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CREEP TESTING OF FOIL-GAGE METALS AT ELEVATED TEMPERATURE USING AN AUTOMATED DATA ACQUISITION SYSTEM

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INTRODUCTION

Foil-gage materials are being considered for a radiative metallic thermal protection system (TPS) for advanced space vehicles in a number of innovative concepts. One concept focuses on the use of foil-gage titanium alloys in the fabrication of test panels for multiwall TPS [1,2], for use at temperatures in the range of 800°F to 1000°F. The interest in foil-gage materials, however, has raised some concern regarding the adequacy of the mechanical property data base. In addition, there is concern that the commonly used strain measurement techniques and data collection methods may not be adequate for foil gage material in the determination of elevated temperature mechanical properties such as creep. Although literature is available regarding the creep properties of Ti-6Al-4V sheet [3,4], few references are available which address the particular problems associated with mechanical property determinations on foil materials [5], and none have been found which explore the potential for adapting current creep test procedures for foils.

An integral feature of many current strain measurement techniques is the use of bonded, electrical resistance strain gages. However, the operating temperature range of these strain gages is generally limited by the combined performance characteristics of the gage alloy, backing and adhesive to temperatures below 750°F [6].

Strain measurements for elevated temperature creep tests have also been conducted using optics, where a trained operator takes direct readings through a telescope viewing fiducial marks on foil-type strain gages attached directly to the specimens [3]. This method involves extensive use of trained operator time and is subject to inherent operator errors.

Another method for strain measurement involves use of a mechanical extensometer in conjunction with one or more displacement transducers. Use of the extensometer offers the advantage of elevated temperature capability. In addition, the continuous output signal from the displacement transducer is easily incorporated into automated methods of test monitoring and/or data collection. However, the weight of the extensometer when used for elevated temperature creep tests for foil gage materials can be significant, both in terms of the weight contribution of the extensometer to the total maximum test load and the grip pressure required for attachment of the extensometer to the specimen. Therefore, application of this strain measurement technique may require modifications to reduce the effective weight of the extensometer on the specimen.

The use of an automated system for data collection has obvious benefits in terms of the reduced direct labor required to conduct a creep test. In addition, incorporation of a computer into the test method can make available a variety of useful data analysis techniques such as regression analysis [7].

The purpose of this investigation has therefore been to develop a relatively simple and reliable elevated temperature creep test method for foil-gage materials by modifying a commonly available mechanical extensometer for strain measurement and incorporating an automated data acquisition system for test monitoring, data collection and data manipulation and analyses.

EXPERIMENTAL PROCEDURES

Tensile type test specimens were fabricated from nominal 0.003 in. thick foil and 0.049 in. thick sheet using annealed titanium alloy Ti-6Al-4V to the dimensions shown in Figure 1. Titanium doublers were spot-welded to both sides of each end of the foil-gage specimens to prevent localized yielding by the bearing loads induced by the alignment pins during testing. All creep tests were conducted in a constant load creep test machine equipped with a clamshell-type furnace. Uniform temperature over the specimen gage length was achieved in the furnace by an automated, zone-control temperature and power controller. A Chromel-Alumel thermocouple was used to measure specimen temperature. Specimen load was measured with a "mini" load cell positioned in the lower portion of the load train beneath the furnace. Strain measurements were made using an Applied Test Systems, Inc. Series 4100/4200 Metals Testing extensometer with a Linear Variable Displacement Transducer (LVDT). To reduce the axial load imposed by attachment of the extensometer to the foil test specimen to less than one percent of the total maximum test load, a counter-balance was designed and attached to the extensometer as shown in Figure 2. The counter-balance is suspended above the furnace by a support bar attached to the creep frame (Figure 3), and is attached to the extensometer by four connecting rods (Figure 4). Use of the counter-balance also tended to reduce the amount of initial specimen bending by reducing the grip pressure required for attachment of the extensometer to the specimen. The extensometer was calibrated using a stage micrometer in accordance with ASTM E83 to Class B-1 accuracy based on a maximum error of indicated strain of 4×10^{-5} in/in. Demonstration of the strain measurement apparatus was accomplished by comparison of the room temperature modulus of elasticity for a titanium alloy (Ti-6Al-4V) specimen,

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determined using bonded, electrical resistance strain gages, to the elastic modulus determined using the counter-balanced extensometer. Results of several test runs show the extensometer consistently indicates an elastic modulus within 2.5% of that indicated by the strain gages.

Creep tests were conducted on the 0.003 in. thick foil-gage specimens at both 800°F with a nominal applied stress of 45 ksi and 1000°F with an nominal applied stress of 25 ksi. Similar tests were also run using 0.049 in. thick sheet specimens at the same temperatures and stress levels in order to provide a basis for evaluation of the performance of the strain measurement technique for the foil-gage specimens.

The Hewlett-Packard (HP) Data Acquisition System (DAS) used is shown in Figure 5, and consists of the HP 9845A Desktop Computer, the HP 3455A Digital Voltmeter, the HP 3495A Scanner and the HP 98035A Real Time Clock which monitored and recorded specimen load, temperature, strain, power supply voltage for the load cell and extensometer transducer and elapsed time. Computer test monitoring and data collection parameters were accomplished by a modified computer program originally developed for static mechanical property test. After each test, a regression analysis software package [8] was used to provide basic data manipulation, creep curve plots, polynomial regression analysis and residual analysis of the steady-state portions of the creep curves.

RESULTS AND DISCUSSION

Alloy Creep Behavior

Creep curves for the foil and sheet specimens tested at 800°F and 45 ksi are shown in Figure 6. The sheet specimen was tested first and allowed to continue for greater than 200 hours to evaluate the total test system performance for long term testing. During this time, all test system components (e.g. instrumentation, creep test machine and data acquisition system) operated highly satisfactorily. The test run on the foil sample was conducted for approximately 100 hours. Creep curves from tests conducted on the foil and sheet specimens at 1000°F and 25 ksi are shown in Figure 7. Curves for all tests exhibited the classical shape associated with high temperature creep, i.e., an initial stage of high, but decreasing strain rate followed by a second stage in which the creep rate is constant. In addition, these curves show reasonable trends when compared with creep curves plotted from previously cited creep data [3,4], as illustrated in Figure 8. Calculated values for steady state creep rates of the foil and sheet specimens and selected data base values are listed in Table I. Examination of these also shows a favorable trend compared to the data base values. Also included in the table is the total strain determined for the specimens from the onset of loading until termination of each test.

At 800°F and 45 ksi, the foil specimen exhibited a considerably higher creep rate than the sheet sample; four times higher in the steady state portion. At 1000°F and 25 ksi, the .003 in. foil specimen again exhibited the higher creep rate, but the steady state creep rate was only twice as great as the 0.049 in. sheet specimen at this temperature-stress combination.

