# THIRTEENTH PROGRESS REPORT

TO

MATERIALS LABORATORY

WRIGHT AIR DEVELOPMENT CENTER

ON

# FOUR LOW-ALLOY STEELS FOR ROTOR DISKS OF GAS TURBINES IN JET ENGINES

by

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## SUMMARY

This report presents the progress made in an investigation of the high-temperature properties of low-alloy steels for use in jet engines. The period covered by the report was from July 1, 1954 to September 30, 1954.

Data are presented for two phases of work now in progress. Nearly complete data have been obtained for survey tests to evaluate the influence of microstructure as controlled by continuous cooling transformation on the high-temperature properties of SAE 4340, "17-22A"S, and H-40 Steels at temperatures ranging from 700° to 1200°F. Partially complete data are shown for a similar survey to determine the effect of austenitizing temperature on the elevated-temperature properties of the same steels for the same testing temperature range.

For the first phase of study, the structures studied were those obtained by continuous cooling transformation during air cooling of 1-inch and simulated 3- and 6-inch diameter bars. The second phase covered the influence of normalizing temperatures of 1750°, 1950°, and 2100°F for 1-inch diameter rounds. Normalizing of 1-inch diameter bars of 4340 and "17-22A"S Steels at 1750°F resulted in mixed martensitic-bainitic structures, whereas both the slower cooling cycles and the higher austenitizing temperatures tended to produce predominately bainitic structures.

The test data obtained for material transformed under various continuous cooling transformation conditions indicate only small differences in properties as a result of normalizing in section sizes ranging from 1-inch to 6-inch diameter bars. In fact, the most significant observation is that relatively uniform properties may be expected for section sizes from 1-inch to 6-inch in diameter for the normalized condition.

The variations in properties as influenced by austenitizing temperature are not well defined by the partially complete data. Therefore, detailed discussion of the effect of that variable has been withheld pending the completion of the testing program.

# INTRODUCTION

This report covers the work done during the period between July 1, 1954, and September 30, 1954, on an investigation of the metallurgical factors involved in the use of heat-treatable low-alloy steels at elevated temperatures in jet engines. The work is authorized by Contract Number AF 33(038)-13496 and Supplemental Agreement Number S9(54-1203), Expenditure Order Number R-619-11SR-12.

The entire investigation has consisted of several phases of work. Initially, the high temperature properties of four low-alloy steels in the form of rotor wheels for gas turbines of jet engines were evaluated after various heat-treatments. The results of this work have been published as WADC Technical Report 53-277 Part I. A concurrent investigation was conducted to determine the relationships between types of microstructure, as controlled by heat-treatment and the properties of the alloys. Microstructures obtained by isothermal transformation in the pearlitic and bainitic regions were studied as well as those obtained by oil quenching and tempering and normalizing and tempering. A final report covering the results of this study and correlating the results with the evaluation of the rotor wheel properties has been submitted and will be published as WADC Technical Report 53-277 Part II.

Two additional phases of the study were the investigation of (1) the effect of variations in continuous cooling transformation as controlled by section size, and (2) the effect of variations in austenitizing temperature on the elevated-temperature properties of the subject steels. Progress Report Number 12, date June 30, 1954, presented the results of the initial studies on the effect of continuous cooling transformation.

The present report covers the additional data obtained on that subject as well as the information available at this time on the effect of variations in austenitizing temperature on high temperature properties.

The properties of structures produced by cooling rates simulating those existing in the center of 3- and 6-inch diameter rounds have been survey tested in the temperature range of 700° to 1200°F for the SAE 4340, "17-22A"S, and H-40 Steels. It was believed that these cooling rates together with those previously studied, the oil-quenched and normalized 1-inch round bars, cover adequately the range of structures of major interest; that is, from martensite formed on quenching to bainite formed by relatively slow cooling rates. Except for a few tests still in progress, testing has been completed for this phase of the study.

In addition, work has been in progress to evaluate the effect of austenitizing temperature on the properties of normalized 1-inch diameter bars. This work is nearly complete for normalizing temperatures of 1950° and 2100°F for the SAE 4340 and "17-22A"S materials. Future work will involve the completion of the study of the effect of austenitizing temperature on the high-temperature properties of 4340 and "17-22A"S Steels, and the extension of this phase is to include the H-40 Steel. The ultimate objective is to establish the metallurgical principles of heat treatment for producing as nearly optimum properties as possible in such alloys for use at elevated temperatures.

## TEST MATERIALS

The chemical compositions of the alloys being studied were reported by the manufacturers to be as follows:

| Steel | Heat | C | Mn | Si | Cr | Ni | Mo | V | W |
|---|---|---|---|---|---|---|---|---|---|
| 4340 | 19053 | 0.40 | 0.70 | 0.30 | 0.78 | 1.75 | 0.26 | -- | -- |
| "17-22A"S | 10420 | 0.29 | 0.61 | 0.67 | 1.30 | 0.18 | 0.47 | 0.26 | -- |
| H-40 | K-2509 | 0.29 | 0.48 | 0.26 | 3.05 | 0.49 | 0.49 | 0.85 | 0.55 |

# PROCEDURE

## Continuous Cooling Transformation Study

The procedure for evaluating the effects of variation in continuous cooling transformation as a function of section size was outlined in a previous progress report, dated June 30, 1954. Consequently, it will be reviewed only briefly at this time. The general procedure was to heat and cool 1-inch diameter bars in cylinders made from a low heat duty fireclay insulating brick. The thickness of the firebrick cylinder was adjusted so that the cooling cycles of the enclosed bars were similar to those existing at the center of 3- and 6-inch diameter steel bars during air cooling.

## Evaluation of the Effect of Austenitizing Temperature

Experience with alloys of the same type as those being studied has indicated that, at least in some instances, better than usual combinations of high-temperature strength and ductility may be obtained if the austenitizing temperature is just below the grain coarsening temperature of the material. However, this generalization seems to be most applicable to those steels exhibiting a rather sudden transition from fine to coarse grain size and for those steels containing carbides which are difficult to dissolve. Heat treatment above the coarsening temperature may or may not improve the strength properties of such steels, but it almost always results in considerable loss in ductility at rupture. Consideration of these facts lead to the belief that the relationships between properties and austenitizing temperature should be established for the subject steels.

The initial step in this investigation was to determine the variation in the bainitic grain size of the subject steels as a function of normalizing temperature over the temperature range of 1800° to 2200°F. The results of this survey are shown in Figure 1 for the SAE 4340, "17-22A"S, and H-40 Steels. Examination of this graph reveals that none of the steels, with the possible exception of H-40, revealed an abrupt coarsening temperature. Even for H-40, the heat-treating temperature had to be considerably above the temperature where coarsening started to obtain an appreciable increase in the bainitic grain size.

