DEPARTMENT OF ENGINEERING RESEARCH

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Report

on

# CONSTANT STRESS CREEP TEST CHARACTERISTICS OF 0.50 Mo STEEL K-22 AT 850 AND 1000°F.

by

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ON THE EFFECT OF TEMPERATURE ON METALS

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# CONSTANT STRESS CREEP TEST CHARACTERISTICS OF 0.50 Mo STEEL K-22 AT 850 AND 1000°F.

The ASME-ASTM Joint Research Committee on the Effect of Temperature on Metals sponsored a cooperative program on short-time testing of steels to predict long-time load-carrying ability. The program was designated as Project 25. The investigation was limited to a 0.35 carbon steel designated K-20 and a 0.50 Mo steel designated K-22.

The present report presents the constant stress creep test characteristics of steel K-22 at 850 and 1000°F. This work was sponsored at the University of Michigan by the Joint Committee.

In addition to the standard creep test results sufficient data were taken to permit the evaluation of the Hatfield Time-Yield Stresses and the German DIN (DVM) Creep Strength values. Single tensile tests were also conducted at each temperature. Typical microstructures of the original material and the creep test specimens are included.

## Test Material

The test material for this investigation was hot-rolled 0.50 Mo steel supplied by Project 25 of the ASME-ASTM Joint Research Committee on the Effect of Temperature on Metals. This committee designated this particular heat of steel as K-22.

The reported chemical composition was as follows:

Chemical Composition, Per Cent

| C | Mn | N | S | Si | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|
| .16 | .66 | .015 | .027 | .24 | .13 | .09 | .53 |

The steel was produced in a 100 ton basic open hearth furnace. The ladle deoxidation consisted of the addition of 50 per cent ferrosilicon and 1.4 pounds of aluminum per ton. The test material was rolled to one-inch round bar stock. The McQuaid-Ehn grain size was reported to be 6-8.

The hot-rolled bar stock was heat treated by heating at 1650°F. for 1-2/3 hours and air cooling. It was then drawn by reheating to 1200°F. for 2 hours and air cooling. The bars were then machine straightened and stress-relieved by reheating to 1200°F. for two hours and air cooling.

The resulting Brinell hardness was 131-137. The microstructure, as shown in Chart 1, was ferrite and partially spheroidized fine pearlite. The actual grain size was 7-8.

The specimens for this investigation were taken from bar 23A.

## Experimental Procedure

Four constant stress creep tests were conducted at both 850 and 1000°F. Temperature distribution and control was in accordance with ASTM recommended procedure. The elongation of the specimen was measured by means of an extensometer system attached to the gage length of the specimens. The extensometer rods projected from the bottom of the furnace and actuated mirrors mounted on rollers. The optical beam to the telescope gave a sensitivity of 2.8 millionths of an inch per inch for the two-inch gage section of the 0.505-inch diameter specimens.

During the first five days of the tests the extension of the specimens was read at frequent intervals in order to obtain data for Hatfield Time-Yield Stress and DIN (DVM) values. The creep tests were all run for time periods in excess of 1000 hours and in some cases as long as 2000 hours.

The original material and the highest stress creep specimen at each temperature was subjected to metallographic examination. Sections were taken lengthwise to the bar and in the case of the creep specimen at the center of the gage section.

## Short-Time Tensile Tests

A single short-time tensile test was conducted at both 850 and 1000°F. The tests were conducted on a 60,000 pound hydraulic tensile machine equipped with a furnace for automatically controlling the specimen temperature within the prescribed limits. An optical extensometer system measured the elongation of the specimens until 0.2 per cent offset was obtained. The ultimate strengths were then determined at a constant head speed of 0.3 inches per minute. Stress was applied in increments of 2500 pounds per square inch during the stress-strain data measurements and the strain measured between each increment. The sensitivity of the extensometer system was three millionths of an inch per inch in a two-inch gage section.

The stress-strain curves obtained are shown in Figure 1 and the data obtained are tabulated below:

| Temp. °F. | Tensile Strength Lb./Sq.In. | Offset Yield Strength Lb./Sq.In. 0.1% | Offset Yield Strength Lb./Sq.In. 0.2% | Proportional Limit Lb./Sq.In. | Elongation,% in 2 In. | Reduction of Area,% |
|---|---|---|---|---|---|---|
| 850 | 58,500 | 26,250 | 29,250 | 19,500 | 34.0 | 78.7 |
| 1000 | 49,250 | 25,800 | 28,000 | 15,500 | 33.0 | 83.3 |

Only single tests were conducted for the purpose of comparing results from our equipment with those of other cooperators.

## Hatfield Time-Yield Stress

The Hatfield Time-Yield Stress is defined as the stress causing a deformation of 0.000048 inches per inch between the 24th and 72nd hours of a test.

The necessary data were obtained from Figures 2 and 3 and are tabulated below:

| Temperature Deg. Fahr. | Stress Lb./Sq.In. | Deformation Between 24th and 72nd Hours Inches per Inch | Time-Yield Stress Lb./Sq.In. |
|---|---|---|---|
| 850 | 20,000 | 0.000085 | |
| | 22,500 | 0.000140 | 18,000 |
| | 25,000 | 0.000190 | |
| | 27,500 | 0.000390 | |
| 1000 | 5,500 | 0.000014 | |
| | 7,500 | 0.000022 | 10,000 |
| | 10,000 | 0.000045 | |
| | 12,500 | 0.000094 | |

The Time-Yield Stress was obtained by plotting stress against the deformation in Figure 7.

## DIN (DVM) Values

The creep resistance will be within conventional limits if the creep rate between the 25th and 35th hours does not exceed one per cent per 1000 hours and the permanent deformation does not exceed 0.2 per cent after 45 hours.

The necessary data, obtained from Figures 2 and 3, are summarized in Table I.

