THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE
ANN ARBOR, MICH.

NINTH PROGRESS REPORT

TO

MATERIALS LABORATORY

WRIGHT AIR DEVELOPMENT CENTER

ON

EFFECT OF PRIOR CREEP ON MECHANICAL PROPERTIES OF AIRCRAFT STRUCTURAL METALS

by

J. V. Gluck
H. R. Voorhees
J. W. Freeman

Project 2498

Air Force Contract No. AF 33(616)-3368
Supplement Nos. 3(58-1715)
S5(58-2202)
Task No. 73605

July 15, 1958

SUMMARY

This report covers progress under Contract AF 33(616)-3368 for the period from April 1, 1958 to June 30, 1958 on a study of the effect of prior creep on the short-time mechanical properties of aircraft structural sheet metals. The materials under investigation include 17-7PH precipitation hardening stainless steel in the RH 950 condition and two titanium alloys, C110M and MSM 16V-2.5Al.

During this reporting period, a Summary Report covering studies of C110M through the end of 1957 was reproduced and distributed.

Experimental work included the continuation of studies on the 17-7PH alloy (RH 950 condition). Base properties in compression were determined at room temperature, 600°, 800° and 900°F and unstressed exposures were conducted at the elevated temperatures for periods of 10, 50, or 100 hours. Subsequent tensile and compression tests at room temperature and the elevated temperatures revealed increased tension and compression strength and decreased ductility--particularly for the higher exposure temperatures and times.

Tests of 17-7PH after stressed exposure showed that severe losses in room temperature tensile ductility followed prior creep for 100 hours at 600°F. Specimens similarly exposed at 800°F showed a loss of ductility that was more a function of temperature rather than the amount of prior creep.

Orientation studies of C110M revealed appreciable differences in mechanical properties depending on the orientation of the specimen to the sheet rolling direction. Bauschinger effects following creep exposure were found at all specimen orientations studied.

Additional work included phase identification studies on 17-7PH (RH 950), continuation of development of tension-impact stress-strain recording equipment, and initiation of deformation path studies of C110M.

INTRODUCTION

This report, covering the period from April 1 to June 30, 1958, is the ninth progress report to be issued under Air Force Contract No. AF33(616)-3368. Research now in progress is being carried out under Supplemental Agreements Nos. 3(58-1715) and S5(58-2202).

The purpose of the investigation is to study the effects of prior elevated temperature creep-exposure on the mechanical properties of aircraft structural sheet alloys. Materials previously evaluated included 2024-T86 aluminum (Ref. 1), 17-7PH stainless steel in the TH 1050 condition (Ref. 2) and C110M titanium alloy (Ref. 3).

Presently, background studies are being conducted on 17-7PH stainless steel in the RH 950 condition and are scheduled to be conducted on MSM 16V-2.5Al titanium alloy. In addition, the results of the previous evaluation of C110M have led to the initiation of special studies on specimen orientation and Bauschinger effects and a study of the relative influence of short-time strain or creep strain on subsequent mechanical properties.

Basic evaluations of all test materials consist of exposure either stressed or unstressed for periods up to 100 hours at temperatures low, intermediate or high in the creep range. Following the exposures, the tensile, compression, and tension-impact properties are determined both at room temperature and the exposure temperature. The primary exposures are for 10, 50, or 100 hours at either zero stress or to stresses selected to yield 0.2, 0.5, 1.0, or 2.0 percent creep deformation. Exposure temperatures of 600°, 800°, or 900°F are presently being utilized for studies of 17-7PH (RH 950 condition).

The mechanical properties of the exposed material are then compared with those of the unexposed material as established by a number of tests of specimens chosen at random. In all cases, correlations are based on the actual deformation reached during the creep-exposure since the stress employed can only be the average value determined to give the required deformation in the specified time interval. Loading data taken for each test permit the calculation of total deformation and short-time plastic strain, if any.

The test materials are obtained in the form of 0.064-inch thick sheet stock, with the specimens cut from the sheets in the nominally weaker direction. Thus, the stainless steel is tested transverse to the rolling direction, while the titanium alloys are tested in the longitudinal direction.

The titanium alloy, MSM 16V-2.5Al, is furnished by the manufacturer in the solution treated and aged condition, while the 17-7PH stainless steel is heat treated to the RH 950 condition at the University. This process includes solution treatment, refrigeration, and aging.

For ease in planning, accomplishment, and reporting, the research program has been arranged so that it can provide information on a series of topics or sub-projects.

The following list indicates the nature of the topics under consideration:

1. Relation of Heat Treatment to Alteration by Prior Creep of Mechanical Properties of a Heat-Treatable Stainless Steel (A study of 17-7PH in two heat treatments (TH 1050 and RH 950).

2. Metallurgical Characteristics of Titanium Sheet Alloys Governing Alteration of Mechanical Properties by Prior Creep (A study of MSM 16V-2.5Al with comparison to C110M).

3. Anomalous Effects of Prior Creep on Compressive and Tensile Stress-Strain Characteristics of Aircraft Structural Sheet Alloys (An investigation of Bauschinger effects and specimen orientation).

4. Evaluation of the Influence of Prior Creep on the Tensile and Cold-Bend Test Ductility of Aircraft Structural Metals.

5. Tension-Impact Stress-Strain Characteristics of Aircraft Structural Metals After Exposure to Prior Creep.

6. Metallurgical Factors Controlling the Influence of Prior Creep on Mechanical Properties of Aircraft Structural Metals.

7. The Role of Creep Recovery in Aircraft Structural Metals Exposed to Creep.

8. The Relative Importance of Short-Time Strain and Creep Strain on the Alteration of Mechanical Properties of Aircraft Structural Sheet Metals.

TEST MATERIALS AND SPECIMEN PREPARATION

Specimen blanks are sampled at random from the various sheets of test stock. Consistent with the dimensions of the sheets, a repeating sampling and numbering scheme permits identification to be made of the original location of any test specimen. The details of the numbering schemes and specimen dimensions were previously given (Refs. 2 and 3).

All specimens for exposure are machined slightly oversize in the gage section. The excess stock is then removed prior to mechanical testing in order that edge effects, if any, associated with the exposure could be eliminated.

The analysis and heat treatment details for the 17-7PH stainless steel in the RH 950 condition were given previously (Ref. 4). Late in this report period word was received of the shipment of the MSM 16V-2.5Al titanium alloy. The pertinent information for this material is given below.

MSM 16V-2.5Al

Word was received from the Mallory-Sharon Metals Corporation on June 26, 1958 of the shipment of 3 sheets 0.063 x 36 x 92-105 inches of MSM 16V-2.5Al titanium alloy. This material was allocated to the present investigation through the Department of Defense Titanium Sheet Rolling Program. The shipment consists of Sheets 0084-1, -2, and -7 from Heat No. M-22154. The reported heat treatment consisted of a 1/2-hour solution treatment at 1380°F, water quenching, aging for 4 hours at 990°F, and air cooling. The following chemical analysis was furnished:

Element	Wt. Percent
C	0.02
N_2	0.014
H_2	0.0076 - 0.0078 (76-78 ppm)
Fe	0.27
Al	2.56
V	15.79

EQUIPMENT AND PROCEDURES

Wherever applicable, ASTM Recommended Procedures are adhered to in test procedures. Other testing details follow practices developed at the University of Michigan. Equipment and procedures were previously discussed in References 1, 2, and 3.

RESULTS AND DISCUSSION

Experimental work accomplished during this reporting period included: the determination of the base condition compression properties of 17-7PH (RH 950 condition); the determination of the effects of unstressed exposure on tension and compression properties of this material; and partial completion of stressed exposure tests for several conditions of time and temperature. Further work included: A study of the effect of specimen orientation on mechanical properties and Bauschinger effects in C110M titanium; continuation of development of equipment for stress strain recording in tension-impact testing; and attempts to identify phases in 17-7PH (RH 950) by X-ray techniques. A study of the effects of various paths to reach a final deformation was initiated on C110M. Finally, a summary report covering studies of C110M to December 31, 1957 was approved and preliminary copies were reproduced and distributed.

Project 1: Relation of Heat Treatment to Alteration by Prior Creep of Mechanical Properties of a Heat-Treatable Stainless Steel

Compression Properties of 17-7PH (RH 950 Condition). Compression tests were carried out at room temperature, 600°, 800°, and 900°F to establish the average properties of 17-7PH stainless steel as-heat treated to the RH 950 condition. The data are tabulated in Table 1 and plotted as a function of test temperature in Figure 1.

Increasing the test temperature caused the compression yield strength to decrease, with the temperature dependence quite similar to that previously reported for the tensile properties (Ref. 4). The compression yield strength ranged from 10-15 percent higher than the tensile yield strength and was generally equal to the ultimate tensile strength. In this respect the behavior of the RH 950 condition was different from that of the TH 1050 condition, since in the latter, the room temperature and 600°F compression yield strengths were about 10 percent higher than the ultimate tensile strength.

The compression yield strengths developed in this lot of material (Heat No. 55651) at room temperature and 600°F were about 10 percent higher than those indicated by the producer as "typical" (Ref. 5). This was a slightly higher deviation than was found previously in the case of the tensile properties (Ref. 4).

Tensile Properties After Unstressed Exposure of 17-7PH (RH 950 Condition). Tensile tests at room temperature or the exposure temperature were conducted on samples of 17-7PH (RH 950) following exposure without stress for 10, 50, or 100 hours at temperatures of 600°, 800°, and 900°F. The test data are summarized in Table 2. Room-temperature results are plotted in Figure 2 and the elevated-temperature results are plotted in Figure 3.

The room temperature results (Fig. 2) show that no change in strength followed exposure at 600°F. Both the ultimate tensile and yield strengths were increased by exposure at 800° or 900°F with the maximum effect possibly occurring after 100 hours at 800°F. For this condition the tensile and yield strengths were increased about 12-13 percent over the base value. Accompanying the increased strength was a substantial decrease in ductility which was most marked for the 900°F exposures. The accompanying hardness changes (Fig. 2) were neither large nor appeared to be consistent.

Tests at elevated temperature (Fig. 3) revealed possible increases in tensile and yield strength after exposures at 600° and 900°F and a definite effect from 100 hours at 800°F--the condition of maximum effect in the room temperature tests. In this instance, the tensile strength was increased about 10 percent and the yield strength about 15 percent over the base value.

The 600° and 900°F yield strengths were increased somewhat following exposure, however, the 600°F ultimate tensile strengths were not affected.

The 900°F ultimate tensile strength reached a maximum at 50 hours exposure and then decreased after 100 hours exposure.

Ductility tended to decrease with increasing exposure time with the possible exception of the 600°F tests.

