APPENDIX 3
BASIS FOR ESTABLISHING EXTERNAL PRESSURE CHARTS

3-100 GENERAL

The charts in Subpart 3 were established in order to facilitate a conservative approach in determining external pressure ratings for components covering a wide range of geometries, materials, and conditions. The methods provide for a uniform basis of calculation for the referencing Section; the use of the charts eliminates the need for complex calculations by equations and incorporates realistic factors of safety for components of widely varying length-to-diameter and diameter-to-thickness ratios.

3-200 BASIS OF CHARTS IN SUBPART 3

Rules for allowable longitudinal compressive stress, rules for shells and tubes under external pressure, rules for stiffening rings, and rules for formed heads under external pressure make reference to and use material in Subpart 3, Charts and Tables for Determining Shell Thickness of Components Under External Pressure. These charts are pseudo stress-strain curves for the various materials in the Code and incorporate the moduli of elasticity and allowable stress limits at temperature of the materials. Entrance into the charts is via the Factor *A*, abscissa, which, in addition to being a strain term, is also related to certain geometrical considerations of the part in question, such as thickness, diameter, and length. These geometrical considerations are independent of material properties; thus a single geometry chart, Fig. G, applies to all materials and is used in conjunction with the materials charts in Subpart 3.

3-300

External pressure capability of cylinders, spheres, and formed heads, as well as allowable compressive stress for cylinders subject to axial compression, is obtained by reference to the charts in Subpart 3 along with instructions and formulas given in the appropriate paragraphs in the body of the referencing Section.

3-400 BACKGROUND AND DEVELOPMENT OF THEORY

The development of the present rules for external pressure has a long history. Among the principal references used in developing these rules are Timoshenko's *Theory of Elasticity* [3-800(a)], *Theory of Plates and Shells* [3-800(b)], and *Theory of Elastic Stability* [3-800(c)]; a group of papers reprinted as Section 9 in ASME's publication *Pressure Vessel and Piping Design — Collected Papers 1927–1959* [3-800(d)]; and Sturm's 1941 University of Illinois Bulletin 329, *A Study of the Collapsing Pressure of Thin Walled Cylinders* [3-800(e)]. The format for the charts in Subpart 3 is detailed in Sturm's University of Illinois Bulletin 329 [3-800(e)], with additional comments in Bergman's 1952 paper, The New Type Code Chart for the Design of Vessels Under External Pressure [included in 3-800(d)]. The Sturm and Bergman papers detail the mechanics involved in combining the materials and geometrical factors into a nomograph format; an important companion paper to those of Sturm and Bergman is Sturm and O'Brien's 1946 ASME paper, Computing Strength of Vessels Subjected to External Pressure [3-800(f)]. The Michalopoulos paper [3-800(g)] contains a new mathematical approach to the development of external pressure charts, using stress–strain curve fitting techniques rather than the graphical approach used in the recent charts for the design of vessels under external pressure.

3-500 DESIGN BASIS 01

As noted previously, stress and strain values for components are analytically and geometrically distilled

COPYRIGHT American Society of Mechanical Engineers
Licensed by Information Handling Services

into the two chart parameters *A* and *B.* The design is based on the following considerations.

(a) External Pressure on Cylinders. The geometric chart, Fig. G,[1] for components is used in conjunction with the appropriate material chart and a formula for *B* to obtain a design external pressure. This is based on the following considerations.

(1) The assumed critical buckling stress without any reduction for tolerance, etc., is based upon the reference in 3-800(e), assuming pressure on the ends of the vessel as well as radial to the cylinder, and assuming the ends of the cylinder are simply supported.

(2) The parameters and stresses are those at the design temperature.

(3) The tangent modulus is used for buckling stresses above the proportional limit. The point at which yield or creep governs (beyond the transition) is chosen at a relatively high value of *A* (i.e., t/R).

(4) The allowable tolerances are based on empirical relationships intended to limit the buckling pressure to not less than 80% of that for a perfectly uniform vessel.

(b) External Pressure on Spheres. The material charts are used together with formulas to determine *A* from the geometry and to determine the pressure using *B* determined from the chart to determine a design external pressure. This procedure is based upon the following considerations.

(1) The assumed critical buckling stress without any reduction for tolerance, theory versus tests, etc., is based on

$$0.125\,\frac{Et}{R_0}$$

(2) The parameters and stresses are those at the design temperature.

(3) The tangent modulus is used for buckling stresses above the proportional limit [see (a)(3) above].

(4) The allowable tolerances are based upon empirical relationships intended to limit (along with reduction factors based on tests) the buckling pressure to not less than 60% of that obtained using the formula in (1) above.

