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BENDING FROM TENSILE DATA

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Prediction of Creep Failures of Lead in Bending
From Tensile Data

Summary

The creep-rupture lives of lead beams in pure bending have been predicted within a factor of three using tensile creep data. All of the specimens lasted longer than predicted. The underestimates in failure times correspond to overestimates in the maximum fibre stresses by about ten percent. If the nominal stresses reported in the tensile data are corrected for the fact that the tests were conducted under constant load instead of constant stress, the failure times of the bend specimens appear to be in good agreement with the predicted values.

Bend Tests

Small lead beams were subjected to pure bending under constant moment by the pulley arrangement shown in Figure 1. The ends of the specimens were secured at the centers of two plastic wheels, which were suspended by steel bands, attached to their peripheries. Weights were suspended by steel bands, also attached to the peripheries of the wheels in order to produce constant moments. The use of long bands to support the assembly permitted the centers of the wheels to swing together without significantly changing the moment by the resultant lateral loads produced. The rotations of the wheels, from which the strains were calculated, were determined by measuring the change in height of the wheels above a reference surface with a height gage.

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Fig. 1 - Pulley Arrangement for Lead Bending Tests

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Bend Specimens

Several specimens used to obtain data are shown in Figure 2. In order to get the high strains required for failure, it was necessary to use a test section with a small length to thickness ratio, since the total rotation of the beams was limited to 180 degrees¹.

Analysis of Bend Specimens

The method used to analyze the bend specimens is similar to that of a previous analysis². The following assumptions are made.

1. The creep law for lead can be approximated by the equation

$$\dot{\epsilon} = A\sigma^n \quad (1)$$

where

$\dot{\epsilon}$ = creep rate, or time rate of change of strain

σ = stress

A, n = constants of the material.

2. The creep properties are identical for tension and compression.

3. For beams in pure bending the strain, and hence, the strain rate are proportional to the distance from the neutral axis of the beam. That is,

$$\epsilon(y) = \alpha_1 y \text{ and } \dot{\epsilon}(y) = \alpha_2 y \quad (2)$$

¹For symmetrical bending, the maximum fibre strain is given by $\frac{\theta(h)}{2(l)}$ where θ is the angle of rotation of the test section, in radians, h is the height of the beam, and l is the length of the test section.

²See Reference 1.

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Fig. 2 - Lead Bend Specimens

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where

y = distance from the neutral axis

c_1, c_2 = constants of proportionality.

4. Failure occurs when the maximum fibres fail, as determined from the tensile creep-rupture data and the maximum fibre stresses existing in the beam.

The following equilibrium equations may be written for a rectangular beam of width b and applied moment M .

$$b \int_{\text{cross-section}} \sigma(y) dy = 0 \quad (3)$$

$$b \int_{\text{cross-section}} y \sigma(y) dy = M \quad (4)$$

Equations (1), (2) and (3), with the assumption that the creep law is identical in tension and compression, establish that the neutral axis is the geometrical center of the beam. Denoting the height of the beam by h , and the maximum fibre strain by $\dot{\epsilon}_m$, Equations (2) become

$$\dot{\epsilon}(y) = \frac{2\dot{\epsilon}_m}{h} y, \quad \dot{\epsilon}(y) = \frac{2\dot{\epsilon}_m}{h} y \quad (5)$$

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The stress distribution over the cross-section of the beam may be obtained from Equations (1), (4), and (5). Denoting the maximum fibre stress by σ_m ,

$$\sigma(y) = \left(\frac{2}{h}\right)^{\frac{1}{n}} \sigma_m y^{\frac{1}{n}} \quad (6)$$

$$\sigma_m = \frac{2M}{bh^2} \left(\frac{2n+1}{n}\right) \quad (7)$$

By comparison, the maximum fibre stress for elastic behavior is given by

$$\sigma_{el} = \frac{6M}{bh^2} \quad (8)$$

The ratio of the maximum fibre stress for creep to the maximum elastic stress, from Equations (7) and (8) is

$$\frac{\sigma_m}{\sigma_{el}} = \frac{2n+1}{3n} \quad (9)$$

A typical stress distribution from Equation (7) is shown in Figure 3.

