STP-NU-059

CORRECTIONS TO STAINLESS STEEL ALLOWABLE STRESSES

ASME STANDARDS TECHNOLOGY, LLC

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ASME STANDARDS TECHNOLOGY, LLC

Date of Issuance: June 10, 2013

This report was prepared as an account of work sponsored by the U.S. Department of Energy (DOE) and the ASME Standards Technology, LLC (ASME ST-LLC).

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ISBN No. 978-0-7918-6896-6

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FOREWORD

This document is the result of work resulting from Cooperative Agreement DE-NE0000288 between the U.S. Department of Energy (DOE) and ASME Standards Technology, LLC (ASME ST-LLC) for the Generation IV (Gen IV) Reactor Materials Project. The objective of the project is to provide technical information necessary to update and expand appropriate ASME materials, construction and design codes for application in future Gen IV nuclear reactor systems that operate at elevated temperatures. The scope of work is divided into specific areas that are tied to the Generation IV Reactors Integrated Materials Technology Program Plan. This report is the result of work performed under Task 14 titled "Corrections to Stainless Steel Allowable Stresses."

ASME ST-LLC has introduced the results of the project into the American Society of Mechanical Engineers (ASME) volunteer standards committees developing new code rules for Generation IV nuclear reactors. The project deliverables are expected to become vital references for the committees and serve as important technical bases for new rules. These new rules will be developed under ASME's voluntary consensus process, which requires balance of interest, openness, consensus and due process. Through the course of the project, ASME ST-LLC has involved key stakeholders from industry and government to help ensure that the technical direction of the research supports the anticipated codes and standards needs. This directed approach and early stakeholder involvement is expected to result in consensus building that will ultimately expedite the standards development process as well as commercialization of the technology.

ASME has been involved in nuclear codes and standards since 1956. The Society created Section III of the Boiler and Pressure Vessel Code, which addresses nuclear reactor technology, in 1963. ASME Standards promote safety, reliability and component interchangeability in mechanical systems.

Established in 1880, ASME is a professional not-for-profit organization with more than 127,000 members promoting the art, science and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety, and provides lifelong learning and technical exchange opportunities benefiting the engineering and technology community. Visit www.asme.org for more information.

ASME ST-LLC is a not-for-profit Limited Liability Company, with ASME as the sole member, formed in 2004 to carry out work related to newly commercialized technology. The ASME ST-LLC mission includes meeting the needs of industry and government by providing new standards-related products and services, which advance the application of emerging and newly commercialized science and technology and providing the research and technology development needed to establish and maintain the technical relevance of codes and standards. Visit www.stllc.asme.org for more information.

EXECUTIVE SUMMARY

The primary controlling variables for predictable 105 hour creep rupture properties in Type 304H and 316H stainless steel at elevated temperatures have been identified as nitrogen in interstitial solid solution (available nitrogen) and copper above 0.25 wt% [1]. An expression was developed to account for the varying residual strong nitride forming elements in a heat, where targeted nitrogen additions can be made to ensure sufficient available nitrogen levels without complicating the material certification process. Appendix A shows the current 2010 Subsection NH, Appendix X, Table X-1 restrictions for service up to 1100^{o}F (595^{o}C), with Appendix B presenting the new proposed restrictions in Table X-2 for long-term service at temperatures between 1100^{o}F (595^{o}C) and 1337^{o}F (725^{o}C). It is recommended that these proposed Table X-2 restrictions be mandatory for long term service at these temperatures to take advantage of the demonstrated creep performance improvements associated with these restrictions.

A review of 340 recent Type 316 SS heat compositions identified residual titanium, aluminum, boron, niobium and vanadium at sufficient levels to impact the amount of available nitrogen necessary for optimum creep properties. These elements were targeted for restrictions in the proposed Table X-2 nitrogen calculation due to their presence as residuals in steel, their low free energy of nitride formation [2] and the stability of these nitrides in steels at the anticipated service temperatures. Zirconium and tantalum were excluded from the calculation because they are typically present only at trace levels; however, these elements will be reported for future use and control if necessary. It is anticipated that the reporting of zirconium and tantalum could be eliminated if these elements continue to be at trace or less than minimum detection levels (MDL). It is proposed that the copper control be accomplished using a minimum–maximum composition range, with a nominal composition typically found in production heats. This approach of determining the residual nitride forming elements, and adjusting the nitrogen on a heat basis, has been reviewed by a major stainless steel producer and it has concurred that the proposed Table X-2 restrictions are acceptable for production quantities, and would not compromise the material certification process.