Because of the absence of a definite coarsening temperature, as determined by the procedure outlined above, it was decided to evaluate the effect of austenitizing temperature on SAE 4340 and "17-22A"S at 1950° and 2100°F in addition to the 1750°F temperature previously studied. For H-40 Steel an additional temperature of 2100°F was selected since the temperature used for prior work had been 1950°F. A third austenitizing temperature will be selected for further work on the H-40 Steel if the initial results at 2100°F indicate that another heat-treating temperature is desirable. These additional temperatures were selected because it was believed that the range of 1750° to 2100°F was sufficiently wide to provide adequate data for an initial survey of the effect of austenitizing temperature on high-temperature properties.

It should be noted that it is quite difficult to evaluate the grain size of the 4340 and "17-22A"S Steels in the normalized or normalized and tempered condition. However, it is believed that the range in grain size shown in Figure 1 is reasonably representative of the observed bainitic grain size of these steels.

Throughout the previous work, all test bars have been tempered to a hardness range of 280 to 320 Brinell when the as-normalized hardness was at a sufficiently high level. The same hardness levels were employed for the present phase of the investigation. Insofar as possible, the tempering times and temperatures were the same as or similar to those previously employed for the lower austenitizing temperature. However, since the hardness of the 4340 Steel as-normalized from 1950° and 2100°F was only slightly above the 320 Brinell maximum and even slight tempering resulted in hardness below the 280 minimum, this steel was tested in the as-normalized condition. Table I shows the as-normalized and normalized and tempered hardnesses of 4340 and "17-22A"S Steels as well as indicating the microstructure obtained and the tempering procedure employed.

Basis of Evaluation of High-Temperature Properties

The general basis of evaluation of the effect of austenitizing temperature on the elevated temperature properties was the same as previously employed for the isothermally and continuously transformed structures. Briefly, the basis was as follows:

a. The properties were evaluated for the temperature range over which creep and rupture properties would be a controlling factor. For SAE 4340 this range was set at 700° to 1100°F, while 700° to 1200°F was employed for the "17-22A"S Steel.

b. The structures were evaluated on the basis of the property which was the controlling factor at the temperature of interest. Thus, at 700° and 900°F the criteria of comparison were mainly creep rate and total deformation, although approximately 1000-hour rupture tests were conducted for the 4340 material at 900°F. These results were obtained because the relatively low strength of 4340 at 900°F made a knowledge of its stress-rupture properties desirable at that temperature.

c. At 1000°F for 4340 and at 1100°F for "17-22A"S, the temperatures of major interest for these steels, both stress-rupture data and creep and total deformation data from relatively long time rupture tests were obtained.

d. The property considered to be of most interest at 1100°F for the 4340 Steel and at 1200°F for "17-22A"S was the 100-hour rupture strength. However, 1000-hour creep-rupture tests were conducted to permit better correlation between structural variations and temperature of testing.

## RESULTS

### Survey of Relationships Between Section Size and Strength for 4340, "17-22A"S, and H-40 Steels

The additional test data obtained since the last progress report for the 4340, "17-22A"S, and H-40 Steels for variations in cooling cycle as controlled by section size are presented in Table II. Although the test data are not quite complete, a few tests being in progress, the results are summarized in Figures 2, 3, and 4 to illustrate the relations existing between section size, testing temperature, and strength properties for 4340, "17-22A"S, and H-40 respectively. The following observations may be made:

1. Properties of SAE 4340 Steel: The graphs of Figure 2 show excellent agreement in properties between the normalized 1-inch diameter

bar and the test bars normalized to simulate the cooling rates existing at the center of 3- and 6-inch diameter rounds. Apparently little or no difference in strength properties exists for the structures obtained by normalizing section sizes varying from one to six inches in diameter. Also, the ductility at fracture is similar for all three sizes. In all instances, the properties of the normalized bar stock were superior to those of the martensitic structure obtained by oil quenching.

2. Properties of "17-22A"S Steel: The curves of Figure 3 show that at 1100° and 1200°F the effect of variations in section size was similar to that observed for the 4340 Steel in that little or no differences in properties were noted for the bars normalized to simulate 1- to 6-inch diameter rounds. On the other hand, at 900°F there appeared to be considerable difference in that the simulated 3- and 6-inch diameter bars revealed lower creep rates and longer times for one-percent total deformation than did the 1-inch bar. It should be emphasized, however, that the stress-creep rate and stress-time for total deformation curves are probably quite flat at 900°F, and that therefore the differences in creep strength and total deformation strength are much smaller than indicated by the curves of Figure 3. At 700°F the data appear to be somewhat erratic since the simulated 3-inch bar appears to be considerably weaker than either the 1-inch or simulated 6-inch bar. However, the statement made above concerning the 900°F test data also applies to the 700°F tests. Furthermore, since the test stresses must be considerably above the proportional limit of the material to obtain appreciable creep at 700°F, the relative creep rates and times for a specified deformation may vary widely with only a small change in stress. Thus, it is hazardous to compare the different heat-treatments at 700° and 900°F on the basis of a single test.

3. Properties of H-40 Steel: Examination of the data plotted in Figure 4 indicates a trend for slightly higher strength properties with increasing section size. However, the differences are quite small, and probably the most significant observation is that little or no difference in properties occurs as the result of normalizing section sizes varying from 1 to 6 inches in diameter. As for "17-22A"S Steel, rather large differences were noted at 700° and 900°F when the various section sizes were compared on the basis of minimum creep rate and time for a specified total deformation for a single testing stress. However, as was noted for the "17-22A"S Steel, wide variations in minimum creep rate or time for a limited deformation for single stress survey tests may be observed with only slight differences in creep or total deformation strength at low testing temperatures.

## Survey of Relationships Between Austenitizing Temperature and Strength for 4340 and "17-22A"S Steel

The structures obtained by normalizing 1-inch diameter bars at 1750°, 1950°, and 2100°F are outlined in Table I together with the as-normalized and normalized and tempered hardnesses. These structures are illustrated in the as-normalized condition in Figures 5 and 6 for the 4340 and "17-22A"S Steels respectively.

For 4340 Steel the major differences observed as the normalizing temperature was increased were a decrease in the amount of martensite present and an increase in the grain size. Increasing the normalizing temperature from 1750° to 1950°F decreased the amount of martensite from about 35 percent to approximately 15 percent, whereas the further increase to 2100°F apparently did not reduce the amount of martensite present. As the normalizing temperature was increased from 1750° to 1950°F, the average as-normalized hardness decreased from 373 BHN to 328 BHN and remained practically constant upon further increase of normalizing temperature to 2100°F. As mentioned previously, the grain size in the bainitic condition was difficult to ascertain. However, the grain size appeared to 6 to 7, 5, and 3 for the 1750°, 1950°, and 2100°F normalizing temperatures respectively.

The changes in microstructure for the "17-22A"S Steel with increasing temperature of normalizing were similar to those for 4340 Steel. However, for "17-22A"S Steel, the higher normalizing temperatures completely eliminated the martensite observed after a 1750°F normalize. Increasing the normalizing temperature resulted in a decrease in the as-normalized hardness. The average as-normalized hardness was 353 BHN, 335 BHN, and 313 BHN for normalizing temperatures of 1750°, 1950°, and 2100°F respectively. The increase in grain size appeared to be about the same as observed for 4340 Steel.

