EFFECT OF HYDROGEN ON THE CREEP PROPERTIES OF
VANADIUM, NIOBIUM AND MOLYBDENUM

John Charles Mather

M. S. Thesis Submitted to Iowa State University

Ames Laboratory, ERDA
Iowa State University
Ames, Iowa 50010

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Date Transmitted: February 1975

MASTER

PREPARED FOR THE U.S. ENERGY RESEARCH AND DEVELOPMENT
ADMINISTRATION UNDER CONTRACT NO. W-7405-eng-82

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

—NOTICE—

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Available from: National Technical Information Service
U. S. Department of Commerce
P.O. Box 1553
Springfield, VA 22161

Price: Microfiche \$2.25

Effect of hydrogen on the creep properties of
vanadium, niobium and molybdenum

by

John Charles Mather

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Major: Metallurgy

Approved:

In Charge of Major Work

For the Major Department

For the Graduate College

Iowa State University
Ames, Iowa

1975

TABLE OF CONTENTS

	Page
I. INTRODUCTION	1
A. Purpose of the Present Investigation	2
B. Effects of Test Environment on Creep Data	3
II. SAMPLE PREPARATION	6
A. Vanadium	6
B. Niobium	8
C. Molybdenum	9
III. APPARATUS AND EXPERIMENTAL PROCEDURE	11
A. Basic Creep-Test Apparatus	11
B. Data Processing	14
C. Perspective	19
IV. RESULTS	21
A. Performance of Test Apparatus	21
B. Data Processing	24
C. Behavior of Tested Materials	24
V. RECOMMENDATIONS	28
VI. LITERATURE CITED	32
VII. ACKNOWLEDGEMENTS	34
VIII. APPENDIX A. FIGURES	35
IX. APPENDIX B. RAW AND PROCESSED NUMERICAL DATA	49
X. APPENDIX C. POLYNOMIAL EXPRESSIONS FOR SHEAR STRAIN (γ) AND SHEAR STRAIN RATE ($\dot{\gamma}$) AS FUNCTIONS OF TIME (t) IN HOURS	69

I. INTRODUCTION

A diagram of a conceptual core structure for a Controlled Thermonuclear Reactor (CTR), taken largely from the design of Fraas and Postma (1), is shown in Figures 1 and 2. Cylindrical walls with struts in the coolant zone have been indicated, but other designs have also been proposed. However, the importance of this figure is not to display specific details, but rather to indicate that the "first wall" will be loaded statically: a liquid metal blanket envelops the wall's exterior and a vacuum exists in the interior. For a reactor of this sort to be useful to society, service life must be measured in years. Therefore, the long-term resistance to deformation under constant load--generally denoted as creep properties--of the materials used in the first wall and at other locations must be known and be compatible with service requirements.

Current designs for projected CTR's are based on the deuterium-tritium (D-T) fuel cycle. The tritium inventory in the breeding blanket, the D-T fuel, plus the protons created in the structural material (particularly the first wall) by (n,p) reactions all combine to present potentially serious material integrity problems. Ultimately, these problems must be surmounted to achieve a successful CTR design. Even without an established design for the projected CTR, it is evident that the effect of hydrogen and its isotopes on the mechanical

behavior of the first wall material and other structural components is a potential design limiting factor. Unfortunately, essentially no information is available about the effects of tritium or deuterium on the mechanical behavior of materials. Accordingly, it is necessary to assume that the effects of hydrogen will provide a reasonably accurate picture of what problems to expect from its isotopes. Neutronic properties and mechanical strength requirements for the CTR operating temperature range, 600°C to 1000°C, tend to favor vanadium, niobium, molybdenum, or their alloys for the first wall material.

A. Purpose of the Present Investigation

The preceding brief background provides the impetus for the nature of, and assists in understanding the scope of, this research. The first need to be met in this research program was to design and construct a test apparatus which would permit evaluation of the effect of hydrogen on the creep properties of candidate CTR first wall refractory materials in the 600 to 1000°C temperature range. Accomplishing this was a major step toward the specific goal of determining whether a hydrogen environment significantly affects the high-temperature creep properties of unalloyed vanadium, niobium, or molybdenum.

B. Effects of Test Environment on Creep Data

Intuitively it might be anticipated that creep properties determined in air would differ from creep properties determined in a vacuum. Indeed, differences were found in creep-rupture data for pure nickel tested in air and in vacuum (2,3). These differences were qualitatively explained by a mechanism involving competition between two processes: 1) oxidation strengthening, and 2) enhanced crack propagation due to surface free energy reduction resulting from gas adsorption. Another example is the influence of a growing oxide film on the Herring-Nabarro creep in magnesium (4).

Even small amounts of common gases in a test environment can contaminate the test material and have a discernible effect on measured properties. Contamination of refractory metal alloys by oxygen and nitrogen can occur under vacuum conditions of 10^{-6} Torr: it has been stated that vacuums of better than 1×10^{-8} Torr are required to obtain creep measurements which are representative of basic material properties (5,6,7,8). For example, the creep strength of Nb-0.6 Zr was found to be strongly dependent on test vacuum in the range 10^{-5} to 10^{-7} Torr (9). This dependence was attributed to effects of contamination from residual gases. Nitrogen and oxygen have been shown to improve creep-rupture strength of niobium for temperatures $< 0.5 T_m$ (10); and oxygen, carbon, and nitrogen as interstitial species have shown a marked effect on creep strength

of Nb-Mo alloys (11).

Because of the above sensitivity of creep properties of refractory metals to even small amounts of contaminants in the test environment, much of the data available from the literature may be only marginally useful relative to this study. In many cases the gas pressure under which tests were conducted was greater than 1×10^{-8} Torr. In the cases where inert gas atmospheres were used it is likely that the "pure" inert gas contained impurity bases at levels far in excess of what would be present in a vacuum of 1×10^{-8} Torr.

Disregarding these finer details of test environment, there is meagre data relating to the effect of the presence of hydrogen on creep properties of engineering materials. The creep strength of Inconel was found to be less in hydrogen than in argon at 704 and 815°C (12). Similar results were found for Nickel 200, Nickel 270, electron-beam zone-refined nickel and high purity copper (13). An abundance of elongation and reduction in area data from tensile tests has established that niobium and vanadium are catastrophically embrittled by relatively low concentrations of dissolved hydrogen near room temperature. Evidence also indicates that molybdenum is not embrittled by hydrogen at low temperatures (9,14).

The effects of hydrogen at low pressures (<1 Torr) on metals at temperatures in the CTR operating range are virtually unexplored. By extrapolating from data in the low temperature range, it is speculated that substantial hydrogen

concentrations would be necessary to produce a ductile-to-brittle transition in niobium or vanadium at CTR operating conditions. For example, extrapolation predicts that about 36 atom per cent (6000 ppmw) hydrogen in niobium and about 93 atom per cent (2×10^5 ppmw) in vanadium would be required to raise the DBTT to the CTR temperature range. It is not likely that these concentrations of hydrogen could be attained from the anticipated hydrogen gas pressures of 10^{-6} to 10^{-3} Torr at or near the first wall.

Insufficient information is available to predict what the hydrogen pressure dependence of the creep behavior of these materials might be. However, McCoy and Douglas (15) found the creep rate of niobium stressed to 3500 psi at about 980°C to be greatly accelerated by moist or dry hydrogen flowing at 0.2 cfh as shown in Figure 3. There is no established mechanism to explain this modification of creep behavior in the presence of hydrogen. It may be due to a hydrogen-impurity interaction which weakens the grain boundaries, hydrogen reduction of strengthening surface oxide films or some unexplored mechanism.

II. SAMPLE PREPARATION

A. Vanadium

The vanadium metal used in this investigation was originally prepared by the iodide refining process described by Carlson and Owen (16). The material was cut from a 1/4-inch diameter rod which had been cold-swaged from ingot form. Chemical analysis of the metal appears as Table 1. Oxygen, nitrogen, and hydrogen concentrations were determined by the vacuum fusion method. The metallic impurities were determined by spectrographic analysis.

Table 1. Chemical analysis of vanadium

Element	Content, ppm	Element	Content, ppm
Cr	<5,000	Ti	<40
Cu	<200	O	400
Fe ^a	<5,000	H	2
Ni	<2,000	N	140
Si	<400		

Processing the material into its ultimate helical shape was a multi-step procedure, the highlights of which are elucidated below.

1. Major reduction was by cold-swaging. The swaging sequence used was adapted from the work done by Sherman (17). Each step in the swaging process

reduced the entering cross-sectional area by 60 to 70 per cent. Details are given in Table 2 below.

2. To ensure uniform specimen conditions at the start of each test, it was decided that in-situ anneals would be performed prior to load application. The small amount of plastic strain introduced while wrapping a wire into the helix-configuration could cause undesirable grain size and/or grain size gradients in the sample after annealing. To ensure uniform grain size, and to make the wires easier to handle during cleaning and wrapping, they were uniaxially strained approximately eight per cent in a tensile test machine prior to final cleaning and wrapping into helices.
3. The chemical cleaning sequence always started with a wash in trichloroethane and rinse in acetone (for oil and grease removal). Actual "etching" was done in a 50/50 by volume $\text{HNO}_3/\text{H}_2\text{O}$ solution at room temperature. Doing this with straight wires rather than helices was found to give more uniform material removal. Chemical cleaning was followed by a water rinse, acetone rinse, and dry.
4. The helical shape was achieved by individually wrapping each wire around a piece of 1/4-20 UNC threaded rod. This "mandrel", covered with Teflon tape for protection of the sample surface, was chucked in a

lathe and rotated by hand. Because of the initially straight wires and the type of mandrel used, the helix pitch and coil straightness were fairly consistent.

Table 2. Swage/anneal sequence

Operation	Starting diameter	Final diameter	% Area reduction	Comment
Anneal	0.250	0.250	---	1000°C for 4 hours @ $<10^{-6}$ Torr
Swage	0.250	0.230	---	
	0.230	0.187	0.662	
	0.187	0.150	0.643	
	0.150	0.125	0.693	
	0.125	0.100	0.640	
Anneal	---	---	---	1000°C for 4 hours
Swage	0.100	0.078	0.608	
	0.078	0.063	0.652	
	0.063	0.051	0.655	
	0.051	0.040	0.615	
	0.040	0.031	0.601	
Anneal	---	---	---	1000°C for 4 hours

B. Niobium

The niobium metal used in this investigation was obtained in the form of annealed 1/4-inch thick sheet from the Metals Division of Fansteel, Inc. Manufacturer's analysis (ingot) is given in Table 3 below.

A 1/4 x 1/4 x 5-inch piece was cut from the sheet, and its edges were generously rounded to allow swaging without producing folds in the material. The cleaning operations were the same as given above for vanadium, except the polishing solution consisted of 40/40/20 per cent by volume of

$\text{HNO}_3/\text{H}_2\text{SO}_4/\text{HF}$ respectively. Major reduction was by cold swaging, as described for vanadium in the previous section. The initial anneal was not required because the material was received in the annealed condition. Intermittent anneals were at 1100°C for two hours. The pre-straining and wrapping procedures were the same as for vanadium.

Table 3. Chemical analysis of niobium

Element	Content, ppm	Element	Content, ppm	Element	Content, ppm
C	<10	Fe	<50	V	<20
O	31	Ni	<20	Co	<10
N	27	Si	<50	B	<1
H	<5	Mn	<20	Cd	<5
Ta	560	Ca	<20	Mg	<20
W	<100	Al	<20	Pb	<20
Zr	<50	Cu	<20	Hf	<100
Mo	<50	Sn	<20	Nb	Balance
Ti	<20	Cr	<20		

C. Molybdenum

The molybdenum used in this investigation was procured as a spool of 0.030-inch diameter wire, labeled "commercially pure". Chemical analysis of the metal is given in Table 4. Oxygen, nitrogen, and hydrogen concentrations were determined by the vacuum fusion method. The metallic impurities were determined by spectrographic analysis.

After being cut to length, each wire was prestrained approximately six per cent for straightness and for introduction of cold-work, as before. This was followed by the clean-

ing sequence given for vanadium, except that the chemical etchant was 50 parts HF to 50 parts HNO_3 by volume. Wrapping the wires into helices was as given for vanadium.

Table 4. Chemical analysis of molybdenum

Element	Content, ppm	Element	Content, ppm
Cr	<2,000	Si	<3,000
Cu	<200	Ti	<40
Fe	<30,000	O	38
Mn	<1,000	H	<1
Ni	<3,000	N	2

III. APPARATUS AND EXPERIMENTAL PROCEDURE

A. Basic Creep-Test Apparatus

As delineated in the Introduction, the purpose of this research was to obtain data such that the effects of a hydrogen atmosphere on creep properties could be ascertained. The temperature range of interest is approximately 900 to 1300°K: the estimated temperature range to be endured by the "first wall" of a fusion reactor. Determination of "base" data required a vacuum of better than 1×10^{-8} Torr, and the system needed to be as free from vibration as possible.

The combination of high vacuum and high temperature made direct electronic readout of sample elongation unfeasible for several reasons:

1. Transducers able to operate anywhere near the test temperatures were not readily available.
2. Using vacuum-tight bellows as "feedthroughs" to connect samples to load and transducers is fraught with problems of calibration of the bellows for its spring factor as a function of position (K-factor of the bellows alone), barometric pressure, and quality of vacuum.
3. Use of external electronic transducers reduces the flexibility of the test apparatus as regards sample loading, placement of electric furnace element and power feedthroughs, temperature sensors, and thermal shielding.

A logical alternative to electronic readout is optical measuring of sample elongation. An optical cathetometer was procured: its scale showed a least count of 0.05 millimeters. Obtaining good resolution of sample strain with this device required that the samples be quite long. Proper sample length was obtained by having the specimen assume a helical shape.

Based on information in the Introduction and in the above, the general design criteria for the test apparatus can be itemized as follows:

1. HIGH VACUUM is required for elimination of contaminating interstitials from the environment around the samples, and from the surfaces of the samples themselves.
2. HIGH TEMPERATURE capability was required for in-situ anneals of all materials being used. This criterion, plus the need to sustain high temperatures for long test periods dictated that the heater be inside the vacuum chamber rather than an external split-furnace in a muffle arrangement.
3. OPTICAL READOUT of sample elongation required that a view-port be part of the system. A rotatable shield was installed to protect the viewport from intense heat radiated during the in-situ anneals.
4. SIMULTANEOUS TESTING OF SEVERAL SAMPLES was desirable because of the long-term nature of creep tests. The chamber was made of a size which would allow for

three "columns" of samples to be tested concurrently. Each column could contain either one or two samples-- it was found that more than two samples in any one column caused axial alignment problems.

5. ANNEALING IN-SITU required a method for loading and unloading the samples such that the anneal could proceed with samples unloaded, and that the load could be applied after completing the anneal and stably attaining the test temperature. This requirement was really quite difficult since at the temperatures and vacuum used, sintering was a problem between the "prop" used for weight removal and the base which the "prop" contacted.
6. Use of hydrogen as a test environment made material selection a problem because of possible brittle hydride formation during test. Also, vacuum gages had to be judiciously placed such that readings could be taken during hydrogen runs when the vacuum pump would be sealed from the test chamber. Because bottled hydrogen gas or hydrogen obtained by exothermic decomposition of uranium hydride could contain substantial impurities, a purification "membrane" of palladium-25 silver was installed in the system. Bottled hydrogen could then be used as the gas source.

An annotated photograph of the complete test apparatus appears as Figure 4. Figure 5 is a detailed "cutaway" view similar to the photograph, showing some of the internal parts. It can be seen that the physical aspects of the design criteria have been fulfilled.

B. Data Processing

Raw data compiled for each test instance¹ included information about the test environment, the sample, and the behavior of the sample. The following items were recorded for each sample as it was assembled into the test rig: wire diameter, helix diameter, number of active turns, and load. When pressure and temperature conditions stabilized, data for the plots were taken. This consisted of noting the date, the time of day, the position of a characteristic point on the sample holder at the top of the sample, and the position of a characteristic point on the weight attached to the bottom of the sample. System pressure and temperature were recorded each time positional data were taken.

A large amount of the computational work required in this investigation was performed with the aid of a digital computer. A program was developed such that its output would be a complete record for each test instance. Expressions for the primary items of interest in the output are developed and

¹A test instance is determined by assigning a value to each of the four major variables: material, temperature, stress level, and environment.

discussed in detail below.

Figures 6a and 6b depict a helical spring and the wire in the spring, respectively. The symbols and parameters used to describe the stress state and strain condition of a test specimen are given in Table 5.

