DIVISION OF MATERIALS ENGINEERING

College of Engineering
The University of Iowa
Iowa City, Iowa   52242

EFFECTS OF MISALIGNMENT ON
MECHANICAL BEHAVIOR OF METALS IN CREEP
Final Report

by

Han C. Wu

Division of Materials Engineering
The University of Iowa
Iowa City, Iowa   52242

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In this project, under Grant No. NSG 1499, we have investigated the effects of misalignment on the mechanical testing of metals. The primary objective is to assess the errors caused by test system misalignment in a creep test. Due to the importance of the prehistory of a creep test, which has been shown in this study to seriously affect the subsequent creep behavior, the effect of misalignment in a tension test has also been studied. The latter investigation included the strain-rate effect.

In connection with the misalignment analysis, we have developed the endochronic creep equation. The development was based on the endochronic theory of viscoplasticity. We have carried out creep tests for 6061-0 aluminum alloy at 150°C using a closed loop servo-hydraulic test system. Parameters of the theory have been determined based on these test results.

We believe that the project has been successful. The effect of system misalignment has been thoroughly analyzed. In this comprehensive analysis, several assumptions made by other investigators have been relaxed. They are:

1. the constant relationship between the axial load P and the bending moment M applied at the ends of the creep specimen;

2. the condition that $\frac{dM}{dt} = 0$ when $\frac{dP}{dt} = 0$;

3. the fixed neutral axis of the specimen;

4. the absence of pull-rod effect.

In addition, the endochronic creep equation, which has been shown to satisfactorily describe the experimental data for some aluminum alloys has been used in the analysis.

Due to the relaxation of the above assumptions, some of the results of this analysis are different than those found in the literature. We will now summarize our findings in the following paragraphs. These findings are

presented in three parts. The first part is for misalignment analysis of a tension test under static loading condition. The second part is for analysis of a tension test under dynamic loading condition and the third part is for misalignment analysis of a creep test. Although these findings are based on 1100-0 aluminum specimens, it is anticipated that they are also valid for other metallic materials as long as the shape of their stress-strain curves is similar to 1100-0 aluminum.

I. TENSION TEST UNDER STATIC LOAD

The following conclusions have been drawn from this investigation of 1100-0 aluminum specimens:

(1) The stress-strain curve is not significantly affected by misalignment at strain levels greater than 0.003.

(2) The strain at the outermost fibers of the specimen is strongly affected by misalignment.

(3) The misalignment effects are smaller for load trains with longer pull rods.

(4) The symmetric case is the most severe case of all the cases considered.

(5) Bent pull rods do not affect strain errors due to symmetrical misalignments.

The second conclusion mentioned above has important implications when properties sensitive to local strain concentrations are being investigated. Fatigue strength in a strain-controlled test is such a property. In this test, an error band in the strain will induce an even larger error band in the fatigue life. This is due to the small slope of the fatigue curve. Fatigue data usually have been known to have a large scatter. It is conceivable that a major factor causing this scatter is testing system misalignment.

II. DYNAMIC TENSION TEST

The following conclusions have been drawn from the study of 1100-0 aluminum specimens:

(1) Based on the endochronic constitutive equation, the formulation of the misalignment problem in the dynamic tension test has been developed. Two assumptions have been made: (a) plane cross-sections remain plane during deformation; and (b) the strain rate history effect is negligible in the computation of stress. The second assumption is justifiable due to the extremely small variation in the strain rate throughout the tension test for each element of the discrete model.

(2) The lower the strain rate is at the tension test, the more significant the misalignment errors become. Three levels of strain rate, i.e., 1.30×10^{-5}, 1.24×10^{-2}, and 7.63×10^{-1} sec^{-1} have been investigated. In this strain rate range, the misalignment error at the geometrical centerline of the specimen is within 2% and vanishes mostly as the plastic strain increases beyond 2%. At the extreme fibers of the specimen, the misalignment errors approach to 50% at the very small plastic strain range. Therefore, any investigation related to the local deformation of the extreme fibers will have to account for the misalignment effect.

(3) In the range of plastic deformation, the error introduced by misalignment decreases with the magnitude of plastic strain. Hence, it is conjectured that the most significant effect of misalignment occurs at the interface between the elastic and the plastic range. This conjecture is in agreement with the finding of the investigation reported in part I, in which it has been found that the most significant error occurs at the knee portion of the stress-strain curve.

(4) At the midspan of the specimen, the variation of strain rate between

extreme fibers decreases with increasing plastic strain. The strain rate reaches a uniform value at plastic strain equal to 0.8%.

(5) The neutral axis (N.A.) will shift toward the geometrical centerline of the specimen as the plastic strain increases. But, it will reach a limit and will not move back to the geometrical centerline at large plastic strain as anticipated by the uniform strain rate formulation.

