STP-PT-049

INVESTIGATION OF TEMPERATURE DERATING FACTORS FOR HIGH-STRENGTH LINE PIPE

ASME STANDARDS
TECHNOLOGY, LLC

STP-PT-049

INVESTIGATION OF TEMPERATURE DERATING FACTORS FOR HIGH-STRENGTH LINE PIPE

Prepared by:

Donovan A. Richie and M. J. Rosenfeld, PE
Kiefner and Associates, Inc.

ASME STANDARDS TECHNOLOGY, LLC

Date of Issuance: September 28, 2012

This report was prepared as an account of work sponsored by ASME Pressure Technologies Codes and Standards and the ASME Standards Technology, LLC (ASME ST-LLC).

Neither ASME, ASME ST-LLC, the authors, nor others involved in the preparation or review of this report, nor any of their respective employees, members or persons acting on their behalf, make 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 upon privately owned rights.

Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer or otherwise does not necessarily constitute or imply its endorsement, recommendation or favoring by ASME ST-LLC or others involved in the preparation or review of this report, or any agency thereof. The views and opinions of the authors, contributors and reviewers of the report expressed herein do not necessarily reflect those of ASME ST-LLC or others involved in the preparation or review of this report, or any agency thereof.

ASME ST-LLC does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a publication against liability for infringement of any applicable Letters Patent, nor assumes any such liability. Users of a publication are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this publication.

ASME is the registered trademark of the American Society of Mechanical Engineers.

ASME Standards Technology, LLC
Three Park Avenue, New York, NY 10016-5990

ISBN No. 978-0-7918-3426-8

TABLE OF CONTENTS

Foreword v

Executive Summary vi

1 BACKGROUND, APPROACH, AND FINDINGS 1
  1.1 Introduction 1
  1.2 Background 2
  1.3 Technical Approach 3
  1.4 Findings 3

2 A REVIEW OF THE AVAILABLE DATA 5
  2.1 Introduction 5
  2.2 Study by Benfell, Morris and Barsanti 5
  2.3 Study by Bredenbruch, Gehrmann, Schmidt, and Träger 8
  2.4 Study by Gray 12
  2.5 Other pipeline design standards 14
    2.5.1 CSA Z662 14
    2.5.2 AS 2885 15
    2.5.3 ISO 13623 15
    2.5.4 DNV-OS-F101 15

3 AN OVERVIEW OF THE STRENGTHENING MECHANISMS AND ROLLING PROCESSES OF HSLA STEELS FOR MODERN LINE PIPE 17
  3.1 Introduction 17
  3.2 Strengthening Mechanisms 17
  3.3 Rolling Processes 17

4 AN ASSESSMENT OF THE AVAILABLE DATA 19
  4.1 Introduction 19
  4.2 Variables Related to Pipe Manufacturing 19
  4.3 Variables Related to the Tensile Test Procedure 23

5 IMPLICATIONS OF THE AVAILABLE DATA FOR ASME CODES 25
  5.1 Other ASME codes affected 25
  5.2 Possible B31.8 Code Committee Response 26

6 RECOMMENDATIONS FOR ADDITIONAL TENSILE TESTING 28

References 30

Acknowledgements 31

Abbreviations, Acronyms and Variables 32

LIST OF TABLES

Table 1—Effect of Elevated Temperature on the Microstructure in X60 Line Pipe 8

Table 2—Plate Rolling Processes and Microstructures in X52-X120 Line Pipe 20

Table 3—Pipe Forming and Seam Welding Methods for X52-X120 Line Pipe 20

Table 4—Alloying Approaches and Microstructures in X52-X120 Line Pipe....................................21
Table 5—Variables Related to Pipe Manufacturing in Each Study..22
Table 6—Variables Related to the Tensile Test Procedures in Each Study 24
Table 7—Pipe Manufacturing Variables to Include in a Future Test Program 28
Table 8—Tensile Test Procedures for a Future Test Program...28

LIST OF FIGURES

Figure 1—Transverse Yield Strength in X52-X70 Line Pipe as a Function of Temperature..................1
Figure 2—Longitudinal Yield Strength in X60-X70 Line Pipe Steel..6
Figure 3—Derating Factors for Transverse Yield Strength in X52-X70 Line Pipe Steel 7
Figure 4—Derating Factors for Longitudinal Yield Strength of X60-X70 Line Pipe Steels.................7
Figure 5—Longitudinal Yield Strength of X70 Line Pipe...9
Figure 6—Longitudinal Yield Strength of X60 Line Pipe...9
Figure 7—Longitudinal Yield Strength of X65 Line Pipe...10
Figure 8—Derating Factors for Longitudinal Yield Strength of X70 Line Pipe 11
Figure 9—Derating Factors for Longitudinal Yield Strength of X60 Line Pipe 11
Figure 10—Derating Factors for Longitudinal Yield Strength of X65 Line Pipe 12
Figure 11—Yield Strength of ASTM A841, Grade F Plate Steel...13
Figure 12—Derating factors of ASTM A841, Grade F Plate Steel 14

FOREWORD

This report reviews the ASME derating factors, identifies the range of line pipe steel grades that may be affected and the potential impacts to ASME pipeline and piping design standards, and makes recommendations for further study or experimental investigation as necessary.

Established in 1880, the American Society of Mechanical Engineers (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.

The ASME Standards Technology, LLC (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 current ASME B31.8 code gives no derating of line pipe steels for temperatures below 250°F. For pipeline steels in the Grade X60-X70 range, data show that a reduction of the yield strength may be exhibited at temperatures below 250°F in some cases. Some pipeline design standards developed for other countries (e.g., Norway, Netherlands, and Australia) already apply derating factors at temperatures well below 250°F. Thus, the ASME derating factors appeared to be in need of review.

This report reviews the available information, identifies the range of line pipe steel grades that may be affected, identifies the potential impacts to ASME pipeline and piping design standards, and makes recommendations for further study or experimental investigation as necessary.

A review of data suggests that (a) there is a high likelihood of some decrease in the actual yield strength of high-strength low-alloy grades of line pipe in current usage at temperatures between 75°F and 250°F; (b) against a limited set of data the current Code derating factors appear to be adequate, provided room temperature yield strength is at least 5% above specified minimum levels; (c) there are insufficient data to recommend a change in the Code at this time; (d) there are insufficient data to determine whether the present Code derating factor is adequate for all variables of alloy design and steel processing used with current grades of high strength pipe; and (e) further investigation by testing a broader sample base is needed to adequately address these issues.

1 BACKGROUND, APPROACH, AND FINDINGS

1.1 Introduction

The current ASME B31.8 standard (“the Code”) requires no derating of line pipe steels for temperatures below 250°F. For pipeline steels in the Grade X60-X70 range, data show that a reduction of the yield strength may be exhibited at temperatures below 250 °F in some cases. For example, Figure 1 presents a reduction in measured yield strength with increasing temperature above 50°C (122°F) in high strength line pipe observed by one manufacturer. Some pipeline design standards developed for other countries (e.g., Norway, Netherlands, and Australia) already apply derating factors at temperatures well below 250°F. Thus, the ASME derating factors are in need of review.

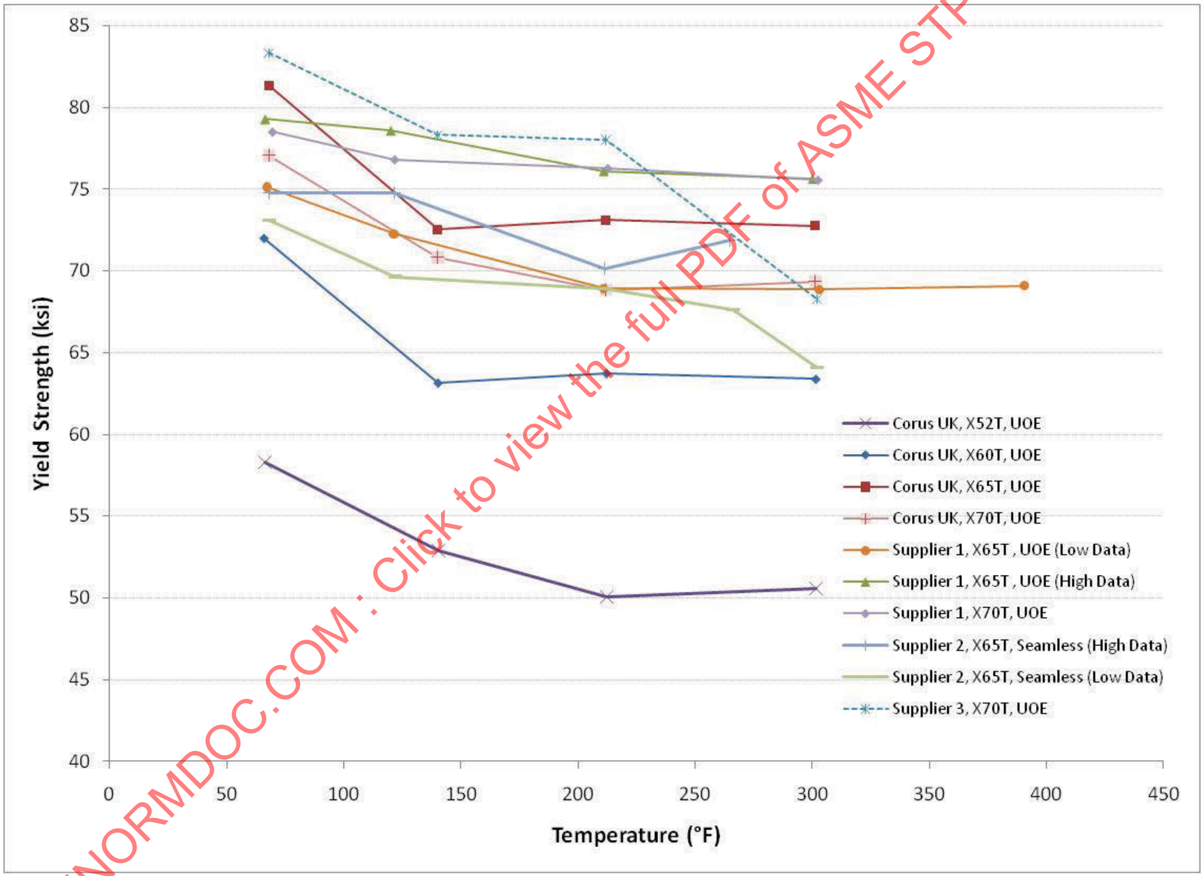

Figure 1—Transverse Yield Strength in X52-X70 Line Pipe as a Function of Temperature [1]

The goal of this project is to develop an understanding of available information, identify the range of line pipe steel grades that may be affected, identify the potential impacts to ASME pipeline and piping design standards, and make recommendations for further study or experimental investigation as necessary.

