EFFECT OF PRIOR CREEP ON SHORT-TIME MECHANICAL

PROPERTIES OF 17-7PH STAINLESS STEEL

(RH 950 Condition Compared to TH 1050 Condition)

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FOREWORD

This report was prepared by the University of Michigan Research
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ABSTRACT

A study was carried out on the effect of elevated temperature creep exposure on the short-time mechanical properties of 17-7PH stainless steel in the RH 950 condition of heat treatment. The results were correlated with an earlier study of the TH 1050 condition of the alloy. Exposures were conducted for times of 10, 50, or 100 hours either unstressed or at stresses causing up to 2 percent creep deformation at 600°, 800°, or 900°F.

Following the exposures, short-time tension, compression, or tension-impact tests were conducted at either room temperature or the temperature of exposure. A substantial loss in ductility was observed in the room temperature tests following the creep-exposures of the RH 950 condition. At either room temperature or 600°F, a substantial Bauschinger effect was observed in the material subjected to 600°F creep-exposure. This caused an increase in the tension yield strength and a decrease in the compression yield strength as the amount of creep was increased. The ultimate strength was also increased following creep-exposure at 600°F. Little change was found in the other mechanical properties as the result of exposure to creep.

Compared to the TH 1050 condition, the RH 950 condition was initially stronger and maintained its strength better after creep-exposure. The RH 950 condition had a greater loss in room temperature ductility following 800° or 900°F exposure than the TH 1050 condition.

The changes in properties are believed due principally to an aging reaction caused by the continuation of the precipitation of an aluminum-nickel compound under the influence of stress and/or temperature. Plastic strain was also a factor as it produced the Bauschinger effect. Any effects due to strain hardening were minor.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Richard R. Kennedy
Chief, Metals Branch
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

A study of the effect of prior creep-exposure at elevated temperatures on subsequent short-time mechanical properties of typical aircraft structural metals has been conducted for the past three years at the University of Michigan under the sponsorship of the Materials Laboratory, Wright Air Development Center, U. S. Air Force. The research has been carried out under Air Force Contract AF 33(616)-3368 and accompanying Supplemental Agreements.

The results of the past research have been presented in a series of reports; each dealing generally with one material. The materials studied have included 2024-T86 Aluminum alloy (Ref. 1), C110M titanium alloy (Ref. 2) and 17-7PH stainless steel in the TH1050 condition of heat treatment (Ref. 1 and 3), while forthcoming reports will deal with a Ti-16V-2.5Al titanium alloy and a study of the creep-induced Bauschinger effect in C110M titanium.

The present report is a study of the effects of prior creep on the properties of 17-7PH stainless steel in the RH 950 condition of heat treatment. This treatment which utilizes a refrigeration step, results in tensile and yield strengths of approximately 237,000 and 222,000 psi respectively as compared the corresponding values of 203,000 and 193,000 psi obtained with the TH 1050 treatment. The elongation values for both treatments were approximately 7 to 8 percent. The research thus permitted comparison of the relative stability towards creep-exposure of two commonly used heat treatments of a precipitation hardening stainless steel.

The purpose behind the studies of various structural metals is to accumulate background information to aid in the formulation of rules for the prediction of creep damage to short time properties. The need for this type of information has become increasingly important as flight vehicle design and performance requirements have progressed to the point where creep conditions are attained during a portion of the operating cycle. Not only is adequate creep strength important to withstand these conditions but the material must retain satisfactory short-time mechanical properties.

EXPERIMENTAL PROGRAM

Creep-exposure tests of 17-7PH(RH 950) were conducted at the same temperatures studied for the TH1050 condition of this material; 600°, 800°, or 900°F. The test specimens were exposed for time periods of 10, 50, or 100 hours either at no stress or those stresses selected to produce 0.2, 0.5, 1.0 or 2.0 percent creep deformation in the specified time interval. The creep deformation was defined as the deformation occurring between the completion of loading and the end of the test period. Creep deformation, therefore, does not include either the elastic or plastic deformation, if any, during loading. These values were determined, however, and reported for each exposure test.

The creep stresses used were those which had been determined to give, on the average, the desired amount of creep. Since the time, temperature, and stress of testing were fixed, the inherent scatter in creep properties caused the actual deformations for some specimens to be greater or less than the desired value. In most cases, the tests run covered the full range of deformations up to 2-percent.

Time-elongation data were taken for each creep-exposure test. The deformation data were broken down as follows: Total loading deformation, plastic loading deformation, creep deformation, total plastic deformation (both short-time and creep), and total deformation (all deformation occuring during the application of the load and to the end of the subsequent creep period).

Following the exposures, the following tests of mechanical properties were carried out:

1. Tension tests at room temperature and the exposure temperature.

2. Compression tests at room temperature and the exposure temperature.

3. Tension-impact tests at room temperature on specimens exposed 10 or 100 hours at the three test temperatures and at the exposure temperature for specimens exposed for 10 hours at 600° or 900°F.

4. Hardness determinations on representative tensile specimens. Metallographic and X-ray examination was also made of selected specimens.

These properties were generally correlated with the creep deformation.

All test specimens were taken from the sheets in the direction

crosswise to the sheet rolling direction. This is the nominally weaker direction of the material.

The properties of the specimens subjected to creep-exposure or unstressed exposure were compared to the average properties originally established for as-treated material by a series of duplicate tests intended to define the normal scatter of each property. In order to give more confidence in the test results, duplicate exposure tests were run in a number of instances.

TEST MATERIAL

Sixteen sheets of 17-7PH precipitation hardening stainless steel were purchased from the Armco Steel Corporation in the early part of 1956. All material received was from Heat No. 55651. The material was supplied in sheets 0.064-inches thick by 36 inches by 120 inches in No. 2D finish and in Condition A. (Condition A consists of annealing at 1925°F followed by air cooling). The sheets were arbitrarily numbered from 1 to 16.

The certified chemical analysis furnished for this material follows:

Element	Nominal (percent)	Actual (percent)
Carbon	0.09 Max	0.072
Manganese	1.00 Max	0.55
Phosphorus	0.04 Max	0.018
Sulfur	0.03 Max	0.011
Silicon	1.00 Max	0.33
Chromium	16.00-18.00	17.03
Nickel	6.50-7.50	7.25
Aluminum	0.75-1.50	1.28
Iron	Balance	Balance

For tests conducted on the TH 1050 condition of this alloy, (Ref. 3) sheets number 1, 2, and 3 were completely consumed, while sheets 4, 5, and 6 were partially consumed. The balance of the untreated specimen blanks from sheets 4, 5, and 6 were treated to the RH 950 condition, while additional specimens were prepared from sheets 7 and 8.

Heat treatment to the RH 950 condition was carried out at the University using the following sequence on batches consisting of six bundles, each containing six one-inch wide specimen blanks 22 inches long.

1. Condition A material heated in a gas-fired furnace for
   10 minutes at 1750°F±15°F; followed by air cooling.

2. 2-hour delay.

3. Refrigeration at -100°F for 8 hours. (This step accomplished
   in a 36-inch deep stainless steel Dewar Flask containing a
   saturated acetone-dry ice mixture.)

4. 30-minute delay.

5. Reheat at 950°F±10°F for 1 hour in a recirculating air
   furnace; followed by air cooling.

The time delays employed in steps 2 and 4 were adopted merely
for consistency in processing and ease in scheduling. Heat treatment
studies carried out by the producer of the material to develop optimum
properties (Refs. 4 and 5) showed that delay times were not especially
critical.

This treatment was different from the TH 1050 treatment with
respect to both the times and temperatures employed. In the TH 1050
treatment, the first step was carried out at 1400°F for 1-1/2 hours;
(this rendered the material susceptible to martensite transformation at
room temperature). The material was then cooled from 1400°F in air
for 10 minutes (to reach approximately 500°F) and then quenched in
60°F water. The final treatment was carried out for 1-1/2 hours at
1050°F. Further discussion of the differences between the treatments
is included in the section on Metallographic Examination (page 21).

TEST SPECIMENS

As mentioned in the section on Test Material, the specimens
for tests of 17-7PH (RH 950) were taken from among five sheets of the
original sixteen sheets of material that were purchased. The
specimens were so chosen to provide a measure of the variation in
properties both between sheets and within individual sheets. This
necessitated the use of a coding system in order to identify the
origin of each test specimen.

Records were kept of the blanks included in each heat treatment
batch. In so far as is known, the specimens tested represented random
choices of test material.

The sampling scheme designed for the 17-7PH stainless steel
is illustrated in Figures 1 and 2. Each sheet of material was
divided into a number of modules or panels over the length of the sheet.

Within each panel the specimen blanks were arranged in a pattern across the width of the sheet. This pattern was of course extended throughout the sheet by the repetition of the panels. All specimen blanks were one-inch wide; the panel widths being 6 to 7 inches. As each strip was sheared, a code number was stamped on it identifying the sheet number, panel number, and specimen position within the panel--in that order. Thus, the specimen labeled 5F-T6 is a tensile specimen taken from strip No. 6 of panel F in sheet 5.

The configuration and dimensions of the various test specimens are shown in Figure 3. All the specimens for the mechanical property tests were designed so that they could be machined from the creep specimen following exposure. For the exposure tests themselves, the width of the gage was machined 0.030 inches over the 0.5-inch nominal width. This practice permitted the subsequent tests to be carried out on material subjected to the same machining practice whether the tests be tension, compression, or tension-impact. In addition, this also permitted the measurement of properties to be unaffected by the particular edge effects, if any, associated with the prior exposure of the specimen.

For convenience and uniformity in machining the specimens, jigs were constructed so that five or six could be made concurrently. The blanks were milled to rough dimensions and the shoulder radii and gage sections were ground to the finished dimensions.

TEST EQUIPMENT AND PROCEDURES

Detailed discussion of the development of the test equipment and procedures has been previously given (Refs. 1, 2, and 3) and will not be repeated in the present report. Wherever applicable, ASTM Recommended Practices were adhered to in test procedures.

The creep-exposure tests were carried out in individual creep-testing machines with heating provided by a wire-wound resistance furnace fitting over the specimen assembly. Strain measurements were accomplished using a modified Martens optical extensometer system.

Tension and compression tests were conducted in a Baldwin-Southwark hydraulic tensile machine equipped with a strain pacer. A strain rate of 0.005 inches per inch per minute was used. A recording extensometer system employing a micro-former strain gage was employed to give a continuous plot of the test results. A special compression testing fixture which included a loading ram and a pair of guide blocks to restrain lateral buckling of the specimen was constructed for use in this investigation.

Specimens prepared for metallographic examination were mounted in bakelite and wet ground in rotating laps using a series of silicon carbide papers through 600 mesh. Final polishing was carried out first with fine diamond compound on a rotating lap and then on a Syntron vibratory polisher in an acqueous media of Linde "B" polishing compound.

The samples examined optically were etched in Marble's reagent. A number of etchants were tried to prepare the samples for electron microscope examination with the best results being obtained by the use of modified Nital--15% HCl, 5% HNO_3, 80% alcohol.

For electron microscope examination, collodion replicas were made from the surface of the etched specimens. The replicas were shadowed with palladium to increase contrast and reveal surface contours. Polystyrene latex spheres of approximately 3400 Å diameter were placed on the replicas prior to shadowing to indicate the angle and direction of shadowing and provide an internal standard for the measurement of magnification. The micrographs reproduced in this report are direct prints from the original negatives; consequently the polystyrene spheres appear black and the shadows appear white. Since the latex spheres are raised on the replica, a phase casting a shadow opposite to that cast by the latex spheres is in relief on the metal specimen; conversely, areas casting shadows in the same direction as cast by the latex spheres are depressions in the surface of the metal specimen and represent a phase that was attacked by the etchant.

EXPERIMENTAL RESULTS

The results of the exposure tests were tabulated and correlated with respect to the amount of prior creep, the temperature, and the time of exposure. In the tabulations of the test data the specimen is described both by nominal exposure conditions and the actual exposure conditions.

The properties of the unexposed material and the material exposed without stress are used as the basis for the evaluation of the effects of prior creep. A consistent trend in the curve of residual properties versus the amount of prior creep was taken as a measure of a significant change in the property in question. In some instances, however, the change was slight and hardly outside the range established for the unexposed material. These instances are discussed where they are encountered.

The results are presented in the following order: the base properties of the material and the stress-versus time for creep deformation curves at each test temperature; the unstressed exposure tests; the creep-exposures followed by room temperature tension and compression tests, elevated temperature tension and compression tests, and finally, room temperature and elevated temperature tension-impact tests. Hardness determinations are discussed with the mechanical property data. The metallographic studies are discussed following the creep-exposure results.

BASE PROPERTIES BEFORE CREEP-EXPOSURE

Tension Properties. Tension tests at room temperature, 600°, 800°, and 900°F were conducted to establish a measure of the base properties of as-treated 17-7PH in the RH 950 condition. The test data are summarized in Table 1 and plotted as a function of test temperature in Figure 4. The six tests run at each test temperature consisted of two specimens from each of three sheets of material treated in several different heat treatment batches.

Increasing the test temperature caused a drop of about the same order of magnitude in both the ultimate tensile and yield strengths. Ductility values from the 600°F tests were slightly lower than those obtained at room temperature and then increased substantially at 800° and 900°F. This behavior was similar to that observed for the TH 1050 condition.

The room temperature properties developed in this heat by the RH 950 treatment agree well with those reported by the producer (Ref. 5). The agreement in this case was better than that observed previously for the TH 1050 heat treatment (Ref. 1). This is indicated by the following summary of the data from Table 1.

Treatment and Data Source *	Test Temp(°F)	Ult. Tensile Strength (psi)	Yield Strength(psi)	Elongation (%)
RH 950 "DESIGN"	Room	236,000	219,000	7
Heat 55651	Room	237,650	222,480	8.2
TH 1050 "DESIGN"	Room	200,000	185,000	10
Heat 55651	Room	203,000	193,910	6.7

Treatment and Data Source *	Test Temp. (°F)	Ult. Tensile Strength (psi)	Yield Strength(psi)	Elongation (%)
RH 950 "DESIGN"	600	190,000	175,000	6
	800	170,000	150,000	8
	900	142,000	130,000	11
Heat 55651	600	199,000	171,830	7.8
	800	166,783	148,000	14.4
	900	137,433	121,233	17.9

NOTES:* "DESIGN" - from design curves - Ref. 5, p. 96B
Heat 55651 - U. of M. average values from 3 sheets of 0.064-inch sheet.

The comparison between the actual values and the "design" values was generally close although the ductility of Heat 55651 in the RH 950 condition became increasingly higher than the "design" values as the test temperature was increased. This was reflected in appreciably lower strengths only at 900°F although at this temperature the variation in the average strengths between the two sources of data was only 7 percent.

It appears, therefore, that the tension properties developed in the present material by the RH 950 treatment were in better agreement with the design data than were the properties developed by the TH 1050 condition.

Compression Properties. Compression tests were carried out at room temperature, 600°, 800°, and 900°F to establish base properties of 17-7PH stainless steel as-heat treated to the RH 950 condition. The data are tabulated in Table 2 and plotted as a function of test temperature in Figure 5.

Increasing the test temperature caused the compression yield strength to decrease, with the temperature dependence quite similar to that previously reported for the tension properties. The compression yield strength was 10-15 percent higher than the tension 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 6-10 percent higher than those indicated by the producer as "typical" (Ref. 5). This was a slightly higher deviation than was found in the case of the tensile properties of RH 950.

Comparative data are tabulated below:

Treatment and Data Source*	Test Temp (°F)	Compression Yield Strength (psi)
RH 950 - "DESIGN"	Room	232,000
	600	181,000
Heat 55651	Room	245,000
	600	199,142
	800	167,357
	900	134,833
TH 1050 - "DESIGN"	Room	194,000
	600	160,000
	800	130,000
	900	98,000
Heat 55651	Room	220,667
	600	185,500
	800	146,800
	900	113,877

*Notes: "DESIGN" - from design curves - Ref. 5, p. 96B
   Heat 55651 - average values determined at University of Michigan

Tension-Impact Properties. The results of the tension-impact tests at room temperature and the elevated temperatures to establish base properties are summarized in Table 3 and plotted as a function of the test temperature in Figure 6. Some decrease in the tension-impact strength accompanied by slightly increased ductility occurred as the test temperature was increased. Fairly good agreement was obtained between duplicate tests at each temperature. In addition, the data for the RH 950 condition were considerably more consistent than the previous data for the TH 1050 condition (Ref. 3) which had a comparable level of strength. This is shown by the following tabulation.

	Tension-Impact Strength--ft-lb.			
	RH 950		TH 1050	
Test Temp.	Range	Average	Range	Average
Room	38-46	43	33-70	49
600°F	38-46	42.6	31-57	40.1
800°F	26-41	32.7	24-33	29.9
900°F	27-29	28	34-50	43.8

Hardness. The hardness of the material as-heat treated was determined to be Rockwell "C" 48.2. This value is the average of five determinations made on each of six different specimens. The six specimens consisted of two each from three different sheets. The producer of the material indicated that a hardness range of 46-48 could be expected from this treatment. (Ref. 5). In contrast, the average hardness of the TH 1050 condition was determined to be Rockwell "C" 43.8, compared to the 42-43 indicated by the producer.

ESTABLISHMENT OF EXPOSURE STRESSES

Curves of stress versus time to reach creep deformations of 0.2, 0.5, 1.0 and 2.0 percent at 600°, 800°, or 900°F were determined to aid in the selection of stresses for creep-exposure tests. Six or seven tests were run at each temperature with the higher stress tests allowed to creep until fracture occurred. The test specimens removed from the creep units before fracture were tested in tension at room temperature in order to gain some idea of the effects to be expected from creep-exposure. The data from the creep tests and the tensile tests are summarized in Table 4.

The curves of stress versus time for creep deformation are plotted in Figure 7. The slopes of these curves generally follow the slope of the rupture curve at the same temperature. Several inconsistencies in the data were observed in the 600°F tests and the curves drawn at this temperature are based on average values. The data obtained at 800°F and 900°F exhibited better consistency although a deviation was noted between duplicate tests at 800°F and 90,000 psi. The ultimate tensile strength was used as the 0.1-hour rupture strength to aid in fixing the curves. Plastic deformation during loading occurred in all tests at 600°F and the majority of tests at 800°F.

The nominal stresses for the required creep-exposures were determined from the intersection of the creep deformation curves with the ordinate at 10, 50 or 100 hours. In some cases, later experience with the creep exposure tests required readjustment of the stresses.

Hardness increases of one or two points on the Rockwell "C" hardness scale were observed in most specimens after creep. The ductility after fracture increased moderately as the rupture time was increased.

Tension tests of unfractured creep specimens revealed that increases in tensile and yield strength and decreases in ductility took place as a result of exposure to stress and temperature. Figure 8 is a plot of total plastic deformation versus room temperature tension properties for several specimens creep tested at 600°F for times between 331 and 437 hours. The plot shows that a severe drop in elongation occurred following creep. Increases in tensile and yield strength of as

much as 18 percent over the base value were noted. In addition, the yield strength was found to be equal to the ultimate strength for the three specimens tested after creep at 600°F.

The fragmentary data also indicated that similar effects followed creep at 800° and 900°F.

TENSION AND COMPRESSION PROPERTIES AFTER EXPOSURE

Unstressed Exposure

Tension Properties. Tension 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 5.

The room temperature results (Fig. 9) show that no significant change in strength followed exposure at 600°F. Both the ultimate tensile strength and tensile yield strength 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 decrease in ductility which was most marked for the 900°F exposures. The accompanying hardness changes (Fig. 9) were neither large nor appeared to be consistent.