The maximum surface shear stress in the coil at the start of the test was calculated using accepted equations for torsional stress, adapted to helical coils.

$$\tau = K \left[\frac{Tr}{J} \right]; \text{ or } \tau_{\max} = K \left[\frac{Tr_{\max}}{J} \right]$$

$$\tau_{\max} = K \left[\left(\frac{PD}{2} \right) \left(\frac{d}{2} \right) \left(\frac{32}{\pi d^4} \right) \right]$$

$$\tau_{\max} = K \left[\left(\frac{8}{\pi} \right) \left(\frac{PD}{d^3} \right) \right]$$

Propagation of error techniques were employed to determine an expression for the uncertainty in the computed stress (18).

$$\omega_{\tau_{\max}}^2 = \left(\frac{\partial \tau}{\partial K} \right)^2 \omega_K^2 + \left(\frac{\partial \tau}{\partial P} \right)^2 \omega_P^2 + \left(\frac{\partial \tau}{\partial D} \right)^2 \omega_D^2 + \left(\frac{\partial \tau}{\partial d} \right)^2 \omega_d^2$$

$$\omega_{\tau_{\max}}^2 = \left(\frac{8PD}{\pi d^3} \right)^2 \omega_K^2 + \left(\frac{8DK}{\pi d^3} \right)^2 \omega_P^2 + \left(\frac{8PK}{\pi d^3} \right)^2 \omega_D^2 + \left(\frac{-24KPD}{\pi d^4} \right)^2 \omega_d^2$$

Relating shear strain to measured elongation of the sample was computed using the expressions developed below.

Consider the wire in Figure 6b.

$$Ld\gamma = rd\alpha = \frac{d}{2}(d\alpha)$$

Table 5. Nomenclature for sample geometry, stress state and strain condition

Symbol	Definition	Expression	Approx. nom. value	Max. error (est)
d	Wire diameter	----	0.787 mm	0.03 mm
r	Distance from neutral axis to point of interest: thus $r_{\max} = d/2$	----	----	----
J	Polar moment of inertia for wire cross-section area	$\pi d^4/32$	----	----
P	Axial load, grams	----	----	1.0 gm
D	Helix diameter from center line to center line of the wire (OD - d/2)	----	7.1 mm	0.15 mm
T	Torque or moment applied to wire in spring	$P(D/2)$	----	----
N	Number of active turns in the helix	----	10 turns	0.1 turn
L	"Active length" of wire in helix	πDN	----	----
y, Δ	Axial coil deflection	----	----	0.2 mm
K	Stress concentration factor ($C = D/d$)	$\frac{4C-1}{4C-4} + \frac{0.615}{C}$	1.162	0.117 ^a
h	Spacing of adjacent turns in helix	----	1.27 mm	.38 mm

^aComputed by separate propagation of error analysis.

$$\text{or } dY = \left(\frac{d}{2L}\right) d\alpha$$

But the load P has a moment arm (D/2), so the differential deflection dY is as follows:

$$\begin{aligned} (dY) &= (d\alpha)(D/2) \\ \text{or} \quad (d\alpha) &= (2dY)/D \end{aligned}$$

Then, $dY = (d/2L)(2dY/D) = d(dY)/LD$.

Now an expression must be developed to relate the extension of the helix to actual helix diameter. Take a helical coil and "unwind" it, keeping proper relationships with respect to its axis as illustrated in Figure 7.

From the figure, the following relationships are apparent:

$$L \sin \theta = Y$$

$$L \cos \theta = ND\pi$$

Then, squaring and adding,

$$\begin{aligned} L^2 &= Y^2 + (ND\pi)^2 \\ \text{or} \quad D^2 &= (L^2 - Y^2) / (\pi N)^2 \end{aligned}$$

Then the expression for dY becomes:

$$dY = \left(\frac{d}{L}\right) \frac{dY}{\left[\frac{L^2 - Y^2}{(\pi N)^2}\right]^{1/2}} = \left[\frac{\pi Nd}{L}\right] \left[\frac{dY}{(L^2 - Y^2)^{1/2}}\right]$$

or

$$Y = \left[\frac{\pi Nd}{L}\right] \int_{Y_0}^Y \frac{dY}{(L^2 - Y^2)^{1/2}}$$

From integration tables,

$$\int \frac{du}{[a^2 - u^2]^{1/2}} = \sin^{-1}\left(\frac{u}{a}\right) + C$$

Therefore:

$$\gamma = \left[\frac{\pi Nd}{L}\right] \left[\sin^{-1}\left(\frac{Y}{L}\right) - \sin^{-1}\left(\frac{Y_0}{L}\right)\right]$$

Or, in terms of measured data;

$$\gamma = [\pi d] [\pi^2 D_0^2 + h_0^2]^{-1/2} \{ \sin^{-1} [(h_0 + \Delta N^{-1}) (\pi^2 D_0^2 + h_0^2)^{-1/2}] \\ - \sin^{-1} [(h_0 (\pi^2 D_0^2 + h_0^2)^{-1/2})] \}$$

Computation of uncertainty limits on shear strain is similar to that given previously for stress.

Employing the expressions developed above, a shear stress level and its uncertainty were computed utilizing the raw data for each test instance. Additionally, a shear strain value was computed for every data point recorded, and the maximum uncertainty in the shear strain was determined. A linear least squares regression (18) of strain on time was performed on those data values judged to be in the region of secondary creep. In addition to providing the equation of the best-fit straight line, the computer subroutine used for this regression utilizes the uncertainty in the strain values and the randomness of the data points about the best-fit line to compute and output values of several statistical parameters for each data set. These parameters are required if the F-test and the t-test are used to determine whether the presence of hydrogen

has a significant effect on the secondary creep rate of the samples being compared.

While plots of shear strain versus time are enlightening and allow comparison of material performance, it was found that plots of strain rate versus strain assist greatly in making those relative comparisons. To obtain the latter plot, several polynomial functions were first fitted to each shear strain versus time plot. The lowest order curve which adequately fit the data, usually fourth or fifth order, was selected for each test instance. Its derivative was determined and evaluated at several values of time for which strain values had also been determined.

C. Perspective

Because of the creep condition, the helix diameter (D) and the wire diameter (d) varied during the test period. In addition, the stress condition varied throughout the helix, and therefore the amount of relaxation occurring during the test also varied from location to location within the sample. The stress condition in the wire and the location of the neutral axis of the test piece varied as a function of location in the sample and as a function of time for each location. Even though a rather detailed analysis of stress distribution during creep testing of helical spring specimens has been accomplished (19), it will not be considered here because it was not required for this research. The real concern of this

investigation was to determine whether the presence of hydrogen significantly affects creep properties of the subject materials, with secondary creep rate being the key property under study. To ascertain this, the only data actually required for each test instance was "percent elongation versus time". The data reported herein are in units of strain for convenience in comparing with published data.

To ensure legitimate comparisons and accurate conclusions, many precautions were taken. Among those are the following. Samples to be compared were loaded as closely as possible to the same stress level, and were located in the same place inside the test apparatus to avoid effects of temperature gradients. Compared sets of samples also received the same thermal history.

IV. RESULTS

A. Performance of Test Apparatus

It was found that a significant amount of time was required to get from the design concept stage to a satisfactory operational mode. Before any useful test data was obtained, many problems unforeseen in the initial design concept had to be solved. Several problems originally considered to be minor were not, and also had to be overcome.

It was found that the original method for applying load to the test specimens would not work satisfactorily. The final design of the sample holder consisted of a square-threaded screw onto which the helical sample is threaded. This method is very convenient.

Sintering problems were encountered. Most of the test apparatus exposed to the high test and annealing temperatures is fabricated from 304 stainless steel. At the specimen annealing temperature of 1100°C this material will easily sinter to itself, to niobium, and to vanadium, if sufficient force is present. Where possible, wafers or sheets of tungsten were judiciously placed to avoid stainless-to-stainless contact. In other cases it was determined that sintering did not affect the test, but did create problems during sample loading and unloading because of the tendency for galling to occur after the initial sintered joint was broken. This tendency is a result of the extremely clean surface present, and

can be reduced substantially by flooding the joints with methyl alcohol prior to unscrewing. This wets the potential galling surface and acts as a lubricant during assembly and disassembly. Methyl alcohol is chosen because it evaporates easily and volatile residuals are pumped adequately by the ion pump.

While a Titanium Sublimator Pump (TSP) significantly augments the pumping speed of a standard ion pump, it was found that the TSP must be shielded from the main test chamber. Figure 4 shows the location of the TSP at the lower end of the test chamber, just above the large gate valve. When operated in this location, a fairly thick layer of titanium condenses on the system walls just above the valve, and a much finer layer is condensed on the remainder of the chamber walls. When hydrogen is admitted to the test chamber, there is so much titanium surface and mass available that an equilibrium pressure of hydrogen could not be reached even after over 12 hours of steady hydrogen input. Additionally, the hydrided titanium flaked off of the chamber walls and fell to the bottom of the system. When an attempt to pump a respectable vacuum on this system was made, the titanium hydride outgassed severely, especially when external heat was applied.

With the interior of the system thus contaminated, a complete disassembly and cleanup was required.

Upon reassembly and repair of a leak precipitated by the

acid cleaning procedure, very good vacuum performance was achieved. After bakeout, pumpdown to better than 2×10^{-9} Torr was achieved with the system cold. As expected, vacuum levels deteriorate rapidly due to outgassing as system temperature increases. However, vacuum levels during the 900°C test were generally near 5×10^{-8} Torr or better, indicating an acceptably clean system.

After new samples are loaded into the test apparatus, the chamber is pumped down and baked out. After a satisfactory vacuum level is reached, the system wall is cooled and the samples are annealed in situ. The system is then brought to test temperature. For a vacuum test run, the samples are lifted into place and data recording commences as soon as test temperature is reached.

For a test run in a hydrogen environment the procedure after reaching test temperature is as follows. The ion pump is isolated from the test chamber. The system is allowed to sit in this static condition for from one to five minutes until a "base" static vacuum level is reached. Commercial hydrogen gas from a large cylinder is admitted to the opening of the Pd-Ag tube which serves as a hydrogen purifier. Purified hydrogen is admitted to the chamber until the desired pressure is read on the ion gage or until the range of the ion gage is exceeded. When the desired hydrogen pressure is reached, the samples are lifted into place and data recording commences.

The power source for the furnace element supplies alternating current power. It was found in one test that one sample was sympathetic to the 120 Hz vibration generated in the large conductors carrying the 300-plus ampere current. It is felt that this problem did not have a detrimental effect on the data obtained. However, inexpensive methods of eliminating the problem are being investigated.

Reading the position of the samples with the optical cathetometer provided a convenient and sensitive method of data collection. It was found that the least count on the cathetometer was smaller than the error of this human's eye in placing the cross-hairs on a desired location.

B. Data Processing

The computer program written for processing of raw creep data into a complete test record is well documented and convenient to use. The program includes a subroutine to fit the best straight line through selected data points, as designated by the user. An additional program to fit a polynomial to the creep curve was utilized in preparing Figures 10 and 12. It is intended that these programs be fully combined into a complete data analysis package to achieve unbiased curve-fitting and statistical comparison of future data sets.

C. Behavior of Tested Materials

The expressed purpose of this research project was to ascertain whether the presence of hydrogen affects the creep

properties of unalloyed vanadium, niobium, and molybdenum metals. Plots of each metal's creep performance at 900°C in vacuum and in hydrogen are given in Figures 8, 9, and 11. The pressure level during the vacuum run was approximately 5×10^{-8} Torr; the hydrogen pressure level during the hydrogen environment run was between one atmosphere and 1×10^{-3} Torr, over a "base" static vacuum of 1×10^{-6} Torr. Raw and processed numerical data are contained in Appendix B; polynomial expressions for shear strain and shear strain rate as functions of time are presented in Appendix C.

Figure 8 shows the results for niobium. It is apparent that, for the 900°C test temperature, the stress level was far too low to produce a suitable creep curve. Indeed, the ordinate axis is shear strain $\times 10^4$: only 5×10^{-4} strain was reached after 500 hours. In fact, the resolution of the instrumentation can be seen in the data as plotted: note the discrete increments in strain values. These data are of little significance except to indicate that under the conditions and time limits imposed, the presence of hydrogen has no effect on the creep rate of niobium. But the conditions and/or time limits imposed are not considered proper.

Figure 9 displays the creep curves obtained for molybdenum in vacuum and in hydrogen. As expected, the hydrogen environment data overlay the vacuum data almost exactly. The hydrogen data lie wholly beneath the vacuum data for times greater than 250 hours, but the difference is very small and

the straight lines through those points of the respective curves appear nearly parallel. Indeed, Figure 10 illustrates that strain rate as a function of strain behaves nearly identically for both environments. The curve shapes are similar and each curve has a minimum in the neighborhood of 3.7×10^{-3} strain. Additionally, the minimum strain rates are quite close to each other. It is suggested that these results support the conclusions by other researchers that the presence of hydrogen has little or no effect on the creep properties of molybdenum, at least under the prevailing test conditions.

The results obtained for vanadium are by far the most dramatic and exciting. It should be noted that the range of shear strain covered was the greatest of all samples tested. It is also important to observe that the character of the curve for hydrogen-environment data is different from that for the vacuum data. The slopes in the central and final portions of the hydrogen curve are steeper than for comparative locations on the curve for the test run in vacuum. Extension to 3.9% strain was achieved 120 hours sooner, or 27% faster, in hydrogen than in vacuum. The plot of strain rate versus strain in Figure 12 vividly displays the differences in the creep curves. The strain rate of the vacuum data does not appear to have reached a constant value during the time span of the test, but the hydrogen data shows a leveling off at the end of the test period. This suggests that the hydrogen environment enhances creep, because second stage is reached more rapidly in this

environment than in vacuum. Additionally, there is a substantial difference between the final values of strain rate for the two curves: the rate for the hydrogen is nearly three times that of the vacuum data. It appears that the presence of hydrogen does have an effect on the creep properties of vanadium metal. The results presented here warrant conducting more research.

V. RECOMMENDATIONS

The real value of this research effort lies in the design, construction, and successful operation of a sensitive creep test apparatus; the development of a computer program and other related procedures for data analysis; and in the accrual of data which indicate that a hydrogen environment affects creep, thereby substantiating the need for extensive investigation of the phenomenon.

In the two-plus years since the start of this project, many things have happened which can be attributed to lack of experience with high vacuum/high temperature test equipment and procedure. While two years' experience is not sufficient qualification for "expert" status, there are several changes which, in the researcher's opinion, should be made to the test apparatus and experimental procedure to improve overall capability, flexibility, and efficiency.

The first recommendation, however, is not one regarding the system but rather one concerning the data generated. It is assumed that concentration will at least temporarily turn to vanadium, since it appeared to react most dramatically to the presence of hydrogen. In order to have confidence in the data presented herein, they should be confirmed by more tests at the same conditions. It is suggested that three additional samples be loaded to the proper stress level and tested in vacuum and in hydrogen. With this amount of data, a statisti-

cal comparison (t-test) of the hydrogen and vacuum environment data can be made, and some unbiased conclusions may be drawn from the statistical analysis.

As additional tests are conducted it will become increasingly important to obtain accurate measurements of the following parameters: helix diameter (D_o), wire diameter (d), number of active turns (N), advance per turn (h_o), load, and deflection. As experience is gained regarding their measurement, the error limits on their values should be closely examined to determine if the error limits written into the computer program can be reduced. These error, or uncertainty, values enter into statistical computations in the least squares best fit straight line subroutine, and will affect the user's ability to ascertain significant differences between minimum creep rates.

The helix should be appropriately proportioned so the load required for the desired stress level is much greater than the weight of the sample. This will minimize the effect of the stress gradient in the sample due to sample weight relative to nominal stress level.

It is recommended that several changes be made to the test apparatus and associated hardware:

- To ensure that samples will easily assemble into their holders, a square-threaded mandrel identical to the holders should be fabricated for use in sample preparation.

- Since sample geometry is fairly consistent and only minor variations occur in critical dimensions, the loading weights should be redesigned to allow minor changes in their total mass to be made conveniently and quickly.
- A method should be devised to reduce the possibility of vibration excitation of the test chamber from the furnace power supply. The best--but probably the most expensive--solution would be to procure a DC power supply.
- System components should be rearranged as necessary to allow incorporation of a titanium sublimator pump which would be shielded from the main chamber and valved-off during hydrogen runs. This change will increase pumping speed and thus reduce the time required for system bake-out, as well as maintain superior vacuum levels during sample anneal and high-temperature vacuum test runs.
- Obtain a gage with high vacuum integrity to measure system pressure in the range 10^{-1} to 10^{-6} Torr. Standard ion gages are not usable above 1×10^{-3} Torr, and thermocouple-type vacuum gages do not have sufficient integrity to allow high vacuums to be pumped on them.
- The amount of hydrogen admitted to the system, as measured by system pressure, cannot presently be controlled accurately. It is felt that a manual system would not allow the continuous monitoring and control which will ultimately be required for test runs to determine creep

properties as a function of hydrogen pressure. Equipment to accurately control the pressure of the chosen environment should be procured.

