LBL-23604

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

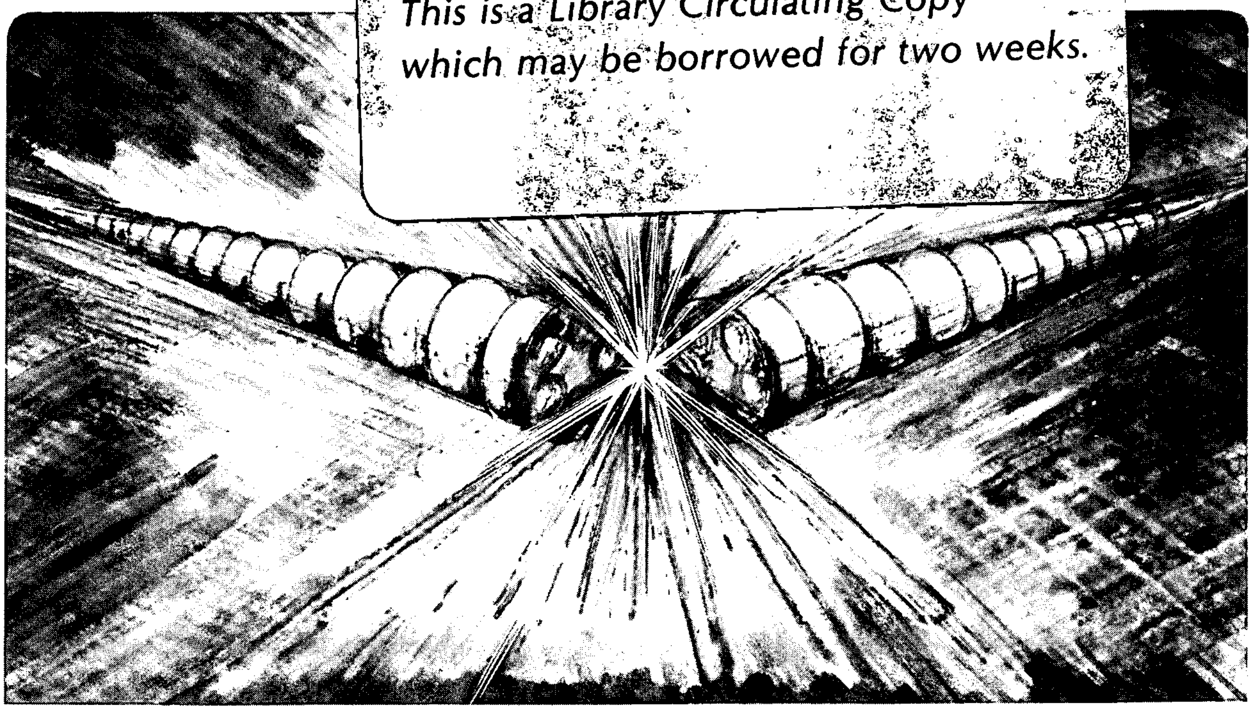
Accelerator & Fusion Research Division

Presented at the International Cryogenic Materials Conference (ICMC), St. Charles, IL, June 15–18, 1987, and to be published in Advances in Cryogenic Engineering — Materials, Vol. 34