Compression Properties After Unstressed Exposure of 17-7PH (RH 950 Condition)

Compression tests at room temperature or the temperature of exposure were run on specimens of 17-7PH (RH 950 Condition) given unstressed exposure at 600°, 800°, or 900°F for 10, 50, or 100 hours. The results of these tests are presented in Table 3 and plotted in Figures 4 and 5.

The suggested increase in strength at room temperature (Fig. 4) following exposure at 600°F was probably not significant since the test values fell within the range for unexposed material. Larger and probably significant increases followed exposures at 800° or 900°F. The maximum increase in strength (for the 50 and 100 hours exposure at 800° or 900°F) was about 9 percent above the average value for the base condition. This was somewhat above the range of values obtained in tests of the as-treated material (Fig. 1) and is, therefore, probably a real effect. A check test on a second specimen exposed for 50 hours at 800°F showed excellent agreement with the first test of this condition.

The elevated temperature test results (Fig. 5) exhibited some increase in strength with increased exposure time. The maximum increases, those for the 100 hours exposure at each temperature, ranged from 6-12 percent above the average base value. Check tests were run on several exposure conditions.

Properties After Creep-Exposure of 17-7PH (RH 950 Condition)

Available results of room temperature tensile and compression tests of 17-7PH (RH 950 condition) following creep-exposure are summarized in Tables 4 (tensile data) and 5(compression data). Combined plots of the tensile and compression results at room temperature and elevated temperature are presented in Figures 6 and 7. The inclusion of both the tension and compression yield strengths on the same plot helps emphasize the possible existence of Bauschinger effects. The conditions for which enough tests have been completed to warrant presentation include 100 hours prior creep at 600° and 800°F and 10 hours at 900°F.

The 100-hour exposure to creep at 600°F had a marked effect on the strength and ductility at room temperature (Fig. 6), while the properties following the 800°F exposure appeared to be more a function of the exposure to temperature alone. The 900°F results showed a large temperature effect and a possible fall-off in properties with increased creep.

The room temperature results indicate that small amounts of prior creep at 600°F were very potent in increasing the ultimate tensile and tensile yield strengths and decreasing the compression yield strength. The ratio between the yield strengths was also changed drastically. It should be recognized, however, that some plastic strain--up to 25 percent of the total plastic strain obtained in the exposure--occurred during loading.

The behavior of the yield strengths following creep at 600°F was similar to that observed for the TH 1050 condition of this material at 600°F and C110M titanium at 650° and 700°F (Ref. 2 and 3). In the C110M alloy this was identified as Bauschinger-type behavior. In addition to effects on strength, the elongation of the tensile test samples was sharply reduced from the as-treated value; appearing to level off at about 1 percent for creep of about 0.5-1.0 percent. Thus, in another respect, the behavior of the RH 950 condition after creep at 600°F was quite similar to that of the TH 1050 condition.

Specimens pre-crept at 800°F were little changed in strength from those exposed to 800°F in the absence of stress.

Elongation values for samples crept at 800°F were low, but not much lower than those of samples given exposure to temperature alone. The presence of Basuchinger effects following prior creep at 800°F is questionable.

Prior creep for 10 hours at 900°F was followed by a decrease in the ultimate and tensile and compression yield strengths at room temperature. Elongation values were relatively unaffected, although a minimum may exist for samples subjected to intermediate amounts of creep deformation.

Contrary to the experience from tests at 600°F, the total plastic strain obtained at 800° and 900°F was entirely due to creep deformation in all but two tests. Even in these two instances, the plastic loading deformation was almost negligible.

The results of mechanical property tests at the exposure temperature on samples subjected to prior creep are plotted in Figure 7. As Tables 4 and 5 indicate, the test data are as yet sparse and the plots should be regarded merely as indications of possible trends.

Prior creep for 100 hours at 600°F appears to increase the ultimate and tensile yield strengths while decreasing the compression yield strength and tensile elongation. A substantial Bauschinger effect appears to be present in the 600°F data.

The effects of prior creep at 800° and 900°F on the mechanical properties at these temperatures do not appear to be large (Fig. 7). Some decrease was observed in the ultimate strength, and there are indications of a reversal in the tension and compression yield strengths. The elongation values for these tests were inconsistent.

Further testing will include both check tests and the extension of exposure conditions to the full range of times, temperatures, and deformations indicated in the introduction. When this is complete, appropriate comparisons will be made with the data for the TH 1050 condition.

Project 3: Anomalous Effects of Prior Creep on Compressive and Tensile Stress-Strain Characteristics of Aircraft Structural Sheet Alloys

Specimen Orientation and Bauschinger Effects

In the initial studies of the C110M titanium alloy (Ref. 3) an apparent anomaly was discovered between the relative magnitudes of the tension and compression yield strengths of as-received specimens taken in the rolling direction. This was the fact that, instead of being almost equal to the tension yield strength--so-called "normal" behavior--the compression yield strength was about 25 percent lower. The original test results--nine tests each in tension and compression--were rechecked by an additional five compression tests at room temperature and three tests at 700°F. In two instances, the specimen support force was drastically increased with no significant change in the previously determined compression yield strength (Ref. 3). In addition, C110M stock was exchanged with the Republic Aviation Corporation and the University and Republic each ran tests on the other's material. Good agreement was obtained between test results (Ref. 6). This confirmed first that the test procedures used at both organizations were valid and secondly, that the anomaly in the yield strengths of the University's test stock was indeed a real one. Further investigation revealed the existence of Bauschinger effects, probably resulting from the presence of residual tensile stress in the rolling direction of the as-produced material. Limited tests of specimens taken transverse to rolling revealed almost the opposite situation. It was further noted that exposure to temperature alone, particularly at 700° or 800°F, could eliminate the disparity between the two yield strengths.

The evaluation of mechanical properties of this alloy following creep was confined to longitudinal specimens. These studies showed that exposure to creep in tension resulted in an increase in the tensile yield strength and a decrease in the compression yield strength. For example, after prior creep to 1 percent in 10 hours at 700°F, the room-temperature tensile yield strength was some 50 percent higher than the compression yield strength.

Inasmuch as these studies were carried out on longitudinal specimens, a question remained concerning the generality of the results. Consequently, a study was undertaken of the effect of specimen orientation on mechanical properties and the behavior following creep. The results to date of this investigation are summarized in Table 6 and plotted in Figures 8 and 9. Specimen blanks were cut from the sheet at 30°, 45°, 60° and 90° to the rolling direction. Creep exposures were conducted at 700°F for 10 hours at stresses expected to yield creep deformations up to 2 percent.

Figure 8 is a plot of the effect of specimen orientation on the short-time mechanical properties of C110M at room temperature. The values for the orientation of 0° to rolling are the averages of the nine tension tests and fourteen compression tests previously referred to. This figure shows that a very definite increase in compression yield strength occurred as the specimen orientation deviated from the rolling direction. Of course, this results in a changing relationship between the tension and compression yield strengths. Only at 30° to the rolling direction were the tension and compression yield strengths equal. At orientations of 60° and 90° to rolling, the compression yield strength was about 15-20 percent higher than the tensile yield strength. The maximum ductility appears to fall between 30° and 45° to the rolling direction, while the minimum occurs at 60°. Modulus values were calculated from the slopes of the stress-strain curves and, therefore, should not be regarded as precise.

Figure 9 summarizes the effect of prior creep for 10 hours at 700°F on the subsequent room-temperature properties. In general, increased creep in the tension direction of this material--regardless of the orientation of the specimen--had the following effects on mechanical properties: The ultimate tensile and tensile yield strengths were increased; the tensile yield strength became equal to the ultimate strength; the compression yield strength was decreased; and except at 60°, the ductility was decreased. Hardness changes (Table 6) were small and inconsistent.

The increase of tensile yield strength and decrease of compression yield strength with increased plastic deformation are manifestations of Bauschinger effects. Even in those cases where compression yield strength was originally higher than tensile yield strength, i.e., for orientations above 30°, the increase in strength was dissipated; partially by exposure to temperature alone, and then by deformation. The fact that the tensile yield strength became equal to the ultimate tensile strength indicates that the shape of the stress-strain curve had changed to include the sharp "knee" associated with the Bauschinger effect.

Although the plots in Figure 9 are based on creep deformation, it should be realized that an appreciable plastic deformation occurred during the loading of a number of the tests. Examination of Table 6 shows that this was especially true for specimens oriented at 30° and 45° to the rolling direction. In fact, the plastic deformation of these specimens was so rapid and so large during loading that in some cases, the final deformation could only be estimated from the full scale travel of the extensometer system. Thus, the actual deformation might be even higher than the estimate. The behavior of C110M in first stage creep appears to be subject to considerable directionality.

Tentatively, it can be concluded that the effects of prior creep on mechanical properties of C110M are fairly general for all orientations even though the initial properties may vary.

Project 5: Tension-Impact Characteristics of Aircraft Structural Sheet Alloys After Prior Exposure to Creep

Development of Equipment

Work has continued on the development of equipment and instrumentation for the recording of stress-strain data in tension-impact testing. The basic system was described previously (Ref. 4).

Present experiments are concerned with the use of 34-gage nichrome wire for a strain gage. A set of miniature collars was constructed to clamp directly on the impact specimen gage section. The nichrome wire looped between these collars forms one side of a two-gage bridge with the compensating gage consisting of a similar length of nichrome taped to the impact specimen holder. The gages are connected to an Ellis BA-2 Bridge and Amplifier Unit which is in turn connected to a dual-channel oscilloscope. The other channel of the oscilloscope is connected to a similar amplifier which receives the output of a four-arm SR-4 strain gage bridge mounted on a tension link in the impact strain.

Using this arrangement, several photographic recordings have been made of stress and strain versus time during impact fracture. Experimentation has been directed towards selection of the proper triggering point, amplitude, and sweep speed in order to record the largest possible trace on the face of the oscilloscope. Further work is required on the initial balancing of the strain measuring circuit. When this is complete, the unit will be calibrated.

Project 6: Metallurgical Factors Controlling the Influence of Prior Creep on Mechanical Properties of Aircraft Structural Metals

Metallographic and X-Ray Examination of 17-7PH (RH 950 Condition).

Specimens of 17-7PH (RH 950 condition) were examined both in the as-treated condition and after creep at 800°F in an attempt to relate changes in mechanical properties to metallurgical factors. The techniques employed were those of light microscopy and X-ray diffraction analysis.

The microstructure produced by the RH 950 treatment has been described as consisting of tempered martensite, chromium compounds, and aluminum compounds (presumably aluminum nickel) (Ref. 5).

Figure 10 shows the material in the as-treated condition. The stringers observed in Figure 10 have the appearance of delta ferrite but a positive identification has not been made. Figure 11 is a micrograph of a specimen subjected to 100 hours creep at 800°F and 115,000 psi. Total plastic deformation was 0.94 percent--all of which occurred during creep. Visible microstructural differences between the two samples were slight and probably as much due to a difference in the response to etching as to the over-aging of the background constituent.