VI. LITERATURE CITED

1. Fraas, A. P. and Postma, H., USAEC Report ORNL-TM-2822, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Nov. 1970.
2. Stegman, R. L., Shahinian, P., and Achter, M. R., Trans. Met. Soc. AIME, 245, 1759 (Aug. 1967).
3. Shahinian, P. and Achter, M. R., Trans. Met. Soc. AIME, 215, 37 (Feb. 1959).
4. Hales, R., Dobson, P. S., and Smallman, R. E., Acta Met., 17, 1323 (Nov. 1969).
5. Sawyer, J. C., and Steigerwald, E. A., J. Mater., 2, no. 2, 341 (June 1967).
6. Inouye, H., USAEC Report ORNL-3674, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1964.
7. Bourgette, D. T., Trans. Vac. Met. Conf., 8, 57 (1965).
8. Buckman, R. W., Jr., Trans. Vac. Met. Conf., 9, 25 (1966).
9. Schmidt, F. F., Maykuth, D. J., and Ogden, H. R., DMIC Report 205, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio, August 20, 1966.
10. Stoop, J. and Shahinian, P., ASM Trans. Quart., 39, 411 (1966).
11. Jackson, R., Carvalhinhos, H. J., and Argent, B. B., J. Inst. Metals, 96, 210 (1968).
12. Douglas, D. A., in "High Temperature Materials", Hehemann, R. F. and Ault, G. M., eds., John Wiley and Sons, New York, 1959, p 429.
13. McCoy, H. E., Jr., Effects of Hydrogen on the High Temperature flow and Fracture Characteristics of Metals. Ph.D. Thesis, University of Tennessee, June 1964.
14. Machlin, I., J. Metals, 20, no. 9, 21 (Sept. 1968).
15. McCoy, H. E., Jr. and Douglas, D. A., in "Columbium Metallurgy", Douglass, D. L. and Kunz, F. W., eds., Interscience Publishers, New York, 1961, p 85.

16. Carlson, O. N. and Owen, C. V., J. Electrochem. Soc., 108, 88-93 (1961).
17. Sherman, D. H., An Investigation of the Characteristics of Hydrogen Charged Vanadium Metal, M.S. Thesis, Iowa State University, 1967.
18. Neville, A. M. and Kennedy, J. B., "Basic Statistical Methods for Engineers and Scientists," International Textbook Company, Scranton, Pa., 1964, pp 163, 171-198.
19. Lewthwaite, G. W. and Smith, R. T., Brit. J. Appl. Phys. 18, 1012-1016 (1967).

VII. ACKNOWLEDGEMENTS

I would like to take this opportunity to thank all who have contributed their efforts to this investigation. Special thanks are extended to:

Dr. Tom Scott, who instigated, sustained, and guided this investigation, and who gave generously during preparation of this manuscript;

Dr. C. R. Mischke, for assistance in computer programming, data analysis, and in maintaining perspective in this research effort;

Dr. A. Henkin, for assisting in evaluation of the test apparatus and of this investigation;

C. V. Owen, who supplied helpful knowledge concerning materials processing;

Lester Reed, for his ever-present sense of humor, and for his willing assistance in sample preparation, equipment design, and equipment assembly;

Miss Verna Thompson, for excellent typing service and assistance in properly executing the assembly of this thesis;

My wife, Lois, for continuous emotional and financial support during the pursuit of this degree.

VIII. APPENDIX A. FIGURES

Fig. 1. A conceptual CTR core cross-section after Fraas and Postma (1)

Fig. 2. An enlarged view of the first wall region of the conceptual CTR core illustrated in Figure 1 showing anticipated environmental conditions

Fig. 3. Experimental results from McCoy and Douglas (15) showing the effect of a hydrogen environment on creep of niobium

Fig. 4. Overall view of creep test apparatus showing major components. Refer to key on following page

Key for Figures 4 and 5

- A - Handle of vacuum-tight (bellows-type) translational motion feedthrough for raising and lowering samples
- B - Electrically-insulated feedthroughs for thermocouples
- C - Viewport
- D - All-metal valve to isolate sorption (roughing) pump from system
- E - Bayard-Alpert type ion vacuum gage
- F - Thermocouple-type vacuum gage
- G - Sorption pump
- H - High current, water-cooled electrical feedthrough for furnace element power
- I - #4-0 electrical cable for furnace power
- J - Location of Titanium Sublimator Pump
- K - Gate valve to isolate ion pump from system for hydrogen runs and loading
- L - 100 L/S ion pump
- M - Port for residual gas analyser head
- N - Water lines for cooling test apparatus
- O - Molybdenum sheet stock rolled into cylinder to provide thermal shielding in radial direction
- P - Tungsten support rods and electrical conductors for tungsten mesh furnace elements
- Q - Tungsten mesh furnace element (only one is shown: the other portion of the element is cut away)
- R - Main support rod connecting samples to plunger "A"
- S - Portion of internal "cage"

Fig. 5. Test apparatus. (a) Front view of test apparatus; (b) cutaway view of (a). Refer to key on previous page

(a)

(b)

Fig. 6. Sketch of a helical spring (a), and a wire of circular cross-section under torsional loading condition (b); used in derivation of expression which relates sample elongation to shear strain

Fig. 7. Sketch of helical spring in coiled and in uncoiled condition; used in derivation of expression which relates sample elongation to shear strain

Fig. 8. Shear strain versus time for niobium metal at 900°C in hydrogen and in dynamic vacuum

Fig. 9. Shear strain versus time for molybdenum metal at 900°C in hydrogen and in dynamic vacuum

Fig. 10. Shear strain rate versus shear strain for molybdenum metal at 900°C in hydrogen and in dynamic vacuum

Fig. 11. Shear strain versus time for vanadium metal at 900°C in hydrogen and in dynamic vacuum

Fig. 12. Shear strain rate versus shear strain for vanadium metal at 900°C in hydrogen and in dynamic vacuum

IX. APPENDIX B. RAW AND PROCESSED
NUMERICAL DATA

```

$JCB      'MATHER',TIME=10,PAGES=40
C
C      CREEP TEST DATA ANALYSIS--
C      VALID FOR DATA TAKEN BY OPTICAL CATHETOMETER ON
C      HIGH TEMP. HIGH VACUUM CREEP TEST APPARATUS LOCATED IN
C      METALLURGY GROUP THIRTEEN OF AMES LAB, USAEC.
C
C      THIS PROGRAM IS SET UP FOR A MAXIMUM OF 50 DATA POINT PAIRS
C      PER DATA SET, BUT AS MANY DATA SETS AS DESIRED MAY BE RUN.
C
C      THE FIRST FOUR READ STATEMENTS ENTER PERTINENT TEST RUN
C      INFORMATION, SAMPLE INFORMATION, AND COMPUTATIONAL DIRECTIONS
C      INTO THE COMPUTER. THE TERMS ARE DEFINED AS FOLLOWS--
C      MM = INTEGER DENOTING THE NUMBER OF DATA SETS TO BE ANALYSED.
C      DATE= SIX-DIGIT DATE CODE, WITH TWO EACH FOR MONTH, DAY, YEAR.
C      PGNO= PAGE NUMBER IN RECORD BOOK SHOWING LOADING DATA FOR RUN
C      TEMP= NOMINAL TEST TEMPERATURE IN DEGREES CENTIGRADE.
C      SMATL= SAMPLE MATERIAL, ATOMIC NUMBER USED FOR IDENTIFICATION.
C      SMPLNO= SAMPLE NUMBER
C      POSNO= POSITION NUMBER DENOTING LOCATION IN RIG DURING TEST.
C          TOP LEFT IS NUMBER ONE
C          TOP CENTER IS NUMBER TWO
C          TOP RIGHT IS NUMBER THREE
C          BOTTOM LEFT IS NUMBER FOUR
C          BOTTOM CENTER IS NUMBER FIVE
C          BOTTOM RIGHT IS NUMBER SIX
C      ATMOS= TEST ATMOSPHERE- 1 FOR VACUUM AND 2 FOR HYDROGEN GAS
C      GMLOAD= LOAD IN GRAMS ON SAMPLE BEING CONSIDERED
C      ATURNS= NUMBER OF ACTIVE TURNS IN SAMPLE
C      WIREDM= WIRE DIAMETER OF SAMPLE, IN INCHES.
C      COLDIA= COIL DIAMETER, FROM CENTER LINE OF WIRE TO CENTER LINE
C              OF WIRE, NOT OUTSIDE DIAM. MEASURED IN MILLIMETERS.
C      K = INTEGER DENOTING THE NUMBER OF DATA POINT PAIRS IN
C          THE SET OF DATA BEING ANALYSED.
C      L = INTEGER DENOTING THE NUMBER OF THE DATA POINT WITH WHICH
C          THE LEAST SQUARES ANALYSIS SHOULD START.
C      M = INTEGER DENOTING THE NUMBER OF THE LAST DATA POINT
C          INCLUDED IN THE LEAST SQUARES ANALYSIS.
C
C      PLEASE NOTE THAT THE T-STATISTIC AND THE F-STATISTIC REQUIRED
C      FOR THE SUBROUTINE BOTH DEPEND ON THE NUMBER OF DATA POINT
C      PAIRS TRANSMITTED TO THE SUBROUTINE. SEE DOCUMENTATION FOR
C      SUBROUTINE ME0226, BY C. MISCHKE.
C
C
C      REQUIREMENTS FOR DATA INPUT---
C
C      THE FOLLOWING CARD IS ENTERED ONLY ONCE PER SUBMITTAL-
C      THIS CARD HAS ONE ENTRY, AND IT IS AN INTEGER. SPACE ALLOTTED
C      IS TEN SPACES WIDE, AND THE NUMBER SHOULD BE PLACED SO IT
C      ENDS IN COLUMN NUMBER 10. ENTER MM.
C
C      EACH DATA SET MUST HAVE THE FOLLOWING INFORMATION-
C      FIRST CARD HAS SIX ENTRIES, EACH ENTRY IS TEN SPACES WIDE WITH
C      NO DIGITS AFTER THE DECIMAL POINT. FOR FEWER ERRORS, DECIMAL
C      POINT SHOULD BE PUNCHED. ENTER DATE, PGNO, TEMP, SMATL,
C      SMPLNO, AND POSNO ON THIS CARD.
C
C      SECOND CARD HAS FIVE ENTRIES. EACH ENTRY IS TEN SPACES WIDE

```



```

C      WITH UP TO THREE DIGITS ALLOWED AFTER THE DECIMAL POINT.
C      FOR FEWER ERRORS, DECIMAL POINT SHOULD BE PUNCHED. ENTER
C      ATMOS, GMLCAD, ATURNS, WIREDM, AND COLDIA ON THE CARD.
C
C      THIRD CARD HAS THREE ENTRIES, AND THEY ARE INTEGERS. EACH
C      ENTRY HAS TEN SPACES ALLOTTED---PLACE EACH NUMBER SO IT ENDS
C      IN LAST ALLOWABLE RIGHT-HAND COLUMN. ENTER K,L, AND M.
C
C      THE FOURTH CARD HAS TWO ENTRIES. EACH ENTRY IS TEN SPACES
C      WIDE, WITH UP TO FOUR DIGITS ALLOWED AFTER THE DECIMAL
C      POINT. FOR FEWER ERRORS, PUNCH THE DECIMAL POINT.
C      ENTER TSTAT AND FSTAT.
C
C      THE FIFTH AND ALL SUCCESSIVE CARDS HAVE THREE ENTRIES. EACH
C      ENTRY IS TEN SPACES WIDE WITH UP TO THREE DIGITS ALLOWED
C      AFTER THE DECIMAL. FOR FEWER ERRORS, PUNCH THE DECIMAL POINT.
C      ENTER ELTIME, TOPPOS, BOTPOS.
C      ELTIME IS THE ELAPSED TIME FROM START OF TEST TO THE
C      READING OF THE DATA POINT IN QUESTION.
C      TOPPOS IS THE CATHETOMETER READING OF THE POSITION
C      OF THE TOP OF THE SAMPLE.
C      BOTPOS IS THE CATHETOMETER READING OF THE POSITION
C      OF THE BOTTOM OF THE SAMPLE.
C
C
C
C
1      DIMENSION X(50),Y(50), B7(50),B8(50),B9(50),B10(50),B11(50),
1      B12(50),B16(50),B17(50), ELTIME(50), TOPPOS(50), BOTPOS(50),
2      CLNGTH(50),DELTA(50),TERMS(50),ARG3(50),STRAIN(50)
C      ERROR LIMITS ON MEASUREMENTS ARE GIVEN BELOW--
3      SCCILD=.15
3      SWIRD=.03
4      SN=.1
5      SK=.117
6      SLGAC=1.
7      SY=.2
8      SHC=.35
C
C      CONSTANTS ARE AS FOLLOWS
9      PI= 3.1415927
10     HO=1.4
C
11     READ(5,19) MM
12     19 FORMAT(I10)
13     DO 60 LL=1,MM
14     READ(5,10) DATE,PGNO,TEMP,SMATL,SMPLNO, POSNO,ATMOS,GMLOAD,
15     1 ATURNS,WIREDM,COLDIA
16     10 FORMAT(6F10.0/5F10.3)
16     WIRDIA=WIREDM*.25.4
17     CPATIO=COLDIA/WIRDIA
18     CK=(4.*CPATIO-1.)/(4.*CPATIO-4.)+(0.615/CPATIO)
19     READ(5,11) K,L,M
20     11 FORMAT(3I10)
21     READ(5,13) TSTAT,FSTAT
22     13 FORMAT(2F10.4)
C
C      COMPUTATION OF SHEAR STRESS LEVEL IN GM/SQ MM--THIS IS A MAX.
23     TAU=(CK*.8.*GMLOAD*COLDIA)/(PI*WIRDIA*WIRDIA*WIRDIA)
24     TAUW=TAU
C      CONVERT SHEAR STRESS TO PSI UNITS

```

```

25     TALPSI= TAU*1.4223
      C     COMPUTE ERROR ON STRESS LEVEL--
      C     FIRST, CONTRIBUTION FROM STRESS CONCENTRATION TERM--
26     ERRSCN=(8.*GMLOAD*COLDIA*SK)/(PI*WIRDIA*WIRDIA*WIRDIA)
      C     CONTRIBUTION FROM LOAD--
27     ERRLOD=(8.*COLDIA*CK*SLD)/(PI*WIRDIA*WIRDIA*WIRDIA)
      C     CONTRIBUTION FROM COIL DIAMETER
28     ERRCOM=(8.*GMLOAD*CK*SCD)/(PI*WIRDIA*WIRDIA*WIRDIA)
      C     CONTRIBUTION FROM WIRE DIAMETER
29     ERRWDM=(24.*CK*GMLOAD*COLDIA*SWIRD)/((PI)*(WIRDIA**4))
      C     COMPUTE ERROR ON MAXIMUM SHEAR STRESS(GM/MM**2)
30     STAU=SQRT((ERRSCN**2.)+(ERRLOD**2.)+(ERRCOM**2.)+(ERRWDM**2.))
31     STAUMM= STAU
      C     CONVERT TO PSI
32     STAUPS= STAU*1.4223
      C
33     WRITE(6,20) DATE,PGNC,TEMP,SMATL,SMPLNO,POSNO,ATMOS,TAUMM,TAUPSI,
      1 STAUMM,STAUPS,GMLOAD,ATURNS,WIREDM,COLDIA
34     20 FORMAT(1H1,
      1' RESULTS OF HIGH TEMPERATURE CREEP TEST--',/,
      2' RESEARCHER--J C MATHER ',/,
      2' TEST BEGUN ON ',F9.0,/,
      3' REFER TO RECCRD BOOK PG NO ',F5.0,' FOR LOADING INFO',/,
      4' TEST TEMPERATURE',F6.0,' DEGREES C.',/,
      5' MATERIAL TESTED HAS ATOMIC NUMBER',F4.0,' SAMPLE NO.',F5.0,/,
      6' SAMPLE LOCATION IN TEST APPARATUS WAS NUMBER',F4.0,/,
      7' TEST ENVIRONMENT CODE NUMBER',F3.0,/,
      8' NOMINAL SHEAR STRESS LEVEL-',F7.0,'GM/MM**2',F7.0,'PSI',/,
      9' ERROR ON STRESS LEVEL-',F7.0,'GM/MM**2',F7.0,'PSI',/,
      1' LOAD ON SAMPLE-',F5.1,' GRAMS',/,
      2' NUMBER OF ACTIVE TURNS-',F3.0,/,
      3' WIRE DIAMETER IN INCHES-',F6.4,/,
      4' DIAMETER OF HELIX IN MILLIMETERS-',F4.2,/,
      5' CHARACTERISTIC',/,
      5' TIME POSITION LENGTH LENGTH CHANGE SH
      6' (HOURS) TOP BOTTOM (CM) DELTA(MM) ST
      8RAIN',/)
35     READ(5,12)(ELTIME(I),TOPPOS(I),BOTPOS(I), I=1,K)
36     12 FORMAT(3F10.3)
37     DO 50 N=1,K
      C     COMPUTATION OF CHARACTERISTIC LENGTH FROM READINGS
38     CLNGTH(N)= TOPPOS(N)-BOTPOS(N)
      C     COMPUTATION OF LENGTH CHANGE
39     DELTA(N)=(CLNGTH(N)-CLNGTH(1))*10.
40     50 CONTINUE
41     TERM1=PI*WIRDIA
42     TERM2=SQRT((PI*PI*COLDIA*COLDIA)+(HO*HO))
43     TERM3=HO+DELTA(K)/ATURNS
44     ARG1=TERM3/TERM2
45     ARG2=HO/TERM2
46     TERM4=ARSIN(ARG1)-ARSIN(ARG2)
47     DO 51 N=1,K
      C     COMPUTE REAL ENGINEERING SHEAR STRAIN CONDITION
      C     WHICH TAKES COIL DIAMETER CHANGES INTO ACCOUNT
48     TERM5(N)=HO+DELTA(N)/ATURNS
49     ARG3(N)=TERM5(N)/TERM2
50     STRAIN(N)=(TERM1/TERM2)*(ARSIN(ARG3(N))-ARSIN(ARG2))
51     51 CONTINUE
52     WRITE(6,29)(ELTIME(N),TOPPOS(N),BOTPOS(N),CLNGTH(N),DELTA(N),