NOTE: This gives results similar to those for the cylinder in the elastic range. However, the present material charts give more restrictive results for spheres than for cylinders in the plastic range.

(c) Axial Compression on Cylinders.[2] A formula is used to determine *A* from the geometry. Then *A* is used with the material chart to determine *B,* the allowable compressive stress for that geometry. This is based upon the following considerations.

(1) The assumed critical buckling stress without any reduction for tolerance, theory versus tests, etc., is based upon

$$0.25\,\frac{Et}{R_0}$$

(2) The parameters and stresses are those at the design temperature.

(3) The tangent modulus is used for buckling stresses above the proportional limit [see (a)(3) above].

(4) The allowable tolerances are based upon empirical relationships intended to limit (along with reduction factors based upon tests) the critical buckling stress to 50% of that obtained in using the formula in (1) above for R/t values.

(d) Elevated Temperature Effects

(1) The design basis described here does not include the effects of creep on buckling. The Subpart 3 external pressure charts and tables are based on instantaneous stress–strain properties. At elevated temperatures, the effect of creep is to reduce buckling stress depending on the magnitude of load and time at load. At some temperatures for which limits are provided in the Subpart 3 charts, the material is in the creep range and buckling stresses are reduced, with the reduction increasing with time at load. The result is that for temperatures in the creep range, the actual design margins will be less than those intended by this design basis and the associated criteria for allowable stresses (see 3-600). However, the design margins may still be adequate due to conservatism of the design limits and the specific nature of creep buckling.

(2) Design limits for elevated temperature buckling and instability are given in Section III, Division 1 — Subsection NH, Appendix T, T-1500. Design guidance is given that may be used to address creep buckling for components designed to the limits of the Subpart 3 external pressure charts. However, if the design temperature of a component is less than the temperature limits provided in Fig. 3-500.1 for a cylinder under external pressure, Fig. 3-500.2 for a cylinder under axial compression, or Fig. 3-500.3 for a sphere under external pressure, the design margin of the Subpart 3 charts is not reduced by creep.

(3) The temperature limits of Figs. 3-500.1, 3-500.2, and 3-500.3 were obtained using the analysis method of WRC Bulletin 443, *External Pressure: Effect of Initial Imperfections and Temperature Limits* [see

[1] This chart is used only for this condition and is only applicable to uniform external pressure.

[2] This applies to unstiffened cylinders.

COPYRIGHT American Society of Mechanical Engineers
Licensed by Information Handling Services