Test Technique Considerations

Visual inspection of the creep curves for all the specimens tested suggests the counter-balanced extensometer is responding to specimen strain in an appropriate manner, even for relatively low creep strains. A more quantitative description of the extensometer response to actual sample strain in the foil specimens can be achieved by analysis of the residuals from the steady state portion of the creep curves. Use of residuals as a criteria for adequacy of extensometer response to actual strain requires the assumption that the steady state portion of a creep curve is linear and can be accurately represented by the equation of a line generated by a first order polynomial regression analysis of the observed data. With this assumption, a residual value is the difference between actual sample strain and strain indicated by the extensometer and recording system at any given time. As such, the magnitude of the residuals provide a quantitative means of assessing the extensometer response. Figures 9 and 10 show plots of the steady state portions of the creep curves from data collected on tests of the foil specimens at 800°F and 1000°F, respectively. Superimposed on each curve is the straight line representing the assumed actual specimen behavior determined by a first order polynomial fit of the data. Residual analyses were then performed to determine the magnitude of the deviation of each observed data value from that obtained by the regression analysis. Figures 11 and 12 show plots of the residuals versus time for the foil specimens tested at 800°F and 1000°F, respectively. Examination of all the residuals for the foil tested at 800°F shows a typical residual of less than $\pm 1 \times 10^{-4}$. Similar examination of the residuals for the specimen tested at 1000°F indicates a typical residual value of less than $\pm 3 \times 10^{-5}$. Considering the total amounts of strain typically measured in creep tests even for low creep strains, the magnitude of these residuals is quite small and indicates that the test technique is suitable for creep testing of foil gage metals.

The automated DAS performed extremely well, providing increased speed and accuracy in all aspects of data handling. A demonstration of the utility of automated data collection can be seen in Figure 7, where interruption in computer service required that a number of data values be recorded by direct reading of the voltage signals. Examination of these data points suggests a reduced accuracy due to operator error. Also, fewer data observations were recorded because of the time required to take direct readings.

In addition to increased frequency and quality of data collection, use of appropriate software with the DAS computer results in greatly increased speed and precision in data manipulations such as curve plotting and data transformations. It has also made routinely available, sophisticated analysis techniques such as regression, basic statistical and residual analysis. This variety of analysis techniques and speed of data manipulation result in significant improvements in the ability to represent and interpret creep data.

CONCLUDING REMARKS

A limited number of elevated temperature creep tests have been performed on foil-gage and sheet specimens of Ti-6Al-4V using a technique employing a counter-balanced extensometer for strain measurment and an automated data acquisition system for test monitoring, data collection and data analysis. Creep tests were conducted on both the foil and sheet specimens at 800°F with an applied stress of 45 ksi and 1000°F with an applied stress of 25 ksi. Examination of the results has led to the following conclusions regarding material creep behavior and overall performance of the creep test technique.

1. The counter-balanced extensometer, specifically designed for use with foil-gage materials, performed very well, with no apparent deleterious effect on measurement of actual strain, as demonstrated by residual analysis.

2. The automated data acquisition system performed extremely well. Although the software for test monitoring and data collection has not yet been optimized for creep tests, it has proven to be extremely reliable, requiring minimum operator involvement and offering great flexibility in establishing the conditions for data collection. In addition, the HP Regression Analysis software package provided a variety of programs for data manipulation and analysis which significantly increased the speed and accuracy of basic data handling and made routinely available several advanced analysis techniques.

3. Limited examination of the creep behavior of Ti-6Al-4V sheet and foil indicates the creep rate of the foil was higher than that of the sheet, with the difference being more significant in the 800°F tests than in the 1000°F tests.

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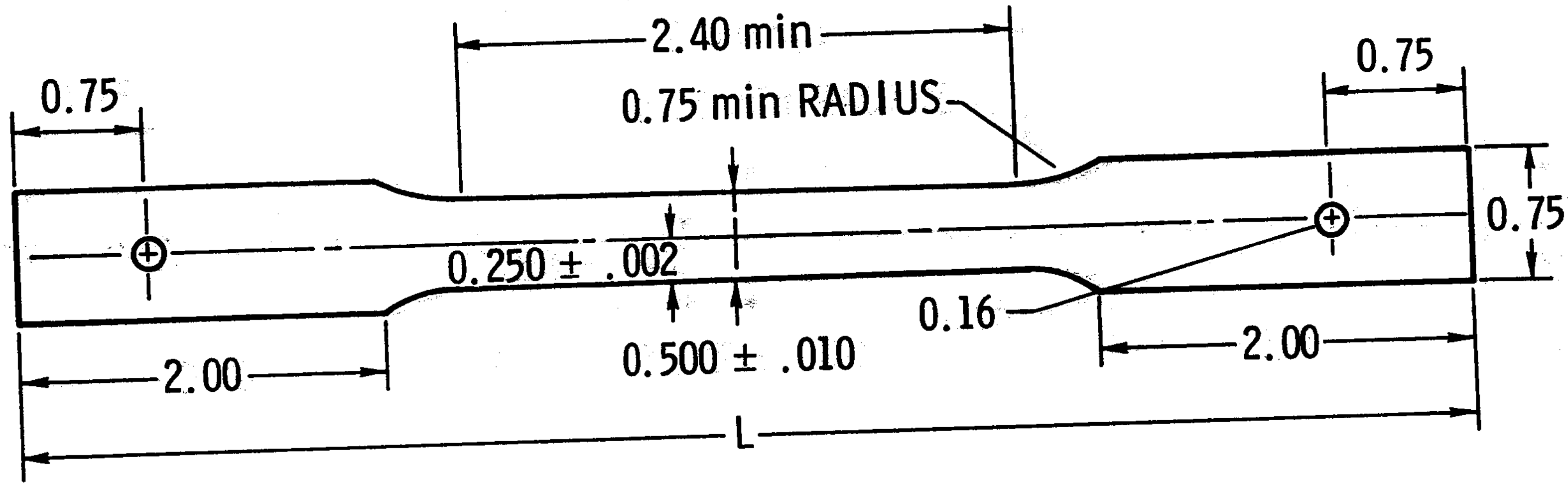

Figure 1. Creep test specimen configuration (dimensions are in inches).

