.95	14.95	14.95	14.95	14.95	14.95	13.93	11.77	9.75	8.17	7.51
1150	14.66	14.66	14.66	14.66	14.66	14.66	13.31	10.99	9.19	7.50	6.21	5.67
1200	14.31	14.31	14.31	14.31	14.31	12.66	10.55	8.60	7.10	5.72	4.67	4.23
1250	13.87	13.87	13.87	13.87	12.37	10.07	8.30	6.68	5.44	4.31	3.46	3.12
1300	13.34	13.34	13.34	12.02	9.90	7.96	6.48	5.13	4.12	3.21	2.53	2.26
1350	11.89	11.89	11.89	9.66	7.87	6.23	5.00	3.90	3.08	2.35	1.82	1.61
1400	10.01	10.01	9.73	7.72	6.20	4.84	3.83	2.93	2.27	1.70	1.28	1.11
1450	8.06	8.06	7.82	6.12	4.84	3.72	2.89	2.17	1.64	1.19	0.87	0.74
1500	6.07	6.07	6.07	4.81	3.75	2.83	2.16	1.57	1.17	0.81	0.56	0.47

Type 316H SS, S_{mt}—Allowable Stress Intensity Values (MPa), SI Units												
Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01
450	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03
475	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13
500	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23
525	106.27	106.27	106.27	106.27	106.27	106.27	106.27	106.27	106.27	106.27	105.99	98.75
550	105.19	105.19	105.19	105.19	105.19	105.19	105.19	105.19	105.19	99.21	84.61	78.49
575	103.92	103.92	103.92	103.92	103.92	103.92	103.92	103.92	95.18	79.43	67.08	61.92
600	102.40	102.40	102.40	102.40	102.40	102.40	102.40	90.79	76.53	63.16	52.77	48.46
625	100.55	100.55	100.55	100.55	100.55	100.55	88.90	73.26	61.12	49.85	41.16	37.59
650	98.31	98.31	98.31	98.31	98.31	86.47	72.09	58.73	48.46	39.01	31.80	28.86
675	95.61	95.61	95.61	95.61	86.45	70.41	58.08	46.75	38.12	30.25	24.31	21.90
700	92.39	92.39	92.39	85.78	70.78	56.99	46.49	36.92	29.71	23.21	18.36	16.42
725	85.05	85.05	85.05	70.56	57.62	45.83	36.93	28.91	22.93	17.60	13.67	12.11
750	73.62	73.62	72.47	57.74	46.62	36.59	29.10	22.42	17.49	13.17	10.02	8.78
775	61.77	61.77	59.68	46.97	37.47	28.98	22.72	17.19	13.17	9.69	7.20	6.22
800	49.62	49.62	48.87	37.96	29.89	22.76	17.55	13.02	9.78	6.98	4.98	4.22
825	37.35	37.35	37.35	30.47	23.65	17.69	13.40	9.72	7.07	4.84	3.32	2.75

Type 316H SS, S_t—Allowable Stress Intensity Values (ksi), U.S. Customary Units												
Temp., °F	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
800	26.14	26.14	26.14	26.14	26.14	26.14	26.14	26.14	26.14	26.14	26.14	26.14
850	25.82	25.82	25.82	25.82	25.82	25.82	25.82	25.82	25.82	25.82	25.82	25.82
900	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50	22.28	20.90
950	25.18	25.18	25.18	25.18	25.18	25.18	25.18	25.18	23.68	20.27	17.54	16.39
1000	24.85	24.85	24.85	24.85	24.85	24.85	24.85	21.92	18.89	16.01	13.71	12.75
1050	24.53	24.53	24.53	24.53	24.53	24.17	20.77	17.53	14.97	12.54	10.63	9.84
1100	24.21	24.21	24.21	24.21	23.29	19.60	16.68	13.93	11.77	9.75	8.17	7.51
1150	23.89	23.89	23.89	21.97	18.97	15.80	13.31	10.99	9.19	7.50	6.21	5.67
1200	23.57	23.57	20.95	18.26	15.37	12.66	10.55	8.60	7.10	5.72	4.67	4.23
1250	23.24	19.89	17.50	14.86	12.37	10.07	8.30	6.68	5.44	4.31	3.46	3.12
1300	21.93	16.66	14.55	12.02	9.90	7.96	6.48	5.13	4.12	3.21	2.53	2.26
1350	18.56	13.89	12.03	9.66	7.87	6.23	5.00	3.90	3.08	2.35	1.82	1.61
1400	15.64	11.53	9.73	7.72	6.20	4.84	3.83	2.93	2.27	1.70	1.28	1.11
1450	13.13	9.51	7.82	6.12	4.84	3.72	2.89	2.17	1.64	1.19	0.87	0.74
1500	10.97	7.81	6.24	4.81	3.75	2.83	2.16	1.57	1.17	0.81	0.56	0.47