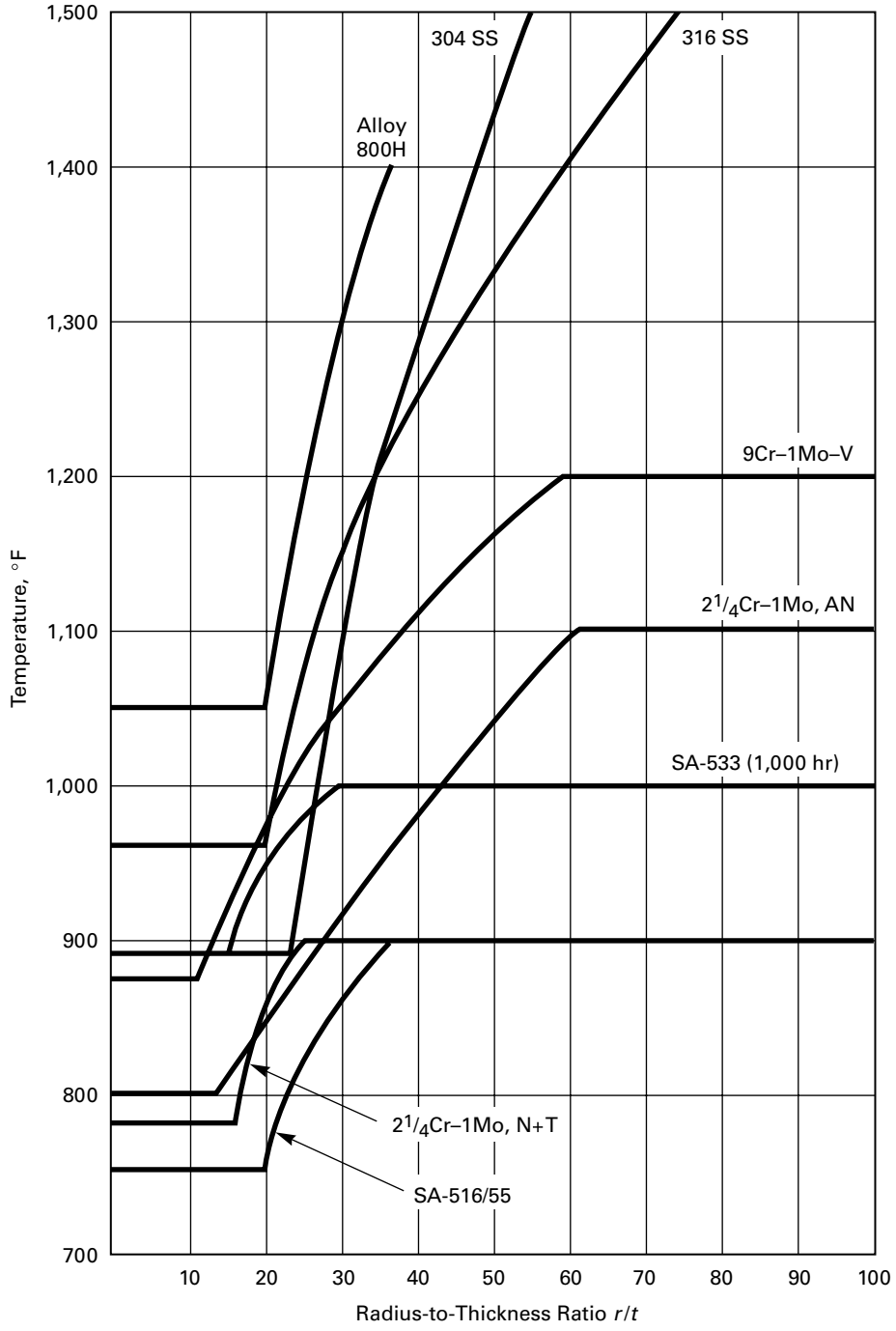
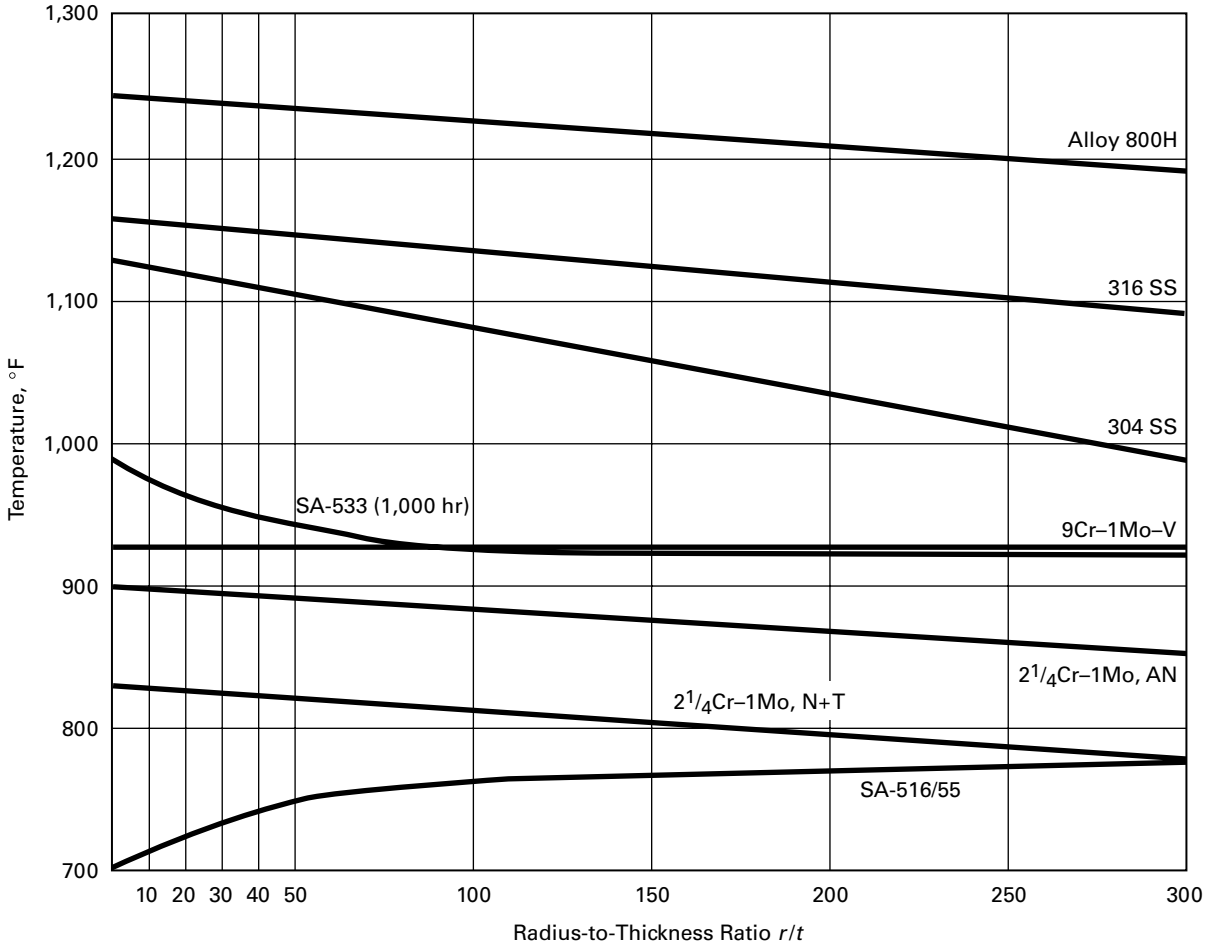