The creep rates and permanent deformations are presented graphically in Figure 8. This figure shows that the creep rates and permissible deformations are very close together at 850°F. and the limiting creep stress is defined by the allowable deformation at 26,000 pounds per square inch.

Table I

DIN (DVM) Test Data for 0.50 Mo Steel K-22 at 850 and 1000°F.

| Temperature Deg. Fahr. | Stress Lb./Sq.In. | 25-35th Hr. Creep Rate %/1000 Hour | 45th Hr. Deformation In./In. | Estimated Elastic Deformation In./In. | Permanent Deformation Per Cent |
|---|---|---|---|---|---|
| 850 | 20,000 | 0.24 | 0.00132 | 0.00070 | 0.062 |
| | 22,500 | 0.38 | 0.00170 | 0.00070 | 0.100 |
| | 25,000 | 0.50 | 0.00227 | 0.00070 | 0.157 |
| | 27,500 | 1.20 | 0.00362 | 0.00070 | 0.292 |
| 1000 | 5,500 | 0.035 | 0.00026 | 0.00020 | 0.006 |
| | 7,500 | 0.065 | 0.00039 | 0.00029 | 0.010 |
| | 10,000 | 0.140 | 0.00060 | 0.00039 | 0.021 |
| | 12,500 | 0.265 | 0.00076 | 0.00051 | 0.025 |

At 1000°F. the deformations are far less than the allowable values. Likewise the creep rates are much lower than the permissible 1.0 per cent per 1000 hours. A rather dubious extrapolation of the creep rates indicates a permissible stress of 15,000 pounds per square inch.

Constant Stress Creep Tests

Four tests were run at both 850 and 1000°F. The stresses were selected to cover the creep rate range from 0.01 to 0.10 per cent per 1000 hours. The time-elongation curves are shown as Figures 4 and 5 and the creep rates for 500 hour time intervals are summarized in Table II.

The 800 to 1300 hour time period was selected for determination of creep strength since the data are most complete for this time interval and the rates for most of the tests are reasonably constant. The stresses and corresponding creep rates are plotted to logarithmic coordinates in Figure 6 and the following creep strengths were obtained from the curves.

| Temperature Deg.Fahr. | Stress, Lb./Sq.In. for Indicated Creep Rate 0.01%/1000 Hours | 0.10%/1000 Hours |
|---|---|---|
| 850 | 20,000 | 28,500 |
| 1000 | 5,200 | 15,000 |

The higher stresses at both temperatures show decreasing rates over the time periods considered for these tests. It

Table II

Creep Rates for 0.50 Mo Steel K-22 at 850 and 1000°F.

| Temperature Deg. Fahr. | Stress Lb./Sq.In. | Creep Rates, % per 1000 Hours, for Indicated Time Intervals 500 to 1000 Hr. | 800 to 1300 Hr. | 1000 to 1500 Hr. | 1500 to 2000 Hr. |
|---|---|---|---|---|---|
| 850 | 20,000 | 0.010 | ----- | ----- | 0.010 |
| | 22,500 | 0.040 | 0.026 | ----- | ----- |
| | 25,000 | 0.058 | 0.046 | 0.045 | ----- |
| | 27,500 | 0.15 | 0.08 | 0.066 | ----- |
| 1000 | 5,500 | 0.013 | 0.012 | ----- | ----- |
| | 7,500 | 0.019 | 0.020 | ----- | ----- |
| | 10,000 | 0.045 | 0.043 | 0.043 | 0.044 |
| | 12,500 | 0.070 | 0.065 | 0.062 | 0.062 |

is probable that longer time tests would revise the strengths upward. The only slight tendency of the lower stresses to decrease with time probably indicates that the time required for minimum rates would be extended to several thousand hours. An experimental reason for irregularities in some of the curves was not observed.

## Metallographic Examination

The microstructure of the original material and the highest stress creep test specimens at each temperature are shown in Charts 1, 2 and 3. Metallographic specimens were taken lengthwise to the specimen at the center of the gage length. The grain size was 7-8 and the carbide areas were fine slightly spheroidized pearlite. Very little difference in structure could be found between the original material and the creep test specimens.

## Discussion of Results

A tabular comparison of the results of the short- and long-time tests follows:

| | Test Strength, Lb./Sq.In. 850°F. | 1000°F. |
|---|---|---|
| Hatfield Time Yield | 18,000 | 10,000 |
| DIN (DVM) | 26,000 | 15,000 |
| Constant Stress Creep Test | | |
| 0.01%/1000 Hr. Strength | 20,000 | 5,200 |
| 0.10%/1000 Hr. Strength | 28,500 | 15,000 |

At 850°F. the Time-Yield test predicted the 0.01% per 1000 hour creep strength rather closely while the DIN (DVM) test predicted the 0.10% per 1000 hour strength. At 1000°F., however, the Time-Yield stress was intermediate while the DIN (DVM) test again predicted the 0.10% per 1000 hour strength. It should be recognized, however, that the DIN (DVM) stress at 1000°F. was based on a very dubious extrapolation of test data.

