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SECOND PROGRESS REPORT
TO
MATERIALS LABORATORY
WRIGHT AIR DEVELOPMENT CENTER
ON
EFFECT OF PRIOR CREEP ON MECHANICAL PROPERTIES OF AIRCRAFT STRUCTURAL METALS

by

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SUMMARY

This report, the second to be issued under Contract AF33(616)3368, Task No. 73605, covers the period from April 21, 1956 to June 20, 1956.

The investigation is a study of the effects of prior creep on the short-time mechanical properties of three aircraft sheet metals. The materials to be studied are: 2024-T86 aluminum alloy; C110M titanium alloy; and 17-7PH (TH1050) precipitation hardening stainless steel.

The aluminum alloy and the stainless steel have been received. The survey of creep-rupture properties for the stainless steel has been virtually completed. The effects on the room temperature tensile properties of exposures of up to 100 hours in the range between 600° and 900°F have been evaluated for the stainless steel. The results indicate that the strength is increased for exposures of over 10 hours at 800° and 900°F. A few completed tests cover the effects of stressed exposure for this material. An added strengthening effect appears to have taken place as a result of the creep strain.

The fixture for tension-impact testing has been completed and its use and calibration are discussed.

INTRODUCTION

This second bi-monthly progress report issued under Air Force Contract No. AF33(616)-3368, Task No. 73605 covers the period from April 21, 1956 to June 20, 1956.

This investigation is concerned with a study of the effects of elevated temperature creep-exposure on the mechanical properties of three aircraft sheet metals.

The materials under consideration and the temperature ranges to be investigated follow:

1. An aluminum alloy (2024-T86) from 350° to 500°F
2. A titanium alloy (C 110M) from 650° to 800°F
3. A precipitation hardening stainless steel (17-7PH, TH 1050) from 600° to 900°F. The exposure periods to be studied are from zero to 100 hours and the range of total deformation is from 0.5 percent to 3.0 percent.

The combined effects of deformation, surface attack, and structural alterations are all possible contributors to changes in the strength and ductility of a metal. The net effect of these factors is considered a measure of the stability of the material and an aid in defining the operating limits for design purposes.

The properties to be studied both before and after creep-exposure are the short-time tensile properties, tension-impact strength, short-time compressive properties, and the hardness. Where significant effects are noted, metallographic studies will be used to study them.

TESTING PROGRAM

In the present investigation a study is being made of the effects of exposure on the mechanical properties of three aircraft sheet metals. The emphasis of this study is an evaluation of the effect of creep, although unstressed exposure is also under consideration. The testing program was discussed in detail in the First Progress Report (ref. 1). The discussion following summarizes the more important features of the program.

The materials under investigation and the temperature ranges to be considered were listed in the Introduction. In addition, it was noted that time periods up to 100 hours and total deformations up to 3 percent were to be studied. This total deformation is all deformation occurring during application of the load and during creep of the specimen at the testing temperature and stress.

Time periods for exposure were fixed at 10, 50, and 100 hours. The exposures were to be carried out at no stress and at those stresses resulting in 0.5, 1.0, 2.0, and 3.0 percent total deformation in the three time intervals listed above.

As a matter of policy it was decided that the time of exposure would be fixed. The tests were to be run at the stresses determined to give the indicated deformation in the indicated time period, however, it was expected that the actual amount of deformation might vary slightly from the nominally specified amount. By fixing the temperature, time, and stress it is necessary to accept the deformation obtained. Because of the large number of tests that were expected to be run, this procedure was adopted so that the problems of test scheduling, unit utilization, and laboratory administration could be made as simple as possible.

Three primary test temperatures were selected for each material. They are the following:

a. 2024-T86	350°, 400°, 500°F
b. C110M	650°, 700°, 800°F
c. 17-7PH	600°, 800°, 900°F

After the completion of the exposure period the following tests are to be carried out:

1. Tensile tests at both room temperature and the exposure temperature.
2. Compression tests at the same temperatures.
3. Tension-impact tests at the same temperatures.
4. Hardness determinations at room temperature. Where deemed useful, metallographic examination will be made.