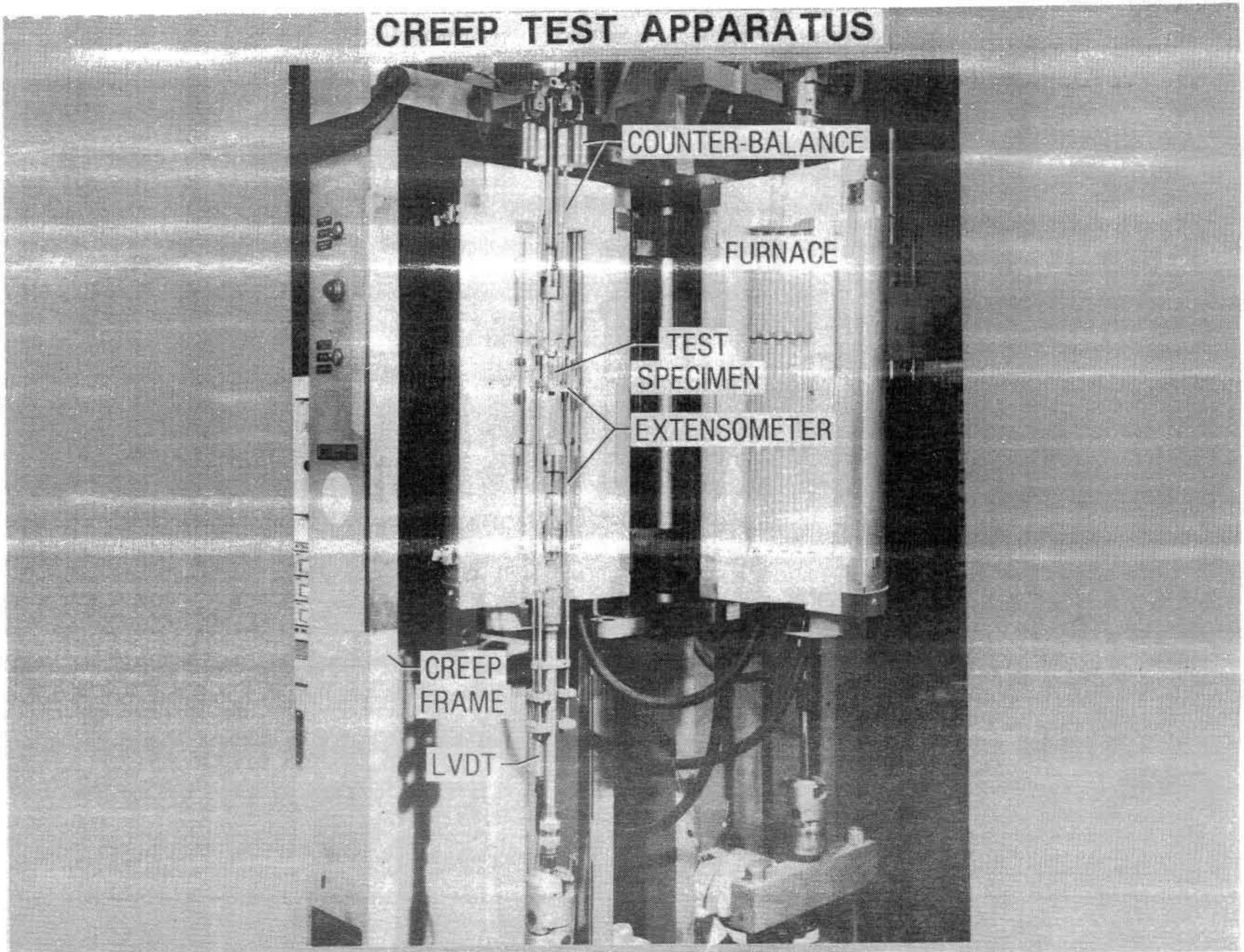

Figure 2. Creep test apparatus.

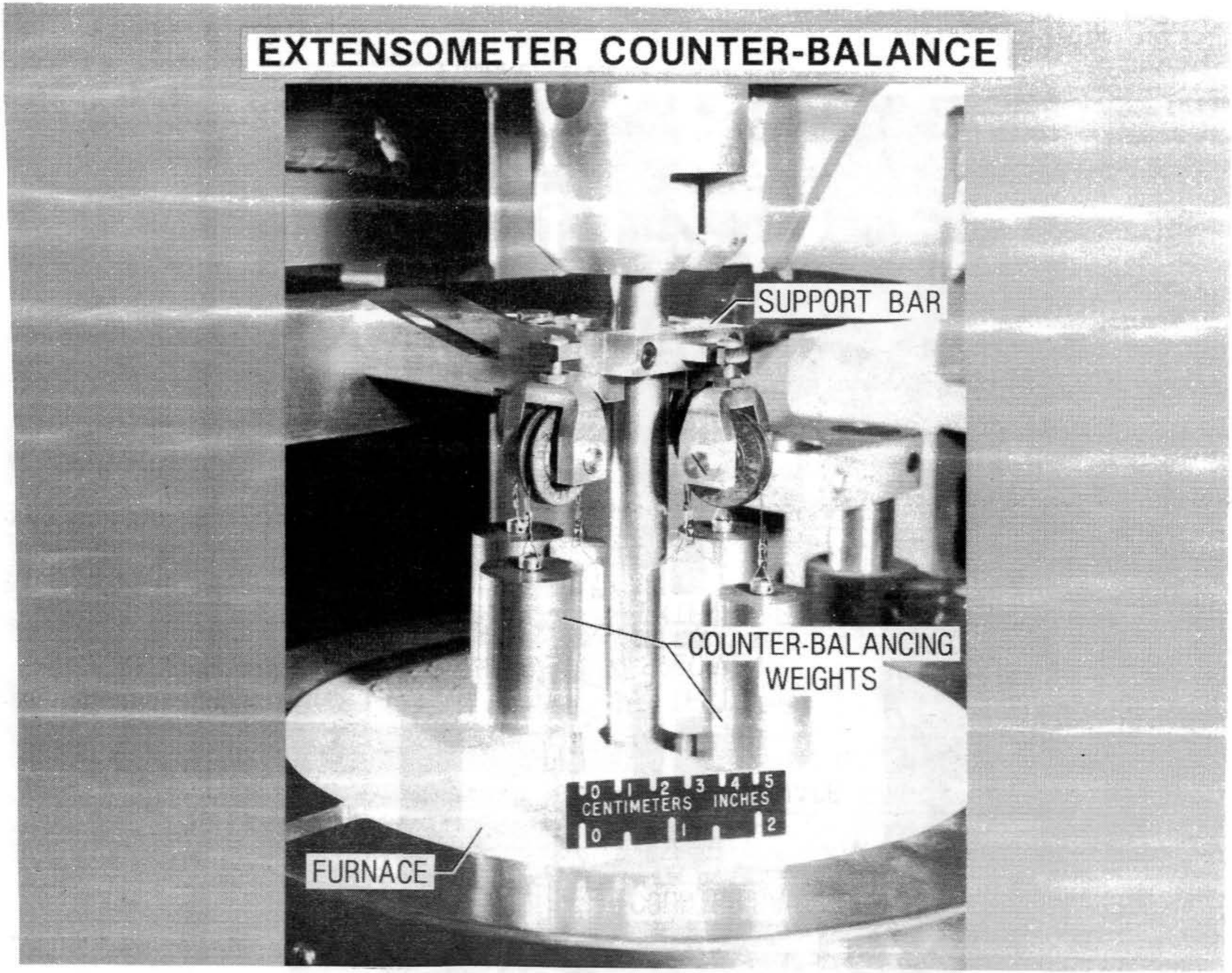

Figure 3. Extensometer counter-balance.