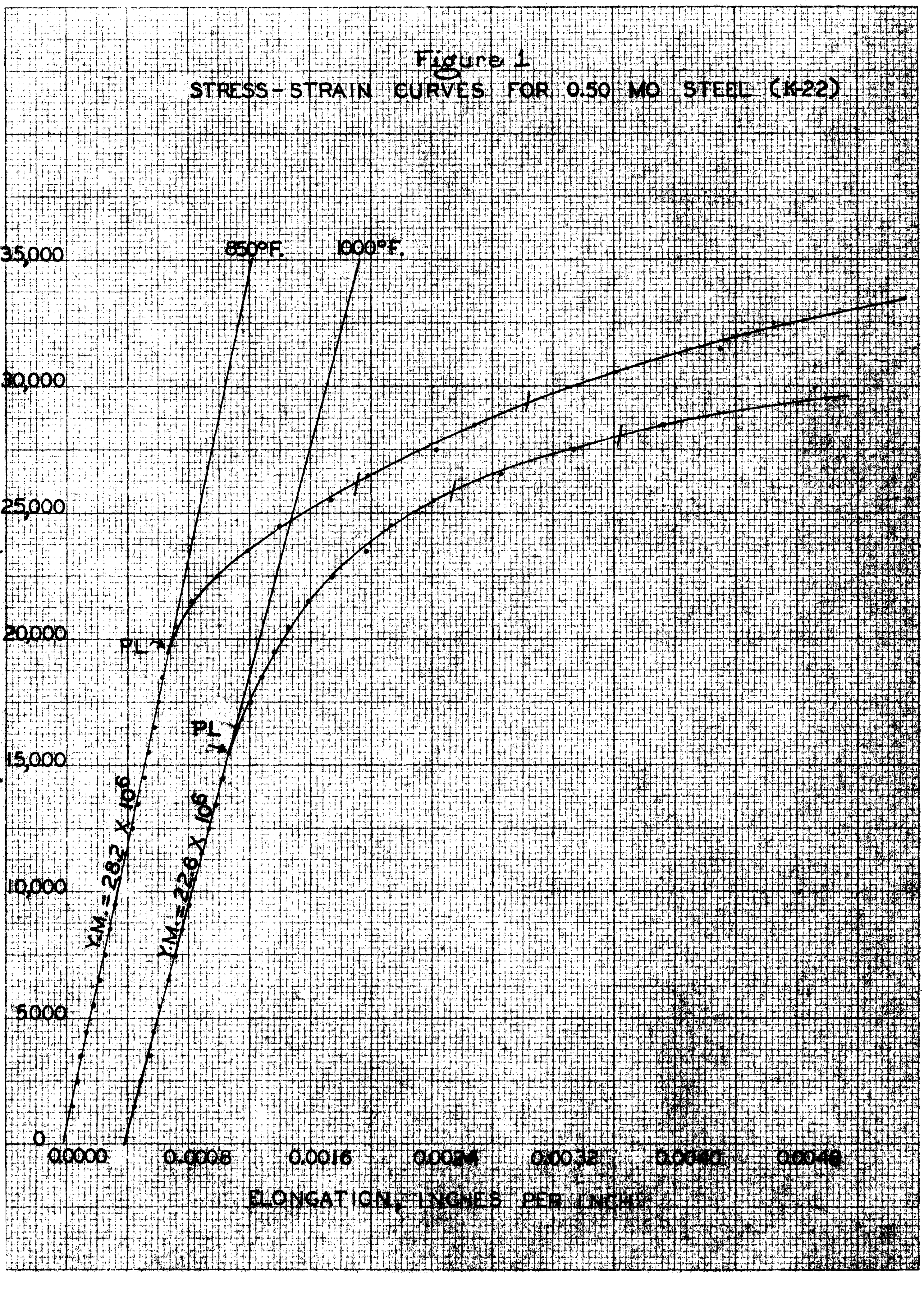
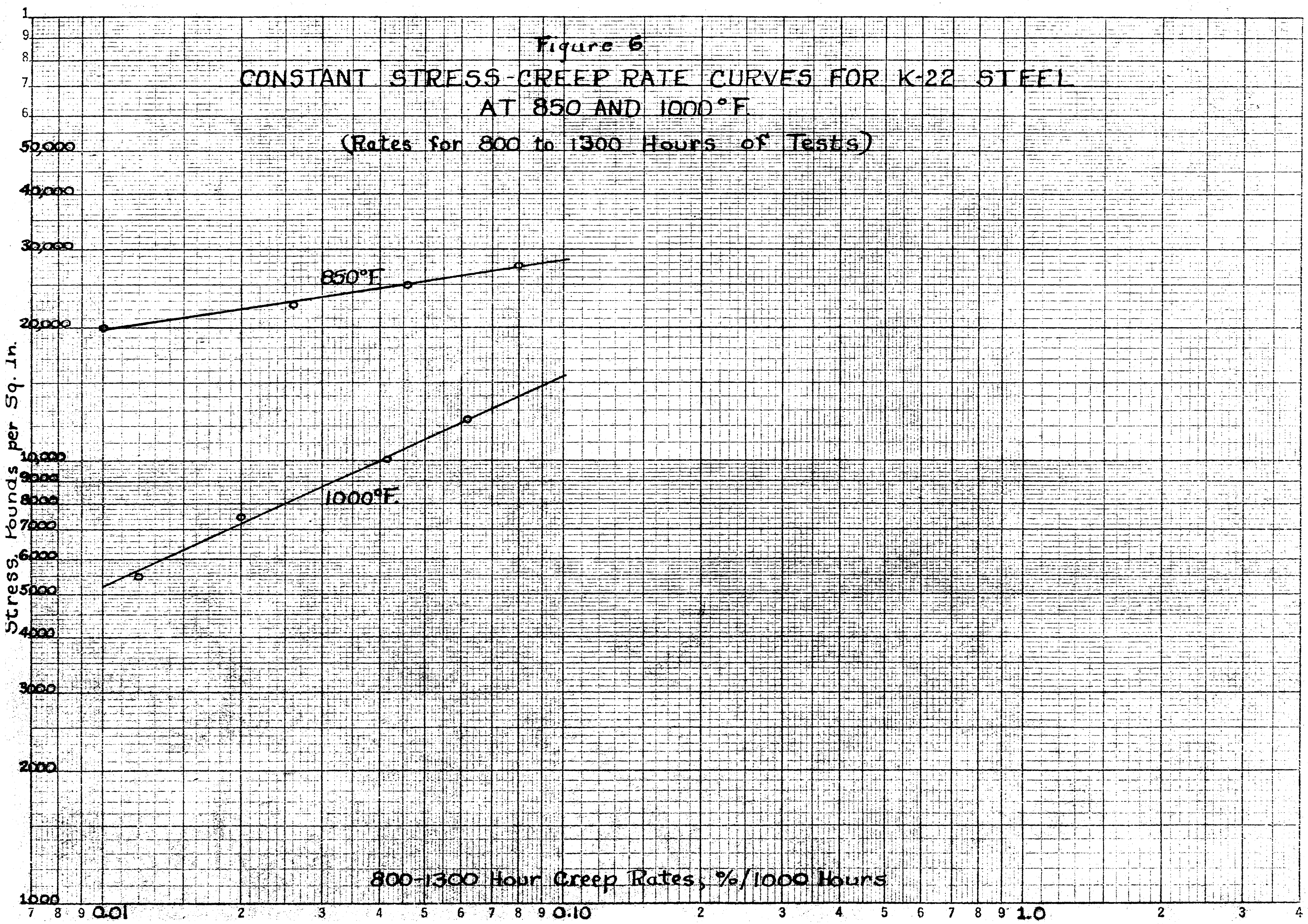