Although the testing program is still in progress, the following observations may be tentatively made concerning the effect of austenitizing temperature on the high-temperature properties.

1. <u>SAE 4340 Steel</u>: At the present time the data of Table III indicate only small changes in the strength properties as a result of variations in austenitizing temperature. The short-time rupture tests completed to date also indicate little or no change in ductility at fracture with austenitizing temperature. These conclusions may have to be altered as more tests are completed.

2. <u>"17-22A"S Steel</u>: The limited data available for "17-22A"S Steel, Table IV, indicate slightly higher strengths and lower ductility for rupture tests of 1000-hours duration at 1100°F for the higher austenitizing temperatures. However, more complete data are required to thoroughly establish the relationships between strength, testing temperature, and austenitizing temperature for this steel.

# DISCUSSION

The nearly complete data obtained from the survey tests to evaluate the high-temperature properties of structures formed during continuous cooling at various rates indicate the following:

1. The most significant observation that can be made is that little or no differences in creep-rupture properties exist for the normalizing of section sizes varying from 1- to 6-inch rounds for the three steels studied.

2. Normalizing of 1-inch and simulated 3- and 6-inch diameter bars gave strength values consistently higher than those of oil-quenched 1-inch bars for all three steels.

3. With the exception of the 4340, the slower heating and cooling cycles resulted in coarser microstructures than previously observed in the bar stock material.

4. In general, the elongation at fracture in the rupture test did not appear to be affected by the variations in section size.

5. More detailed analysis of the results of the complete data together with microexamination of the completed creep-rupture specimens may indicate trends not yet apparent.

The test data to evaluate the effect of variations in austenitizing temperature on the high-temperature properties of the subject steels is to incomplete to establish definite effects at this time. There is some tendency toward higher strengths and lower ductility in the rupture test and toward lower minimum creep rates as the normalizing temperatures are increased. However, detailed discussion of the effects of variations in austenitizing temperature is being withheld pending the completion of the testing program.

# FUTURE WORK

Future work shall consist of the completion of survey tests to evaluate the effect of normalizing temperature on the high-temperature properties of the three steels--4340, "17-22A"S, and H-40.

TABLE I

Microstructure, Hardness, and Tempering Conditions for 4340 and "17-22A"S Steels

Normalized from 1750°, 1950°, and 2100°F as 1-Inch Diameter Bars

| Steel | Austenitizing Temp (°F) | Avg. Hardness BHN | Microstructure Obtained | Tempered | | Avg. Hardness BHN |
|---|---|---|---|---|---|---|
| | | | | Temp (°F) | Time (hrs) | |
| 4340 | 1750 | 373 | 35% martensite + 65% bainite | 1100 | 1 | 300 |
| | 1950 | 328 | 15% martensite + 85% bainite | None | -- | 328 |
| | 2100 | 333 | 15% martensite + 85% bainite | None | -- | 333 |
| "17-22A"S | 1750 | 353 | 15% martensite + 85% coarse bainite | 1200 | 10 | 307 |
| | 1950 | 335 | 100% bainite | 1200 | 6 | 298 |
| | 2100 | 313 | 100% bainite | 1200 | 6 | 306 |

## TABLE II

Rupture, Total Deformation, and Creep Data at 700° to 1200°F for SAE 4340 and "17-22A"S Normalized at 1750°F as 1-Inch Rounds and H-40 Steel Normalized at 1950°F as 3/4-Inch Rounds and with Cooling Rates Simulating the Normalizing of 3- and 6-Inch Rounds

| Steel | Temp (°F) | Size of Round (in.) | BHN | Stress (psi) | Rupture Time (hours) | Elong. (% in 2 in.) | Reduct. of Area (%) | Deformation on Loading(%) | Time to Reach Specified Total Deformation (hrs) 0.1% | 0.2% | 0.5% | 1.0% | Minimum Creep Rate (%/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4340 | 900 | 1 | 300 | 55,000 | 842 | 12(f) | 22.3 | 0.26 | a | a | 8 | 64 | 0.00414 |
| | | 3 | 327 | 55,000 | In progress 960 hours | | | 0.305 | a | a | 3 | 30 | 0.0013 |
| | | 6 | 315 | 55,000 | In progress 1008 hours | | | 0.290 | a | a | 3 | 45 | 0.00085 |
| | 1100 | 1 | 311 | 4,000 | 1056(c) | -- | -- | 0.017 | 18 | 96 | 484 | 1400(b) | 0.00052 |
| | | 3 | 327 | 4,500 | In progress 220 hours | | | 0.022 | 15 | 60 | 270(b) | -- | -- |
| | | 6 | 315 | 4,500 | In progress 240 hours | | | 0.030 | 15 | 60 | 300(b) | -- | -- |
| "17-22A"S | 700 | 1 | 307 | 102,000 | 1194(c) | -- | -- | 0.465 | a | a | ~1 | >2000(b) | 0.00007 |
| | | 3 | 291 | 102,000 | 1793(c) | -- | -- | 0.62 | a | a | a | 150 | 0.00016 |
| | | 6 | 294 | 102,000 | In progress 960 hours | | | 0.660 | a | a | a | d | 0.00002 |
| | 1200 | 1 | 313 | 7,500 | 918 | 10.0 | 14.9 | 0.046 | 6 | 46 | 176 | 333 | 0.0023 |
| | | 3 | 313 | 7,500 | In progress 162 hours | | | 0.036 | 37 | 155 | -- | -- | -- |
| | | 6 | 322 | 7,500 | In progress 210 hours | | | 0.037 | 37 | 152 | -- | -- | -- |
| H-40 | 700 | 3/4 | 310 | 90,000 | 1292(c) | -- | -- | 0.416 | a | a | 13 | 1700(b) | 0.00017 |
| | | 3 | 313 | 90,000 | 1272(c) | -- | -- | 0.390 | a | a | 135 | d | 0.00008 |
| | | 6 | 322 | 90,000 | 1124(c) | -- | -- | 0.410 | a | a | 60 | d | 0.00008 |
| | 900 | 3/4 | 320 | 65,000 | 1052 | 18.0(f) | 36.0 | 0.301 | a | a | 10 | 85 | 0.00328 |
| | | 3 | 313 | 65,000 | 1131(c) | -- | -- | 0.390 | a | a | 20 | 1500(b) | 0.00011 |
| | | 6 | 322 | 65,000 | 1130(c) | -- | -- | 0.414 | a | a | 15 | ~2200(b) | 0.00008 |

(Continued on following page)

TABLE II, Continued

| Steel | Temp (°F) | Size of Round (in.) | BHN | Stress (psi) | Rupture Time (hours) | Elong. (% in 2 in.) | Reduct. of Area (%) | Deformation on Loading(%) | Time to Reach Specified Total Deformation (hrs) 0.1% | 0.2% | 0.5% | 1.0% | Minimum Creep Rate (%/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H-40 | 1100 | 3/4 | 318 | 30,000(e) | 800 | -- | -- | 0.149 | a | 9 | 300 | 750 | 0.00096 |
| | | 3 | 313 | 30,000 | 1317(c) | -- | -- | 0.201 | a | a | 160 | 725 | 0.00079 |
| | | 6 | 322 | 30,000 | 1318(c) | -- | -- | 0.205 | a | a | 215 | 910 | 0.00068 |

(a) Specimen reached specified deformation on loading.
(b) Extrapolated value.
(c) Test Discontinued at indicated time.
(d) Deformation not obtained during testing period and to indicate time would have required excessive extrapolation.
(e) Interpolated value.
(f) 0.250-inch diameter specimen--elongation given is percent in 1.0 inch.