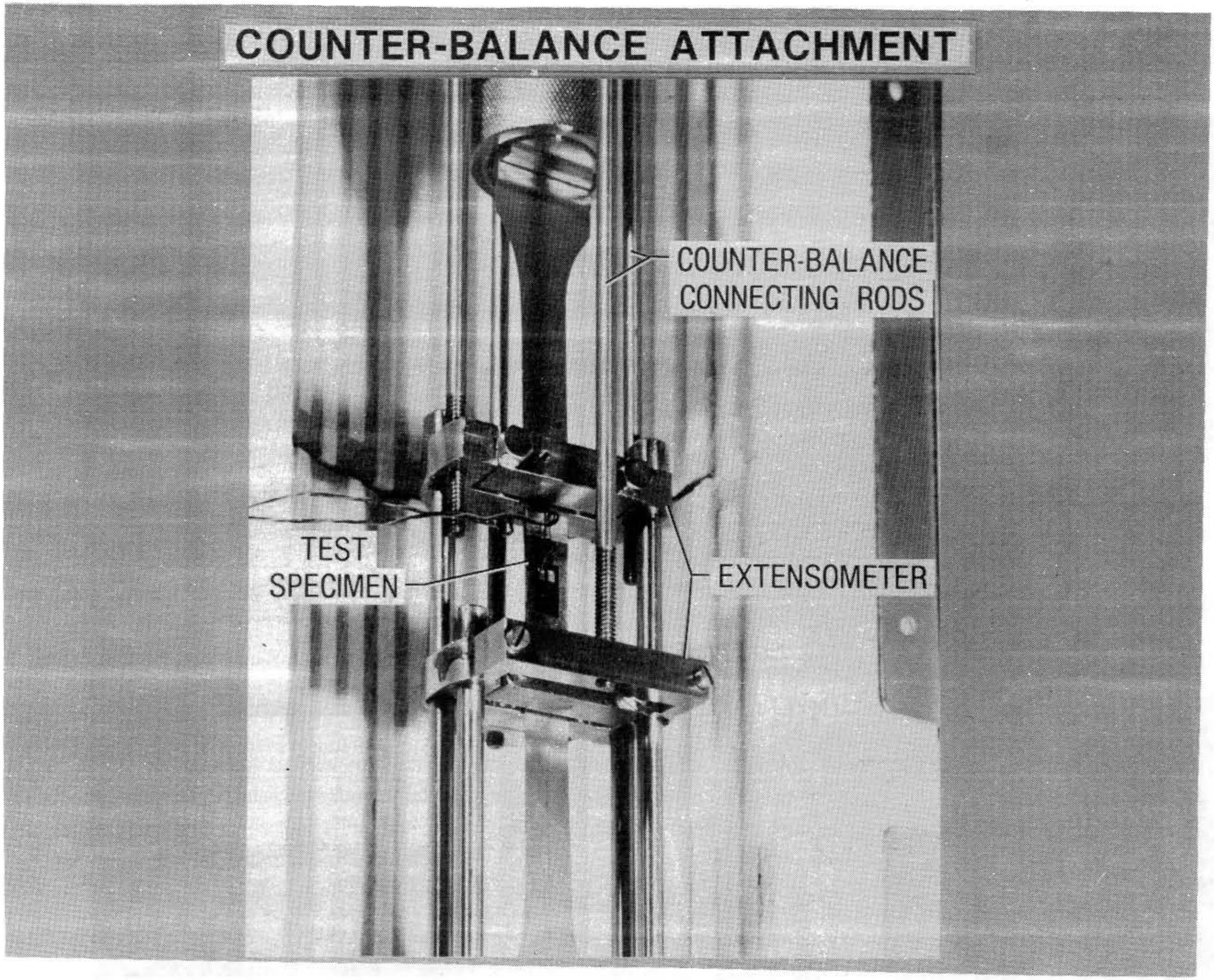

Figure 4. Attachment of counter-balanced extensometer to foil-gage specimen.

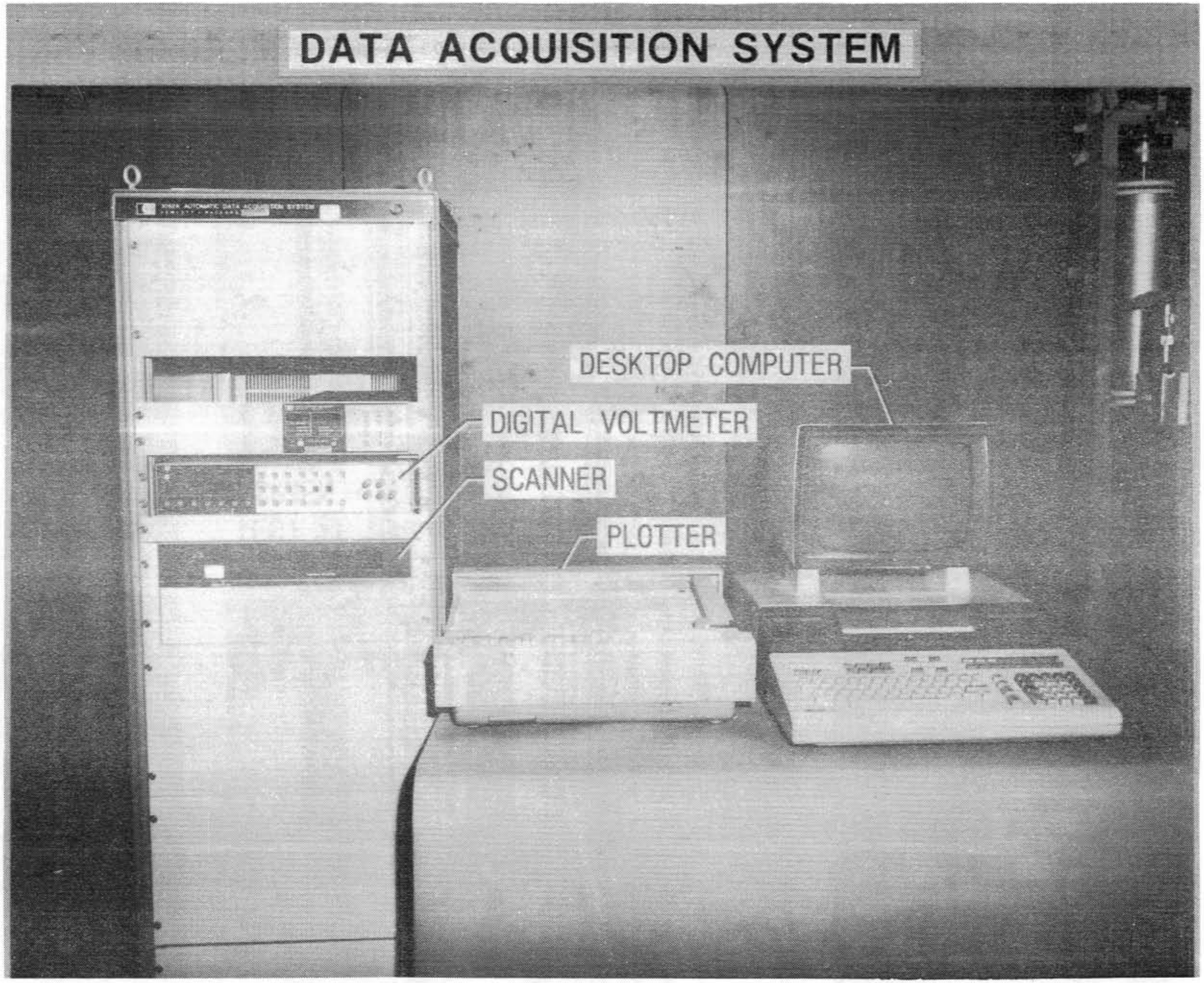

Figure 5. Data acquisition system.