1.2 Background

Design of pipe for internal pressure in accordance with ASME B31.8 is based on SMYS via the Steel Pipe Design Formula given in Paragraph 841.1.1 as:

$$P = \frac{2St}{D}FET$$

Equation 1—Steel Pipe Design Formula

The variables are as defined under 'Abbreviations, Acronyms and Variables' at the end of this report. Of concern is the temperature derating factor, T, which is specified in Table 841.1.8-1. Factor T has a value of 1.000 for temperatures of 250 °F or less, and decreases linearly to a value of 0.867 as temperature increases to 450 °F as listed below:

Temperature, °F (°C)	Factor T
250 (121) or less	1.000
300 (149)	0.967
350 (177)	0.933
400 (204)	0.900
450 (232)	0.867

The temperatures in °C units are rounded by ASME to the nearest whole degree. Interpolation of the derating factor for intermediate temperatures is permitted.

The factor T first appeared in the pressure design formula in the 1955 Edition of ASA B31.1.8. The values for T were the same as that which appears in the Code today. The T factor has its origins in the first edition of B31.8 in 1952 as a separate book publication of Section 8 of the ASA B31.1 *Code for Pressure Piping*. (Prior to this edition, different services e.g. power piping, refineries, oil pipelines, and gas pipelines were covered by their own chapters within a B31.1 published as a single volume.) The T factor was not in the 1952 pressure design formula however the allowable stresses for design were listed for all pipe grades in a table contained in section 827. The allowable stress for temperatures up to 100° F was 60% of the SMYS at room temperature, and at a temperature of 450 °F was 86.7% of the allowable stress for temperatures below 100 °F. A footnote instructed the user to linearly interpolate to determine the allowable stress at service temperatures between 100 °F and 450 °F. It is noted that in going from the 1952 to the 1955 editions of B31.8, the room temperature allowable stress was extended from 100 °F to 250 °F.

These derating factors were almost certainly derived from tensile tests at elevated temperatures that had been performed on carbon steel pipe samples to support the allowable stresses specified in other service chapters of the ASA B31.1 Code (e.g. for refineries and power plants). The allowable stresses for various grades of carbon steel pipe in the 1942 ASA B31.1 (in which all services appear together in one volume) for power plant piping shows that the room temperature design stress was maintained up to a temperature of 150 °F, but at a temperature of 450 °F the allowable design stress was between 85% and 88% of the allowable stress for 150 °F. This brackets the 86.7% factor adopted by B31.8. Also, the allowable stresses at 250 °F were only 4% to 5% below the allowable stress for 150 °F. This may have provided the justification for extending the room temperature rating all the way to 250 °F in B31.8. The listed grades of carbon steel pipe were typically A106, A53, or API 5L Grades A, B, and C, or similar, having yield strengths between 30 ksi and 45 ksi. It is not uncommon for these grades of material to exhibit room temperature yield strength considerably greater than specified minimum properties, even in pipe contemporary for that time. A 4% to 5% decrease in actual strength at a temperature of 250 °F relative to that at 100 °F or 150 °F might have been considered tolerable.

The present derating factor appears to have its origins in an early Code era, and is almost certainly associated with the observed characteristics of hot-finished plain carbon steel or C-Mn steel pipe of low to intermediate strength. These early pipe varieties are sufficiently different from modern HSLA pipe in terms of strengthening mechanisms that there can be some doubt that factors derived from them are applicable to the more modern grades.

1.3 Technical Approach

The project was divided into three phases. Phase 1 entailed collecting and evaluating available mechanical properties data for line pipe steel grades X60 through X100 at temperatures ranging from 100 °F to 500 °F. This range of pipe grades covers most modern line pipe steels that are in use today. We have excluded X52 and lower-strength grades for two reasons. One is that in order to make the low to moderate strength grades of pipe including X52, it is unnecessary to resort to the microalloy additions and control-rolled thermomechanical processing of the cast slab that is typically used to manufacture grades X60 and greater. Secondly, X42 and X52 pipe often is manufactured concurrently with materials identified as Grade B on which the temperature derating factors are thought to be based and for which the current factors are thought to be appropriate.

It was recommended that the temperature range for investigation be extended to 500 °F, which is beyond the maximum temperature of 450 °F within the scope of B31.8. This was intended to encompass temperatures at which fusion-bonded epoxy (FBE) coatings are applied to line pipe. Mechanical properties may (or may not) change after exposure to the temperatures the pipe experiences when FBE coatings are applied, as a result of strain aging.

Phase 2 consisted of proposing a testing plan that would generate the “missing” data not found during Phase 1. In the future, ASME may decide to solicit proposals from contractors to implement the proposed testing plan.

In Phase 3 portions of the ASME B31.8 code that could be affected by changes to the derating factors were identified. In addition, the extent to which changing the derating factors could affect other ASME piping standards, namely B31.4, B31.12, and B31.3, was described. If sufficient data had been found in Phase 1, tentative recommendations would have been made at the end of Phase 3 as to whether, and how, ASME should change its derating factors. However, as will be discussed, there are insufficient data available at this time to make recommendations for revisions.

1.4 Findings

In an earlier Code era, pipe was primarily manufactured from plain carbon steel or C-Mn steel. The means to achieve the moderate levels of specified minimum strength were not highly varied because, for the most part, the steel was processed above the austenite transformation temperature. The effect of elevated temperatures on strength was typical across many common grades.

High-strength low-alloy steel pipe is not so simple. Line pipe grades are recognized in the Code and in the primary pipe product specification, API 5L, by specified minimum yield strength (SMYS) alone. But more than one alloy design and skelp rolling process exists for producing plate or coil used to manufacture pipe meeting the specified properties. These different processes produce differing microstructures with associated strengthening mechanisms that could exhibit susceptibilities to strength reduction with temperatures that differ from each other and from the behavior of plain or C-Mn steels that are the basis for present Code temperature derating factors.

The findings of this study can be summarized as follows:

a) there is a high likelihood of some decrease in the actual yield strength of high-strength low-alloy grades of line pipe in current usage at temperatures between 75 °F and 250 °F;

b) when compared to a limited set of data, the current Code derating factors appear to be adequate, provided room temperature yield strength is at least 5% above specified minimum levels;

c) there are insufficient data to recommend a change in the Code at this time;

d) there are insufficient data to determine whether the present Code derating factor is adequate for all variables of alloy design and steel processing used with current grades of high strength pipe; and

e) further investigation by testing a broader sample base is recommended.

2 A REVIEW OF THE AVAILABLE DATA

2.1 Introduction

An extensive search through the technical literature yielded only three published studies dealing with the yield strength of line pipe steels at elevated temperatures.[1] The data from these studies are summarized below.

2.2 Study by Benfell, Morris and Barsanti [1]

Benfell et al measured yield strengths of UOE and seamless pipe covering grades X52 to X70 at test temperatures from 68 °F to 302 °F. They performed tensile tests on pipe from Corus UK and compared their results to the tensile data from four unnamed European manufacturers of line pipe.

As shown in Figure 1, the transverse yield strength of grades X52-X6 seamless and UOE pipe tended to decrease sharply as the temperature increased from room temperature to 140 °F, and then leveled out above 212 °F. In contrast, the yield strength of Supplier 3's grade X70 material continually decreased with increasing temperature; the authors did not offer a reason for this. The figure also shows that, except for Supplier 2's X65 material, the yield strength was never less than SMYS over the tested temperature range.

The same study included the temperature dependence of longitudinal yield strengths in X65 and X75 UOE pipes from two manufacturers. These data are shown in Figure 2 below. The figure illustrates three important points. First, the longitudinal yield strength is much less than the transverse yield strength. Second, the X70 pipe exhibited a peak longitudinal yield strength at an intermediate test temperature; this was not observed in any other pipe included in the study. Third, at temperatures above 212 °F, the longitudinal yield strengths of both grades approached nearly constant values. The latter trend is similar to what was observed for transverse yield strength.

---

[1] A study entitled "Characterization of Burst for Line-grade Steel" was commissioned in 1996 by the Pipeline Research Council, Inc. under contract PR-106-9629. An abstract reported that samples of seamless duplex alloy pipe and X52 line pipe were burst tested at temperatures ranging from 75 F to 425 F to determine the effects of elevated operating temperatures. The work was never published and was unavailable for this review.

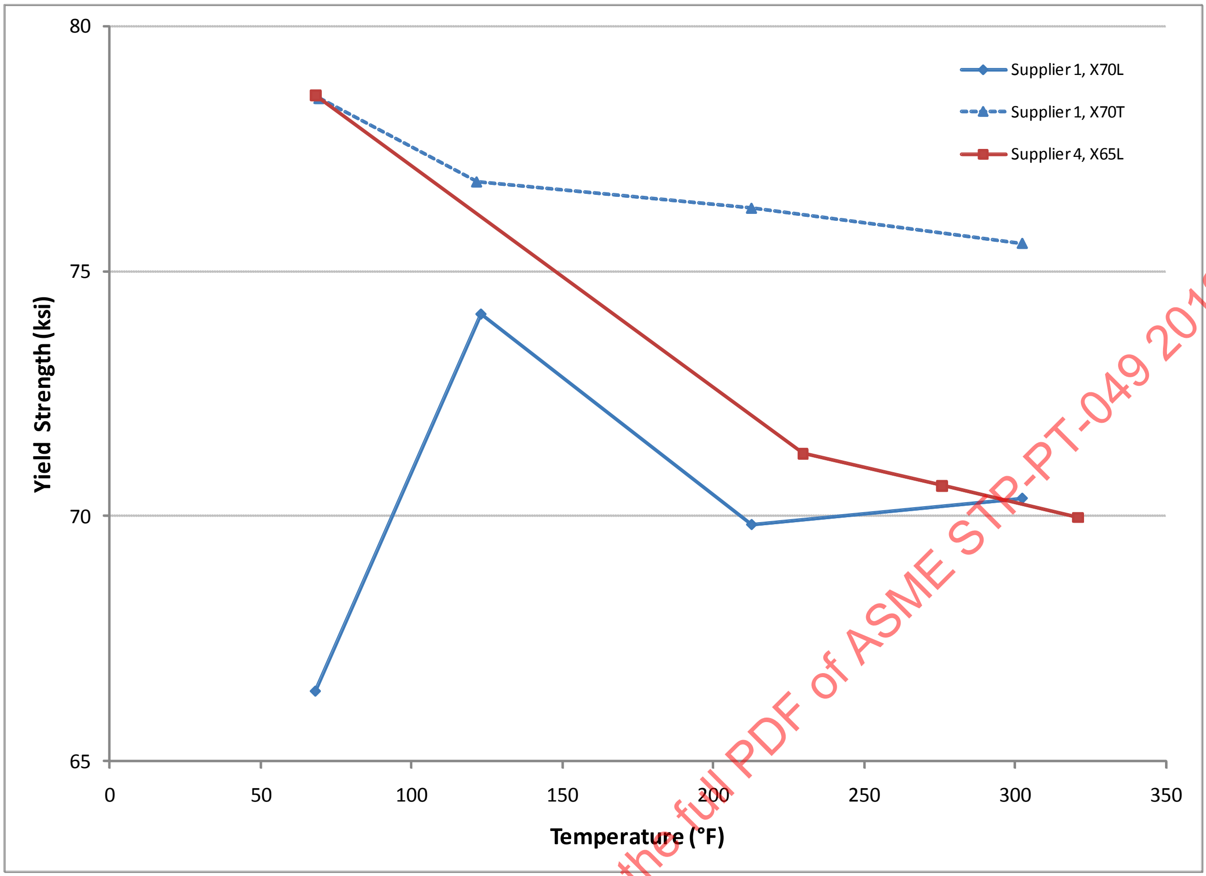

Figure 2—Longitudinal Yield Strength in X60-X70 Line Pipe Steel [1]

