By acceptance of this article, the publisher or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering the article.

CONF-760547--1

THE RELATIONSHIP BETWEEN VARIOUS PRESSURE VESSEL AND PIPING CODES*

D. A. Canonico

Metals and Ceramics Division, Oak Ridge National Laboratory

Oak Ridge, Tennessee 37830

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ABSTRACT

Section VIII of the ASME Code provides stress allowable values for material specifications that are provided in Section II Parts A and B. Since the adoption of the ASME Code over 60 years ago the incidence of failure has been greatly reduced. The Codes are currently based on strength criteria and advancements in the technology of fracture toughness and fracture mechanics should permit an even greater degree of reliability and safety.

This lecture discusses the various Sections of the Code. It describes the basis for the establishment of design stress allowables and promotes the idea of the use of fracture mechanics.

---

*Research sponsored by Energy Research and Development Administration under contract with Union Carbide Corporation.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

By acceptance of this article, the publisher or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering the article.

THE RELATIONSHIP BETWEEN VARIOUS PRESSURE VESSEL AND PIPING CODES*

D. A. Canonico

Metals and Ceramics Division, Oak Ridge National Laboratory

Oak Ridge, Tennessee 37830

The ASME Boiler and Pressure Vessel Code has been adopted into law by nearly all of the United States of America. Pressure vessels are usually designed, fabricated and inspected in accordance with one of the Sections of the Code. My talk today will be directed toward vessels built in accordance with the rules of Section VIII Division 1. Most vessels built in the United States are constructed in accordance with that Code.

The jurisdiction of the pressure vessel code over external piping terminates at the first circumferential joint (paragraph U-1 in Section VIII Division 1). The piping installations in the systems which contain these pressure vessels are designed and built in accordance with ANSI (American National Standards Institute) Code B-31.

Pressure vessels may be built in accordance with Division 2 of Section VIII, however, that Code is more restrictive. Paragraph A-100(e) describes the basic difference between Divisions 1 and 2.

A-100 Scope

"(e) In relation to the rules of Division 1 of Section VIII, these rules of Division 2 are more restrictive in the choice of materials which may be used but permit higher design stress intensity values to be employed in the range of temperatures over which the

---

*Research sponsored by Energy Research and Development Administration under contract with Union Carbide Corporation.

design stress intensity value is controlled by the ultimate strength or the yield strength; more precise design procedures are required and some common design details are prohibited; permissible fabrication procedures are specifically delineated and more complete examination testing and inspection are required."

It should be noted that the reward for the restrictive nature of Division 2 lies in the higher allowable stress values. These higher allowable stress values will become an important factor in the near future as the coal conversion industry becomes commercialized. There are vessels being considered in some concepts that are nearly 300 feet in height and 31 feet in diameter. These vessels will operate at about 1000 psig and, hence, require wall thicknesses of 8 to 12 inches. These vessels will weigh in excess of 3000 tons. The higher allowable stresses in Division 2 will provide a reduction in the amount of material. This reduction will be reflected in a lower cost of fabrication and relief of problems associated with shipping and siting. Further, and perhaps of even more importance, Division 1 has a 3000 psi pressure limitation, paragraph U-1(b) and this fact may necessitate the employment of Division 2 rules. Division 2 has no pressure limitation (see paragraph A-110).

Regardless of which section of the Code is employed the philosophy for their existence is essentially the same; they were established to provide the engineering requirements necessary for the safe design and fabrication of pressure vessels. They provide minimum requirements for construction and all the codes emphasize this point. The ANSI Code, B-31.3, specifically mentions that "the Code does not do away with the need for the engineer or component engineering judgment." The success of the Codes is illustrated in my first slide[1]. Prior to the establishment of the ASME there were a number of failures in which many people were killed. Today the incidence of pressure vessel failures[1]

[1]S. H. Bush, "Pressure Vessel Reliability," Transactions of ASME, February 1975, p. 54.

is near 10^{-5} to 10^{-6} per plant year.

The responsibility for compliance with the requirements of Section VIII, Division 1 [Para. U-2(b)] or Division 2 (Para. A-301) rules rests with the manufacturer. The owner is responsible only for provision of the Design Specification. However, the ANSI B-31.3, paragraph 300 places the overall responsibility for compliance with that Code with the owner of the completed piping installation. The two Codes, ANSI B-31.3 and Section VIII, are dissimilar in their rigidity. The ANSI Code is more lenient in that it permits the use of design stress values based on the criteria employed for Division 2 without imposing the restrictions found in that document. Perhaps the greater degree of leniency in the piping codes contributes to the higher incidence of piping failures (10^{-4} to 10^{-5} failures per plant year).[2] The bases for the allowable stresses in Divisions 1 and 2 and the ANSI B-31.3 for materials other than bolting materials are shown in the next slide.[2]

The criteria for providing the allowable stresses are based solely on strength. This slide illustrates that point. At temperatures below those which result in creep the allowable stresses are governed by tensile properties; the lower of either a fraction of the minimum yield or the minimum ultimate tensile strength. Usually the values of the ASME Code are dictated by the room temperature minimum requirements as established by the specifications in Section II, Materials Specifications, of the ASME Code.