The data are to be correlated with respect to the conditions of exposure. The bases for comparison are the properties of the unexposed material, established by a series of replicate tests designed to define the normal scatter of each material.

The aluminum and titanium alloys are to be tested in the conditions as received from the manufacturers. The C110M titanium alloy is furnished as-hot rolled and annealed and the 2024-T86 aluminum alloy is furnished in the cold worked and aged condition. The stainless steel, 17-7PH, is to be tested in the TH1050 condition. This is a double aging treatment carried out at 1400° and then 1050°F and is to be performed at the University. The aluminum and stainless steel alloys are to be tested in the direction crosswise to the sheet rolling direction, while the titanium alloy is to be tested in the direction parallel to the rolling direction.

Under the current contract, testing priority will be placed on evaluation of the aluminum alloy.

Before final establishment is made of the temperatures to be investigated for the stainless steel, a survey will be made of the effects of prior creep to 2 percent total deformation in 100 hours on the room temperature tensile properties. The temperatures studied will be over the range from 600°F to 900°F. For the purpose of this survey, temperature increments of 50°F will be used in order to better establish the temperature of maximum effect.

In addition to the above the feasibility of running notched tension-impact tests will be investigated.

TEST MATERIALS

To date, the aluminum alloy and the stainless steel have been received, while the titanium alloy remains on order with delivery promised about Septembe 1, 1956. The specifications of the materials are as follows:

Armco 17-7PH Stainless Steel

Sixteen sheets of 17-7PH precipitation hardening stainless steel were received from the Armco Steel Corporation in the period covered by the First Progress Report. (ref 1). The material was supplied as 0.064-inch thick sheets 120 inches long by 36 inches wide and was furnished in No. 2D finish and in Condition A. (Condition A consists of an annealing treatment carried out at 1925°F followed by air cooling). All the material was from Heat No. 55651. The certified chemical analysis furnished by Armco was within the nominal composition limits for this alloy. These limits are as follows:

Element	Nominal	Actual (heat 55651)
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	6.50-7.75	7.25
Aluminum	0.75-1.50	1.28
Iron	Balance	Balance

The material is to be tested in the TH 1050 condition. The details of this treatment are as follows: (ref 2)

1. Condition A material heated in air at 1400°F for 1-1/2 hours
2. Air Cool 10 minutes (to approximately 500°F)
3. Quench in 60°F water
4. Hold 8-12 hours at 60°F
5. Age at 1050°F for 1-1/2 hours, then air cool.

2024-T86 Aluminum Alloy

Nineteen Al-clad sheets of the aluminum alloy, 2024-T86, were received from the Kaiser Aluminum and Chemical Corporation in the period covered by this report. The sheet dimensions were 0.065-inches thick by 48 inches wide by 72 inches long. The chemical analysis and heat number have not yet been received.

This material, formerly designated as Aluminum 24S, is a high strength heat treatable wrought alloy. The nominal composition limits for this material are the following:

Element	Range (per cent)
Copper	3.8-4.9
Manganese	0.3-0.9
Magnesium	1.2-1.8
Silicon	0.50 Max
Iron	0.50 Max
Chromium	0.25 Max
Zinc	0.10 Max
Others	0.10 Max
Aluminum	Balance

The T86 condition of this material is a cold worked and aged condition and is carried out by the producer. It consists of the following steps:

1. Solution Treatment: 910-930°F, quench in cold water
2. Cold Work: Approximately 5.5% reduction
3. Aged: 370-380°F

C110M Titanium Alloy

The C110M titanium alloy, formerly designated RC 130A, remains on order from the Rem-Cru Titanium Corporation. The material is to be procured as 0.064-inch sheet in the annealed condition. The alloy is a binary containing from 7-9 percent manganese, the balance being titanium.