The yield strength data, transverse and longitudinal, from Benfell et al were converted into actual temperature derating factors, and then compared to the derating factors from ASME B31.8. In general, the transverse derating factors, shown in Figure 3 below, followed the same decreasing trend with increasing temperature as was observed in the yield strength data. The transverse derating factors were, in general, greater than the B31.8 derating factors throughout the temperature range studied. There was one exception to this trend: at 212 °F, the transverse derating factor of one of the grade X70 pipes was less than the B31.8 curve but was greater than the B31.8 curve at all other test temperatures. Across the entire range of test temperatures, the longitudinal derating factors of the X65 material were greater than the B31.8 curve (see Figure 4). However, the longitudinal derating factors of the X70 material is less than the B31.8 curve at room temperature and 212 °F, but it is greater than the B31.8 curve at all other test temperatures.

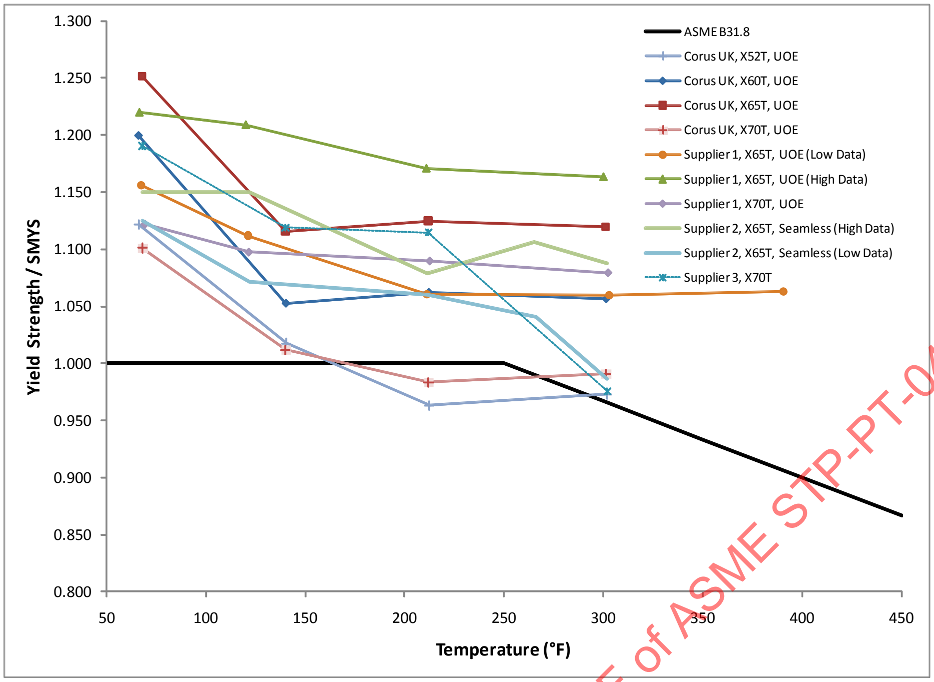

Figure 3—Derating Factors for Transverse Yield Strength in X52-X70 Line Pipe Steel [1]

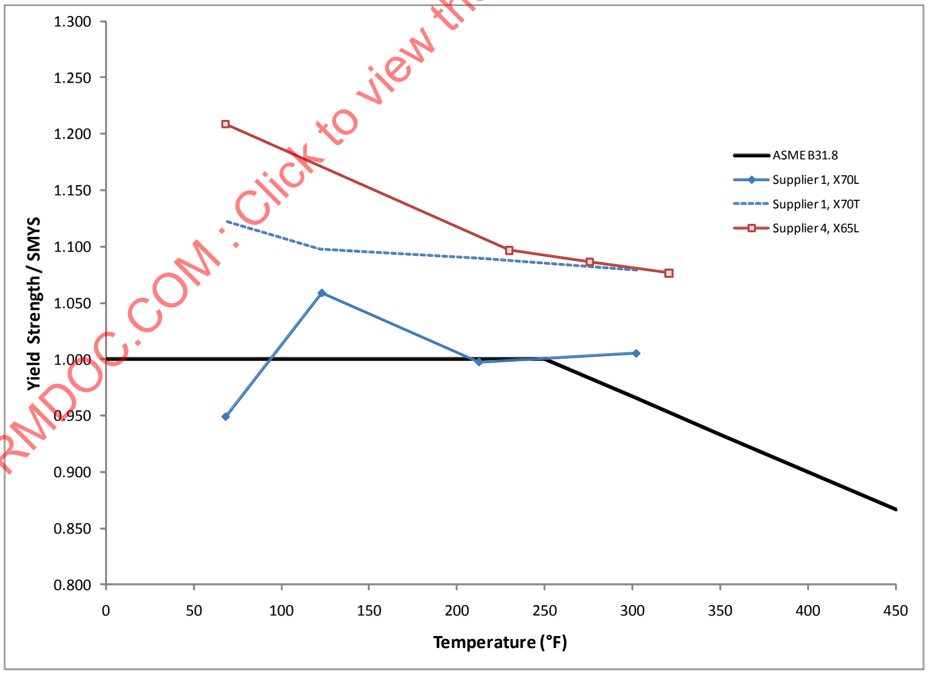

Figure 4—Derating Factors for Longitudinal Yield Strength of X60-X70 Line Pipe Steels

All of the grades included in the study by Benfell et al had ferrite-pearlite microstructures. The effect of elevated temperature on this microstructure was examined in tensile specimens from one of the X60 pipes. Ferrite grain size and volume fractions of ferrite and pearlite were measured in transverse metallographic sections, which were prepared after the elevated-temperature tensile tests. In addition, one sample was held at 302° F for 10^3 hours and then subjected to a tensile test at the same temperature. The results of the short- and long-term tensile tests are shown in Table 1.

Table 1—Effect of Elevated Temperature on the Microstructure in X60 Line Pipe*

	Grain Size (μm)		% Ferrite	% Pearlite	
	Mean	Std. Dev.	Mean	Mean	Std. Dev.
Room Temperature	5.1	0.4	84.5	15.5	2.35
140 °F	5.7	0.4	86.0	14.0	2.00
212 °F	6.6	0.4	84.8	15.2	1.72
302 °F	5.5	0.2	85.6	14.3	1.86
302 °F (after 1000 h at 302 °F)	6.0	0.3	85.0	15.0	2.10

*TMCP/UOE pipe manufactured by Corus UK. The data in this table are taken from Reference [1].

Because the average ferrite grain size remained constant with increasing temperature and the standard deviation remained consistently small, ferrite grain coarsening did not occur. Since the relative amounts of ferrite and pearlite were unaffected by increasing temperature, no appreciable amount of eutectoid decomposition took place even after prolonged exposure. In other words, the lack of visible changes in the microstructure of this steel indicates that the loss in yield strength at 150 °F was due to changes in strengthening mechanisms that are not resolvable by optical microscopy. Some possible candidates are: polygonization, which reduces dislocation density inside subgrains; dissolution or coarsening of precipitates, neither of which are likely at this relatively low temperature; or decreased Peierls-Nabarro stress, the stress necessary to move a dislocation within a plane of atoms.

2.3 Study by Bredenbruch, Gehrmann, Schmidt, and Träger [2]

Bredenbruch et al measured the longitudinal yield strength of seamless line pipe steels in grades X60, X65 and X70 at temperatures ranging from room temperature to 302 °F. Details about the pipe processing route and tensile test procedure are summarized in Section 4.2 and Section 4.3 respectively.

The temperature-dependence of the longitudinal yield strengths in all three steels are summarized in Figures 5 through 7 below. In each figure the solid curve corresponds to the average yield strength and the dotted curves above and below it correspond to the maximum and minimum yield strengths respectively. The specified minimum yield strength is indicated by the horizontal dashed line in each figure. The authors of this study did not report how many data points were represented by each average value.

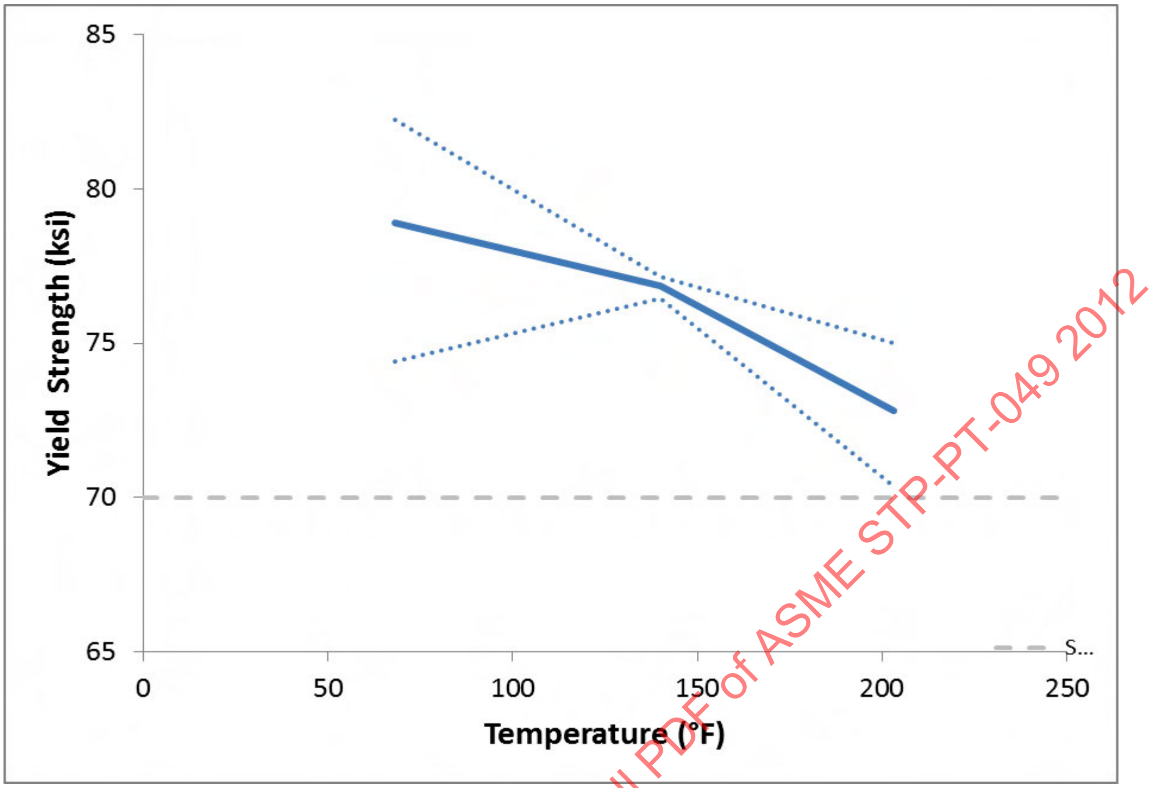

Figure 5—Longitudinal Yield Strength of X70 Line Pipe [2]

