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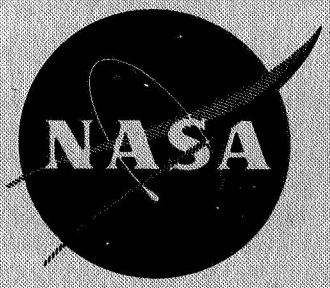

DETERMINATION OF BIAXIAL CREEP STRENGTH OF T-111 TANTALUM ALLOY

SEMI-ANNUAL REPORT

Period September 8, 1968 to March 8, 1969

by
L. B. Engel, Jr.

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS 3-9437
Robert L. Davies, Project Manager

NUCLEAR SYSTEMS PROGRAMS
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prepared by
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R. W. Harrison

NUCLEAR SYSTEMS PROGRAMS
MISSILE AND SPACE DIVISION
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Period September 8 to March 8, 1969

June 17, 1969

CONTRACT NAS 3-9437

NASA Lewis Research Center
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DETERMINATION OF BIAXIAL CREEP STRENGTH OF T-111 TANTALUM ALLOY

I. INTRODUCTION

This report covers the period from September 8, 1968 to March 8, 1969, of a program to document the creep behavior of seamless and welded and reworked T-111 alloy tubing under a biaxial state of stress, and to evaluate the effects of stress on the corrosion behavior of T-111 alloy with potassium. Potassium refluxing capsules of seamless and welded and reworked T-111 alloy tubing are being tested under conditions which will result in one to five percent equivalent uniaxial strain during a 5000-hour exposure. The capsule test temperature is 2200°F. The capsule walls are reduced in the potassium liquid region and in the vapor condensing region to provide gauge sections where the extent of creep can be measured. The testing is being done in a manner similar to that developed under an earlier NASA contract.[1]

---

[1] Harrison, R. W., "The Compatibility of Biaxially Stressed D-43 Alloy with Refluxing Potassium," NASA CR-807, June, 1967.

II. SUMMARY

Machining and ultrasonic inspection of a test capsule from the welded and reworked T-111 alloy tube has been completed. The capsule is now ready for postweld annealing.

Testing of Biaxial Creep Capsule I, fabricated from seamless T-111 alloy tubing, was initiated. As of March 8, 1969, 3635 hours of testing have been completed with the capsule at 2200°F. At that time the equivalent uniaxial creep was 0.98% in the liquid zone and 0.93% in the condensing zone.

The fourth preliminary uniaxial test has been completed.

The first 5000-hour uniaxial creep test was initiated at 2200°F with a stress of 8100 psi. As of March 8, 1969, 1914 hours of testing have been completed.

III. PROGRAM STATUS

A. T-111 ALLOY TEST CAPSULE MANUFACTURE

As a result of the cracking and lack of straightness in the finished, welded and reworked T-111 alloy tube, there is only sufficient material to make one test capsule from this tube. Manufacture of a second capsule from the welded and reworked T-111 alloy tube would require significant reductions of the capsule's dimensional tolerances.

Honing of the ID of the welded and reworked T-111 alloy tubing to be used in making the test capsule was completed at Delta Tool Inc., Warren, Michigan. Ultrasonic inspection of the tubing after honing indicated one small defect near the ID of the tube and 1.5 inches in from one end of the tube. This location places the defect within the stress attenuating fillet at a point where the wall thickness will be approximately 0.027 inch thick. A defect of significant size in this area could influence the creep behavior of the adjacent test section. Therefore to more accurately determine the size and location of the defect, a reference mark was placed on the capsule for locating the defect area after machining and the OD fillet contours were machined into the test capsule. Following machining, the defect area was re-examined using ultrasonic techniques to determine in more detail the nature of the defect. No defect was observed in the area where a defect had been detected in the inspection prior to final machining.

Pretest dimensioning and assembly of the test capsule has been completed in the same manner as that used for Biaxial Creep Capsule I, made from the seamless T-111 alloy tube.[2] The test capsule, Biaxial Creep Capsule II, made from the welded and reworked T-111 alloy tube, is now ready for postweld annealing.

---

[2] Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semi-annual Report, NASA-CR-72528, General Electric Company, NSP, NASA Contract NAS 3-9437, Period March 9, 1968, to September 8, 1968.

B. BIAXIAL CREEP CAPSULE TESTING

Biaxial Creep Capsule I, made from the seamless T-111 alloy tube, was installed in the test facility as shown in Figure 1. The linear variable differential transformers (LVDT's) were calibrated prior to installation and their precision was found to be approximately ± 0.0001-inch. The 18-inch diameter, getter-ion pumped, vacuum chamber was sealed and evacuated to approximately 5×10^{-7} torr before bakeout was initiated. The chamber was baked out at 500°F for 12 hours. During this time the argon gas pressure system which is connected to the potassium pressure transducer was also evacuated and baked out at approximately 500°F. Following bakeout, the gas pressure system was filled with argon and evacuated three times before final filling to a pressure of approximately 5 psia.

