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CREEP RATE CORRELATION
IN SOLUTION-TREATED
TYPE 304 AND 316 STAINLESS STEELS

J. F. Bates
E. R. Gilbert
A. J. Lovell

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J. F. Bates, E. R. Gilbert and A. J. Lovell

ABSTRACT

Creep rate data on annealed AISI Types 304 and 316 stainless steel were analyzed. Empirical equations which relate the minimum creep rate, testing stress, and testing temperature are described.

Temperatures and stresses vary from 900 to 1700°F and 1.5 to 58 psi for the 304 data, and from 1000 to 1400°F and 10 to 63 ksi for the 316 data.

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INTRODUCTION

A description of minimum creep rates as a function of applied stress and temperature is important for design equations and data representation. Creep rate data on austenitic stainless steels cannot be uniquely described by a simple power law or an exponential function with stress. It is the purpose of this study to determine if the creep rates obtained over rather wide ranges of stress and temperature could be uniquely described by a combination of the power and exponential functions. The form of the equation which was selected for the correlation is:

$$\dot{\epsilon} = S \exp(-Q/RT) [\sinh(\alpha\sigma)]^n \quad (1)$$

where $\dot{\epsilon}$ is the minimum creep rate in h^{-1} , σ is the engineering stress in psi, T is temperature in $^{\circ}\text{K}$, R is the gas constant, Q is the activation energy, and S , α , and n are constants.

EXPERIMENTAL PROCEDURE

Constant load creep tests were performed on AISI Types 304 and 316 stainless steel in the solution-treated condition.⁽¹⁾ Data were also extracted from References 2 through 5 in which some details of test technique, heat treatment, and composition are given. A nonlinear regression analysis (described in References 6 and 7) was made of the data.

Temperatures and stresses for the data vary from 480°C (896°F) to 923°C (1693°F) and 1.5 to 58 ksi for the Type 304 stainless steel, and from 538°C (1000°F) to 760°C (1400°F) and 10 to 63 ksi for the Type 316 stainless steel.

RESULTS

The values derived for the constants of Equation (1) are as follows.

304 Stainless Steel

$$\dot{\epsilon} = \exp(49.7 - 93,400/RT) [\sinh(2.14 \times 10^{-5} \sigma)]^{6.87} \quad (2)$$

316 Stainless Steel

$$\dot{\epsilon} = \exp(62.48 - 116,000/RT) [\sinh(1.79 \times 10^{-5} \sigma)]^{8.23} \quad (3)$$

The data points are plotted for Type 304 stainless steel in Figure 1 and for Type 316 stainless steel in Figure 2 as $\log Z$ versus $\log \sinh(\alpha\sigma)$. Z is the Zener-Hollomon temperature-compensated, creep rate parameter $\log_{10}(\dot{\epsilon} \exp Q/RT)$. The slope on this plot is the exponent n of the sinh function.

DISCUSSION

As observed in Figures 1 and 2, Equation (1) provides good correlation of the creep rate data. It is interesting to note that a dependency of both n and Q on temperature observed on the Type 316 stainless steel data by Lovell and Blackburn⁽¹⁾ is not observed on the Zener-Hollomon plot. Therefore it may be concluded that the Zener-Hollomon parameter is not very sensitive to variations of n and Q with temperature. This is also partly due to the scatter in the value of the parameter. Nearly an order of magnitude scatter

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FIGURE 1. Zener-Holloman Temperature-Compensated Strain Rate Parameter versus $-\log_{10} [\sinh(\alpha\sigma)]$ for 304 Stainless Steel in the Solution-Treated Condition (1950°F/1 hour)

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FIGURE 2. Zener-Holloman Temperature-Compensated Strain Rate Parameter versus $-\log_{10}[\sinh(\alpha\sigma)]$ for 316 Stainless Steel in the Solution-Treated Condition (1950°F/1 hour)

is observed at some stress values. This scatter does not appear to be very large compared to the 8 to 10 orders of magnitude range in the Zener-Hollomon, but if the creep rate were to be computed for a given stress and temperature, it would have an uncertainty of nearly an order of magnitude.

