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Effect of Pressure on Creep in Tin*

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Bending creep of tin is reported with an activation volume of approximately 8.5×10^{-24} cm^3, essentially independent of temperature between 0° and 5... and pressure to 8 kbar. Pressure dependence of the output of resistance-type strain gauges is given.

INTRODUCTION

HIGH-PRESSURE phenomena in solids have been discussed.[1–3] Christy[4] found the activation volume for creep in silver bromide to be $6.3\pm0.5\times10^{-23}$ cm^3, slightly less than the $7\text{–}7.6\times10^{-23}$ cm^3 for diffusion as determined by Tannhauser.[5] Butcher and Ruoff[6] and DeVries, Baker, and Gibbs[7] found the activation volume for creep in lead (fcc) to be approximately the atomic volume. This is nearly equal to that for self diffusion in lead as determined by Nachtrieb, Resing, and Rice.[8] Tin has a tetragonal structure.

SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURE

Samples were prepared from three grades of tin. The first was of unknown origin, but marked 99.99+%. The second was 99.9+% tin purchased from Morris P. Kirk and Sons, Inc. 99.999% tin was purchased from the ... Chemical Corporation. An ingot of the tin was rolled to approximately 0.35-cm thickness, after which samples were cut and filed to finished size: 2.4 cm long, 0.275 cm wide, and 0.25 to 0.35 cm thick. Specimens spontaneously recrystallized completely between preparation and use, with a final average grain size of approximately 0.1 mm.

The tin samples were loaded under 3-point loading as described for lead.[7] The distance between end supports was ...1 cm and the central load of approximately ... kg was applied by a spring.

Two methods were employed to measure sample deformation: A differential transformer and resistance-type strain gauges. The differential transformer was basically the same unit described for use on lead. It had a linear region of approximately 1-cm length and an output of approximately 5 V/cm.

The resistance strain gauges (BLH AB-7 and ABF-32) were bonded directly to the sample with Eastman 910, and measured directly the strain at the tension surface of the sample. The effect of pressure on strain-gauge output was determined by attaching the strain gauge to a spring steel beam which was bent about a form of known radius of curvature. The beam was secured in this position by a glass wire that was broken at various pressures allowing the beam to straighten out. Noting the strain indication at various pressures gave an indication of the effect of pressure on strain-gauge output. The results of these tests are shown in Fig. 1.

A large transient output of the gauge upon any pressure change was encountered with resistance type gauges. Upon initial application of pressure, the gauges indicated an apparent shortening of the samples, the rate of which decreased approximately exponentially with time. Soft metals such as tin, showed very large effects (apparent transient strains of ... to 0.2% at 10 kbar). The effect was considerably less on brass and very small for steel. The time required for the transient to disappear was often as long as 12 h for tin at 10 kbar and only a few minutes when the gauge was attached to steel under the same conditions. These transients made pressure changes and subsequent rapid strain readings difficult. As an alternative method,

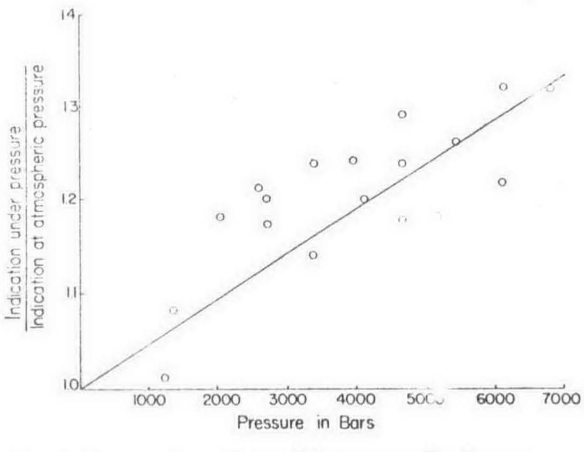

FIG. 1. Pressure dependence of the output of resistance strain gauges (BLH type AB-7 and type ABF-32).