SPECIMEN PREPARATION

The preparation of specimens under this program was discussed in some detail in the First Progress Report. (ref 3)

A sampling procedure was set up in order to randomize the results with respect to both the sheet to sheet variations and the variations within an individual sheet. The sampling procedure for the 17-7PH material was illustrated and detail drawings were presented of the various test specimens.

Because of the different sheet size of the 2024-T86 aluminum alloy, the above procedure was slightly modified. The as-received size of the aluminum alloy was 48 by 72 inches. The specimens were specified to be taken in the direction crosswise to the rolling direction, i.e., in the 48-inch direction.

Three sheets were arbitrarily selected for the initial tests of the scatter of normal properties and for obtaining the necessary time-deformation data to establish creep-exposure stresses. The three sheets were designated 2, 3, and 4. (Sheet 1 was laid aside since the clad coating was inadvertently scratched during handling).

The two sampling schemes were designated Q and R. Scheme Q is that used for obtaining the specimen blanks for the scatter tests. Scheme R is similar and used for locating the creep tests specimen blanks.

Each 72 inch long sheet was divided into 14 panels approximately 5 inches wide. The panels were labeled alphabetalically (omitting I and O).

The panels selected for each sampling scheme and the sampling schemes themselves are indicated in Figure 1.

Since the First Progress Report was issued, design of the specimen for tension impact testing has been slightly modified. A drawing of the modified specimen is shown in Figure 2. The changes were made to reduce the over-all length to six inches and to change the fillet radius to 1 inch. This was done in order to reconcile the dimensions with a contemplated notched tensile-impact specimen.

TEST EQUIPMENT

Stress-Strain Recording Equipment

In the period covered by this progress report an automatic stress-strain recording system was installed on the Baldwin-Southwark tensile test machine. This system supersedes the use of the Martens optical extensometer system for tensile testing, although the Martens system continues to be used for creep tests. In addition, a strain pacer was also installed to permit greater accuracy and flexibility in conducting tensile tests at known strain rates.

The recording system was made by the O. S. Peters Company. The extension is measured by a linear variable transformer (or Microformer) which is part of a strain follower fastened to the gage section of the specimen.

To permit the use of the strain recording equipment at elevated temperatures a transfer unit is under construction for transfer of motion outside the furnace. The transfer unit consists of a pair of specimen gripping screws fastened to a concentric rod and tube. The strain follower is to be attached to the bottom ends of the rod and tube. This device is also to be used for the measurement of extension in compression tests. It was originally hoped that this equipment would be ready for use during the period covered by this report, however, delay was encountered in obtaining tungsten carbide points for the specimen gripping screws. These are necessary because of the high hardness of the 17-7PH material. In addition, some difficulty was encountered with slack in the transfer unit. It is anticipated that these difficulties will be resolved shortly. Since no compression tests have been run, the discussion of the fixture for this test will be deferred to a subsequent report.

Tension-Impact Test Equipment

An existing Olsen impact testing machine was modified to permit carrying out tension-impact tests on sheet specimens. The modifications included the construction of a pair of specimen holding jaws that could be attached to the pendulum of the impact machine and the extension of the striking surfaces so that the impact occurred at the maximum downward point of the pendulum swing. In addition, it was necessary to re-calibrate the scale of the machine to obtain true values of impact strength under the test conditions employed.

The design of the specimen holding jaws is shown in Figure 3 and a schematic representation of the test set-up is shown in Figure 4.

The specimen holding jaws were modified from the design of Muhlenbruch (ref 4). The grip assembly was made to screw into a holding assembly fixed to the pendulum head. The specimen itself is held in the split grip sections. A cavity was machined into one side of the split grip to accommodate the specimen. The other half of the split grip has a plane surface and is fixed into position by an indexing pin located at the back end of the grip. The two halves of each grip are locked together by a snap ring. Stiffening rods fixed to the front holder and allowed to "float" in holes in the rear holder reduce the bending tendency of the assembly as the pendulum falls. The striker, which is screwed onto the rear holder provides the necessary tension impact loading as it hits the striking plates of the machine.