Tests at elevated temperature (Fig. 10) revealed 10-15 percent increases in the 800°F tensile and yield strengths after 100 hours exposure at 800°F--the condition also producing the maximum effect in the room temperature tests.

The 600°F yield strengths were increased somewhat following exposure at 600°F, however, the 600°F ultimate tensile strengths were apparently not affected. The 900°F ultimate tensile strength and yield strengths were changed slightly and reached a possible maximum value at 50 hours exposure time and then decreased to slightly below the as-treated strength for the 100 hour exposure. Ductility tended to decrease with increased exposure time with the exception of the 600°F tests.

Both the room temperature and elevated temperature tension properties of the RH 950 condition exhibited slightly different behavior than did specimens of the TH 1050 condition subjected to unstressed exposure under the same conditions. (Ref. 3). The maximum effects in room temperature tests of the TH 1050 condition were found for 50 hours exposure time at 900°F--an increased tensile strength of 15 percent and an increased yield strength of 18 percent. The 100 hour

exposure at 800°F increased the tensile strength by 10 percent and the yield strength by about 14 percent--amounts similar to those obtained with the RH 950 condition. The hardness changes accompanying the exposures of the TH 1050 condition were somewhat larger than for the RH 950 tests. The ductility behavior was not significantly different.

In the elevated temperature tests of TH 1050 following unstressed exposure, the 600°F tensile and yield strengths decreased moderately with increased exposure time, while the 800° and 900°F strengths were either unchanged or increased slightly with increased exposure time.

It appears, therefore, that the tension properties of the RH 950 condition were slightly more stable after unstressed exposure than those of the TH 1050 condition.

Compression Properties. Compression tests at room temperature or the temperature of exposure were conducted on specimens of 17-7PH (RH 950) exposed without stress at 600°, 800°, or 900°F for 10, 50 or 100 hours. The results of these tests are presented in Table 6 and plotted in Figures 11 and 12.

The suggested slight increase in yield strength at room temperature (Fig. 11) following exposure at 600°F was probably not significant since all the test values fell within the range for unexposed material. Larger and probably significant increases followed exposures at 800° and 900°F. since all the values fell either just at or above the high side of the range established for the base conditions. The maximum increase in strength (for the 50 and 100 hours exposure at 800° and 900°F) was about 9 to 10 percent above the value for the base condition. This was somewhat above the range of values obtained in tests of the as-treated material (Fig. 5) and is, therefore, probably a real effect. Check tests on a second specimen exposed for 50 hours at 800°F and one exposed 10 hours at 900°F showed excellent agreement with the first tests of these conditions, although there was a discrepancy between the two tests of specimens exposed 10 hours at 600°F.

The elevated temperature test results (Fig. 12) generally exhibited increased strength with increased exposure time. Maximum increases, those for the 100 hours exposure at each temperature, ranged from 6-12 percent above the base value. The check tests run on several exposure conditions showed fair agreement.

The comparison of the results with those for the TH 1050 condition revealed good consistency for the elevated temperature tests and some discrepancies in the room temperature results. In the room temperature tests, the TH 1050 condition showed little or no change in yield strength following the 800° or 900°F exposures, while there was an apparent 20 percent loss in strength for either the 10 or 100 hour exposures at 600°F. However, a considerable amount of

scatter made interpretation of these data difficult. For the elevated temperature tests of the two conditions, the general trends at each test temperature were the same while the absolute amount of the change was slightly less for the TH 1050 condition.

Creep Exposure

Room Temperature Tests. The results of tension and compression tests at room temperature following prior creep for 10, 50, or 100 hours are reported in Tables 7 and 8, and plotted as a function of the creep deformation for each exposure time and temperature in Figures 13, 14, and 15. The inclusion of both the tension and compression yield strengths in the same plot serves to emphasize the possible existence of Bauschinger effects. A summary of these data is presented in Figure 16, while the hardness data are included in Table 7. A correlation based on total plastic strain is presented in Figure 17. Figure 18 presents comparative data for the TH 1050 condition.

Figure 13 shows that prior creep at 600°F had an effect on the room temperature tension and compression properties for all exposure times studied. The ultimate tensile strength and tensile yield strength were increased and the compression yield strength and elongation were decreased as the amount of prior creep increased. The increased tension yield strength and decreased compression yield strength indicate that a Bauschinger effect was operative in the material exposed at 600°F. (The Bauschinger effect will be discussed in greater detail on page 29).

Examination of Figure 13 reveals that the amount of creep apparently had a slightly greater effect on the ultimate tensile and tensile yield strengths in the 50 and 100 hour exposures than it did in the 10 hour exposures. The compression yield strength was decreased most with creep in the 10 hour exposures and progressively less as the creep time was increased to 50 and 100 hours. The elongation decreased about the same extent regardless of the creep time.

It should be recognized, as Table 7 shows, that short-time plastic strain was obtained during loading of most of the 600°F tests since the loads necessary to obtain the desired amounts of creep were generally above the proportional limit of the material. In most cases the short-time plastic strain ranged from about 10 to 20 percent of the total plastic strain of the test, while in only one case was it as much as 40 percent of the total plastic strain.

A correlation of the 600°F data as a function of total plastic strain is presented in Figure 17. The curves had the same shape as the ones based on creep deformation and there was no difference in the indicated time dependency. The changes in strength were not excessive compared to the as-treated strength. The maximum increase in ultimate tensile strength was about 12 percent over the base value, while

the tensile yield strength was increased about 19 percent at its highest. The maximum reduction in compression yield strength for 10 hours creep was 20 percent below the base value. The elongation, however, was significantly affected. From the original value of 8.2 percent the elongation was reduced to as little as 1 percent. The drop in elongation was rapid, reaching 1-2 percent for creep up to about 0.5 percent and then leveling off with greater amounts of creep. Hardness changes following creep-exposure at 600°F were limited to increases of only one to two points Rockwell "C".

Prior creep at 800°F had a mixed effect on the room temperature tension or compression properties. (Figure 14). As the exposure time was increased, the properties were governed more by the exposure to temperature and were not as much a function of the amount of creep.

Ten hours creep at 800°F resulted in behavior quite similar to that noted for all the 600°F exposures. The tension yield strength was increased and the compression yield strength was decreased with increased creep. Although the elongation was reduced somewhat by the exposure to temperature alone for 10 hours at 800°F, it showed a further tendency to decrease as the amount of creep was increased.

The behavior following exposure to creep for 50 hours at 800°F was similar to that following the 10 hour exposures, however, the extent of the change was not as large as creep increased. This was particularly noticeable with respect to the ultimate tensile strength and the compressive yield strength.

Exposure to creep for 100 hours at 800°F had only a slight effect on any of the properties except the tension yield strength. The ultimate strength was increased about 12 percent while the tension yield strength was increased about 15 percent by the exposure without stress. The addition of about 0.2 percent creep then caused the tension yield strength to increase about 7 percent over the as-treated value. Meanwhile, the 8 percent increase in compression yield strength produced by the exposure to temperature alone was affected very little by creep of up to 2 percent. The loss in elongation was almost all due to the exposure to temperature. Hardness increases in the 800°F exposures ranged from 2 to 5 points Rockwell "C".

In contrast to the 600°F tests, the creep-exposures at 800°F were conducted with short-time plastic loading strain being involved in only a very few instances.

Creep-exposure at 900°F (Figure 15) produced small changes in the room temperature properties, however, the direction of the changes was not always the same as those produced by creep-exposure at the lower temperatures. The compression yield strength exhibited a tendency to decrease with increased creep for the 10 or

100 hour exposures and possibly for the 50 hour exposures, while the tensile yield strength and ultimate tensile strength were apparently decreased with creep in the 10 or 50 hour exposures but not in the 100 hour exposure.

The greatest change in strength from the 900°F exposures resulted from the exposure to temperature alone. Even then, however, the maximum increase, that of the tensile yield strength after 100 hours exposure, was only about 10 percent over the as-treated strength. The ultimate tensile strength and compression yield strength were increased to a lesser extent by the unstressed exposure. The creep exposures at 900°F either had no further influence on the strengths or caused them to be reduced to the level of the as-treated material.

On the other hand, the exposure to temperature alone caused the elongation to drop to between one to two percent, while creep apparently resulted in no further decrease in the elongation.

A comparison of these results with the data obtained for the TH 1050 condition subjected to similar creep-exposures revealed both similarities and differences in behavior. Figure 18 taken from Reference 3, summarizes the data for the TH 1050 condition. Although this plot correlates the data on the basis of total deformation, the general trends are valid for comparison with the plots of the RH 950 data based on creep deformation. The two conditions showed the greatest similarity in their response to 600°F creep. The ultimate tensile strength and tensile yield strength were increased with creep, while the compressive yield strength and tensile elongation were decreased. The TH 1050 condition did not show an apparent time dependency for the loss in compressive yield strength as did the RH 950 condition.

The behavior of the ultimate strength and yield strengths of the two conditions after creep-exposure at 800°F was also fairly similar, however, loss in ductility of the TH 1050 condition was not as marked. Where the elongation of the RH 950 condition ranged from one to three percent, the elongation of the TH 1050 condition was reduced only to about four to five percent.

The difference in behavior of the ductilities was also very evident following the 900°F creep-exposures. The severe loss in elongation for the RH 950 condition after unstressed exposure was not obtained in the TH 1050 condition; however, the RH 950 condition had a smaller tendency for changes in the ultimate strength and yield strengths after 900°F creep-exposure than did the TH 1050 condition.

Elevated Temperature Tests. The results of the tension tests conducted at the exposure temperature following creep-exposure are summarized in Table 9 and the compression test data are summarized

in Table 10. Plots of the test results are presented for each temperature and time in Figures 19, 20, and 21. Summary curves for the RH 950 condition are included in Figure 22 and similar curves for the TH 1050 condition are presented for comparison purposes in Figure 23.

Tension and compression tests at 600°F following creep-exposure at 600°F (Figure 19) revealed effects very similar to those obtained from the room temperature tests following the same creep conditions. The ultimate strength and tensile yield strength were increased and the compression yield strength and elongation were decreased as the amount of creep was increased. The yield strength behavior in these tests was again consistent with the Bauschinger effect.

The increase in ultimate strength following 3 to 4 percent creep was about 9 percent over the value for the unstressed exposure. This compares with a 12 percent increase in the ultimate strength at room temperature following similar creep-exposure. The maximum increase in the tension yield strength was about 18 percent (compared to 19 percent in the room temperature tests) while the maximum decrease in compression yield strength ranged from 20 to 25 percent (compared to 20 percent for the room temperature tests). The elongations were reduced to an almost identical extent following creep in both the room temperature tests and the 600°F tests.

The similarity of the results of the room temperature and elevated temperature tests following creep-exposures at 600°F indicates that the subsequent properties were almost entirely governed by the amount of plastic strain. Research carried out in another phase of this investigation (Ref. 6) indicated that there is no apparent difference in the relative effect of short-time plastic strain and creep strain in cases where the short-time strain ranged up to 30 percent of the total plastic strain and where there was no opportunity for no-load recovery period during the test. These conditions were fulfilled by the present creep-exposure.

In the tests conducted at 800°F following creep-exposure at 800°F (Figure 20) little or no change was observed in either the ultimate tensile strength or the tensile elongation. Depending on the exposure time there was a tendency for the tensile yield strength to be raised as the amount of creep was increased. The maximum extent of the increase was 13 percent in the 10 hour exposures which was reduced to about 5 percent for the 100 hour exposure.

The compression yield strength appeared to undergo a transition in its behavior as the creep time was increased. In the 10 hour tests it was increased as the amount of creep increased, while in the 100 hour tests an initial increase due to the unstressed exposure was reduced as the creep increased.

The tests conducted at 900°F following creep-exposure at 900°F showed a mixture of effects. (Figure 21). The ultimate strength was affected very little by the 10 or 100 hour creep exposures, while the apparent decrease in strength with increased creep in the 50 hour tests may not be a true effect. It is conceivable that the point for the 50 hour unstressed exposure was high due to experimental variability. This appears to be a possibility since the ultimate strength values obtained in the 900°F tests were all fairly close to the as-treated strength.

Changes in elongation following creep-exposure at 900°F were generally small and confined to slight increases. The compressive yield strength decreased with increased creep for all three exposure times, while the tensile yield strength was changed only slightly by creep. The directions of the changes were not consistent. However, since the changes were small, the apparent inconsistency may be merely an effect due to experimental variability.

A comparison of the elevated temperature data for the RH 950 condition (Figure 22) with the data for the TH 1050 condition (Figure 23) shows a greater similarity in the effects of creep-exposure than was the case in the room temperature tests. This similarity was particularly evident in the case of the 600°F data, and also in the behavior of the elongation data for all three test temperatures.

Effect of Long-Time Creep Exposure

An indication of the effect of creep-exposure on RH 950 material for periods longer than 100 hours was gained from the room temperature tensile tests on specimens used to establish the creep deformation properties of the RH 950 condition. These data were included with the creep deformation data in Table 4 and mentioned briefly on page 10.

In Figure 24, the test points for the long-time creep test specimens are super-imposed on a plot of the relationships developed for the 100 hour creep-exposure at each of the test temperatures. The figures in parentheses are the creep time in hours.

At 600°F the creep-exposure for periods between 331 hours and 637 hours caused some additional increase in the ultimate strength and tensile yield strength beyond the values established for 100 hours exposure, while the elongation did not appear to be significantly affected by the longer exposure time. Nevertheless, both the strength and ductility continued to be more a function of the amount of prior creep than of the time of exposure.

At 800°F, exposures of 381 to 437 hours produced little or no further change in properties beyond those produced by the 100 hour exposures. The ultimate tensile strength and tensile yield strength

were increased about 15 percent over the as-treated value, while the elongation was reduced to about one percent.

The two points obtained from specimens crept at 900°F show that a longer exposure time caused a reduction in the strength and an increase in the ductility from the values established by the 100-hour exposure. In particular, the ultimate tensile strength and tensile yield strength of the sample exposed for 843 hours were very close to those for the as-treated condition while the sample crept for 336 hours showed a smaller decrease from the 100 hour value. The elongations of both specimens were increased to about 4 percent from the one to two percent of the 100 hour exposures. Nevertheless, these values were well below the 8.2 percent elongation of the as-treated condition.

Apparently, an intermediate exposure time at 900°F had the greatest effect on the room temperature properties.

These limited data for exposure periods beyond 100 hours did not materially affect the validity of conclusions to be drawn from the test data for shorter exposures.

TENSION-IMPACT PROPERTIES AFTER EXPOSURE

Tension-impact tests at room temperature or the exposure temperature were run on specimens exposed without stress for 10, 50, or 100 hours at 600°, 800°, and 900°F. Specimens exposed to creep for 10 or 100 hours at these temperatures were also tested at room temperature while the elevated temperature tests after creep-exposure were confined to specimens crept for 10 hours at 600° or 900°F.

Attempts were made to correlate the impact ductilities on the basis of both the elongation or the reduction of area.

Unstressed Exposure

Room-Temperature Tests. Data from the room temperature tension-impact tests following unstressed exposure are tabulated in Table 11 and plotted as a function of exposure time and temperature in Figure 25. In general, the unstressed exposure caused a decrease in the tension-impact strength. With the exception of the 100 hour exposure at 800°F which caused little change from the as-treated strength, the loss in strength became greater as both the exposure temperature and time were increased. A duplicate specimen which showed excellent agreement with the original data was run for 100 hours at 800°F.

The ductility of these specimens also tended to decrease as the exposure time and temperature were increased. The elongation values appeared to be less severely affected than were the reduction of area values although the values were low and difficult to measure with accuracy.

Considerably different behavior was noted for the TH 1050 condition subjected to similar unstressed exposures. (Ref. 3). The TH 1050 condition had a slightly increased tension-impact strength as the exposure time was increased at 600° or 800°F. The exposure at 900°F for 10 hours caused substantial increase in strength which then dropped off somewhat for 50 hours exposure until for the 100 hour exposure it was only slightly above the as-treated value. The elongation of TH 1050 material was either unchanged or slightly increased by unstressed exposure.

Elevated Temperature Tests. The results of the elevated temperature tension-impact tests of the RH 950 condition following unstressed exposure are summarized in Table 11 and plotted in Figure 26.

A different effect was observed for each testing temperature. In the 600°F tests the strength was decreased as the exposure time was increased; in the 800°F tests there was a tendency for the strength to be increased; while in the 900°F tests the exposure apparently had no effect on the strength. The ductilitiy values in the 600° and 800°F tests were not affected by the exposure, while the ductility of the specimens exposed and tested at 900°F was reduced slightly.

This behavior was again different from the case of the TH 1050 condition. In the TH 1050 tests the 600° and 800° exposures showed little or no change in strength while in the 900°F tests there was a sharp rise in strength for the 10 hour exposure which then dropped off for the longer exposure times. The elongation values also were slightly increased.

Creep Exposure

Room Temperature. The results of room temperature tension-impact tests following creep-exposure are summarized in Table 12 and plotted in Figure 27.

Changes in the tension-impact strength produced by creep-exposure at 600°F were small and almost all within the range of strength of the as-treated material. The unstressed exposures at 600°F caused some decrease in strength which then appeared to be partially restored by the

creep-exposure. The ductilities of these specimens decreased as the amount of creep was increased. The limited data did not indicate if the exposure-time was of any significance.

The exposure time may have had some effect on the tension-impact strength of specimens subjected to creep at 800°F. The specimens crept for 10 hours did not exhibit much change in strength from the decreased value obtained by the exposure to temperature alone for 10 hours, however, the two specimens crept for 100 hours showed a considerable reduction in strength from the value obtained by the 100 hour unstressed exposure. This reduction in strength appeared to be a function of the amount of prior creep.

The ductilities of the samples exposed to creep at 800°F were all decreased from the as-treated value. Most of the loss in ductility apparently resulted from the exposure to temperature alone.

The specimens exposed at 900°F were all subject to a loss of tension-impact strength and ductility that was due to the exposure to temperature alone. As far as could be determined, the addition of creep to these exposures did not at all contribute to the reduction in properties. The tension-impact strength was reduced about 50 percent, while the elongation and reduction of area were reduced to almost negligible amounts. The time of exposure also did not appear to be of any significance.

Because of scatter in the test results for the TH 1050 condition (Ref. 3) it was difficult to reach conclusions comparing the effect of creep-exposure on the two treatments. The strengths of the TH 1050 condition after all temperatures of creep-exposure ranged from either no change to a decrease of almost 50 percent with no apparent temperature dependence. There was some indication that the tension-impact strength and ductility of the TH 1050 material declined as the amount of creep was increased, although the effects of exposure time could not be separated.

No such loss of strength was obtained from the 600°F creep-exposures of the RH 950 condition. There were some losses in strength from the 800°F creep-exposures, while in almost all of the specimens exposed at 900°F the tension-impact strengths were about one-half the as-treated value. None of the TH 1050 specimens exhibited the severe loss in ductility noted in the RH 950 specimens exposed at 800° or 900°F. The majority of the TH 1050 specimens had reduction of area values of about 15 percent, while the lowest value found was 7.5 percent. In the RH 950 specimens exposed at 800° and 900°F the reduction of area values ranged from zero to 5 percent.

Elevated Temperature. A limited number of tension-impact
tests were run at the temperature of exposure for specimens exposed
to creep for 10 hours at either 600° or 900°F. The data are
summarized in Table 12 and plotted in Figure 28.

