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Evaluation of Material Strength Data for Use in API Std 530

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WRC – The Welding Research Council, Inc. (WRC) brings together science and engineering specialists in developing the solutions to problems in welding and pressure vessel technology. They exchange knowledge, share perspectives, and execute R and D activities. As needed, the Council organizes and manages cooperative programs.

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FOREWORD – 3rd Edition, August 2020

This WRC Bulletin entitled "Evaluation of Material Strength Data for Use with API Std 530" is one of a series of Welding Research Council, Inc. (WRC) Bulletins intended to capture in detail the technical information that supports important and widely used international codes and standards such as those of ASME and API.

Data for the first edition of this bulletin was originally collected by MPC under an API contract. It was logical that MPC was selected for this study of properties applicable to high-temperature tubular materials. More than 50-years ago Dr. George V. Smith, acting under the auspices of MPC and its forerunner, the ASTM-ASME Joint Committee on the Effects of Temperature on the Properties of Materials, collected and evaluated much of the data that was used by API to support the design curves that would eventually appear in API Std 530. The Joint Committee and MPC later pioneered statistically rigorous computerized techniques for analyzing and extrapolating elevated time-dependent mechanical property data. The methods developed were applied to optimize Larson-Miller Parameter (LMP) stress-rupture constants for each material for use in the latest API Std 530. Optimization of LMP constants enhances the accuracy of property extrapolation for the purpose of remaining life assessment and creep damage as well as design.

The polynomial expressions provided for the LMP parameters and all other mechanical properties in this WRC Bulletin are intended to support computerized design and life assessment activities. For further details about tools for life assessment the reader is referred to API 579-1/ASME FFS-1 on Fitness-For-Service. Detailed presentations of solutions to the example problems in this Bulletin demonstrate implementation of the methods recommended.

The following updates and corrections have been made in this 3rd Edition.

- The Creep Rupture Design Factor, F_{CR}, has been introduced with the intent of allowing greater flexibility in the use of materials for design of fired heater tubes per API Std 530. The impact of this factor on the use of the 300-series "L" Grade stainless steels is emphasized. In this 3rd Edition, an F_{CR} value equal to 0.8 is recommended for the L-grade 300-series stainless steels (Types 304L, 316L, and 317L). Prior Editions of this bulletin stated a maximum use temperature of 1500°F for the L-grades, with a note that the maximum temperature for creep-governed designs should be limited to 1100°F. The intent of this note was to avoid reliance on the L-grade creep properties for the temperature range of 1100°F -1500°F, where very little rupture data for any of the L-grades exists. This was considered appropriate at the time since API Std 530 uses 100% of the minimum stress to produce rupture in the stated design life to determine allowable stress curves. However, in implementation of this, API Std. 530 stated that 1100°F was the maximum use temperature for the L-grades, precluding their use for fired heater applications above this temperature (API Std 530 7th Ed., Add. 1, 2019). This approach allows the use of L-grades up to 1500°F (where the material is already in service, in some instances), and to avoid potential non-conservatism and premature creep rupture. For some materials besides L-grade 300-series stainless steels, an F_{CR} value less than 1.0 is used, where appropriate. F_{CR} values can apply to an entire material's temperature range or to a subset of the range, where data are particularly sparse.