Because of the location of the specimen holding assembly, it was necessary to add an auxiliary set of striking surfaces to the existing impact machine base. This modification is indicated in Figure 4. The location of the striking plates was fixed such that the distance L on Figure 4 was the same for the pendulum head and the striking surface in relation to the center of rotation of the pendulum arm. This arrangement permitted the impact blow to take place at the maximum downward point of the pendulum swing.

The impact data can not be read directly from the scale of the machine, because of the added weight of the grips and because the rear portion of the grips falls from the head immediately after the impact blow.

The scale of the machine can be used, however, in the sense that it indicates the height to which the pendulum rises on the up-swing. This is accomplished by an arm concentric with the pendulum arm and one-fifth of its length. This arm contacts a sine-curve rectifier that slides on a pair of vertical rods. The rectifier in turn contacts an indicating disk which provides a reference point on the scale of the machine. The height to which the indicating disk is pushed above its rest position is directly proportional to the height of the pendulum head.

A measurement of the scale showed that 0.73 inches corresponded to 20 scale divisions. It was then possible to obtain an expression that would convert scale divisions to pendulum height, since a 5:1 ratio exists between the lengths of the pendulum arm and the indicator arm. The expression follows:

$$H' = \frac{S}{20} \quad \frac{(0.73)(5)}{(12)} = (0.0152)(S)$$

where H' is the pendulum height in feet after impact, and S is the number of scale divisions traversed by the indicating disk.

Using the terms indicated on Figure 4, the kinetic energy just before impact is $E_p = WH - \alpha F$

where E_p = initial energy, ft-lb H = initial height of pendulum center of gravity, ft.

W = pendulum weight, lb α = angle of rotation on downswing, degrees

F = friction loss per degree

and the final energy just after impact is

$$E_f = WH' + \beta F$$

where E_f = final energy, ft-lb

H' = final pendulum height, ft

β = angle of rotation on up-swing, degrees

The difference between these terms is I, the energy absorbed by the impact.

$$I = E_p - E_f = WH - \alpha F - WH' - \beta F$$

$$I = W(H - H') - F(\alpha + \beta)$$

The calibration of the machine consisted of the determination of the friction loss and the effective initial height of the pendulum head. Because of the irregular shape of the pendulum head it was necessary that the initial height of the center of gravity of the pendulum be calculated from the characteristics of the machine.

The basis of the calibration was the fact that where no specimen was fixed onto the pendulum head, there would be no impact energy absorbed. Thus, the difference in heights would represent the friction loss of the machine. The equation then reduced to the following:

$$I = O = W(H - H') - F(\alpha + \beta)$$

$$W(H - H') = F(\alpha + \beta)$$

The pendulum was removed from the machine and weighed. This was found to be 57.5 pounds. The side plates and front specimen holder were found to weigh 5 pounds and the complete specimen holding assembly was found to weigh 7.7 pounds. Using these various pendulum weights, the assembly was allowed to fall from the initial height and the final height was determined.

Weight	S (avg)	H'	Angle of Rotation ($\alpha + \beta$)
W = 57.5	117	1.78 ft.	151°
W + 5 = 62.5	122	1.85	153°
W + 7.7 = 65.2	123.5	1.88	154°

The angle of rotation was determined by laying out the various distances on a sheet of paper and measuring with a protractor. This procedure was approximate and possibly an average angle could have been used.

From these data, a series of three equations could be written. Since only two unknowns were present it was possible to use the third equation as a check of the accuracy of the determinations.

$$(57.5)(H - 1.78) = 151\ F$$
$$(62.5)(H - 1.85) = 153\ F$$
$$(65.2)(H - 1.88) = 154\ F$$

Solving these equations leads to values of $F = 0.40$ ft-lbs per degree for the friction loss, and the effective initial height $H = 2.82$ feet.