On October 2, 1968, heating of the test capsule was initiated. When the test capsule temperature reach 1000°F, power was applied to the boiling nucleator heater and the nucleator temperature was maintained between 100 and 150°F above the test capsule temperature during subsequent capsule heat up. Slightly less uniform boiling was noted in the capsule when the capsule reached approximately 1300°F but this condition subsided at approximately 1500°F. When the test capsule temperature reached 1800°F, the power to the boiling nucleator was turned off and no changes in boiling stability were observed. During capsule heat up the argon gas pressure in the pressure transducer gas system was increased so as to produce a minimum pressure differential on the transducer diaphragm. The capsule reached the 2200°F test temperature on October 7, 1968. The maximum chamber pressure reached during capsule heat up was 7×10^{-7} torr. As of March 8, 1969, 3635 hours of testing of the planned 5000 hours have been completed. The vacuum chamber pressure at that time was 5.9×10^{-9} torr.

The average potassium pressure in the test capsule at this time is 267.0 psia and results in average equivalent uniaxial stresses in the test sections of 8229 psi in the liquid zone and 8106 psi in the condensing zone.

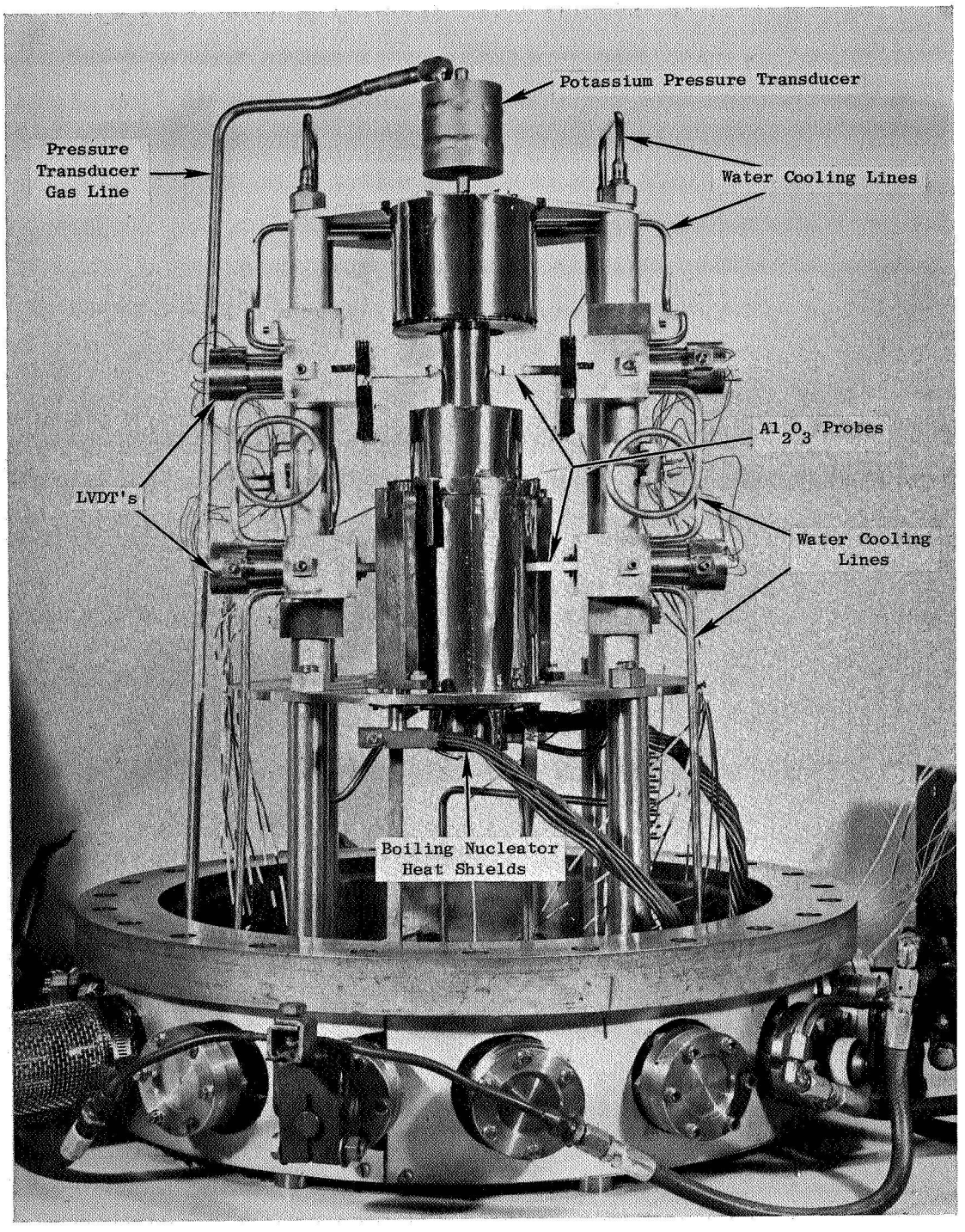

Figure 1. T-111 Alloy Biaxial Creep Capsule Test Facility. (P68-9-45B)

The equivalent uniaxial creep data for Biaxial Creep Capsule I in the liquid zone and condensing zone are shown in Figures 2 and 3, respectively. The data for the liquid zone was computed from capsule diameter measurements obtained with LVDT's. The data for the condensing zone was computed from capsule diameter measurements obtained with an optical extensometer. The LVDT's being used in the condensing zone became inoperative during testing and could not be used. The scatter in the data for the condensing zone is the result of not being able to accurately locate the sides of the capsule with the optical extensometer. The curves shown in Figures 2 and 3 were developed by iterative least squares solutions[3] of the Garofalo creep-time equation:[4]

$$\epsilon = \epsilon_o + \epsilon_t(1-e^{-rt}) + \dot{\epsilon}_s t$$

where:

ϵ = strain at time t

ϵ_o = strain observed upon loading

ϵ_t = limiting transient creep strain

r = ratio of transient creep rate to transient creep strain

$\dot{\epsilon}_s$ = secondary creep rate.