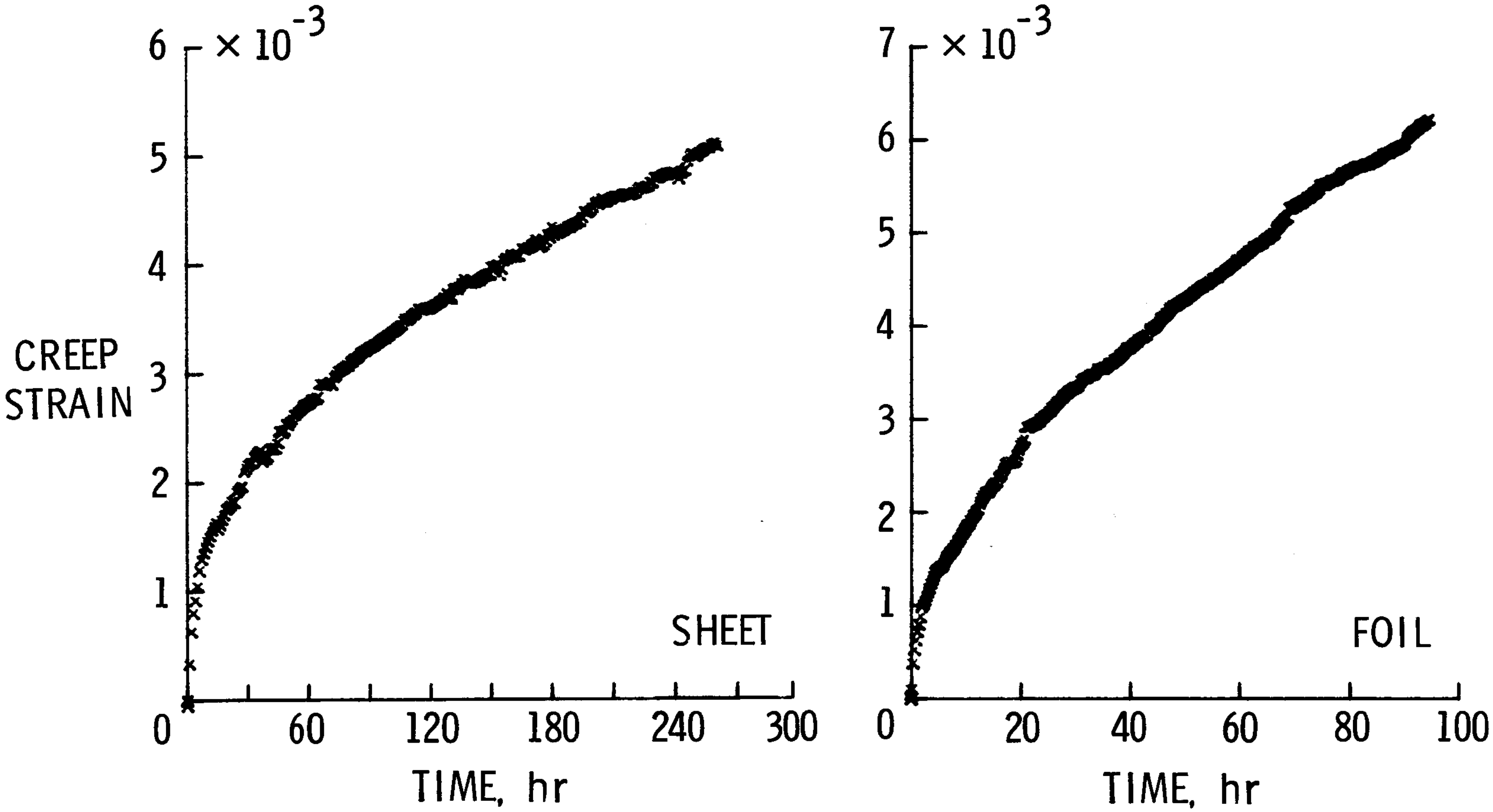

Figure 6. Creep curves for Ti-6Al-4V at nominal 800°F and 45 ksi.