```

```

1 STRAIN(N), N=1,K)
53 29 FORMAT(F11.3,3F10.3,F13.3,E15.4)
54 KK=M+1-L
55 DO 54 N=1,KK
56 X(N)= ELTIME(N+L-1)
57 Y(N)= STRAIN(N+L-1)
58 54 CONTINUE
C COMPUTATION OF MAXIMUM ERROR ON STRAIN--
C TO BE USED IN SUBROUTINE ME226R
C PRTL1 IS THE PARTIAL DERIVATIVE OF STRAIN WITH RESPECT TO THE
C NUMBER OF ACTIVE TURNS
59 PRTL1=(TERM1*DELTA(K))/((ATURNS*ATURNS*TERM2*TERM2)*(SQRT(1.-ARG1*
1 APG1)))
C
C PRTL2 IS THE PARTIAL DERIVATIVE OF STRAIN WITH RESPECT TO DELTA
60 PRTL2=TERM1/(TERM2*TERM2*ATURNS*(SQRT(1.-ARG1*ARG1)))
C PRTL3 IS THE PARTIAL DERIVATIVE OF STRAIN WITH RESPECT TO
C WIRE DIAMETER
61 PRTL3=PI*TERM4/TERM2
C
C PRTL4 IS THE PARTIAL DERIVATIVE OF STRAIN WITH RESPECT TO
C COIL DIAMETER
62 AA1=TERM1*TERM4*PI*PI*COLDIA/TERM2**3
63 AA2=PI*PI*COLDIA*TERM3/((TERM2**3)*SQRT(1.-ARG1*ARG1))
64 AA3=HC*PI*PI*COLDIA/((TERM2**3)*SQRT(1.-ARG2*ARG2))
65 PRTL4=(TERM1/TERM2)*(AA3-AA2)-AA1
C
C PRTL5 IS THE PARTIAL DERIVATIVE OF STRAIN WITH RESPECT TO
C INITIAL SPACING BETWEEN TURNS OF THE COIL.
66 BB1=TERM1*TERM4*HO/TERM2**3
67 BB2=TERM3*HO/((TERM2**3)*SQRT(1.-ARG1*ARG1))
68 BB3=1./((TERM2*SQRT(1.-ARG1*ARG1))
69 BB4=HO*HO/((TERM2**3)*SQRT(1.-ARG2*ARG2))
70 BB5=1./((TERM2*SQRT(1.-ARG2*ARG2))
71 PRTL5=(TERM1/TERM2)*(BB3-BB2+BB4-BB5)-BB1
72 SGAMMA=SQRT((PRTL1*SN)**2 +(PRTL2*SY)**2 +(PRTL3*SWIRD)**2 +(PRT
1 L4*SCOILD)**2 +(PRTL5*SHD)**2)
73 CALL ME226R(1,KK,X,Y,TSTAT,FSTAT,SGAMMA,B1,B2,B3,B4,B5,B6,B7,B8,
1 B9,B10,B11,B12,B13,B14,B15,B16,B17)
74 60 CONTINUE
75 STOP
76 END

77 SUBROUTINE ME226R(MUN,N,X,Y,TSTAT,FSTAT,PP,A,B,XBAR,YBAR,SA,SB,UP, 00C1
1 DOWN,CUP,CDOWN,FUP,FDCWN,R,SYX,SYBARX,SYI,SFUT) 00C2
C STRAIGHT LINE REGRESSION OF Y ON X. Y=A+B*X MISCHKE-HALLAC 00C3
C REVISED BY MATHER FOR INCLUSION OF ERROR VALUE FOR Y-COORDINATES. BC 03
C ME226R(I1,I2,A3,A4,A5,A6,A7,B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12, 00C4
C 1 B13,B14,B15,B16,B17) 00C5
C 00C6
C THIS SUBROUTINE PERFORMS A LINEAR LEAST SQUARES REGRESSION OF Y ON X. 00C7
C THE ROUTINE ACCEPTS MONITOR PRINT SIGNAL, NUMBER OF DATA PAIRS, COLUMN 00C8
C VECTORS OF DATA, T-STATISTIC AND F-STATISTIC FOR CONFIDENCE BOUNDS, A 00C9
C AND VALUE OF UNCERTAINTY FOR ORDINATES. BC 09
C THE ROUTINE RETURNS INTERCEPT AND SLOPE OF REGRESSION LINE, DATA 00C10
C CENTROID COORDINATES, STANDARD DEVIATION OF INTERCEPT AND SLOPE, 00C11
C UPPER AND LOWER CONFIDENCE BOUNDS POINT-BY-POINT, UPPER AND LOWER 00C12
C CONFIDENCE BOUNDS FOR THE LINE-AS-A-WHOLE, 00C13
C CONFIDENCE BOUNDS FOR A FUTURE POINT, CORRELATION COEFFICIENT 00C14
C STANDARD DEVIATION OF Y ON X, YBAR ON X, YBARI AND FUTURE 00C15

```

```

C
C SEE NATIONAL BUREAU OF STANDARDS SPECIAL VOLUME 300, PAGE 204 ETAL. 0016
C 0017
C 0018
C CALLING PROGRAM REQUIREMENTS 0019
C 0020
C PROVIDE THE EQUIVALENT TO THE FOLLOWING DECLARATION: 0021
C 0022
C DIMENSION A3(12),A4(12),B7(12),B8(12),B9(12),B10(12),B11(12),B12(12), 0023
C B16(12),B17(12) 0024
C 0025
C CALL LIST ARGUMENTS 0026
C 0027
C I1=0 MONITOR AND PLOTTING TABULATION DOES NOT PRINT 0028
C I1=1 MONITOR AND PLOTTING TABULATION PRINTS ON SEPARATE PAGE 0029
C I2=NUMBER OF DATA POINT PAIRS 0030
C A3=COLUMN VECTOR OF DATA X-COORDINATES 0031
C A4=COLUMN VECTOR OF DATA Y-COORDINATES 0032
C A5=T-STATISTIC T(I2-2) FOR 1-ALPHA/2, ALPHA = SIGNIFICANCE LEVEL OF BOUND 0033
C A6=F-STATISTIC F(2,I2-2) FOR 1-ALPHA, ALPHA = SIGNIFICANCE LEVEL OF BOUND 0034
C A7= UNCERTAINTY VALUE FOR DATA Y-COORDINATES 0035
C 0036
C B1=ORDINATE INTERCEPT OF REGRESSION LINE 0037
C B2=SLOPE OF REGRESSION LINE 0038
C B3=X-COORDINATE OF DATA CENTROID 0039
C B4=Y-COORDINATE OF DATA CENTROID 0040
C B5=STANDARD DEVIATION OF ORDINATE INTERCEPT OF REGRESSION LINE 0041
C B6=STANDARD DEVIATION OF SLOPE OF REGRESSION LINE 0042
C B7=COLUMN VECTOR UPPER CONFIDENCE BOUND POINT-BY-POINT 0043
C B8=COLUMN VECTOR LOWER CONFIDENCE BOUND POINT-BY-POINT 0044
C B9=COLUMN VECTOR UPPER CONFIDENCE BOUND LINE-AS-A-WHOLE 0045
C B10=COLUMN VECTOR LOWER CONFIDENCE BOUND LINE-AS-A-WHOLE 0046
C B11=COLUMN VECTOR UPPER CONFIDENCE BOUND FOR FUTURE POINT 0047
C B12=COLUMN VECTOR LOWER CONFIDENCE BOUND FOR FUTURE POINT 0048
C B13=CORRELATION COEFFICIENT 0049
C B14=STANDARD DEVIATION Y ON X, SYX 0050
C B15=STANDARD DEVIATION YBAR ON X, SYBARX 0051
C B16=COLUMN VECTOR OF STANDARD DEVIATION YBARI ON X, SYBARI 0052
C B17=COLUMN VECTOR OF STANDARD DEVIATION YFUTURE ON X, SYFUT 0053
C 0054
C PREEMPTED NAMES 0055
C 0056
C 0057
C 0058
C 0059
C 0060
C 0061
C 0062
C 0063
C 0064
C 0065
C 0066
C 0067
C 0068
C 0069
C 0070
C 0071
C 0072
78 DIMENSION X(1),Y(1),UP(1),DOWN(1),CUP(1),CDOWN(1),FUP(1),FDOWN(1),
1 SYI(1),SFUT(1)
79 GO TO 100
80 1 SUMX=0.
81 SUMY=0.
82 SUMXX=0.
83 SUMYY=0.
84 SUMXY=0.
85 SUM1=0.
86 SUM2=0.
87 SUM3=0.
88 SUM4=0.
89 DO 2 I=1,N
90 SUMX=SUMX+X(I)
91 SUMY=SUMY+Y(I)
92 SUMXX=SUMXX+X(I)*X(I)

```

```

93      SUMY=SUMY+Y(I)*Y(I)                                0073
94      SUMXY=SUMXY+X(I)*Y(I)                                0074
95      2 CONTINUE                                           0075
96      XBAR=SUMX/FLOAT(N)                                    0076
97      YBAR=SUMY/FLOAT(N)                                    0077
98      ANUM=SUMXX*SUMY-SUMX*SUMXY                           0078
99      BNUM=FLOAT(N)*SUMXY-SUMX*SUMY                         0079
100     DENOM=FLOAT(N)*SUMXX-SUMX*SUMX                         0080
101     IF(DENOM.NE.0.) GO TO 1070                             0081
102     WRITE(6,106)                                           0082
103     106 FORMAT(' *****ERROR MESSAGE SUBROUTINE ME226P*****./,
104     1' INTERCEPT AND SLOPE UNDETERMINANT, CHECK DATA') 0083
105     RETURN                                                 0084
106     1C7C A=ANUM/DENOM                                       0085
107     B=BNUM/DENOM                                           0086
108     DO 3 I=1,N                                             0087
109     SUM1=SUM1+(X(I)-XBAR)*(X(I)-XBAR)                       0088
110     SUM2=SUM2+(Y(I)-YBAR)*(Y(I)-YBAR)                       0089
111     SUM3=SUM3+(X(I)-XBAR)*(Y(I)-YBAR)                       0090
112     SUM4=SUM4+(Y(I)-A-B*X(I))**2                           0091
113     3 CONTINUE                                           0092
114     IF(SUM1.NE.0.) GO TO 1C8                                0093
115     WRITE(6,107)X(1)                                       0094
116     107 FORMAT(' *****ERROR MESSAGE SUBROUTINE ME226R*****./,
117     1' ALL X-OBSERVATIONS SAME.'G15.7.', CHECK DATA') 0095
118     IERROR=1                                               0096
119     1C8 IF(SUM2.NE.0.) GO TO 110                             0097
120     WRITE(6,109)Y(1)                                       0098
121     109 FORMAT(' *****ERROR MESSAGE SUBROUTINE ME226R*****./,
122     1' ALL Y-OBSERVATIONS SAME.'G15.7.', CHECK DATA') 0099
123     IERROR=1                                               0100
124     110 IF(IERROR.NE.C) RETURN                             0101
125     P=SQRT((SUM2-SUM4)/SUM2)                               0102
126     SYX=SQRT((SUM4/FLOAT(N-2))+P**2)                      0103
127     SYBARX=SYX/SQRT(FLOAT(N))                             0104
128     SB=SQRT(SYX*SYX/SUM1)                                  0105
129     S2A=(SYX*SYX*(1./FLOAT(N)+XBAR*XBAR/SUM1))             0106
130     SA=SQRT(S2A)                                           0107
131     AUP=A+TSTAT*SA                                         0108
132     ALOW=A-TSTAT*SA                                         0109
133     BUP=B+TSTAT*SB                                         0110
134     BLOW=B-TSTAT*SB                                         0111
135     YUP=YBAR+TSTAT*SYBARX                                  0112
136     YLOW=YBAR-TSTAT*SYBARX                                  0113
137     DO 4 I=1,N                                             0114
138     YHAT=A+B*X(I)                                          0115
139     ARG2=SYX*SYX*(1./FLOAT(N)+(X(I)-XBAR)**2/SUM1)         0116
140     SYI(I)=SQRT(ARG2)                                       0117
141     UP(I)=YHAT+TSTAT*SYI(I)                                 0118
142     DOWN(I)=YHAT-TSTAT*SYI(I)                               0119
143     CUP(I)=YHAT+SQRT(2.*FSTAT)*SYI(I)                     0120
144     CDOWN(I)=YHAT-SQRT(2.*FSTAT)*SYI(I)                   0121
145     ARG3=SYX*SYX*(1.+1./FLOAT(N)+(X(I)-XBAR)**2/SUM1)     0122
146     SFUT(I)=SQRT(ARG3)                                      0123
147     FUP(I)=YHAT+TSTAT*SFUT(I)                              0124
148     FDOWN(I)=YHAT-TSTAT*SFUT(I)                            0125
149     4 CONTINUE                                           0126
150     IF(MCN.EC.0) GO TO 99                                  0127
151     WRITE(6,5)                                             0128
152     5 FORMAT('1'./,                                         0129

```

```

1* MONITOR AND PLOTTING DISPLAY IOWA CADET SUBROUTINE ME226R MISOH
2E. HALL, REVISED BY MATHER'./././
3*   X       Y       Y       Y       Y       Y       Y
4   DATA      DATA      REGRESSION  UPPER BOUND  LOWER BO
6UND  UPPER BOUND  LOWER BOUND  UPPER BOUND  LOWER BOUND'././
7*   LINE      POINT-BY-POINT POINT-BY-
8POINT LINE-AS-WHOLE LINE-AS-WHOLE FUTURE POINT  FUTURE POINT'./)
150  DO 6 I=1,N
151  YR=A+B*X(I)
152  WRITE(6,9) X(I),Y(I),YF,UP(I),DOWN(I),CUP(I),CDOWN(I)
153  9 FORMAT(9(1X,G13.6))
154  6 CONTINUE
155  WRITE(6,7)A,AUP,ALOW,B,BUP,BLOW,XBAR,YBAR,YUP,YLOW,TSTAT,FSTAT,R,
156  7 FORMAT(/,
1* ORDINATE INTERCEPT A OF REGRESSION LINE .....G14.7./,
2* UPPER CONFIDENCE BOUND ON ORDINATE INTERCEPT A .....G14.7./,
3* LOWER CONFIDENCE LIMIT ON ORDINATE INTERCEPT A .....G14.7./,
4* SLOPE B OF REGRESSION LINE .....G14.7./,
5* UPPER CONFIDENCE BOUND ON SLOPE B .....G14.7./,
6* LOWER CONFIDENCE BOUND ON SLOPE B .....G14.7./,
7* X-COORDINATE OF DATA CENTROID .....G14.7./,
8* Y-COORDINATE OF DATA CENTROID .....G14.7./,
9* UPPER CONFIDENCE BOUND ON YBAR .....G14.7./,
10* LOWER CONFIDENCE BOUND ON YBAR .....G14.7./,
11* T-STATISTIC T(N-2) FOR (1-ALPHA), TWO TAILED .....G14.7./,
12* F-STATISTIC F(2,N-2) FOR (1-ALPHA), ONE TAILED .....G14.7./,
13* CORRELATION COEFFICIENT R .....G14.7./,
14* SUM OF X .....G14.7./,
15* SUM OF Y .....G14.7./,
16* SUM OF X**2 .....G14.7./,
17* SUM OF Y**2 .....G14.7./,
18* SUM OF XY,SUM1,SUM2,SUM3,SUM4,SYX,SYBARX,SA,SB
157  WRITE(6,8) SUMXY,SUM1,SUM2,SUM3,SUM4,SYX,SYBARX,SA,SB
158  8 FORMAT(
1* SUM OF XY .....G14.7./,
2* SUM OF (X-XBAR)**2 .....G14.7./,
3* SUM OF (Y-YBAR)**2 .....G14.7./,
4* SUM OF (X-XBAR)*(Y-YBAR) .....G14.7./,
5* SUM OF (Y-YHAT)**2 .....G14.7./,
6* UNBIASED ESTIMATOR STANDARD DEVIATION Y ON X, SYX .....G14.7./,
7* UNBIASED ESTIMATOR SYBARX .....G14.7./,
8* UNBIASED ESTIMATOR OF STANDARD DEVIATION OF A, SA .....G14.7./,
9* UNBIASED ESTIMATOR OF STANDARD DEVIATION OF B, SB .....G14.7./,
10* )
159  52 RETURN
160  C .....PROTECTION.....
161  100 IERROR=0
162  IF(MON.EQ.0.OR.MON.EQ.1) GO TO 102
163  WRITE(6,101) MCN
164  101 FORMAT(' *****ERROR MESSAGE SUBROUTINE ME226R*****./,
165  1* ARGUMENT 11,'.I15,'. NOT EQUAL TO ZERO OR ONE')
166  IERROR=1
167  102 IF(N.GT.2) GO TO 104
168  WRITE(6,103)N
169  103 FORMAT(' *****ERROR MESSAGE SUBROUTINE ME226R*****./,
170  1* ARGUMENT 12,'.I15,'. NOT GREATER THAN TWO')
171  IERROR=1
172  104 IF(TSTAT.GT.0.AND.FSTAT.GT.0) GO TO 1050
173  WRITE(6,105)TSTAT,FSTAT
174  105 FORMAT(' *****ERROR MESSAGE SUBROUTINE ME226R*****./,
175  1* ARGUMENT 15 OR 16,'.G16.7,G16.7,'. NOT GREATER THAN ZERO')
176  IERROR=1
177  1050 IF(IERROR.NE.0) RETURN
178  IERROR=0
179  GO TO 1
180  END
SENTRY