With these values known, it was then possible to compute the equation for the actual testing conditions of 65.2 pounds initial pendulum weight and 62.5 pounds final weight. (This comes about since the rear grips fall from the assembly after impact.)

With the aid of a cord attached to the rear grips it was possible to simulate the operation of the equipment without a specimen being present. Thus, the rear grips were pulled from the assembly at the maximum downward position. In this case H' was found to correspond to 124 scale units. A value of 155° was used for the angle of rotation and the calibrating equation was written as follows:

$$I = O = W_1H - W_2H' - F\ (\alpha + \beta)$$

$$I = (65.2)(2.82) - 62.5\ (.0152S) - 0.40\ (155)$$

$$I = 122 - 0.95\ S \qquad (1)$$

where I is the impact energy absorbed in ft-lbs

S is the scale difference

This equation was then plotted so that values of impact energy could be read directly.

TESTING PROCEDURES

Tensile-Test Procedure

The use of the automatic stress-strain recording equipment has changed to some extent the tensile test procedure described in the First Progress Report. (ref 5) The principal difference is the fact that a constant and accurately known strain rate can be maintained throughout the test with the aid of the strain pacing equipment. At the request of Mr. E. L. Horne of WADC, a strain rate of 0.005 inches per inch per minute has been adopted for all tests.

The data are obtained in the form of a continuous curve of load versus deformation. From this curve are calculated the 0.2 percent offset yield strength and the elastic modulus. In addition, the maximum load can be observed from the recorder trace.

Tension-Impact Test Procedure

The only tension impact tests run to date have been those at room temperature. Prior to assembling the specimen in the holding grips (see Figure 3) measurements are made of the shoulder to shoulder distance and the cross sectional area of the specimen gage section.

The actual running of the test is very simple. The specimen grip assembly is screwed to the holder at the back of the pendulum head which has been previously raised to the fixed initial height. The latch holding the pendulum is released and the head allowed to fall between the striking surfaces fracturing the trailing specimen. The final pendulum height is obtained from the distance which the indicating disc rises on the impact machine scale. This value is converted to energy absorbed using the equation (1), page 12. Measurements of the specimen elongation are made on the fractured specimen.

Creep-Exposure Test Procedure

Creep exposure tests run under load are conducted using the procedure discussed in the First Progress Report. (ref 6) For the tests carried out under no load, i.e., temperature exposure only, the same general scheme is used. That is, all the steps of a normal creep test are followed with the exception of the loading. The two duplicate specimens for each unstressed exposure are wired together and run in the same unit at the same time. The slight additional thickness of the material has no effect on the temperature distribution within the furnance.

For tests in which more than a few per cent of creep are to be measured, excessive deformation of the gauge section makes impractical the direct attachment of extensometer to a uniform-area test length. Fastening the extensometer from the specimen shoulders allows deformation measurements to be made during the entire test, all the way to rupture. But in this case, due allowance must be made for the elastic and plastic deformations in the fillet and shank portions included between the points of extensometer attachment. Corrections for these deformations outside the uniform gauge length are covered in the next section.

After sufficient time-deformation data were available from tests in which extensometers were fixed from the specimen shoulders, stressed exposure tests with limited total deformations could be run with extensometers attached to collars clamped directly onto the gage section of the specimen. This procedure which minimizes errors in computation of deformation has proved to be satisfactory in tests with 2% total deformation and can presumably be used in all creep-exposure tests of the present program.

Calculation of Effective Gage Length for Extension Measurements

Creep test data for the preliminary studies of total deformation were made with extensometers located between collars attached to pin holes on the shanks of the specimens. Thus, the deformation recorded included not only the extension in the gage section but also in the fillets and shanks. Consequently, it was necessary to calculate an effective gage length for these specimens that would take into account the deformation of the fillets and shanks.

Two different corrections were needed, depending on whether elastic or plastic deformation was being measured. In general, the elastic correction was used for loading deformations or short time tensile tests, while the plastic correction was used for creep tests.