Figure 1
STRESS-STRAIN CURVES FOR 0.50 MO STEEL (K-22)
850°F.
1000°F.
PL
PL
Y.M. = 28.2 X 10⁶
Y.M. = 22.6 X 10⁶
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
0.0000
0.0008
0.0016
0.0024
0.0032
0.0040
0.0048
STRESS, POUNDS PER SQ. IN.
ELONGATION, INCHES PER INCH

Figure 6

CONSTANT STRESS-CREEP RATE CURVES FOR K-22 STEEL
AT 850 AND 1000°F
(Rates for 800 to 1300 Hours of Tests)



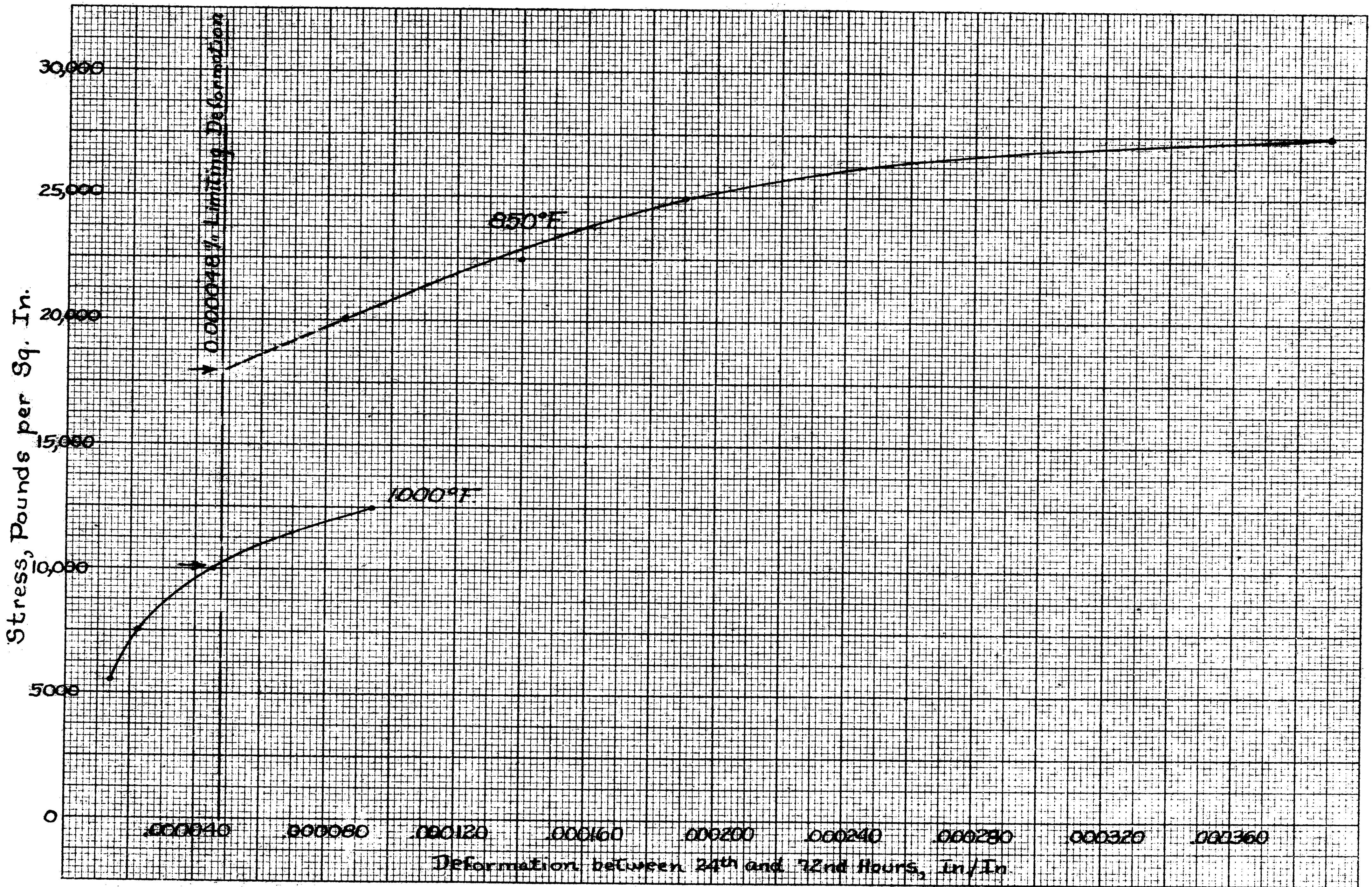



Figure 7. HATFIELD "TIME YIELD" DATA FOR K-22 (0.50 Mo) STEEL AT 850 AND 1000°F.

Figure 8

GRAPHICAL PRESENTATION OF DIN (DVM) DATA FOR 0.50 Mo STEEL K22 AT 850 AND 1000° F.