Prior creep generally had only a slight effect on the elevated
temperature tension-impact strength of the RH 950 condition. In the
600°F tests neither the strength nor the ductility was changed
significantly from the values established by exposure to temperature
alone. In the 900°F tests there was small indication of increased
strength and decreased ductility as the amount of creep was increased.
The reduction of area data from the 900°F tests was subject to a
considerable scatter.

The test data for the RH 950 condition were slightly different
from those obtained for the TH 1050 condition after comparable
creep-exposures. In the TH 1050 tests, a slight decrease in the
tension-impact strength with increased creep was obtained in the
600°F tests, while in the 900°F tests, an initial increase caused by
exposure to temperature alone for 10 hours was lost rapidly as the
amount of creep was increased. The elongation values for all the
tests were low but were apparently more affected by the exposure
to temperature alone than by the amount of creep.

METALLOGRAPHIC EXAMINATION

Optical and electron microscope techniques were used to
study the microstructure of 17-7PH as-treated to the RH 950 condition
and following creep exposure. In the as-treated condition the
structure consisted of martensite, delta ferrite, various carbides,
aluminum compounds and inclusions.

Although the creep exposures and the exposures to temperature
alone resulted in changes in mechanical properties and hardness,
no gross microstructural effects correlating with the changes in
properties were observed by the techniques employed. X-ray studies
to be discussed later (page 23) suggested that a continuation of the
precipitation of a compound tentatively identified as NiAl was
associated with decreased room temperature ductility, however, no
positive microstructural evidence was obtained to confirm this.

Optical micrographs of 17-7PH are presented in Figures 29
to 34. The direction of observation specified on these figures are with
respect to the axis of creep testing. This axis was transverse to the
sheet rolling direction. As received from the producer, the material

was in condition A (Figures 29 and 30)--that is, solution annealed at 1925°F and air-cooled. The structure consisted of austenite and between 5 to 20 percent of delta ferrite appearing as stringers in the rolling direction. In addition, cubic particles of titanium carbo-nitride, Ti(C,N) were present.

The production of the high strength RH 950 condition of the material was a three-step heat treatment consisting of heating at 1750°F, refrigeration at -100°F., and re-heating at 950°F. The purpose of the 1750°F treatment was to "condition" the material for transformation to martensite. A conditioning treatment at 1400°F results in martensite transformation at room temperature and is the basis for the TH 1050 treatment previously studied (Refs. 1 and 3). Conditioning at 1750°F for the RH 950 treatment produces a material that is stable at room temperature(i.e., the Ms temperature is well below room temperature) and is suitable for mild forming and straightening operations. Transformation to martensite is then obtained by refrigeration for 8 hours at -100°F. This can be carried out conveniently in an acetone-dry ice mixture. The higher conditioning temperature of the RH 950 treatment over that for the TH 1050 treatment also permitted retention of more carbon in solid solution in the austenite, which results in a stronger and harder martensite after transformation. The final treatment at 950°F caused additional hardening believed to occur principally by precipitation of an aluminum-nickel compound.

The structure of the material as-treated to the RH 950 condition is shown in Figures 31 and 32 at 1000X optical magnification. The only noticeable change from condition A is the martensitic structure of the matrix and the appearance of carbides at the delta ferrite boundaries. Figures 33 and 34 show the structure of a specimen crept to 0.94 percent deformation in 100 hours at 800°F. The elongation of this specimen was 1.5 percent in a room temperature tension test. This was in contrast to the 8.2 percent elongation of the as-treated condition. No readily noticeable structural change from the as-treated condition was apparent.

Due to the inconclusive results from the optical examination, recourse to electron microscope techniques was used in an attempt to resolve the structure. Although considerable effort was expended, the results were not entirely satisfactory due to the difficulties in finding a suitable etchant. Of the large number of etchants tried, only a modified nital, a 15% HCL, 5% HNO_3, 80% alcohol mixture, appeared to bring out the structure without causing widespread pitting. Even so, the etching response was not entirely uniform from sample to sample and some doubt exists as to whether all phases of interest were delineated.

Representative electron micrographs at 3500X of samples etched with modified nital are shown in Figs. 35 - 42. Also included are the elongations obtained in room temperature tensile tests of the specimens. A noticeable difference in structure exist between Condition A (Fig. 35) and the as-treated Condition RH 950. (Figure 36). In the RH 950 sample, carbide particles appear to have formed at the delta ferrite grain boundaries, the delta ferrite shows a roughening, and the matrix exhibits a transformation. The differences between the as-treated structure (Figure 36) and the specimens exposed to creep (Figures 37 - 42) are very slight if any. The roughness in the delta ferrite is less evident in the samples exhibiting low ductility after exposure, but otherwise neither the matrix nor the carbides appear to have been affected. A positive identification of the precipitating aluminum-nickel phase could not be made from these studies. It could be speculated that the roughness in the ferrite is associated with the precipitation reaction, however, this is not at all conclusive. The decrease in the roughness in the crept samples may merely be due to the application of the stress and only coincidentally associated with the decrease in elongation.

X-RAY STUDIES

A limited X-ray diffraction study was made of two samples of 17-7PH (RH 950) in a further attempt to identify the structural changes, if any, resulting from exposure to creep. The specimens examined were an as-treated specimen and a specimen exhibiting a change in room temperature mechanical properties following 100 hours creep at 800°F. Optical micrographs of this specimen were presented in Figures 33 and 34. The mechanical properties of both specimens are summarized in Table 13. Specimen 6L-T6 exhibited an 11-12 percent increase in the ultimate tensile and yield strengths and an 80 percent decrease in elongation following 0.94 percent creep. Hardness increased almost 3 points in the Rockwell "C" scale. It should be recognized, however, that a major portion of the change in properties probably resulted from the exposure to temperature. This is evident from an examination of Figure 14.

Three types of X-ray diffraction examinations were carried out on the specimens. A powder pattern was made from filings of the as-treated specimen, patterns were made from the solid samples themselves, and finally the minor phases were investigated with the aid of powder patterns from extraction residues. The data obtained from the diffraction films are summarized in Table 13, parts A, B, and C.

Part A, Table 13, summarizes the measurements made from the Hull-Debye-Scherrer powder patterns of filings from the as-treated specimen. Exposure was for 6 hours in a 114.6 mm diameter camera utilizing vanadium-filtered chromium radiation. Only three diffraction lines were obtained and they were all identified as being produced by martensite having an average lattice parameter of 2.88A.

The solid samples were subjected to diffraction in a Phragmen-type camera. (Table 13, Part B). In this case, 10 hours exposure to unfiltered chromium radiation was used. A number of additional lines were obtained, however, the analyses of the films were complicated by the presence of beta reflections. Since the camera was uncalibrated, the martensite lines were used to index the films.

As far as could be determined, the patterns from both specimens were identical. Apparently, therefore, no new phases were present in specimen 6L-T6. Due to the over-all weakness of the patterns it was not possible to determine if there was any significant change in intensity of any of the lines. An increase in intensity of certain lines would be good evidence for continued precipitation of an existing phase during the creep exposure. In these patterns, the martensitic lines were readily accountable, however, the other weak lines could not be identified. Three of the lines--at "d" values of 2.07, 1.80 and 1.29--fit the patterns for CrC and others fit the patterns for NiAl or Ni3Al, or even austenite, however, the evidence for the existence of any of these compounds from these patterns must be considered inconclusive.

The factors making difficult the identification of the patterns from the solid samples were the following:

1. Several phases might be present for which only the stronger lines were recorded in the film. Since many carbide precipitates have their stronger lines at the same or very similar "d" value the differentiation between phases is rendered very difficult.

2. Additional lines that could be used to differentiate between carbides may be superimposed on matrix lines.

3. Due to the physical limitations of the diffraction camera, lines falling at "d" values of less than 1.17 were not recorded. Thus, many conceivably useful lines were not available.

4. Finally, standard patterns may not even be available for some of the phases.

Since the results of the examination of solid samples were inconclusive, a further study was carried out on the minor phases. These phases were obtained by either electrolytic or chemical extraction from the solid samples. This procedure has the advantage of concentrating the minor phases so that a greater amount is available for diffraction and also eliminating possible interference from matrix lines.

The extractions were performed by using an electrolytic separation in 10 percent (volume) hydrochoric acid or a chemical separation in a warm 10 percent bromine-anhydrous methyl alcohol solution.

The hydrochloric acid extraction was carried out for 2 hours at a current density of 1.5-2 amperes per square inch. The resulting solution and residues were centrifuged and washed with distilled water repeatedly until a clear centrifuged solution was obtained.

The bromine extractions were carried out for 2 hours with care taken that the solutions did not become overheated. The separated particles and solutions were then centrifuged and washed in anhydrous methyl alcohol.

In the case of the electrolytic hydrochloric acid extractions, a fine dispersion of particles was found adhering to the side of the centrifuge tube after the residue and solution had been centrifuged. This was scraped from the tube and subjected to X-ray analysis as were the major residues.

The dried residues were placed in 0.03 mm diameter glass capillary tubes for diffraction analysis in a 114.6-mm diameter Hull-Debye-Scherrer Camera. Vanadium filtered chromium radiation (40 KV, 10 Amps) was used for the 7-10 hour exposures.

The diffraction patterns from the extraction residue are tabulated in Part C, Table 13. The patterns from the fine "adhered" particles from the hydrochloric acid extraction were identical to those obtained from the major residue. This was determined by visual comparison and consequently the films were not measured or reported in Table 13.

The patterns for the hydrochloric acid and bromine extractions were fairly similar. The major difference between the patterns was the observation of the 2.03, 1.62, 1.44 and 1.18 "d" value lines in the HCl residues and not from the bromine residues. These represent a compound or compounds soluble in bromine but not in

hydrochloric acid. There is further evidence from the intensity differences of the patterns from the HCl extracts that a larger amount of this phase was present in specimen 6L-T6 than in the as-treated condition. No other consistent difference was observed between the patterns.

Specific identification of the compounds present in these patterns is quite complex. In Table 13, Part C are listed the standard patterns of a number of compounds exhibiting fairly close correspondence to the lines present in the residues. A majority of the lines match the standard pattern for $M_{23}C_6$, however, it is very difficult to obtain accurate identification of carbides by the present technique when more than one is present. This can be readily seen by the similarity of "d" values for the several carbides listed. Furthermore, it is either known or suspected that substitution of various elements can occur in most of the carbides. For example, $M_{23}C_6$, where M = Cr, and/or Fe. This could appreciably alter the lattice parameter and structure factors so that the "d" values and intensities might be considerably changed from the standard patterns.

The set of lines have "d" values of 2.03, 1.62, 1.44, and 1.18 which were found not only to be increased in intensity in specimen 6L-T6 but also to be from a compound insoluble in HCl, show a fairly good fit to the pattern for NiAl. This could be taken as evidence of further precipitation of NiAl during creep exposure. Lines that fit the pattern for Ni_3Al were also present, but the intensity evidence is not as suggestive as that for the NiAl. In addition, interference from other possible compounds is present for some of the stronger Ni_3Al lines. The evidence for other compounds is even less conclusive and consequently, all identification must be regarded as highly tentative.

Several lines were found that show good agreement with the pattern for TiN. Although titanium is not an alloying constituent in 17-7PH steel, optical examination revealed the presence of Ti(C, N)--titanium carbonitride--in the structure. This is probably the source of the TiN lines. The stronger lines from the standard pattern for TiC did not fit any of the measured lines. A few additional lines were observed that did not fit any of the standard patterns that were consulted.

The conclusions to be drawn from this limited X-ray study are the following:

1. The as-treated structure consists of martensite and several compounds.

2. A tentative identification of $M_{23}C_6$ was made for one of the compounds.

3. Several other carbides are probably present--notably Cr_7C_3.

4. Titanium nitride was tentatively identified.

5. A set of lines, tentatively identified as NiAl--and/or possibly Ni_3Al--was found to show increased intensity after a creep exposure that produced increased strength and decreased ductility.

6. The compound showing this behavior was soluble in bromine but not in HCl.

7. No apparent change in the matrix or the carbides was observed as the result of creep-exposure.

8. Optical microscopy indicated the presence of delta ferrite and titanium carbonitride, but no specific confirmation of these phases was found by X-rays.

Thus, it was fairly well established by these studies that the change in mechanical properties following creep-exposure of specimen 6L-T6 resulted from a continuation of an existing precipitation reaction rather than the appearance of a new phase. The precipitate concerned is probably NiAl.

FACTORS GOVERNING PROPERTY CHANGES

Examination of the data shows that the short-time mechanical properties of 17-7PH (RH 950) following creep-exposure were governed by two major factors:

1. An inherent structural instability.

2. The plastic deformation produced by creep.

These factors acted either independently or concurrently depending on the temperature of exposure. In addition, the time of exposure had modifying effects on each one.

In the 600°F exposures the amount of plastic strain governed subsequent properties; in the 900°F exposure it was the exposure to temperature that was important; while in the 800°F exposures there was an inter-mixture of the two major factors which was further influenced by the exposure time.

From the standpoint of microstructure, in the RH 950 condition of this material the properties were developed by a multi-step heat treatment that had the following effects:

1. Caused the formation of carbides.
2. Caused the transformation of austenite to martensite.
3. Caused precipitation of an aluminum-nickel compound.

Metallographic and X-ray studies indicated that there was apparently no change in the carbides as the result of creep exposure.

There was a possibility that some strengthening could have taken place by additional austenite-to-martensite transformation during creep-exposure. This would imply that complete transformation had not been attained originally during the 8 hour refrigeration treatment at -100°F. This was possible inasmuch as heat treatment studies by the producer of the material had indicated that an increase in the refrigeration time to 24 hours produced slightly higher strength and lower ductility (Ref. 4). The metallographic studies in the present investigation failed to indicate any such change in the martensite matrix. There was evidence, however, that a continuation of the precipitation of the aluminum-nickel compound took place during creep-exposure. This reaction appears to have been stress-accelerated and occurred at a lower temperature or a shorter time than if the stress had been absent. An additional possibility is the occurrance of "strain-aging" type reactions which so frequently occur in the temperature range of the exposures. However, verification of the presence or absence of strain-aging was not specifically investigated.

Microscopic examination was also made to determine if micro-cracking could have been a factor in the creep-exposure. Samples were carefully examined in both the etched or unetched conditions after creep-exposure. No indications of internal microcracking were found. In addition, none of the electron microscope replicas exhibited any evidence of microcracks. Some evidence of inter-granular surface corrosion was observed, however.

In order to account for the possible contribution of strain-hardening an experiment was performed in which a specimen was plastically pre-strained 0.5 percent in tension prior to a tension test at room temperature. The ultimate strength of this specimen was virtually unchanged from the base value while the ductility was reduced only from 8.2 percent to 7.5 percent. The tensile yield strength was increased about 14,000 psi. These changes in the ultimate strength and ductility were only a small fraction of the changes observed in these properties following the same amount of creep at 600°F.

Therefore, it was possible to rule out strain hardening as a major factor. The change in the yield strength can be accounted for by the Bauschinger effect.

The application of the concepts of stress-accelerated aging and the Bauschinger effect can be seen from Figure 43 which generally summarizes the results of the room temperature tests. In this plot, the short-time properties are related to the temperature of exposure for two conditions: exposure without stress for 100 hours, or creep to one percent strain in 100 hours. The data for the unstressed exposure provide a measure of the inherent structural instability of the material.

The exposure at 600°F in the absence of stress had a slight effect on room temperature strength and ductility. An increase in the exposure temperature to 800°F caused an increase in the strength and a decrease in the ductility, while the 900°F exposure resulted in some drop in strength from the 800°F value and a continuation of low ductility. This behavior is typical of an aging reaction. The maximum aging effect occurred at 800°F while overaging caused the drop to 900°F.

The application of one-percent creep strain caused large effects, (in addition to those produced by the exposure alone) following 600°F creep, some effects following 800°F creep and little or no effect following 900°F creep.

For instance, the increase in the tension yield strength and the decrease in the compression yield strength following 600°F creep is behavior characteristic of the Bauschinger effect. The Bauschinger effect is caused by the residual stress associated with plastic deformation of a structure whose properties are orientation sensitive. For most materials the Bauschinger effect is at a maximum for plastic strains of between one and three percent.

Since the Bauschinger effect has been observed both in single crystals and in polycrystalline materials, the usual explanation for the effect based on the differences in orientation between grains in a poly-crystalline aggregate is not rigorous. A better approach is to consider the effect to be related to the differential orientation of residual stresses around slip bands. For instance, following removal of a given applied tensile load, some portions of the structure can be in residual compression. When the load is re-applied, this residual compressive stress first must be overcome before the entire structure is again in tension. Therefore, the net tensile load to cause a given

amount of yielding is increased. Conversely, if portions of the structure are in residual compression following pre-strain in tension, then a smaller net compressive load must be applied in order to cause compressive yielding. The Bauschinger effect therefore causes an increase in the yield strength in the direction of pre-strain and a decrease in yield strength in the opposite direction.

Whatever the ultimate cause, the Bauschinger effect follows plastic deformation, and therefore, the usual effects of plastic deformation on mechanical properties must be considered. However, the change in properties from 600°F creep-exposure is greater than can be accounted for by strain-hardening alone and thus other factors must have been present. The fact that a slight change in properties also accompanied unstressed exposure at 600°F indicates that the aging reaction was also present during the creep-exposure. Therefore, the changes in properties were due to a combination of stress-accelerated aging, a possible slight contribution due to strain-hardening, and to the Bauschinger effect.

The aging reaction as it occurred in 100 hours at 600° or 800°F is one that increased both the tension and compression yield strengths and the ultimate strength. Thus, if there was an inherent tendency for the compression yield strength to be increased by aging, the value of the compression yield strength observed after the application of tensile creep must be a net strength, reflecting the positive contribution of the aging reaction and the decrease caused by the Bauschinger effect. Similarly, the increased tension yield strength must include both the increase from the Bauschinger component plus the increase from the aging component.

This explanation would account for the increased **tension** yield strength and the apparent lack of a decrease in the compression yield strength following the 800°F creep-exposure. The slight additional decrease in ductility could then be explained by the combined action of strain hardening and a stress-induced aging reaction.

The exposure without stress for 100 hours at 900°F appears to be overaging since it caused a reduction in the ultimate tensile strength and tensile yield strength. At this point the compression yield strength may have been at its peak value since it could be possible that the yield strengths were affected at slightly different rates by the aging reaction. If this were true, then the decrease in the compression yield strength following creep at 900°F could then have been due to over-aging and not to a Bauschinger effect. The Bauschinger effect could be ruled out since if it had been operative there should have been an increase in the **tension** yield

strength after 900°F creep exposure--in addition to the decrease in compression yield strength. Recovery effects tend to minimize the Bauschinger effect at 800° or 900°F . The decrease in the elongation after 900°F exposure can be attributed to stress-induced overaging.

Stress-accelerated aging also can be used to account for the effect of creep-exposure on the tension-impact properties. The reduction in tension-impact properties after 900°F creep-exposure was governed by the exposure to temperature. At 800°F there was a loss in strength for a large amount of creep in 100 hours, while there was apparently little effect of creep in the 10 hour exposure. Again at 600°F, creep had some effect in reducing the ductility after the 100 hour exposure but not the 10 hour exposure. Thus, the addition of stress caused a deterioration in properties to take place at a lower temperature or perhaps shorter time than it would normally have occurred at in the absence of stress.

Consideration also was given to the mechanism by which creep took place. It can be reasoned that the tensile and compression properties which in a short-time test depend on slip with grains should be most affected by creep that takes place by the same means. Similarly, properties that depend more on the strength of grain boundaries should be most affected by creep in the boundaries. Thus, damage to short-time properties produced purely by creep might be predictable if the mechanism of creep is known and if there are no extraneous microstructural effects.