The effective gage length for the elastic case was calculated from the specimen geometry alone. A sketch of a typical specimen is presented in Figure 5. This drawing defines the various terms used in the calculation of the effective gage length. The measurements made on a typical specimen were the widths at equal increments of distance from the fillet shoulder to the actual gage section. The distance increments used were 0.050 inches and the widths are tabulated in column (b) of Table 1. In the elastic case the strain in any section is inversely proportional to the area, so that the effective gage length for each short interval was simply the interval length multiplied by the ratio of the relative area of that interval to the area in the gage section. For a sheet specimen, the relative areas (column g) were merely the interval widths. The ratio between this width and the gage section width was multiplied by the interval length (column h) and summed to give the total contribution of the fillet. This was doubled to account for both fillets. The equivalent shank length was the total shank length multiplied by the ratio between the gage section width and the shank width. The shank length is the pin to pin distance minus the shoulder to shoulder distance. The effective gage length then was calculated by subtracting the actual fillet lengths from the shoulder to shoulder distance and adding the effective lengths of the fillets and shanks. This is indicated in Table 1 and was equal to SS + 0.45" for the particular specimen design under consideration.

For the calculation of the plastic case, it was necessary to have information on the stress-creep rate relationships for the material at the test conditions. This information was obtained from the test data themselves. Examination of the rough time-elongation data showed that the minimum deformation rate occurred at about 25 percent of the rupture life. A calculation was made of the minimum creep rate in scale units ($\Delta L + \Delta R$) per hour at the time corresponding to 25 percent of the rupture life for that particular stress. A plot of stress versus creep rate was made from these data and is presented in Figure 6.

For the case illustrated in Table 1 a gage section stress of 110,000 psi was considered for a test at 800°F. From the specimen geometry, the stress was then calculated at each previously measured interval in the fillet. The stresses are tabulated in column (c). The creep rate at 800°F corresponding to each stress was obtained from Figure 6 and recorded in column (d) and finally the average creep rate was calculated for each 0.050 inch interval of fillet length. The effective length for each 0.050-inch interval was then calculated by multiplying the length by the ratio of the creep at that particular stress to the creep rate in the gage section (i.e., at 110,000 psi). This calculation is indicated in column (f) and was then doubled to account for both fillets. The equivalent length of the shank was computed by multiplying the shank length by the ratio of the shank creep rate to the gage section creep rate. The effective gage length for creep at 800°F was then expressed in terms of the shoulder to shoulder distance by first subtracting the actual fillet lengths and then adding the calculated effective lengths of the fillets and shanks. The value obtained for 800°F was SS - 0.905". The values for 600° and 900°F obtained in a similar manner are as follows:

$$EGL_{600°F} = SS - 1.01''$$

$$EGL_{900°F} = SS - 0.83''$$

RESULTS AND DISCUSSION

Tensile Test Results--17-7PH Stainless Steel

The results of ten tensile tests run at room temperature on samples of the 17-7PH precipitation hardening stainless steel in the TH1050 condition are summarized in Table

Six of the tests were run on samples from sheet 1 and two each were run on samples from sheets 2 and 3.

The data indicate that the samples from sheet 1 were somewhat stronger and less ductile than the samples from sheets 2 and 3. There was little difference between the hardnesses of the samples from all three sheets.

The average properties were calculated for each sheet and for all ten tests. Since six specimens were run from sheet 1 and only two each from sheets 2 and 3, a second set of averages, that of the average of the sheet averages, was calculated. The reason for computing this average was to reduce the bias that would result from the simple average of all ten tests. The basis for this was that an average of all sheets should not be weighted 60 percent with values from sheet 1. These values show good agreement with those given by Armco Steel Corporation (ref 2) as "typical" and "minimum" properties and also with the results noted by Brisbane (ref 7) for "high strength" heats of 17-7PH.

The variation in properties appears to be principally concerned with sheet to sheet differences. The variations within the sheets are no larger than the variation between sheets.