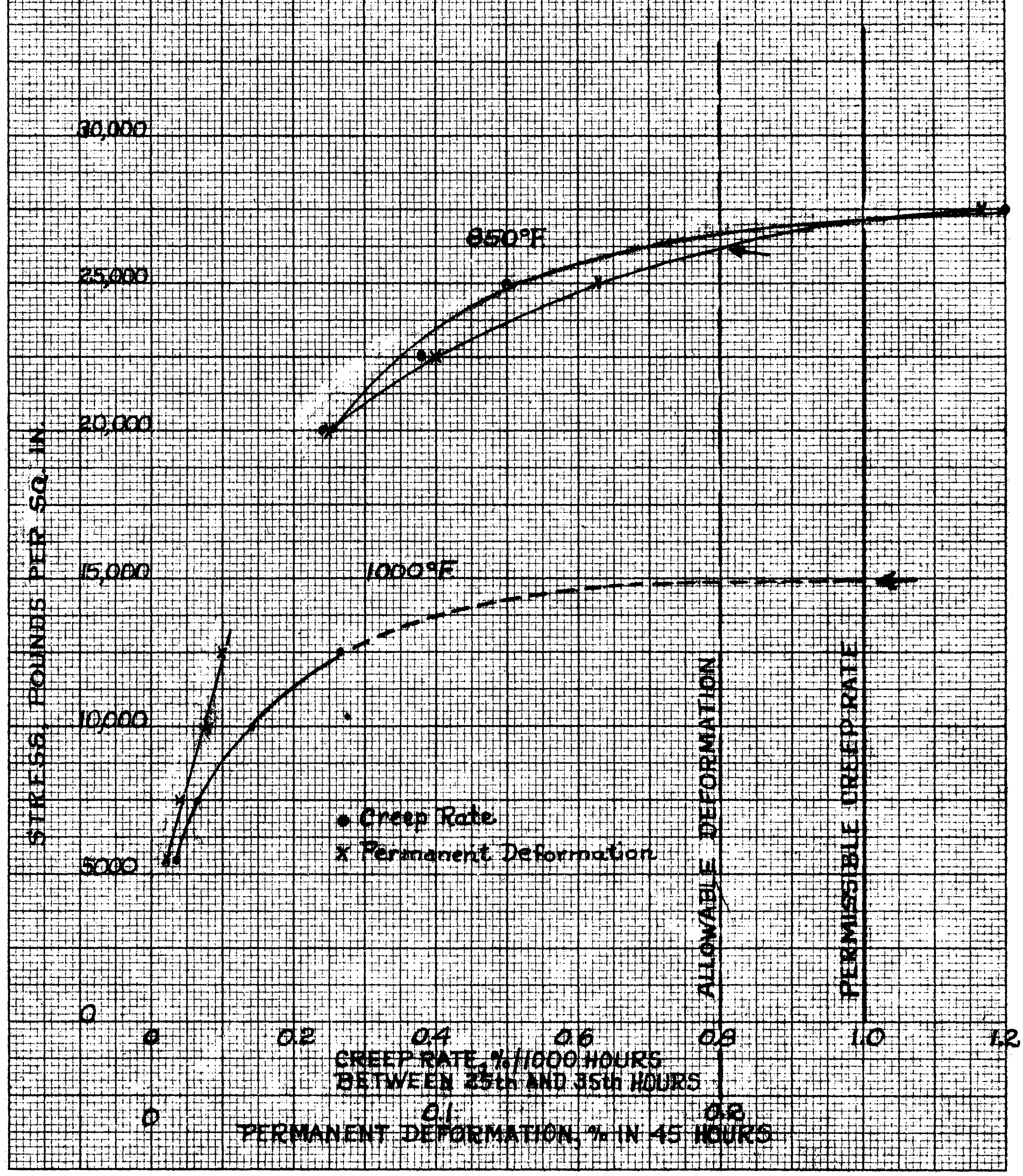
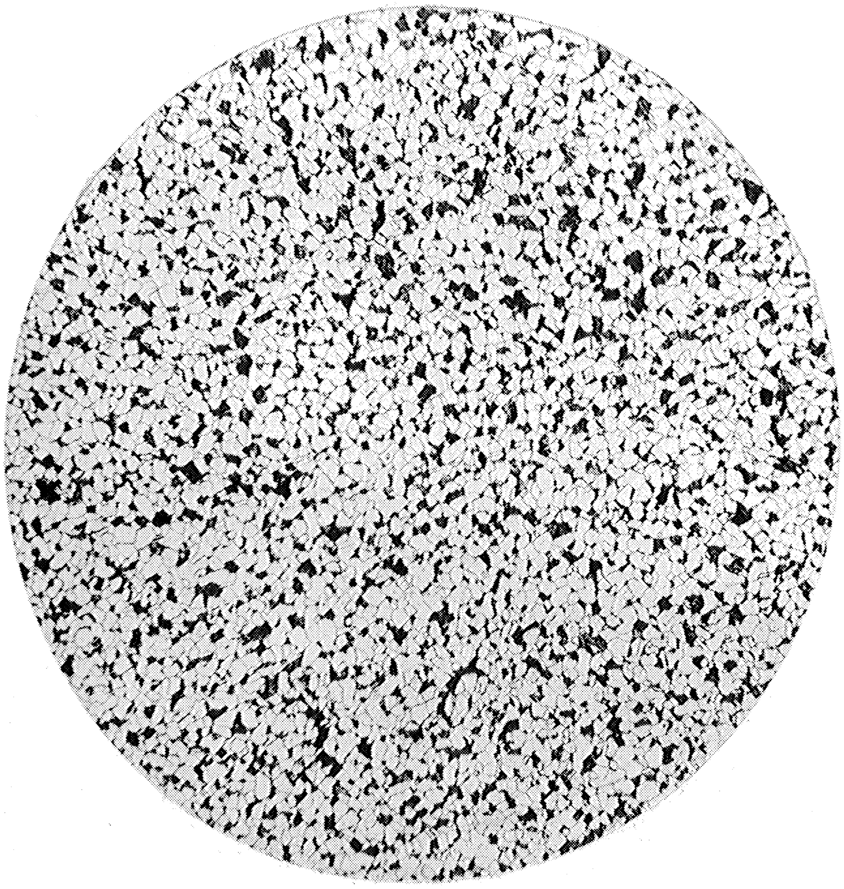