## TABLE III

Rupture, Total Deformation, and Creep Data at 700°, 900°, 1000°, and 1100°F

for SAE 4340 Steel Normalized as 1-Inch Diameter Bars from 1750°, 1950°, and 2100°F

| Normalizing Temperature (°F) | BHN | Stress (psi) | Rupture Time (hours) | Elong. (% in 2 in.) | Reduct. of Area (%) | Deformation on Loading (%) | Time to Reach Specified Total Deformation (hrs) 0.1% | 0.2% | 0.5% | 1.0% | Minimum Creep Rate (%/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **700°F** | | | | | |
| 1750 | 300 | 90,000 | 1294(c) | -- | -- | 0.467 | a | a | 1 | 1000 | 0.00016 |
| 1950 | 328 | 90,000 | 1293(c) | -- | -- | 0.628 | a | a | a | 167 | 0.00014 |
| 2100 | 336 | 90,000 | 1293(c) | -- | -- | 0.527 | a | a | a | 565 | 0.00016 |
| | | | | | | **900°F** | | | | | |
| 1750 | 300 | 55,000 | 842 | 12.0 | 22.3 | 0.260 | a | a | 8 | 64 | 0.00414 |
| 1950 | 336 | 55,000 | In progress 320 hours | | | 0.305 | a | a | 5 | 237 | -- |
| 2100 | 328 | 55,000 | In progress 344 hours | | | 0.285 | a | a | 5 | 280 | -- |
| 1750 | 300 | 40,000 | 1919(c) | -- | -- | 0.164 | a | 5 | 1160 | >3000(b) | 0.00015 |
| 1950 | 336 | 40,000 | 1461(c) | -- | -- | 0.163 | a | 2.5 | 475 | d | 0.00013 |
| 2100 | 328 | 40,000 | 1650(c) | -- | -- | 0.194 | a | ~1 | 425 | d | 0.00012 |
| | | | | | | **1000°F** | | | | | |
| 1750 | 290 | 31,000 | 371 | 5.5 | 7.4 | 0.126 | a | ~5 | 50 | 145 | 0.0050 |
| 1950 | 321 | 31,000 | 283.3 | 6.0 | 3.5 | 0.148 | a | ~2 | 35 | 142 | 0.0042 |
| 2100 | 328 | 31,000 | 489.7 | 4.5 | 4.0 | 0.148 | a | ~2 | 50 | 220 | 0.0028 |

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TABLE III, Continued

| Normalizing Temperature (°F) | BHN | Stress (psi) | Rupture Time (hours) | Elong. (% in 2 in.) | Reduct. of Area (%) | Deformation on Loading (%) | Time to Reach Specified Total Deformation (hrs) 0.1% | 0.2% | 0.5% | 1.0% | Minimum Creep Rate (%/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1100°F | | | | | | |
| 1750 | 293 | 18,000 | 69.6 | 7.0 | 11.7 | 0.116 | a | -- | -- | -- | -- |
| 1950 | 321 | 18,000 | 105.0 | 5.7 | 7.0 | 0.093 | <1 | ~2 | 12 | 45 | -- |
| 2100 | 328 | 18,000 | 122.8 | 5.5 | 4.9 | 0.105 | a | 2.5 | 14 | 40 | -- |

(a) Specimen reached specified deformation on loading.
(b) Extrapolated value.
(c) Test discontinued at indicated time.
(d) Deformation not obtained during testing period and to indicate time would have required excessive extrapolation.

TABLE IV

Rupture, Deformation, and Creep Data at 700°, 900°, 1100°, and 1200°F for "17-22A"S Steel

Normalized as 1-Inch Diameter Bars from 1750°, 1950°, and 2100°F

| Normalizing Temperature (°F) | BHN | Stress (psi) | Rupture Time (hours) | Elong. (% in 2 in.) | Reduction of Area (%) | Deformation on Loading(%) | Time to Reach Specified Total Deformation (hrs) 0.1% | 0.2% | 0.5% | 1.0% | Minimum Creep Rate (%/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 900°F | | | | | | |
| 1750 | 303 | 70,000 | 1482(c) | -- | -- | 0.335 | a | a | 24 | 1400 | 0.00030 |
| 1950 | 302 | 70,000 | 1277.5(c) | -- | -- | 0.355 | a | a | 60 | >1400 | 0.00012 |
| | | | | | 1100°F | | | | | | |
| 1750 | 309 | 41,000 | 111.5 | 2.5 | 3.1 | 0.212 | a | a | 26 | -- | -- |
| 1950 | 298 | 41,000 | 74.5 | 2.5 | 1.2 | 0.172 | a | <1 | 16 | -- | -- |
| 2100 | 317 | 41,000 | 78.8 | 1.0 | 1.0 | 0.205 | a | a | 54 | -- | -- |
| 1750 | 311 | 19,000(e) | 900 | 2.0 | -- | 0.085 | 5 | 80 | 550 | 800 | 0.00070 |
| 1950 | 298 | 19,000 | 1205.6 | 1.5 | 1.0 | 0.080 | 10 | 150 | 940 | -- | 0.00028 |
| 2100 | 317 | 19,000 | In progress 1600 hours | | | 0.090 | 1 | 425 | 1800 | -- | 0.00012 |
| | | | | | 1200°F | | | | | | |
| 1750 | 304 | 14,000 | 167.1 | 4.0 | 5.0 | 0.066 | 5 | 22 | 89 | -- | 0.0031 |
| 1950 | 302 | 14,000 | 129.1 | 3.5 | 3.5 | 0.073 | 2 | 16 | 92 | -- | -- |
| 2100 | 317 | 14,000 | 214.4 | 1.5 | 3.9 | 0.080 | 1 | 60 | 212 | -- | 0.00155 |

(a) Specimen reached specified deformation on loading.
(b) Extrapolated value.
(c) Test discontinued at indicated time.
(d) Deformation not obtained during testing period and to indicate time would have required excessive extrapolation.
(e) Interpolated values.