A study of the creep-rupture data suggests that the creep at 600°F took place principally by slip within the grains. This was indicated by the fact that the fracture ductilities of the specimens rupturing at 600°F (Figure 7) were not changed particularly from the elongation in the short-time tensile test at this temperature. In the 900°F ruptures, fairly ductile fractures were observed at the longer rupture times, while in the 800°F ruptures there appeared to be a transition in the relative fracture ductility at a stress level of 110,000 psi. A transition in the fracture ductility from brittle to ductile is often taken as an indication of a change in the mode of creep.

Attempts to analyze the creep-exposure data on the basis of the concentration of plastic flow were rendered difficult by the necessity of accounting for the structural instability of the material.

The bulk of the evidence indicates that the creep deformation affected properties principally by its influence on the aging reaction. That is, the stress was mainly a vehicle for producing the aging reaction that governed many of the properties. However, the stress was important by itself at 600°F and for 10 hours at 800°F in producing the Bauschinger effect.

It cannot be emphasized too strongly that evidence to support these contentions is based on inference. There are indications that creep damage to short-time properties might take place by the suggested mechanism; however, in the absence of data free from the effects of microstructural instability, the matter must remain one for speculation. Research conducted on an "ideally simple, structurally stable" material would be of value in testing this hypothesis.

So far the discussion has been based on the properties measured at room temperature after creep at an elevated temperature. An understanding of the results from the short-time tests conducted at the exposure temperature might also be gained by a simple extension of the preceding arguments. That is, the mechanism by which deformation occurs in the elevated temperature short-time test should be related to the mechamism by which creep took place at that temperature. If it is evident that both processes took place in the same way, then prior creep might have a significant effect on the properties. A review of the experimental results reveals that the strength at elevated temperatures generally had about the same dependency or lack of dependency on the amount of prior creep as did the room temperature strength. The major difference in properties was the drop in room temperature ductility following exposure at 800° and 900°F that was not found in the corresponding elevated temperature tests.

It appears fairly well established, therefore, that with the exception of the Bauschinger effect on yield strengths, prior creep affected the properties of 17-7PH (RH 950) by its influence on the aging reaction.

COMPARISON OF RH 950 AND TH 1050 CONDITION

In most respects the effect of creep-exposure on the short-time mechanical properties of the TH 1050 and RH 950 conditions of 17-7PH stainless steel was similar for the particular exposure conditions studied: creep of up to 2 percent in 100 hours in the temperature range from 600° to 900°F. For both conditions there was a decrease in the ductility and the occurrence of a Bauschinger effect in the tests at room temperature or 600°F following creep-

exposure at 600°F. Again for both conditions, the properties following exposure at 800° or 900°F were governed mainly by the exposure to temperature and not by the amount of creep. For neither condition was there a pronounced decrease in the tensile strength after any of the creep-exposures. Whatever change occurred in the tension-impact properties was also similar for both conditions.

Despite these similarities in behavior, there were nevertheless two major differences between the TH 1050 condition and the RH 950 condition. One difference was the behavior of the ductility of the RH 950 condition in room temperature tension tests following 800° or 900°F creep-exposure. In these tests the elongation was reduced to only about one to two percent, principally by the exposure to temperature alone, while the corresponding creep-exposure of the TH 1050 condition did not cause a reduction in the elongation below about 5 percent.

The other difference was the initially higher strength of the RH 950 condition which was also better maintained after creep-exposure. Although the trends in strength behavior of both conditions were similar, the absolute strength level of the RH 950 condition remained from 30,000 to 60,000 psi higher than that of the TH 1050 condition. Where the strength of both conditions was changed as a function of the amount of creep, the relative change of the RH 950 condition was also less.

Most other differences between the two conditions were minor and may have been due to experimental variability.

The higher strength of the RH 950 condition was due to two factors associated with the initial heat treatment. First, the higher conditioning temperature permitted retention of more carbon in solid solution in the austenite. This resulted in a stronger and harder martensite after transformation. Secondly, the precipitation hardening treatment was conducted at 950°F instead of 1050°F. This could have affected the size or distribution of the precipitate or the degree of completion of the aging reaction. Continuation of the reaction during creep-exposure could have accounted for the decreased ductility of the RH 950 condition while the TH 1050 condition could have become overaged during the similar exposure.

In applications where an initially high and well-maintained strength level is of importance, the RH 950 condition has obvious advantages over the TH 1050 condition. Where there is occasion to be concerned with the yield strength behavior the Bauschinger effects

observed for both conditions must be considered. Where ductility
is of importance, the less favorable behavior of the RH 950
condition must be taken into account.

CONCLUSIONS

The study of the influence of prior creep on short-time mechanical properties of 17-7PH stainless steel in the RH 950 condition shows that:

1. The ductility at room temperature and the exposure temperature decreased significantly following prior creep at 600° and for short-times at 800°F.

2. The ductility was also reduced by exposure to temperature alone for exposures at 900°F and for longer times at 800°F. The amount of prior creep at these temperatures had little effect.

3. Short-time tests at 800° and 900°F following creep-exposures at these temperatures showed that there was little effect on ductility either from the temperature alone or the amount of creep.

4. The room temperature and 600°F tension yield strengths were increased and the room temperature and 600°F compression yield strengths were decreased by prior creep at 600°F.

5. The ultimate tensile strength and hardness were not significantly altered.

6. The tension-impact strength appeared to be decreased by creep-exposure although the effects were erratic.

The effects of creep exposure observed on the RH 950 condition of 17-7PH were generally similar to the effects observed on the TH 1050 condition with the following exceptions:

1. The RH 950 condition was initially stronger and maintained its strength better after creep-exposure.

2. The RH 950 condition exhibited a greater loss in room temperature ductility following 800° or 900°F exposure.

The information available on the RH 950 condition indicates that the observed effects on short-time mechanical properties were mainly due to an aging reaction. This reaction took place at 800° and 900°F under the influence of temperature alone. At 600°F the reaction was stress-activated. The data suggested that this occurred by additional

precipitation of a nickel-aluminum compound although it should be recognized that strain aging reactions which so frequently occur in this temperature range could have been involved.

In addition, the divergence between the tension and compression yield strengths following the 600°F creep exposures was due to the Bauschinger effect. The Bauschinger effect following the 800° and 900°F exposure was minimized by the combination of aging and possible recovery effects.

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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).

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TABLE 1

TENSILE DATA FOR 17-7PH ALLOY (RH 950 CONDITION)

Test Temp. (°F)	Spec. No.	Ult. Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus, E (10^6 psi)	Hardness R"C"
Room	4D-T3	237,500	224,500	8.5	16.2	27.8	49.2
	4S-T5	237,500	218,500	8.0	15.2	29.8	49.2
		237,500	221,500	8.2	15.7	28.8	49.2
	5A-T5	242,500	227,500	8.0	11.5	28.8	47.4
	5G-T2	237,500	223,500	8.0	15.0	28.0	47.0
		240,000	225,500	8.0	12.8	28.4	47.2
	6C-T6	235,400	221,400	8.0	15.3	28.4	47.2
	6P-T6	235,500	219,500	9.0	17.0	29.3	49.4
		235,950	220,450	8.5	16.2	28.8	48.3
Average - 6 Tests		237,650	222,480	8.2	15.0	28.7	48.2
600	4S-T6	200,000	178,000	9.0	16.4	28.1	
	4B-T4	205,000	174,000	8.5	12.1	28.0	
		202,500	176,000	8.8	14.2	28.0	
	5G-T6	200,000	173,000	8.0	16.0	28.4	
	5Q-T1	198,000	167,000	6.5	12.5	28.0	
		199,000	170,000	7.2	14.2	28.2	
	6D-T2	199,000	170,000	5.5	14.2	28.4	
	6H-T2	192,000	169,000	9.3	14.0	29.2	
		195,500	169,500	7.4	14.1	28.8	
Average - 6 Tests		199,000	171,830	7.8	14.2	28.4	
800	4D-T6	171,000	157,000	10.0	29.4	27.4	
	4H-T4	163,000	140,000	13.0	29.0	21.2	
		167,000	148,500	11.5	29.2	24.3	
	5A-T2	171,200	151,000	17.3	28.4	25.5	
	5R-T6	162,000	142,000	13.3	27.5	29.1	
		166,600	146,500	15.0	28.0	27.3	
	6P-T2	167,500	147,000	19.5	33.0	22.6	
	6L-T4	166,000	151,000	13.0	31.6	24.8	
		166,750	149,000	16.2	32.3	23.7	
Average - 6 Tests		166,783	148,000	14.4	29.8	25.1	
900	4D-T1	131,800	114,000	19.0	36.0	23.0	
	4E-T5	142,000	116,000	11.8	33.4	23.6	
		136,900	115,000	15.4	34.7	23.3	
	5C-T1	140,000	126,000	14.5	33.8	24.5	
	5M-T1	135,000	125,000	18.0	38.2	21.8	
		137,500	125,500	16.2	36.0	23.2	
	6C-T5	131,800	122,400	25.8	45.4	25.6	
	6S-T1	144,000	124,000	18.3	31.6	23.5	
Average - 6 Tests		137,433	121,233	17.9	36.4	23.7	

TABLE 2

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 3

TENSION-IMPACT TEST DATA FOR 17-7PH (RH 950 CONDITION)

Test Temp. (°F)	Spec. No.	Tension-Impact Strength ft.-lb.	Elongation (%)	Reduction of Area (%)
Room	4E-T43	44	3.5	18.4
	4H-T52	38	3.0	12.8
	5Q-T33	44	3.0	12.4
	6S-T33	46	3.0	12.0
	Average	43	3.1	13.9
600	4P-T31	46	*	15.6
	5L-3X	38	4.5	20.0
	6S-T31	44	4.5	15.6
	Average	42.6	4.5	17.0
800	4H-T11	26	2.5	19.4
	5B-3X	35	3.5	18.0
	5S-3X	41	*	--
	6D-T12	29	3.0	20.0
	Average	32.7	3.0	19.1
900	4H-T13	27	*	19.9
	5Q-T31	28	*	21.6
	6J-3X	29	3.5	26.0
	Average	28	(3.5)	22.5

* Speciman inadvertently bent following fracture.

TABLE 4

RUPTURE AND CREEP DEFORMATION DATA FOR 17-7PH (RH 950 CONDITION)

Test Temp. (°F)	Spec. No.	Stress (psi)	Rupture Time (hrs)	Elongation (% in 2 in.)	R.A. (%)	Hardness After Test (R"C")	Total Loading Def. (%)	Plastic Loading Def. (%)	Time to Reach Indicated Creep Deformation (hrs) 0.2	0.5	1.0	2.0	Final Creep Deformation (%)	Total Plastic Deformation (%)	Ult. Tensile Strength (%)	0.2% Offset Yield Strength (psi)	Elongation (% in 2 in.)	R.A. (%)	Modulus, E (10⁶psi)
600	4C4	183,000	310.7	12	22	50.4	0.95	0.30	0.1	0.8	8.2	41	>7.95	--	--	--	--	--	--
	5A6	178,000	2228.8	11.5	--	--	0.80	0.20	0.5	7.5	43	218	9.20	9.40	--	--	--	--	--
	6P4	175,000	1180.4	13	26	50.5	0.95	0.21	1	4	24	136	>>3.4	--	--	--	--	--	--
	4S4	172,500	673 *	--	--	49.4	0.66	0.11	8	105	640	--	1.02	1.13	267,000	267,000	3.0	9.8	30.7
	4S2	170,000	437 *	--	--	47.9	0.83	0.18	12	44	310	--	1.12	1.30	263,000	263,000	1.5	11.0	29.0
	5G1	160,000	331.1*	--	--	49.2	0.69	0.12	23	272	--	--	0.53	0.65	256,000	256,000	2.5	12.1	30.3
	6TT5	150,000	361 *	--	--	49.4	0.55	0.05	248	--	--	--	0.21	0.26	250,000	250,000	5.0	11.0	29.0
800	4D5	132,000	27.5	16	31	51.3	0.61	0.06	.15	.8	3.3	8.4	10.9**	--	--	--	--	--	--
	6P6	125,000	74.1	19	33	51.9	0.47	0.04	.8	3.5	11.5	28.5	>>3.6	--	--	--	--	--	--
	4ET6	117,000	167.4	13	38	--	0.50	nil	1	8.5	45	97	4.9**	4.9	--	--	--	--	--
	4D2	110,000	247.5	13	31	51.8	0.46	0.05	5.5	32	101	169	>>2.4	--	--	--	--	--	--
	6C4	100,000	437.1*	--	--	51.3	0.38	0.02	16	100	425	--	2.11	2.13	265,000	260,000	<2.0	1.2	29.5
	5A4	90,000	381.7*	--	--	51.9	0.36	nil	9	140	346	--	1.11	1.11	>266,000	263,000	--	--	29.2
	6C1	90,000	1615	28.5	47	--	0.36	nil	29	250	490	730	15.2**	15.2	--	--	--	nil	--
	5JT3	80,000	575.2*	--	--	51.0	0.31	nil	140	558	--	--	0.52	0.52	--	264,000	<1.0	--	30.3
900	5G3	72,000	48.6	34	43	50.0	0.28	0.03	0.7	2.6	5.6	13.5(est.)	>>2.0	--	--	--	--	--	--
	4S3	70,000	70±6	46	51	50.0	0.28	nil	Off scale-reference point lost,				>1.7	--	--	--	--	--	--
	6C2	60,000	194.9	40	54	50.2	0.22	nil	3	8	18	38	>>3.3	--	--	--	--	--	--
	5G5	50,000	613.9	38	53	49.3	0.21	nil	7.5	25	62	134	>9.5	--	--	--	--	--	--
	4D6	35,000	336.5*	--	--	49.8	0.14	nil	20	108	315	--	>1.04	1.04	247,000	243,000	4.0	7.3	28.2
	5A3	20,000	843 *	--	--	49.1	0.10	nil	94	1100(est.)	--	--	0.43	0.43	236,000	232,000	4.0	16.0	29.1

> Greater than.
>> Much greater than.
< Less than.
* Stopped at.
** Estimate.

TABLE 5

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

Spec. No.	Exposure Conditions Temp. (°F)	Stress (psi)	Time (hr)	Test Temp (°F)	Ult. Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (% in 2 in.)	Reduction of Area (%)	Modulus E (10⁶psi)	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
8S-T1	800	none	100	room	262,000	245,000	2.0	2.5	31.0	--
					264,500	247,750	2.8	3.6	30.2	51.0
6T-T6	900	none	10	room	258,000	242,000	2.8	6.7	31.5	47.9
7J-T44	900	none	10	room	256,000	244,000	1.0	1.0	28.7	--
					257,000	241,000	1.9	3.8	30.1	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
7Q-T4	800	none	50	800	178,200	164,200	10.0	26.4	23.5	--
					173,600	159,950	12.2	27.2	23.7	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
8K-T2	900	none	100	900	124,000	112,500	14.5	43.5	19.0	--
					128,000	119,750	14.2	39.3	19.6	50.0

TABLE 6

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

| | Exposure Conditions | | | | Compression Properties After Exposure | |
| | | | | | 0.2% Offset | Compression |
Spec. No.	Temp (°F)	Stress (psi)	Time (hr)	Test Temp. (°F)	Yield Strength (psi)	Modulus, E (10⁶psi)
4K-T45	600	none	10	room	237,000	28.9
8S-T4	600	none	10	room	249,000	28.8
					243,000	28.8
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
4N-T33	900	none	10	room	264,000	29.4
					263,500	30.0
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 7

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

Nominal Exposure Conditions				Actual Exposure Conditions							Room Temperature Tensile Properties After Exposure					
Temp. (°F)	Time (hrs)	Creep Def. (%)	Spec. No.	Time (hrs)	Stress (psi)	Total Load Def. (%)	Plastic Load Def. (%)	Creep Def. (%)	Total Plastic Def. (%)	Total Def. (%)	Ult. Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (%)	Reduction of Area (%)	Modulus, E (10⁶ psi)	Hardness (R"C")
680	10	0.2	7B-T5	10.0	171,000	0.76	0.07	0.32	0.39	1.08	252,000	252,000	2.0	6.9	31.2	49
		0.5	6F-T7	10.0	176,000	0.92	0.31	0.44	0.75	1.36	229,000	229,000	1.5	5.9	28.0	--
		1.0	8U-T2	10.0	182,069	0.88	0.21	1.12	1.33	2.00	251,000	251,000	2.5	13.8	29.5	--
		2.0	7A-T6	10.0	188,000	1.07	0.53	3.48	4.01	4.55	261,500	261,500	1.5	8.0	28.0	--
	50	0.2	8M-T3	50.0	158,000	0.63	0.03	0.17	0.20	0.80	248,000	247,000	4.0	17.6	26.6	--
		0.5	7P-T4	50.0	172,000	0.85	0.13	1.05	1.18	1.90	259,000	259,000	2.0	12.0	26.4	--
		1.0	8K-T5	50.0	179,000	0.91	0.26	1.27	1.53	2.18	260,500	260,500	2.5	12.2	31.5	--
		2.0	7H-T6	50.0	183,000	1.02	0.30	3.46	3.76	4.48	272,000	265,500	1.0	5.7	31.6	--
	100	0.2	5R-T3	100.0	152,000	0.60	0.06	0.17	0.23	0.77	247,000	239,000	7.5	15.6	29.1	49
		0.5	4K-T2	100.0	179,000	0.84	0.16	0.68	0.84	1.52	258,000	254,000	1.5	9.0	28.6	48
		1.0	6L-T1	100.0	177,000	0.90	0.30	1.12	1.42	2.02	261,000	261,000	1.0	nil	28.6	50
		2.0	4P-T4	100.0	181,200	1.02	0.34	1.64	1.98	2.66	263,000	263,000	1.0	7.4	30.3	50
800	10	0.2	7J-T5	10.0	102,000	0.40	nil	0.19	0.19	0.59	252,000	240,500	2.5	4.2	27.3	--
		0.5	5M-T3	10.0	118,000	0.44	nil	0.52	0.52	0.96	258,000	256,000	2.3	4.7	29.4	51
		1.0	7Q-T1	10.0	126,000	0.53	0.05	1.30	1.35	1.83	260,000	260,000	1.0	3.5	29.1	52
		2.0	8T-T5	10.0	131,000	0.53	0.05	1.58	1.63	2.11	261,000	261,000	<5	3.1	29.6	52
	50	0.2	8M-T4	50.0	91,478	0.35	nil	0.21	0.21	0.56	257,500	248,000	3.5	6.5	29.6	--
		0.5	7G-T6	50.0	106,000	0.42	nil	0.57	0.57	0.99	263,800	260,000	1.5	2.2	28.3	--
		1.0	8L-T6	50.0	118,000	0.46	nil	1.22	1.22	1.68	263,000	259,000	1.5	3.1	26.9	--
		2.0	7Q-T2	50.0	122,000	0.55	nil	4.45	4.45	5.00	263,000	261,500	1.5	5.6	28.4	--
	100	0.2	5R-T5	100.0	82,000	0.32	nil	0.21	0.21	0.53	>258,000	--	.	.	.	52
			8T-T2	100.0	82,000	0.31	nil	0.24	0.24	0.55	268,000	261,000	2.0	2.8	28.8	53
		0.5	4P-T5	100.0	100,000	0.40	0.03	0.51	0.54	0.91	>264,000	--	-	-	27.8	50
			7C-T6	100.0	101,000	0.38	0.01	0.55	0.56	0.93	266,000	263,000	nil	nil	30.2	53
		1.0	6L-T6	100.0	115,000	0.43	nil	0.94	0.94	1.37	267,000	246,000	1.5	3.0	29.8	61
			8U-T3	100.0	115,000	0.50	nil	1.22	1.22	1.72	266,000	264,000	nil	nil	28.0	52
		2.0	5C-T4	100.0	117,000	0.46	nil	1.16	1.16	1.62	262,000	260,000	1.0	1.7	27.2	52
			7Q-T5 (failed)	91.0	118,000	0.52	nil	--	-- (at 83 hrs)5.1	--	--	.	.	.	
	10	0.2	4E-T3	10.0	45,000	0.18	nil	0.23	0.23	0.41	>248,000	--	-	-	-	49
			8T-4	10.0	45,000	0.18	nil	0.27	0.27	0.45	254,000	246,000	2.0	4.0	28.1	51
		0.5	6H-T4	10.0	58,000	0.22	nil	0.52	0.52	0.74	244,000	237,000	2.5	5.7	27.2	51
		1.0	5T-T5	10.0	66,000	0.28	nil	0.70	0.70	0.98	251,000	242,000	1.0	2.2	33.1	51
		2.0	5Q-T5	10.0	76,000	0.30	0.02	2.09	2.11	2.39	246,500	231,000	5.0	7.8	28.1	49
			7A-T1	10.0	76,000	0.29	nil	3.21	3.21	3.50	235,000	229,000	nil	nil	29.4	--
	50	0.5	8E-T3	50.0	42,000	0.17	0.07	0.58	0.65	0.75	242,000	236,000	2.5	nil	29.4	--
		1.0	5F-T1	50.0	52,000	0.21	nil	1.31	1.31	1.52	256,000	240,000 (est.)	2.0	3.5	28.6	--
		2.0	7C-T1	50.0	59,000	0.24	nil	3.50	3.50	3.74	237,000	228,000	nil	nil	28.1	--
	100	0.2	4S-T5	100.0	18,000	0.07	nil	0.16	0.16	0.23	230,000	230,000	1.5	6.6	28.4	--
		0.5	5T-T3	100.0	36,000	0.15	nil	0.54	0.54	0.69	252,000	243,000	1.5	2.2	32.3	50
		1.0	8T-T3	100.0	45,000	0.20	nil	1.34	1.34	1.54	252,000	248,000	2.0	2.5	29.4	50
		2.0	7C-T3	100.0	52,000	0.21	0.02	2.34	2.36	2.55	254,000	254,000	1.5	2.5	31.6	51