The derivatives of the curves in Figures 2 and 3, which yield the creep rates for the tests, are shown in Figures 4 and 5, respectively, and indicate that secondary creep was established after approximately 2000 hours of testing. An extrapolation of the Garofalo equation to 5000 hours predicts that approximately 1.3 percent creep should be obtained in the capsule in 5000 hours of testing.

---

[3] Deming, W. E., Statistical Adjustment of Data, Dover Publications, Inc., New York (1964).

[4] Garofalo, F., Fundamentals of Creep and Creep-Rupture in Metals, The Macmillan Company, New York, p. 16-17 (1965).

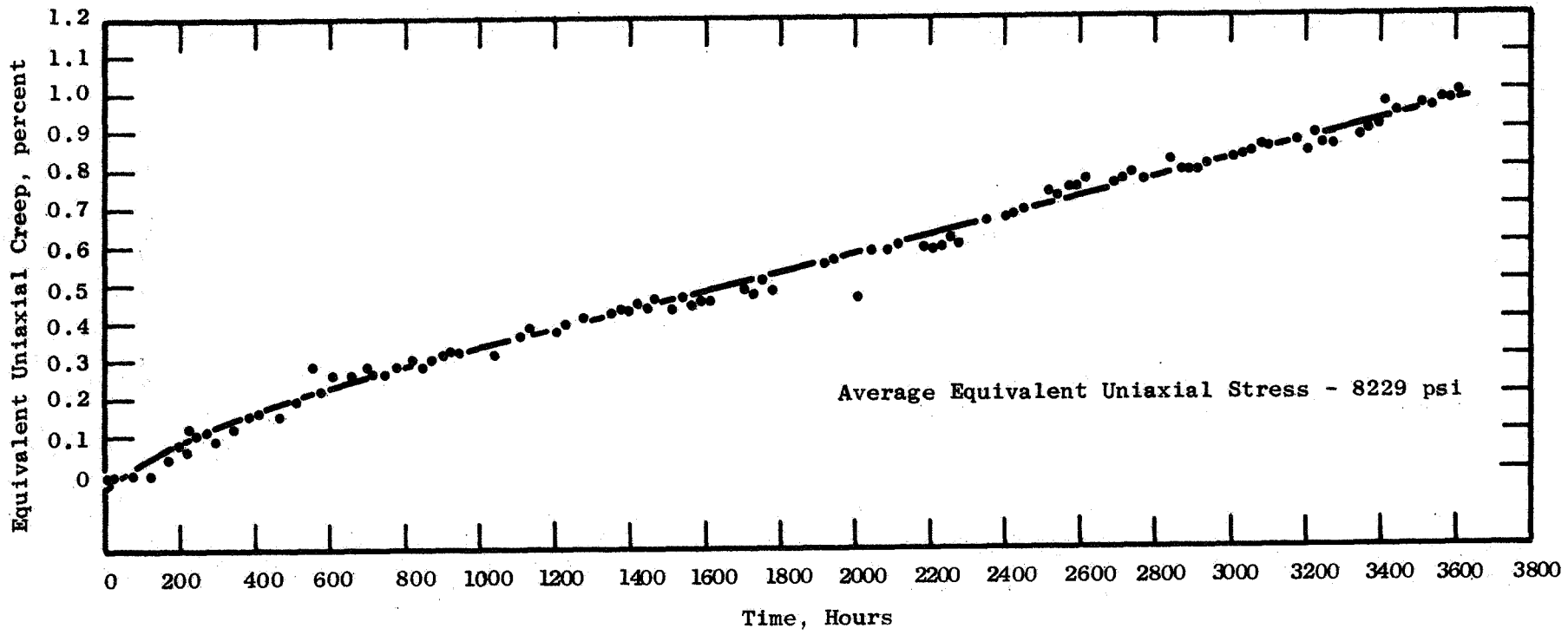

Figure 2. Equivalent Uniaxial Creep in the Liquid Zone (2220°F) of Biaxial Creep Capsule I.