Table 7 summarizes the mechanical properties of the samples and the results of X-ray diffraction examination. As the table shows, an increase in the ultimate tensile and tensile yield strengths and a severe loss of ductility occurred after creep at 800°F. Hardness was also increased.

An asymmetric Phragmen-type camera was used to obtain x-ray diffraction patterns from the solid samples. Exposure was for 10 hours using unfiltered chromium radiation. Since this particular camera was not calibrated, filings were made of the as-treated sample (specimen G-1) and a Hull-Debye-Scherrer pattern was made in a 114.6 mm diameter camera. An exposure of 6 hours was used with vanadium-filtered chromium radiation.

The diffraction patterns from the filings were identified (Table 7, Part A) as martensite (matrix) with an average lattice parameter of 2.88Å. No other lines were observed.

These lines were then used to index the patterns obtained in the Phragmen-type camera (Table 7, Part B). Analysis of these films was somewhat complicated by the presence of the β reflections.

The diffraction patterns from both solid samples were found to consist of matrix lines (martensite) and several other weak lines which could not be completely identified. Factors which precluded the identification include the following:

1. Several phases may exist for which only the stronger lines are recorded on the film. This would tend to make identification very difficult since many of the carbide-type precipitates have their stronger lines at the same or very similar "d" values.

2. Some of the lines which might be used to differentiate between various carbides could be superimposed on the matrix lines.

3. Many diffraction lines that might conceivably be useful fall at "d" values of less than 1.17. These are not recorded by the camera used--the only one presently available for exposures on solid samples.

4. The actual lines might be from compounds not yet identified. Thus, there might not even be standard patterns in existence for comparison purposes.

A possible case could be made for identification of the unknown lines as coming from CrC. This would be based on the 2.07, 1.80, and 1.29 "d"-value lines. However, the remaining lines cannot be accounted for.

As far as could be determined, the patterns from the two samples were identical. Therefore, if further precipitation occurred during the creep exposures, it was probably the same compound or compounds that were produced in the original RH 950 treatment, since, if a reasonable amount of new phase did precipitate, it should be evidenced in the pattern for specimen G-2. Due to the weakness of the diffraction lines it was not possible to determine if a change in the intensity occurred as a result of the creep exposure. If this could be established, then a determination could be made of the occurrence of further precipitation of the original compound or compounds.

Further study is being given to the use of more refined techniques for the analysis of these sepcimens. These procedures would include phase separation in solutions such as bromine-methyl alcohol and/or electrolytic hydrochloric acid. X-ray diffraction patterns would then be run on the residues. The above technique has a serious drawback in that extremely fine residues might be lost. This difficulty might be surmounted by the use of extraction replicas and selected area electron diffraction--or possibly chemical or fluorescent analysis of the residues. It should be realized, however, that the above techniques are not only difficult and time-consuming, but the possibility of obtaining definitive results is not assured. Therefore, the extension of effort too far along these lines will be the subject of careful consideration.

Project 8: The Relative Importance of Short-Time Strain and Creep-Strain on the Alteration of Mechanical Properties of Aircraft Structural Metals

In studies previously conducted on the 17-7PH alloy (TH 1050 condition) (Ref. 2) and C110M (Ref. 3), prior creep-exposure was found to have an appreciable effect on mechanical properties. Analyses of the creep-exposures revealed that, in many cases, the total deformation consisted not only of that occurring in the creep process, but also short-time plastic strain during loading. Consequently, the relative influence of the two sources of plastic strain was not immediately apparent.

During the present report period, additional work was authorized under Supplement S5(58-2202) to the basic contract for so-called "deformation-path" studies. Such studies involve the production of a given amount of final plastic strain, the strain to be achieved by following a number of different paths. Examples of the paths include:

1. Pre-strain; unload, then time at temperature
2. Time at temperature; then post strain
3. Creep only (no plastic loading deformation)
4. Plastic loading deformation plus creep
5. Cyclic loading (combinations of paths 1-4 with no-load periods of exposure, etc.

These studies are to be carried out on the C110M titanium alloy and will be integrated, if possible, with the Bauschinger effect studies of Project 3. In order to cover as wide a range of creep deformation as possible, a basic exposure of 100 hours at 700°F has been selected. Specimens are to be exposed under these conditions to reach total plastic strains of approximately 0.5 and 1.5 percent. Following this, short-time tensile and compression tests are to be conducted at room temperature.

Specimens have been exposed to date under Paths 1, 2, and 3, although mechanical property tests have not yet been conducted. Fairly good success has been achieved in producing the required deformations in the "post-strain" and "creep-only" paths. Extension of the exposures to cyclic paths will be undertaken shortly.

FUTURE WORK

Work planned for the near future includes the following:

Project 1

a. Continuation of creep-exposure tests of 17-7PH (RH 950).

Project 2

a. Determination of base properties of MSM 16V-2.5Al.

b. Establishment of curves of stress-versus time for creep deformation of MSM 16V-2.5Al for selection of creep-exposure conditions.

Project 3

a. Conclusion of orientation studies of C110M.

Project 5

a. Completion of development of tension-impact stress-strain recording equipment.

Project 6

a. Phase identification studies of 17-7PH (RH 950).

b. Familiarization with microstructure of MSM 16V-2.5Al.

Project 8

a. Mechanical property tests of "path study" specimens.

b. Extension of paths to cyclic loading.

REFERENCES

1. Gluck, J. V., Voorhees, H. R., and Freeman, J. W., "Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals," WADC Technical Report 57-150, January 1957.

2. Gluck, J. V., Voorhees, H. R., and Freeman, J. W., "Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals," WADC Technical Report 57-150 Part II, November 1957.

3. Gluck, J. V., Voorhees, H. R., and Freeman, J. W., "Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals," WADC Technical Report 57-150 Part III, January 1958.

4. Gluck, J. V., Voorhees, H. R., and Freeman, J. W., "Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals," WADC Progress Report 8 on Contract AF 33(616)-3368, April 15, 1958.

5. Marshall, M. W., Perry, D. C., and Harpster, N. R., "Enhanced Properties in 17-7 Stainless" Metal Progress, V. 70, No. 1, p. 94-98 (July 1956).

6. Private Communication from Republic Aviation Corporation, Farmingdale, New York, dated May 6, 1958.

TABLE 1

COMPRESSION TEST DATA FOR AS-HEAT TREATED 17-7PH ALLOY (RH 950 CONDITION)

Test Temp. (°F)	Spec. No.	0.2% Offset Yield Strength (psi)	Compression Modulus, E (10^6 psi)
Room	4B-T25	236,000	30.2
	4K-T46	254,000	31.2
		245,000	30.7
	5J-T26	234,000	31.6
	5E-3X1	252,000	31.3
		243,000	31.4
	6J-X2	232,000	30.3
	6E-X2	248,000	29.9
		240,000	30.1
	8ST47	259,000	30.0
Average - 7 tests		245,000	30.6
600	4B-T27	222,000	29.8
	4K-T42	194,500	29.0
		207,250	29.4
	5R-T27	200,000	28.8
	5J-T24	186,000	28.5
		193,000	28.6
	6GX2	199,500	27.0
	6AX2	201,000	28.8
		200,250	27.9
	8S-T41	191,000	27.3
Average - 7 tests		199,142	28.4
800	4K-T47	176,000	26.4
	4B-T23	163,500	25.6
		169,250	26.0
	5J-T23	167,000	26.6
	5R-T23	175,000	26.6
		171,000	26.6
	6L-T51	170,000	25.8
	6L-T54	152,000	25.9
		161,000	25.8
	8S-T45	168,000	23.3
Average - 7 tests		167,357	25.7
900	4K-T44	138,000	23.8
	4B-T21	120,000	22.6
		129,000	23.2
	5R-T22	141,000	23.4
	5R-T25	137,000	23.1
		139,000	23.2
	6L-T56	136,000	25.4
	6L-T53	137,000	23.6
		136,500	24.5
Average - 6 tests		134,833	23.6

TABLE 2

EFFECT OF UNSTRESSED EXPOSURE ON TENSILE PROPERTIES OF 17-7PH (RH 950 CONDITION)

	Exposure Conditions			Tensile Properties After Exposure						
Spec. No.	Temp. (°F)	Stress (psi)	Time (hr)	Test Temp. (°F)	Ult. Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus, E (10^6 psi)	Hardness (R"C"*)
4E-T2	600	none	10	room	241,000	226,000	7.0	14.5	30.0	48.9
6F-T5	600	none	50	room	242,000	224,000	7.5	16.5	29.8	--
5M-T6	600	none	100	room	238,000	226,000	7.0	10.4	28.5	49.0
5R-T1	800	none	10	room	244,000	233,000	5.0	16.4	29.2	49.0
4H-T2	800	none	50	room	253,500	236,000	5.5	12.1	28.3	49.0
7A-T5	800	none	100	room	267,000	250,500	3.5	4.7	29.5	51.0
6T-T6	900	none	10	room	258,000	242,000	2.8	6.7	31.5	47.9
5T-T6	900	none	50	room	252,000	240,000	2.5	4.3	28.3	49.5
5J-T6	900	none	100	room	254,000	246,000	2.8	8.5	29.4	46.5
5C-T6	600	none	10	600	198,000	183,000	6.0	15.7	25.2	49.4
4K-T6	600	none	50	600	202,500	171,000	6.5	16.6	27.2	50.0
6D-T6	600	none	100	600	203,000	184,500	7.0	14.2	29.5	45.0
4N-T5	800	none	10	800	174,000	157,000	11.5	23.6	22.9	51.4
5T-T1	800	none	50	800	169,000	155,700	14.5	28.0	23.9	49.0
5Q-T2	800	none	100	800	185,000	169,000	8.5	21.0	25.2	50.8
4P-T1	900	none	10	900	142,000	130,400	18.5	36.8	20.5	51.1
6H-T6	900	none	50	900	151,500	136,000	14.0	38.8	21.9	51.0
4K-T1	900	none	100	900	132,000	127,000	14.0	35.2	20.3	50.0

TABLE 3

EFFECT OF UNSTRESSED EXPOSURE ON COMPRESSION PROPERTIES OF 17-7PH (RH 950 CONDITION)