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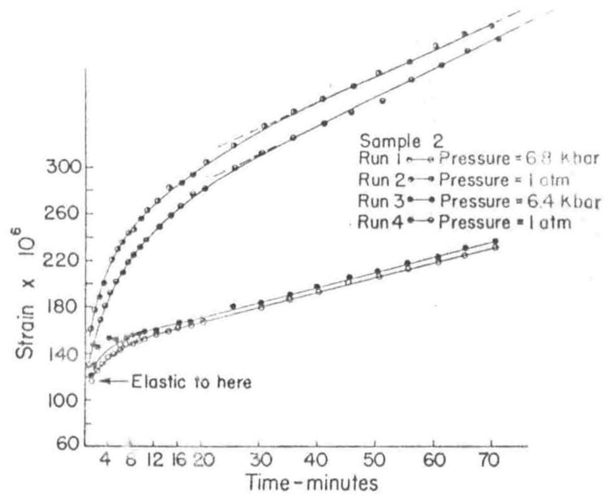

FIG. 2. Pressure dependence of creep in tin at 27°C. All curves were taken on the same sample with the sample unloaded at room temperature and pressure for approximately 1 h between runs. Strain measurements taken with resistance-type strain gauges.

creep at different pressures was measured on the same sample by first dropping the pressure, removing the load from the sample, putting the sample back to the new pressure, and reloading the sample by fusing the wire after the transients had disappeared.

The pressure vessel has been described.[7] The pressure medium was usually kerosene with a few studies made in Dow Corning 200 fluid. No difference in creep was observed in the two fluids.

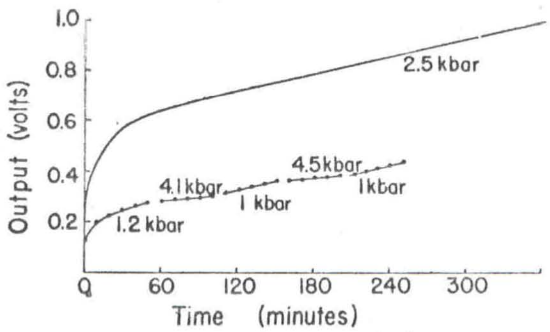

FIG. 3. Typical creep run and creep series on tin. Measurements made with a differential transformer. Data taken at 27°C.

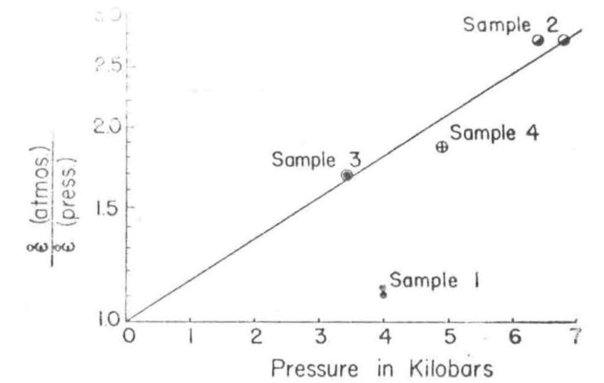

FIG. 4. Pressure dependence of the creep rate in tin. Measurements made with resistance-type strain gauges.

EXPERIMENTAL RESULTS

Figure 2 shows typical creep data taken with resistance strain gauges. Dashed lines indicate assumed steady-state creep values. Figure 3 shows a typical creep curve where the pressure was held constant and a creep series where at periodic intervals the pressure was changed as shown. Figure 4 shows a log plot of the ratio of strain rate at atmospheric pressure to the rate at high pressure as a function of pressure. The line shown represents an activation volume of approximately 9×10^{-24} cm³ calculated from

$$\Delta V^{\neq}=[KT/(p_2-p_1)]\ln(\dot{\epsilon}_1/\dot{\epsilon}_2), \qquad (1)$$

where $\Delta V^{\neq}$ is the activation volume, K is Boltzman constant, T the temperature, and $\dot{\epsilon}_i$ the deformation rate at pressure p_i. With the differential transformer, four to ten series of runs were made at each of the temperatures 0°, 27°, and 57°C. While the more impure tin deformed more slowing under a given load and environment than the 99.999% tin, the effect of pressure was the same. All the data on tin could be fit by $\Delta V^{\neq}=(8.5\pm2)\times10^{-24}$ cm³. Within experimental error $\Delta V^{\neq}$ showed no temperature dependence. The observed value is approximately $\frac{1}{3}$ of the atomic volume of the tetragonal tin (atomic volume about 27×10^{-24} cm³) compared to $\frac{2}{3}$ of the atomic volume for the face-centered cubic lead as reported previously.