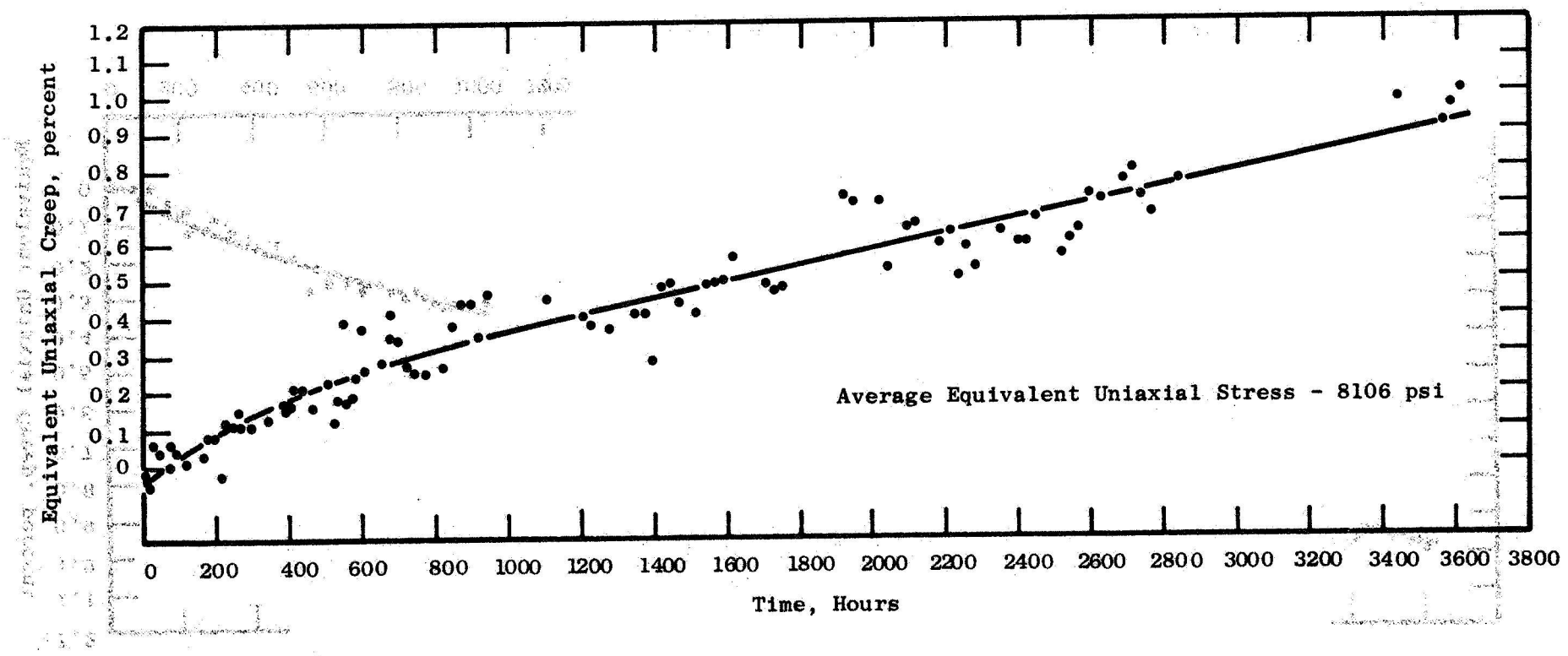

Figure 3. Equivalent Uniaxial Creep in the Condensing Zone (2200°F) of Biaxial Creep Capsule I.