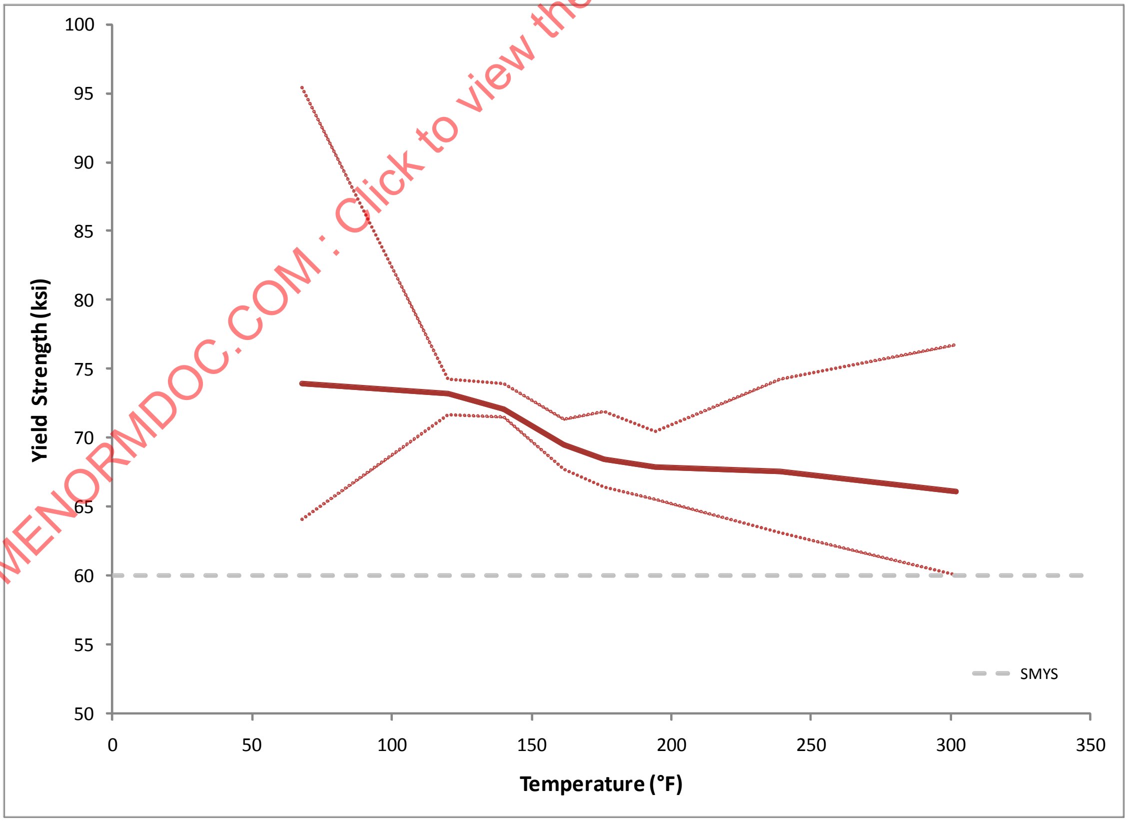

Figure 6—Longitudinal Yield Strength of X60 Line Pipe [2]

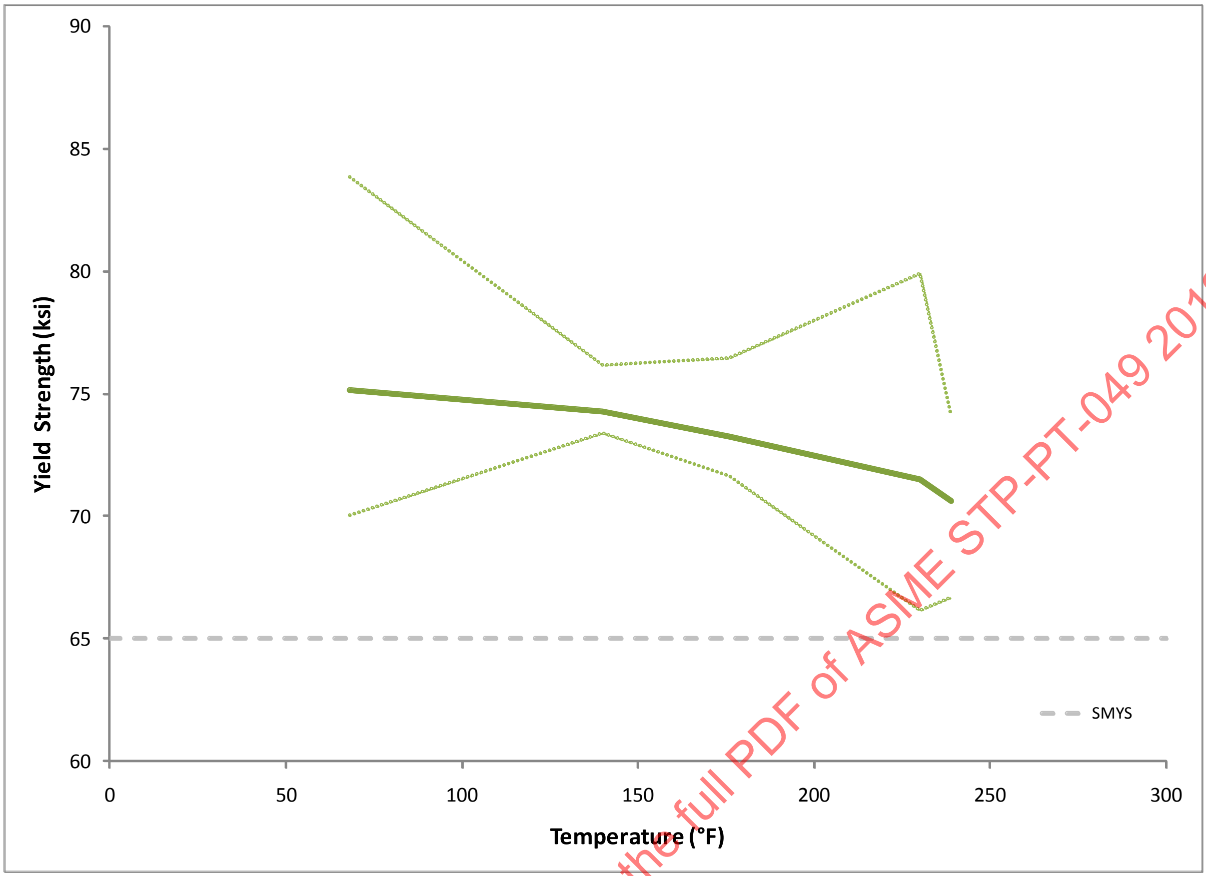

Figure 7—Longitudinal Yield Strength of X65 Line Pipe [2]

In general, the yield strengths of Steels 1 and 2 continually decreased with increasing temperatures up to the maximum test temperature of 250 °F. The yield strength of Steel 3, which was tested up to a maximum temperature of 302 °F, continually decreased until a test temperature of about 200 °F was reached and then leveled out at greater temperature. Thus the yield strength data for Steel 3 duplicated the trend that was observed in the Benfell study. If the temperature range for Steels 1 and 2 were extended to 302 °F, then perhaps the yield strengths of these steels would exhibit the same trend. Despite the wide scatter in Figures 5 through 7, the lowest yield strength at each temperature never dropped below the specified minimum yield strength.

Derating factors were computed from the yield strength data in the Bredenbruch study and were compared to the derating factors from ASME B31.8. This is shown graphically in Figures 8 through 10 below. The derating factors mirror the trends observed in the yield strength data described previously. Moreover, although the scatter in the data is wide, the actual derating factors are not less than the B31.8 factors at any of the test temperatures.

Additionally, Bredenbruch et al claimed that the strain rate during elevated temperature tests had virtually no effect on the yield strengths of Steels 2 and 3 in the temperature range 77-302 °F. The authors performed two series of tensile tests for each steel. Each series included a separate tensile test at room temperature and at every 22.5 °F between 77 °F and 302 °F. The strain rate of the tensile test was faster in one series than in the other, but the authors did not report the magnitudes of the strain rates or the difference between them. At each test temperature, the yield strengths measured at both strain rates was virtually the same.

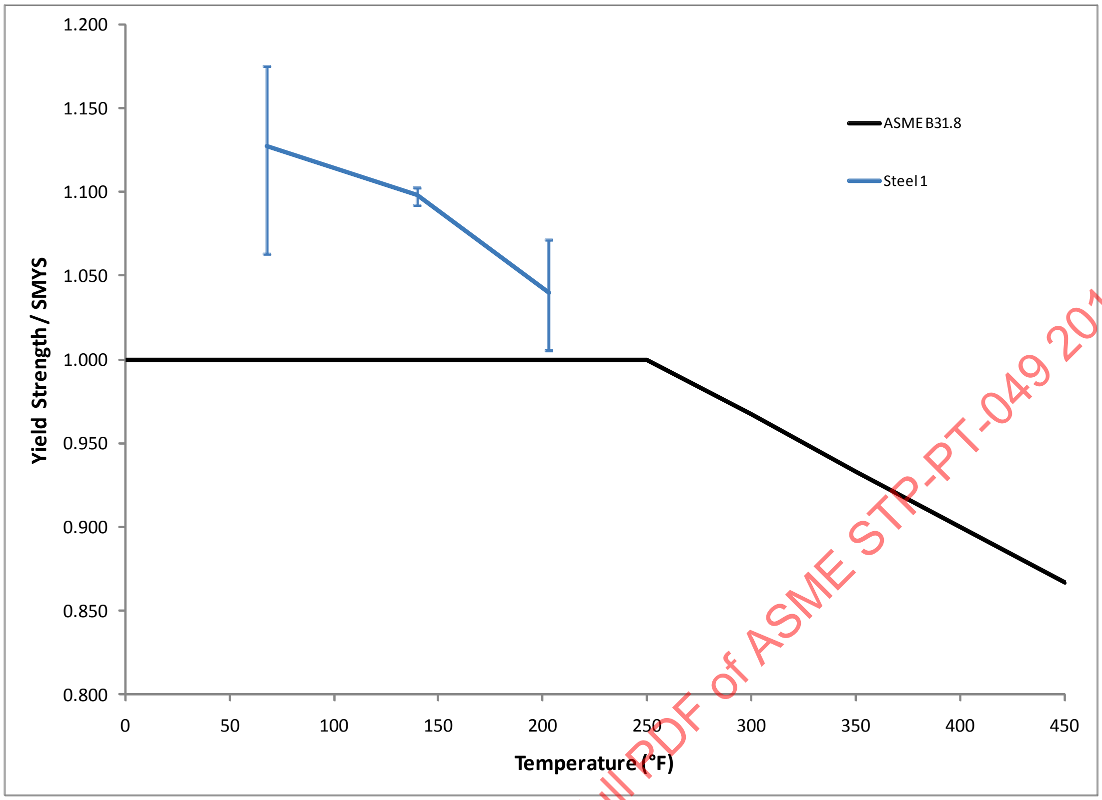

Figure 8—Derating Factors for Longitudinal Yield Strength of X70 Line Pipe [2]