Section II, Material Specifications, of the ASME Code is divided into three parts, Part A — Ferrous, Part B — Nonferrous and Part C — Welding Rods, Electrodes and Filler Metals. I will focus my attention on Part A during this

[2]E. C. Rodabaugh and A. G. Pickett, *Survey Report on Structural Design of Piping Systems and Components*, TID 25553, December 1970.

lecture. Basically, the role of Section II is to provide standards that specify quality levels commensurate with design rules. Adequate quality sometimes requires limiting the chemical composition of an alloy, the melting process that can be employed and quite often the heat treatment to which it is to be subjected. About half of the specifications in Section II Part A are identical to corresponding ASTM specifications, the remainder are modified to satisfy Code useage. Quite often the only differences lie in the nondestructive examination and toughness requirements. The specifications in Section II are referred to as SA numbers (S for specification, A identifies the fact that the specification is from Part A). Section II Parts A, B and C are in essence reference documents. They contain numerically identified specifications that are easily referenced and assure that the product form supplied to a fabricator possesses a minimum quality level. Examples of the information contained in a SA specification that is of direct interest to the fabricator are provided in the next slide[3]. Section II provides the chemical composition requirements within a given specification, a suggestion of the maximum plate thickness that is available for that analysis and the minimum tensile properties. It should be noted that the minimum properties are indeed that. Most often the tensile properties of a given grade of steel cover an extremely wide range. The next slide[4] is an example of the wide variation in the ultimate tensile strength of annealed 2 1/4 Cr-1 Mo steel. The data were obtained for SA 387 Grade 22 Class 1 material, one of the specifications cited in the previous slide. However, over 50% of the data points also satisfy the minimum room temperature requirements of SA 387 Grade 22 Class 2. The Class 2 properties, minimum ultimate tensile strength of 517 MPa (75 ksi), are usually achieved through a normalizing heat treatment. Hence, there is an overlap of proper and quite often a heat of steel that satisfies the requirements of one grade specification can also satisfy a second grade of the same nominal cl composition.

In both Divisions 1 and 2 of Section VIII the use of materials other than those allowed by the Code must be approved by the Boiler and Pressure Vessel Committee (paragraphs UG-5(c) and AM-100, respectively). The data needs and procedure for obtaining permission to use unlisted materials or to extend the limits of use of a permitted material are provided in the Appendices to the two Divisions of Section VIII. Authorization to use materials not specified in Section II requires that data be submitted to the Boiler and Pressure Vessel Committee and upon their approval, a Code Case is issued. This procedure does not permit the design engineer the freedom to determine the amount of testing necessary to establish allowable stresses for unlisted materials. This practice is permitted by some Code bodies.

The use of materials at elevated temperatures (creep range) is permitted in Division 1 of Section VIII. The criterion for establishing the allowable stress levels are based on:

100% of the average stress for a creep rate of 0.01% per 1000 hrs

67% of the average stress for rupture at the end of 100,000 hrs

80% of the minimum stress for rupture at the end of 100,000 hrs

Criteria for establishing the stress intensity values in the creep range for Division 2 are in preparation. It is anticipated, however, that the criteria that will be established will be similar to those of Code Case 1592 of Section III. The bases for the stress allowables at temperatures below the creep range are identical and Division 2 tends to follow the more restrictive rules of Section III. The next slide[5] provides examples of the allowable stress intensity values for Section VIII Division 2 and their extension to temperatures in the creep range (per the rules of Code Case 1592). Note that there are no allowable stress intensity values at temperatures above 1500°F. Indeed, if [illegible]ffort is made to [illegible]ablish stress intensity values on the same basis as Division 1 at te[illegible]tures in excess of 1500°F, the margin of excess strength in real psi rapidly disappears. The next slide[6] helps illustrate this point. This slide shows rupture properties of a number of high temperature alloys. If we only consider the stainless steel curve, we find that the average stress for rupture in 100,000 hours is less than 1000 psi at 1600°F. If we use 80% of the average stress for rupture as the basis for selecting the allowable stress at 1600°F the value is about 670 psi. There is only 330 psi difference between a "safe" stress and a stress that might cause failure in half of the components built in accordance with this allowable value.

As mentioned earlier, Section VIII Division 1 provides design allowable stresses in the creep range. The next two slides provide design allowable stress values over the entire range permitted by Division 1 for SA 515, grades 55 and 70, and Incoloy 800. The first of these slides[7] compares the SA 515 allowable stresses and those of ANSI B-31.3. The ANSI B-31.3 criteria for calculating allowable stresses for temperatures below the creep range are identical to those employed by Division 2. The allowable stresses based on the criteria of ANSI B-31.3 (Division 2) are higher than the Division 1 values below about 750°F. At temperatures above that value the allowable stresses are nearly identical. Note also that at temperatures of 900°F and higher the design allowable stress values are identical for Grades 55 and 70.