A Creep Measurement of Unidirectional Epoxy-Fiberglass Rod

N.A. Munshi and R.C. Wolgast

June 1987



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

A CREEP MEASUREMENT OF UNIDIRECTIONAL EPOXY-FIBERGLASS ROD

N.A. Munshi and R.C. Wolgast

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

INTRODUCTION

This creep measurement was made to prove the capability of a unidirectionally reinforced, epoxy-fiberglass rod to hold stable dimensions in compression over a 10 year period, during which operating temperatures of 40°C (104°F) could occur. This material has a high modulus of elasticity in tension and compression (~$6x10^6$ psi) and strengths in excess of 100,000 psi. It's high strength and low thermal conductivity in the range from 300K to cryogenic temperatures make it ideally suited for cryogenic supports. The sample tested was taken from a mass produced lot. It was 16 mm in diameter (0.625 in.), overall length of 229 mm (9 in.), extensometer length 143 mm (5.62 in.). It was tested in compression at 52 MPa (7500 psi) at 40°C for 1000 hours. The measurements were analyzed according to the creep correlation that the logarithm of the "creep modulus" is linear with the logarithm of time. The creep modulus is the constant test stress value divided by the total fractional deflection measured as a function of time. The measured fractional deflection due to creep after 1000 hours was $3x10^{-5}$. Extrapolation of the data to 10 years under the test load of 52 MPa predicts a fractional deflection of $6x10^{-5}$.

The low stress level was appropriate to a conservative design for the dipole magnet support struts for the Superconducting Super Collider cryostat (alternate design), an application requiring long term accurate positioning of the magnet. The struts carry the weight of the magnet, at liquid helium temperature, to the base at ambient temperature. An elevated ambient standby or storage temperature is the critical temperature for creep deflection in this case.

THE TEST SPECIMEN

The test specimen was commercially manufactured by molding and is described by the manufacturer* as made with a modified cyclo-aliphatic epoxy and type E glass with a commercial finish (Owens-Corning OCF-462 CA**); the finish has been modified since the production of the test specimen before 1985). Mechanical properties of this and similar materials are available in Refs. 1–3.

---

*Ohio Brass Co., Mansfield, Ohio; Mr. Wayman Goch; the brand name of the rod is "Hi-Lite."

**Tradenames are used in this report for clarity, in no way does this imply endorsement by the Lawrence Berkeley Laboratory, nor does it imply that the material is the best available.

DESCRIPTION OF APPARATUS

Deflection of the specimen was measured by linear variable differential transformers (LVDT). Strain gages were added to check for bowing and consistency of the measurements. A schematic diagram of the apparatus is shown in Fig. 1. The upper and lower grips are made of mild steel, and the sample is partially insulated thermally from the metal by Bakelite.

The holders for the LVDTs and the control rods were made of stainless steel, and attached by means of set screws and epoxy adhesive. The strain gages and thermocouples were attached by epoxy adhesive. There were five thermocouples on the sample, and two each on the control rods, with one thermocouple in the polystyrene foam chamber. Three strain gages, spaced 120° around the rod, were mounted on the sample at the center of the test length, with one strain gage each on the control rods. In order to compensate for the variation in length due to temperature fluctuations, two control rods made of the same material were mounted on either side of the sample. Incomplete compensation was achieved, however, because the control rods were shorter than the sample rod—necessary to accommodate the LVDTs in the tester. The use of two control rods compensated for possible bowing of the sample. The LVDTs used to monitor the deflection were Schaevitz model LBB-375-TA-060, which have the following specifications: a choice of range from ±0.010 to ±0.060 inches, a linearity of ±0.2% of full range, a repeatability of 4 x 10^{-6} inches, and an operating temperature range of 0°C to 40°C. The manufacturer assured us that the LVDTs would be stable and linear to at least 50°C. Two temperature sensors were placed on the sample rod—one above the top stainless steel holder, and the other in the center of the sample. Initially the sample was wrapped with two heater wires—one above and below the sample/LVDT holders, and the other in the center gage section. This provided for very non-uniform temperature distribution, and so the heaters were removed from the sample and placed on the outside of a box constructed from Q-tip sticks and aluminum foil. One heater was placed on automatic control, and the other on manual—later constant—setting. The whole assembly was placed in a one inch thick polystyrene box lined with aluminum foil. A heater tape was wrapped around the top grip and lower actulator rod, controlled by a variac. A small fan was placed inside the chamber to distribute the heat more uniformly.