	Exposure Conditions				Compression Properties After Exposure	
Spec. No.	Temp. (°F)	Stress (psi)	Time (hr)	Test Temp. (°F)	0.2% Offset Yield Strength (psi)	Compression Modulus, E (10^6 psi)
4K-T45	600	none	10	room	237,000	28.9
5E3X2	600	none	50	room	244,000	29.7
6L-T52	600	none	100	room	248,000	30.7
5R-T24	800	none	10	room	256,000	30.7
4K-43	800	none	50	room	262,000	29.8
8S-T46	800	none	50	room	260,500	30.8
					261,250	30.3
4K-T41	800	none	100	room	261,000	30.2
4B-T22	900	none	10	room	263,000	30.3
5J-T22	900	none	50	room	267,000	30.8
5J-T25	900	none	100	room	266,000	30.0
5R-T26	600	none	10	600	173,000	30.0
4N-T31	600	none	10	600	202,000	28.7
					187,500	29.3
6MX2	600	none	50	600	201,000	28.9
4B-T26	600	none	100	600	214,000	29.3
6L-T57	800	none	10	800	157,000	28.3
5J-T21	800	none	50	800	180,000	27.8
6RX2	800	none	100	800	189,500	27.9
4N-T32	800	none	100	800	182,000	26.5
					185,750	27.2
5R-T21	900	none	10	900	138,000	23.6
4B-T24	900	none	50	900	130,500	23.9
8S-T42	900	none	50	900	153,000	25.2
					141,750	24.6
6L-T55	900	none	100	900	147,000	25.0

TABLE 4

EFFECT OF PRIOR CREEP-EXPOSURE ON TENSILE PROPERTIES OF 17-7PH (RH 950 CONDITION)

Nominal Exposure Conditions				Actual Exposure Conditions							Tensile Properties After Exposure						
Temp. (°F)	Time (hrs)	Creep Def. (%)	Spec. No.	Time (hrs)	Temp. (°F)	Stress (psi)	Total Load. Def. (%)	Plastic Load. Def. (%)	Creep Def. (%)	Total Plastic Def. (%)	Test Temp. (°F)	Ult. Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus, E (10^6 psi)	Hardness (R"C")
600	100	0.2	5R-T3	100.0	600	152,000	0.60	0.06	0.17	0.23	room	247,000	239,000	7.5	15.6	29.1	49
600	100	0.5	4K-T2	100.0	600	179,000	0.84	0.16	0.68	0.84	room	258,000	254,000	1.5	9.0	28.6	48
600	100	1.0	6L-T1	100.0	600	177,000	0.90	0.30	1.12	1.20	room	261,000	261,000	1.0	--	28.5	50
600	100	2.0	4P-T4	100.0	600	181,200	1.02	0.34	1.64	1.98	room	263,000	263,000	1.0	7.4	30.3	50
800	100	0.2	5R-T5	100.0	800	82,000	0.32	nil	0.21	0.21	room	>258,000	--	--	--	--	52
800	100	0.2	8T-T2	100.0	800	82,000	0.31	nil	0.24	0.24	room	268,000	261,000	2.0	2.8	28.8	53
800	100	0.5	4P-T5	100.0	800	100,000	0.40	0.03	0.51	0.54	room	>264,000	--	--	--	27.8	50
800	100	1.0	6L-T6	100.0	800	115,000	0.43	nil	0.94	0.94	room	267,000	246,000	1.5	3.0	29.8	51
800	100	2.0	5C-T4	100.0	800	117,000	0.46	nil	1.16	1.16	room	262,000	260,000	1.0	1.7	27.2	52
900	10	0.2	4E-T3	10.0	900	45,000	0.18	nil	0.23	0.23	room	>248,000	--	--	--	--	49
900	10	0.2	8T-T4	10.0	900	45,000	0.18	nil	0.27	0.27	room	254,000	246,000	2.0	4.0	28.1	51
900	10	0.5	6H-T4	10.0	900	58,000	0.22	nil	0.52	0.52	room	244,000	237,000	2.5	5.7	27.2	51
900	10	1.0	5T-T5	10.0	900	66,000	0.28	nil	0.70	0.70	room	251,000	242,000	1.0	2.2	33.1	51
900	10	2.0	5Q-T5	10.0	900	75,000	0.30	0.02	2.09	2.11	room	246,500	231,000	5.0	7.8	28.1	49
600	100	0.2	6S-T4	100.0	600	153,000	0.61	nil	0.15	0.15	600	206,000	196,000	8.5	21.1	26.4	49
600	100	2.0	4B-T6	100.0	600	181,200	1.02	0.30	3.66	3.96	600	220,000	220,000	2.5	10.9	26.6	49
800	100	0.2	4B-T3	100.0	800	82,000	0.33	nil	0.21	0.21	800	185,000	177,000	13.5	23.9	25.5	51
800	100	2.0	6D-T4	100.0	800	117,000	0.51	0.05	2.73	2.78	800	174,500	174,000	14.0	29.4	25.0	52
900	10	0.2	6S-T6	10.0	900	45,000	0.19	nil	0.32	0.32	900	137,000	126,000	13.5	35.5	23.7	47
900	10	2.0	4K-T3	10.1	900	75,000	0.28	nil	2.49	2.49	900	137,000	135,000	21.0	45.0	20.4	51

TABLE 5

EFFECT OF PRIOR CREEP-EXPOSURE ON COMPRESSION PROPERTIES OF 17-7PH (RH 950 CONDITION)

Nominal Exposure Conditions				Actual Exposure Conditions							Compression Properties After Exposure		
Temp. (°F)	Time (hrs)	Creep Def. (%)	Spec. No.	Time (hrs)	Temp. (°F)	Stress (psi)	Total Load. Def. -(%)	Plastic Load. Def. (%)	Creep Def. (%)	Total Plastic Def. (%)	Test Temp. (°F)	0.2% Offset Yield Strength (psi)	Compression Modulus, E (10^6 psi)
600	100	0.2	4H-T6	100.0	600	153,000	0.56	nil	0.16	0.16	room	215,000	30.0
600	100	0.2	6S-T2	100.0	600	154,000	0.68	nil	0.34	0.34	room	235,000	30.1
600	100	2.0	5C-T3	100.0	600	181,000	1.02	0.30	1.84	2.14	room	223,000	29.8
800	100	0.2	6T-T3	100.4	800	82,000	0.34	nil	0.23	0.23	room	263,000	31.9
800	100	0.5	5C-T2	100.0	800	100,000	0.37	nil	0.45	0.45	room	247,000	30.4
800	100	1.0	4K-T5	100.0	800	115,000	0.43	nil	1.07	1.07	room	261,000	31.6
800	100	2.0	5J-T5	100.0	800	117,000	0.49	0.08	1.70	1.78	room	258,000	30.0
900	10	0.2	5Q-T6	10.0	900	45,000	0.19	nil	0.27	0.27	room	264,000	30.5
900	10	0.5	4P-T2	10.0	900	58,000	0.24	nil	0.38	0.38	room	259,000	32.7
900	10	1.0	6H-T5	10.0	900	67,000	0.27	nil	1.04	1.04	room	253,000	31.6
900	10	2.0	6L-T3	10.0	900	75,000	0.32	0.02	2.51	2.53	room	246,000	29.3
600	100	0.2	5T-T4	100.0	600	153,000	0.57	nil	0.11	0.11	600	187,000	30.4
600	100	2.0	6F-T2	100.0	600	181,200	1.11	0.36	1.75	2.11	600	162,000	28.8
800	100	0.2	4B-T1	100.0	800	82,000	0.30	nil	0.20	0.20	800	188,000	29.1
900	10	0.2	6D-T3	10.0	900	45,000	0.19	0.03	0.29	0.32	900	131,000	21.4
900	10	2.0	4E-T1	10.0	900	75,000	0.29	nil	2.36	2.36	900	119,000	22.7

TABLE 6

EFFECT OF SPECIMEN ORIENTATION ON ROOM TEMPERATURE MECHANICAL PROPERTIES OF C110M AFTER 10 HOURS PRIOR CREEP-EXPOSURE AT 700°F