This study examined 105 hour creep rupture data from the Japanese National Institute for Materials Science (NIMS), and consisted of nine Type 304HTB and nine Type 316HTB heats that exhibited considerable scatter in creep results. The compositions of the NIMS heats indicate that they were likely produced to requirements similar to the conventional Type 304H (UNS# S30409) and Type 316H (UNS# S31609) requirements. Given that several of the NIMS heats did not meet the current Subsection NH, Appendix X, Table X-1 composition restrictions, they nonetheless exhibited significantly reduced scatter in the creep results, and, in fact, were the best performers. These data indicate that a review of the applicability of the current Table X-1 restrictions is warranted given the strong correlations established between available nitrogen and creep properties. The proposed Table X-2 is an attempt to further reduce scatter in creep data by using targeted restrictions mostly for copper and nitride forming species, as presented herein, to modify the conventional UNS alloy composition requirements for Type 304H and 316H SS. A potential economic benefit may be realized by re-establishing the conventional H grade composition ranges for non-restricted species, by providing suppliers some leeway to achieve the desired creep rupture properties.

After eliminating the Type 316H heats in the NIMS database that did not satisfy the proposed Table X-2 restrictions, and then extrapolating the remaining compliant heat creep results to 1337^{o}F (725^{o}C), the data suggests that these compliant heats represent a minimum creep rupture strength of approximately 2553 psi (17.6 MPa) vs. the Section III, Division 1, Subsection NH allowable of 2321 psi (16 MPa) at 1337^{o}F (725^{o}C). Given that only three relevant data points from the NIMS study satisfy the proposed Table X-2 restrictions, additional confidence in the 1337^{o}F (725^{o}C) upper temperature limit could be realized by including additional 105 hour creep rupture data from other sources. An additional benefit of evaluating additional Table X-2 compliant heat creep data may

allow a more definitive upper service temperature limit that the NIMS data suggests may, in fact, be slightly above 1337^{o}F (725^{o}C).

Regardless of whether the proposed Table X-2 is adopted or not, it is recommended that additional available 105 hour plus creep rupture data be screened for compliance to the proposed Table X-2 restrictions, and the minimum stress to rupture be recalculated for comparison to the current Section III, Division I, Subsection NH allowables. This approach is expected to allow a more accurate determination of the acceptable upper service temperature limits for Type 304H and 316H materials, and improve the confidence for designers of high temperature components.

Additional recommendations include considering if ongoing creep testing organizations should begin recording ferrite number data for Type 304H and 316H creep samples and begin to consider the effects of weld ferrite content on creep performance.

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1 OBJECTIVE

ASME Standards Technology, LLC has sponsored a thorough review of current allowable stress values in ASME Boiler and Pressure Vessel Code, Section III, Division I, Subsection NH, and to identify inconsistencies and potential limitations on the use of some current values in Subsection NH for austenitic stainless steel. More specifically, long term creep tests on AISI Type 304H and 316H stainless steel (SS), completed after the current allowable stress values were established, identified some heats whose rupture life fell below currently published allowable values, particularly above 1200ºF (650ºC). Since some of these errors and limitations could impact near term design activities for Gen IV applications, there is an urgent need to address this issue.

1.1 Technical Approach

The technical approach to address this objective was to break the effort into three distinct parts where at the conclusion of Part 1, it would be evident as to whether the Part 2 stress modifications would be necessary. The scope of work for each part is identified as follows:

Part 1 – Assess Available Data

Assess available data on Type 304H and 316H SS (Note: 316H SS is the primary material of interest in this assessment) to determine if there are restrictions that could be placed on specifications and procurement packages or additional acceptance test and examination requirements, e.g., chemical composition, physical or mechanical properties or processing variables, that would exclude from use those heats of material that are not representative of the database from which the currently published allowable stress values were derived.

Part 2 – Determine Time and Temperature Limits

In the event that the results of the Part 1 assessment do not identify applicable restrictions and/or additional acceptance requirements, the time and temperature limits beyond which the validity of the current allowable stress values cannot be guaranteed shall be determined. Allowable stresses beyond their range of validity should be recommended for deletion.

Part 3 – Draft Code Rules

Based on the results obtained after completion of Parts 1 and 2, above, prepare a submittal of draft code rules with supporting information. Recommendations should include specific Code words or modifications to tables implementing the restrictions that are ready for consideration as a Code Case or Code revision. This submittal shall be a formal proposed standard action and shall have an assigned tracking number.