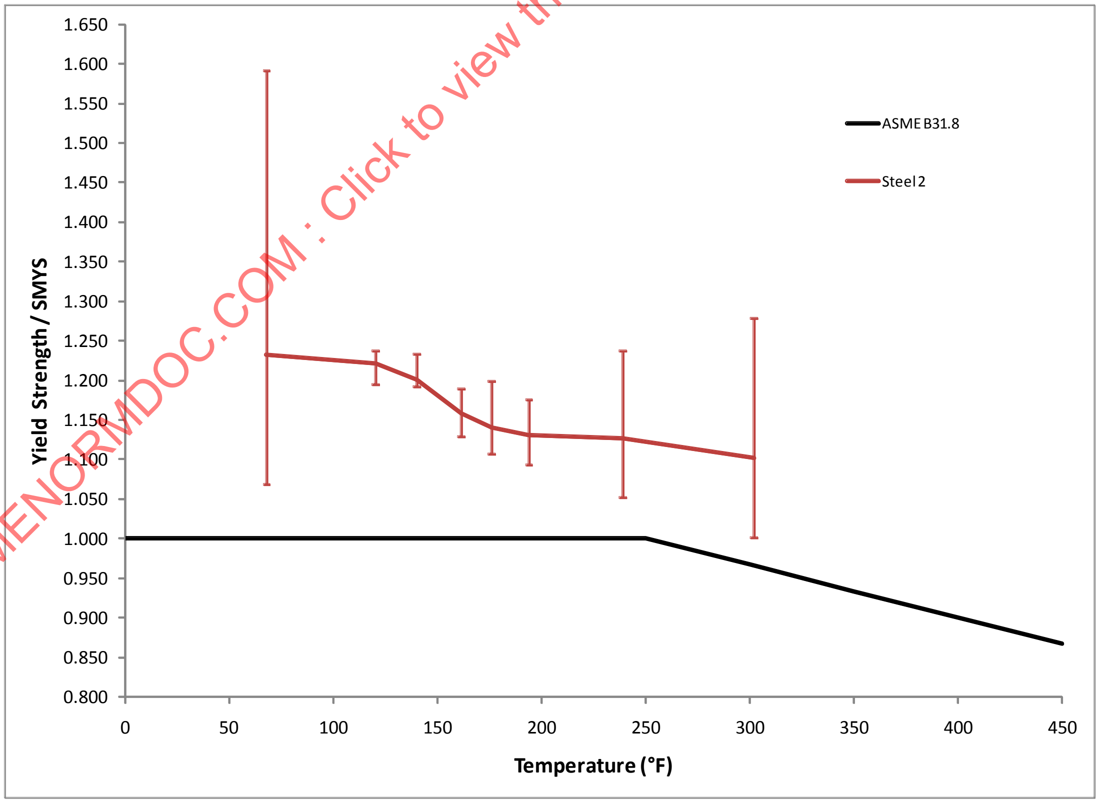

Figure 9—Derating Factors for Longitudinal Yield Strength of X60 Line Pipe [2]

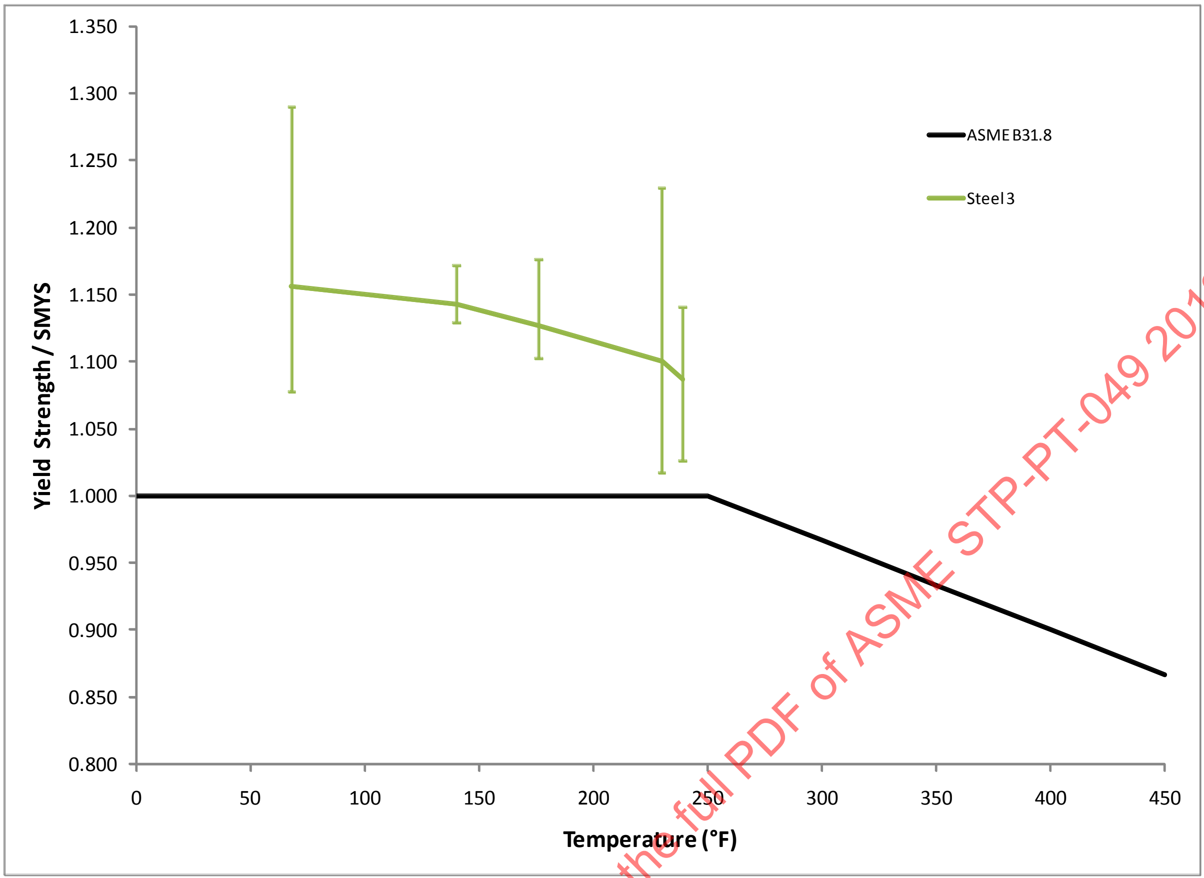

Figure 10—Derating Factors for Longitudinal Yield Strength of X65 Line Pipe [2]

2.4 Study by Gray [3]

Gray et al measured the yield strength of plate steel at temperatures from ambient to 800 °F. The plate was ASTM A841, Grade F steel. Plates having two thicknesses, 0.827 inch and 1.181 inch, were produced corresponding to strength Classes 6 and 7 in the standard. The standard specified a minimum yield strength of 70 ksi for Class 6 plate and 75 ksi for Class 7 plate. The pipes that were eventually cold-formed from the plates met the strength requirements for X70 and "X75" line pipe respectively [4]. (X75 is not a standard grade recognized by API 5L, though there is precedent of intermediate grades within API 5L by agreement between manufacturer and purchaser.) However, elevated-temperature tensile tests were conducted on specimens removed from the plates rather than the pipes.

The plates were rolled using a thermo-mechanically controlled processing (TMCP) rolling and cooling schedule [4]. Steel from five different "heats," or batches of steel produced at different times, was used to make each class of plate. Details about the initial rolling schedule were described as a "standard X70/X75 procedure." The different stages of the subsequent TMCP process consisted in reheating the plates to 2282 °F, further reducing their thicknesses, then maintaining them below 1670 °F during a 69% reduction. The final rolling temperature was 1472 °F, after which the plates were water-cooled to the ambient temperature at a rate of 10 °C/s.

The resulting microstructures in the steel plates consisted of ferrite and acicular ferrite [4]. The primary strengthening mechanisms were grain refinement, dislocation substructure, and precipitation strengthening by niobium carbides (NbC) and vanadium carbides (VC) [4].

The results of the tensile tests conducted at elevated temperatures are shown in Figure 11 below. The yield strength of both plates tends to decrease with increasing temperature across the entire temperature range. At each test temperature, from room temperature to about 366 °F, about half of the yield strengths measured for the Class 6 plate was less than the specified minimum yield strength. At the rest of the test temperatures (i.e., ~470-800 °F), the yield strength of the Class 6 plate was at or below the specified minimum. In most cases the yield strengths for the Class 7 plate were greater than the specified minimum yield strength although some data points were below the specified minimum at specific test temperatures.

