27-6-82
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I-6747

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DR 1031

UCID-19597

UCID--19597

DE83 003310

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Variation of the Yield Strength and Strain-Rate
Sensitivity Exponent of Type 21-6-9 Stainless Steel
over a Wide Temperature Range

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November 15, 1982

Lawrence
Livermore
Laboratory

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under Contract W-7405-Eng-48.

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VARIATION OF THE YIELD STRENGTH AND STRAIN-RATE
SENSITIVITY EXPONENT OF TYPE 21-6-9 STAINLESS STEEL
OVER A WIDE TEMPERATURE RANGE

ABSTRACT

The yield strength of solution-annealed 21-6-9 austenitic stainless steel was determined over a wider temperature range (-195 to 1100°C) than has been previously reported. The most noteworthy characteristic of the variation of yield stress with temperature was the dramatic decrease in yield strength from -195°C to 300°C. The strain-rate sensitivity exponent, N , was determined using strain-rate change tests. A plot of N vs temperature showed that N dramatically increases at about 850°C and that N is approximately independent of strain (structure).

INTRODUCTION

The yield strength of solution-annealed 21-6-9 austenitic stainless steel was determined over a wider temperature range (-195 to 1100°C) than has been previously reported. Also determined was the strain-rate sensitivity exponent, N , which was defined as

$$N = \left(\frac{\partial \ln \sigma}{\partial \ln \dot{\epsilon}} \right)_{T, \epsilon} \quad (1)$$

where σ is stress, $\dot{\epsilon}$ is strain rate, T is temperature, and ϵ is strain. The values of N were determined over the same temperature range of -195 to 1100°C.

EXPERIMENTAL PROCEDURE

The 21-6-9 austenitic stainless steel used in this study was provided in the form of 76-mm-diameter stock. The chemical analysis is given in Table 1. Tensile specimens were machined from this stock to a 6.4-mm diameter round

with a 51-mm gauge length. All specimens were initially solution annealed at 1080°C for one hour in vacuum. The resulting ASTM grain size was 4.5 to 5. Mechanical testing was performed on an Instron 10,000-lb screw drive model TTC-L. In all cases, the yield stress was determined using a 0.2% strain offset.

In this study, the strain-rate sensitivity exponent, N , was determined by strain-rate change tests. This kind of test is illustrated in Fig. 1. In this test, the stainless steel is deformed from the solution-annealed condition at the strain rate of 10^{-4} s^{-1} . After a specific amount of plastic strain (0.002, 0.03, or 0.15 in this study), the imposed strain-rate is changed to the higher rate of 10^{-2} s^{-1} . In response to this change, the stress elastically "jumps" from the value of σ_1 (Fig. 2). Eventually, the material plastically deforms at this higher strain-rate. With the experimental apparatus used, the onset of plastic deformation can only be discriminated after about 0.0002 plastic strain (σ_2 , Fig. 2). Since 0.0002 plastic strain is small, the structures at σ_1 and σ_2 can be regarded as identical. Therefore, the stress exponent N , which can be approximated by

$$N = \left(\frac{\partial \ln \sigma}{\partial \ln \dot{\epsilon}} \right)_{T, \epsilon} \approx \frac{\ln (\sigma_2 / \sigma_1)}{\ln (\dot{\epsilon}_2 / \dot{\epsilon}_1)}, \quad (2)$$

is a constant structure stress exponent.

Figure 2. Variation of yield stress of annealed 21-6-9 stainless with temperature.

It should be mentioned that, at ambient temperature, N for annealed 21-6-9 was previously determined to be about 0.040.¹ This value contrasts with an average value of about 0.022 in Fig. 3. This disparity can be explained, in part, by the fact that, in the previous investigation, N was determined by comparing the 0.2% offset yield stress of two annealed specimens, deformed at different strain rates. In this case,

$$N \approx \frac{\ln (\sigma_{y_2} / \sigma_{y_1})}{\ln (\dot{\epsilon}_2 / \dot{\epsilon}_1)} . \quad (3)$$

Perhaps the N values determined from the yield stress difference technique [Eq. (3)] are higher than those determined using the strain-rate change test [Eq. (2)] because the assumption of constancy of structure is more relaxed in the former case. That is, a fraction of the difference between the yield stresses at the different strain-rates is accounted by a difference in substructure.

REFERENCE

1. M. E. Kassner, A Simple Constitutive Equation to Predict the Low Temperature Yield Strength of Type 21-6-9 Stainless Steel, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-87772 (1982).