Creep-Rupture Tests of 17-7PH Alloy

The results of creep-rupture tests run on the TH1050 condition of the 17-7PH stainless steel at 600, 800, and 900°F are summarized in Table 3. The primary purpose of these tests was to establish curves of time -versus total deformation to aid in the selection of stresses for the stressed exposure tests. The tests were allowed to run to rupture since the scatter in rupture properties is another measure of the inherent variability of the material.

The data obtained from these tests are presented in graphical form in Figure 7 as curves of rupture and total deformation time versus stress for the three temperatures under consideration. The rupture times and fracture elongation show good consistency at each of the test temperatures.

Hardness measurements were also taken on the specimens after the completion of testing and show that a moderate increase in hardness resulted from the exposure to time, stress, and temperature. Six random hardness impressions were taken on each sample, three in the shanks and three in the gage section. No significant differences in hardness were noted between the shanks and gage section. A statistical analysis of the hardness date indicated that the hardness change at all test temperatures was significant with respect to the as-treated (base) condition, but that there was no significant difference between the average hardness changes for 800° and 900°F exposures, while the difference between the 600°F exposures and the other two temperatures was on the borderline of significance. In this analysis, the effects of exposure time were neglected--the basis of comparison was exposed versus unexposed specimens hardness.

A similar analysis, taking into account the effects of time, temperature, and deformation, will be made on the data from the regular exposure tests.

Curves of stress versus total deformation were established at each of the test temperatures from the available data. At 600°F, none of the test stresses used was low enough to give less than 0.5 percent loading deformation. Consequently, additional tests will be required at this temperature and one or two low stress tests remain to be run at the two higher temperature.

In order to fit curves to the available time-deformation data it was necessary to allow for slight breaks in the curves. In general, these curves tend to follow the same slopes as the rupture curves at the same temperature.

A check of the data was possible by a comparison with the results of Hanlon, Salvaggi, and Guarnieri (ref 8) for tests at 800°F. Figure 8 compares the two investigations. The agreement appears to be good.

The stresses estimated from experimental data at 600°, 800° and 900°F for the achievement of specified total deformations in the time periods required in this investigation are presented in Table 4. The figures in parentheses were obtained by extrapolation of the total deformation curves. The stresses required for deformations at intermediate temperatures will be estimated by interpolation from these data.

Effect of Re-Machining on Tensile Test Results

In the First Progress Report (ref 9) the statement was made that after creep exposure the edges of the gage sections of the tensile test specimens would be remachined. This was done for two reasons. First, it was desired that the final tests measure the properties of the sheet material itself and not the particular specimen's edge effects. Second, it was desired that the practice for subsequent tensile test specimens conform to that adopted for the tension-impact and compression specimens in that these specimens were designed to be machined from the gage section of an exposed creep specimen.

Consequently, the creep-exposure specimens were originally machined to a 0.530 inch wide gage section. Following the exposure, the specimens were ground to a final gage section width of 0.500 inch prior to tensile testing.

The question did arise as to what effect, if any, the subsequent remachining operation would have on the tensile properties of an exposed specimen. Advantage was taken of a specimen that had been originally intended for exposure at 700°F and 120,000 psi to reach 2 percent total deformation in 100 hours. This specimen 2R-T2 was given the standard remachining operation after exposure. Another specimen 3Q-T6 was given the identical exposure and then tensile tested without remachining; i.e., with 0.530 inch wide gage section. The results of these tests are as follows:

Specimen	Total Def-%	Ult. Tensile psi	0.2% Yield psi	Elong. %-2 in.	Red. Area %	$E \times 10^6$ psi	Hardr R"C'
Remachined (2R-T2)	2.54	219,000	218,000	2.2	13.7	30.6	44.0
Not Remachined (3Q-T6)	1.95	220,000	219,000	3.5	13.8	29.6	44.2

The result of these two tests indicates that the remachining operation has no significant effect on the tensile properties. This conclusion should be checked further at other conditions.