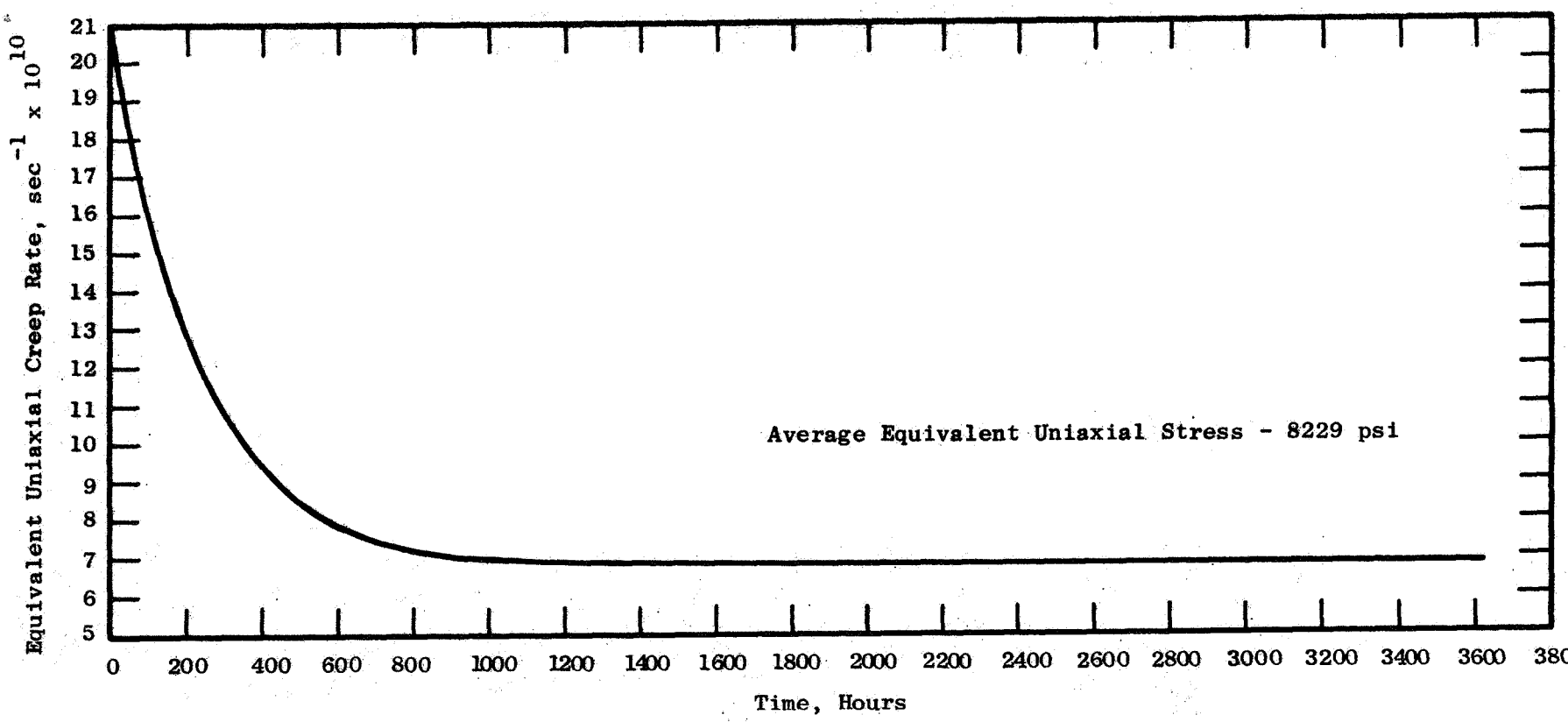

Figure 4. Equivalent Uniaxial Creep Rate in the Liquid Zone (2220°F) of Biaxial Creep Capsule I.

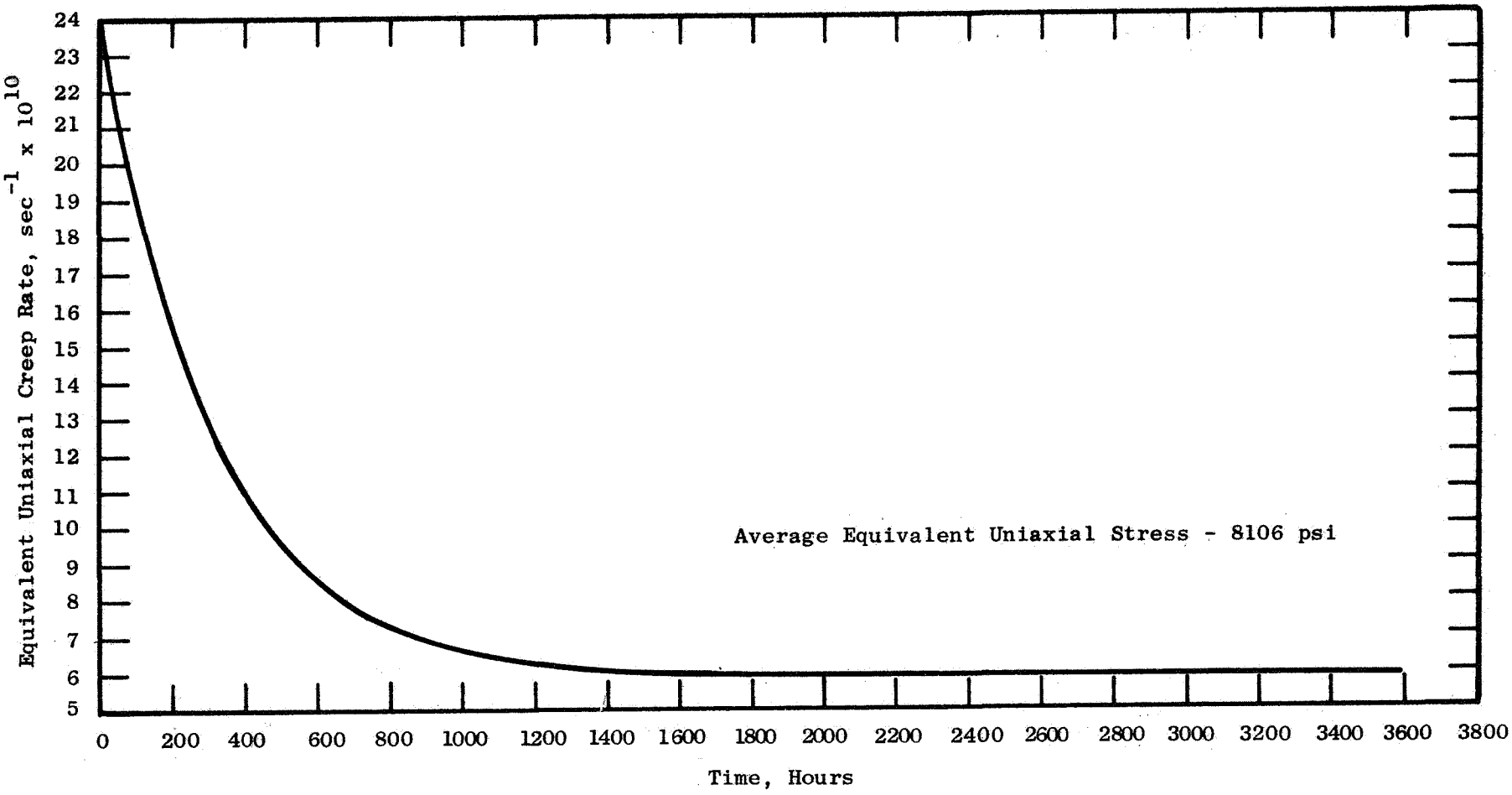

Figure 5. Equivalent Uniaxial Creep Rate in the Condensing Zone (2200^{o}F) of Biaxial Creep Capsule I.