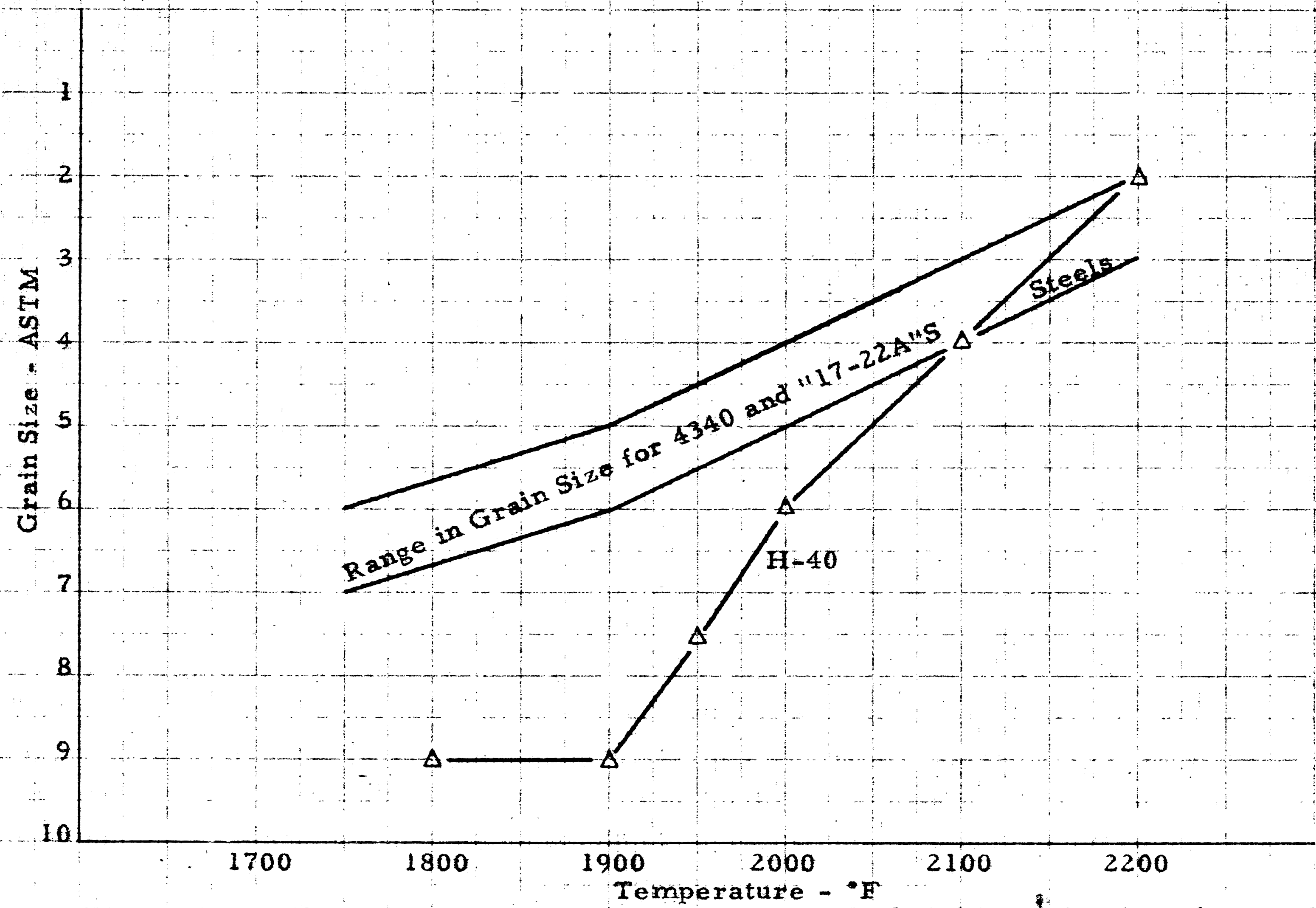



Figure 1. - Effect of austenitizing temperature on the bainitic grain size of normalized 1-inch diameter bars of SAE 4340, "17-22A"S, and H-40 Steels. (Note: Because of the difficulty in ascertaining the grain size of the "17-22A"S and 4340 Steels in the normalized condition, a band representing the predominant bainitic grain size is shown.)

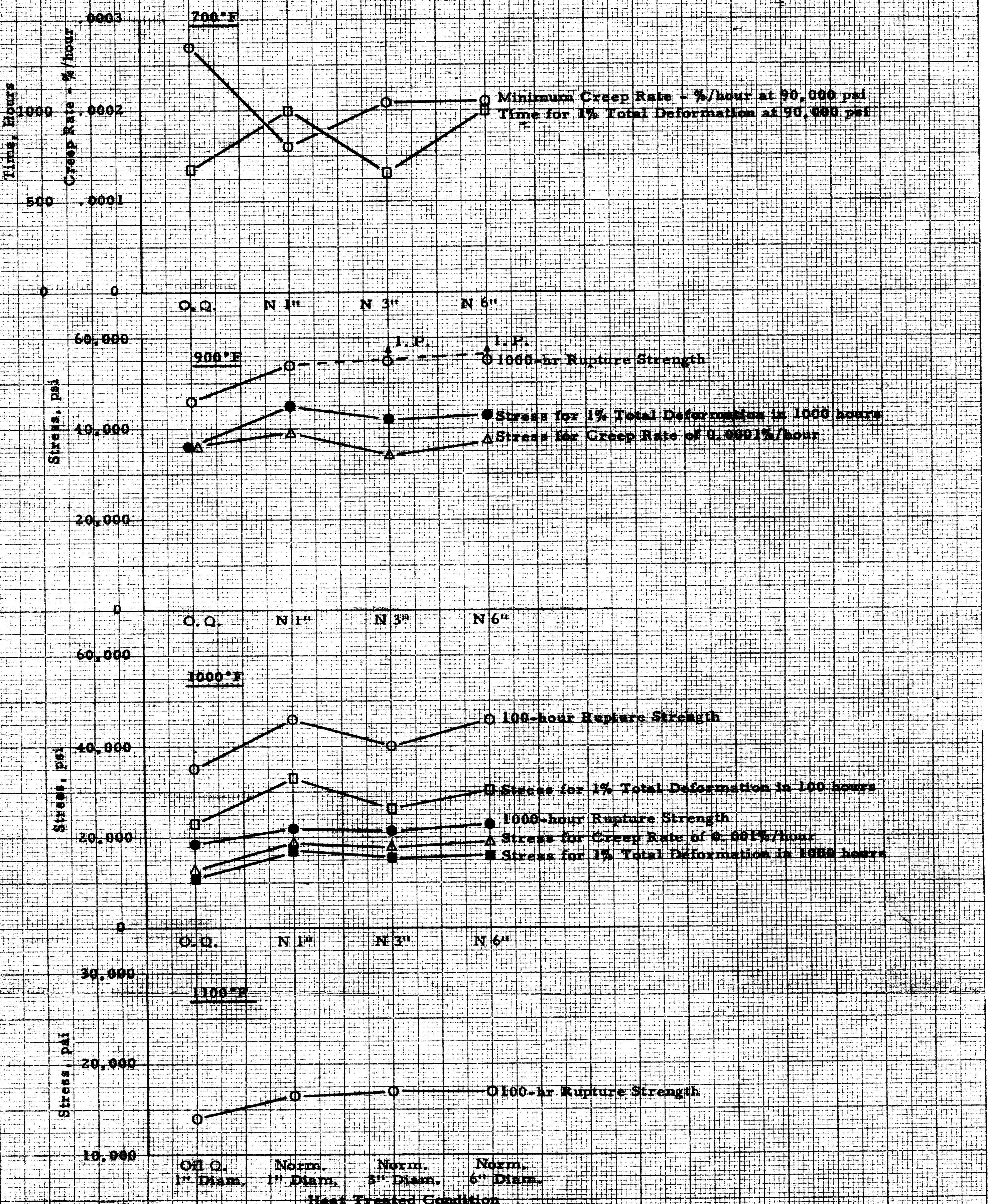



Figure 2 - Influence of cooling rate as controlled by section size and quenching medium on the high-temperature properties of SAE 4340 Steel oil quenched and normalized from 1750°F

