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DEVELOPMENT OF WELD STRENGTH REDUCTION FACTORS AND WELD JOINT INFLUENCE FACTORS FOR SERVICE IN THE CREEP REGIME AND APPLICATION TO ASME CODES

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Prepared by:

J. Shingledecker, Electric Power Research Instiitute
B. Dogan, Electric Power Research Instiitute
J. Foulds, Clarus Consulting, LLC
R. Swindeman, Cromtech, Inc.
D. Marriott, Stress Engineering Services
P. Carter, Stress Engineering Services

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FOREWORD

This publication was prepared by ASME ST-LLC and sponsored by ASME and EPRI. The project was conducted by EPRI under a cost-sharing agreement with ASME ST-LLC.

Longitudinal seam-welded, high-temperature piping, given its susceptibility to premature failure with sometimes catastrophic consequences, continues to be of concern. In an effort to provide additional safeguards at the construction phase, the ASME Board on Pressure Technology Codes and Standards (BPTCS) formed a project team to address the concern. To develop a consistent set of Code requirements on long seam-welded piping construction, the project team identified specific needs relating to laboratory data, field experience data, and methods for structural evaluation that could be used in developing the safeguards for use in the Boiler and Pressure Vessel Code and the B31 Power Piping Codes. These needs have been defined as (a) weld strength reduction factors that can be considered inherent to the materials and methods of construction; (b) weld joint influence factors that capture specifics of the structure; and (c) guidance for application of the weld strength reduction factor and the weld joint influence factor in design rules. Consistent with these needs as identified in ASME ST-LLC's request for proposal, this document is presented in three separate parts (reports) as follows.

Part 1: Development and Application of Weld Strength Reduction Factors Guideline (Task 1b/3 project report)

This report ties the elements of Parts 2 and 3 into an application guideline. The guideline includes description of a framework for analyzing laboratory data and using the weld joint influence factor development methods. The Part 1 report provides examples of application to two weld/weldment databases for longitudinal seam welds, illustrating the usefulness of the methodology. The examples are for Grade 91 steel that is susceptible to weld heat-affected zone failure, and Grade 22 steel that has and continues to be used in long seam-welded piping construction. The results are compared with current Code rules, literature findings, and experience.

Part 2: Literature Review, Industry Approach, and Data Compilation in Support of WSRF Development (Task 1a project report)

This report includes a compilation of laboratory and experience data on weldments for select materials of common use and interest – carbon steel, low alloy CrMo steels, austenitic stainless steels, Alloy 800/800H, and Grade 91. A critical part of this extensive database development was collecting relevant information not available to the ASME Code committees when allowable stresses were set for some of these materials. Also given in this report is a summary of approaches that have been taken in establishing weld strength reduction factors worldwide.

Part 3: Development of Weld Joint Influence Factors (Task 2 project report)

The report describes an analysis tool to evaluate the creep rupture strength of a weldment relative to that of base metal, benchmarked against select cases of field experience and laboratory component testing. The methodology can be used for calculating weld joint influence factors for any practical combination of materials and weldment geometries in a relatively quick and computationally efficient manner, also allowing for use of relatively simple materials models readily available to designers.

This publication references the original project task reports that have been reproduced here in the three parts as identified above: Part 1-Tasks 1b and 3; Part 2-Task 1a; Part 3-Task 2.

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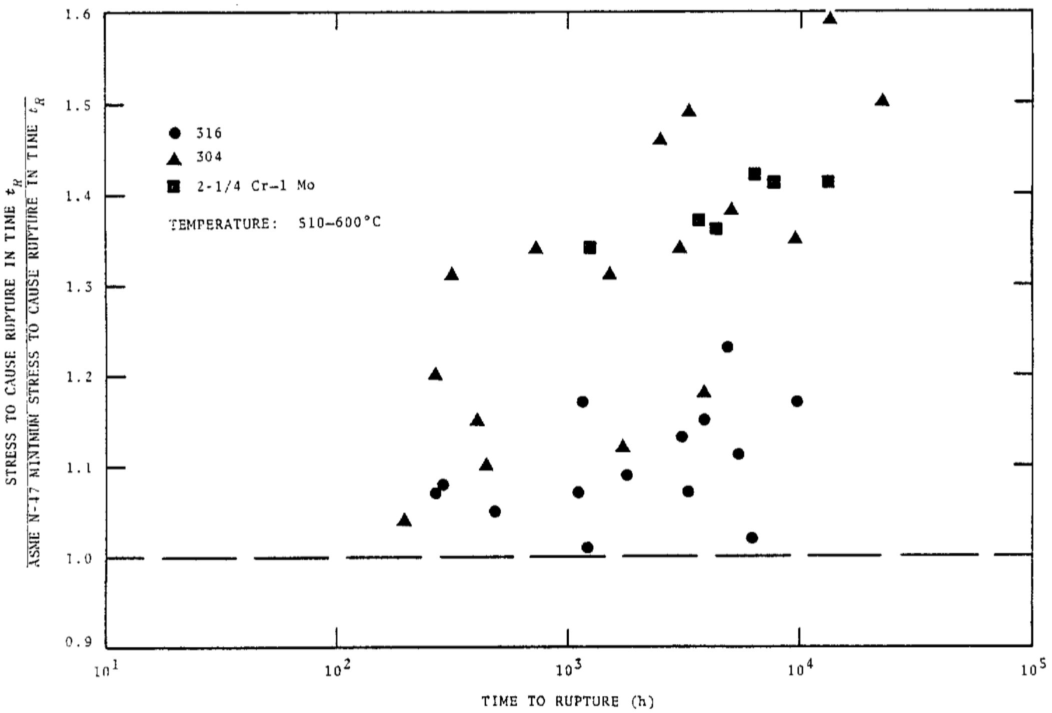
PART 1: DEVELOPMENT AND APPLICATION OF WELD STRENGTH REDUCTION FACTORS GUIDELINE