C. PRELIMINARY UNIAXIAL CREEP TESTING

Preliminary uniaxial creep tests are being used to obtain baseline creep data for the final selection of test conditions for the 5000-hour tests and to evaluate a special uniaxial creep test specimen design which more closely resembles the biaxial capsule test section design.

In the three previously completed preliminary uniaxial tests, a more conventional test specimen, shown in Figure 6, was utilized. From the results of these tests, a test temperature of 2200°F was selected for the 5000-hour biaxial creep capsule test.[5] Presently, a fourth preliminary uniaxial creep test has been completed using the special uniaxial test specimen shown in Figure 7. As mentioned earlier, this specimen more closely resembles the biaxial capsule test section in that it has a similar reduced wall test section with stress attenuating fillets. The fourth preliminary uniaxial creep test was conducted at the same test conditions as the third preliminary test, i.e., 2300°F at a stress of 12,500 psi in a vacuum of $<1 \times 10^{-8}$ torr. From the least squares linear correlation of the data plotted in Figure 8, one percent creep was found to occur in 58.6 hours. A similar treatment of the data from the third test showed one percent creep to occur in 84.1 hours. The creep rates were found to be 1.052×10^{-4} in/in/hr and 1.173×10^{-4} in/in/hr for the third and fourth tests respectively. Possible explanation of the differences in the test results because of test specimen design are not straight forward since a statistical treatment of the data shows the creep rate for the third test to be $1.052 \times 10^{-4} \pm 0.043 \times 10^{-4}$ in/in/hr, and for the fourth test $1.172 \times 10^{-4} \pm 0.146 \times 10^{-4}$ in/in/hr using a 95 percent confidence level. Although the creep rate for the fourth test appears larger than that for the third test, consideration of the error limits indicates that the creep rates may not be significantly different. More tests of longer duration would be needed to improve the evaluation.

---

(5) Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semiannual Report, NAS-CR-72528, General Electric Company, NSP, NASA Contract NAS 3-9437, Period March 9, 1968, to September 8, 1968.