The load was applied using a hydraulically operated MTS machine capable of carrying a load of 100 kN (22,500 lb). The grips were screwed into the actuator which has a built-in calibrated load cell. The load is read as a voltage output; this was set at 2.05 volts, which corresponds to 52 MPa stress in the specimen. It was checked every day, and no drift was detected. Stroke is the voltage readout which records and adjusts the movement of the actuator rod to maintain the regulated load value. The readout has a sensitivity of 10 volts per 100 mm. Drift is approximately one-tenth per cent. Stroke excursions as high

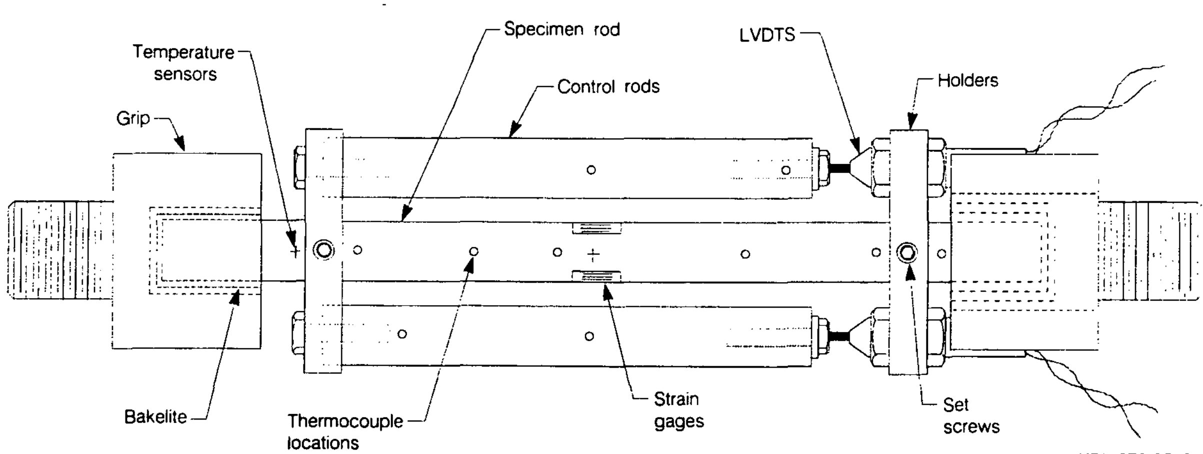


Fig. 1. Mounting of the specimen. The length of specimen between holders is 14.24 cm (5.6208 in.). The specimen and control rods were cut from the same piece of material.

as 0.05 volts were recorded during the run. The mechanical tester was used to avoid the delay of providing a dead weight tester.