1 APPLICATION GUIDELINE

1.1 Overview

The purpose of the ASME-EPRI research project is to develop the methodology and data to help establish weld strength reduction factors (WSRF) for service in the creep regime for a wide range of materials with applicability to various sections of ASME Boiler & Pressure Vessel Codes. A review of how various codes address creep behavior of welded structures and pressure vessels in the Task 1a literature review [1] showed that no clear consensus exists between or even within various sections of codes around the world. The range of approaches include: no rules, requirements to follow 'good engineering practice,' simple factors on design irrespective of material, and factors on design which may depend on material, class/group of material, time, or combination of material and weld metal (based primarily on assessments of weld metal only data). ASME Section III-NH contains the most extensive set of rules for welded components based on design life, material and weld metal combination, and temperature. The origins of the strength factors applied in Section III-NH are primarily based, for stainless and nickel-based alloys, on the ratio of weld metal strength to base metal strength, the source for the chromium-molybdenum steels is not known, and the grade 91 values are biased on some cross-weld data with more recent data showing the assessment to be non-conservative at higher-temperatures and/or longer-times [1]. The applicability of these rules has been assessed for a few of the material-weld metal combinations by Corum [2] for a large body of structural 'feature' tests, and the results are provided in Figure 1. The figure shows that in all cases, the application of the Section III-NH rules to welds produced conservative lifetimes relative to measured life in the test, suggesting a material/material class grouping approach is appropriate for design purposes.

Figure 1: Summary of the Ratio of Stress to Cause Rupture to the Calculated Minimum Stress from ASME Section III-NH (formerly N-47) Rules as a Function of Rupture Time for Structural Feature Tests on 316, 304, and 2 1/4Cr-1Mo Showing All Ratios, Regardless Of Material and Rupture Time, Are Greater Than 1, i.e. the Calculated Stresses Are Conservative [2]



Most weld strength reduction factors (WSRFs) have been based on a relatively simple comparison of laboratory-measured material properties, but the application of these factors are to components or designs. How the weld affects the performance of the structure is critical to the success of any approach for developing and applying WSRFs. It should be also understood that the cross-weld creep-rupture test that has been employed for much of the recent laboratory testing around the world can be viewed as not only a material property test but a structural test as well. Therefore, specimen configuration can have an important impact on the test results. If cross-weld data are to be analyzed, the structural analysis used to evaluate the cross-weld data should ideally be the same as that to develop the WSRFs. Based on this discussion, it is clear that a modeling methodology/tool was necessary for this project.

In Task 2, a brief review of modeling method for creep of welded structures was provided [3]. Detailed finite element analysis (FEA) methods are routinely used for high-temperature creep assessment of structures. When applied to welded structures, the amount of input data is very high, often requiring material constitutive models for the various zones of the weldment such as: base metal, weld metal, coarse-grained heat-affected zones (HAZ), etc. Obtaining such data requires testing of materials heat-treated to simulate the zone processes or by specialized techniques. Therefore, very limited data exist for limited materials and test conditions. Considering the variability in material creep properties and welding processes, the suitability of broadly applying such data, which are not necessarily produced to recognized standards, is questionable. For cases involving life assessments of specific components, detailed FEA modeling with constitutive equations has been successfully employed. For design purposes, however, this type of FEA modeling is not easy to implement within current design codes, especially those based on design by rule approaches.