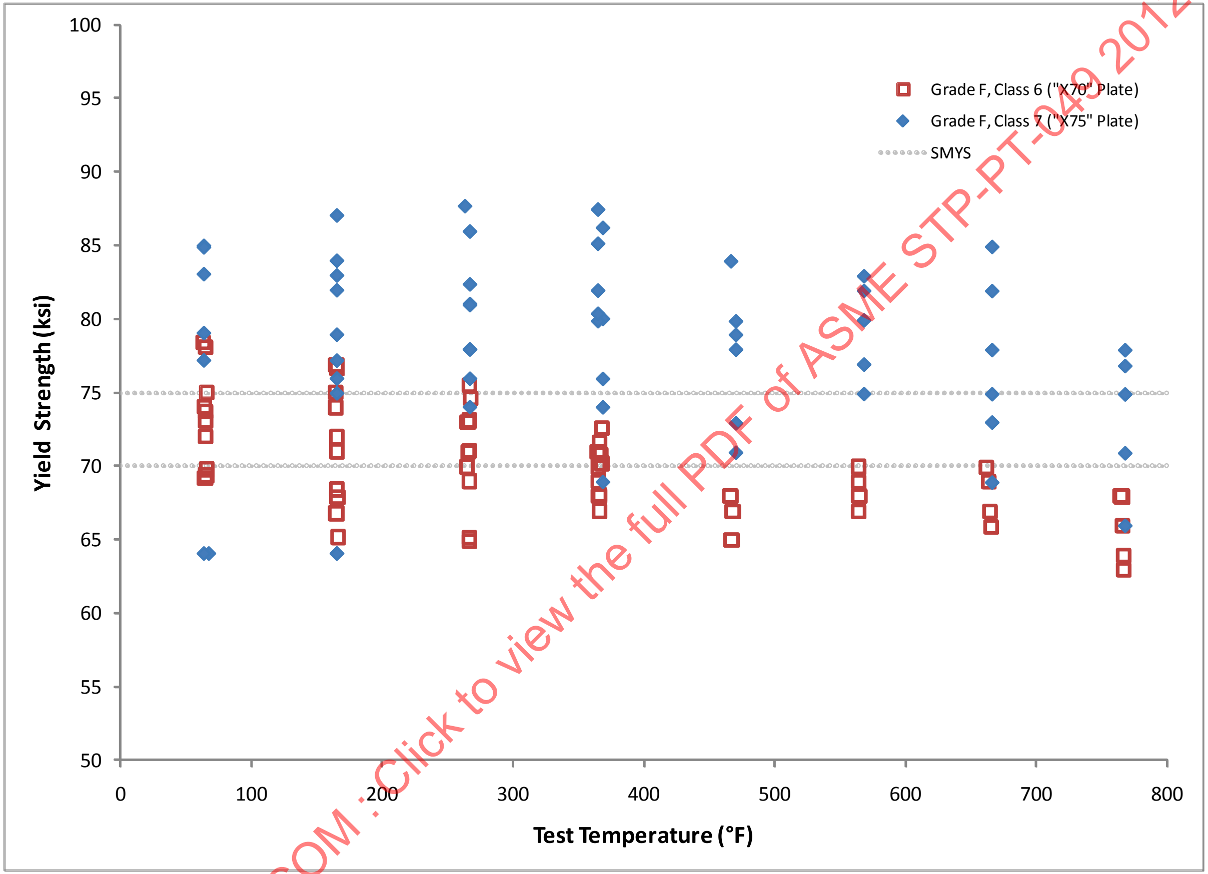

Figure 11—Yield Strength of ASTM A841, Grade F Plate Steel [3]

In Figure 12, the computed strength derating factors are compared to the derating factors from ASME B31.8. The Code-specified derating factors are not, in general, conservative for either class of plate steel (i.e., in the RT-450 °F temperature range). However, at test temperatures ranging from 450 °F to 800 °F, the linearly extrapolated derating factors are conservative for both classes of plate steel.

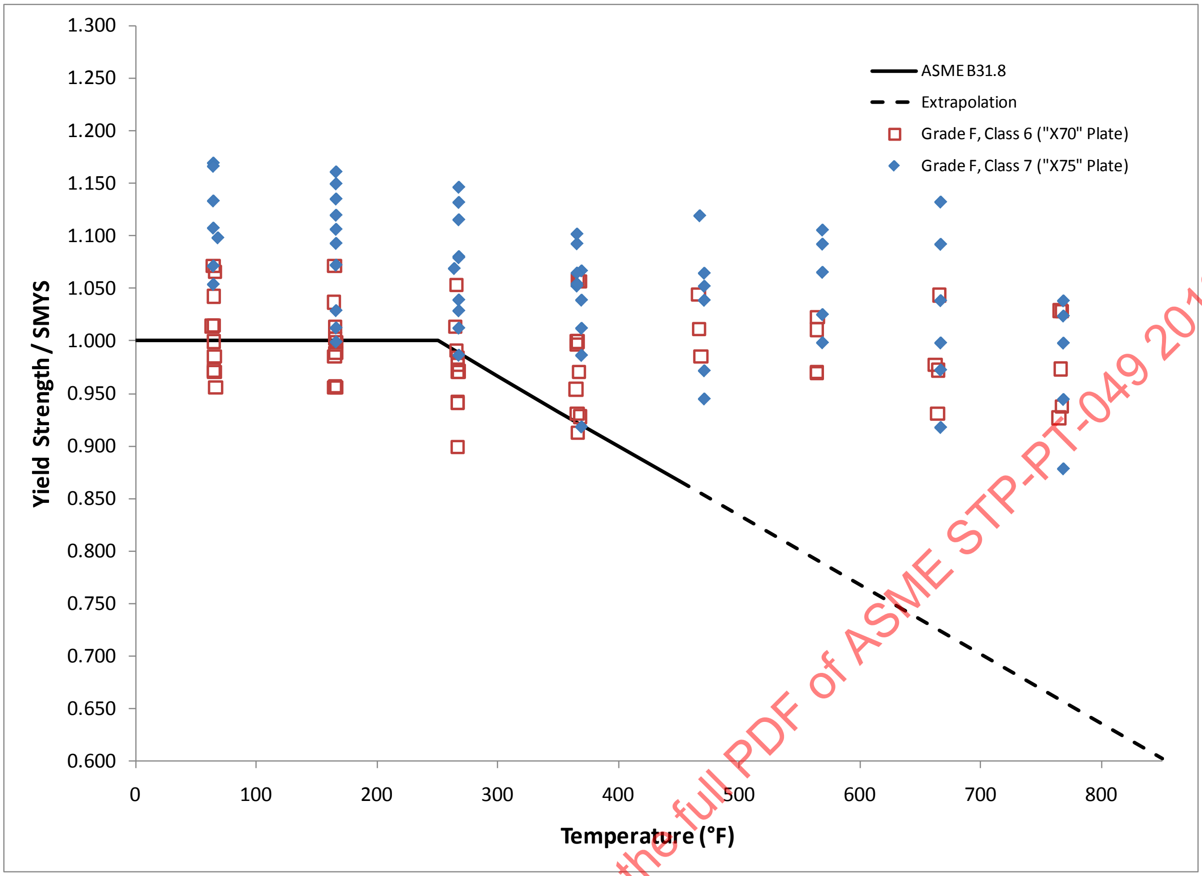

Figure 12—Derating factors of ASTM A841, Grade F Plate Steel [3]

2.5 Other pipeline design standards

Pipeline design standards have been developed and published by other standards-writing organizations typically for general use, or for non-US pipelines onshore or offshore. A sampling of alternative standards was reviewed to learn how they address the derating of line pipe strength for elevated temperatures.

2.5.1 CSA Z662

The standard used by the Canadian pipeline industry is CSA Z662 "Oil and Gas Pipeline Systems" [5]. Paragraph 4.3.5.1 specifies a pressure design formula that includes a temperature factor, T. The temperature factor, T, is specified in Table 4.4 under Paragraph 4.3.9 as given below:

Temperature, °C *(°F)*	Factor T
Up to 120 *(248)*	1.00
150 *(302)*	0.97
180 *(356)*	0.93
200 *(392)*	0.90
230 *(446)*	0.87

The temperatures converted to °F units are shown in italics because they are not part of the Z662 document. Interpolation of the temperature factor for intermediate temperatures is permitted. A quick comparison with the table presented earlier shows that the temperature factor in the Canadian standard is essentially the same as the factor in B31.3, with minor differences due to units conversion and rounding. Paragraph 4.3.9 also presents a Note that "Notwithstanding the derating associated with temperatures above 39 °C specified by some referenced standards, the design stress level need not be reduced for pipe metal temperatures below 120 °C". This note is a reference to certain flange standards, e.g. ASME B31.5, that reduce pressure ratings for temperatures in excess of 100 °F.

Paragraph 4.3.12 "Pressure design for components – General", clause 4.3.12.4 requires that the pressure rating for components, other than flanges, operating temperatures in excess of 230 °C be reduced by the temperature factors for pipe from Table 4.4. Paragraph 5.2.1 "Design temperatures – Steel materials", clause 5.2.1.1 further requires that "Where the maximum design temperature exceeds 120 °C, particular attention shall be given to the tensile properties of steel materials to ensure that the derating for temperature specified by Clauses 4.3.9 and 4.3.12.4 is adequate". Thus the approach adopted by Z662 for accounting for the effects of operating temperature on material strength are essentially the same as that of B31.8, but with the addition of the cautionary statement in 5.2.1.1 to verify that the temperature factors are adequate.

2.5.2 AS 2885

The standard used by the Australian pipeline industry is "Pipelines – Gas and Liquid Petroleum" AS 2885 published by Standards Australia [6]. Part 1 discusses design and construction. Paragraph 4.3.3 "Design Temperatures" lists material strength as a factor to consider when selecting a design temperature. The pressure design formula for the wall thickness necessary for the design internal pressure includes no temperature factor accounting for reduction in material strength at elevated temperature.

2.5.3 ISO 13623

The International Standards Organization (ISO) prepares technical standards for worldwide use and may be supplemental to individual national requirements or regulations. "Petroleum and Natural gas Industries – Pipeline Transportation Systems", ISO 13623, was prepared by the technical committee ISO/TC 67, "Materials, equipment and offshore structures for the petroleum, petrochemical and natural gas industries", Subcommittee SC 2, "Pipeline transportation systems" [7].

Part 6.4.2 "Strength criteria", Clause 6.4.2.2 "Yielding" specifies that the hoop stress due to internal fluid pressure be less than the SMYS at the maximum design temperature multiplied by a location-related design factor. It further states that for temperatures above 50 °C (122 °F), the material strength shall be documented in accordance with Clause 8.1.7. Part 8 "Materials and coatings", clause 8.1.7 "Higher-temperature service" states: "The mechanical properties at the maximum operating temperature of materials for operations above 50 °C should be documented unless specified in the referenced product standard or complementary justification." No further guidance or criteria concerning the effect of temperature on material strength is provided.

2.5.4 DNV-OS-F101

A standard widely used internationally for the design and construction of offshore pipeline systems is "Submarine Pipeline Systems", DNV-OS-F101 [8]. Section 5 "Design – Limit State criteria", Part C300 "Characteristic material properties", clause 302 states that the characteristic yield strength $f_y=(SMYS-f_{y,temp})\alpha_U$ where $f_{y,temp}$ is a strength derating value due to the effect of temperature, and α_U is a strength factor related to how the pipe is manufactured. A similar equation is provided for the characteristic ultimate strength, $f_u=(SMYS-f_{u,temp})\alpha_U$. The user is referred to clause 304 which requires consideration of temperature effects on strength for C-Mn steels operating above 50 °C (122 °F). If no information on temperature derating is available, the factors in a Figure 2 are recommended. Figure 2 therein shows a “Stress De-Rating” value versus temperature. At temperatures below 50 °C (122 °F), the derating value is zero; at a temperature of 100 °C (212 °F), the derating value is 30 MPa (4.35 ksi); at a temperature of 200 °C (392 °F), the derating value is 70 MPa (10.15 ksi). Straight lines are drawn between these points. In the absence of specific information otherwise the same derating values may be applied to the ultimate strength. The effective derating factor thus varies with the room temperature strength.