PROCEDURE

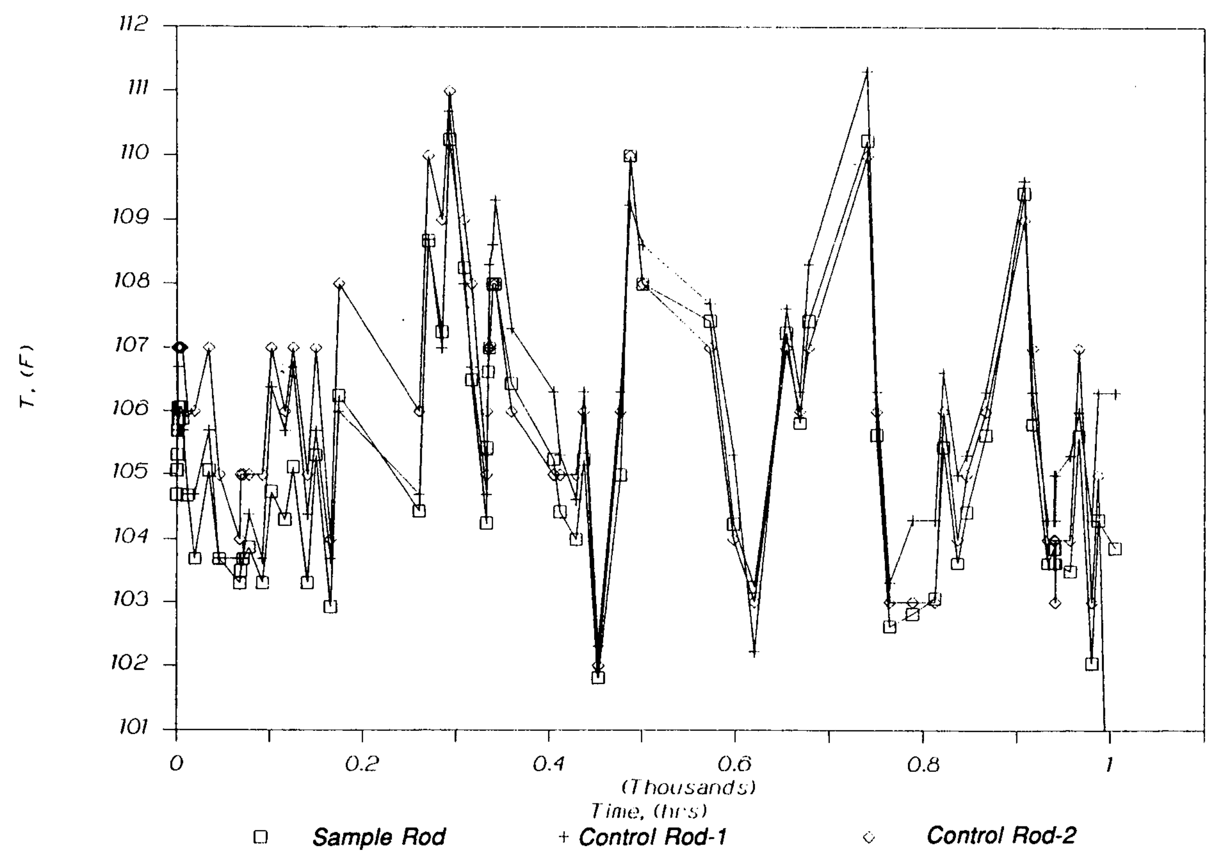
The specimen was seated in the grips by three load cycles to 104 MPa (15,000 psi), twice the test load for the creep measurement. The readings of the LVDTs, and of the strain gages, were virtually identical for loading and unloading. Data from these load cycles were used to calculate the Young's Modulus for compression at this low end of the stress-strain curve: 6.3 x 10^6 psi from the LVDT data and 6.8 x 10^6 psi from the strain gage data.

The load was then set for the constant creep test stress of 52 MPa (7500 psi) with the tester operating in the regulated constant load mode. Readings were taken after one minute and then every 5 minutes for the first 2 hours. The test was continued for 1005 hours.

RESULTS AND DISCUSSION

In order to accomplish the purpose of the test it was necessary to measure small deflections using every sensitive instruments. An unfavorable signal to noise ratio had to be anticipated, but a signal clear enough to place an upper bound on the creep deflection, at least, was considered possible.

Repeated temperature excursions occurred during the test, some evidently due to the room temperature ambient rising over the weekends when the building air conditioner was turned off. The excursions showed some correspondence to changes in the LVDT and strain gage readings. Figure 2 shows the weighted average temperature of the specimen and control rods during the test. The weighted average temperature was calculated to approximate



XBL 876-8514

Fig. 2. The weighted average temperature of the specimen and control rods as a function of time.