	Exposure Conditions							Room Temperature Short-Time Mechanical Properties After Exposure						
Spec. No.	Temp. (°F)	Time (hrs)	Stress (psi)	Total Load. Def. (%)	Plastic Load. Def. (%)	Creep Def. (%)	Total Plastic Strain (%)	Type of Test	Ult. Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus, E (10⁶ psi)	Hardness R"C"
Specimens Taken in Rolling Direction														
(avg. of 9)	not exposed		--	--	--	--	--	Tensile	146,200	142,900	22.4	31.3	16.5	33.4
(avg. of 9)	not exposed		--	--	--	--	--	Comp.	--	108,000	--	--	16.2	--
1CD15	700	10	none	--	--	--	--	Tensile	143,000	140,000	23.8	34.0	15.4	39.1
3CD33	700	10	none	--	--	--	--	Tensile	146,000	--	24.0	27.9	15.4	38.7
1A4	700	10	56,000	0.43	nil	0.12	0.12	Tensile	138,000	135,000	21.0	30.0	14.7	38.5
3AB8	700	10	79,000	0.62	0.10	0.17	0.27	Tensile	149,000	144,000	23.2	31.4	15.5	36.6
2AB16	700	10	93,000	1.77	1.07	0.96	2.03	Tensile	150,500	149,500	21.0	31.2	15.2	37.9
3CD14	700	10	100,000	3.76	3.00	5.44	8.44	Tensile	177,000	175,000	7.8	18.2	15.6	34.2
1CD24	700	10	none	--	--	--	--	Comp.	--	147,000	--	--	16.1	
3CD9	700	10	none	--	--	--	--	Comp.	--	136,000	--	--	15.7	
1CD33	700	10	56,000	0.43	nil	0.11	0.11	Comp.	--	125,000	--	--	16.4	
2A2	700	10	82,000	0.62	nil	0.32	0.32	Comp.	--	115,000	--	--	15.3	
3C27	700	10	90,500	1.27	0.58	0.66	1.24	Comp.	--	94,400	--	--	16.8	
1AB18	700	10	92,000	2.16	1.45	1.43	2.88	Comp.	--	103,000	--	--	16.6	--
Specimens Taken 30° to Rolling Direction														
S4A-T32	not exposed		--	--	--	--	--	Tensile	142,400	140,800	29.0	43.7	13.8	34
S4A-T37	not exposed		--	--	--	--	--	Tensile	140,000	138,000	26.0	36.2	13.7	36
									141,200	139,400	27.5	40.0	13.8	35
S4C-C11	not exposed		--	--	--	--	--	Comp.	--	140,500	--	--	19.0	--
S4C-C14	not exposed		--	--	--	--	--	Comp.	--	143,200	--	--	18.7	--
										141,850	--	--	18.9	--
S4A-T30	700	10	none	--	--	--	--	Tensile	139,000	139,000	27.5	45.5	14.5	--
S4A-T36	700	10	80,000	0.98	0.33	0.47	0.80	Tensile	146,000	146,000	25.5	40.6	14.5	--
S4A-T35	700	10	88,000	3.97(est)	3.0 (est)	1.71(	) 4.70(est)	Tensile	162,500	162,500	11.0	35.5	14.7	--
S4C-C12	700	10	none	--	--	--	--	Comp.	--	140,000	--	--	16.8	--
S4C-C13	700	10	none	--	--	--	--	Comp.	--	141,000	--	--	16.8	--
S4A-T31	700	10	80,000	0.96	0.25	0.47	0.72	Comp.	--	112,000	--	--	15.4	--
S4A-T33	700	10	88,000	1.90	1.22	3.34	4.56	Comp.	--		--	--		--
Specimens Taken 45° to Rolling Direction														
S4C-T1	not exposed		--	--	--	--	--	Tensile	136,200	134,400	20.5	49.7	15.1	30
S4C-T7	not exposed		--	--	--	--	--	Tensile	131,000	--	27.0	46.2	14.7	35
S4C-T5	not exposed		--	--	--	--	--	Tensile	136,200	129,900	19.0	46.3	15.1	36
									134,500	132,200	22.1	45.7	14.9	33.3
S4C-C1	not exposed		--	--	--	--	--	Comp.	--	147,700	--	--	18.2	--
S4C-C3	not exposed		--	--	--	--	--	Comp.	--	149,500	--	--	18.3	--
										148,600	--	--	18.2	--
S4C-T10	700	10	none	--	--	--	--	Tensile	136,000	135,000	26.5	49.0	14.6	36
S4C-T6	700	10	75,000	0.99	0.40	0.34	0.74	Tensile	150,000	150,000	22.0	44.5	14.9	--
S4C-T3	700	10	90,500	3.15	2.5 (est)	2.00	4.5 (est)	Tensile	160,700	159,000	8.5	37.0	15.6	37
S4C-C6	700	10	none	--	--	--	--	Comp.	--	150,500	--	--	17.0	--
S4C-C4	700	10	none	--	--	--	--	Comp.	--	148,000	--	--	19.9	--
S4C-T2	700	10	78,000	1.00	0.39	0.37	0.76	Comp.	--	121,500	--	--	15.2	--
S4C-T9	700	10	88,000	4.5 (est)	3.8 (est)	4.10	7.9	Comp.	--	118,000	--	--	15.0	--
Specimens Taken 60° to Rolling Direction														
S4A-T67	not exposed		--	--	--	--	--	Tensile	146,000	120,500	21.0	39.4	13.6	35
S4A-T60	not exposed		--	--	--	--	--	Tensile	145,000	139,000	11.0	14.1	13.9	36
									145,500	129,750	16.0	26.7	13.8	35.5
S4C-C8	not exposed		--	--	--	--	--	Comp.	--	160,500	--	--	19.3	--
S4C-C10	not exposed		--	--	--	--	--	Comp.	--	164,000	--	--	22.3	--
										162,250	--	--	20.8	--
S4A-T65	700	10	none	--	--	--	--	Tensile	144,000	144,000	15.0	16.3	15.2	--
S4A-T61	700	10	80,000	0.90	0.40	0.41	0.81	Tensile	153,000	153,000	18.5	40.8	15.2	--
S4A-T66	700	10	88,000	1.15	0.48	0.76	1.24	Tensile						
S4C-C7	700	10	none	--	--	--	--	Comp.	--	151,000	--	--	16.4	--
S4C-C9	700	10	none	--	--	--	--	Comp.	--	162,000	--	--	17.7	--
S4A-T64	700	10	80,000	0.89	0.24	0.39	0.63	Comp.	--	119,000	--	--	16.6	--
S4A-T62	700	10	90,000	1.48	0.78	1.37	2.15	Comp.	--		--	--		--
Specimens Taken 90° to Rolling Direction														
T44	not exposed		--	--	--	--	--	Tensile	149,000	134,000	21.0	29.8	15.8	37.9
T43	not exposed		--	--	--	--	--	Tensile	145,500	131,000	21.8	33.0	16.0	37.0
									147,250	132,500	21.4	31.4	15.9	37.4
T41	not exposed		--	--	--	--	--	Comp.	--	162,000	--	--	16.3	--
T42	not exposed		--	--	--	--	--	Comp.	--	153,000	--	--	16.9	--
										157,500	--	--	16.6	--
T4-AT5	700	10	none	--	--	--	--	Tensile	156,200	152,000	27.5	33.6	15.9	36
T4A-T6	700	10	90,500	0.81	0.20	0.38	0.58	Tensile	162,500	162,500	19.0	33.3	16.6	35
T4A-T8	700	10	96,000	1.37	0.80	0.90	1.70	Tensile	166,300	166,300	19.0	19.7	16.6	--
T47	700	10	none	--	--	--	--	Comp.	--	161,500	--	--	16.1	--
T4A-T10	700	10	92,000	0.96	0.35	0.49	0.84	Comp.	--	144,500	--	--	17.0	--
T4A-T7	700	10	97,000	1.05	0.45	0.72	1.17	Comp.	--	146,000	--	--	16.0	--

TABLE 7

X-RAY DIFFRACTION STUDIES OF 17-7PH (RH 950 CONDITION)
BEFORE AND AFTER CREEP-EXPOSURE AT 800°F

Mechanical Properties of Specimens

Spec. No.	Condition	Ult. Tensile Strength (psi)	Yield Strength (psi)	Elongation (%)	Reduction of Area (%)	Modulus, E (10^6 psi)	Hardness R"C"
G-1 (Fig. 10)	As Treated (avg. values)	237,650	222,480	8.2	15.0	28.7	48.2
G-2 (Fig. 11) (6L-T6)	100 hr creep at 800°F - 115,000 psi (yielding 0.94% creep deformation)	267,000	246,000	1.5	3.0	29.8	51.0

X-Ray Diffraction Data

A. Hull-Debye-Sherrer Powder Pattern (114.6 mm diameter camera)

Spec. No. G-1	Measured "d" Values		"d" Values for Martensite (from literature)		
	"d"	Intensity	"d"	Intensity	(hkl)
	2.03	S	2.035	1	110
	1.44	M	1.44	0.4	200
	1.17	MS	1.175	0.8	211

B. Phragmen-Type Camera (Solid Samples)

Spec. No. G-1	"d"	I	Spec. No. G-2	"d"	I	Identification Martensite	Identification ?
	2.41	VW	(identical to G-1)				✓
	2.27	VW					✓
	2.07	W					✓ *
	2.03	VS				✓	
	1.80	W					✓ *
	1.44	M				✓	
	1.29	M					✓ *
	1.17	M				✓	

Notes:
"d" - interplanar spacing
I - Intensity, i.e., Very Weak, Medium, Very Strong, etc.
(hkl) - Miller indices of diffracting plane
* - possibly CrC lines

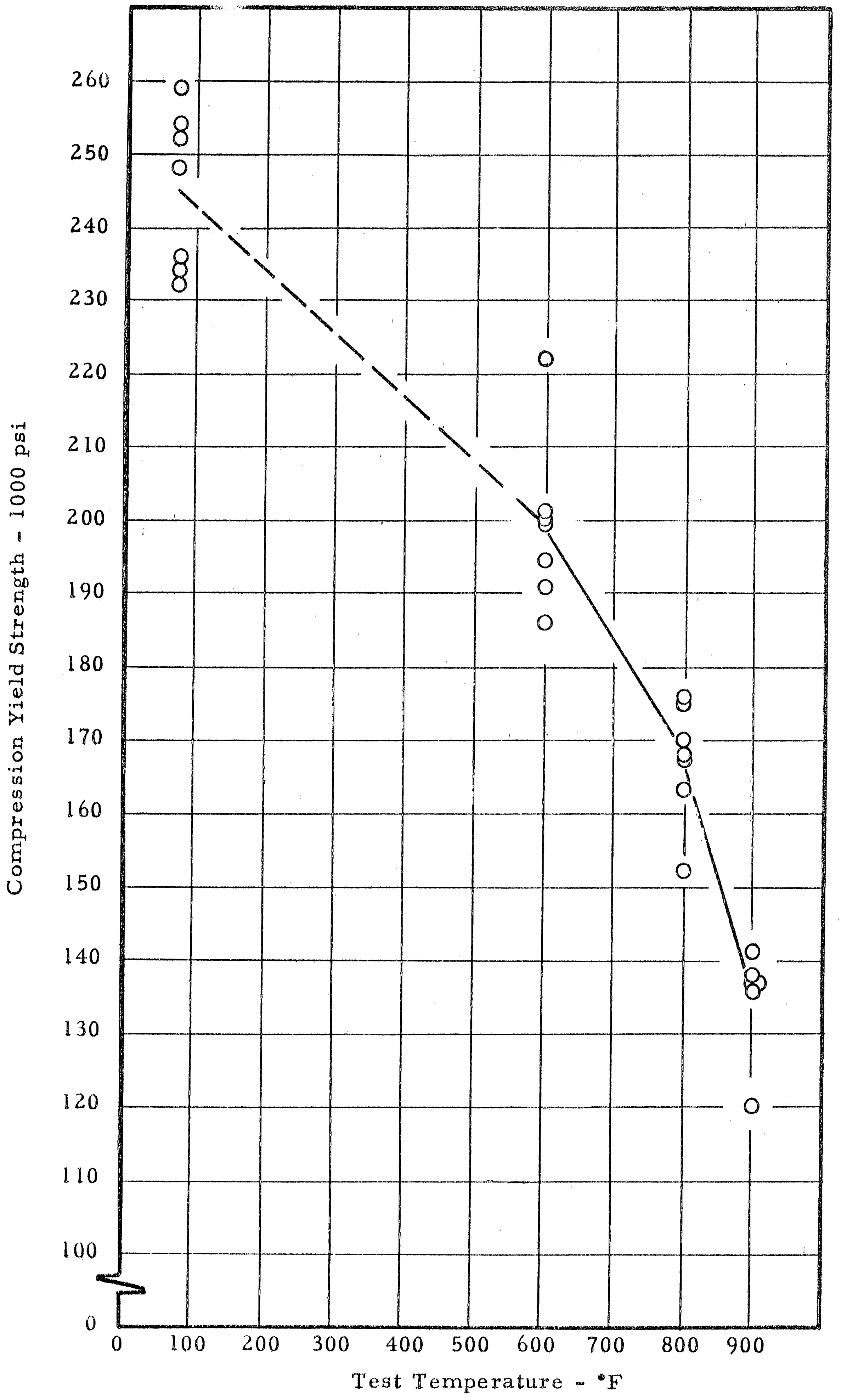

Figure 1. - Effect of Test Temperatures on Compression Yield Strength of As-Treated 17-7PH (RH 950 Condition).