(6) The misalignment errors and the shifting of the N.A. predicted by the uniform strain rate formulation in which the strain rate is constant for the whole specimen are always overestimated at the small plastic strain range and underestimated at the larger plastic strain range.

(7) The formulation of the work reported in part I belongs to the case of uniform strain rate formulation.

III. CREEP TEST

The formulation of a misaligned specimen subjected to the creep test has been presented. The investigation is restricted to the symmetric case of test system misalignment. The specimens used in the calculation are the sheet type rectangular specimens of 1100-0 aluminum. Three cases have been investigated in detail which correspond to different pull rod lengths and different initial strains. The following results have been obtained from this investigation:

(1) During the creep test, the stress is quite constant for all fibers. The total change in stress for the 8-hour creep period for the top and bottom fibers is within 2% for all cases considered.

(2) The difference between the creep strains at the geometric centerline and the the N.A. decreases with the creep time in spite of the test system misalignment.

(3) The center error and the errors at the extreme fibers are always decreasing during creep.

(4) For the same pull rod length but with different amounts of prestrain, the smaller the prestrain is (in the plastic range) the greater is the misalignment error at the onset of creep and the longer creep time it takes for the misalignment effect to vanish. For the same prestrain but with different pull rod lengths, the error is greater for the shorter pull rod than for the longer.

(5) In order to effectively reduce the misalignment error in a creep test, long pull rod should be used and the test should be conducted with a large prestrain.

In addition to the misalignment analysis we have carried out an investigation on the creep behavior of metallic materials. This investigation consists of two aspects which are the theoretical and the experimental studies.

Theoretically, the endochronic creep equation has been developed. The development was based on the endochronic theory of viscoplasticity. The following results have been obtained:

(1) The governing equations for constant-strain rate stress strain behavior, creep, creep recovery, and stress relaxation have been derived by imposing appropriate constraints on the general endochronic constitutive equation.

(2) A set of material constants has been fou d which correlate strain-hardening, creep, creep recovery, and stress relaxation for 1100-0 aluminum at 150°C.

(3) The theory predicts with reasonable accuracy the creep and creep recovery behaviors at short time.

(4) The strain-rate history at prestraining stage affects the subsequent creep.

(5) A critical stress is established which distinguishes forward creep from normal strain recovery.

(6) It has been found that a logarithmic function is a reasonably good form for the strain-rate sensitivity function for 1100-0 aluminum, and an archyperbolic sine function is for 6061-0 aluminum.

(7) A nonlinear intrinsic time scale function has been proposed which will achieve a steady state at large intrinsic time.

Although the conventional time-hardening or strain-hardening (or their combination) models have been employed in the literature to describe creep and the effect of stress variation during creep, the approach is valid only for the description of creep and may not be applicable to describing stress variation arising from other loading histories. At the service load, it is likely that several types of loading histories may be present (possibly including creep and cyclic loading, etc.) either simultaneously or in sequence. The description of this complex behavior calls for a unified approach which is the objective of this theoretical investigation.

The experiments have been conducted by use of a servo-controlled materials test system, and we used a PDP-11/04 mini-computer to control the test. The specimens were made of 6061-0 aluminum and were tested in an environmental chamber at a temperature of 150°C. We have performed the constant-strain-rate tension test, the creep test, the creep recovery test, and the stress relaxation test.

The difference between this series of experiments and the conventional creep or stress relaxation test is that the loading prehistory of the creep or stress relaxtion test may be programmed and recorded.

Investigation of Creep by Use of

Closed Loop Servo-Hydraulic Test System

by   Han C. Wu and J. C. Yao

ABSTRACT

Creep tests have been conducted by means of a closed loop servo-controlled materials test system. These tests are different from the conventional creep tests in that the strain history prior to creep may be carefully monitored. Tests have been performed for aluminum alloy 6061-0 at 150°C and have been monitored by a PDP 11/04 minicomputer at a preset constant plastic-strain rate prehistory. The results show that the plastic-strain rate prior to creep plays a significant role in creep behavior.

The endochronic theory of viscoplasticity has been applied to describe the observed creep curves. The concepts of intrinsic time and strain rate sensitivity function are employed and modified according to the present observation.

The following publications are related to this project. Abstracts of some of these publications are attached.

(1) Wu, H.C. and Rummler, D.R., "Analysis of Misalignment in the Tensile Test", Eighth U.S. National Congress of Applied Mechanics, Abstracts, P. 48, University of California, Los Angeles, June 26-30, 1978.

(2) Wu, H.C. and Rummler, D.R., "Analysis of Misalignment in the Tension Test", The ASME Journal of Engineering Materials and Technology, Vol. 101 pp. 68-74, January 1979.