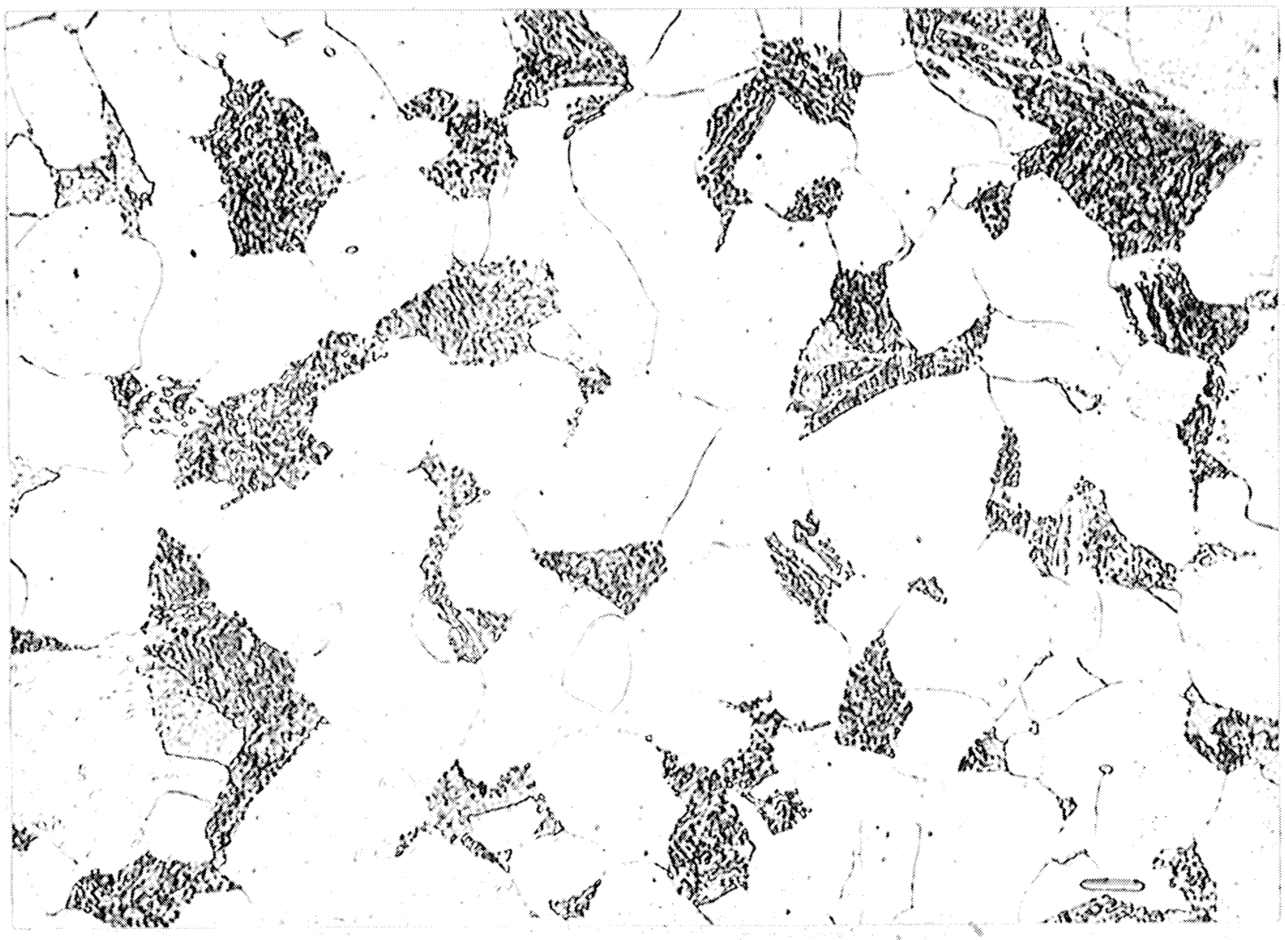