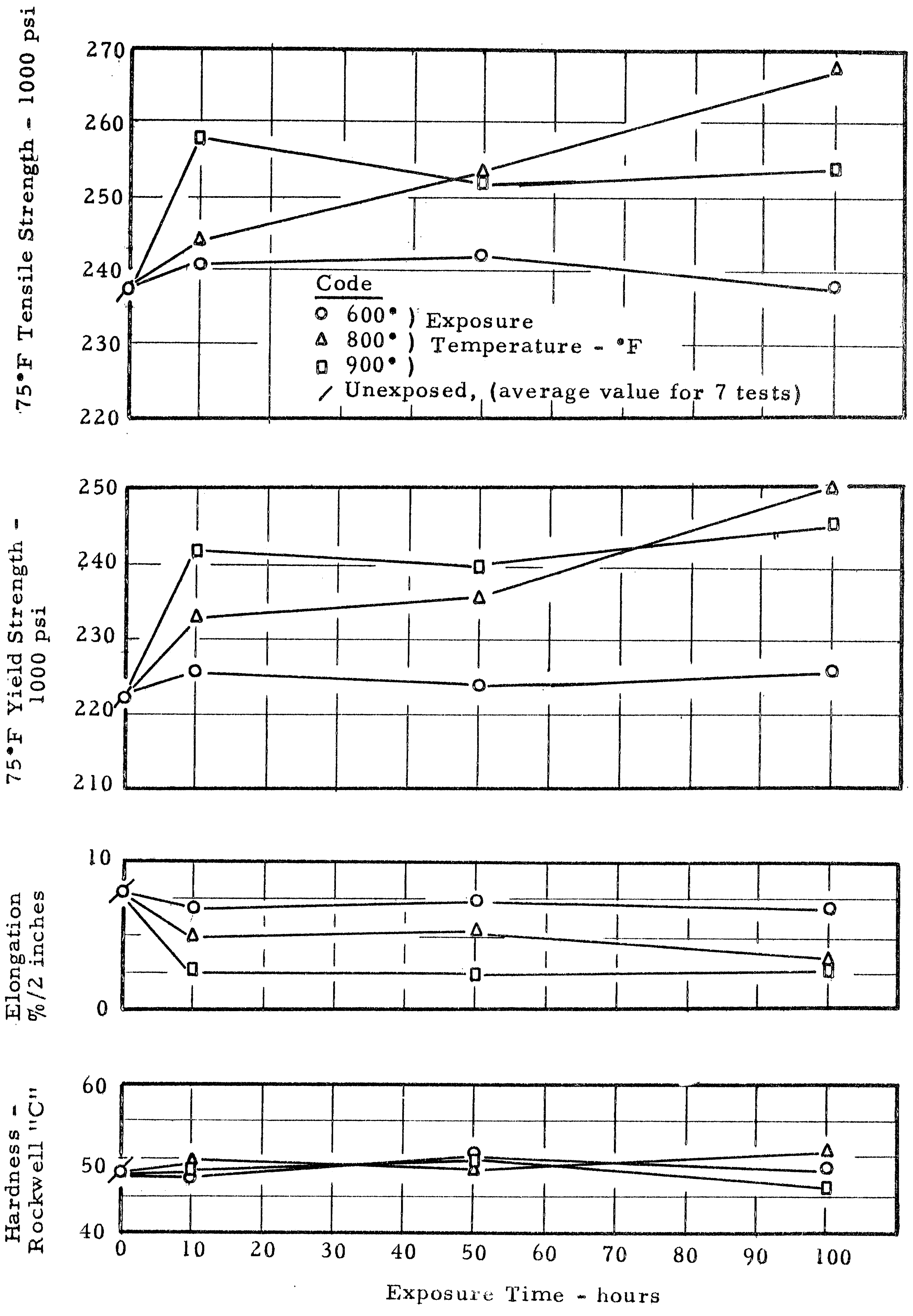

Figure 2. - Effect of Unstressed Exposure at 600°, 800°, or 900°F on Room Temperature Tensile Properties and Hardness of 17-7PH (RH 950 Condition).

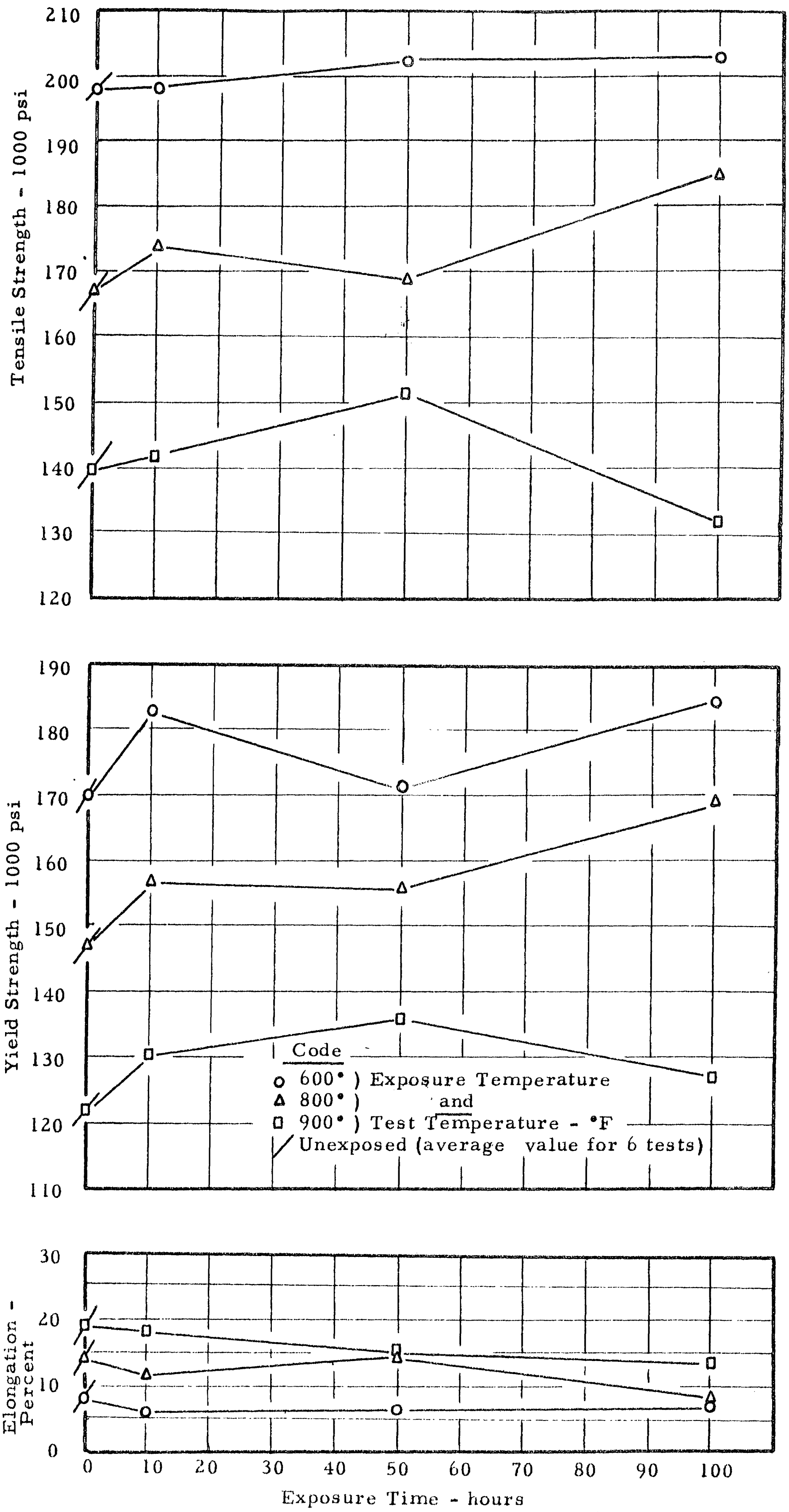

Figure 3. - Effect of Unstressed Exposure at 600°, 800°, or 900°F on Tensile Properties of 17-7PH (RH 950 Condition) At Exposure Temperature.

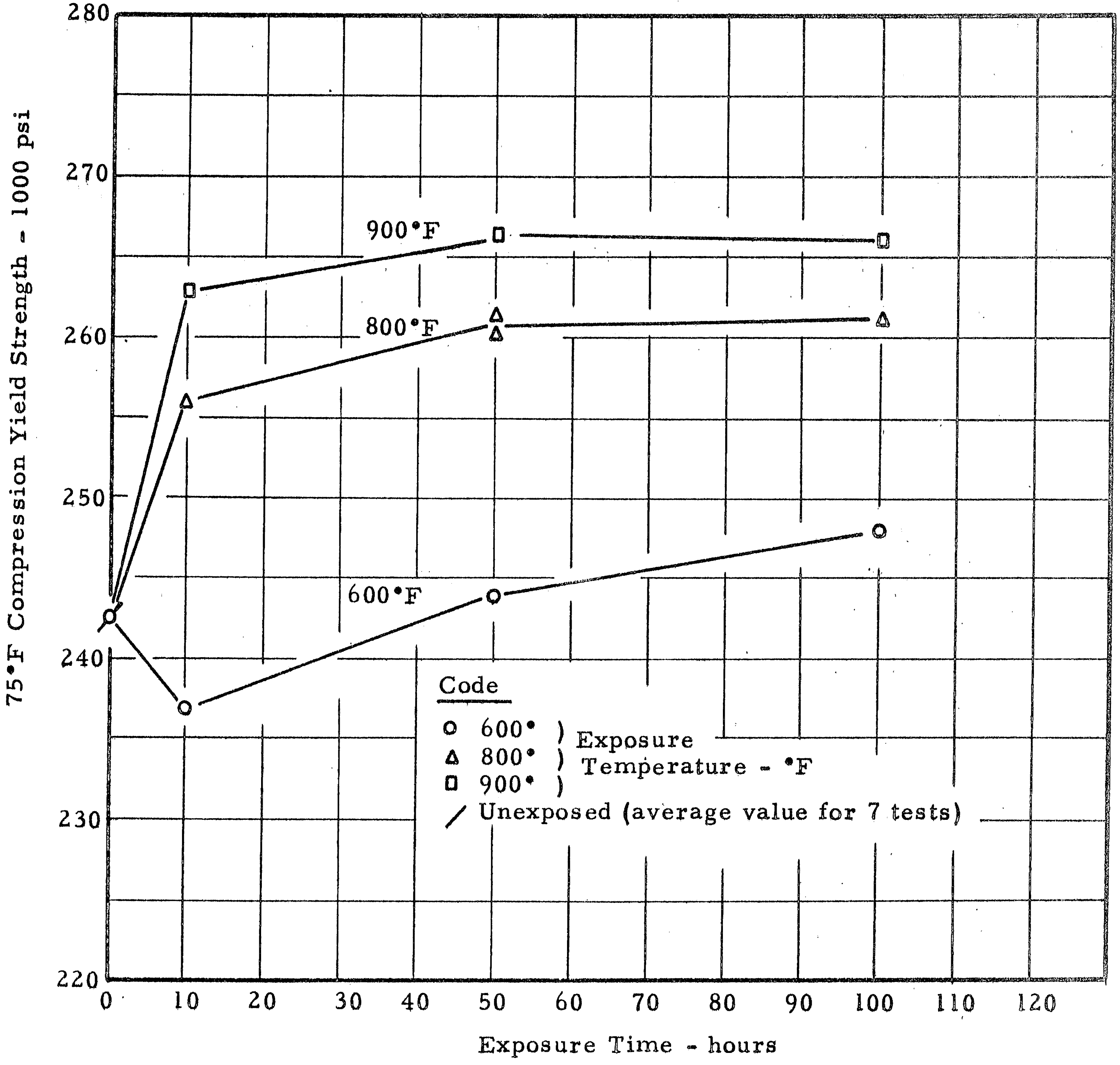

Figure 4. - Effect of Unstressed Exposure on Room Temperature Compression Yield Strength of 17-7PH (RH 950 Condition).