- LMP regressions as a function of stress have been revised to ensure that predicted behavior for materials satisfies physical constraints, specifically that the predicted rupture time always decreases for increasing stress (at constant temperature), even at the extremes of the stress ranges, outside of the typical practical design stress range for the materials. Background to the constraints imposed in this 3rd Edition is provided in WRC Bulletin 554. As a result of these constraints the CASE 2 LMP vs stress fits (quadratic polynomials) have been replaced with CASE 3 fits (cubic polynomials). Materials that have been revised are shown in yellow in Table 3.
- Two new materials have been added, which have recently become candidate materials for use in refinery fired heater applications (shown in blue):
  - Advanced 347AP Stainless Steel, UNS S34752, as documented in WRC Bulletin 582
  - Alloy 115 (10.5Cr-V) Creep Strength Enhanced Ferritic, UNS K91060, as documented in WRC Bulletin 576
- Maximum use temperature for Type 347LN (UNS S34751) has been increased to 1282°F, from 1100°F, to reflect additional data made available for this material since the 2nd Edition of this bulletin was published, as documented in WRC Bulletin 558, 2nd Edition.
- The yield strength trend curve for 800HT material have been revised to match typical material behavior for this alloy and to correct an error in the trends shown in the 2nd Edition of this bulletin.
- The yield strength and tensile strength curves for Type 316/316H Stainless steel were updated based on additional data collected at temperatures greater than 1400°F. The intent of the revised strength trends is to ensure physical behavior over the entire material use temperature range.
- Material property curves for grade 91 material have been updated based on an expanded dataset for this material. ASME recently executed a thorough reanalysis of grade 91 data using an expanded dataset for grade 91 material. This ASME dataset (ASME Record number 16-958) contained 2046 data points, of which 1279 were used for the analysis. As part of a separate ASME project, WRC, in conjunction with E^{2}G | The Equity Engineering Group, Inc. compiled a database of to the one considered by this Bulletin. ASME's reanalysis resulted in a lowering of the allowable stresses for all product forms of this material. Similarly, the average and minimum creep rupture curves presented in this 3rd edition are lowered relative to those properties presented in the 2nd Edition. Recently, a "Type 2" grade 91 designation has been added to the relevant ASTM/ASME Specifications, with tighter chemistry controls and reduced tramp element limits. WRC is currently developing guidance on the material properties (to be published in separate WRC bulletin[s]) for traditional, or "Type 1" (or typical) grade 91 as well as "Type 2" grade 91 components. As a key part of this work, WRC is examining the high temperature material property differences between materials with and without the new "Type 2" chemistry controls. This work is in progress and will be incorporated into future editions of this Bulletin.

Dr. Martin Prager
Executive Director
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FOREWORD – 2nd Edition, October 2015

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The data for the project resulting in this publication were gathered and analyzed by MPC under an API contract. It was logical that MPC was selected for this study of properties applicable to high-temperature tubular materials produced by modern steel making practices for petroleum refinery heaters designed to API Std 530. More than 50-years ago Dr. George V. Smith acting under the auspices of MPC and its forerunner, the ASTM-ASME Joint Committee on the Effects of Temperature on the Properties of Materials, collected and evaluated much of the data that was used by API to support the design curves that would appear in API Std 530. The Joint Committee and MPC later pioneered in development of statistically rigorous computerized techniques for analyzing and extrapolating elevated time-dependent mechanical property data. The methods developed were applied to optimize Larson-Miller Parameter (LMP) stress-rupture constants for each material as desired by API for use in the latest API Std 530. Optimization of LMP constants enhances the accuracy of property extrapolation for the purpose of remaining life assessment and creep damage as well as design.

The polynomial expressions provided for the LMP parameters and all other mechanical properties in this WRC Bulletin are intended to support computerized design and life assessment activities. For further details about tools for life assessment the reader is referred to API/ASME FFS-1 on Fitness-For-Service. Detailed presentations of solutions to the example problems in this Bulletin demonstrate implementation of the methods recommended.

The following updates and corrections to errata have been made in this 2nd Edition.

- Data are provided for a material designated as UNS S34751 or 347LN. A proprietary version of UNS S34751 was developed for refinery and chemical plant applications where resistance to polythionic acid is needed in conjunction with creep strength superior to that of conventional low carbon grades of stainless steels. However, it was reported that the creep and rupture properties of the proprietary grade are also generally applicable to UNS S34751 and on that basis the alloy's properties are included herein. However, where enhanced resistance to polythionic acid is required the source, processing and suitability of the material specified should be verified.

- A new data analysis, including additional data, has been performed on 9Cr-1Mo and the coefficients have been updated. The new correlations provide longer life estimates for lower temperatures. Note that these new coefficients have not yet been accepted by API for use in API Std 530. However, they have been accepted for use in API 579-1/ASME FFS-1.

- Please note that the Larson-Miller Parameter coefficients for Alloy 800H and Alloy 800HT were not printed correctly in the 1st Edition. Corrections have been made in this volume. The other information provided for these alloys was correct in the 1st Edition.

- The ”Proposed” curves and equations found in the original version of WRC Bulletin 541 have now been accepted by API for use in API Std 530 and have therefore been relabeled in each figure in the document as “New “ curves. The “Existing” curves have been renamed “Prior”. They present data from API Std 530, 6th Edition, September 2008.

- An explanation has been provided to address the calculation of the rupture exponent using average rupture properties rather than minimum rupture properties.

- The plots of all data and related property curves for all materials are now presented in SI units as well as USC units for the convenience of those using metric units.

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The assistance of Tom Dirham and Tiffany Shaughnessy of The Equity Engineering Group, Inc. in carefully documenting and checking this document is gratefully acknowledged.

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