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Figure 3 Typical Stress Distribution for Rectangular Beam Undergoing Creep in Bending

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Tensile Data

Tensile creep data for the lead used in the bending tests is shown in Figures 4 through 6. Figure 5 is a log-log plot of stress against creep rate for various times after loading. Although the creep rates vary somewhat with time the variation of stress with creep rate remains fairly linear, and with a constant slope. Since the value of n in the creep law is determined by this slope, n also remains fairly constant. Furthermore, since by Equations (6) and (7) the stress distribution is a function of n only and not the magnitude of the creep rate, the stress distribution remains almost constant. It should be possible, then, to predict failure on the basis of constant stress tensile creep data and the maximum stresses existing in the beams.

Using an average slope to represent the curves of Figure 5 gives a value of 7.8 for n . By Equation (9), the maximum fibre stress is reduced to 71 percent of its initial elastic value after the stresses redistribute to accommodate creep.

Correlation of Failures and Creep Rates

Three bend specimens were taken to failure. The lives of all three specimens were underestimated by a factor of three. The failures are shown in Figure 6 along with the tensile data to indicate the predicted failure times corresponding to the calculated maximum stresses. Two of the failures are given as a time range because exact failure times are unknown.

Times for various maximum fibre strains are also shown in Figure 6 for several specimens, some of which were not taken to failure. It is expected that these values could be somewhat in error due to the difficulty in estimating true strains in the bend specimens. These points are plotted as times for 5, 10, and 20 percent strains, against the calculated fibre stresses.

The minimum creep rates for the outer fibres of the bend specimens are shown in Figure 5, plotted against the calculated stresses. These rates were overestimated by about a factor of two.

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Figure 4. TENSILE CREEP DATA FOR LEAD

Figure 5 Tensile Creep Data Showing Stress vs Creep Rate

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Figure 6 Tensile Creep Data Showing Stress vs Time for Various Strains and Failure, With Experimental Values from Bending Tests

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Conclusions

The errors in the predicted failure times and creep rates might be explained as follows. The tensile creep data is constant load and not constant stress. As the tensile specimens elongate their effective cross-sectional areas are reduced by cracks or "necking down", or both, so that the true stresses are not constant, but increase throughout the lives of the tests. Thus, if a specimen has elongated by 20 percent, the cross-sectional area can be assumed reduced by 20 percent, in first approximation, to keep the total volume of material constant. The true stress is then 20 percent greater than the nominal stress. Since the tensile specimens elongate at a fairly uniform rate to about 20 or 30 percent before final acceleration to failure, or third stage creep, the true stresses vary from the initial nominal values to about 20 or 30 percent above the nominal values, over the life of the tests. The true stresses can then be taken to represent an average of say ten percent above nominal for predicting creep-rupture lives.

In the bend tests only the tensile side of the specimens exhibit cracking, and any reduction in area on the tensile sides are accompanied by an increase in area on the compressive sides of the specimens. It may be assumed, in first approximation, that these two effects tend to cancel one another so that the maximum fibre stresses remain essentially constant over the life of the tests.

If a true tensile creep-rupture curve is constructed by assuming true stresses to be ten percent above the nominal values, the creep-rupture lives are increased by a factor of two to three. This appears to account for the discrepancies in the bending failure times, as indicated by the dotted line in Figure 6.

The overestimates in minimum creep rates for the outer fibres of the bend specimens are consistent with the above explanation. If the creep rates for the curves of Figure 5 corresponded to true stresses about ten percent above the nominal values, the measured creep rates would be in good agreement.

References

1. D. L. Platus, "Stress Analysis of a Heat Exchanger Tube in Creep Bending", ORNL 57-2-101 (Secret)
2. G. H. MacCullough, "An Experimental and Analytical Investigation of Creep in Bending", Journal of Applied Mechanics, 1933.
3. Y. Pao and J. Marin, "Deflection and Stresses in Beams Subjected to Bending and Creep", Journal of Applied Mechanics, December, 1952.

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