```

RESULTS OF HIGH TEMPERATURE CREEP TEST--

RESEARCHER--J C MATHER
 TEST RUN ON 91874.
 REFER TO RECORD BOOK PG NO 62. FOR LOADING INFO
 TEST TEMPERATURE 900. DEGREES C.
 MATERIAL TESTED HAS ATOMIC NUMBER 41.. SAMPLE NO. 6.
 SAMPLE LOCATION IN TEST APPARATUS WAS NUMBER 3.
 TEST ENVIRONMENT CODE NUMBER 1.
 NOMINAL SHEAR STRESS LEVEL- 1890.GM/MM**2 2688.PSI
 ERROR ON STRESS LEVEL- 287.GM/MM**2 409.PSI
 LOAD ON SAMPLE- 51.7 GRAMS
 NUMBER OF ACTIVE TURNS- 9.
 WIRE DIAMETER IN INCHES-0.0317
 DIAMETER OF FELIX IN MILLIMETERS-6.31

TIME (HOURS)	POSITION		CHARACTERISTIC LENGTH		SHEAR STRAIN
	TOP	BOTTOM	(CM)	LENGTH CHANGE DELTA(MM)	
0.000	1.215	0.000	1.215	0.000	0.0000E 00
5.066	1.215	0.000	1.215	0.000	0.0000E 00
17.066	1.215	0.000	1.215	0.000	0.0000E 00
25.330	1.220	0.000	1.220	0.050	0.3572E-04
31.330	1.220	0.000	1.220	0.050	0.3572E-04
41.330	1.215	0.000	1.215	0.000	0.0000E 00
49.066	1.225	0.000	1.225	0.100	0.7146E-04
67.580	1.230	0.000	1.230	0.150	0.1072E-03
77.600	1.225	0.000	1.225	0.100	0.7146E-04
89.670	1.230	0.000	1.230	0.150	0.1072E-03
99.830	1.230	0.000	1.230	0.150	0.1072E-03
113.900	1.235	0.000	1.235	0.200	0.1429E-03
121.670	1.235	0.000	1.235	0.200	0.1429E-03
137.200	1.235	0.000	1.235	0.200	0.1429E-03
144.900	1.240	0.000	1.240	0.250	0.1786E-03
150.000	1.230	0.000	1.230	0.150	0.1072E-03
161.200	1.230	0.000	1.230	0.150	0.1072E-03
170.900	1.235	0.000	1.235	0.200	0.1429E-03
185.900	1.235	0.000	1.235	0.200	0.1429E-03
197.600	1.230	0.000	1.230	0.150	0.1072E-03
209.400	1.235	0.000	1.235	0.200	0.1429E-03
225.400	1.235	0.000	1.235	0.200	0.1429E-03
237.400	1.240	0.000	1.240	0.250	0.1786E-03
257.670	1.240	0.000	1.240	0.250	0.1786E-03
269.670	1.245	0.000	1.245	0.300	0.2144E-03
280.830	1.250	0.000	1.250	0.350	0.2501E-03
289.670	1.255	0.000	1.255	0.400	0.2858E-03
305.000	1.260	0.000	1.260	0.450	0.3216E-03
313.500	1.255	0.000	1.255	0.400	0.2858E-03
317.830	1.260	0.000	1.260	0.450	0.3216E-03
329.100	1.255	0.000	1.255	0.400	0.2858E-03
337.500	1.260	0.000	1.260	0.450	0.3216E-03
353.330	1.255	0.000	1.255	0.400	0.2858E-03
361.430	1.250	0.000	1.250	0.350	0.2501E-03
377.840	1.255	0.000	1.255	0.400	0.2858E-03
386.160	1.255	0.000	1.255	0.400	0.2858E-03
401.600	1.260	0.000	1.260	0.450	0.3216E-03
425.670	1.260	0.000	1.260	0.450	0.3216E-03
434.320	1.255	0.000	1.255	0.400	0.2858E-03
450.520	1.260	0.000	1.260	0.450	0.3216E-03
462.600	1.265	0.000	1.265	0.500	0.3573E-03
473.500	1.265	0.000	1.265	0.500	0.3573E-03

MONITOR AND PLOTTING DISPLAY FOR ACADET SUBROUTINE M222P MISCHEF, HALL, REVISED BY WATHER

X DATA	Y DATA	REGRESSION LINE	UPPER BOUND POINT-BY-POINT	LOWER BOUND POINT-BY-POINT	UPPER BOUND LINE-AS-WHOLE	LOWER BOUND LINE-AS-WHOLE	UPPER BOUND FUTURE POINT	LOWER BOUND FUTURE POINT
C.000000	C.000000	C.192435E-04	C.111440E-03	C.1749622E-04	C.128073E-03	C.895456E-04	C.750566E-03	C.121012E-03
5.77660	C.000000	C.231115E-04	C.114719E-03	C.096957E-04	C.130067E-03	C.840441E-04	C.162897E-03	C.114974E-03
17.0660	C.000000	C.314896E-04	C.121043E-03	C.057263E-04	C.134841E-03	C.071061E-04	C.170933E-03	C.107044E-03
25.1100	C.357244E-04	C.380036E-04	C.124747E-03	C.0447394E-04	C.138172E-03	C.062164E-04	C.176311E-03	C.100104E-03
41.3300	C.357244E-04	C.424426E-04	C.127457E-03	C.0425716E-04	C.140615E-03	C.055729E-04	C.180011E-03	C.099542E-03
49.0660	C.714565E-04	C.555791E-04	C.135593E-03	C.0244346E-04	C.147977E-03	C.0368184E-04	C.192224E-03	C.091066E-03
67.5800	C.107181E-03	C.692616E-04	C.144279E-03	C.0575613E-05	C.155890E-03	C.0173668E-04	C.404754E-03	C.0266231E-03
77.6000	C.714565E-04	C.766748E-04	C.149092E-03	C.0425754E-05	C.160300E-03	C.0695061E-05	C.411595E-03	C.0258246E-03
99.6700	C.107181E-03	C.856046E-04	C.155094E-03	C.0162056E-04	C.165745E-03	C.0546461E-05	C.419886E-03	C.0248676E-03
99.8300	C.107181E-03	C.931213E-04	C.160088E-03	C.0261546E-04	C.170453E-03	C.0157900E-04	C.426906E-03	C.0240663E-03
113.000	C.142913E-03	C.102865E-03	C.166846E-03	C.388839E-04	C.176749E-03	C.0289814E-04	C.436063E-03	C.023033E-03
121.670	C.142913E-03	C.102799E-03	C.171410E-03	C.471488E-04	C.181026E-03	C.0375328E-04	C.442127E-03	C.0223569E-03
137.200	C.142913E-03	C.120769E-03	C.179844E-03	C.616943E-04	C.188987E-03	C.0525512E-04	C.453060E-03	C.0211522E-03
144.900	C.178637E-03	C.126466E-03	C.184162E-03	C.687694E-04	C.193092E-03	C.0598356E-04	C.458515E-03	C.020583E-03
150.000	C.107181E-03	C.130239E-03	C.187077E-03	C.714011E-04	C.195874E-03	C.0646042E-04	C.464213E-03	C.0201662E-03
161.200	C.107181E-03	C.138525E-03	C.193641E-03	C.834094E-04	C.202171E-03	C.0748790E-04	C.470135E-03	C.0193085E-03
170.000	C.142913E-03	C.145701E-03	C.199520E-03	C.018826E-04	C.207850E-03	C.0835530E-04	C.477099E-03	C.0185666E-03
185.000	C.142913E-03	C.156133E-03	C.208418E-03	C.0103849E-03	C.216510E-03	C.0957566E-04	C.487285E-03	C.0175018E-03
197.600	C.107181E-03	C.165455E-03	C.216747E-03	C.0114163E-03	C.224685E-03	C.0106225E-03	C.496451E-03	C.0165541E-03
205.400	C.142913E-03	C.174185E-03	C.224891E-03	C.0123480E-03	C.232738E-03	C.0115632E-03	C.505091E-03	C.0156721E-03
225.400	C.142913E-03	C.186023E-03	C.236484E-03	C.0135561E-03	C.244294E-03	C.0127751E-03	C.516891E-03	C.0144846E-03
237.400	C.178637E-03	C.194901E-03	C.245600E-03	C.0144201E-03	C.253447E-03	C.0136354E-03	C.525805E-03	C.0136004E-03
257.670	C.178637E-03	C.209897E-03	C.261802E-03	C.0157992E-03	C.269835E-03	C.0149959E-03	C.540989E-03	C.0121195E-03
269.670	C.214385E-03	C.218775E-03	C.271844E-03	C.0165705E-03	C.280058E-03	C.0157492E-03	C.550751E-03	C.0112501E-03
280.830	C.259109E-03	C.227032E-03	C.281464E-03	C.0172599E-03	C.289889E-03	C.0164175E-03	C.558529E-03	C.0104466E-03
289.670	C.285849E-03	C.231572E-03	C.289261E-03	C.0177882E-03	C.297880E-03	C.0169263E-03	C.565274E-03	C.0098134E-04
305.000	C.321581E-03	C.244913E-03	C.303124E-03	C.0186703E-03	C.312133E-03	C.0177694E-03	C.577042E-03	C.0087251E-04
311.500	C.285849E-03	C.251702E-03	C.310970E-03	C.0191425E-03	C.320231E-03	C.0182173E-03	C.583619E-03	C.0081214E-04
317.830	C.321581E-03	C.254405E-03	C.318523E-03	C.0193789E-03	C.324409E-03	C.0184406E-03	C.586974E-03	C.0078163E-04
329.100	C.285849E-03	C.262744E-03	C.325674E-03	C.0199813E-03	C.335414E-03	C.0190073E-03	C.595742E-03	C.00702546E-04
337.500	C.321581E-03	C.268958E-03	C.333721E-03	C.0204195E-03	C.343744E-03	C.0194172E-03	C.602307E-03	C.00643912E-04
351.330	C.285849E-03	C.280670E-03	C.349107E-03	C.0212232E-03	C.359699E-03	C.0201640E-03	C.614752E-03	C.00534110E-04
361.430	C.250109E-03	C.286662E-03	C.357080E-03	C.0216244E-03	C.367979E-03	C.0205346E-03	C.621156E-03	C.00478118E-04
377.840	C.285849E-03	C.298803E-03	C.373414E-03	C.0224191E-03	C.384962E-03	C.0212644E-03	C.634205E-03	C.00365990E-04
386.160	C.285849E-03	C.304958E-03	C.381778E-03	C.0228138E-03	C.393668E-03	C.0216249E-03	C.640854E-03	C.00309418E-04
401.600	C.321581E-03	C.316381E-03	C.397427E-03	C.0235335E-03	C.409971E-03	C.0222792E-03	C.653273E-03	C.00205103E-04
425.670	C.321581E-03	C.334189E-03	C.422104E-03	C.0246274E-03	C.435711E-03	C.0232667E-03	C.672799E-03	C.001442076E-05
434.320	C.285849E-03	C.340589E-03	C.431044E-03	C.0250134E-03	C.445044E-03	C.0236134E-03	C.679867E-03	C.00131067E-05
450.520	C.321581E-03	C.352574E-03	C.447871E-03	C.0257277E-03	C.462621E-03	C.0242528E-03	C.693175E-03	C.00119731E-04
463.600	C.357313E-03	C.362251E-03	C.461530E-03	C.0262972E-03	C.476896E-03	C.0247607E-03	C.703988E-03	C.00105149E-04
473.500	C.357313E-03	C.369576E-03	C.471906E-03	C.0267245E-03	C.487744E-03	C.0251407E-03	C.712211E-03	C.0009471E-04

ORDINATE INTERCEPT A OF REGRESSION LINE 0.1926353E-04
 UPPER CONFIDENCE BOUND ON ORDINATE INTERCEPT A 0.1134892E-03
 LOWER CONFIDENCE BOUND ON ORDINATE INTERCEPT A 0.7496215E-04
 SLOPE B OF REGRESSION LINE 0.7398359E-06
 UPPER CONFIDENCE BOUND ON SLOPE B 0.1095915E-05
 LOWER CONFIDENCE BOUND ON SLOPE B 0.3837566E-06
 X-COORDINATE OF DATA CENTROID 223.4827
 Y-COORDINATE OF DATA CENTROID 0.1846040E-03
 UPPER CONFIDENCE BOUND ON YBAR 0.2350609E-03
 LOWER CONFIDENCE BOUND ON YBAR 0.1341472E-03
 T-STATISTIC (N-2) FOR (1-ALPHA), TWO TAILED 2.201000
 F-STATISTIC F(2,N-2) FOR (1-ALPHA), ONE TAILED 3.230000
 CORRELATION COEFFICIENT R 0.9532912
 SUM OF X 9386.273
 SUM OF Y 0.775336E-02
 SUM OF X**2 2941005.
 SUM OF Y**2 0.1939252E-05
 SUM OF XY 2.356673
 SUM OF (X-YBAR)**2 843328.5
 SUM OF (Y-YBAR)**2 0.5079418E-06
 SUM OF (X-YBAR)*(Y-YBAR) 0.6239229
 SUM OF (Y-YHAT)**2 0.4634243E-07
 UNBIASED ESTIMATOR STANDARD DEVIATION Y ON X, SYX 0.1485689E-03
 UNBIASED ESTIMATOR SYEARX 0.2292452E-04
 UNBIASED ESTIMATOR OF STANDARD DEVIATION OF A, SA 0.4281449E-04
 UNBIASED ESTIMATOR OF STANDARD DEVIATION OF B, SB 0.1610707E-06

RESULTS OF HIGH TEMPERATURE CREEP TEST--

RESEARCHER--J C MATHER
 TEST BEGUN ON 101474.
 REFER TO FECCRD BOOK PG NO 65. FOR LOADING INFO
 TEST TEMPERATURE 900. DEGREES C.
 MATERIAL TESTED HAS ATOMIC NUMBER 41., SAMPLE NO. 11.
 SAMPLE LOCATION IN TEST APPARATUS WAS NUMBER 3.
 TEST ENVIRONMENT CODE NUMBER 2.
 NOMINAL SHEAR STRESS LEVEL- 1873.GM/MM**2 2664.PSI
 ERROR ON STRESS LEVEL- 284.GM/MM**2 405.PSI
 LOAD ON SAMPLE- 51.7 GRAMS
 NUMBER OF ACTIVE TURNS- 9.
 WIRE DIAMETER IN INCHES-0.0318
 DIAMETER OF HELIX IN MILLIMETERS-6.28