Chart 1
Original Microstructure of Steel K22 (0.50 Mo)

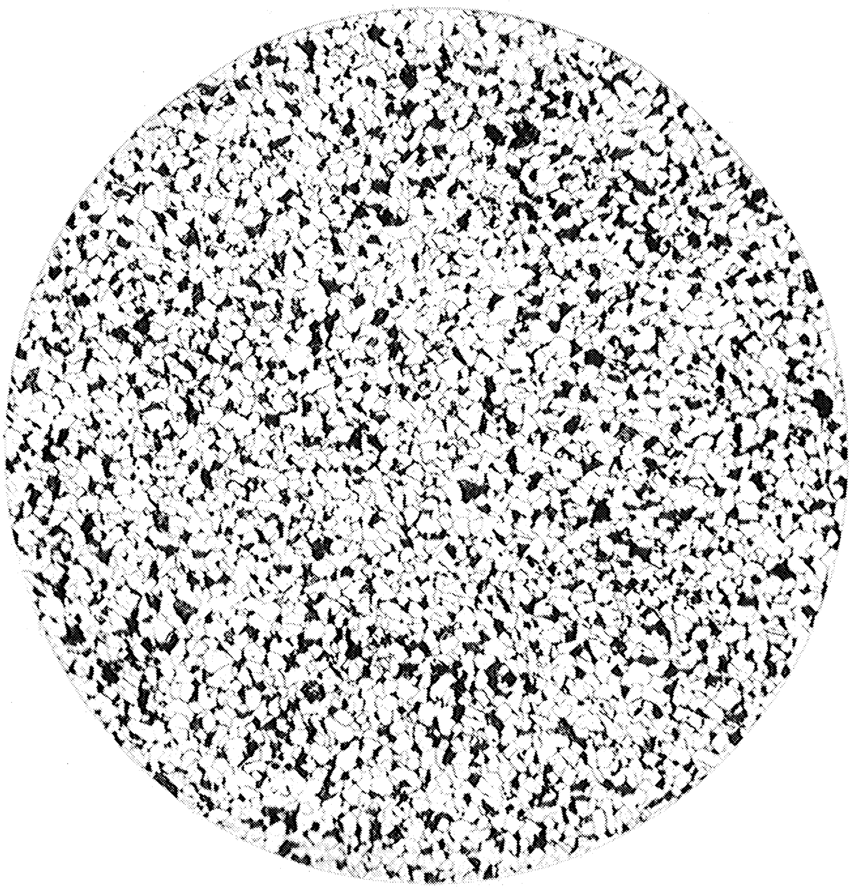


X100D

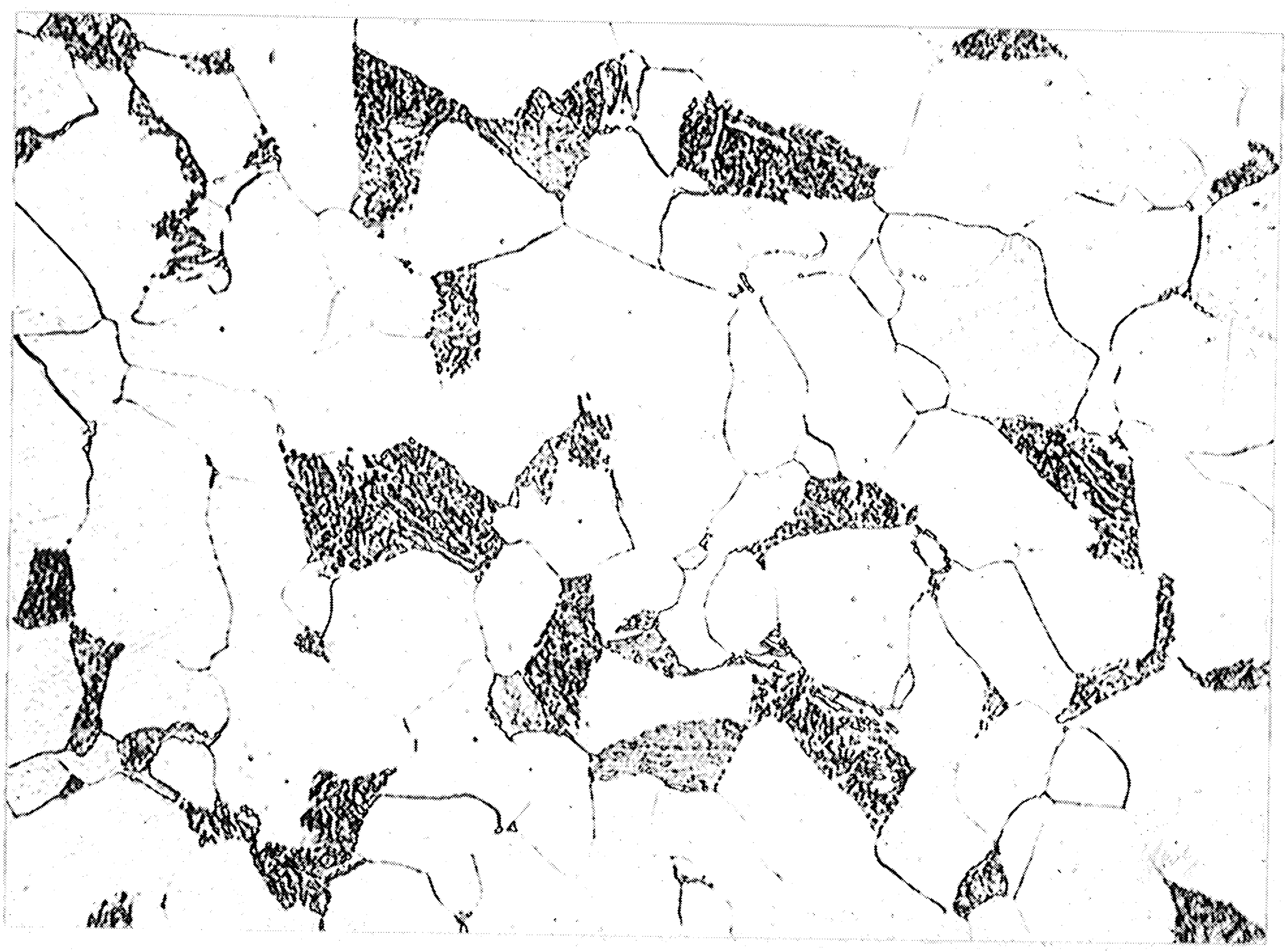


X1000D

Chart 2
Microstructure of Steel K22 (0.50Mo) Completed Creep Test Specimen
1453 Hours at 850°F. Under a Stress of 27,500 Pounds