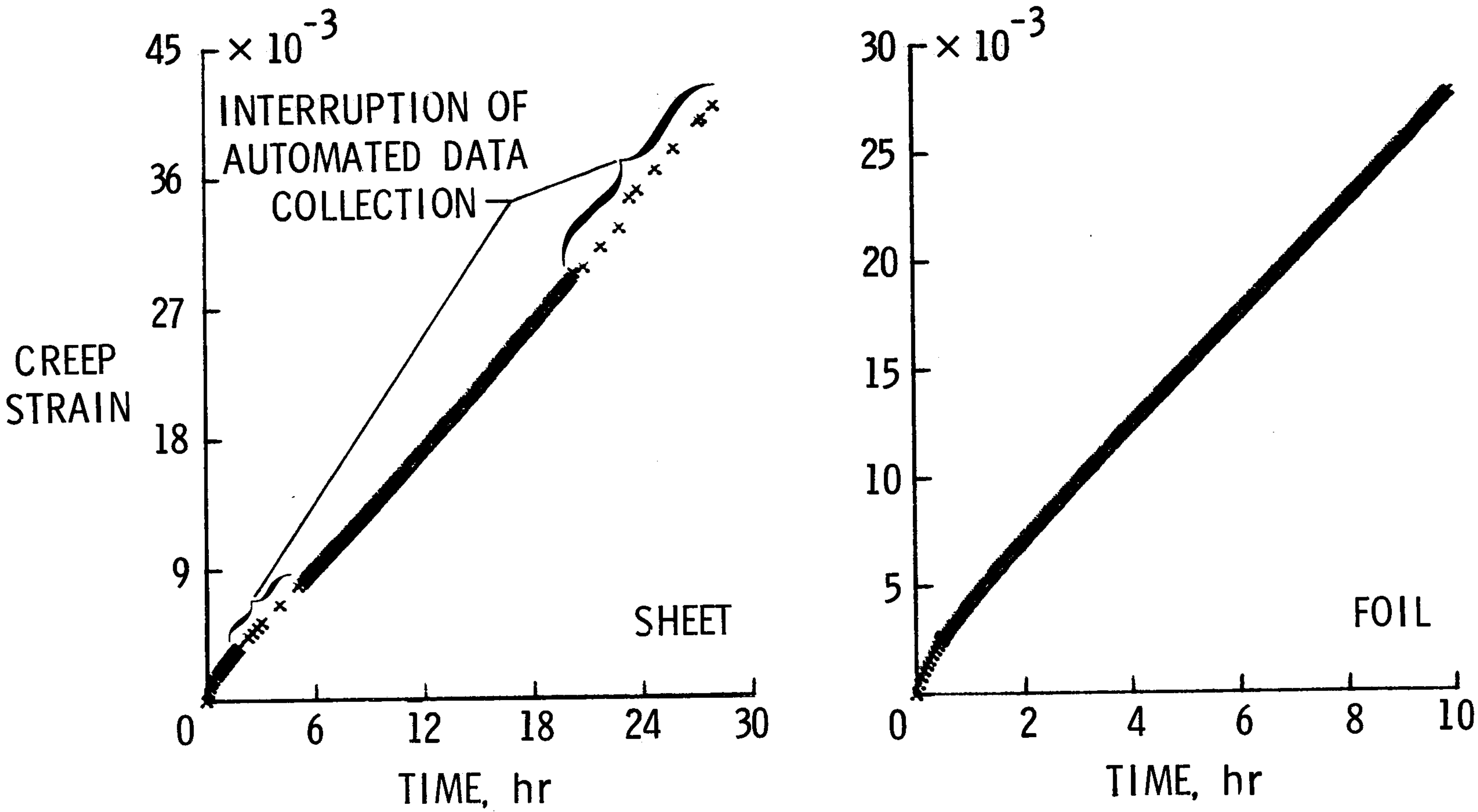

Figure 7. Creep curves for Ti-6Al-4V at nominal 1000°F and 25 ksi.

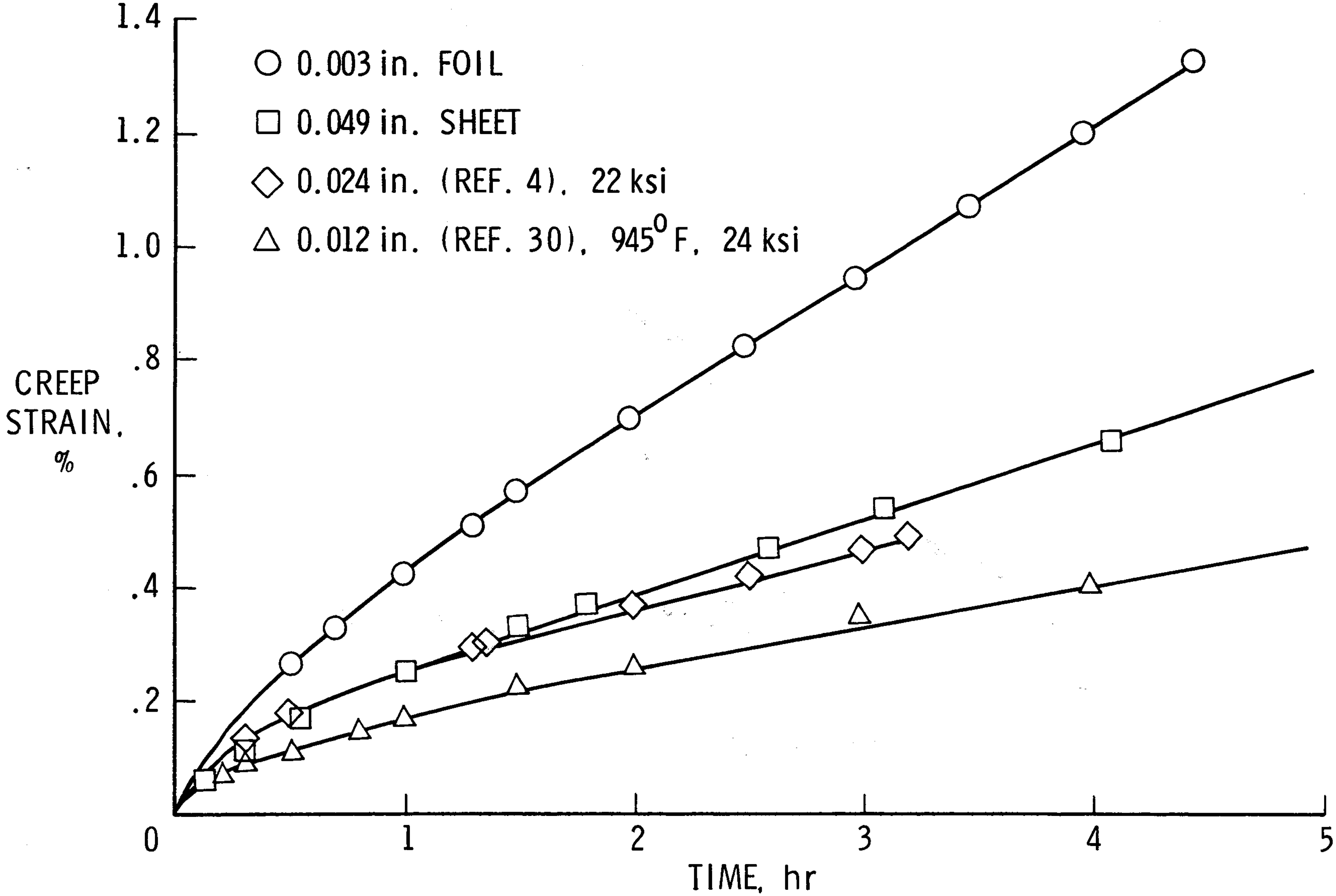

Figure 8. Comparison of creep curves for Ti-6Al-4V.