FIG. 3-500.1 TEMPERATURE LIMITS FOR APPLICATION OF SECTION II EXTERNAL PRESSURE CHARTS FOR CYLINDER UNDER EXTERNAL PRESSURE 01

COPYRIGHT American Society of Mechanical Engineers
Licensed by Information Handling Services



01 FIG. 3-500.2 TEMPERATURE LIMITS FOR APPLICATION OF SECTION II EXTERNAL PRESSURE CHARTS FOR CYLINDER UNDER AXIAL COMPRESSION

3-800(h)]; the design limits of Subsection NH; and 100,000 hr materials property data except as noted for SA-533. Limits were developed only for materials where the necessary creep properties were available.

3-600 CRITERIA FOR ALLOWABLE STRESSES

In establishing allowable stresses for preparing the material charts, consideration is given not only to the available mechanical property data but also to service experience. The external pressure charts are based on short-term tensile properties and may not adequately account for creep effects. Creep reduces the critical buckling stress. In evaluating new or modified materials, reliance is also placed on comparison with test data and service experience for similar materials. Except for the overriding consideration of experience, the allowable stresses are based on the factors and properties given below.

(a) For cylindrical shells, under external pressures, the allowable stress is the least of:

(1) 33% of the assumed critical buckling stress as defined in 3-500(a)(1) but limited by allowable tolerances defined in 3-500(a)(4);

(2) 33% of the specified minimum yield strength and yield strength at temperature;

(3) 66% of the average stress to produce a creep rate of 0.01% per 1000 hr;

(4) 100% of the allowable stress in tension.

(b) For spheres and spherical portions of heads under external pressure, the allowable stress is the least of:

COPYRIGHT American Society of Mechanical Engineers
Licensed by Information Handling Services