The Incoloy 800 design allowable stresses are nearly the same at room temperature. The next slide[8] provides the design allowable stresses for Incoloy 800 as a function of temperature. At slightly higher temperatures, 300 to 800°F, the ANSI B-31.3 and Division 1 allowable stresses diverge. At 1100°F the two Codes again have identical stress values.

Up to this point we have discussed the design allowable stresses that are provided in Section VIII for a number of alloys that are specified in Section II Part A. However, before a material is selected for use in the fabrication of a component, there are a number of other factors that must be considered. It should be emphasized that often these factors are even more important than strength. The next slide[9] lists a few of these factors. Of particular interest are the loading and environmental conditions. These two items introduce us to two topics which only recently are getting the attention they deserve in Section VIII. Even Section III, Nuclear Power Plant Components, tends to gloss over the effect of environment on material properties and decrees that concern for this factor is the responsibility of the owner (paragraph NB-2160).

Division 1 of Section VIII recommends that the user assure himself of the stability of the material he selected over the expected life of the component. Mechanical properties are specifically cited in paragraph UG-5. Of particular concern is the loss of toughness of a material as a consequence of its extended exposure to various temperatures and environments.

Section VIII Division 1, contains minimal toughness requirements for materials used in construction. These requirements are based on Charpy V-notch tests, as cited in paragraph UG-84. Paragraphs AM-204 and AM-210 of Division 2 cover the same subject. The requirements are quite similar. The Codes require that the impact tests be conducted at the lowest temperature to which a vessel may be subjected in its operating cycle and minimum Charpy V-notch impact values are required. The next slide[10] is a copy of Table AM-211.1 of Division 2. This table provides the minimum Charpy V-notch impact test requirements. None of the Codes requires that upper shelf values be determined. There is no assurance in any of the Code rules that the toughness properties are greater than the 15 or 20 ft-lbs required. The pitfall of this approach is illustrated in the next slide[11]. This material probably demonstrated 15 ft-lbs Charpy V-notch impact energy at the lowest operating temperature. However, it also demonstrates only 15 ft-lbs on its upper shelf. In view of the recent advancements in the field of Fracture Mechanics, the approach to toughness taken in Section VIII might be updated. Testing procedures are currently available that permit a quantitative analysis of a material's toughness. An evaluation of the material's ability to resist propagation of a crack from a preexisting sharp flaw is possible.

One of the more important areas of consideration that assures safe and reliable service is that of inspection and examination procedures. For example, the failure of the Thompson vessel during hydrostatic testing in England in 1965 would have been avoided if the defect in the heat-affected-zone had been detected. The practice of nondestructive testing is often maligned but it is indeed extremely beneficial to both the fabricator and the buyer. Division 1 requires that all butt-welded joints in a vessel that is to contain a lethal substance shall be fully radiographed. The definition of a lethal substance is open to interpretation, however, for a safe installation (basis for all Codes) the most liberal interpretation should be employed. Moreover, Division 1 requires full radiographic examination of specified thicknesses of butt-welded joints of certain P number materials. It is important to note that all thicknesses of 2 1/4 Cr-1 Mo, 3 Cr-1 Mo, 3 Cr-0.9 Mo, 5 Cr-1/2 Mo, 7 Cr-1/2 Mo, and 9 Cr-1 Mo steels (P-5 alloys) must be fully radiographed (paragraph UCS-57). These alloy steels, because of their excellent resistance to corrosive environments, are frequently candidate materials for the fabrication of pressure vessels and piping for applications that involve hostile environments.

The rules in Section VIII for fabricating vessels are quite restrictive. Division 1 [UCS-5(b)] restricts welding carbon and low alloy steels to those grades that contain less than 0.35% carbon. Table ACS-1 of Division 2 also limits (note 4) the carbon content of some nominal compositions and further, specifically delineates permissible fabrication procedures.

Prior to final acceptance of a system an Authorized Inspector must be satisfied that the pressure vessel or piping installation satisfies the requirements of the Code to which the component was manufactured. Section VIII states that the Inspector can be an employee of a State or Municipality of the United States, a Canadian Providence, or an insurance company authorized to underwrite boiler and pressure vessel insurance or by the owner (when the owner has purchased the pressure vessel for his own use). A Section VIII inspector is qualified by a written examination under the rules of any State of the United States or Providence of Canada.

In summary, the role of the Codes is to assure the safe and reliable service of the component being fabricated. The Codes, in particular Section VIII Divisions 1 and 2, provided allowable stress values for steels that are specified in Section II. Through this process the Code does assure that failure of a component will not occur by plastic instability or creep while operating at or near design conditions. One shortcoming of Section VIII lies in the toughness requirements for ferritic materials. This is an area that should and is being expanded to include current technology based on fracture mechanics.