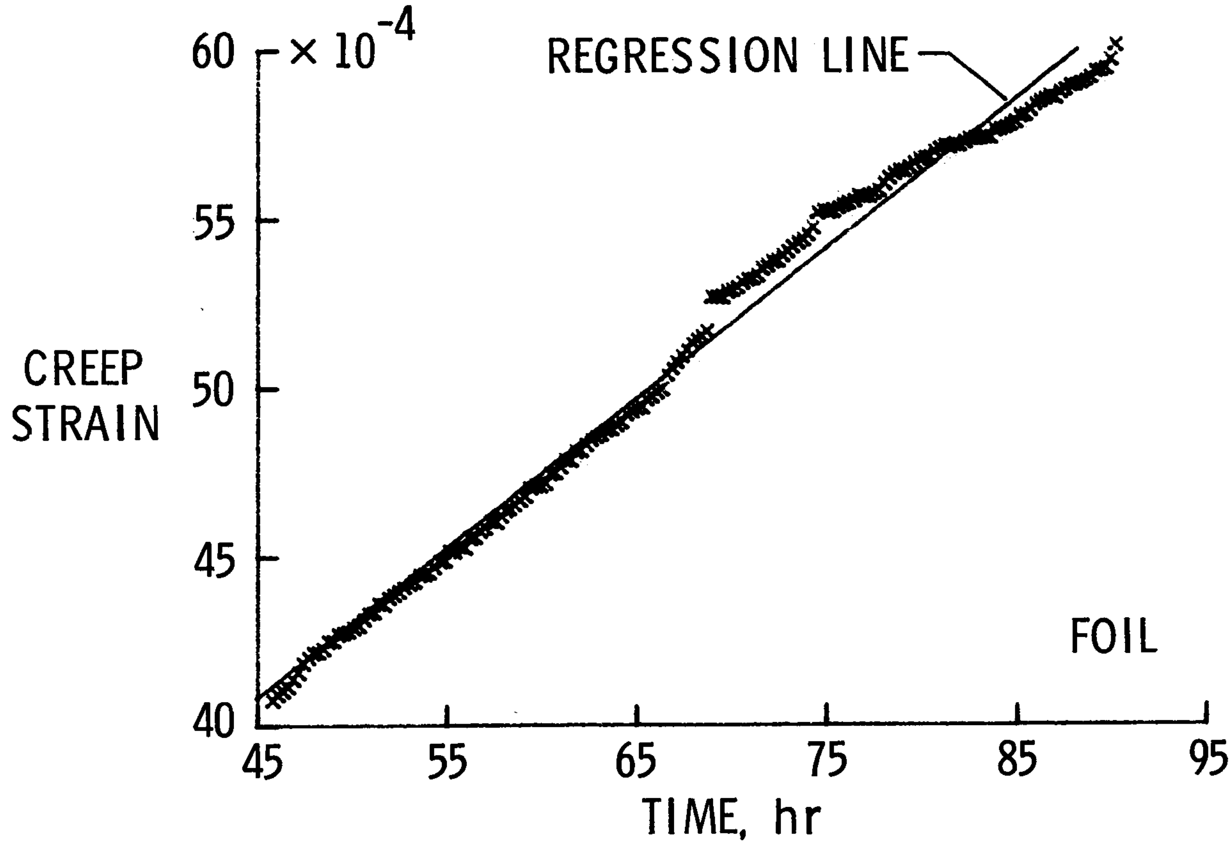

Figure 9. Steady state portion of creep curve for Ti-6Al-4V foil specimen tested at 800°F and 45 ksi.

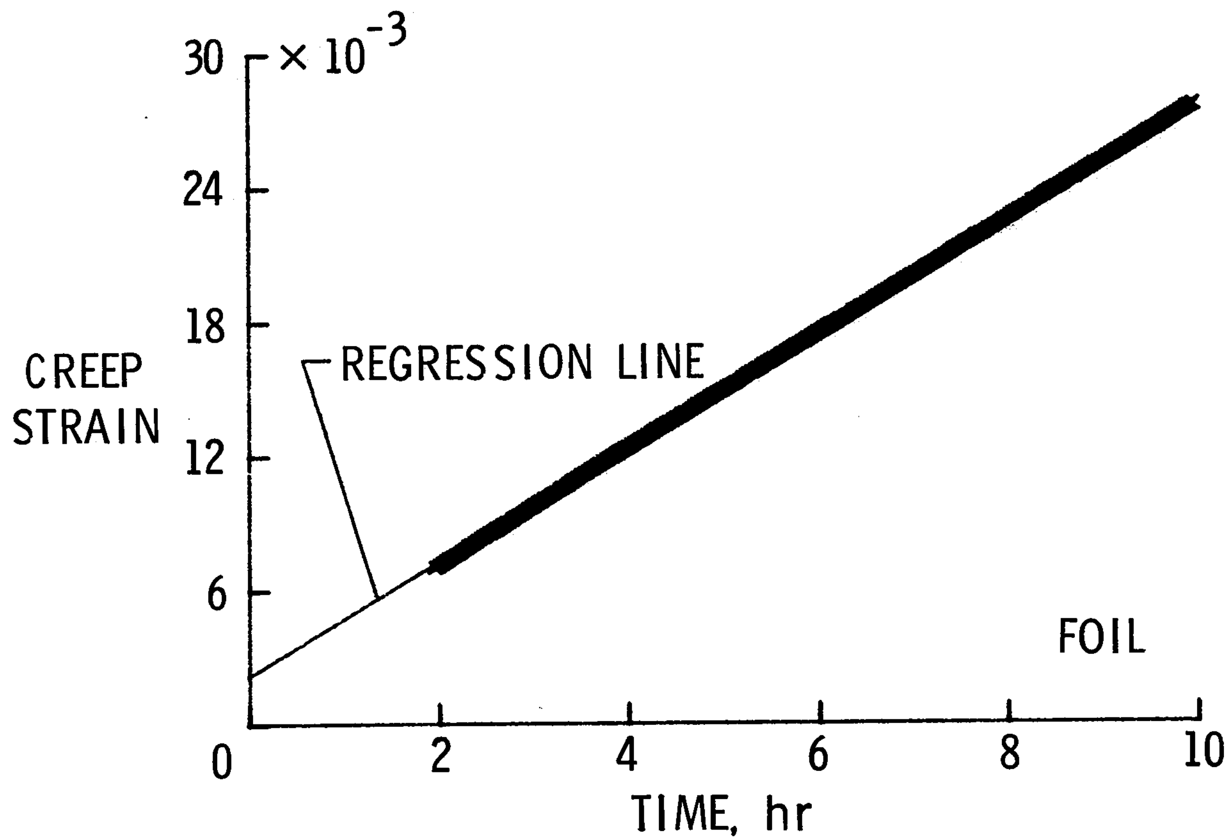

Figure 10. Steady state portion of creep curve for Ti-6Al-4V foil specimen tested at 1000°F and 25 ksi.