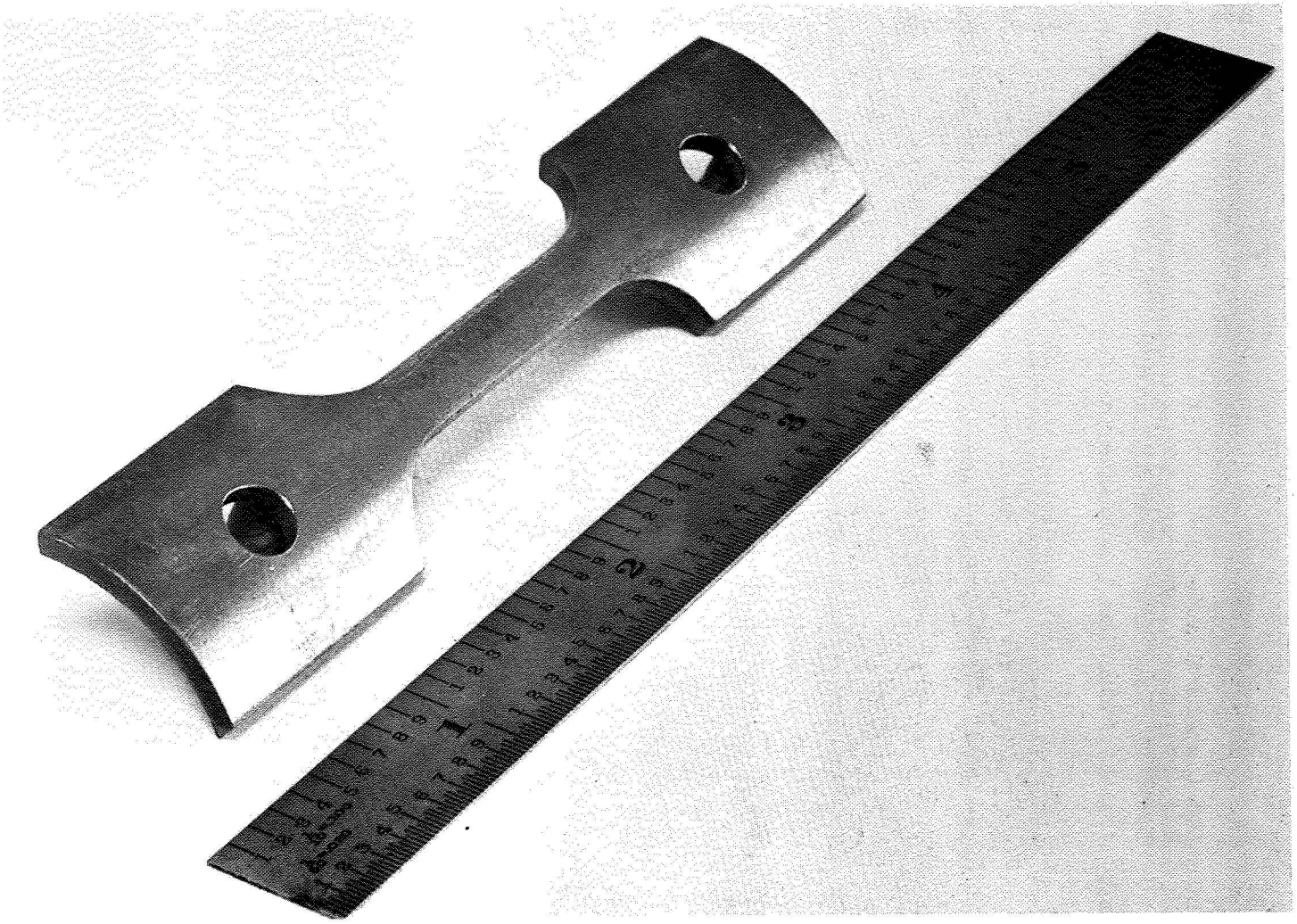

Figure 6. Conventional T-111 Alloy Uniaxial Creep Test Specimen Prior to Testing. (C68050719)

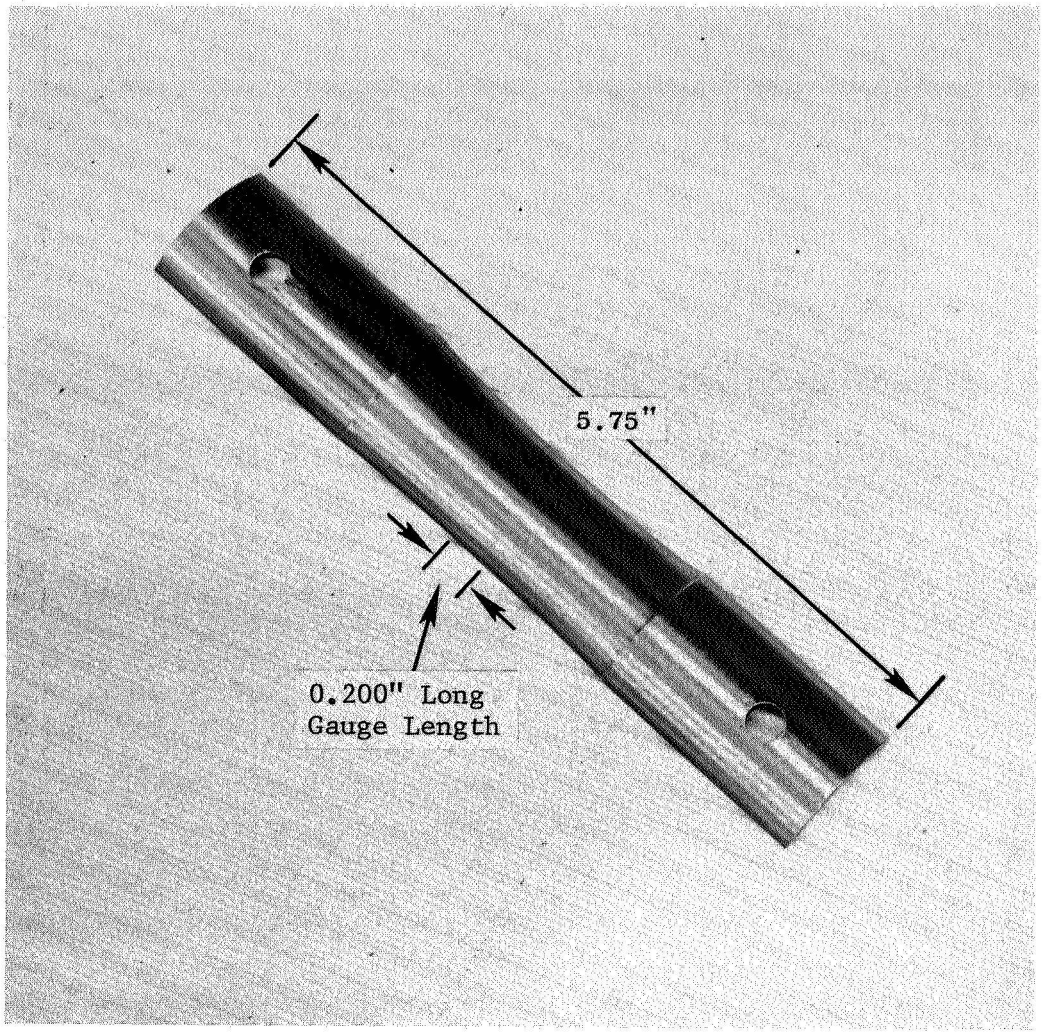

Figure 7. Special Uniaxial Creep Test Specimen Made from Seamless T-111 Alloy Tubing. The Contour of the Specimen is Identical to the Biaxial Creep Capsule Contour in the Test Section and Stress Attenuating Fillets and is a Quarter Section of the Tube. (C680719170)