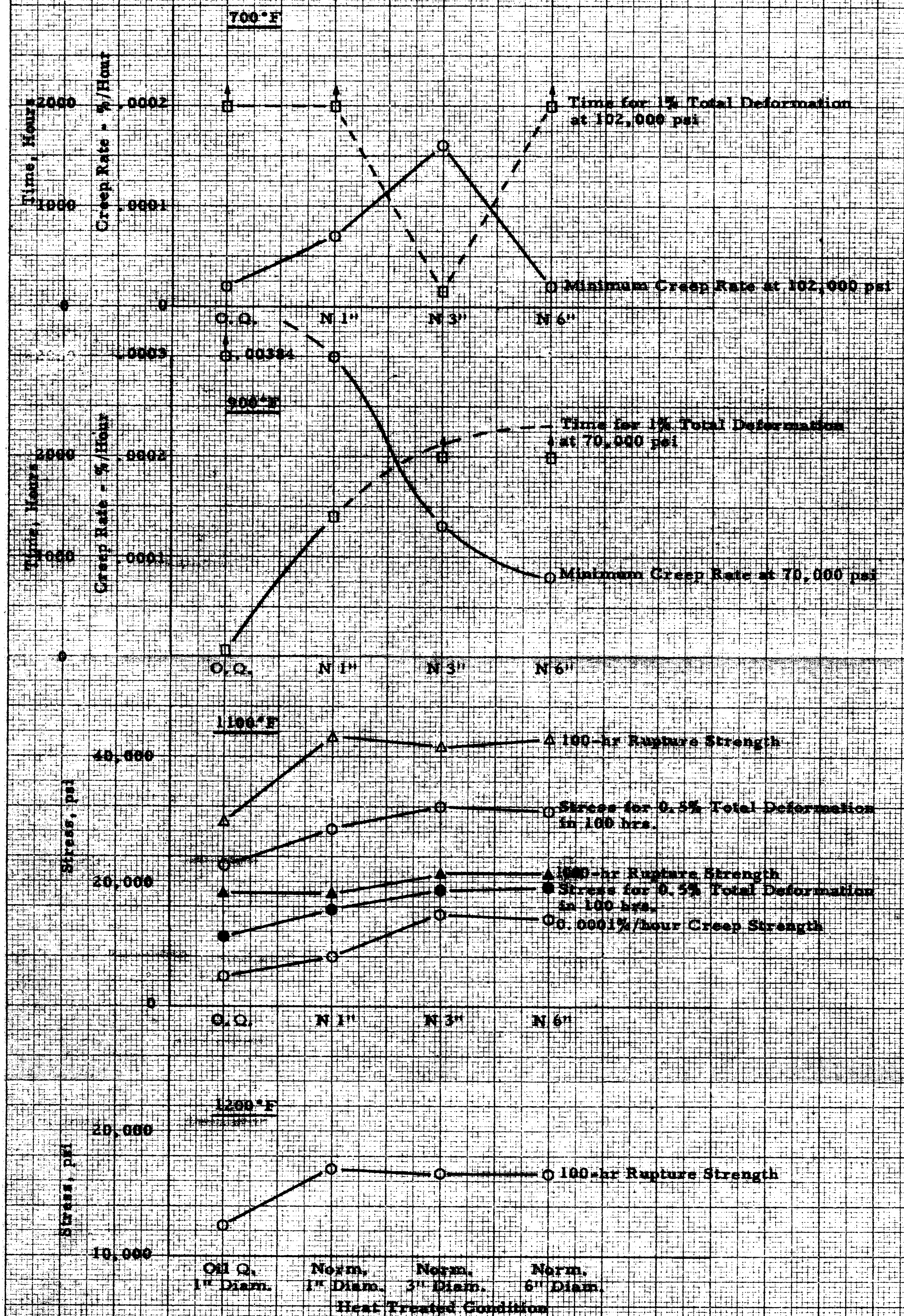



Figure 3. - Influence of cooling rate as controlled by section size and quenching medium on the high-temperature properties of "17-22A"S Steel oil quenched and normalized from 1750°F.