The table below compares the effective derating factors derived from the derating values given in DNV-OS-F101 to the factors in B31.8:

Temperature		**Derating value**		**Effective derating factor, T**				
Deg C	**Deg F**	**MPa**	**ksi**	**X52**	**X60**	**X65**	**X70**	**B31.8**
50	122	0	0.00	1.000	1.000	1.000	1.000	1.000
75	167	15	2.18	0.958	0.964	0.967	0.969	1.000
100	212	30	4.35	0.916	0.927	0.933	0.938	1.000
125	257	40	5.80	0.888	0.903	0.911	0.917	1.000
150	302	50	7.25	0.861	0.879	0.888	0.896	0.967
175	347	60	8.70	0.833	0.855	0.866	0.876	0.933
200	392	70	10.15	0.805	0.831	0.844	0.855	0.900

The effective temperature factor, T, derived from the DNV derating values decreases as SMYS increases. It is seen to become effective at a lower temperature than B31.8.

Summarizing, a sampling of alternative pipeline design standards was reviewed to determine how they account for the effect of elevated operating temperature on line pipe strength. A range of methods for adjusting the strength to account for temperature effects was identified:

- CSA Z662 provides the same derating factors as B31.8, but with the additional requirement that the user verify that the factors are adequate;
- AS 2885 provides no adjustment of strength for temperature effects;
- ISO 13623 requires documenting the appropriate strength values above 50 °C unless the effect of temperature on material strength is already accounted for in a referenced product standard;
- DNV-OS-F101 provides a strength derating value that results in a lower effective temperature factor, T, than what is found in ASME B31.8.

Other national standards may provide similar or different methods for accounting for the effects of temperature on material strength than those identified above.

3 AN OVERVIEW OF THE STRENGTHENING MECHANISMS AND ROLLING PROCESSES OF HSLA STEELS FOR MODERN LINE PIPE [9]-[13]

3.1 Introduction

Most modern line pipe is made from flat-rolled, high-strength low-alloy (HSLA) steel in strip or plate form. From the same low-C-Mn-Si base, a wide range of strength levels (i.e., X52 to X120) can be achieved by manipulating a few strengthening mechanisms through alloying additions and hot deformation. These strengthening mechanisms are described in the following sections. Although pipe forming and seam welding processes alter the relative magnitude of each strengthening mechanism in the pipe, they do not introduce any *new* strengthening mechanisms.

3.2 Strengthening Mechanisms

Three strengthening mechanisms are common in all grades of modern line pipe steels: precipitation strengthening, grain refinement, and solid solution strengthening. The most important strengthening precipitates are the carbides and nitrides of niobium, vanadium, and titanium. For precipitation strengthening to occur in the finished pipe, very fine, closely spaced precipitates must be dispersed throughout the ferrite phase. This is achieved by rapidly cooling supersaturated austenite to the A_{r3} temperature, followed by hot rolling at or just below that temperature. The most important grain-refining precipitates are the nitrides of aluminum and titanium. They form in austenite and inhibit the growth of recrystallized austenite during the rolling process. At lower temperatures the newly formed ferrite (or acicular ferrite) inherits the fine-grained quality of the parent austenite. As the plate or coil cools from austenitic temperatures, the grain-refining precipitates tend to coalesce and become too large to participate in precipitation strengthening. Substitutional solutes like molybdenum, manganese, copper, silicon, phosphorous, copper, nickel and chromium also increase the yield strength. Interstitial carbon and nitrogen provide a minor strengthening effect due to their low solubilities in ferrite.

In addition to the above strengthening mechanisms, the higher grades (X80 through X120) depend on "second phase" strengthening by acicular ferrite, bainite and/or martensite. To enable these microconstituents to form, the kinetics of austenitic transformation and eutectoid decomposition are altered by specific alloying additions. In grades X80 to X100, increased additions of solute alloys (Cu, Cr, Ni), together with molybdenum or niobium, are used to make acicular ferrite and bainite. In grade X120 increased additions of solute alloys (Cu, Ni, Cr, Mn, and Mo) and boron are used to produce acicular ferrite, bainite and martensite.

Lastly, all ferritic steels share an intrinsic strengthening mechanism that is sensitive to temperatures in the RT – 500 °F. The Peierls-Nabarro stress refers to the minimum force required to move a dislocation through a crystal lattice. Since the Peierls-Nabarro stress is a characteristic of the crystal lattice, all ferritic line pipe steels have this strengthening mechanism in common.

3.3 Rolling Processes

Currently three rolling processes are used to make plate and strip suitable for line pipe: controlled rolling (CR), thermo-mechanical control processing (TMCP), and high temperature processing (HTP). Each process begins with a slab that has been reheated to produce a fully solutionized, austenitic microstructure. Then a two-stage rolling sequence begins the details of which depend on the particular rolling process. The first stage of rolling is called the roughing stage; the second is called the finishing stage. In the roughing stage, the slab is reduced to plate or strip above the no-recrystallization temperature of the austenite. The finishing stage occurs below the no-recrystallization temperature. After the finishing stage, the plate or strip is cooled in air or water to the ambient temperature (for plate) or to the coiling temperature (for strip). This two-stage rolling strategy enables all reductions to be performed while the steel is in its softest form (i.e., austenite) while still yielding a fine-grained, ferrite-based microstructure that contains fine, closely spaced precipitates.

Controlled rolling is used to produce grade X52 line pipe with a ferrite-pearlite microstructure. The first stage of rolling is conducted in the rapid recrystallization region, which is above ~1814 °F. The slab is reduced by up to two times the amount of the final desired thickness. This produces coarse, recrystallized austenite. Then the plate or strip is cooled, without rolling, into the non-recrystallization region (1814 °F to 1472 °F). Partial recrystallization occurs resulting in a mixed grain structure. The second stage of rolling occurs in the non-recrystallization region but above the austenite-to-ferrite transformation temperature. This produces fine-grained austenite, which will transform into fine-grained ferrite during subsequent cooling.

Thermomechanical control processing (TMCP) is used to produce grades X60 through X120. Grades X60 through X70 have ferrite-pearlite microstructures; grades X70 through X80 have ferrite-acicular ferrite microstructures; and the higher grades have acicular ferrite-bainite microstructures with (X120) or without (X100) small amounts of martensite. Two major differences distinguish TMCP from CR. First, during the roughing stage in TMCP, the slab thickness is reduced by a greater amount than in CR. Second, the finishing stage in TMCP terminates closer to the austenite-to-ferrite transformation temperature than in CR. For some TMCP steels, the finishing stage continues for ~32 F below the transformation temperature. During the latter process, which is sometimes referred to as "two-phase rolling," a dislocation sub-structure is created in the newly formed ferrite grains. This dislocation sub-structure persists after cooling further increasing the yield strength.

High temperature processing (HTP) is used to produce grades X65 through X80 with ferrite-acicular ferrite microstructures. Essentially, HTP is TMCP applied to high-Nb (i.e., ≤0.11% Nb) line pipe steel. Because niobium increases the no-recrystallization temperature, both stages of rolling can begin at higher temperatures than are possible in TMCP. Higher rolling temperatures are desirable because this causes less wear and tear on the rolling equipment. Niobium also leads to additional gains in the yield strength. By inhibiting the transformation of austenite to ferrite, niobium creates the opportunity for a greater volume fraction of bainite to form. In addition, higher niobium contents allow more niobium carbide precipitates to form in ferrite.

Hot rolling used to be used to produce ferrite-pearlite line pipe steels in grades less than X52, but this process is not widely practiced any longer. In this process, C-Mn steel slabs were reheated and solutionized in the austenitic temperature range. Removal of the slab from the reheat furnace marked the end of temperature control for the rest of the rolling process. The slab cooled naturally during the rolling reductions which were completed before the transformation of austenite to ferrite could occur. A ferrite-pearlite microstructure evolved while the newly formed plate air cooled. Strength was largely a function of the volume fraction of pearlite that formed.

4 AN ASSESSMENT OF THE AVAILABLE DATA

4.1 Introduction

Because Gray's samples came from plate steel, not line pipe, it is probably inappropriate to base decisions about the derating factors on data from that study. The YS of pipe is known to be different from that of the plate from which it was made. These differences are a result of the strain history imposed while forming the finished pipe product, as well as the additional strain history associated with flattening the transverse tensile test specimen, if the steel exhibits a strong Bauschinger effect. (The Bauschinger effect is a phenomenon that generally occurs in polycrystalline materials and is manifested as a decrease in yield strength in a reversed direction from prior plastic straining. The effect occurs where strengthening mechanisms are reversible, for example where internal stresses associated with obstacles to dislocation movement assist dislocation mobility in the opposite direction, or where dislocations of opposite sign interact and are annihilated, reducing dislocation density. Sensitivity to the Bauschinger effect increases with strength and varies with pipe forming method.)

However, Gray's data are useful because they suggest that the strengthening mechanisms in the TMCP F-AF microstructure (i.e., grain refinement, precipitation hardening and dislocation substructures) are insensitive, or only mildly sensitive, to temperatures from RT to 800 °F. It is reasonable to expect that the same would be true of any pipe formed from the type of plate Gray described. If this were true, then it would suggest that a single derating factor, constant within the RT-800 °F range, might be appropriate for steels with this microstructure and strengthening mechanisms. More testing of TMCP F-AF pipe at elevated temperatures is needed to test this notion. Also, Gray's data involved measuring YS of plate from multiple heats by one manufacturer and his data illustrates how wide the scatter can be in YS data from a single manufacturer. More scatter is expected in YS data from more than one manufacturer due to process variability. This has important implications for the design of a future test program.

Longitudinal data (all of Bredenbruch, some of Benfell) may not be the best data to use because pipe product acceptance (for large diameters) and pipe design are based on the transverse property. But the ***trends*** would probably be the same in transverse YS as they are in longitudinal YS data, so the Benfell and Bredenbruch studies data are useful for that. (Arguably, use of longitudinal testing might be preferred because it eliminates the Bauschinger effect associated with flattening, but skelp can still exhibit directional properties.) Those trends are:

- The YS of TMCP F/P steels (strengthening mechanisms: grain refinement and precipitation strengthening with Nb,V carbides) levels off at and above ~200°F.
- At temperatures lower than that, down to RT, these steels lose YS relative to SMYS.
- The YS, however, never dips below SMYS.