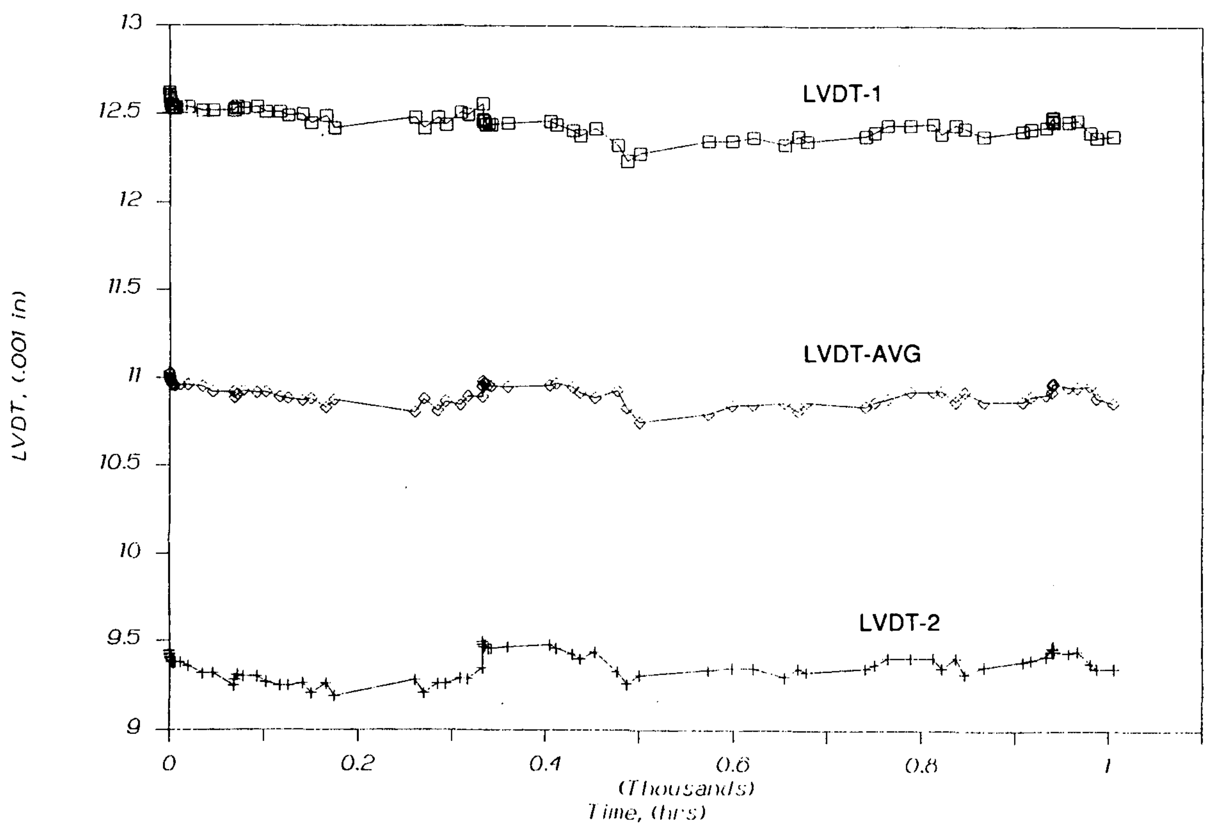
the integral of T•dl, where T is the thermocouple reading and dl is the length of rod associated with that thermocouple. This is the relevant parameter in trying to correlate the temperature variations with the strain variations.

The readings of the two LVDTs and their average value are shown in Fig. 3. The value of the average reading before the application of load was 18.3 x 10^{-3} inches.

During the test there were two power failures which caused unloading of the specimen; these occurred after 332 hours and after 939 hours. Figure 4 is a plot on a sensitive scale of the specimen strain (fractional) calculated from the LVDT-AVG values. The power outages are noted on the graph and the effect of specimen unloading is evident. The data points with high temperatures were: at 292 hrs (42.8°C), 334 hrs (42.8°C), 342 hrs (43.3°C), 486 hrs (44.4°C), 500 hrs (46.7°C), 572 hrs (42.8°C); 660 hrs (42.8°C); 740 hrs (44.4°C); 908 hrs (44.4°C).

Figure 5 shows the readings of the specimen rod strain gages and their average value—showing very much the same behavior as the LVDTs.

In order to estimate the strain of the material after a 10 year operation, the data was analyzed according to the correlation that the logarithm of the creep modulus is linear with the logarithm of time until the onset of tertiary creep.[4,5] The creep modulus, Ecr, is the constant test stress value divided by the total fractional strain measured as a function of time, starting from the unloaded conditions. (At the end of a short term loading period the creep modulus is equal to the Young's modulus—assuming linear stress-strain behavior). The data is plotted in Fig. 6. The dashed line shows the fit to the data used to extrapolate to 100,000 hours. The line was drawn to discount the effect of the power outages.