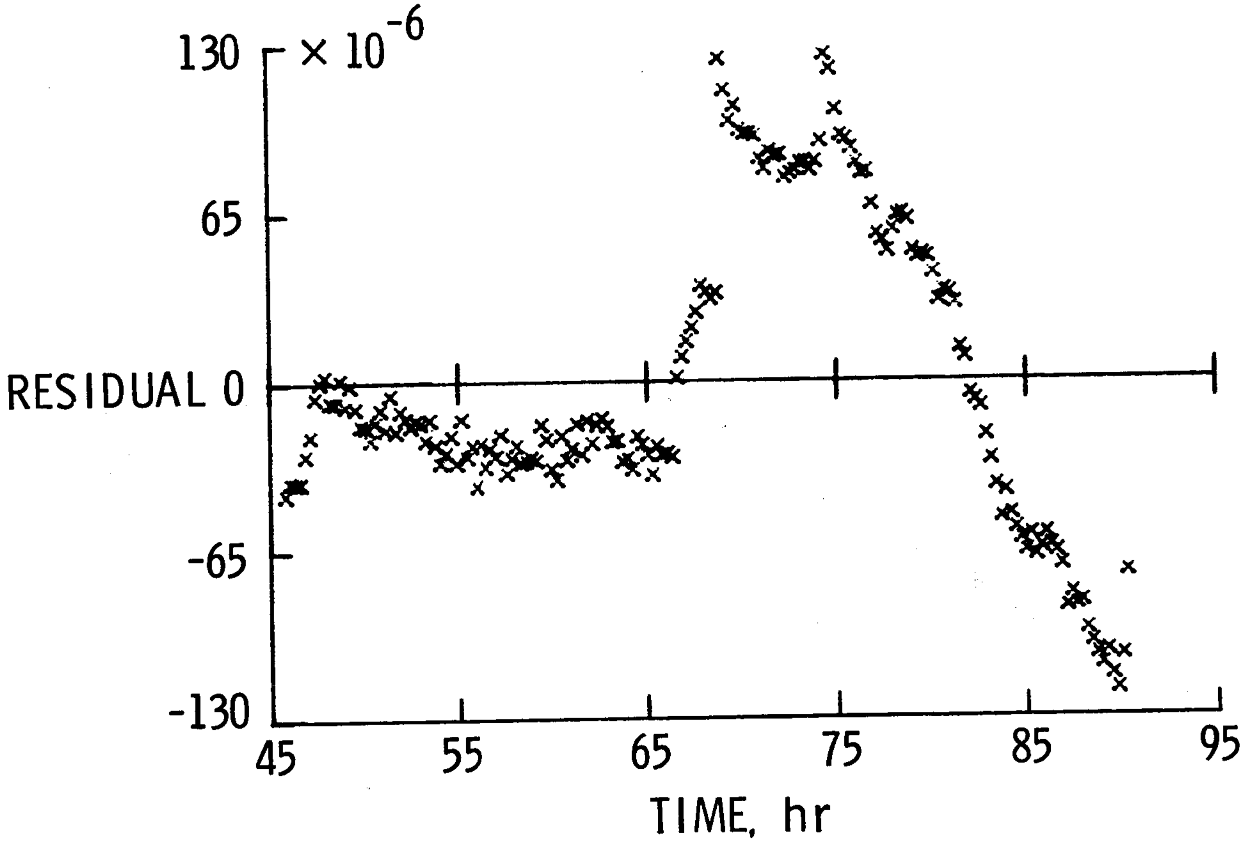

Figure 11. Steady state creep residuals for Ti-6Al-4V foil specimen tested at 800°F and 45 ksi.

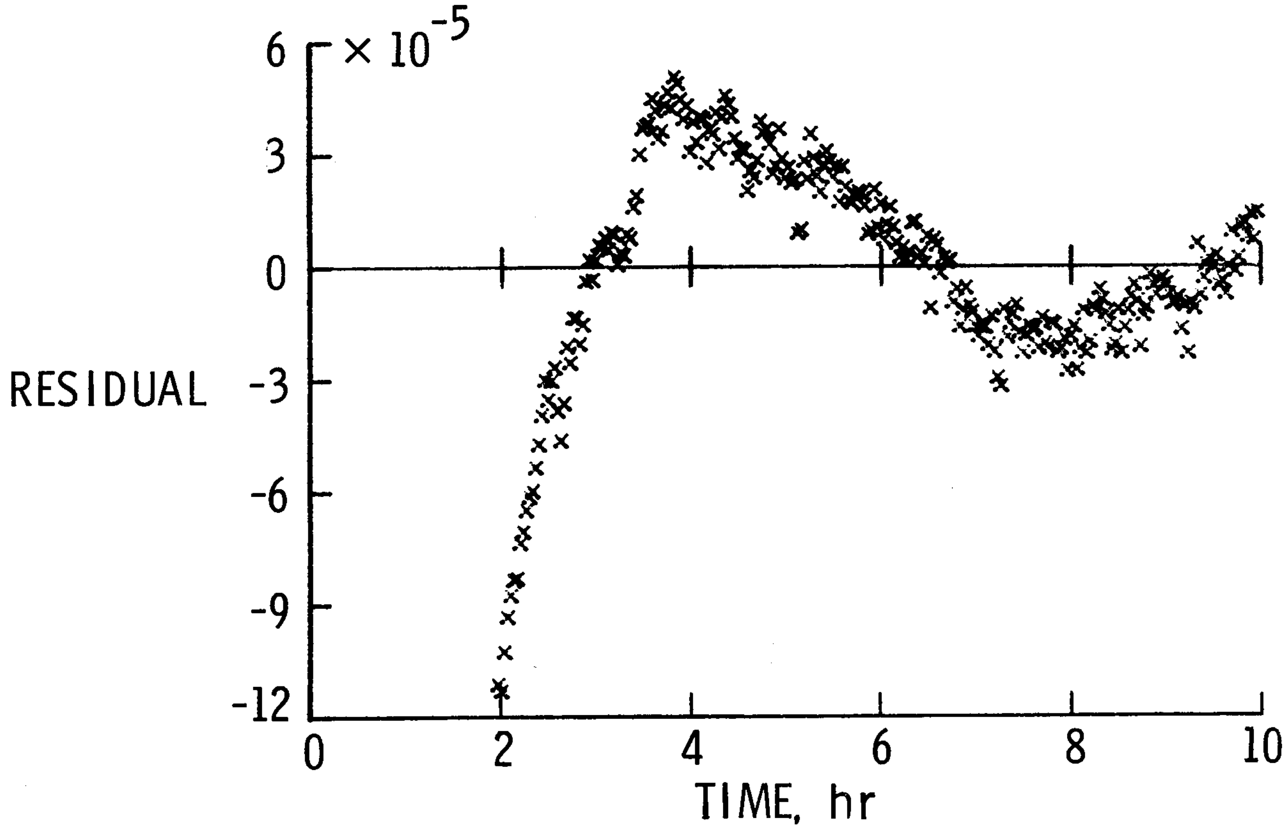

Figure 12. Steady state creep residuals for the Ti-6Al-4V foil specimen tested at 1000°F and 25 ksi.

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15. Supplementary Notes

16. Abstract

A method is currently being developed to obtain creep data on foil-gage metals at elevated temperatures using an automated data acquisition system in conjunction with a mechanically counter-balanced extensometer. The automated system components include the Hewlett-Packard (HP) 9845A Desktop Computer, the HP 3455A Digital Voltmeter and the HP 3495A Scanner. Software for test monitoring and data collection was developed; data manipulation, including curve plotting was done with a HP Regression Analysis software package. Initial creep tests were conducted on .003 in. thick foil specimens of Ti-6Al-4V at temperatures of 800°F and 1000°F and at stress levels of 25 ksi and 45 ksi. For comparison, duplicate tests were run on .049 in. thick specimens sheet of the same alloy. During testing, the furnace and specimen temperature, bridge voltage, strain and load output were automatically monitored and recorded at predetermined intervals. Using the HP Regression Analysis program, recorded strain output was plotted as a function of time. These resultant creep curves indicate that, under similar conditions of temperature and stress, foil-gage specimens exhibit a higher creep rate than sheet specimens. Examination of the total creep curve, and residual analysis of the steady-state portion, suggests the counter-balanced extensometer performs very well for both sheet and foil-gage materials. Results of this study indicate that programmable computers, with various peripheral components and associated software, can provide greatly expanded capacity and increased flexibility for creep test monitoring and control, data collection and data manipulation.

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