The values of n and Q for Type 304 stainless steel do not appear to vary with temperature. Cuddy⁽⁸⁾ has reported an apparent activation energy of 91 ± 9 kcal/mole for the creep of Type 304 stainless steel. He found this value to be independent of both temperature and stress. While the insensitivity of the activation energy to temperature and stress is suggestive of diffusion controlled creep, the value of 85 kcal/mole computed after correcting for the temperature dependence of the modulus of rigidity is considerably higher than the 67 kcal/mole which has been measured in diffusion experiments for gamma iron,^(9,10) Type 347 stainless steel,⁽¹¹⁾ 25/20 stainless steel,⁽¹²⁾ and computed by simulation methods^(13,14) for gamma iron.

REFERENCES

1. A. J. Lovell and L. D. Blackburn. Unpublished Data. WADCO Corporation, Richland, Washington, 1970.
2. W. F. Simmons and J. A. VanEcho. "The Elevated-Temperature Properties of Stainless Steels," ASTM Data Series Publication DS5-S1, Data and Publications Panel Data Sheet 9-12, p. 75. 1965.
3. W. F. Simmons and J. A. VanEcho. "The Elevated-Temperature Properties of Stainless Steels," ASTM Data Series Publication DS5-S1, Data and Publications Panel Data Sheet 9-316, p. 86. 1965.
4. J. A. Williams and J. W. Carter. "Creep and Annealed Type 304 Stainless Steel During Irradiation and Its Engineering Significance," The Effects of Radiation on Structural Metals, Mater., Spec. Tech. Publ., vol. 426, pp. 149-160. 1968.
5. E. R. Gilbert and N. E. Harding. "Comparison of In-Reactor Creep and Postirradiation Creep Tests for Structural Materials for Nuclear Applications," Irradiation Effects in Structural Alloys for Thermal and Fast Reactors, ASTM STP 457, Am. Soc. Testing Mater., Spec. Tech. Publ., pp. 17-37. 1969.
6. B. H. Duane. Maximum Likelihood Nonlinear Correlated Fields (BNW Program LIKELY), BNWL-390. Battelle-Northwest, Richland, Washington, September 1967.
7. G. D. Seybold. User's Aid: Programs LEARN and LIKELY, BNWL-1057. Battelle-Northwest, Richland, Washington, May 1969.
8. L. J. Cuddy. "Internal Stresses and Structures Developed During Creep," TMS-AIME, vol. 1, pp. 395-401. 1970.
9. F. S. Buffington, I. D. Bakalar, and M. Cohen. The Physics of Powder Metallurgy, edited by W. E. Kingston. McGraw-Hill, New York, N.Y., 1951. Ch. 6, p. 103.
10. T. Heumann and R. Imm. "Self-Diffusion and Isotope Effect in γ -Iron," J. Phys. Chem. Solids, vol. 29, pp. 1613-1621. 1968.

11. V. Linnenbom, M. Tetenbaum, and C. Cheek. "Tracer Diffusion of Iron in Stainless Steel," J. Appl. Phys., vol. 26, pp. 932-936. 1955.
12. A. F. Smith and G. B. Gibbs. "Volume and Grain-Boundary Diffusion in 20 Cr/25Ni/Nb Stainless Steel," Metal Sci. J., vol. 3, pp. 93-94. 1969.
12. R. A. Johnson. "Calculations of Small Vacancy and Interstitial Clusters for an fcc Lattice," Phys. Rev., vol. 152, pp. 629-634. 1966.
14. R. E. Dahl, Jr. A Computer Simulation Study of Tilt Grain Boundaries in Gamma-Iron and Their Interactions with Point Defects. North Carolina State University at Raleigh, North Carolina, 1970. (Ph.D. Dissertation)

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