TABLE 8

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

| Nominal Exposure Conditions | | | | Actual Exposure Conditions | | | | | | | | Compression Properties After Exposure | |
Temp. (°F)	Time (hrs)	Creep Def. (%)	Specimen No.	Time (hrs)	Stress (psi)	Total Load Def. (%)	Plastic Load Def. (%)	Creep Def. (%)	Total Plastic Def. (%)	Total Def. (%)	Test Temp. (°F)	0.2% Offset Yield Strength (psi)	Modulus, E (10⁶psi)
600	10	0.2	6F-T6	10.0	171,000	0.82	0.15	0.43	0.58	1.25	room	231,000	28.3
		0.5	5M-T4	10.0	176,000	0.80	0.15	0.53	0.68	1.33	room	206,000	28.8
		1.0	4H-T3	10.0	182,000	1.38	0.64	1.56	2.20	2.94	room	193,000	28.9
		2.0	6H-T3	10.0	189,000	1.27	0.61	2.59	3.20	3.86	room	192,000	26.8
	50	0.2	6U-T3	50.0	159,000	0.64	0.07	0.31	0.38	0.95	room	238,500	27.1
		0.5	7H-T3	50.0	172,000	0.74	0.13	0.58	0.71	1.32	room	211,000	28.6
		1.0	8M-T5	50.0	179,000	0.92	0.26	0.91	1.17	1.83	room	202,000	27.6
		2.0	7Q-T6	50.0	183,000	0.72	0.17	0.65	0.82	1.37	room	205,800	31.0
			7B-T1	50.0	183,000	0.85	0.21	1.61	1.82	2.46	room	206,000	28.7
	100	0.2	4H-T6	100.0	153,000	0.56	nil	0.16	0.16	0.72	room	215,000(?)	30.0
			6S-T2	100.0	154,000	0.68	nil	0.34	0.34	1.02	room	235,000	30.1
		0.5	5M-T5	100.0	169,000	0.79	0.11	0.67	0.78	1.46	room	222,000	30.6
		1.0	6T-T4	100.0	177,000	0.89	0.14	1.47	1.61	2.36	room	208,000	31.9
		2.0	5C-T3	100.0	181,000	1.02	0.30	1.84	2.14	2.86	room	223,000	29.8
800	10	0.2	8U-T4	10.0	102,000	0.46	nil	0.30	0.30	0.76	room	257,000	31.1
		0.5	7H-T4	10.0	118,000	0.47	nil	0.56	0.56	1.03	room	249,000	30.1
		1.0	8S-T2	10.0	126,000	0.52	nil	1.17	1.17	1.69	room	243,000	29.2
		2.0	7P-T1	10.0	132,000	0.55	nil	1.36	1.36	1.91	room	242,000	30.1
	50	0.2	5F-T3	50.0	91,500	0.34	nil	0.32	0.32	0.68	room	272,000	29.8
		0.5	7J-T1	50.0	106,000	0.44	nil	0.70	0.70	1.14	room	258,000	27.8
			4U-T3	50.0	106,000	0.42	nil	0.64	0.64	1.06	room	264,000	30.4
		1.0	7A-T4	50.0	118,000	0.52	0.06	1.28	1.34	1.80	room	252,000	30.7
		2.0	8L-T3	50.0	121,000	0.55	0.08	3.68	3.76	4.13	room	254,000	29.7
	100	0.2	6T-T3	100.4	82,000	0.34	nil	0.23	0.23	0.57	room	263,000	31.9
		0.5	5C-T2	100.0	100,000	0.37	nil	0.45	0.45	0.82	room	247,000	30.4
		1.0	4K-T5	100.0	115,000	0.43	nil	1.07	1.07	1.50	room	261,000	31.6
		2.0	5J-T5	100.0	117,000	0.49	0.08	1.70	1.78	2.19	room	258,000	30.0
900	10	0.2	5Q-T6	10.1	45,000	0.19	nil	0.27	0.27	0.46	room	264,000	30.5
		0.5	4P-T2	10.0	58,000	0.24	nil	0.38	0.38	0.62	room	259,000	32.7
		1.0	6H-T5	10.0	67,000	0.27	nil	1.04	1.04	1.23	room	253,000	31.6
		2.0	6L-T3	10.0	75,000	0.32	0.02	2.19	2.21	2.51	room	246,000	29.3
	50	0.5	4U-T2	50.0	41,000	0.15	nil	0.48	0.48	0.63	room	271,000	29.6
		2.0	8F-T3	50.0	59,000	0.45	nil	3.39	3.39	3.84	room	259,000	32.1
	100	0.2	5Q-T4	100.0	18,000	0.05	nil	0.16	0.16	0.21	room	257,000	31.8
		0.5	4N-T1	100.0	36,000	0.14	nil	0.44	0.44	0.58	room	261,000	32.5
		1.0	6F-T3	100.0	45,000	0.18	nil	1.17	1.17	1.35	room	262,000	29.2
		2.0	5J-T1	100.0	52,000	0.19	nil	2.43	2.43	2.62	room	254,000	29.4

TABLE 9

EFFECT OF PRIOR CREEP EXPOSURES ON ELEVATED TEMPERATURE 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)	Stress (psi)	Total Load Def (%)	Plastic Load Def (%)	Creep Def (%)	Total Plastic Def (%)	Total Def (%)	Test Temp. (°F)	Ult. Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (%)	R.A. (%)	Modulus,E (10⁶psi)	Hardness Rockwell "C"
600	10	0.2	8U-T6	10.0	169,000	0.79	0.11	0.31	0.42	1.10	600	198,000	198,000	7.5	14.3	25.5	49
		0.5	6D-T5	10.0	176,000	0.80	0.05	0.74	0.79	1.54	600	216,000	216,000	2.0	7.0	25.6	50
		1.0	8S-T5	10.1	182,000	1.11	0.39	0.99	1.38	2.10	600	213,000	213,000	1.5	7.6	25.6	50
		2.0	7P-T5	10.0	187,000	1.18	0.45	2.18	2.63	3.36	600	217,000	214,000(est.)	1.7	8.3	25.5	50
	100	0.2	6S-T4	100.0	153,000	0.61	nil	0.15	0.15	0.76	600	205,900	196,000	8.5	21.1	26.4	49
		0.5	5M-T2	100.0	169,000	0.79	0.15	0.91	1.06	1.70	600	208,000	---	4.5	13.6	25.1	--
		1.0	6F-T1	100.0	177,000	0.96	0.26	1.40	1.66	2.36	600	214,000	214,000	2.0	10.5	26.8	--
		2.0	4B-T6	100.0	181,200	1.02	0.30	3.66	3.96	4.68	600	220,000	220,000	2.5	10.9	26.6	49
800	10	0.2	8S-T3	10.0	100,000	0.36	nil	0.21	0.21	0.57	800	173,000	140,000(?)	13.0	29.8	25.0	--
		0.5	7P-T3	10.0	118,000	0.52	0.03	0.61	0.64	1.13	800	172,500	172,500	14.5	33.3	24.4	--
		1.0	8L-T1	10.0	126,000	0.53	0.06	1.03	1.09	1.56	800	181,800	179,900	11.0	26.1	24.1	--
		2.0	8M-T2 / 7G-T2	10.9 / 10.0	133,000 / -133,000	0.60 / 0.66	? / 0.04	1.07 / 1.91	1.07+ / 1.95	1.67+ / 2.57	800 / 800	177,700 / 180,000	176,300 / 176,200	12.0 / 12.0	30.2 / 25.5	24.3 / 24.4	--
	50	0.5	7C-T3	50.0	106,000	0.44	nil	0.58	0.58	1.02	800	176,000	176,000	12.0	24.8	24.3	--
		1.0	4U-T1	50.0	118,000	0.49	nil	3.58	3.58	4.07	800	182,000	176,000	11.3	24.0	23.0	--
		2.0	6U-T2 (failed)147.1		121,300	0.47	0.09	--	(at 45.5 hrs)	3.47	-	---	---	--	--	--	--
800	100	0.2	4B-T3	100.0	82,000	0.33	nil	0.21	0.21	0.54	800	184,800	177,000	13.5	23.9	25.5	51
		0.5	6F-T4	100.0	100,000	0.39	nil	0.38	0.38	0.77	800	184,000	177,000	13.5	30.2	24.7	--
		1.0	7B-T6	100.0	115,000	0.42	nil	2.04	2.04	2.46	800	179,000	175,000	12.5	27.5	24.0	--
		2.0	6D-T4	100.0	117,000	0.51	0.05	2.73	2.88	3.24	800	174,500	174,000	14.0	29.4	25.0	52
900	10	0.2	6S-T6	10.1	45,000	0.19	nil	0.32	0.32	0.51	900	137,200	125,700	13.5	35.5	23.7	47
		0.5	8U-T1	10.0	58,000	0.25	nil	0.55	0.55	0.80	900	140,000	140,000	29.5	48.0	22.2	51
		1.0	7P-T2	10.0	67,000	0.27	nil	1.05	1.05	1.32	900	136,000	132,000	16.3	40.0	22.6	51
		2.0	4K-T3	10.1	75,000	0.28	nil	2.49	2.49	2.77	900	136,600	134,800	21.0	45.0	20.4	51
	50	0.5	8K-T3	50.0	43,000	0.13	nil	0.73	0.73	0.86	900	124,000	115,000	17.0	45.4	20.8	--
		1.0	7B-T3	50.0	52,000	0.21	nil	1.41	1.41	1.62	900	135,000	128,500	19.5	38.5	20.7	--
		--	7R-T5	50.0	67,000	0.24	0.07	11.19	11.26	11.43	900	130,000	124,000	22.3	37.2	25.3	51
	100	0.2	8M-T6	100.0	19,000	0.08	nil	0.17	0.17	0.25	900	134,000	124,000	31.5	44.0	22.3	--
		0.5	7R-T1	100.0	36,000	0.12	nil	0.57	0.57	0.69	900	141,000	118,000	26.8	41.0	20.8	47
		1.0	7G-T1	100.0	45,000	0.23	nil	1.85	1.85	2.08	900	135,900	121,800	28.0	40.6	21.9	--
		2.0	8T-T1	100.0	52,000	0.21	nil	2.88	2.88	3.09	900	140,000	131,000	21.3	55.5	23.9	50

TABLE 10

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

Nominal Exposure Conditions Temp. (°F)	Time (hrs)	Creep Def. (%)	Spec. No.	Actual Exposure Conditions Time (hrs)	Stress (psi)	Total Load Def. (%)	Plastic Load Def. (%)	Creep Def. (%)	Total Plastic Def. (%)	Total Def. (%)	Compression Properties After Exposure Test Temp. (°F)	0.2% Offset Yield Strength (psi)	Modulus, E (10^6 psi)
600	10	0.2	8L-T2	11.7	171,000	0.75	0.10	0.31	0.41	1.06	600	180,000	27.5
		0.5	7R-T2	10.0	176,000	0.92	0.15	0.47	0.62	1.39	600	185,000	28.4
		1.0	7G-T5	10.0	182,000	0.86	0.30	0.78	1.08	1.64	600	161,000	28.6
			7B-T4	10.0	182,500	1.02	0.22	0.90	1.12	1.92	600	165,000	28.6
		2.0	8K-T1	10.0	188,000	1.23	0.52	2.40	2.92	3.63	600	163,000	28.1
	100	0.2	5T-T4	100.0	153,000	0.57	nil	0.11	0.11	0.68	600	187,000	30.4
		0.5	8U-T5	100.0	168,000	0.71	nil	0.59	0.59	1.30	600	186,000	26.8
		1.0	6T-T1	100.0	175,000	0.84	0.15	1.31	1.46	2.15	600	168,000	25.3
		2.0	6F-T2	100.0	181,200	1.11	0.36	1.75	2.11	2.86	600	162,000	28.8
800	10	0.2	8K-T4	10.0	102,000	0.44	nil	0.27	0.27	0.71	800	168,000	24.2
		0.5	7H-T1	10.0	118,000	0.42	nil	0.55	0.55	0.97	800	175,800	25.9
			5F-T2	9.9	112,000	0.49	nil	0.49	0.49	0.98	800	174,000	26.8
		1.0	8L-T5	10.0	126,000	0.48	0.04	0.80	0.84	1.28	800	153,000	25.2
			7C-T2	10.0	126,000	0.55	nil	0.93	0.93	1.48	800	166,800	27.4
		2.0	6U-T6	10.0	133,000	0.65	0.09	2.90	2.99	3.55	800	174,000	25.7
	50	0.5	7A-T2	50.0	106,000	0.43	0.02	0.62	0.64	1.05	800	189,000	26.2
		1.0	8D-T2	50.0	119,000	0.47	0.03	2.13	2.16	2.60	800	161,000	26.9
	100	0.2	4B-T1	100.0	82,000	0.30	nil	0.20	0.20	0.50	800	188,200	29.1
		0.5	8T-T6	100.3	100,000	0.38	nil	0.49	0.49	0.87	800	176,000	23.0
		1.0	5C-T5	100.0	115,000	0.43	nil	1.27	1.27	1.70	800	166,000	23.9
		2.0	7R-T4	100.3	117,000	0.50	nil	3.78	3.78	4.28	800	154,000	24.0
900	10	0.2	6D-T3	10.0	45,000	0.19	0.03	0.29	0.32	0.48	900	130,800	21.4
		0.5	8S-T6	10.0	58,000	0.24	0.03	0.52	0.55	0.76	900	125,000	24.0
		1.0	7Q-T3	10.0	67,000	0.25	0.01	1.25	1.26	1.50	900	121,000	23.8
		2.0	4E-T1	10.0	75,000	0.29	nil	2.36	2.36	2.65	900	119,000	22.7
	50	0.5	7B-T2	50.0	43,000	0.16	nil	0.56	0.56	0.72	900	144,000	24.4
		2.0	8D-T1	50.0	58,000	0.22	nil	3.03	3.03	3.25	900	131,000	24.8
	100	0.2	8K-T6	100.0	19,000	0.08	nil	0.13	0.13	0.21	900	151,000	24.5
		0.5	8M-T1	100.0	36,000	0.12	nil	0.46	0.46	0.58	900	130,000	21.6
		1.0	7J-T6	100.0	45,000	0.17	nil	1.46	1.46	1.63	900	142,000	23.5
			6U-T1	100.0	44,000	0.20	nil	1.11	1.11	1.31	900	145,000	24.4
		2.0	7H-T5	100.0	52,000	0.24	0.02	2.33	2.35	2.57	900	126,900	22.2

TABLE 11

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

| Exposure Conditions | | Tension Impact Properties After Exposure | | | | |
Temp. (°F)	Time (hrs)	Specimen No.	Test Temp. (°F)	Tension-Impact Strength (ft-lbs.)	Elongation (%)	R. A. (%)
600	10	5H-3X	room	37	2.5	20.0
	50	4P-T32	room	30	*	7.4
	100	6D-T1	room	33	3.0	nil
800	10	4B-T53	room	27	*	nil
	50	6D-T13	room	30	3.7	3.7
	100	5R-T41	room	39	3.5	6.6
		6S-T32	room	41	3.5	2.0
				40	3.5	4.3
900	10	6A-3X	room	21	*	nil
	50	5R-T43	room	19	1.5	nil
	100	4H-T12	room	26	0.8	nil
600	10	6K-3X	600	34	4.0	17.0
	50	5K-3X	600	29	3.5	19.0
	100	4H-T53	600	30	4.5	17.0
800	10	5P-3X	800	29	3.0	17.0
	50	4H-T51	800	43	3.5	19.0
	100	6E-3X	800	35	4.0	17.0
900	10	4E-T41	900	29	3.0	13.0
	50	6Q-3X	900	27	3.5	14.0
	100	5Q-T32	900	27	1.5	12.0

* Specimen inadvertently bent following fracture.