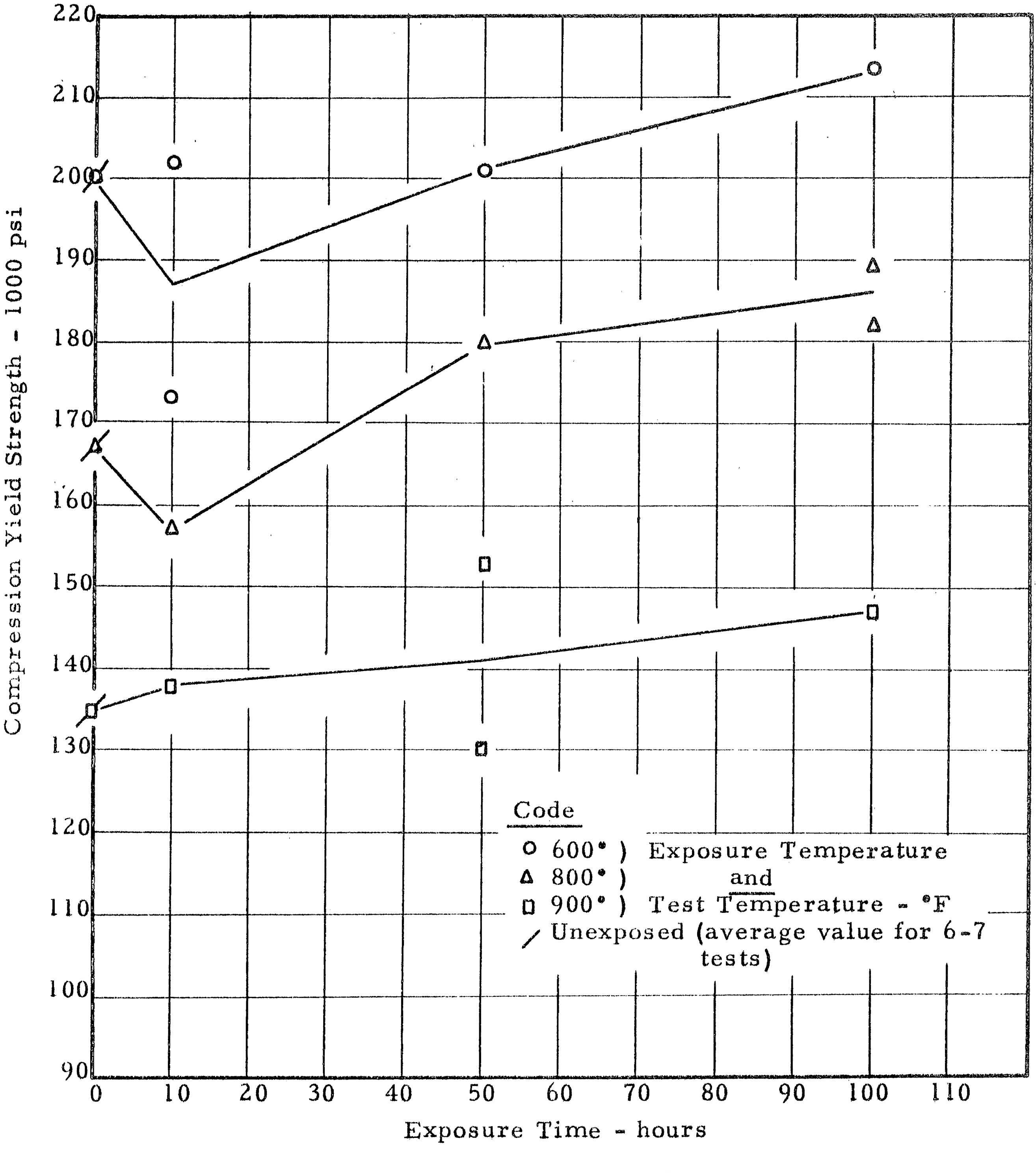

Figure 5. - Effect of Unstressed Exposure at 600°, 800°, or 900°F on Compression Yield Strength of 17-7PH (RH 950) At Exposure Temperature.

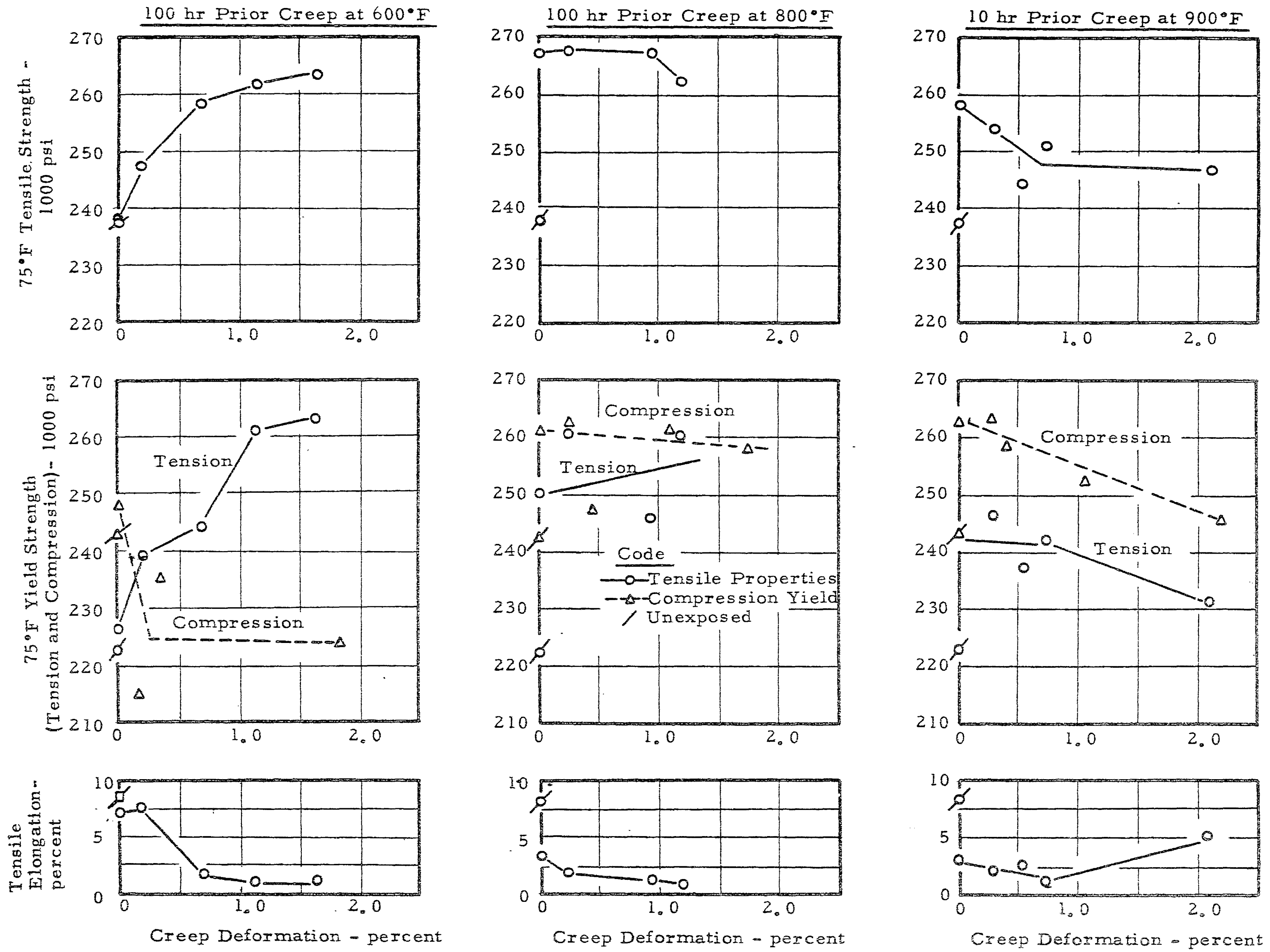

Figure 6. - Effect of Prior Creep-Exposure on Tension and Compression Properties of 17-7PH (RH 950 Condition) At Room Temperature.