XBL 876-8515

Fig. 3. LVDT readings and their average value as a function of time.

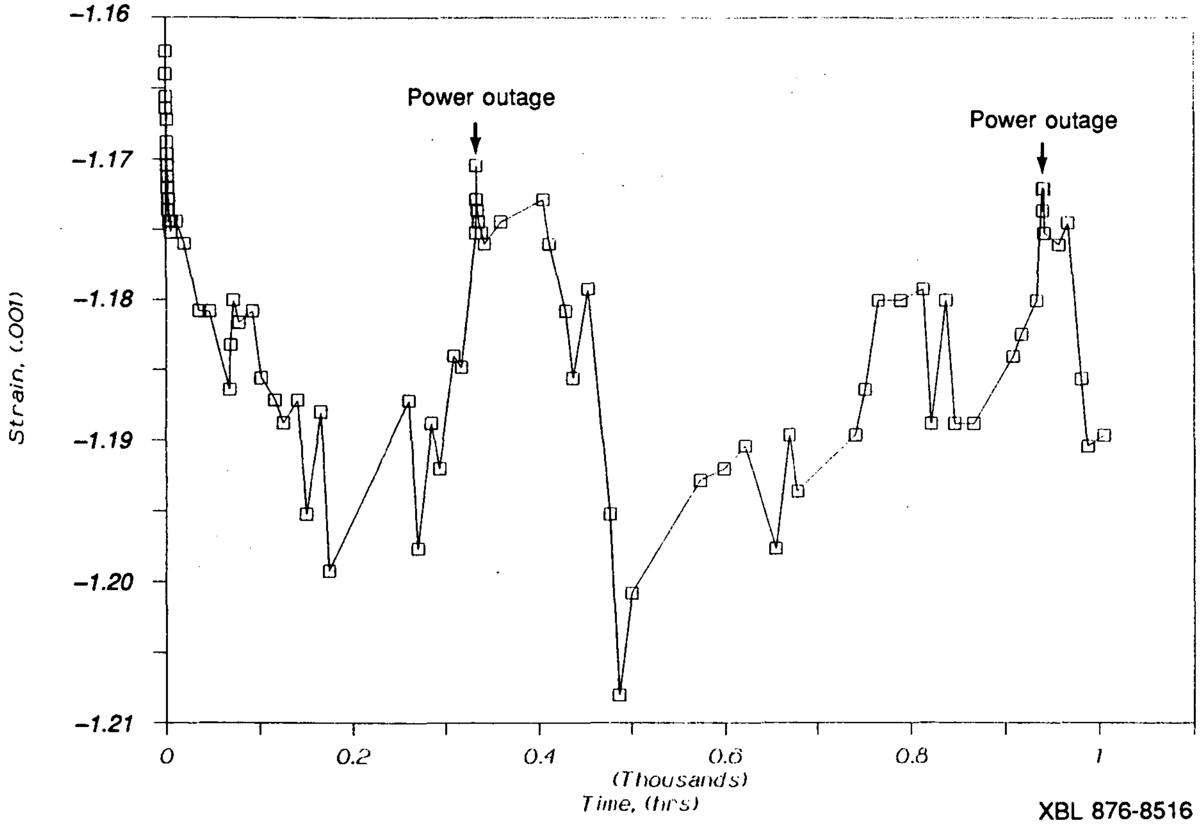


Fig. 4. Fractional strain calculated from LVDT-AVG as a function of time.