TABLE 12

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

Nominal Exposure Conditions			Specimen No.	Actual Exposure Conditions							Tension Impact Properties After Exposure			
Temp. (°F)	Time (hrs)	Creep Def. (%)		Time (hrs)	Stress (psi)	Total Load Def. (%)	Plastic Load Def. (%)	Creep Def. (%)	Total Plastic Def. (%)	Total Def. (%)	Test Temp. (%)	Tension-Impact Strength (ft-lbs)	Elongation (%)	Reduction of Area (%)
600	10	0.2	8F-T2	10.0	170,500	0.64	0.14	0.32	0.56	0.96	room	40	1.5	14.0
		0.5	7J-T3	10.0	176,000	0.86	0.20	0.50	0.70	1.36	room	45	2.3	12.7
		1.0	8L-T4	10.0	182,000	0.82	0.08	0.28	0.36	1.10	room	38	1.5	16.0
		2.0	7G-T4	10.0	188,000	1.15	0.40	2.38	2.78	3.53	room	38	0.8	2.2
	100	0.2	5T-T2	100.0	153,000	0.59	0.06	0.19	0.25	0.78	room	39	2.0	15.5
		2.0	7C-T4	100.0	181,200	0.73	0.11	0.58	0.69	1.31	room	48	1.0	5.2
	10	0.5	5F-T5	9.9	176,000	0.83	0.20	0.58	0.78	1.41	600	27	2.5	17.0
		1.0	6U-T4	10.0	182,000	0.97	0.32	0.95	1.27	1.92	600	37	2.0	12.0
800	10	0.2	8F-T1	10.0	102,000	0.42	nil	0.26	0.26	0.68	room	47	1.5	9.0
		0.5	7G-T3	10.0	118,000	0.54	nil	0.78	0.78	1.32	room	28	1.0	3.7
		1.0	7P-T6	9.9	126,000	0.51	0.03	0.93	0.96	1.44	room	35	1.0	3.7
		2.0	8D-T3	10.0	133,000	0.60	0.08	1.86	1.94	2.46	room	26	0.5	3.0
	100	0.2	6T-T2	100.0	82,000	0.34	nil	0.23	0.23	0.57	room	28	nil	nil
		2.0	4N-T2	100.0	117,000	0.49	0.10	2.00	2.10	2.49	room	11	1.0	nil
900	10	0.2	4N-T7	10.0	45,000	0.18	nil	0.27	0.27	0.45	room	23	1.0	4.6
		0.5	7R-T6	10.0	58,000	0.18	nil	0.61	0.61	0.79	room	18	0.5	nil
		1.0	7A-T3	10.0	67,000	0.26	nil	0.97	0.97	1.23	room	18	0.5	nil
		2.0	5J-T4	10.9	75,000	0.31	0.04	2.85(est.)	2.89(est.)	3.16(est.)	room	18	1.0	nil
	100	0.2	8E-T1	100.0	18,000	0.09	nil	0.20	0.20	0.29	room	35	nil	nil
		2.0	8E-T2	100.0	52,000	0.21	nil	2.25	2.25	2.46	room	16	nil	nil
	10	0.5	8F-T6	10.0	58,000	0.24	nil	0.94	0.94	1.18	900	27	2.5	nil
		1.0	5F-T6	10.0	66,000	0.28	0.02	1.10	1.12	1.38	900	37	3.3	22.0
		2.0	4U-T6	10.0	75,000	0.32	0.03	2.28	2.31	2.70	900	43	1.0	6.0

TABLE 13

X-RAY DIFFRACTION DATA FOR 17-PH (RH 950) BEFORE OR AFTER CREEP EXPOSURE AT 800°F

Mechanical Properties of Specimens Selected for Diffraction Studies

Specimen No.	Condition	Ult. Tensile Strength (psi)	Yield Strength (psi)	Elongation (%)	Reduction of Area (%)	Modulus, E (10 psi)	Hardness R"C"
RH 950	As-Treated	237,650	222,480	8.2	15.0	28.7	48.2
6L-T6	800°F-115,000 psi (0.94% Creep)	267,000	246,000	1.5	3.0	29.8	51.0

X-Ray Diffraction Data

A. Hull-Debye-Sherrer Powder Pattern (Filings)

	Measured "d" Values			Standard Pattern for Martensite		
Specimen	"d"	Intensity		"d"	Intensity (I)	Indices
RH 950	2.03	S		2.035	1	110
	1.44	M		1.44	0.4	200
	1.17	MS		1.175	0.8	211
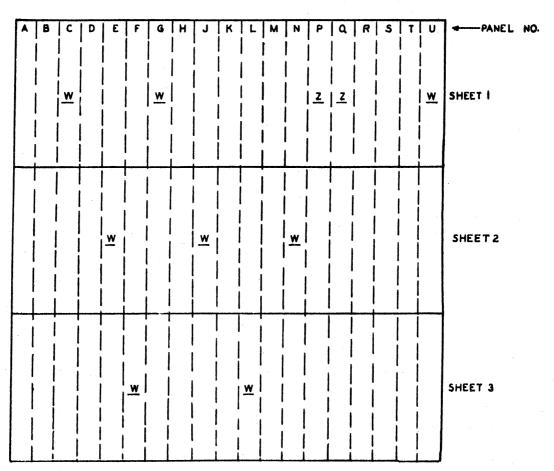
B. Phragmen-Type Camera (Solid Samples)

	Measured "d" Values		Standard Patterns of Possible Phases		
			Martensite		Unknown
Specimen	"d"	Intensity	"d"	I	
RH 950	2.41	VW			✓
6L-T6	2.27	VW			✓
(Patterns Identical)	2.07	W			✓
	2.03	VS	2.035	1	
	1.80	W			
	1.44	M	1.44	0.4	✓
	1.29	M			
	1.17	M	1.175	0.8	✓

C. Powder Patterns (Extracts)

RH 950 (HCl)	6L-T6 (HCl)	RH 950 (Bromine)	6L-T6 (Bromine)	M23C6	NiAl	Ni3Al	Cr7C3	TiN	CrC	Al2Cr3	Unknown*
2.52 W							2.53 MW	2.51 W			
	2.45 VW	2.45 VW									
2.44 VW	2.44 VW			2.43 VW					2.44 M		
	2.38 W	2.38 W		2.38 S							
2.37 W	2.37 W						2.37 M				
2.17 W	2.17 MW	2.17 W	2.17 W	2.17 S			2.28 M				
	2.12 VW	2.12 VW	2.12 W				2.12 S	2.12 VS		2.12 0.8	
	2.06 S						2.07 S		2.08	2.08 1.0	
2.05 M		2.05 S	2.05 S	2.04 S			2.04 S			2.05 0.1	
2.03 VW	2.03 S					2.03 1.0					
	1.89 MW						1.96 M			.1.91 0.2	✓
1.88 W		1.88 W	1.88 W	1.88 M			1.86 S			1.87 0.1	
1.80 W	1.80 MW	1.80 W	1.80 W	1.79 S		1.79 S	1.78 W		1.81		
1.77 VW	1.77 W	1.77 VW	1.77 VW	1.77 MW			1.76 M				
	1.62 VW			1.68 W 1.66 0.2							✓
	1.60 W	1.60 VW	1.60 VW	1.60 MW		1.60 W					
	1.50 VW	1.50 VW	1.50 VW				1.51 M	1.50 S		1.51 0.8	
	1.44 MW					1.44 0.2	1.46 W	1.44 S		1.45 0.4	
	1.33 W	1.33 VW	1.33 VW					1.35 S			✓
1.29 VW	1.29 VW	1.29 VW	1.29 VW	1.29 M							
	1.28 VW		1.28 VW		1.28 0.1	1.27 S			1.28 M 1.28	1.28 0.1	
	1.26 MS			1.26 S				1.26 M		1.25 0.1	
	1.23 M	1.23 W	1.23 W	1.23 S				1.22 S	1.22 M	1.24 0.1	
1.19 VW	1.19 W	1.19 VW	1.19 VW							1.23 1.0	
1.18 VW	1.18 S			1.18 M 1.18 0.7		1.19 VW		1.18 S		1.19 0.8	
1.17 VW	1.17 VW	1.17 VW	1.17 VW					1.17 S		1.16 0.2	

* Measured line does not show reasonable correspondence to a listed possible phase.
** Other possible phases include: Ni3C, Al5Cr3, Al9Cr4, Cr3C2, Al2Cr, Ti(CN)-(identified optically), Delta ferrite, etc.

Sheet Dimensions: 36 x 120 x 0.064 inches
Panel Width: 6-1/4 to 6-1/2 inches
Sheet Designation: 1, 2, 3, etc.
Panel Designation: A, B, C, etc.
Panel Location Code: 1A, 3L, etc. (Sheet No. - Panel No.)
Specimen Blank Sampling Scheme: (See Figure 2 for details)

Sheets 1, 2, 3 : All treated to TH 1050 Condition; Sampling Schemes
W and Z as indicated, all others Scheme Y.

Sheets 4, 5, 6 : Part treated to TH 1050 Condition, balance to
RH 950 Condition; Sampling Scheme Y used
throughout.
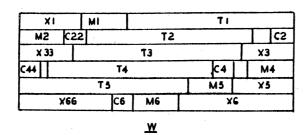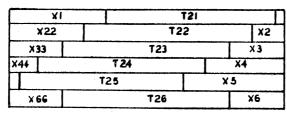
Sheets 7, 8 : Treated to RH 950 Condition; Sampling Scheme Y
used throughout.

Figure 1. - Panel sampling scheme for sheets of 17-7PH stainless steel sheet

W

Y

Z
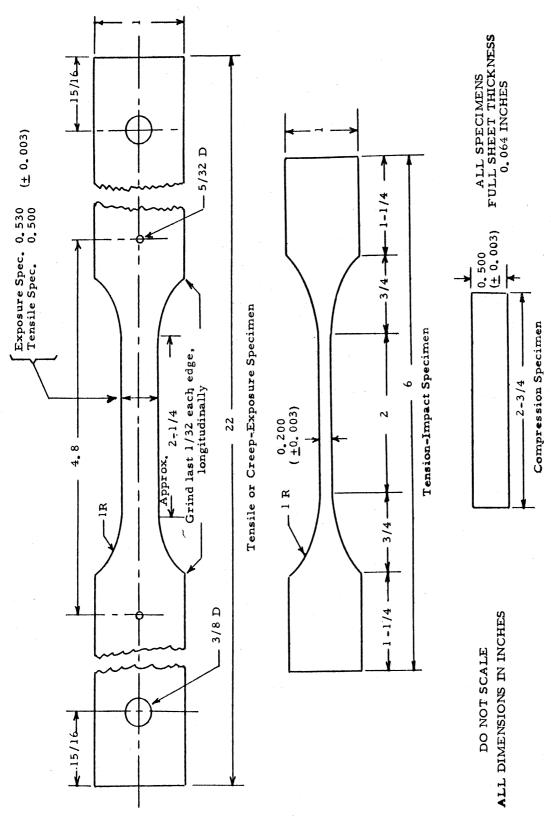
T - TENSILE
C - COMPRESSION
M - TENSION-IMPACT
X - EXTRA

SCALE: 0 _____ 10
INCHES
(LENGTH ONLY)
ALL BLANKS, 1 INCH WIDE
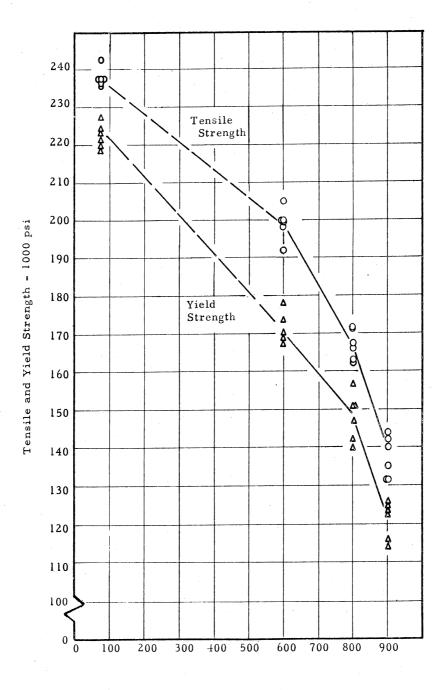
Figure 2. - Specimen blank sampling schemes for panels of 17-7PH stainless steel sheet

Figure 3. - Details of Test Specimens (Tension-Impact and Compression Specimens Designed to be Cut from Creep Specimens after Exposure).

DO NOT SCALE
ALL DIMENSIONS IN INCHES
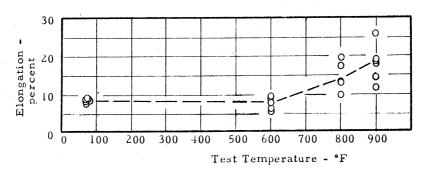
Figure 4. - Effect of Test Temperature on Tensile Properties of 17-7PH (RH 950 Condition) As Heat-Treated.
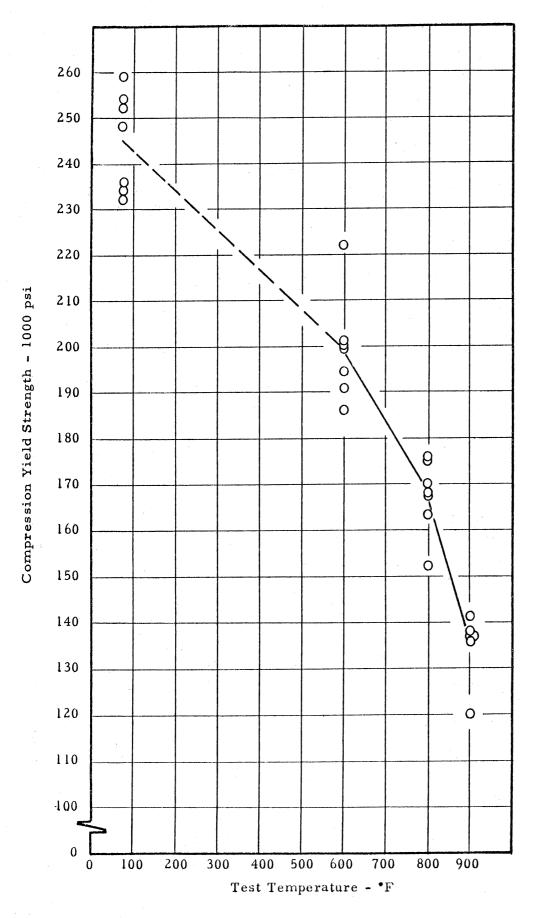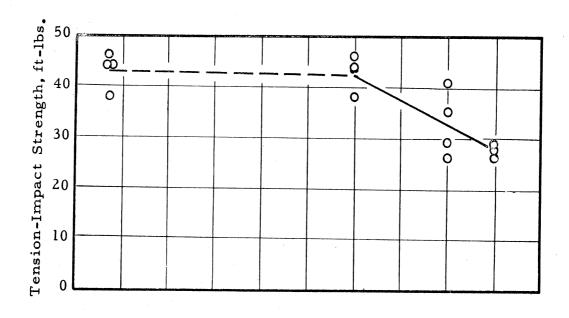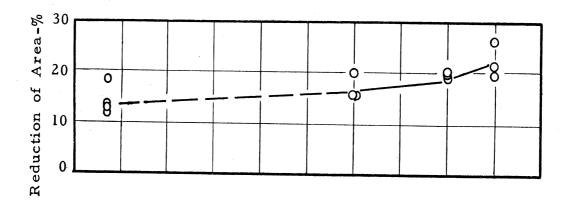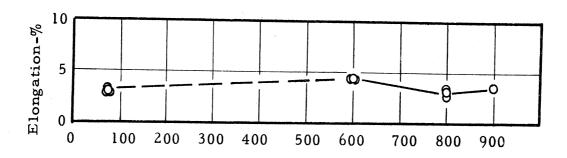
Figure 5. - Effect of Test Temperature on Compression Yield Strength
of As-Treated 17-7PH (RH 950 Condition).

Figure 6. - Effect of Test Temperature on Tension-Impact
Properties of 17-7PH (RH 950 Condition) as
Heat-Treated.
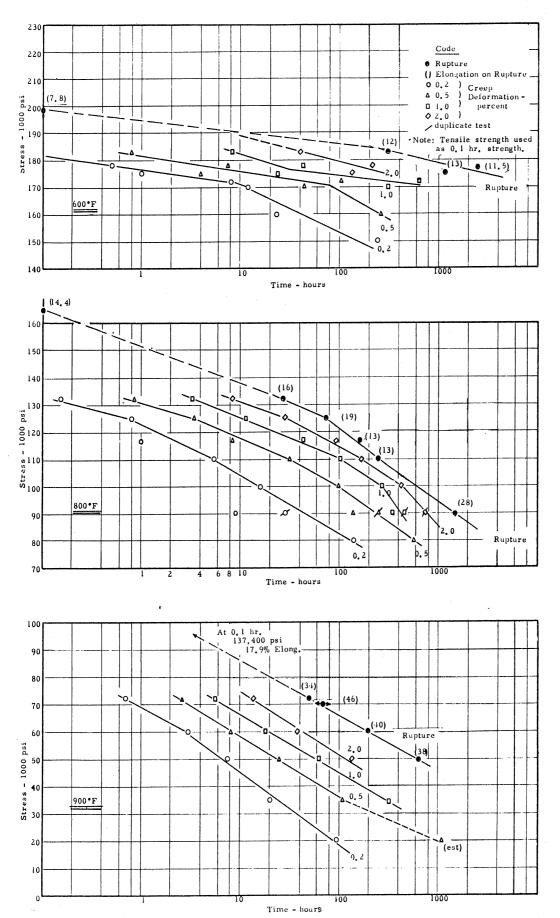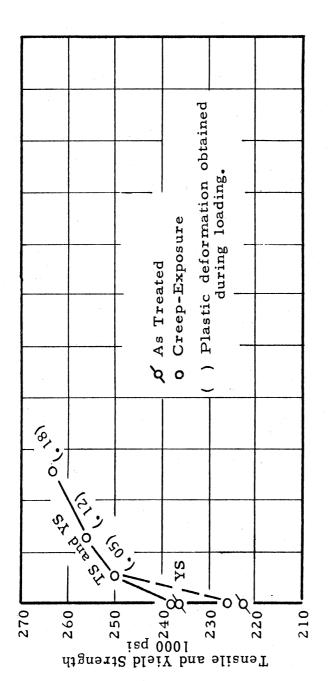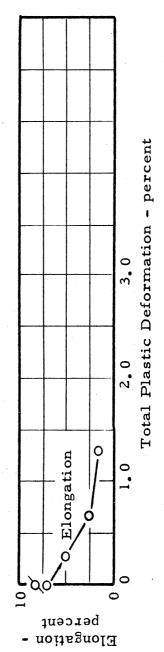
Figure 7. - Stress-Rupture Time and Stress-Time for Creep Deformation Curves for 17-7PH (RH 950 Condition) at 600°, 800°, and 900°F.