TIME (HOURS)	POSITION		LENGTH (CM)	CHARACTERISTIC LENGTH CHANGE		SHEAR STRAIN
	TOP	BOTTOM		DELTA(MM)		
0.000	1.181	0.000	1.181	0.000		0.0000E-00
7.530	1.185	0.000	1.185	0.040		0.2889E-04
15.530	1.190	0.000	1.190	0.090		0.6498E-04
21.670	1.195	0.000	1.195	0.140		0.1011E-03
31.750	1.200	0.000	1.200	0.190		0.1372E-03
40.000	1.195	0.000	1.195	0.140		0.1011E-03
55.600	1.200	0.000	1.200	0.190		0.1372E-03
64.750	1.200	0.000	1.200	0.190		0.1372E-03
69.670	1.210	0.000	1.210	0.290		0.2094E-03
80.700	1.205	0.000	1.205	0.240		0.1733E-03
92.700	1.210	0.000	1.210	0.290		0.2094E-03
105.300	1.210	0.000	1.210	0.290		0.2094E-03
118.250	1.210	0.000	1.210	0.290		0.2094E-03
129.900	1.210	0.000	1.210	0.290		0.2094E-03
136.500	1.210	0.000	1.210	0.290		0.2094E-03
151.500	1.210	0.000	1.210	0.290		0.2094E-03
160.750	1.210	0.000	1.210	0.290		0.2094E-03
176.250	1.210	0.000	1.210	0.290		0.2094E-03
184.330	1.210	0.000	1.210	0.290		0.2094E-03
186.900	1.215	0.000	1.215	0.340		0.2455E-03
199.900	1.220	0.000	1.220	0.390		0.2816E-03
206.250	1.220	0.000	1.220	0.390		0.2816E-03
223.600	1.220	0.000	1.220	0.390		0.2816E-03
231.900	1.220	0.000	1.220	0.390		0.2816E-03
247.800	1.225	0.000	1.225	0.440		0.3177E-03
256.750	1.225	0.000	1.225	0.440		0.3177E-03
271.750	1.225	0.000	1.225	0.440		0.3177E-03
282.100	1.220	0.000	1.220	0.390		0.2816E-03
290.200	1.230	0.000	1.230	0.490		0.3538E-03
309.000	1.230	0.000	1.230	0.490		0.3538E-03
320.750	1.230	0.000	1.230	0.490		0.3538E-03
331.800	1.230	0.000	1.230	0.490		0.3538E-03
344.600	1.240	0.000	1.240	0.590		0.4261E-03
359.000	1.235	0.000	1.235	0.540		0.3900E-03
370.100	1.235	0.000	1.235	0.540		0.3900E-03
381.900	1.235	0.000	1.235	0.540		0.3900E-03
400.400	1.240	0.000	1.240	0.590		0.4261E-03
417.100	1.245	0.000	1.245	0.640		0.4622E-03
441.700	1.250	0.000	1.250	0.690		0.4983E-03
465.300	1.245	0.000	1.245	0.640		0.4622E-03
475.400	1.245	0.000	1.245	0.640		0.4622E-03
498.500	1.250	0.000	1.250	0.690		0.4983E-03

MONITOR AND PLOTTING DISPLAY IOWA CADET SUBROUTINE MF 126R MISCHE, HAL., REVISED BY WATHER

X DATA	Y DATA	Y REGRESSION LINE	Y UPPER BOUND POINT-BY-POINT	Y LOWER BOUND POINT-BY-POINT	Y UPPER BOUND LINE-AS-WHOLE	Y LOWER BOUND LINE-AS-WHOLE	Y UPPER BOUND FUTURE POINT	Y LOWER BOUND FUTURE POINT
21.6700	0.101090E-03	0.118187E-03	0.208157E-03	0.280168E-04	0.231587E-03	0.478701E-05	0.433330E-03	-0.196956E-03
31.7500	0.137195E-03	0.126127E-03	0.213474E-03	0.191793E-04	0.235925E-03	0.167282E-04	0.440618E-03	-0.187965E-03
40.0000	0.101090E-03	0.132989E-03	0.217697E-03	0.482813E-04	0.239519E-03	0.264588E-04	0.446613E-03	-0.180635E-03
55.6000	0.137195E-03	0.145586E-03	0.225775E-03	0.653981E-04	0.246433E-03	0.447401E-04	0.458020E-03	-0.166847E-03
64.7500	0.137195E-03	0.152975E-03	0.230577E-03	0.753738E-04	0.250569E-03	0.553819E-04	0.464755E-03	-0.158804E-03
69.6700	0.209414E-03	0.156949E-03	0.233181E-03	0.897157E-04	0.252820E-03	0.610765E-04	0.468390E-03	-0.154453E-03
80.7000	0.173301E-03	0.165856E-03	0.239080E-03	0.926309E-04	0.257944E-03	0.737667E-04	0.476575E-03	-0.144863E-03
92.7000	0.209414E-03	0.175546E-03	0.245604E-03	0.105488E-03	0.263652E-03	0.874398E-04	0.485534E-03	-0.134442E-03
105.7000	0.209414E-03	0.185721E-03	0.252589E-03	0.118853E-03	0.269816E-03	0.101626E-03	0.495004E-03	-0.123562E-03
118.2500	0.209414E-03	0.196178E-03	0.259934E-03	0.132423E-03	0.276359E-03	0.115998E-03	0.504803E-03	-0.112446E-03
129.0000	0.209414E-03	0.205586E-03	0.266707E-03	0.144465E-03	0.282453E-03	0.128719E-03	0.513677E-03	-0.102505E-03
136.5000	0.209414E-03	0.210916E-03	0.270622E-03	0.151210E-03	0.286003E-03	0.135829E-03	0.518730E-03	-0.968978E-04
151.5000	0.209414E-03	0.223029E-03	0.279753E-03	0.166305E-03	0.294367E-03	0.151691E-03	0.530278E-03	-0.842204E-04
160.7500	0.209414E-03	0.230499E-03	0.285565E-03	0.175432E-03	0.299751E-03	0.161246E-03	0.537446E-03	-0.764490E-04
176.2500	0.209414E-03	0.243015E-03	0.295654E-03	0.190377E-03	0.309215E-03	0.176816E-03	0.549537E-03	-0.635059E-04
184.3300	0.209414E-03	0.249540E-03	0.301105E-03	0.197976E-03	0.314389E-03	0.184692E-03	0.555879E-03	-0.567986E-04
186.9000	0.245528E-03	0.251616E-03	0.302868E-03	0.200363E-03	0.316072E-03	0.187160E-03	0.557902E-03	-0.546707E-04
199.9000	0.281633E-03	0.262114E-03	0.312017E-03	0.212210E-03	0.324873E-03	0.199354E-03	0.568177E-03	-0.439500E-04
209.2500	0.281633E-03	0.269664E-03	0.318847E-03	0.220881E-03	0.331518E-03	0.207810E-03	0.575611E-03	-0.362809E-04
223.6000	0.281633E-03	0.281252E-03	0.329759E-03	0.232784E-03	0.342256E-03	0.220248E-03	0.587091E-03	-0.254871E-04
231.0000	0.281633E-03	0.287954E-03	0.336316E-03	0.239593E-03	0.348775E-03	0.227134E-03	0.593771E-03	-0.178616E-04
247.8000	0.317747E-03	0.309794E-03	0.349385E-03	0.252203E-03	0.361903E-03	0.239685E-03	0.606647E-03	-0.505778E-05
256.7500	0.317747E-03	0.308022E-03	0.357032E-03	0.259011E-03	0.369658E-03	0.246385E-03	0.613941E-03	-0.210246E-05
271.7500	0.317747E-03	0.320135E-03	0.370302E-03	0.269988E-03	0.383226E-03	0.257044E-03	0.626241E-03	-0.140280E-04
282.1000	0.281633E-03	0.328493E-03	0.379771E-03	0.277215E-03	0.392981E-03	0.264005E-03	0.634783E-03	-0.222023E-04
286.2000	0.353845E-03	0.339879E-03	0.393049E-03	0.286708E-03	0.406747E-03	0.273010E-03	0.646492E-03	-0.332657E-04
309.0000	0.353845E-03	0.350215E-03	0.405448E-03	0.294983E-03	0.419677E-03	0.280754E-03	0.657193E-03	-0.432380E-04
320.7500	0.353845E-03	0.359704E-03	0.417086E-03	0.302321E-03	0.431869E-03	0.287538E-03	0.667075E-03	-0.523322E-04
331.8000	0.353845E-03	0.368627E-03	0.428231E-03	0.309023E-03	0.443587E-03	0.293667E-03	0.676421E-03	-0.608331E-04
344.6000	0.426077E-03	0.378964E-03	0.441356E-03	0.316571E-03	0.457430E-03	0.300497E-03	0.687310E-03	-0.706173E-04
359.0000	0.389565E-03	0.390592E-03	0.456362E-03	0.324822E-03	0.473306E-03	0.307878E-03	0.699639E-03	-0.815447E-04
370.1000	0.389565E-03	0.399556E-03	0.468080E-03	0.331031E-03	0.485733E-03	0.313378E-03	0.709201E-03	-0.899106E-04
381.9000	0.389565E-03	0.409085E-03	0.480662E-03	0.337507E-03	0.499102E-03	0.319067E-03	0.719420E-03	-0.987495E-04
400.4000	0.426077E-03	0.424024E-03	0.500613E-03	0.347435E-03	0.520344E-03	0.327704E-03	0.735533E-03	-0.112495E-03
417.1000	0.462192E-03	0.437510E-03	0.518820E-03	0.356199E-03	0.539767E-03	0.335252E-03	0.750233E-03	-0.142786E-03
441.7000	0.498306E-03	0.457375E-03	0.545916E-03	0.368834E-03	0.568726E-03	0.346024E-03	0.772056E-03	-0.142694E-03
465.3000	0.462192E-03	0.476433E-03	0.572158E-03	0.380707E-03	0.596819E-03	0.356046E-03	0.793210E-03	-0.159655E-03
475.4000	0.462192E-03	0.484589E-03	0.583450E-03	0.385728E-03	0.608919E-03	0.360259E-03	0.802328E-03	-0.166850E-03
498.5000	0.498306E-03	0.503243E-03	0.609390E-03	0.397096E-03	0.636735E-03	0.369750E-03	0.823324E-03	-0.183162E-03

ORDINATE INTERCEPT A OF REGRESSION LINE 0.1006876E-03
UPPER CONFIDENCE BOUND ON ORDINATE INTERCEPT A 0.1974913E-03
LOWER CONFIDENCE LIMIT ON ORDINATE INTERCEPT A 0.3883979E-05
SLOPE B OF REGRESSION LINE 0.8075336E-06
UPPER CONFIDENCE BOUND ON SLOPE B 0.1165319E-05
LOWER CONFIDENCE BOUND ON SLOPE B 0.4407975E-06
X-COORDINATE OF DATA CENTROID 234.3922
Y-COORDINATE OF DATA CENTROID 0.2899671E-03
UPPER CONFIDENCE BOUND ON YBAR 0.1383206E-03
LOWER CONFIDENCE BOUND ON YBAR 0.2416135E-03
T-STATISTIC T(2,N-2) FOR (1-ALPHA), TWO TAILED 2.021000
F-STATISTIC F(2,N-2) FOR (1-ALPHA), ONE TAILED 3.230000
CORRELATION COEFFICIENT R 0.9799862
SUM OF X 9141.297
SUM OF Y 0.1130872E-01
SUM OF X**2 2854977.
SUM OF Y**2 0.3762844E-05
SUM OF XY 3.225905
SUM OF (X-XBAR)**2 712319.7
SUM OF (X-XBAR)*(Y-YBAR) 0.4826686E-06
SUM OF (Y-YHAT)**2 0.5752166
SUM OF (Y-YHAT)*(Y-YBAR) 0.1916629E-07
UNBIASED ESTIMATOR STANDARD DEVIATION Y ON X, SYX 0.1494152E-03
UNBIASED ESTIMATOR SYBARX 0.2392557E-04
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF A, SA 0.4789889E-04
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF B, SB 0.1770342E-06

RESULTS OF HIGH TEMPERATURE CREEP TEST--

RESEARCHER--J C MATHER
 TEST BEGUN ON 91874.
 REFER TO RECORD BOOK PG NO 62. FOR LOADING INFO
 TEST TEMPERATURE 900. DEGREES C.
 MATERIAL TESTED HAS ATOMIC NUMBER 42., SAMPLE NO. 8.
 SAMPLE LOCATION IN TEST APPARATUS WAS NUMBER 2.
 TEST ENVIRONMENT CODE NUMBER 1.
 NOMINAL SHEAR STRESS LEVEL- 3465.GM/MM**2 4928.PSI
 ERROR ON STRESS LEVEL- 582.GM/MM**2 828.PSI
 LOAD ON SAMPLE- 61.5 GRAMS
 NUMBER OF ACTIVE TURNS- 9.
 WIRE DIAMETER IN INCHES-0.0270
 DIAMETER OF HELIX IN MILLIMETERS-6.14

TIME (HOURS)	POSITION		CHARACTERISTIC		SHEAR STRAIN
	TOP	BOTTOM	LENGTH (CM)	LENGTH CHANGE DELTA(MM)	
0.000	1.010	0.000	1.010	0.000	0.0000E-00
5.066	1.030	0.000	1.030	0.200	0.1285E-03
17.066	1.065	0.000	1.065	0.550	0.3535E-03
25.330	1.095	0.000	1.095	0.850	0.5464E-03
31.330	1.100	0.000	1.100	0.900	0.5786E-03
41.330	1.140	0.000	1.140	1.300	0.8359E-03
49.086	1.145	0.000	1.145	1.350	0.8679E-03
67.580	1.200	0.000	1.200	1.900	0.1222E-02
77.600	1.215	0.000	1.215	2.050	0.1318E-02
85.670	1.240	0.000	1.240	2.300	0.1479E-02
99.830	1.260	0.000	1.260	2.500	0.1608E-02
113.000	1.290	0.000	1.290	2.800	0.1801E-02
121.670	1.290	0.000	1.290	2.800	0.1801E-02
137.200	1.325	0.000	1.325	3.150	0.2026E-02
144.900	1.340	0.000	1.340	3.300	0.2123E-02
150.000	1.345	0.000	1.345	3.350	0.2155E-02
161.200	1.365	0.000	1.365	3.550	0.2284E-02
170.900	1.375	0.000	1.375	3.650	0.2348E-02
185.000	1.395	0.000	1.395	3.850	0.2477E-02
197.600	1.410	0.000	1.410	4.000	0.2573E-02
205.400	1.425	0.000	1.425	4.150	0.2670E-02
225.400	1.445	0.000	1.445	4.350	0.2799E-02
237.400	1.455	0.000	1.455	4.450	0.2867E-02
257.670	1.485	0.000	1.485	4.750	0.3056E-02
269.670	1.495	0.000	1.495	4.850	0.3121E-02
280.830	1.510	0.000	1.510	5.000	0.3218E-02
289.670	1.520	0.000	1.520	5.100	0.3282E-02
305.000	1.535	0.000	1.535	5.250	0.3379E-02
313.500	1.535	0.000	1.535	5.250	0.3379E-02
317.830	1.540	0.000	1.540	5.300	0.3411E-02
329.100	1.545	0.000	1.545	5.350	0.3443E-02
337.500	1.555	0.000	1.555	5.450	0.3508E-02
353.330	1.565	0.000	1.565	5.550	0.3572E-02
361.430	1.570	0.000	1.570	5.600	0.3604E-02
377.840	1.585	0.000	1.585	5.750	0.3701E-02
386.160	1.590	0.000	1.590	5.800	0.3733E-02
401.500	1.610	0.000	1.610	6.000	0.3862E-02
425.670	1.630	0.000	1.630	6.200	0.3991E-02
434.320	1.635	0.000	1.635	6.250	0.4023E-02
450.520	1.645	0.000	1.645	6.350	0.4088E-02
457.670	1.660	0.000	1.660	6.500	0.4184E-02
463.600	1.665	0.000	1.665	6.550	0.4217E-02
473.500	1.670	0.000	1.670	6.600	0.4249E-02