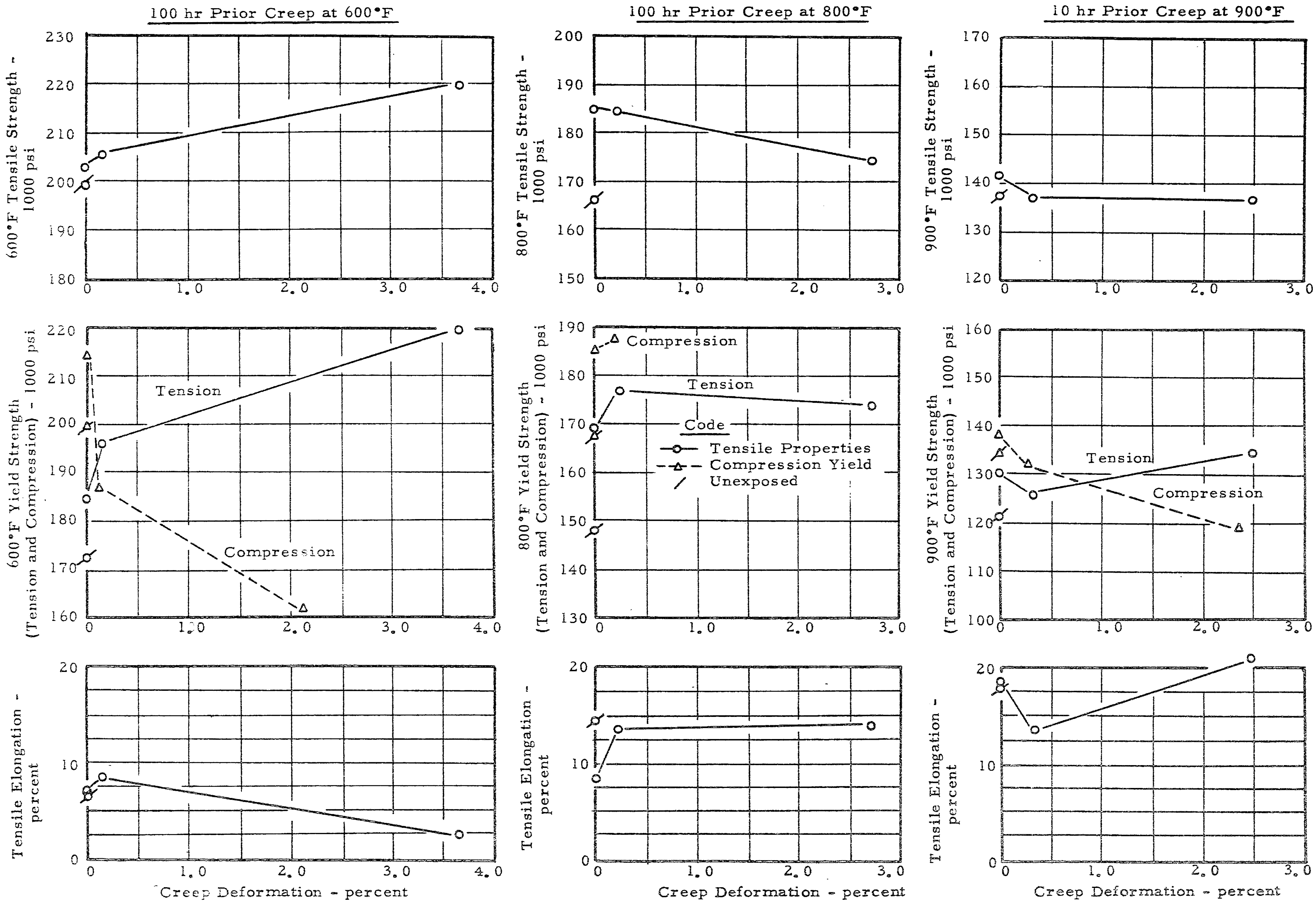

Figure 7. - Effect of Prior Creep-Exposure on Tension and Compression Properties of 17-7PH (RH 950 Condition) At Exposure Temperature.

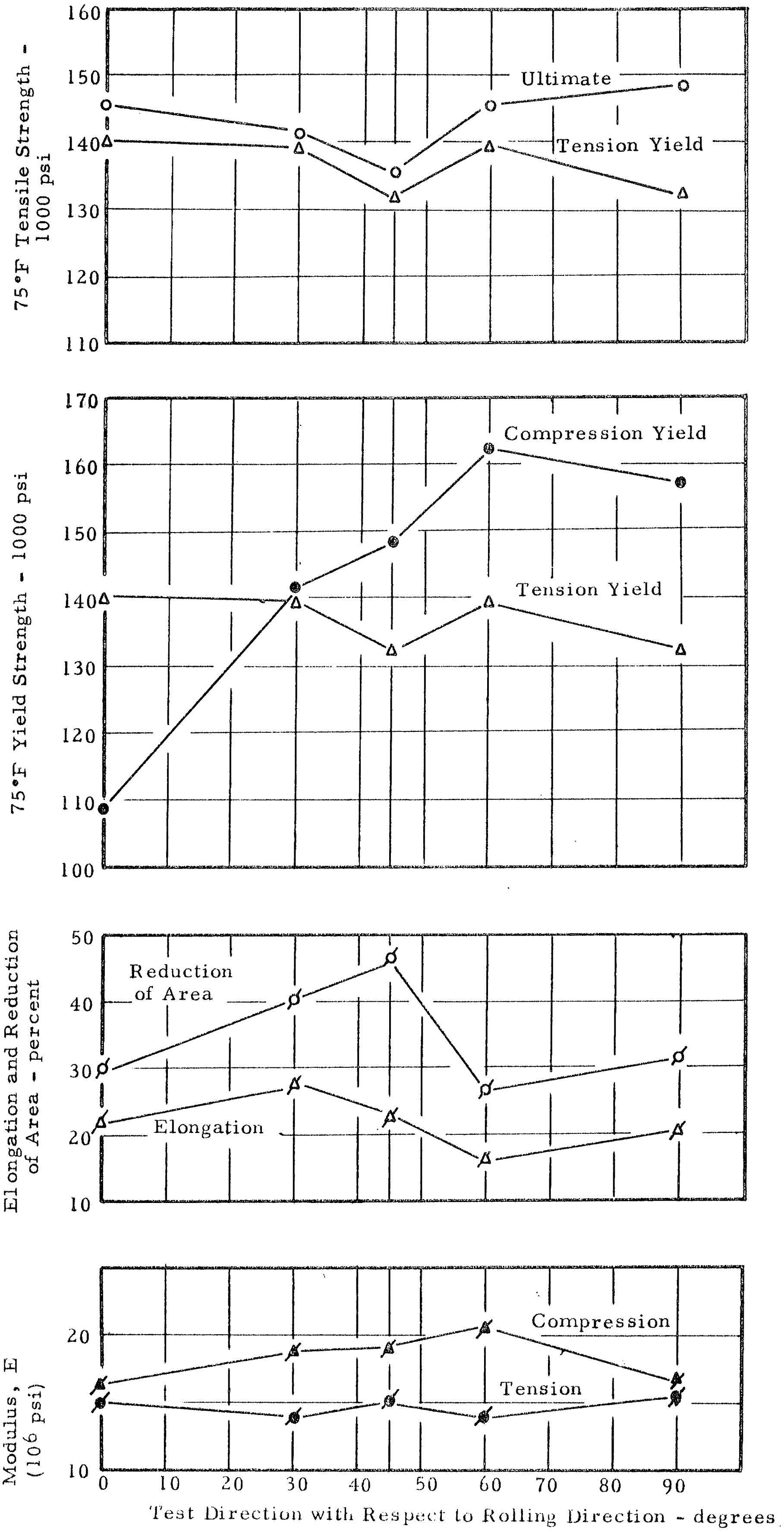

Figure 8. - Effect of Specimen Orientation with Respect to Sheet Rolling Direction on Room Temperature Mechanical Properties of C110M.

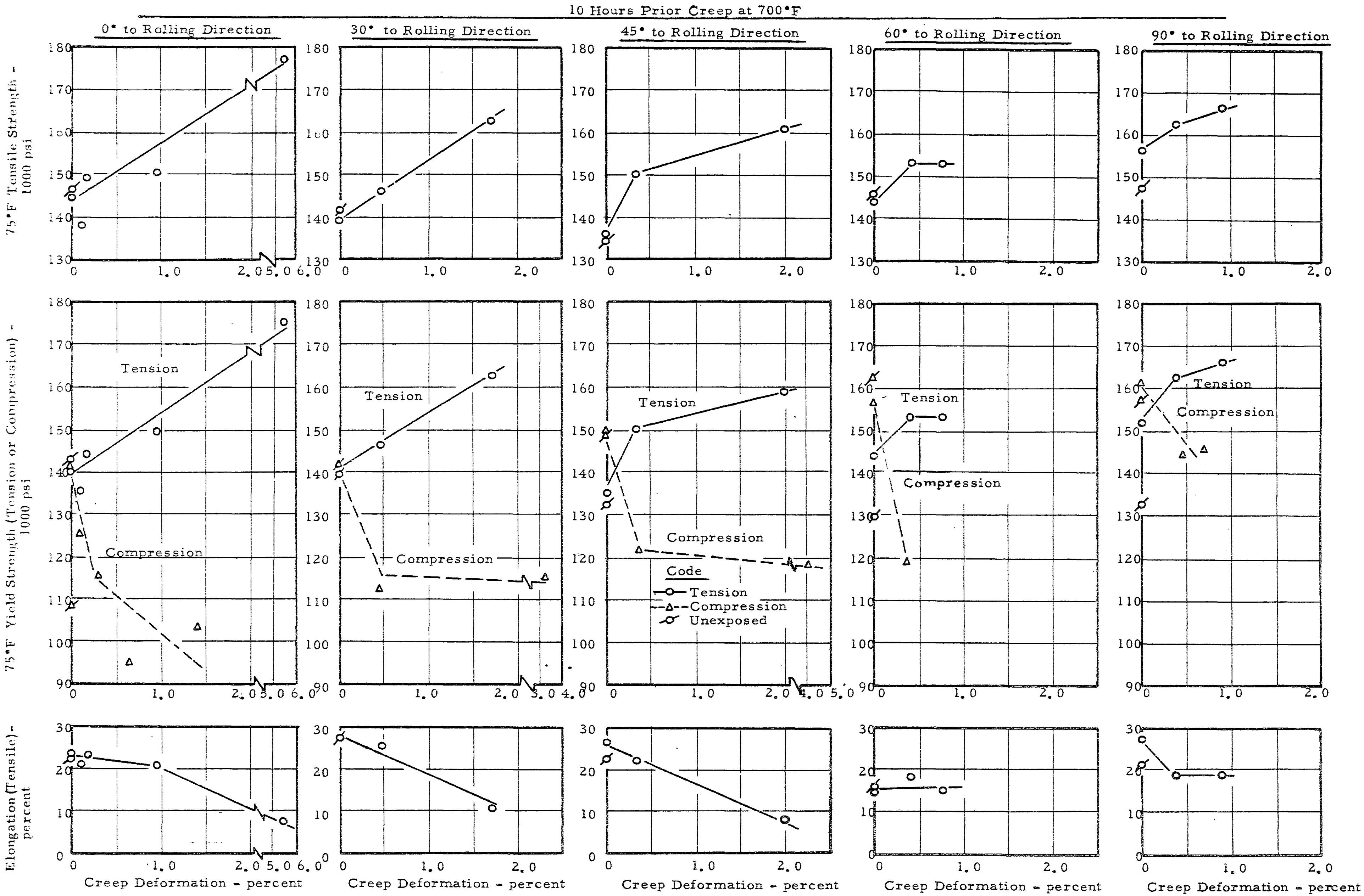

Figure 9. - Effect of Specimen Orientation with Respect to Sheet Rolling Direction on Room Temperature Mechanical Properties of C110M After 10 Hours Prior Creep Exposure at 700°F.

Marble's Reagent X1000

Figure 10. - 17-7PH (RH 950 Condition) As-Heat Treated.

Marble's Reagent X1000

Figure 11. - 17-7PH (RH 950 Condition) Exposed 100 hr at 800°F and 115,000 psi (0.94% Creep Deformation)