Figure 8. – Effect of Creep Exposure at 600°F for 331-437 Hours on Room Temperature Tensile Properties of 17-7PH (RH 950).
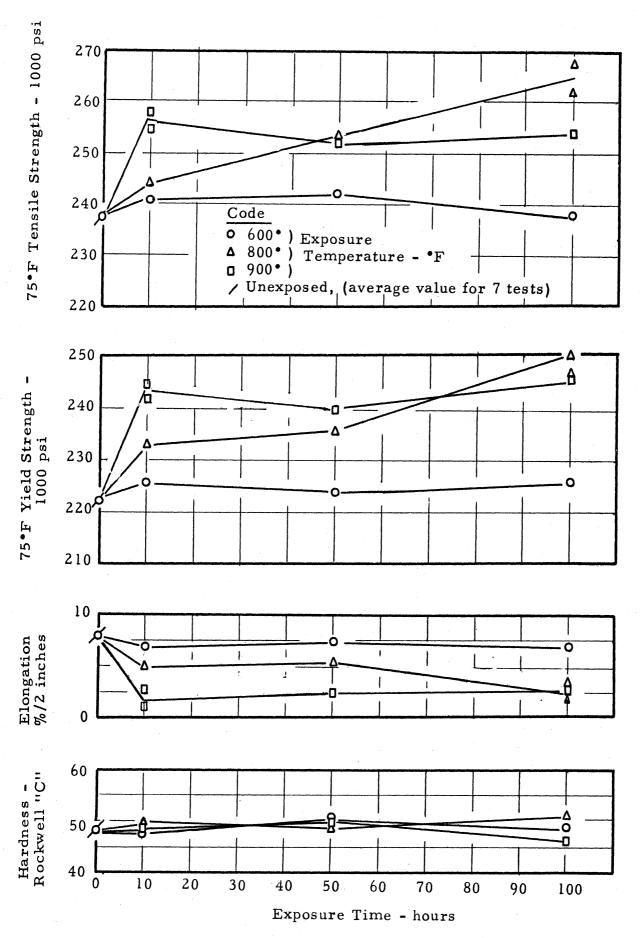
Figure 9. - Effect of Unstressed Exposure at 600°, 800°, or 900°F on Room Temperature Tensile Properties and Hardness of 17-7PH (RH 950 Condition).
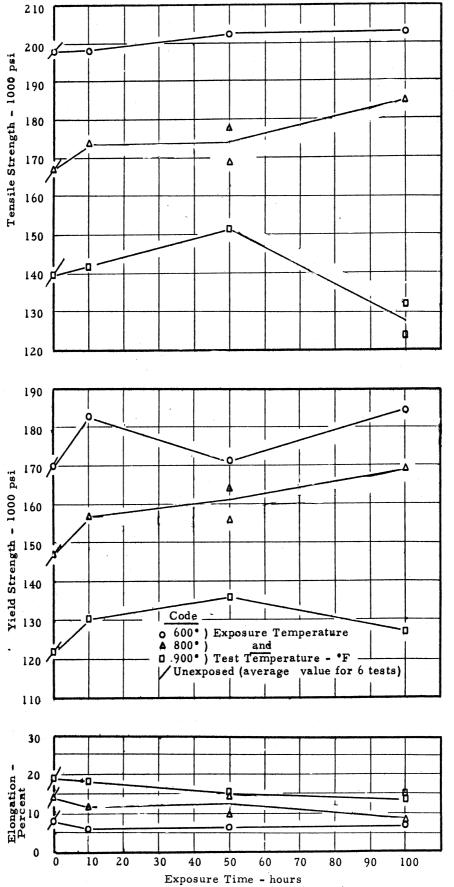
Figure 10. - Effect of Unstressed Exposure at 600°, 800°, or 900°F on Tensile Properties of 17-7PH (RH 950 Condition) At Exposure Temperature.
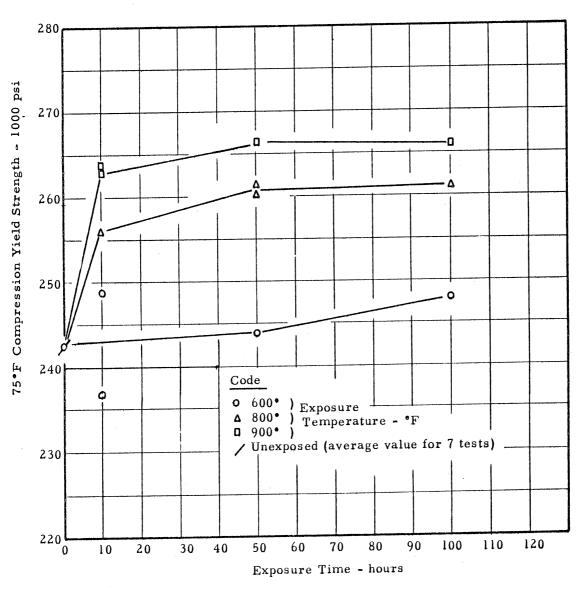
Figure 11. - Effect of Unstressed Exposure on Room Temperature Compression Yield Strength of 17-7PH (RH 950 Condition).
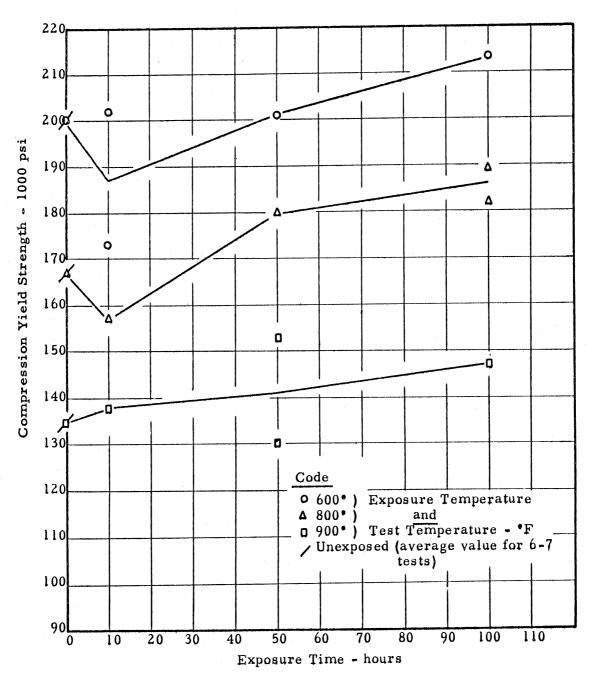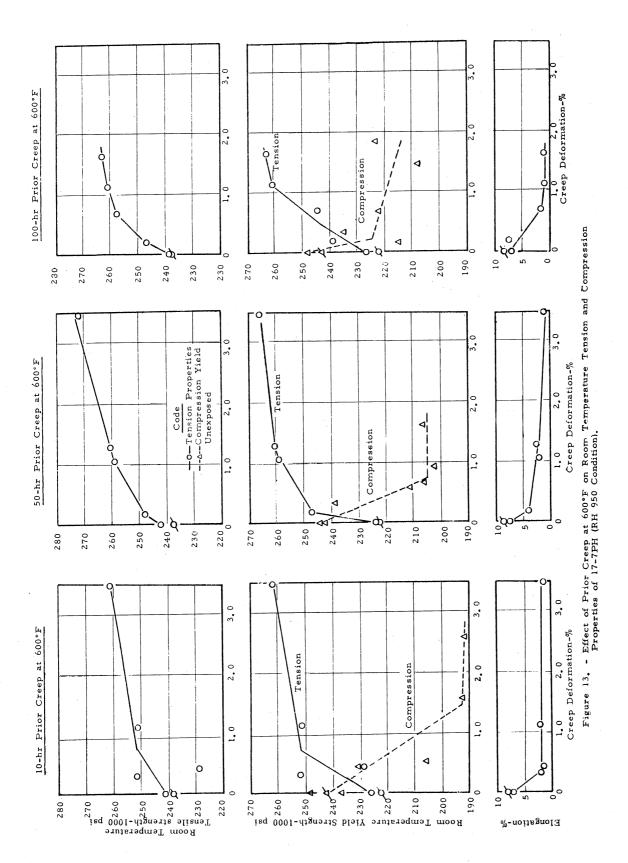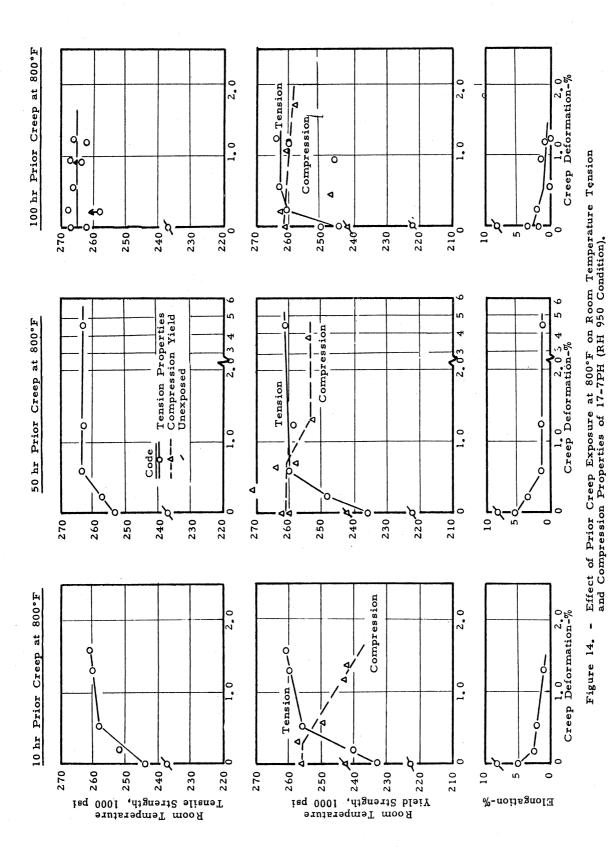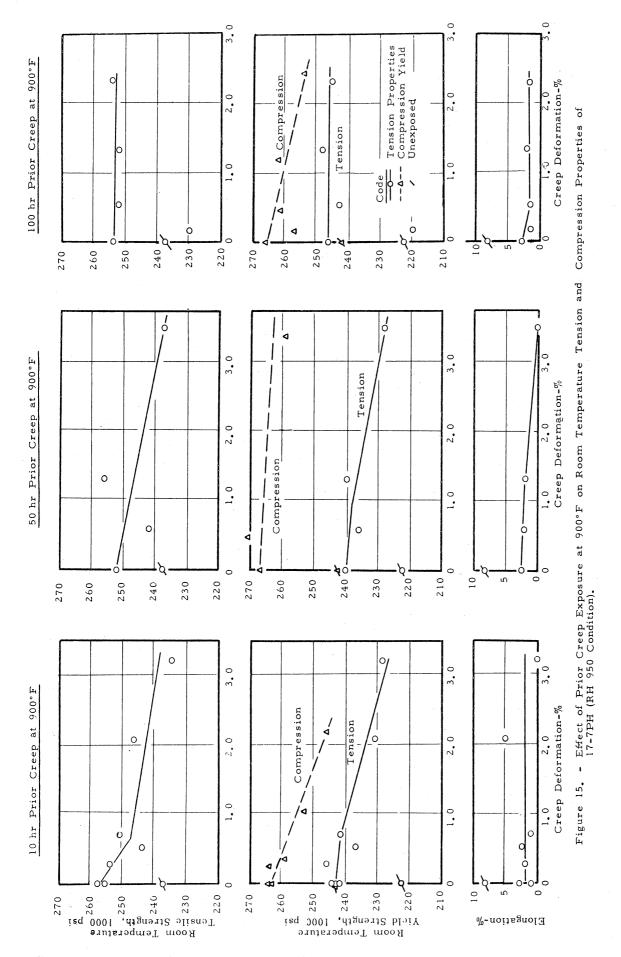
Figure 12. - Effect of Unstressed Exposure at 600°, 800°, or 900°F on Compression Yield Strength of 17-7PH (RH 950) At Exposure Temperature.

Figure 13. - Effect of Prior Creep at 600°F on Room Temperature Tension and Compression Properties of 17-7PH (RH 950 Condition).

Figure 14. - Effect of Prior Creep Exposure at 800°F on Room Temperature Tension and Compression Properties of 17-7PH (RH 950 Condition).

Figure 15. - Effect of Prior Creep Exposure at 900°F on Room Temperature Tension and Compression Properties of 17-7PH (RH 950 Condition).
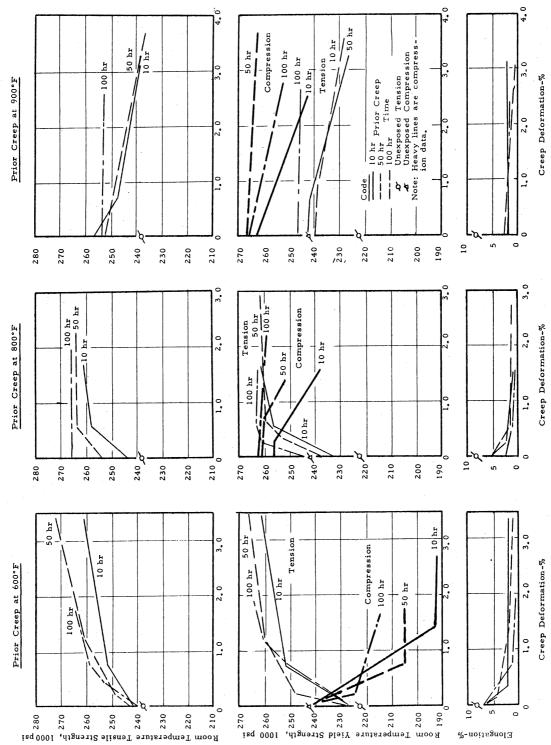
Figure 16. - Summary of Effect of Prior Creep-Exposure on Room Temperature Tension and Compression Properties of 17-7PH (RH 950).