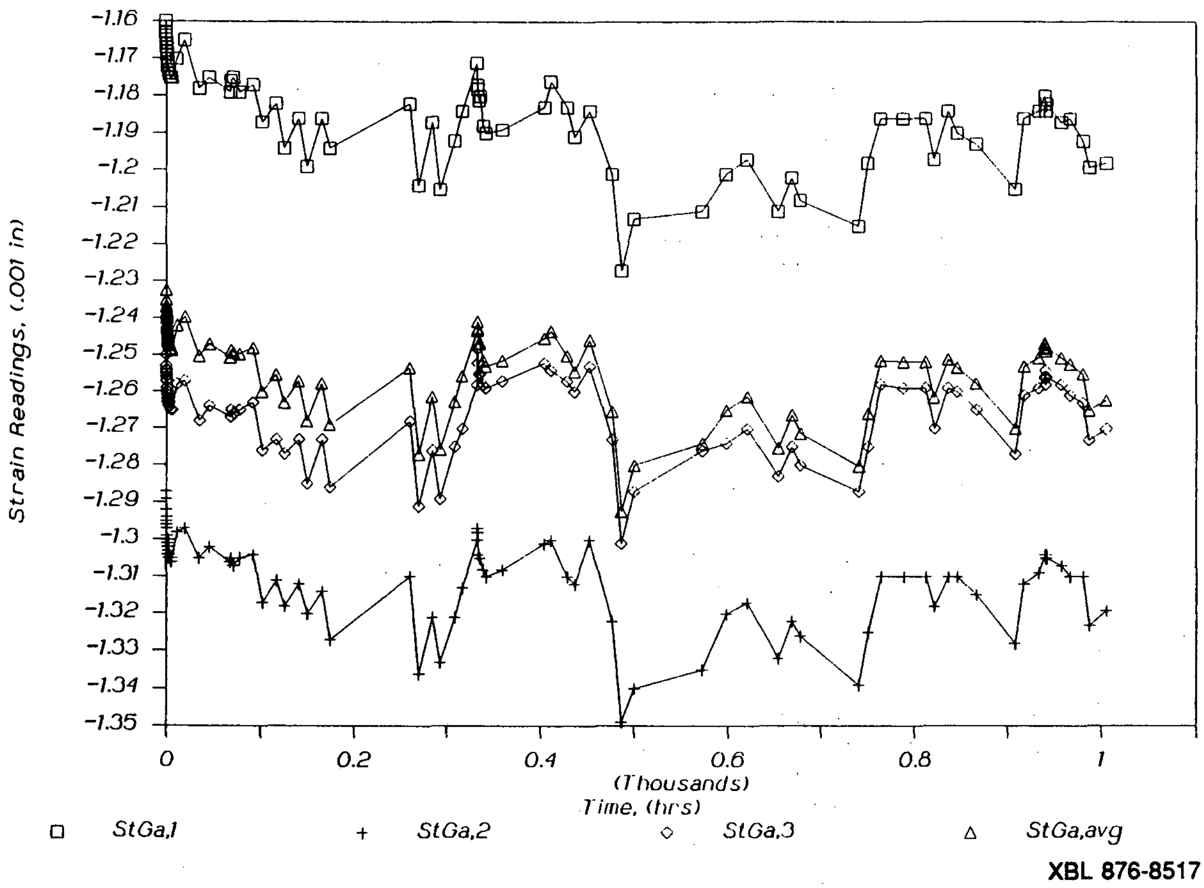


Fig. 5. Strain gage readings and their average value as a function of time.