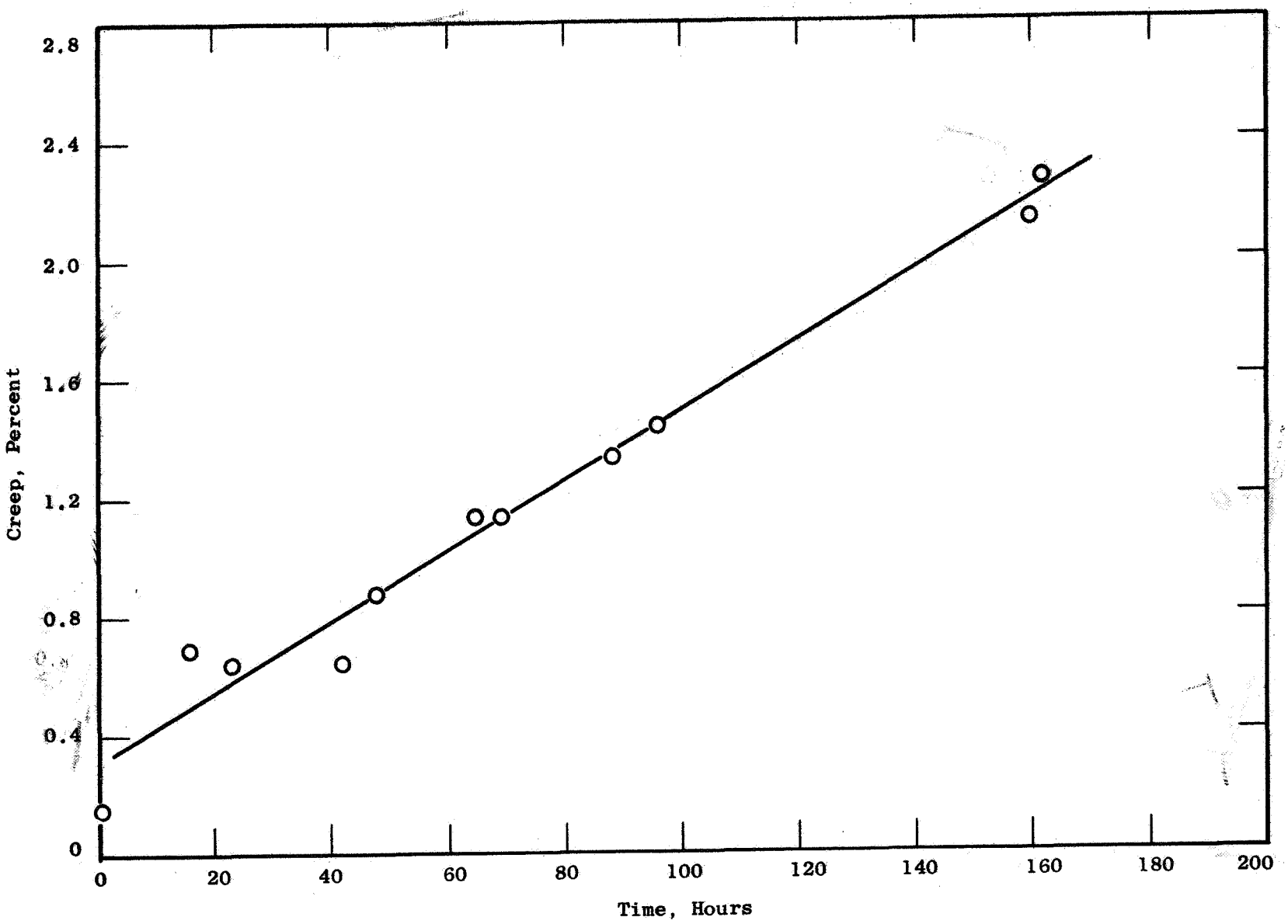

Figure 8. Uniaxial Creep of T-111 Alloy Tested at 2300°F with a 12,500 psi Stress in a Vacuum of $<1 \times 10^{-8}$ Torr. The Special Specimen was Machined from the Seamless Tube (Preliminary Uniaxial Test No. 4).

D. 5000-HOUR UNIAXIAL CREEP TESTING

In the present program, two 5000-hour uniaxial tests are scheduled. Because of the preliminary uniaxial creep test results it has been decided to test one conventional design specimen and one special design specimen. The first 5000-hour uniaxial creep test was initiated on December 18, 1968. The test specimen is the special test specimen shown previously in Figure 7.

Prior to loading the test specimen, it was annealed at 2400°F for one hour in the creep facility at pressures of less than 4×10^{-8} torr as were the previous preliminary uniaxial tests. This heat treatment gives the uniaxial test specimens the same thermal history as the biaxial creep capsule which was postweld annealed at 2400°F for one hour. Following the anneal the specimen temperature was reduced to 2200°F and loaded to a stress of 8100 psi. The test conditions for the uniaxial test are therefore approximately the same as those for the biaxial creep capsule. As of March 8, 1969, 1914 hours of testing have been completed. The vacuum chamber pressure at that time was 4.7×10^{-9} torr. Analysis of the test data is now in progress.

IV. FUTURE PLANS

A. Preparation of the test capsule from the welded and reworked T-111 tube will be completed and the capsule will be put on test.

B. Biaxial Creep Capsule I will complete 5000 hours of testing at 2200°F on May 4, 1969.

C. The first uniaxial creep test will complete 5000 hours of testing at 2200°F on July 14, 1969.

D. The second uniaxial creep test will be initiated.

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