MONITOR AND PLOTTING DISPLAY IDWA CADET SUBROUTINE ME226R MISCHKE, HALL, REVISED BY MATHER

X DATA	Y DATA	Y REGRESSION LINE	Y UPPER BOUND POINT-BY-POINT	Y LOWER BOUND POINT-BY-POINT	Y UPPER BOUND LINE-AS-WHOLE	Y LOWER BOUND LINE-AS-WHOLE	Y UPPER BOUND FUTURE POINT	Y LOWER BOUND FUTURE POINT
257.67C	0.305642E-02	0.307417E-02	0.334717E-02	0.280118E-02	0.342040E-02	0.272795E-02	0.378360E-02	0.236474E-02
269.67C	0.312085E-02	0.313907E-02	0.339057E-02	0.288758E-02	0.345804E-02	0.282011E-02	0.384051E-02	0.243764E-02
280.83C	0.321750E-02	0.319944E-02	0.343176E-02	0.296712E-02	0.349407E-02	0.290480E-02	0.389423E-02	0.250464E-02
289.67C	0.328194E-02	0.324725E-02	0.346507E-02	0.302942E-02	0.352350E-02	0.297099E-02	0.393733E-02	0.255717E-02
305.00C	0.337860E-02	0.333016E-02	0.352474E-02	0.313558E-02	0.357694E-02	0.308339E-02	0.401326E-02	0.264706E-02
313.50C	0.337260E-02	0.337614E-02	0.355915E-02	0.319313E-02	0.360824E-02	0.314404E-02	0.405603E-02	0.269624E-02
317.83C	0.341083E-02	0.339956E-02	0.357711E-02	0.322200E-02	0.362474E-02	0.317437E-02	0.407800E-02	0.272111E-02
329.10C	0.344305E-02	0.346051E-02	0.362552E-02	0.329550E-02	0.366978E-02	0.325124E-02	0.413578E-02	0.278524E-02
337.50C	0.350750E-02	0.350594E-02	0.366341E-02	0.334848E-02	0.370565E-02	0.330624E-02	0.417941E-02	0.283248E-02
353.33C	0.357196E-02	0.359156E-02	0.373989E-02	0.344323E-02	0.377968E-02	0.340344E-02	0.426295E-02	0.292017E-02
361.43C	0.360419E-02	0.353537E-02	0.378192E-02	0.348882E-02	0.382124E-02	0.344951E-02	0.430637E-02	0.296437E-02
377.84C	0.370088E-02	0.372413E-02	0.387343E-02	0.357483E-02	0.391348E-02	0.353478E-02	0.439573E-02	0.305253E-02
386.16C	0.372311E-02	0.376913E-02	0.392296E-02	0.361530E-02	0.396423E-02	0.357403E-02	0.444175E-02	0.309650E-02
401.60C	0.386205E-02	0.385264E-02	0.401974E-02	0.368553E-02	0.406457E-02	0.364071E-02	0.452843E-02	0.317685E-02
425.67C	0.399101E-02	0.398282E-02	0.418032E-02	0.378532E-02	0.423330E-02	0.373235E-02	0.466676E-02	0.329889E-02
434.32C	0.402324E-02	0.402961E-02	0.424010E-02	0.381911E-02	0.429657E-02	0.376265E-02	0.471741E-02	0.334181E-02
450.52C	0.408773E-02	0.411723E-02	0.435412E-02	0.388033E-02	0.441767E-02	0.381679E-02	0.481356E-02	0.342089E-02
457.67C	0.418447E-02	0.415550E-02	0.440512E-02	0.390668E-02	0.447197E-02	0.383983E-02	0.485652E-02	0.345528E-02
463.60C	0.421672E-02	0.418798E-02	0.444757E-02	0.392827E-02	0.451734E-02	0.385861E-02	0.489239E-02	0.348356E-02
473.50C	0.424857E-02	0.424152E-02	0.451914E-02	0.396389E-02	0.459361E-02	0.388942E-02	0.495274E-02	0.353030E-02

ORDINATE INTERCEPT A OF REGRESSION LINE 0.1680522E-02
UPPER CONFIDENCE BOUND ON ORDINATE INTERCEPT A 0.2481110E-02
LOWER CONFIDENCE LIMIT ON ORDINATE INTERCEPT A 0.8799334E-03
SLOPE B OF REGRESSION LINE 0.5408660E-05
UPPER CONFIDENCE BOUND ON SLOPE B 0.7569086E-05
LOWER CONFIDENCE BOUND ON SLOPE B 0.3248235E-05
X-COORDINATE OF DATA CENTROID 364.3196
Y-COORDINATE OF DATA CENTROID 0.3650972E-02
UPPER CONFIDENCE BOUND ON YBAR 0.3797390E-02
LOWER CONFIDENCE BOUND ON YBAR 0.3504554E-02
T-STATISTIC T(N-2) FOR (1-ALPHA), TWO TAILED 2.101000
F-STATISTIC F(2,N-2) FOR (1-ALPHA), ONE TAILED 3.550000
CORRELATION COEFFICIENT R 0.9979733
SUM OF X 7286.395
SUM OF Y 0.7301944E-01
SUM OF X**2 2746446.
SUM OF Y**2 0.2692910E-03
SUM OF XY 27.09930
SUM OF (X-YBAR)**2 91862.50
SUM OF (Y-YBAR)**2 0.2697935E-05
SUM OF (X-YBAR)*(Y-YBAR) 0.4968260
SUM OF (Y-YHAT)**2 0.1092400E-07
UNBIASED ESTIMATOR STANDARD DEVIATION Y ON X, SYX 0.3116613E-03
UNBIASED ESTIMATOR SYBARX 0.6968957E-04
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF A, SA 0.3810511E-03
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF B, SB 0.1028285E-05

RESULTS OF HIGH TEMPERATURE CREEP TEST--

RESEARCHER--J C MATHER
 TEST REGUNION 101474.
 REFER TO RECORD BOOK PG NO 65. FOR LOADING INFO
 TEST TEMPERATURE 900. DEGREES C.
 MATERIAL TESTED HAS ATOMIC NUMBER 42., SAMPLE NO. 21.
 SAMPLE LOCATION IN TEST APPARATUS WAS NUMBER 2.
 TEST ENVIRONMENT CODE NUMBER 2.
 NOMINAL SHEAR STRESS LEVEL- 3518.GM/MM**2 5004.PSI
 ERPOP ON STRESS LEVEL- 594.GM/MM**2 845.PSI
 LOAD ON SAMPLE- 61.5 GRAMS
 NUMBER OF ACTIVE TURNS-10.
 WIRE DIAMETER IN INCHES-0.0268
 DIAMETER OF HELIX IN MILLIMETERS-6.07

TIME (HOURS)	POSITION		CHARACTERISTIC LENGTH		SHEAR STRAIN
	TOP	BOTTOM	(CM)	LENGTH CHANGE DELTA(MM)	
0.000	1.400	0.000	1.400	0.000	0.0000E-00
7.530	1.425	0.000	1.425	0.250	0.1465E-03
15.530	1.465	0.000	1.465	0.650	0.3808E-03
21.670	1.480	0.000	1.480	0.800	0.4688E-03
31.750	1.510	0.000	1.510	1.100	0.6446E-03
40.000	1.535	0.000	1.535	1.350	0.7911E-03
55.600	1.570	0.000	1.570	1.700	0.9963E-03
64.750	1.585	0.000	1.585	1.850	0.1084E-02
69.670	1.600	0.000	1.600	2.000	0.1172E-02
80.700	1.625	0.000	1.625	2.250	0.1319E-02
92.700	1.645	0.000	1.645	2.450	0.1476E-02
105.300	1.675	0.000	1.675	2.750	0.1612E-02
118.250	1.695	0.000	1.695	2.950	0.1729E-02
129.900	1.725	0.000	1.725	3.250	0.1905E-02
136.500	1.730	0.000	1.730	3.300	0.1935E-02
151.500	1.755	0.000	1.755	3.550	0.2081E-02
160.750	1.770	0.000	1.770	3.700	0.2169E-02
176.250	1.795	0.000	1.795	3.950	0.2316E-02
184.330	1.815	0.000	1.815	4.150	0.2433E-02
186.900	1.825	0.000	1.825	4.250	0.2492E-02
199.900	1.850	0.000	1.850	4.500	0.2639E-02
209.250	1.860	0.000	1.860	4.600	0.2698E-02
223.600	1.870	0.000	1.870	4.700	0.2756E-02
231.900	1.880	0.000	1.880	4.800	0.2815E-02
247.800	1.890	0.000	1.890	4.900	0.2874E-02
256.750	1.905	0.000	1.905	5.050	0.2962E-02
271.750	1.915	0.000	1.915	5.150	0.3021E-02
282.100	1.920	0.000	1.920	5.200	0.3050E-02
296.200	1.930	0.000	1.930	5.300	0.3109E-02
309.000	1.945	0.000	1.945	5.450	0.3197E-02
320.750	1.955	0.000	1.955	5.550	0.3255E-02
331.800	1.960	0.000	1.960	5.600	0.3285E-02
344.600	1.970	0.000	1.970	5.700	0.3344E-02
355.000	1.985	0.000	1.985	5.850	0.3432E-02
370.100	1.990	0.000	1.990	5.900	0.3461E-02
381.900	2.000	0.000	2.000	6.000	0.3520E-02
407.400	2.015	0.000	2.015	6.150	0.3608E-02
417.100	2.025	0.000	2.025	6.250	0.3667E-02
441.700	2.045	0.000	2.045	6.450	0.3784E-02
465.300	2.065	0.000	2.065	6.650	0.3902E-02
475.400	2.070	0.000	2.070	6.700	0.3931E-02
498.500	2.085	0.000	2.085	6.850	0.4019E-02

MONITOR AND PLOTTING DISPLAY IOWA CADET SUBROUTINE ME226R MISCHE, HALL, REVISED BY MATHER

X DATA	Y DATA	Y REGRESSION LINE	Y UPPER BOUND POINT-BY-POINT	Y LOWER BOUND POINT-BY-POINT	Y UPPER BOUND LINE-AS-WHOLE	Y LOWER BOUND LINE-AS-WHOLE	Y UPPER BOUND FUTURE POINT	Y LOWER BOUND FUTURE POINT
199.900	0.263887E-02	0.266942E-02	0.290746E-02	0.243138E-02	0.297091E-02	0.236794E-02	0.332785E-02	0.201100E-02
209.250	0.265756E-02	0.271272E-02	0.293925E-02	0.248618E-02	0.299963E-02	0.242580E-02	0.336707E-02	0.205836E-02
223.600	0.275628E-02	0.277916E-02	0.298862E-02	0.25697CE-02	0.304444E-02	0.251388E-02	0.342790E-02	0.213052E-02
231.900	0.281499E-02	0.281759E-02	0.301754E-02	0.261763E-02	0.307084E-02	0.256434E-02	0.346322E-02	0.217196E-02
247.800	0.287371E-02	0.289121E-02	0.307392E-02	0.270850E-02	0.312261E-02	0.265980E-02	0.353171E-02	0.225071E-02
256.750	0.296178E-02	0.293265E-02	0.310632E-02	0.275897E-02	0.315261E-02	0.271269E-02	0.357063E-02	0.229466E-02
271.750	0.302050E-02	0.302210E-02	0.316197E-02	0.284222E-02	0.320458E-02	0.279961E-02	0.363646E-02	0.236773E-02
282.100	0.304987E-02	0.305002E-02	0.320157E-02	0.289847E-02	0.324196E-02	0.285808E-02	0.368234E-02	0.241770E-02
296.200	0.310859E-02	0.311530E-02	0.325743E-02	0.297318E-02	0.329531E-02	0.293530E-02	0.374543E-02	0.248518E-02
309.000	0.319668E-02	0.317457E-02	0.331040E-02	0.303874E-02	0.334660E-02	0.300253E-02	0.380330E-02	0.254583E-02
320.750	0.325542E-02	0.322897E-02	0.336129E-02	0.309674E-02	0.339644E-02	0.306150E-02	0.385694E-02	0.260100E-02
331.800	0.328479E-02	0.328013E-02	0.341104E-02	0.314923E-02	0.344593E-02	0.311434E-02	0.390782E-02	0.265244E-02
344.600	0.334353E-02	0.333940E-02	0.347134E-02	0.320746E-02	0.350550E-02	0.317229E-02	0.396730E-02	0.271149E-02
359.000	0.343164E-02	0.340607E-02	0.354239E-02	0.326975E-02	0.357873E-02	0.323342E-02	0.403491E-02	0.277723E-02
370.100	0.346101E-02	0.345747E-02	0.359930E-02	0.331563E-02	0.363711E-02	0.327783E-02	0.408753E-02	0.282741E-02
381.900	0.351976E-02	0.351210E-02	0.366159E-02	0.336261E-02	0.370144E-02	0.332277E-02	0.414393E-02	0.288027E-02
400.400	0.360789E-02	0.359776E-02	0.376234E-02	0.343317E-02	0.380621E-02	0.338931E-02	0.423332E-02	0.296219E-02
417.100	0.366665E-02	0.367508E-02	0.385583E-02	0.349433E-02	0.390400E-02	0.344616E-02	0.431502E-02	0.303514E-02
441.700	0.378417E-02	0.378898E-02	0.399670E-02	0.358126E-02	0.405206E-02	0.352590E-02	0.443706E-02	0.314090E-02
465.300	0.390170E-02	0.389825E-02	0.413430E-02	0.366220E-02	0.419722E-02	0.359928E-02	0.455596E-02	0.324054E-02
475.400	0.393109E-02	0.394501E-02	0.419372E-02	0.369630E-02	0.426001E-02	0.363001E-02	0.467737E-02	0.328265E-02
498.500	0.401926E-02	0.405197E-02	0.433052E-02	0.377341E-02	0.440477E-02	0.369917E-02	0.472610E-02	0.337764E-02
ORDINATE INTERCEPT A OF REGRESSION LINE		0.1743870E-02						
UPPER CONFIDENCE BOUND ON ORDINATE INTERCEPT A		0.2257382E-02						
LOWER CONFIDENCE LIMIT ON ORDINATE INTERCEPT A		0.1230357E-02						
SLOPE B OF REGRESSION LINE		0.4630092E-05						
UPPER CONFIDENCE BOUND ON SLOPE B		0.6119458E-05						
LOWER CONFIDENCE BOUND ON SLOPE B		0.3140726E-05						
X-COORDINATE OF DATA CENTROID		333.3992						
Y-COORDINATE OF DATA CENTROID		0.3287527E-02						
UPPER CONFIDENCE BOUND ON YBAR		0.3418408E-02						
LOWER CONFIDENCE BOUND ON YBAR		0.3156645E-02						
T-STATISTIC (N-2) FOR (1-ALPHA), TWO TAILED		2.086000						
F-STATISTIC (F(2,N-2) FOR (1-ALPHA), ONE TAILED		3.490000						
CORRELATION COEFFICIENT R		0.9990872						
SUM OF X		7334.785						
SUM OF Y		0.7232559E-01						
SUM OF X**2		2615313.						
SUM OF Y**2		0.2414217E-03						
SUM OF XY		24.89995						
SUM OF (X-XBAR)**2		169893.1						
SUM OF (Y-YBAR)**2		0.3648552E-05						
SUM OF (X-XBAR)*(Y-YBAR)		0.7865973						
SUM OF (Y-YHAT)**2		0.6657069E-08						
UNBIASED ESTIMATOR STANDARD DEVIATION Y ON X, SYX		0.2942898E-03						
UNBIASED ESTIMATOR SYBARX		0.6274279E-04						
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF A, SA		0.2461709E-03						
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF B, SB		0.7139819E-06						

RESULTS OF HIGH TEMPERATURE CREEP TEST--

RESEARCHER--J C MATHER
 TEST BEGUN ON 51E74.
 REFER TO RECORD BOOK PG NO 62. FOR LOADING INFO
 TEST TEMPERATURE 900. DEGREES C.
 MATERIAL TESTED HAS ATOMIC NUMBER 23. SAMPLE NO. 13.
 SAMPLE LOCATION IN TEST APPARATUS WAS NUMBER 1.
 TEST ENVIRONMENT CODE NUMBER 1.
 NOMINAL SHEAR STRESS LEVEL- 1256.GM/MM**2 1786.PSI
 ERROR ON STRESS LEVEL- 199.GM/MM**2 283.PSI
 LOAD ON SAMPLE- 30.2 GRAMS
 NUMBER OF ACTIVE TURNS- 9.
 WIRE DIAMETER IN INCHES-0.0305
 DIAMETER OF HELIX IN MILLIMETERS-6.45