Type 316H SS, S_t—Allowable Stress Intensity Values (MPa), SI Units

Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38
450	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38
475	176.38	176.38	176.38	176.38	176.38	176.38	176.38	176.38	176.38	176.38	163.22	153.30
500	174.39	174.39	174.39	174.39	174.39	174.39	174.39	174.39	174.39	151.94	131.92	123.42
525	172.39	172.39	172.39	172.39	172.39	172.39	172.39	167.08	144.65	123.13	105.99	98.75
550	170.39	170.39	170.39	170.39	170.39	170.39	161.46	137.06	117.67	99.21	84.61	78.49
575	168.40	168.40	168.40	168.40	168.40	155.25	133.00	111.86	95.18	79.43	67.08	61.92
600	166.40	166.40	166.40	166.40	152.92	128.35	109.02	90.79	76.53	63.16	52.77	48.46
625	164.40	164.40	164.40	147.70	127.03	105.62	88.90	73.26	61.12	49.85	41.16	37.59
650	162.41	161.99	143.43	124.92	105.04	86.47	72.09	58.73	48.46	39.01	31.80	28.86
675	160.41	138.60	121.99	103.76	86.45	70.41	58.08	46.75	38.12	30.25	24.31	21.90
700	155.31	118.20	103.38	85.78	70.78	56.99	46.49	36.92	29.71	23.21	18.36	16.42
725	133.70	100.44	87.26	70.56	57.62	45.83	36.93	28.91	22.93	17.60	13.67	12.11
750	114.75	85.03	72.47	57.74	46.62	36.59	29.10	22.42	17.49	13.17	10.02	8.78
775	98.16	71.68	59.68	46.97	37.47	28.98	22.72	17.19	13.17	9.69	7.20	6.22
800	83.68	60.17	48.87	37.96	29.89	22.76	17.55	13.02	9.78	6.98	4.98	4.22
825	68.25	50.26	39.79	30.47	23.65	17.69	13.40	9.72	7.07	4.84	3.32	2.75

Type 316H SS, S_r—Expected Minimum Stress-To-Rupture Values (ksi), U.S. Customary Units

Temp., °F	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
800	64.35	64.35	64.35	64.35	64.35	64.35	64.35	64.35	64.35	59.17	52.53	49.68
850	63.38	63.38	63.38	63.38	63.38	63.38	63.38	61.74	54.59	47.60	41.92	39.49
900	62.09	62.09	62.09	62.09	62.09	62.09	57.84	50.22	44.05	38.07	33.25	31.19
950	60.45	60.45	60.45	60.45	60.45	54.03	47.22	40.64	35.35	30.26	26.18	24.46
1000	58.40	58.40	58.40	58.40	51.62	44.26	38.36	32.71	28.20	23.89	20.47	19.03
1050	55.95	55.95	55.95	49.13	42.46	36.07	31.00	26.16	22.34	18.72	15.87	14.68
1100	53.05	53.05	47.89	40.56	34.76	29.25	24.90	20.79	17.57	14.55	12.19	11.21
1150	49.72	46.47	39.72	33.34	28.31	23.58	19.87	16.41	13.71	11.20	9.27	8.47
1200	45.96	38.71	32.81	27.26	22.94	18.89	15.75	12.84	10.60	8.54	6.97	6.32
1250	41.81	32.12	26.98	22.18	18.47	15.03	12.39	9.97	8.12	6.44	5.17	4.65
1300	37.28	26.53	22.07	17.94	14.78	11.88	9.67	7.66	6.15	4.79	3.78	3.37
1350	32.28	21.81	17.96	14.42	11.74	9.30	7.47	5.82	4.60	3.51	2.71	2.40
1400	26.96	17.84	14.52	11.52	9.26	7.22	5.71	4.37	3.39	2.53	1.91	1.66
1450	21.99	14.51	11.67	9.13	7.23	5.55	4.32	3.24	2.45	1.78	1.31	1.12
1500	16.55	11.73	9.32	7.18	5.60	4.22	3.22	2.35	1.74	1.22	0.87	0.73