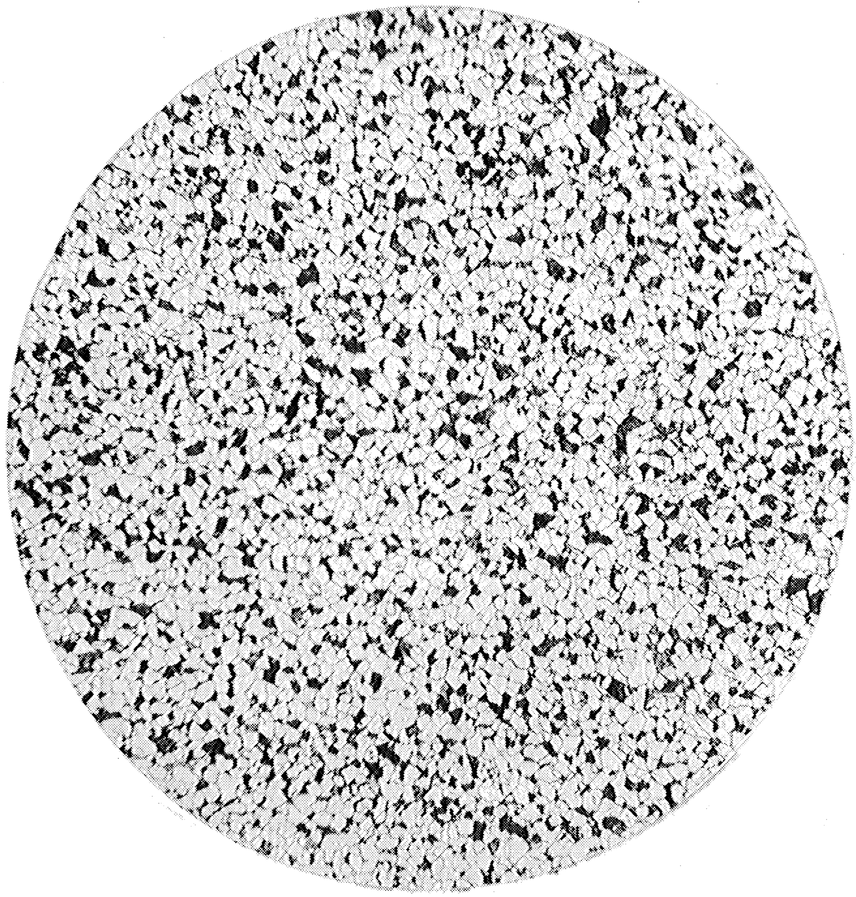


X100D

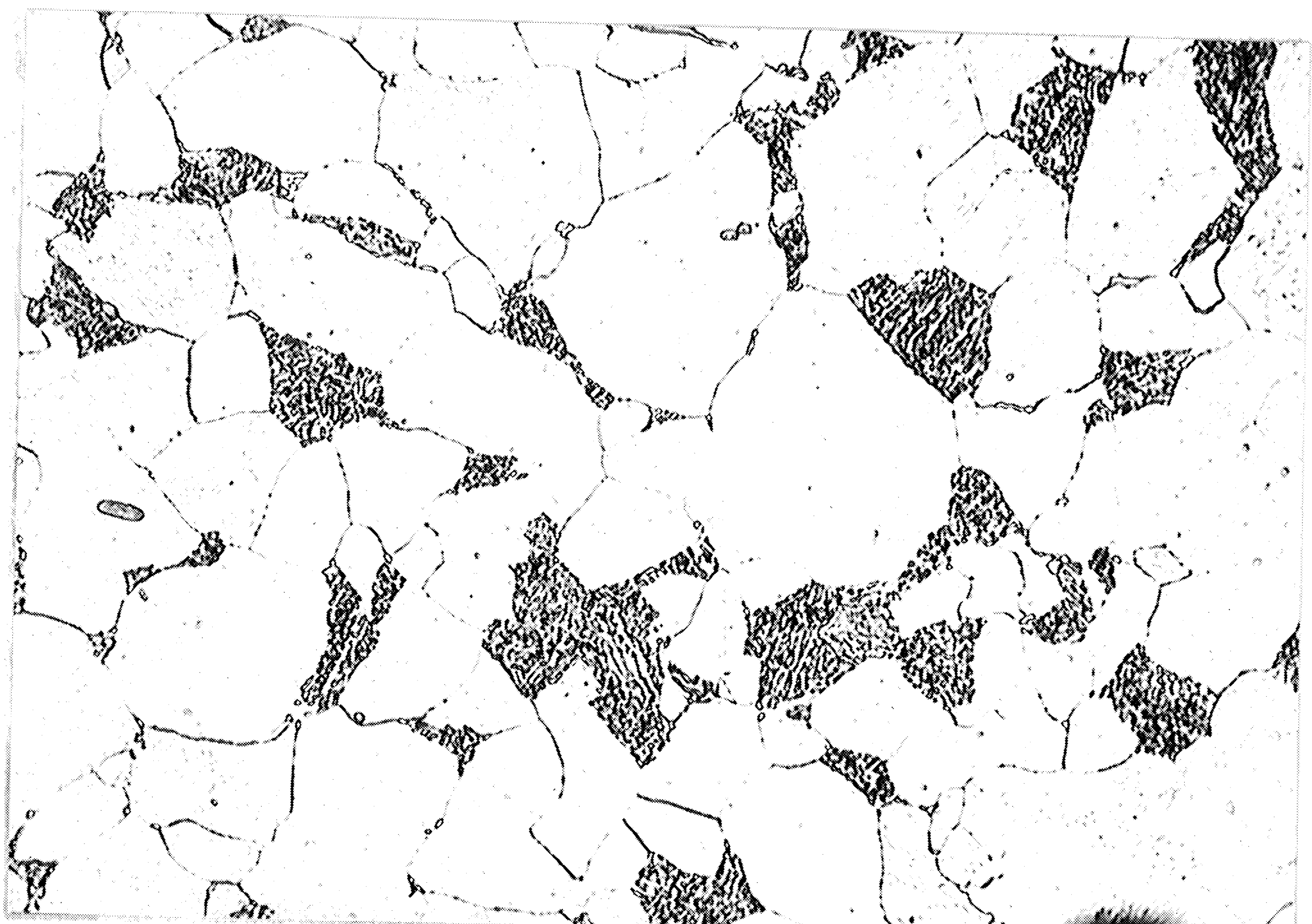


X1000D

Chart 3
Microstructure of Steel K22 (0.50Mo) Completed Creep Test Specimen
2104 Hours at 1000°F. Under a Stress of 12,500 Pounds



X100D



X1000D