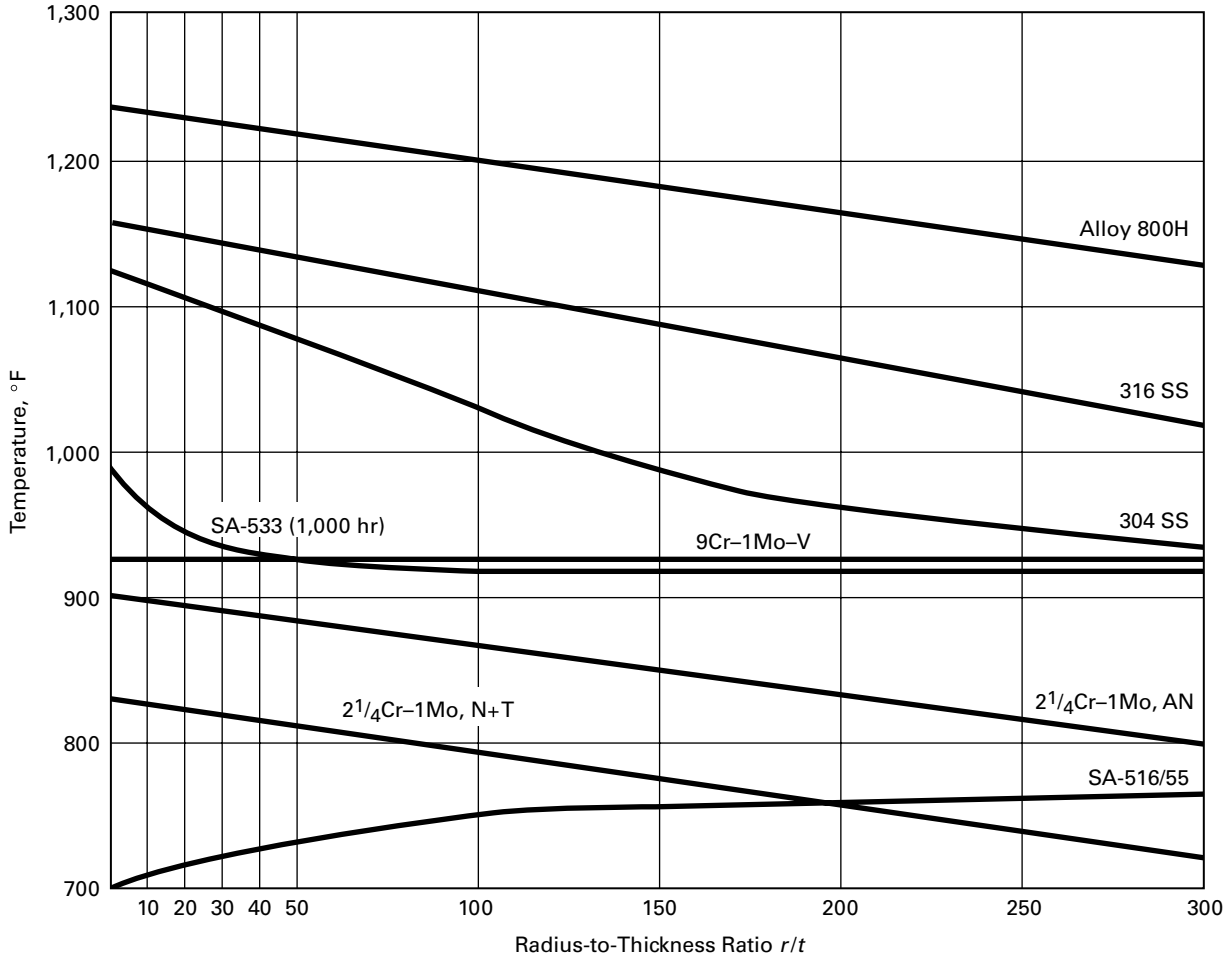


FIG. 3-500.3 TEMPERATURE LIMITS FOR APPLICATION OF SECTION II EXTERNAL PRESSURE CHARTS FOR SPHERE UNDER EXTERNAL PRESSURE 01

(1) 25% of the assumed critical buckling stress as defined in 3-500(b)(1) but limited by allowable tolerances defined in 3-500(b)(4);

(2) 25% of the specified minimum yield strength and yield strength at temperature;

(3) 50% of the average stress to produce a creep rate of 0.01% per 1000 hr;

(4) 100% of the allowable stress in tension.

(c) For cylindrical shells under axial compression, the allowable stress is the least of:

(1) 25% of the assumed critical buckling stress as defined in 3-500(c)(1) but limited by allowable tolerances defined in 3-500(c)(4);

(2) 50% of the specified minimum yield strength and yield strength at temperature;

(3) 100% of the average stress to produce a creep rate of 0.01% per 1000 hr;

(4) 100% of the allowable stress in tension.

3-700

The preparation of charts for Subpart 3 is conducted by the Subgroup on External Pressure of the Subcommittee on Materials.

3-800 REFERENCES 01

(a) Timoshenko, S. and Goodier, J. N., *Theory of Elasticity*, McGraw-Hill Book Co., New York, 1951

COPYRIGHT American Society of Mechanical Engineers
Licensed by Information Handling Services

(b) Timoshenko, S. and Woinowsky-Krieger, S., *Theory of Plates and Shells*, McGraw-Hill Book Co., New York, 1959

(c) Timoshenko, S. and Gere, J. M., *Theory of Elastic Stability*, McGraw-Hill Book Co., New York, 1961

(d) Pressure Vessel and Piping Design — Collected Papers 1927–1959, ASME, New York, 1960

(e) Sturm, R. G., *A Study of the Collapsing Pressure of Thin Walled Cylinders*, University of Illinois Bulletin 329, 1941

(f) Sturm, R. G. and O'Brien, H. L., *Computing Strength of Vessels Subjected to External Pressure*, Transactions of the ASME, May 1947

(g) Michalopoulos, E., *A New Method for the Development of External Pressure Charts*, ASME PVP-Vol. 312-2, pp. 293–301, 1995

(h) Griffin, D. S., *External Pressure: Effect of Initial Imperfections and Temperature Limits*, WRC Bulletin 443

COPYRIGHT American Society of Mechanical Engineers
Licensed by Information Handling Services