Type 316H SS, S_r – Expected Minimum Stress-To-Rupture Values (MPa), SI Units

Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	444.08	444.08	444.08	444.08	444.08	444.08	444.08	444.08	444.08	413.26	367.07	347.19
450	438.25	438.25	438.25	438.25	438.25	438.25	438.25	438.25	389.31	339.94	299.79	282.59
475	430.69	430.69	430.69	430.69	430.69	430.69	420.09	365.54	321.32	278.34	243.61	228.80
500	421.15	421.15	421.15	421.15	421.15	399.86	350.46	302.58	264.01	226.77	196.89	184.21
525	409.43	409.43	409.43	409.43	388.77	334.68	291.22	249.37	215.89	183.77	158.19	147.39
550	395.40	395.40	395.40	376.41	326.75	279.05	240.98	204.56	175.62	148.07	126.29	117.15
575	378.97	378.97	372.66	317.52	273.62	231.72	198.50	166.95	142.06	118.55	100.12	92.42
600	360.12	360.12	315.80	266.91	228.24	191.57	162.72	135.51	114.22	94.27	78.76	72.33
625	338.85	312.38	266.73	223.53	189.59	157.64	132.69	109.34	91.23	74.40	61.43	56.10
650	315.25	264.95	224.48	186.45	156.78	129.06	107.59	87.66	72.33	58.23	47.47	43.07
675	289.44	223.97	188.22	154.86	129.03	105.09	86.69	69.78	56.89	45.15	36.29	32.69
700	261.59	188.65	157.18	128.03	105.64	85.06	69.39	55.11	44.35	34.64	27.40	24.50
725	231.95	158.30	130.69	105.32	86.00	68.40	55.12	43.15	34.22	26.27	20.41	18.08
750	198.41	132.28	108.16	86.18	69.58	54.61	43.43	33.46	26.11	19.65	14.96	13.11
775	168.33	110.06	89.07	70.10	55.92	43.26	33.91	25.66	19.66	14.46	10.75	9.31
800	135.34	91.14	72.94	56.66	44.61	33.97	26.20	19.44	14.59	10.45	7.55	6.44
825	101.87	75.08	59.39	45.48	35.30	26.41	20.00	14.51	10.63	7.38	5.15	4.31

4. SUMMARY

The formulas and numerical values of the corresponding coefficients (in both U.S. Customary and SI units) required to determine the time-dependent allowable stress values of Type 304H and 316H stainless steels are assembled from Sengupta and Nestell [2, 3] and Dabrow and Nestell [5] and documented in this paper. These updates and extensions are being recommended to the ASME Code committees for approval and are subject to change upon feedback from ASME Section III Code committees.

COPYRIGHT NOTICE

ACKNOWLEDGMENTS

The research was sponsored by the U.S. Department of Energy, Office of Nuclear Energy, under Contract No. DE-AC07-05ID14517 with Idaho National Laboratory, managed and operated by Battelle Energy Alliance, LLC. Programmatic direction was provided by the Office of Nuclear Reactor Deployment of the Office of Nuclear Energy.

We would like to thank Heramb Mahajan of Idaho National Laboratory for checking the stress table calculations.

REFERENCES

[1] Swindeman, R. W. "Operating Condition Allowable Stress Values in ASME Section III Subsection NH." Technical Report No. STP-NU-037. American Society of Mechanical Engineers, New York, NY. 2010.

[2] Sengupta, M. and Nestell, J.E. "Correct and Extend Allowable Stress Values for 304 and 316 Stainless Steel." Technical Report No. STP-NU-063. American Society of Mechanical Engineers, New York, NY. 2013.

[3] Sengupta, M. and Nestell, J.E. "The Effect of Tertiary Creep on Allowable Stress Values for Type 304 and 316 Stainless Steel for Elevated Temperature Nuclear Component Design." *Proceedings of the ASME 2015 Pressure Vessels and Piping Conference*. PVP2015-45992. American Society of Mechanical Engineers, New York, NY. 2015. https://doi.org/10.1115/PVP2015-45992.

[4] Third Way, https://www.thirdway.org/graphic/2022-advanced-nuclear-map-charting-a-breakout-year

[5] Dabrow, T. and Nestell, J.E. "Impact of Tertiary Creep on Time Dependent Allowable Stresses for Type 304H and 316H Stainless Steels." Technical Report No. 0300-0003-RPT-001. MPR Associates, Inc., Alexandria, VA. 2020. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML21048A085.

[6] Leyda, W. E. and Rowe, J. P. "A Study of the Time for Departure from Secondary Creep for Eighteen Steels." Technical Report Number P9-6.1. American Society for Metals, Philadelphia, PA. 1969.

[7] Prager, M., Osage, D.A., Panzarella, C.H., and Brown, R.G. "Development of a Material Databook for API STD 530." *Proceedings of the ASME 2014 Pressure Vessels and Piping Conference*. PVP2014-28538. American Society of Mechanical Engineers, New York, NY. 2014. https://doi.org/10.1115/PVP2014-28538.