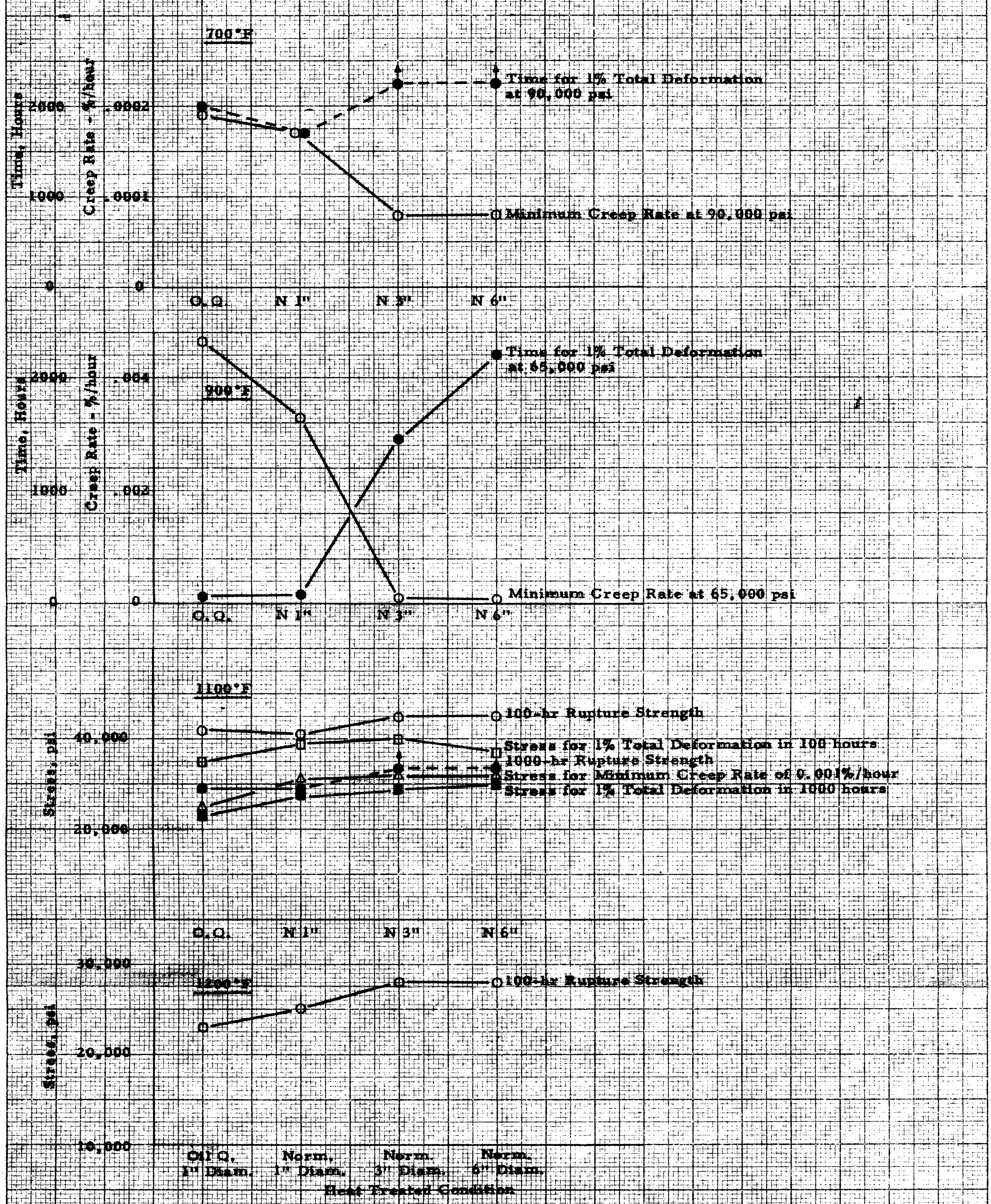
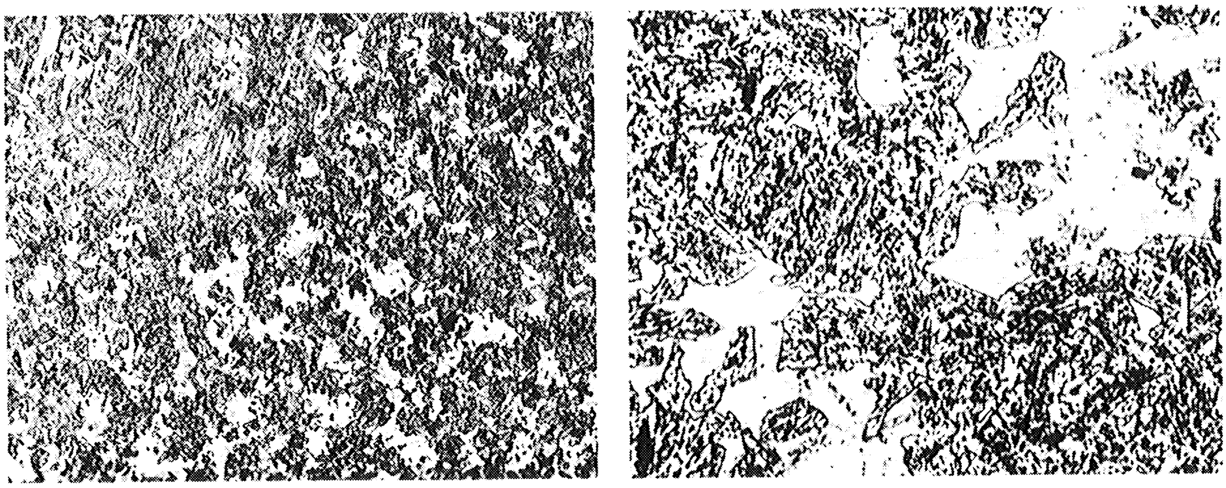
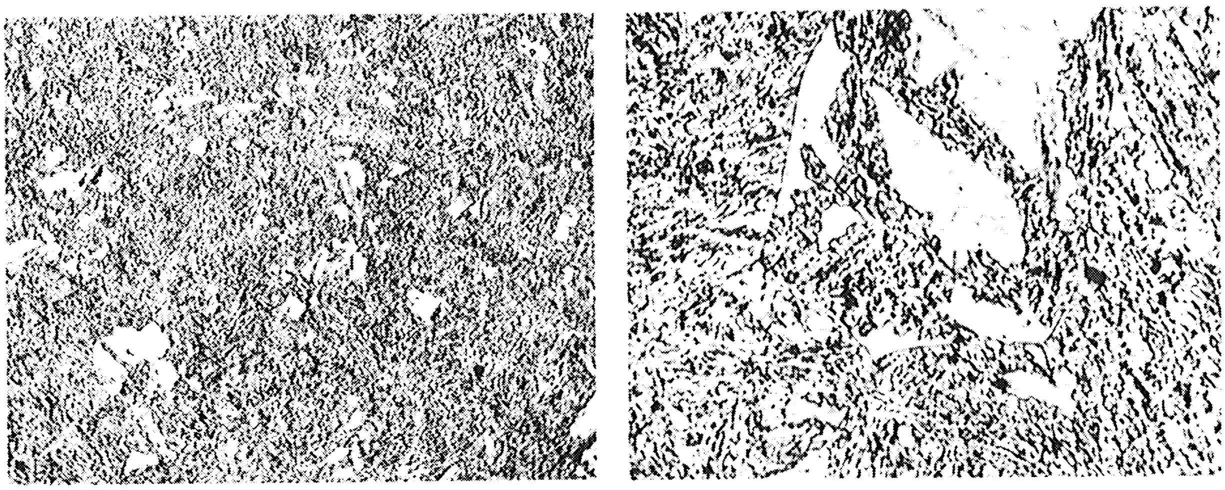



Figure 4. - Influence of cooling rate as controlled by section size and quenching medium on the high-temperature properties of H-40 Steel oil quenched and normalized from 1950°F.

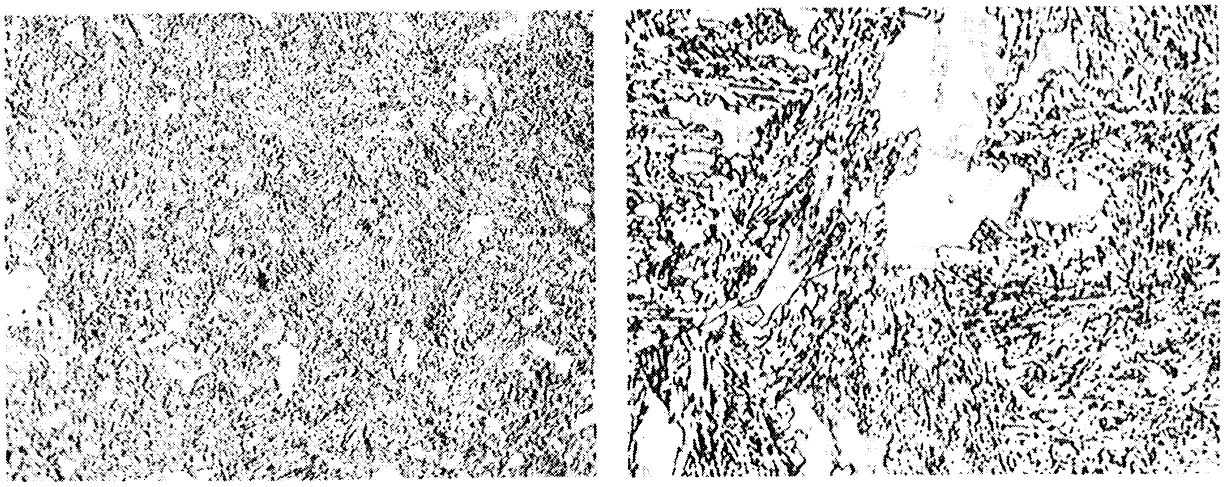
X100D X1000D



(a) Normalized at 1750°F.