TIME (HOURS)	POSITION		CHARACTERISTIC LENGTH		SHEAR STRAIN
	TOP	BOTTOM	(CM)	LENGTH CHANGE DELTA(MM)	
0.000	1.165	0.000	1.165	0.000	0.0000E-00
5.066	1.250	0.000	1.250	0.850	0.5577E-03
17.066	1.610	0.000	1.610	4.450	0.2922E-02
25.330	1.885	0.000	1.885	7.200	0.4731E-02
31.330	2.105	0.000	2.105	9.400	0.6180E-02
41.330	2.435	0.000	2.435	12.700	0.8358E-02
49.086	2.665	0.000	2.665	15.000	0.9880E-02
67.580	3.195	0.000	3.195	20.300	0.1340E-01
77.600	3.445	0.000	3.445	22.800	0.1506E-01
85.670	3.735	0.000	3.735	25.700	0.1700E-01
99.830	3.960	0.000	3.960	27.950	0.1851E-01
113.000	4.225	0.000	4.225	30.600	0.2029E-01
121.670	4.385	0.000	4.385	32.200	0.2137E-01
137.200	4.665	0.000	4.665	35.000	0.2326E-01
144.900	4.785	0.000	4.785	36.200	0.2408E-01
150.000	4.835	0.000	4.835	36.700	0.2442E-01
161.200	5.005	0.000	5.005	38.400	0.2557E-01
170.900	5.115	0.000	5.115	39.500	0.2632E-01
185.000	5.280	0.000	5.280	41.150	0.2745E-01
197.600	5.420	0.000	5.420	42.550	0.2841E-01
209.400	5.545	0.000	5.545	43.800	0.2927E-01
225.400	5.690	0.000	5.690	45.250	0.3027E-01
237.400	5.790	0.000	5.790	46.250	0.3096E-01
257.670	5.960	0.000	5.960	47.950	0.3214E-01
269.670	6.045	0.000	6.045	48.800	0.3273E-01
280.830	6.120	0.000	6.120	49.550	0.3325E-01
289.670	6.175	0.000	6.175	50.100	0.3363E-01
305.000	6.275	0.000	6.275	51.100	0.3433E-01
313.500	6.320	0.000	6.320	51.550	0.3464E-01
317.830	6.350	0.000	6.350	51.850	0.3485E-01
329.100	6.405	0.000	6.405	52.400	0.3524E-01
337.500	6.450	0.000	6.450	52.850	0.3555E-01
353.330	6.540	0.000	6.540	53.750	0.3618E-01
361.430	6.570	0.000	6.570	54.050	0.3639E-01
377.840	6.650	0.000	6.650	54.850	0.3696E-01
386.160	6.695	0.000	6.695	55.300	0.3727E-01
401.600	6.780	0.000	6.780	56.150	0.3787E-01
425.670	6.890	0.000	6.890	57.250	0.3865E-01
434.320	6.920	0.000	6.920	57.550	0.3886E-01

MONITOR AND PLOTTING DISPLAY IOWA CADET SUBROUTINE ME226P MISCHKE, HALL, REVISED BY MATHER

X DATA	Y DATA	Y REGRESSION LINE	Y UPPER BOUND POINT-BY-POINT	Y LOWER BOUND POINT-BY-POINT	Y UPPER BOUND LINE-AS-WHOLE	Y LOWER BOUND LINE-AS-WHOLE	Y UPPER BOUND FUTURE POINT	Y LOWER BOUND FUTURE POINT
305.000	0.343284E-01	0.343875E-01	0.370769E-01	0.317380E-01	0.377927E-01	0.309823E-01	0.404327E-01	0.283422E-01
313.500	0.346427E-01	0.346881E-01	0.370881E-01	0.322891E-01	0.377727E-01	0.316035E-01	0.406283E-01	0.287480E-01
317.830	0.348524E-01	0.348413E-01	0.371208E-01	0.325617E-01	0.377711E-01	0.319114E-01	0.407338E-01	0.289487E-01
329.100	0.352373E-01	0.352399E-01	0.372341E-01	0.332457E-01	0.378030E-01	0.326768E-01	0.410281E-01	0.294518E-01
337.500	0.355525E-01	0.355370E-01	0.373537E-01	0.337203E-01	0.378720E-01	0.332021E-01	0.412664E-01	0.298076E-01
353.330	0.361839E-01	0.360970E-01	0.376984E-01	0.344955E-01	0.381553E-01	0.340387E-01	0.417618E-01	0.304321E-01
361.430	0.363946E-01	0.363835E-01	0.379522E-01	0.348148E-01	0.383997E-01	0.343673E-01	0.420391E-01	0.307278E-01
377.840	0.369574E-01	0.369639E-01	0.386420E-01	0.352858E-01	0.391207E-01	0.348071E-01	0.426509E-01	0.312769E-01
386.160	0.372744E-01	0.372582E-01	0.390708E-01	0.354456E-01	0.395878E-01	0.349286E-01	0.429863E-01	0.315301E-01
401.620	0.378740E-01	0.378043E-01	0.399659E-01	0.356428E-01	0.405825E-01	0.350262E-01	0.436522E-01	0.319564E-01
425.670	0.386519E-01	0.386557E-01	0.415143E-01	0.357971E-01	0.423298E-01	0.349816E-01	0.447955E-01	0.325159E-01
434.320	0.388544E-01	0.389617E-01	0.420965E-01	0.358268E-01	0.429908E-01	0.349326E-01	0.452349E-01	0.326885E-01
ORDINATE INTERCEPT A OF REGRESSION LINE		0.2359923E-01						
UPPER CONFIDENCE BOUND ON ORDINATE INTERCEPT A		0.3726196E-01						
LOWER CONFIDENCE LIMIT ON ORDINATE INTERCEPT A		0.9936512E-02						
SLOPE B OF REGRESSION LINE		0.3537127E-04						
UPPER CONFIDENCE BOUND ON SLOPE B		0.7237029E-04						
LOWER CONFIDENCE BOUND ON SLOPE B		0.2127752E-05						
X-COORDINATE OF DATA CENTROID		361.9397						
Y-COORDINATE OF DATA CENTROID		0.3640112E-01						
UPPER CONFIDENCE BOUND ON YBAR		0.3796970E-01						
LOWER CONFIDENCE BOUND ON YBAR		0.3433252E-01						
T-STATISTIC T(N-2) FOR (1-ALPHA), TWO TAILED		2.228000						
F-STATISTIC F(2,N-2) FOR (1-ALPHA), ONE TAILED		4.100000						
CORRELATION COEFFICIENT R		0.9994625						
SUM OF X		4343.277						
SUM OF Y		0.4368134						
SUM OF X**2		1593001.						
SUM OF Y**2		0.1592679E-01						
SUM OF XY		158.8428						
SUM OF (X-XBAR)**2		20997.14						
SUM OF (Y-YBAR)**2		0.2628431E-04						
SUM OF (X-XBAR)*(Y-YBAR)		0.7424978						
SUM OF (Y-YHAT)**2		0.2824057E-07						
UNBIASED ESTIMATOR STANDARD DEVIATION Y ON X, SYX		0.2438250E-02						
UNBIASED ESTIMATOR SYBARX		0.7040356E-03						
UNBIASED ESTIMATOR CF STANDARD DEVIATION OF A, SA		0.6132282E-02						
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF B, SB		0.1683080E-04						

RESULTS OF HIGH TEMPERATURE CREEP TEST--

RESEARCHER-- J C MATHER
 TEST BEGUN ON 101474.
 REFER TO REC'D BACK PG NC 65. FOR LOADING INFO
 TEST TEMPERATURE 900. DEGREES C.
 MATERIAL TESTED HAS ATOMIC NUMBER 23., SAMPLE NO. 11.
 SAMPLE LOCATION IN TEST APPARATUS WAS NUMBER 1.
 TEST ENVIRONMENT CODE NUMBER 2.
 NOMINAL SHEAR STRESS LEVEL- 1258.GM/MM**2 1790.PSI
 ERROR ON STRESS LEVEL- 196.GM/MM**2 279.PSI
 LOAD ON SAMPLE- 32.4 GRAMS
 NUMBER OF ACTIVE TURNS- 9.
 WIRE DIAMETER IN INCHES-0.0310
 DIAMETER OF FELIX IN MILLIMETERS-6.28

TIME (HOURS)	POSITION		CHARACTERISTIC		SHEAR STRAIN
	TOP	BOTTOM	LENGTH (CM)	LENGTH CHANGE DELTA(MM)	
0.000	1.260	0.000	1.260	0.000	0.0000E-00
7.530	1.280	0.000	1.280	0.200	0.1425E-03
15.530	1.345	0.000	1.345	0.850	0.6055E-03
21.670	1.545	0.000	1.545	2.850	0.2031E-02
31.750	1.795	0.000	1.795	5.350	0.3815E-02
40.000	1.995	0.000	1.995	7.350	0.5245E-02
55.600	2.315	0.000	2.315	10.550	0.7535E-02
64.750	2.530	0.000	2.530	12.700	0.9077E-02
69.670	2.655	0.000	2.655	13.950	0.9975E-02
80.700	2.930	0.000	2.930	16.700	0.1195E-01
92.700	3.215	0.000	3.215	19.550	0.1401E-01
105.300	3.465	0.000	3.465	22.050	0.1582E-01
118.250	3.720	0.000	3.720	24.600	0.1767E-01
129.900	3.935	0.000	3.935	26.750	0.1923E-01
136.500	4.045	0.000	4.045	27.850	0.2004E-01
151.500	4.315	0.000	4.315	30.550	0.2201E-01
160.750	4.480	0.000	4.480	32.200	0.2322E-01
176.250	4.730	0.000	4.730	34.700	0.2506E-01
184.330	4.865	0.000	4.865	36.050	0.2606E-01
186.900	4.925	0.000	4.925	36.650	0.2660E-01
199.900	5.150	0.000	5.150	39.900	0.2817E-01
219.250	5.255	0.000	5.255	39.950	0.2895E-01
223.600	5.450	0.000	5.450	41.900	0.3040E-01
231.900	5.550	0.000	5.550	42.900	0.3115E-01
247.800	5.755	0.000	5.755	44.950	0.3269E-01
256.750	5.865	0.000	5.865	46.050	0.3352E-01
271.750	6.055	0.000	6.055	47.950	0.3495E-01
282.100	6.170	0.000	6.170	49.100	0.3582E-01
296.200	6.350	0.000	6.350	50.900	0.3719E-01
309.000	6.485	0.000	6.485	52.250	0.3822E-01
320.750	6.620	0.000	6.620	53.600	0.3925E-01
331.600	6.740	0.000	6.740	54.800	0.4017E-01
344.600	6.880	0.000	6.880	56.200	0.4125E-01

MONITOR AND PLOTTING DISPLAY IOWA CADET SUBROUTINE ME226P MISCHE, HALL, REVISED BY WATHER

X DATA	Y DATA	Y REGRESSION LINE	Y UPPER BOUND POINT-BY-POINT	Y LOWER BOUND POINT-BY-POINT	Y UPPER BOUND LINE-AS-WHOLE	Y LOWER BOUND LINE-AS-WHOLE	Y UPPER BOUND FUTURE POINT	Y LOWER BOUND FUTURE POINT
199.900	0.281691E-01	0.282548E-01	0.312175E-01	0.252922E-01	0.320525E-01	0.244572E-01	0.347384E-01	0.217713E-01
209.250	0.289498E-01	0.291067E-01	0.317968E-01	0.264135E-01	0.325588E-01	0.256545E-01	0.354716E-01	0.227418E-01
223.500	0.304037E-01	0.304140E-01	0.327226E-01	0.281054E-01	0.333733E-01	0.274548E-01	0.366260E-01	0.242020E-01
231.900	0.311514E-01	0.311702E-01	0.332790E-01	0.290614E-01	0.339734E-01	0.284670E-01	0.373107E-01	0.250296E-01
247.800	0.326890E-01	0.326187E-01	0.344153E-01	0.308222E-01	0.349217E-01	0.303158E-01	0.386592E-01	0.265783E-01
256.750	0.335166E-01	0.334341E-01	0.351115E-01	0.317563E-01	0.355842E-01	0.312841E-01	0.394402E-01	0.274281E-01
271.750	0.349509E-01	0.349007E-01	0.364003E-01	0.332011E-01	0.368512E-01	0.327502E-01	0.407855E-01	0.288159E-01
282.100	0.358219E-01	0.357436E-01	0.373881E-01	0.340992E-01	0.378516E-01	0.336357E-01	0.417406E-01	0.297467E-01
296.200	0.371878E-01	0.370282E-01	0.388515E-01	0.352050E-01	0.393653E-01	0.346911E-01	0.430766E-01	0.309798E-01
309.000	0.382195E-01	0.381944E-01	0.402700E-01	0.361187E-01	0.408551E-01	0.355336E-01	0.443236E-01	0.320651E-01
320.750	0.392525E-01	0.392648E-01	0.416239E-01	0.369058E-01	0.422887E-01	0.362409E-01	0.454957E-01	0.330339E-01
331.800	0.401737E-01	0.402715E-01	0.429277E-01	0.376154E-01	0.436763E-01	0.368668E-01	0.466209E-01	0.339222E-01
344.600	0.412520E-01	0.414377E-01	0.444634E-01	0.384120E-01	0.453161E-01	0.375592E-01	0.479503E-01	0.349251E-01

ORDINATE INTERCEPT A OF REGRESSION LINE 0.1004304E-01
UPPER CONFIDENCE BOUND ON ORDINATE INTERCEPT A 0.1966388E-01
LOWER CONFIDENCE LIMIT ON ORDINATE INTERCEPT A 0.4221909E-03
SLOPE B OF REGRESSION LINE 0.9110459E-04
UPPER CONFIDENCE BOUND ON SLOPE B 0.1260880E-03
LOWER CONFIDENCE BOUND ON SLOPE B 0.5612119E-04
X-COORDINATE OF DATA CENTROID 271.1846
Y-COORDINATE OF DATA CENTROID 0.3474920E-01
UPPER CONFIDENCE BOUND ON YBAR 0.3634870E-01
LOWER CONFIDENCE BOUND ON YBAR 0.3314970E-01
T-STATISTIC $T(N-2)$ FOR $(1-\text{ALPHA})$, TWO TAILED 2.201000
F-STATISTIC $F(2,N-2)$ FOR $(1-\text{ALPHA})$, ONE TAILED 3.980000
CORRELATION COEFFICIENT R 0.9996815
SUM OF X 3525.400
SUM OF Y 0.4517396
SUM OF X**2 983210.3
SUM OF Y**2 0.1592331E-01
SUM OF XY 124.9807
SUM OF $(X-\text{XBAR})$ **2 27176.17
SUM OF $(Y-\text{YBAR})$ **2 0.2257044E-03
SUM OF $(X-\text{XBAR})*(Y-\text{YBAR})$ 2.475854
SUM OF $(Y-\text{YHAT})$ **2 0.1437501E-06
UNBIASED ESTIMATOR STANDARD DEVIATION Y ON X, SYX 0.2620211E-02
UNBIASED ESTIMATOR SYBARX 0.7267159E-03
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF A, SA 0.4371125E-02
UNBIASED ESTIMATOR OF STANDARD DEVIATION OF B, SB 0.1589431E-04

X. APPENDIX C. POLYNOMIAL EXPRESSIONS FOR SHEAR STRAIN (γ)
AND SHEAR STRAIN RATE ($\dot{\gamma}$) AS FUNCTIONS OF TIME (t) IN HOURS

For molybdenum in vacuum environment:

$$\begin{aligned}\gamma &= (0.373)(10^{-4}) + (0.1946)(10^{-4})(t) - (0.424)(10^{-7})(t^2) \\ &\quad + (0.512)(10^{-10})(t^3) - (0.186)(10^{-13})(t^4) \\ \dot{\gamma} &= (0.1946)(10^{-4}) - (0.848)(10^{-7})(t) + (1.536)(10^{-10})(t^2) \\ &\quad - (0.744)(10^{-13})(t^3)\end{aligned}$$

For molybdenum in hydrogen environment:

$$\begin{aligned}\gamma &= (0.618)(10^{-4}) + (0.1796)(10^{-4})(t) - (0.308)(10^{-7})(t^2) \\ &\quad + (0.1287)(10^{-10})(t^3) + (0.1777)(10^{-13})(t^4) \\ \dot{\gamma} &= (0.1796)(10^{-4}) - (0.616)(10^{-7})(t) + (0.3861)(10^{-10})(t^2) \\ &\quad + (0.7108)(10^{-13})(t^3)\end{aligned}$$

For vanadium in vacuum environment:

$$\begin{aligned}\gamma &= (-0.161)(10^{-2}) + (0.275)(10^{-3})(t) - (0.866)(10^{-6})(t^2) \\ &\quad + (0.144)(10^{-8})(t^3) - (0.923)(10^{-12})(t^4) \\ \dot{\gamma} &= (0.275)(10^{-3}) - (1.732)(10^{-6})(t) + (0.432)(10^{-8})(t^2) \\ &\quad - (3.728)(10^{-12})(t^3)\end{aligned}$$

For vanadium in hydrogen environment:

$$\begin{aligned}\gamma &= (-0.199)(10^{-2}) + (0.179)(10^{-3})(t) - (0.122)(10^{-7})(t^2) \\ &\quad - (0.199)(10^{-8})(t^3) + (0.295)(10^{-11})(t^4) \\ &\quad - (0.202)(10^{-14})(t^5) \\ \dot{\gamma} &= (0.179)(10^{-3}) - (0.244)(10^{-7})(t) - (0.357)(10^{-8})(t^2) \\ &\quad + (1.18)(10^{-11})(t^3) - (1.01)(10^{-14})(t^4)\end{aligned}$$