APPENDIX

Type 304H Stainless Steel: LM Parameters for $t_{1\%}$, $n = 1$		
	U.S. Customary	SI
a_0	4.8522084582E+04	3.1856576672E+04
a_1	-1.0516123662E+04	-5.8425117097E+03
C	1.9114970281E+01	1.9115634638E+01
SEE	7.4074359551E-01	7.4070600421E-01

[1] Type 304H Stainless Steel: Leyda-Rowe Coefficient	
A	5.8496589320E-01
$log_{10}A$	-2.3286945499E-01

[2] Type 304H Stainless Steel: LM Parameters for t_r, $n = 2$		
	U.S. Customary	SI
a_0	4.2970314130E+04	2.6425818477E+04
a_1	-6.8450122243E+03	-2.2913459635E+03
a_2	-1.6210014515E+03	-9.0077040205E+02
C	1.6009882436E+01	1.6009230631E+01
SEE	5.0350754673E-01	5.0350040055E-01

Type 304H Stainless Steel: Room Temperature Specification Minimum		
	ksi	MPa
Yield strength	30	205
Tensile strength	75	515

Type 304H Stainless Steel: Coefficients for S_y, $m = 5$		
	U.S. Customary	SI
b_0	3.6885059792E+01	2.3748543900E+02
b_1	-8.8999968624E-02	-9.8304569561E-01
b_2	1.9072822017E-04	3.9349606596E-03
b_3	-2.2390458580E-07	-8.7404041343E-06
b_4	1.3155359568E-10	9.6968453720E-09
b_5	-3.0761297872E-14	-4.2638360876E-12

[1] The Leyda-Rowe coefficient is slightly different from that in Reference [5] due to the use of a larger dataset.

[2] These parameters correct data from Sengupta and Nestell [2] and used by Dabrow and Nestell [5].

Type 304H Stainless Steel: Coefficients for S_u, $m = 5$		
	U.S. Customary	SI
b_0	8.2398018222E+01	5.5473524518E+02
b_1	-7.7408906412E-02	-9.6997266930E-01
b_2	6.4588000314E-05	2.0083520289E-03
b_3	9.9839806130E-08	2.2560432318E-06
b_4	-1.6681520247E-10	-1.0427010763E-08
b_5	5.4882445326E-14	6.7448859244E-12

Type 304H Stainless Steel: Coefficients for $S_{1\%}$, $m = 1$		
	U.S. Customary	SI
b_0	3.3638088531E+01	2.2959385614E+02
b_1	-1.0204828974E-02	-1.2650691057E-01

Type 316H Stainless Steel: LM Parameters for $t_{1\%}$, $n = 2$		
	U.S. Customary	SI
a_0	5.3867821867E+04	3.3157974874E+04
a_1	-8.8277299523E+03	-2.7837285826E+03
a_2	-2.3026608555E+03	-1.2719130660E+03
C	2.1530891697E+01	2.1529535017E+01
SEE	4.9309706080E-01	4.9299721721E-01

Type 316H Stainless Steel: Leyda-Rowe Coefficient	
A	5.3892533403E-01
$log_{10}A$	-2.6847140042E-01

Type 316H Stainless Steel: LM Parameters for t_r, $n = 2$		
	U.S. Customary	SI
a_0	4.3393529502E+04	2.6379178420E+04
a_1	-6.1859858045E+03	-1.9839332057E+03
a_2	-1.5591228059E+03	-8.6609258190E+02
C	1.6282175397E+01	1.6281874052E+01
SEE	3.4958041854E-01	3.4961914935E-01

Type 316H Stainless Steel: Room Temperature Specification Minimum		
	ksi	MPa
Yield strength	30	205
Tensile strength	75	515

Type 316H Stainless Steel: Coefficients for S_y, $m = 3$		
	U.S. Customary	SI
b_0	3.4160594255E+01	2.2520777320E+02
b_1	-5.0113031732E-02	-5.8101778139E-01
b_2	5.2760062251E-05	1.1324283628E-03
b_3	-1.9735492380E-08	-7.8932046453E-07

Type 316H Stainless Steel: Coefficients for S_u, $m = 4$		
	U.S. Customary	SI
b_0	1.3405125516E+02	8.4787876898E+02
b_1	-2.8801522941E-01	-3.1092764327E+00
b_2	5.0103022967E-04	1.0307933731E-02
b_3	-3.6778413652E-07	-1.4361974706E-05
b_4	8.4962509112E-11	6.2125531667E-09

Type 316H Stainless Steel: Coefficients for $S_{1\%}$, $m = 1$		
	U.S. Customary	SI
b_0	3.1296180416E+01	2.1432563938E+02
b_1	-6.4413816231E-03	-7.9876781431E-02

Conversion Factors	
ksi	MPa
1.4503773801E-01	1.0
Rankine	Kelvin
1.8	1.0