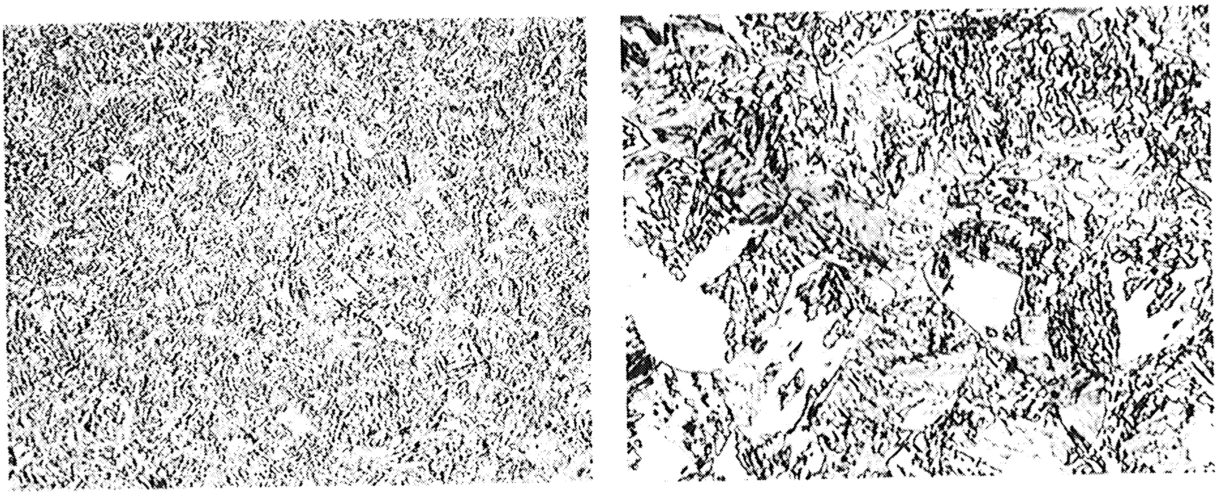
(b) Normalized at 1950°F.



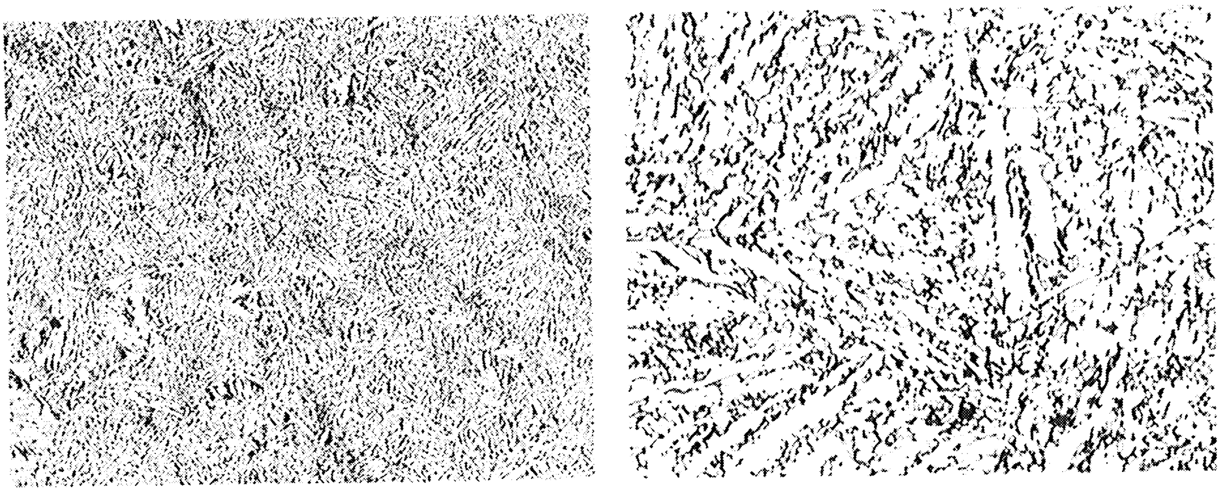
(c) Normalized at 2100°F.

Figure 5. Photomicrographs of SAE 4340 Steel Normalized as 1-Inch Diameter Bar Stock from Various Austenitizing Temperatures.

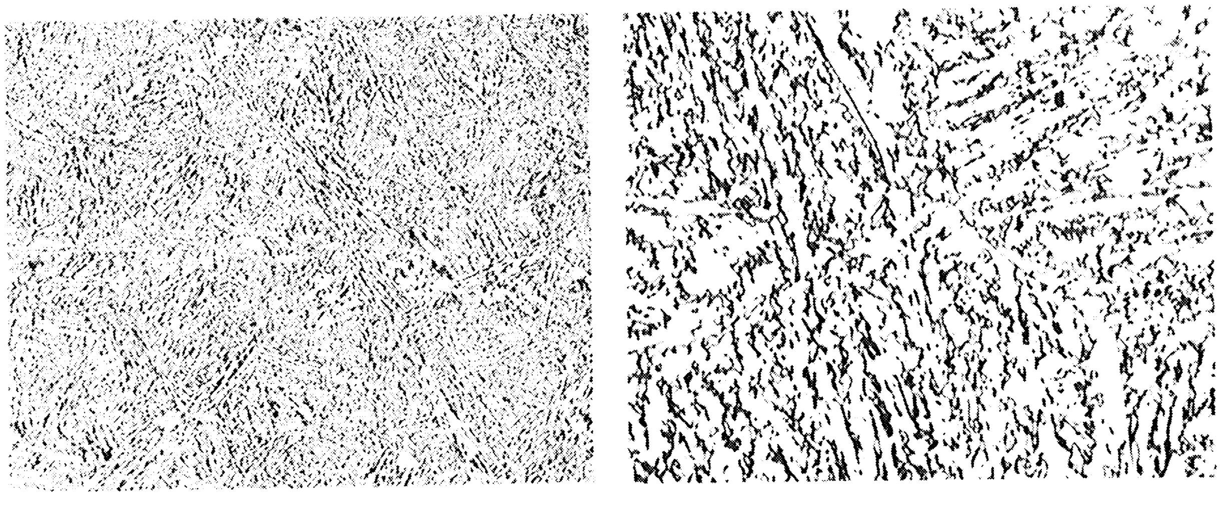
X100D X1000D



(a) Normalized at 1750°F.



(b) Normalized at 1950°F.



(c) Normalized at 2100°F.

Figure 6. Photomicrographs of "17-22A"S Steel Normalized as 1-Inch Diameter Bar Stock from Various Austenitizing Temperatures.