Prior Creep at 600°F
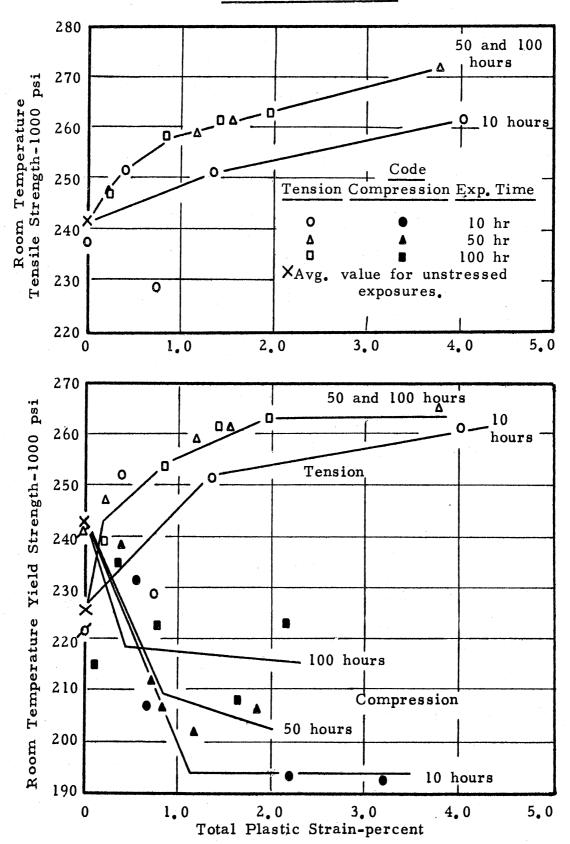
Figure 17. - Room Temperature Tensile and Yield Strength
of 17-7PH (RH 950) After 600°F Creep-
Exposure versus Total Plastic Strain Attained
in the Creep-Exposure.
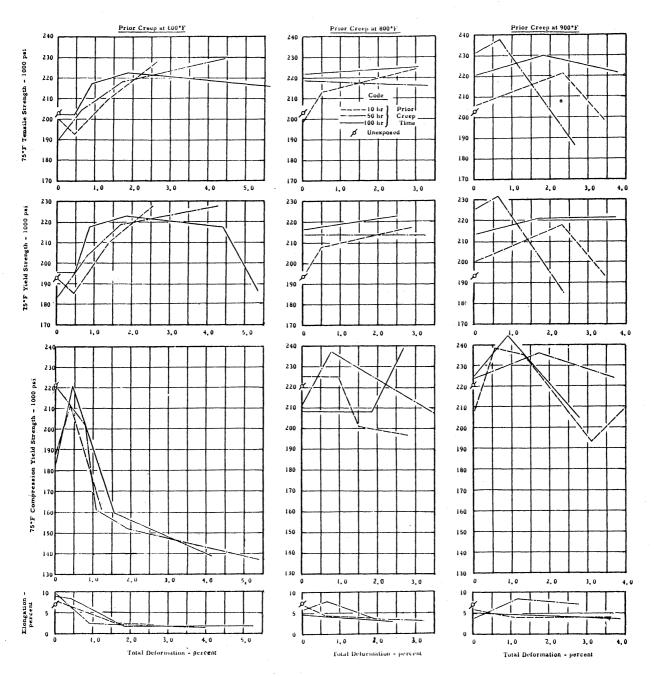
Figure 18. - Summary of Effect of Prior Creep Exposure at 600°, 800°, or 900°F on Room Temperature Properties of 17-7PH (TH 1050 Condition).
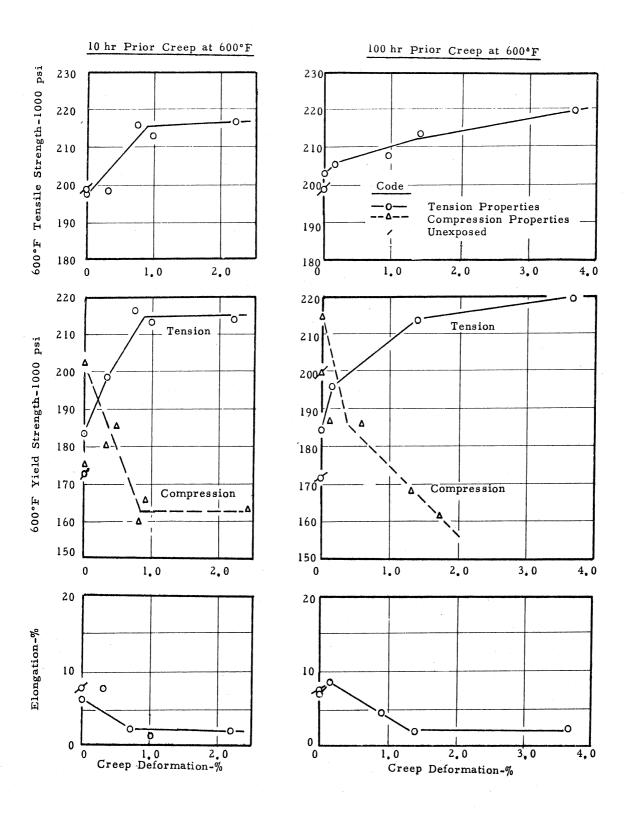
Figure 19. - Effect of Prior Creep Exposure at 600°F on Tension and Compression Properties of 17-7PH (RH 950 Condition) at 600°F.
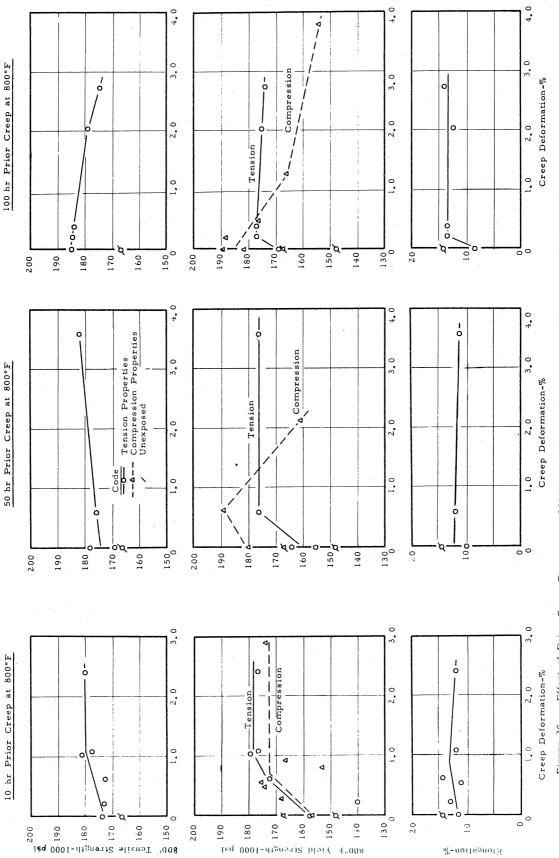
Figure 20. – Effect of Prior Creep Exposure at 800°F on Tension and Compression Properties of 17-7PH (RH 950 Condition) at 800°F.
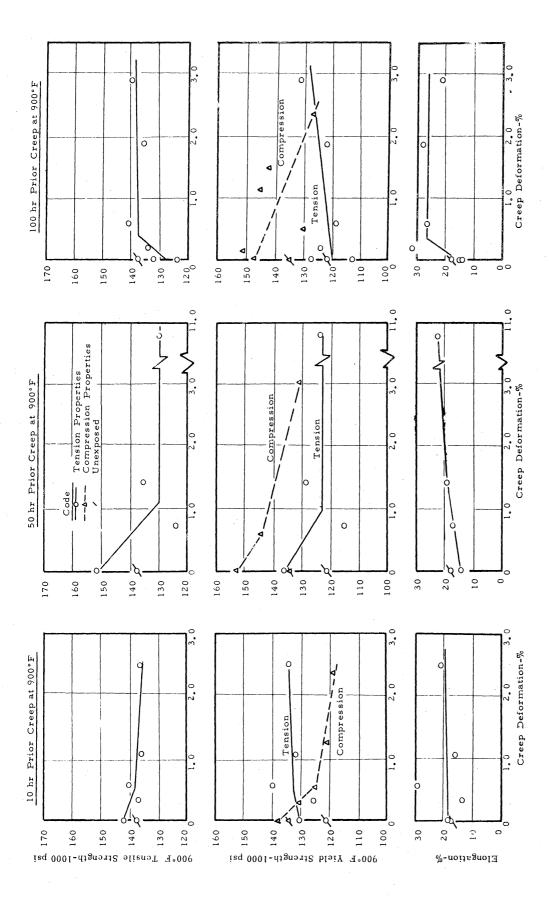
Figure 21. - Effect of Prior Creep-Exposure at 900°F on Tension and Compression Properties of 17-7PH (RH 950 Condition) at 900°F.
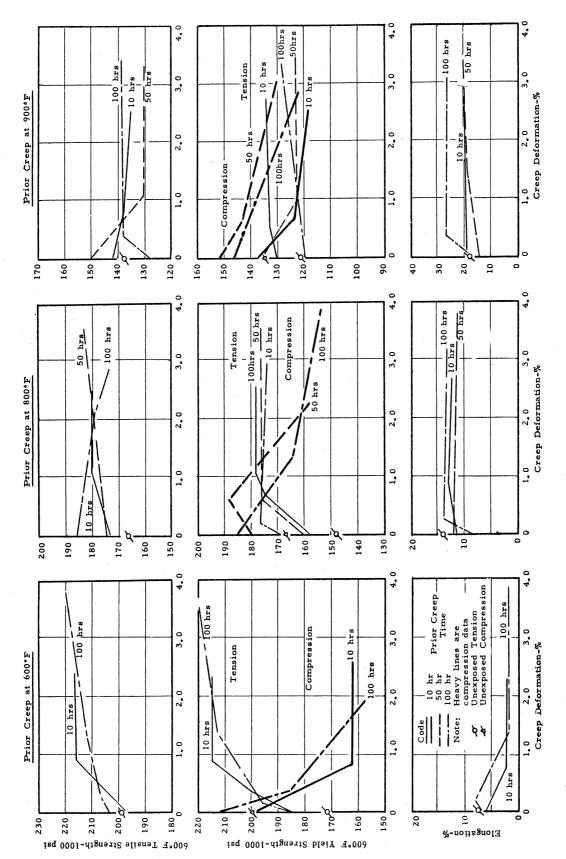
Figure 22. – Summary of Effect of Prior Creep Exposure on Elevated Temperature Tension and Compression Properties of 17-7PH (RH 950).
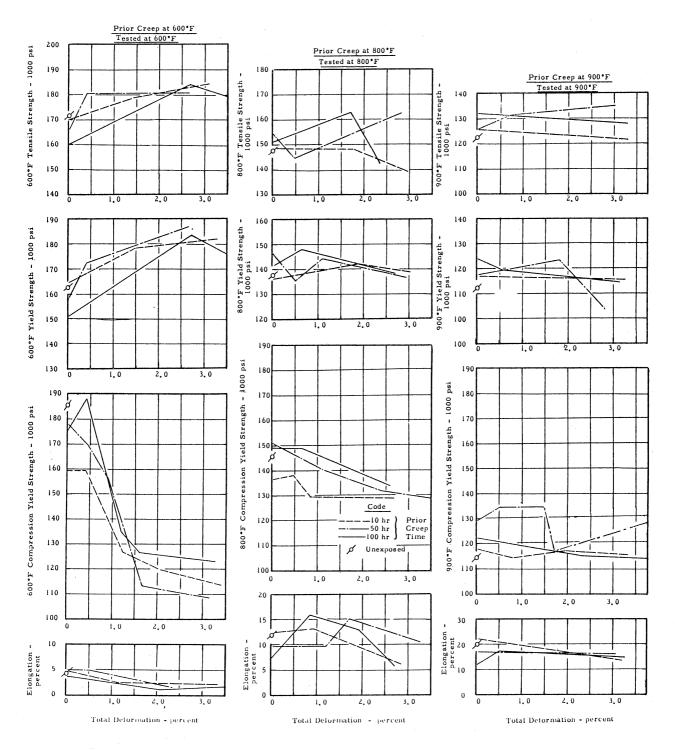
Figure 23. - Summary of Effect of Prior Creep Exposure at 600°, 800°, or 900°F on Properties of 17-7PH (TH 1050 Condition) at Exposure Temperature.
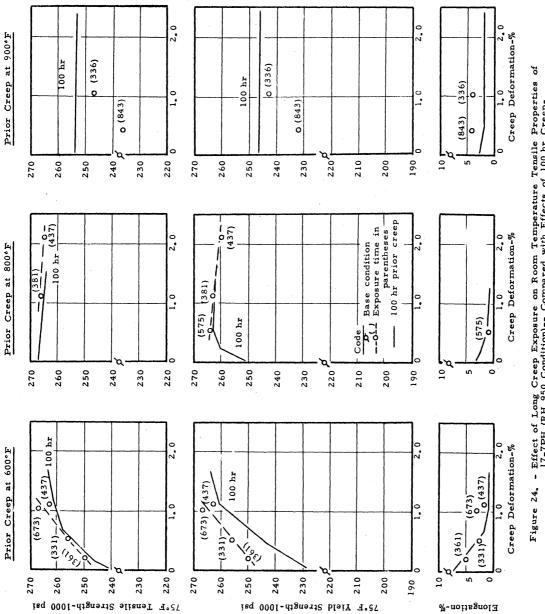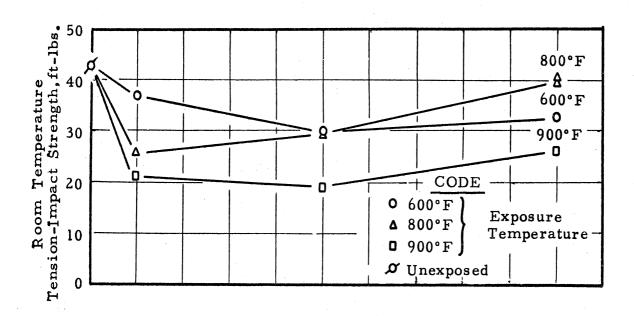
Figure 24. — Effect of Long Creep Exposure on Room Temperature Tensile Properties of 17-7PH (RH 950 Condition)— Compared with Effects of 100 hr Creep-Exposure.
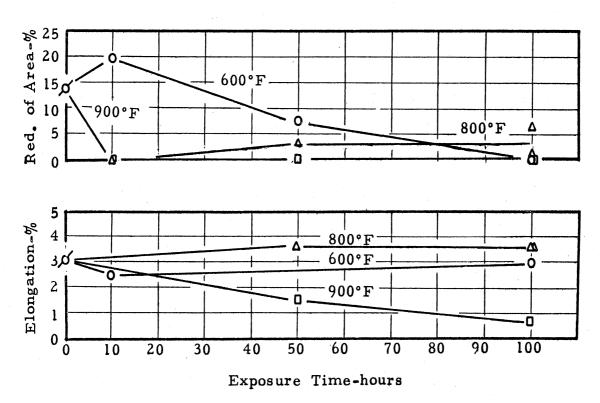
Figure 25. - Effect of Unstressed Exposure on Room Temperature Tension-Impact Properties of 17-7PH (RH 950).
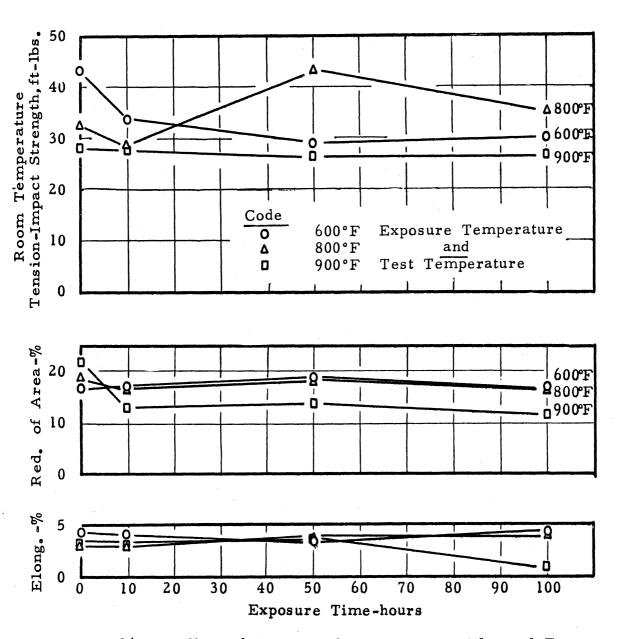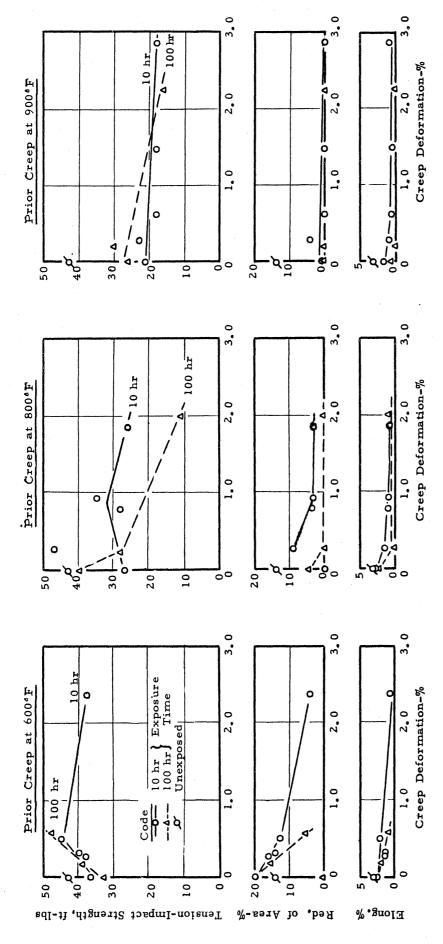
Figure 26. - Effect of Unstressed Exposure on Elevated Temperature Tension-Impact Properties of 17-7PH (RH 950).

Figure 27. - Effect of Prior Creep Exposure at 600°, 800°, 900°F on Room Temperature Tension-Impact Properties of 17-7PH (RH 950).

10 hr Prior Creep at 600°F

10 hr Prior Creep at 900°F
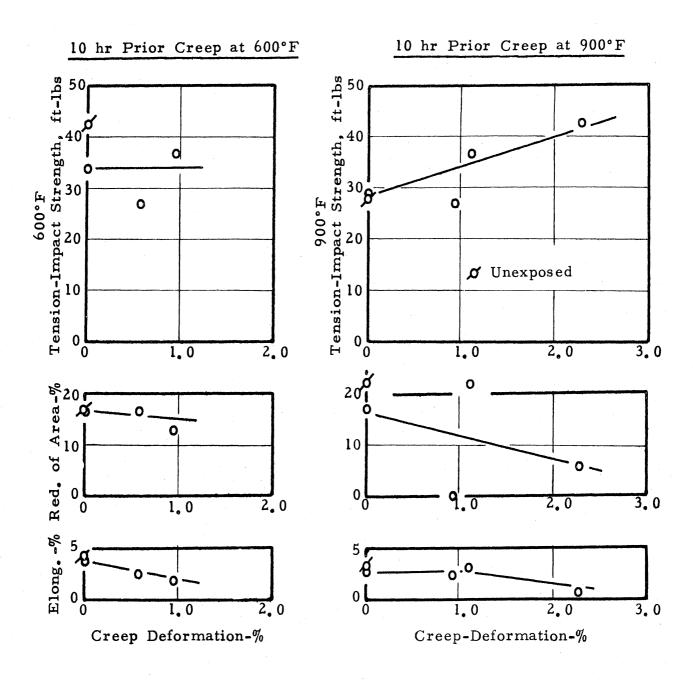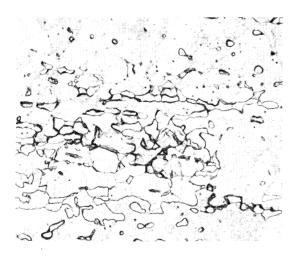
Figure 28. - Effect of Prior Creep Exposure at 600°F or 900°F on Elevated Temperature Tension-Impact Properties of 17-7PH (RH 950).

ʒure 29 (Longitudinal Face) x1000
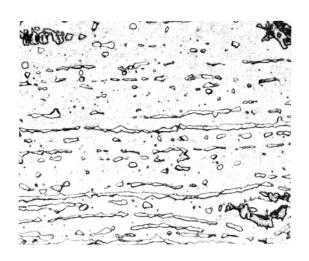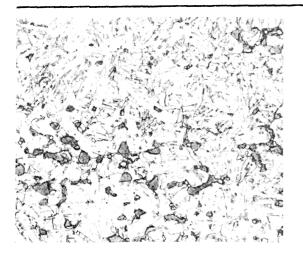
Figure 30 (Transverse Face) x1000

17-7PH Stainless Steel: Condition A

ʒure 31 (Longitudinal Face) x1000
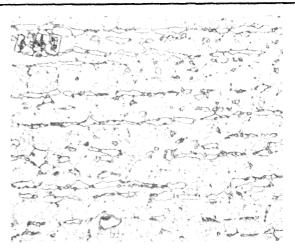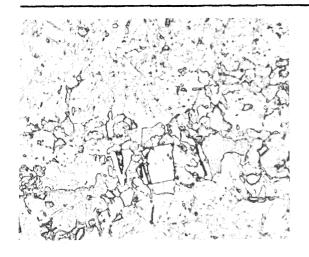
Figure 32 (Transverse Face) x1000

17-7PH Stainless Steel: Condition RH 950

gure 33 (Longitudinal Face) x1000
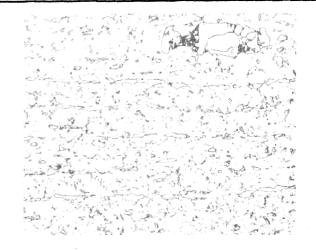
Figure 34 (Transverse Face) x1000

17-7PH Stainless Steel: Condition RH 950
Specimen No. 6L-T6; Creep Tested 100 hours at 800°F to 0.94% Deformation

ʒures 29-34. - Optical Micrographs of 17-7PH Stainless Steel (All samples etched with Marbles Reagent).
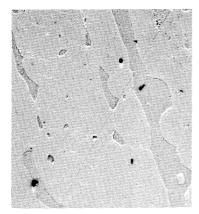
Figure 35   x3500

Condition A
R. T. Elong. 20-30%
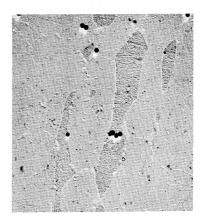
Figure 36   x3500
Condition RH 950
As Treated
R. T. Elong. 8.2%
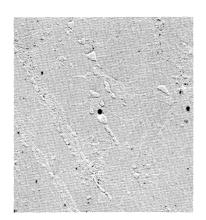
Figure 37   x3500
Condition RH 950
600°F-100 hr-No Stress
R. T. Elong. 7.0%
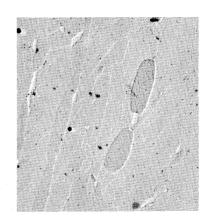
Figure 38   x3500
Condition RH 950
600°F-100 hr-1.12% Def.
R. T. Elong. 1.5%

Note: Specimens subjected to indicated creep-exposure; RT Elong.,
      is elongation in subsequent room temperature tensile test.

Figures 35-38. - Electron Micrographs of 17-7PH Stainless Steel
                (Samples etched in modified Nital).
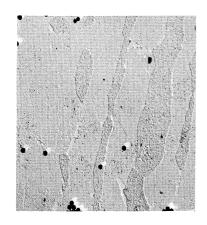
Figure 39   x3500
Condition RH 950
800°F-100 hr-No Stress
R. T. Elong. 3.5%

Figure 40   x3500
Condition RH 950
800°F-100 hr-1.16% Def.
R. T. Elong. 1.0%
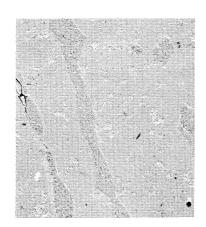
Figure 41   x3500
Condition RH 950
900°F-100 hr-No Stress
R. T. Elong. 2.8%
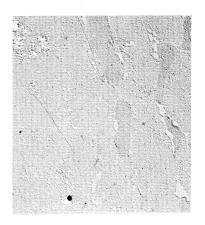
Figure 42   x3500
Condition RH 950
9 00°F-100 hr-0.54% Def.
R. T. Elong. 1.5%

Note: Specimens subjected to indicated creep-exposure; RT Elong.,
       is elongation in subsequent room temperature tensile test.

Figures 39-42. - Electron Micrographs of 17-7PH Stainless Steel
                (Samples etched in modified Nital).
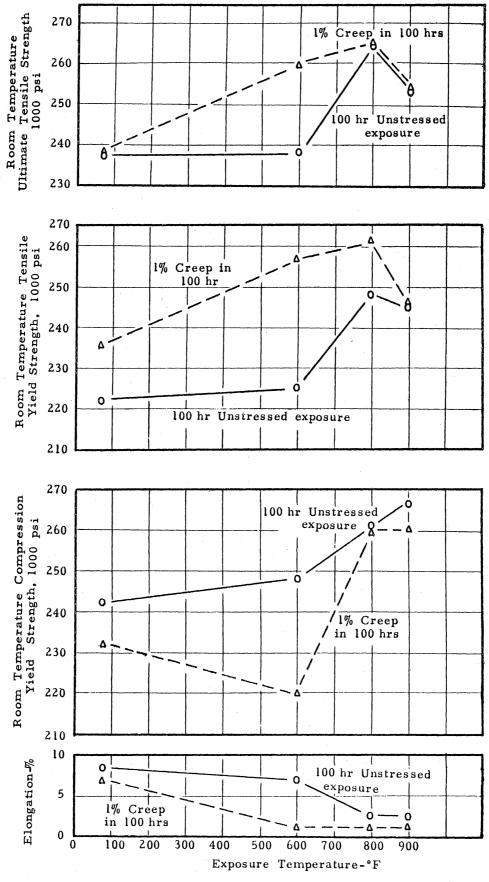
Figure 43. - Effect of 100 hour Exposure Either Unstressed
or to One-Percent Creep on Room Temperature
Tension or Compression Properties of 17-7PH
(RH 950 Condition).

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Compared to TH 1050 Condition),
by J.V. Gluck and J.W. Freeman.
March 1959. 82p. incl. illus.
tables, 6 refs. (Proj. 7360; Task
73604). WADC TR 59-339).
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The effect of creep to 2 percent in 100 hours at temperatures from 600° to 900°F was determined on the tension, compression, and tension-impact properties of 17-7 PH (RH 950 Cond.) at room temperature. A substantial loss in ductility was observed in room temperature tension tests. Material exposed to creep at 600°F exhibited a substantial Bauschinger effect in tension and compression tests. The loss in ductility is attributed to stress and/or temperature induced aging during the creep-exposure.

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The effect of creep to 2 percent in
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the tension, compression, and
tension-impact properties of 17-7
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A substantial loss in ductility was
observed in room temperature ten-
sion tests. Material exposed to
creep at 600°F exhibited a substan-
tial Bauschinger effect in tension
and compression tests. The loss in
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