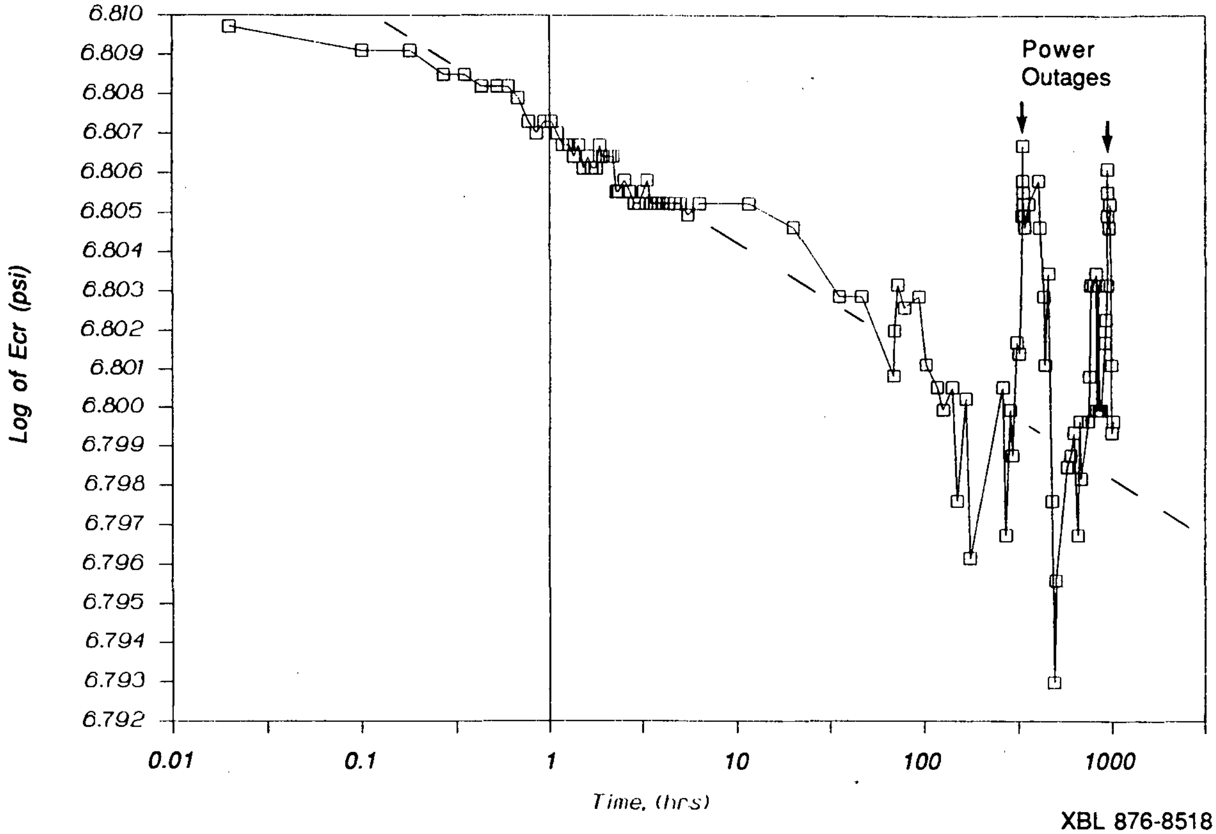


Fig. 6. Log (Ecr) vs Log (time), using log to base 10, Ecr in psi and time in hours.

CONCLUSIONS

The measurements showed a fractional deflection due to creep of 3×10^{-5} over the 1000 hour test period. Extrapolation to 10 yrs by the creep correlation indicated a fractional deflection of approximately 6×10^{-5}. Thus, this type of material would be suitable for long term accurate support of equipment.

The effort also demonstrated that a modest program of 1 year test duration with a number of samples would contribute substantially to our knowledge of creep behavior of this type of composite material.

ACKNOWLEDGMENTS

We would like to thank the staff at the National Bureau of Standards for letting us use their expertise and facilities at Boulder, Colorado, to carry out the test, D. McColskey, B. Kasen and R.P. Reed; and to C.E. Taylor of LBL for advice and fiscal support.

This work was supported by the Office of Basic Energy Science, U.S. Department of Energy, under Contract DE-AC03-76SF00098.

REFERENCES

1. The Ohio Brass Co., Mansfield, Ohio.
2. E.L. Stone and W.C. Young, 7th Symposium on Engineering Problems of Fusion Research, Knoxville, Tennessee, October 25–28, 1977.
3. M.A. Green, LBL Engineering Note AA0100-M5991, October 1982.
4. Modern Plastics Encyclopaedia, 1984–85 edition.
5. G.G. Trantina, "Creep Analysis of Polymer Structures," 42nd Annual Technical Conference "ANTEC 84," pg. 569, Society of Plastics Engineers, Brookfield Center, CT.