Isolated exceptions to these trends were observed in the Benfell and Bredenbruch data. For example, the first trend was not obeyed by Supplier 3's X70 UOE pipe and Supplier 2's X65 Seamless pipe. The study's authors were not able to investigate these anomalies because they were given only the YS data. The design of a future test program should include provisions for investigating anomalies in behavior.

4.2 Variables Related to Pipe Manufacturing

Tables 2 through 4 summarize the plate rolling processes, pipe forming, alloy designs and seam welding methods used to make line pipe throughout the world. Table 5 shows which of these processes was used to make the pipes in each of the studies considered in this report. Clearly, the studies covered some variables related to pipe manufacturing and omitted others. The omitted variables were: plate rolling methods other than TMCP (i.e., hot rolling, controlled rolling and high-temperature processing), steel grades stronger than X70, and seam type. Even for the steel grades (i.e., X52-X70) and microstructures (i.e., ferrite-pearlite and ferrite-acicular ferrite) that were included in the studies, only a small number of manufacturers were represented. This cursory look suggests that a significant amount of additional testing may be required to generate elevated-temperature yield strength data on which to base strength derating factors.

However, this seemingly bewildering array of variables can be reduced to a fairly small sub-set that includes microstructure, primary strengthening mechanisms and, for UOE pipe, the amount of strain produced by cold expansion. These three variables govern the strength of the pipe after it has been manufactured.

Table 2—Plate Rolling Processes and Microstructures in X52-X120 Line Pipe (Adapted from Table 6 in Ref. [9])

API Grade	Microstructure	HR*	CR	TMCP	HTP
X52 Sour Service	F-P		x		
X52	F-P		x		
X60 Sour Service	F-P			x	
X60	F-P			x	
X65 Sour Service	F-P			x	x
X65	F-P			x	
X70	F-P, F-AF			x	x
X80	F-AF			x	x
X100	AF-B			x	
X120	AF-B-M			x	

Table 3—Pipe Forming and Seam Welding Methods for X52-X120 Line Pipe [9]

Pipe Dimensions	Pipe Forming Method	Seam Type	API Grades
<24” OD <0.375” WT	continuous	ERW	Grade B-X65 (some X80)
>24” OD >0.375” WT	UOE/JCOE	DSAW	Grade B-X120

Table 4—Alloying Approaches and Microstructures in X52-X120 Line Pipe (Adapted from Table 3 in Ref. [9])

API Grade	Microstructure	Alloying Approach
X52 Sour Service	F-P	C≤0.05, Mn≤1.10, S≤0.003, Si≤0.30, Cu+Ni+Cr≤0.60, Nb≤0.050 (or Nb+V≤0.10), $P_{cm}\le 0.13$
X52	F-P	C≤0.10, Mn≤1.20, Si≤0.40, Nb≤0.050, $P_{cm}\le 0.17$
X60 Sour Service	F-P	C≤0.05, Mn≤1.20, S≤0.003, Si≤0.30, Cu+Ni+Cr≤0.70, Nb≤0.065 (or Nb+V≤0.12), $P_{cm}\le 0.15$
X60	F-P	C≤0.10, Mn≤1.50, Si≤0.40, Nb≤0.065 (or Nb+V≤0.12), $P_{cm}\le 0.23$
X65 Sour Service	F-P	C≤0.05, Mn≤1.35, S≤0.003, Si≤0.30, Cu+Ni+Cr≤0.70, Nb≤0.065 (or Nb+V≤0.15), $P_{cm}\le 0.15$
X65	F-P	C≤0.10, Mn≤1.65, Si≤0.40, Cu+Ni+Cr≤0.60, Nb≤0.065 (or Nb+V≤0.15), $P_{cm}\le 0.23$
X70	F-P	D/t>50, C≤0.10, Mn≤1.65, Si≤0.40, Nb≤0.065 (or Nb+V≤0.15), $P_{cm}\le 0.20$
	F-AF	D/t<50, C≤0.06, Mn≤1.65, Si≤0.40, Nb≤0.10 (or Nb+Mo), $P_{cm}\le 0.18$ (or 0.21)
X80	F-AF	C≤0.06, Mn≤1.70, Si≤0.40, Nb≤0.10, Cu, Ni, Mo, $P_{cm}\le 0.21$
	F-AF	C≤0.06, Mn≤1.70, Si≤0.40, Nb≤0.10, Cu, Ni, Cr, $P_{cm}\le 0.18$
X100	AF-B	C≤0.06, Mn≤2.0, Si≤0.40, Nb≤0.06, Cu, Ni, Cr, Mo, V, $P_{cm}\le 0.23$
X120	AF-B-M	C≤0.10, Mn≤2.0, Si≤0.40, Nb≤0.06, Cu, Ni, Cr, Mo, V, B, $P_{cm}\le 0.23$

Table 5—Variables Related to Pipe Manufacturing in Each Study

Author	Rolling Method	Pipe Forming Method	Pipe OD and WT	Seam Weld	Steel Grades	Microstructure	Primary Strengthening Mechanisms	# Pipe Mfrs.	# Heats per Mfr.
Benfell	TMCP	UOE, Seamless	?	?	X52-X70	F-P	GR, SS, PS	5	1
Bredenbruch	TMCP	Unknown and Seamless	?	NA	X60-X70	F-P(?)	?	1	> 1
Gray	TMCP	NA	NA	NA	A841, Grade F, Classes 6&7 plate (for X75-X80 pipe)	F-AF	GR, SS, PS	1	5

4.3 Variables Related to the Tensile Test Procedure

Table 6 below lists the variables related to the tensile test procedures that were covered by the studies. In all three studies, the 0.2% offset method was used to obtain a value for the yield strength from the stress-strain curve. The 0.5% EUL method is specified by API 5L and for this reason is preferred for any further testing and analysis. The two methods produce slightly different values of yield strength when they are applied to the same stress-strain curve. It is not known which method was used to generate the existing derating factors for line pipe steels in the ASME Code, however, it is not expected that the method for establishing YS would significantly affect the observed decrease in YS with temperature.

The similarly gradual, minor decreases of the derating factors for both flattened and round-bar tensile specimens suggests that the derating factor is not strongly affected by the presence of the Bauschinger effect (Figure 3and Figure 12, respectively). The Bauschinger effect is the reduction in tensile yield strength that occurs after a component is subjected to uniaxial compression. In welded line pipe, this occurs on the outer pipe wall surface of flattened tensile specimens. Because the inner pipe wall surface of the specimen experiences tensile stresses during flattening, a work hardening effect occurs in this surface. It so happens that the magnitude of the Bauschinger effect on the outer wall surface is greater than the magnitude of the work hardening effect on the inner wall surface, causing the whole specimen to have a lower yield strength than what would have been measured before flattening. It is not surprising that the yield strength of flattened tensile specimens responded to increasing temperature in a manner that was indistinguishable from round-bar specimens which, because they do not experience compressive stresses before the tensile test, do not exhibit a Bauschinger effect. This is because the Bauschinger effect operates via interactions between dislocations and solute atoms in the steel, and neither solubility nor dislocation mobility is sensitive to temperatures as low as those considered in this study.

Table 6—Variables Related to the Tensile Test Procedures in Each Study

Author	Test Standard	YS Type	Strain Rate	Sample Orientation	Sample Form	Test Temp.	Time at Temp.
Benfell	BS EN 10002-1 (RT) BS EN 10002-5 (>RT)	0.2% offset	?	transverse, longitudinal	flattened strap (T), strap (L)	RT – 302 F	<1 h
Bredenbruch	BS EN 10002-1(RT) BS EN 10002-5 (>RT)	0.2% offset	"fast" and "slow" rates unspecified	longitudinal	strap	RT – 302 F	<1 h
Gray	ASTM E8? (RT) ASTM A370 (>RT)	0.2% offset	?	?	strap (RT) round bar (>RT)	RT – 800 F	<1 h

5 IMPLICATIONS OF THE AVAILABLE DATA FOR ASME CODES

5.1 Other ASME codes affected

Natural gas pipelines are not the only services that utilize HSLA steel line pipe. Hazardous liquid pipelines within the scope of ASME B31.4 employ similar line pipe products and construction to gas pipelines. B31.4 does not prescribe a temperature derating factor in the pressure design equation. The scope of B31.4 service extends only to a maximum temperature of 250 °F, and B31.4 specifies that the room temperature allowable stress applies fully up to this temperature. If it is not accurate or conservative to assume that the room temperature SMYS extends to 250 °F for certain types of HSLA line pipe, B31.4 may need to consider adopting a temperature derating factor.

Hydrogen transportation pipelines are covered by Part PL of ASME B31.12. The pressure design of pipe under Part PL uses the same equation as B31.8 with an additional reduction factor to account for the adverse effect of hydrogen at elevated pressures and high material strength levels. The T factor used in B31.12 is the same as that used in B31.8. Therefore, any revisions that are appropriate for B31.8 should apply to B31.12, Part PL.

Flanges and flanged components used in pipeline systems may be specified in accordance with one of several component standards depending on diameter and material, including ASME B16.5, B16.47, or MSS SP-44. All flanges and flanged components are pressure-temperature rated. Pressure rating classes correspond approximately to the allowed working pressure at the temperature of saturated steam in a power plant (around 850 °F where steel has a relatively low strength), with increased allowed working pressures for temperatures below that down to 100 °F or cooler. In the ASME B16 standards, the pressure-temperature ratings are established by a ratio of a reference operating stress level in the hub of the flange to 60% of the YS at temperature for the material as reported in Section II “Materials” of the ASME Boiler and Pressure Vessel Code. These YS values were established by extensive testing which took place historically over a period of decades. Testing was typically supported by the vessel industry and organized by the Pressure Vessel Research Council or the Material Properties Council. ASME B16 flange pressure ratings generally decrease at temperatures above 150 °F based on these tests.

MSS SP-44 provides for design of wrought large-diameter flanges in material grades that specifically match the specified minimum yield and tensile strengths of API 5L line pipe grades. The pressure classes and room temperature working pressure ratings match those used with ASME B16 flanges. However, SP-44 maintains the room temperature working pressure ratings up to 250 °F and derates the working pressures at higher temperatures according to the same derating factors observed by B31.8. Welding neck flanges manufactured to SP-44 must be forged, while blind flanges may be forged or cut from plate. They may be heat treated in order to match strength with HSLA mating pipe. Such components may or may not have similar chemistry or exhibit similar microstructures to the matching-strength line pipe. Thus they may not exhibit the same temperature-dependent behavior as specific types of high-strength pipe.

ASME B31G provides methods for assessing the remaining strength of pipe affected by metal loss caused by corrosion. The 2009 Edition permits evaluation of metal loss defects at temperatures above ambient provided material strength properties at temperature are considered. The safe operating stress is computed using the “flow stress” which is determined from the specified minimum yield and tensile strengths. Thus a conservative assessment of corrosion in pipe operating above room temperature relies on appropriate derating of strength with temperature.