(3) Wu, H.C. and Chen, L., "Endochronic Theory of Transient Creep and Creep Reovery", Report G302-79-001, Division of Materials Engineering, the University of Iowa, April 1979.

(4) Wu, H.C., Wang, T.P. and Yip, M.C., "The Effect of Test System Misalignment in the Dynamic Tension Test", Report G302-80-001, Division of Materials Engineering, The University of Iowa, March 1980.

(5) Wu, H.C., Wang, T.P. and Yip, M.C., "The Effect of Test System Misalignment in the Creep Test", Report G302-80-002, Division of Materials Engineering, The University of Iowa, April 1980.

(6) Wu, H.C., "An Endochronic Description of Creep and Recovery", Developments in Mechanics, Vol. 11, pg. 225 (Abstract), Proceedings of the 17th Midwestern Mechanics Conference, The University of Michigan, Ann Arbor, May 6-8, 1981.

(7) Wu, H.C. and Yao, J. C., "Investigation of Creep by Use of Closed Loop Servo-Hydraulic Test System", Report G302-81-001, Divisopm of Materials Engineering, The University of Iowa, November 1981.

(8) Wu, H.C. and Yao, J.C., "Creep Recovery and Stress Relaxation Tests of 6061-0 Aluminum", Report G302-81-002, Division of Materials Engineering. The University of Iowa, December 1981.

(9) Wu, H.C., "Effects of Misalignment on Mechanical Behavior of Metals in Creep - Final Report", Report G302-81-003, Division of Materials Engineering, The University of Iowa, December 1981.

Analysis of Misalignment in the Tension Test

by Han C. Wu and D. R. Rummler

Abstract

Many experimenters fail to appreciate the significance of test system
alignment during a tensile test. Poor alignment can increase data scatter
and significantly influence some of the test results. In this paper a
comprehensive analytical study of the misalignment problem in the plastic
strain range is presented and errors caused by misalignment estimated.

The results show that the stress-strain curve is not significantly
affected by misalignment. However, the strains at the outermost fibers
of the specimen cross-section are strongly affected by misalignment.
Therefore, the effect of misalignment is most important when properties
sensitive to local strain concentrations are being investigated.

The Effect of Test System Misalignment

in the Dynamic Tension Test

by Han C. Wu, T. P. Wang and M. C. Yip

ABSTRACT

An analysis of test system misalignment is presented for dynamic tension test. Sheet type rectangular 1100-0 aluminum specimens are used for discussion

For a constant strain rate tension test, the strain rate is constant only on the neutral axis of the specimen. The following results have been obtained: (a) The lower the strain rate is, the more significant the misalignment errors become. (b) Misalignment errors of 50% have been found at the extreme fibers of the specimen. (c) The strain rate variation in the cross-section decreases with increasing plastic strain and vanishes at plastic strain equal to 0.8% at the midspan of the specimen. (d) The neutral axis will shift toward the centerline of the specimen as the plastic strain increases. But, it will reach a limit and will not completely move back to the centerline.

A more restricted uniform strain rate formulation is also presented. The result is compared with that of the nonuniform strain rate formulation.

The Effect of Test System Misalignment

in the Creep Test

by Han C. Wu and T. P. Wang

Abstract

An analysis of test system misalignment is presented for the creep test. Sheet type rectangular 1100-0 aluminum specimens are used for discussion. It is found that the creep strain at the geometric centerline of the specimen is different than that at the neutral axis. However, this difference in the creep strain decreases with time. Generally, the effect of misalignment decreases with creep time.

Creep tests conducted with long pullrods and large initial strain level (high creep stress) will tend to minimize the effect of misalignment.

AN ENDOCHRONIC DESCRIPTION
OF CREEP AND RECOVERY

Han-Chin Wu
Division of Materials Engineering
University of Iowa
Iowa City, Iowa   52242

Short time creep and creep recovery have been investigated by means of the modified endochronic theory of viscoplasticity. The intrinsic time is defined in terms of the plastic strain and is further modified by making it depend on plastic strain rate in this investigation. Therefore, the material behavior is linearly elastic before yield and viscoplastic after yield.

The first part of the paper discusses the creep behavior of Aluminum 1100-0 at 150°C (300°F). The strain rate plays a significant role in this consideration and it is shown how the strain rate is accounted for in the present approach.

Creep recovery is treated using equation derived from the same general constitutive equation by imposing appropriate constraint. A critical stress is established which distinguishes forward creep from normal strain recovery.

Investigation of Creep by Use of

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ABSTRACT

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The endochronic theory of viscoplasticity has been applied to describe the observed creep curves. The concepts of intrinsic time and strain rate sensitivity function are employed and modified according to the present observation.