Exposure Test Results--17-7PH Alloy

Results of twenty-one tests of the effects of exposure to elevated temperature on the room temperature tensile properties of the 17-7PH alloy in the TH1050 condition are reported in Table 5. Eighteen of these tests were intended to study the effects of time and temperature alone. In addition, three tests have been completed that add the factor of creep deformation to the evaluation.

The tests after unstressed exposure were run for 10, 50 and 100 hours at temperatures of 600°, 800°, or 900°F. Two specimens from different sheets were run for each exposure condition and the results are reported as averages. The average of the sheet averages of the as-treated material was taken as the base condition for comparing properties. Statistical analysis of the scatter obtained in the as-treated material indicated that changes in tensile and yield strength of the order of 12,000 to 15,000 psi would be significant.

A plot of the average effects of the unstressed exposure conditions on the tensile strength, elongation, and hardness is presented in Figure 9. In conjunction with Table 5 these results indicate that the unstressed exposure at 600°F had little effect on the tensile properties of this material. The 10-hour exposure at 800° or 900°F also had little effect, however, the 50 and 100 hours exposures at 800 and 900°F did have a significant effect on the room temperature properties. The maximum effect at 900°F appears to have been reached at a time less than 100 hours. At 800°F the time to reach a maximum may be somewhat over 100 hours, although the rate of increase in strength appears to have diminished after the initial rise for an exposure of 50 hours. The hardness data confirm the trend indicated by the tensile strength.

The data covering the effects of stressed exposure are as yet sparse. As agreed in a conference with a representative of the Materials Laboratory, WADC it is intended to survey the results of exposure to 2 percent total deformation in 100 hours for this material at 50°F temperature intervals between 600° and 900°F.

One test has been completed at 600°F and the two tests at 800°F are complete. In addition, two tests were peformed at 700°F to check the effects of remachining of tensile specimens. These tests are not reported in Table 5 since the stress used (which was interpolated from the survey total deformation data) resulted in higher deformation than was desired. These test results were noted on page 20.

The test result from the 600°F stressed exposure indicates that the effect of creep deformation may change properties appreciably where unstressed exposure to temperature did not. Of particular interest is the loss of ductility, the increase in the tensile strength, and the increase in the yield strength relative to the tensile strength.

At 800°F the effect of stressed exposure to 2 percent total deformation was similar but not quite as marked. The 700°F stressed exposure also resulted in increased strength over the base properties and an increase in the yield strength relative to the tensile strength.

Further discussion of these results will be deferred until the data are more complete.

Tension-Impact Test Results--17-7PH Alloy

The results of six tension-impact tests run at room temperature on the TH1050 condition of the 17-7PH stainless steel are reported in Table 6. These results include two specimens each from the three sheets sampled for the determination of the scatter in normal properties of the as-treated material. Two to three more tests from different locations in the same sheets remain to be run.

The data reported are the energy absorbed on impact and the elongation of the specimen after fracture. The agreement between the duplicate specimens in each sheet is good, however, there appear to be some scatter in properties between the sheets themselves. The additional tests to be run will enable an estimate to be made of the sheet-to-sheet scatter.

Tensile Test Results--2024-T86

Table 7 summarizes results of three room temperature tensile tests run to data on the 2024-T86 aluminum alloy.

One specimen from each sheet has been tested. Seven more specimens will be tested; two each from sheets 2 and 4, and three from sheet 3.

The three specimens so far tested show good agreement in properties. The variation in reduction of area is not too significant and is probably due to the difficulty in obtaining such measurements on sheet materials.

Further discussion of the tensile properties of this material will be deferred until the results of the other seven tests are available.

FUTURE WORK

During the next two-month period efforts will be made to complete the extensometer fixture for elevated-temperature tension and compression testing.

Priority will be given to determination of scatter in room-temperature tensile properties of the 2024-T86 aluminum alloy, after which tests can be started to cover effects of unstressed exposure and to determine the proper stresses to give the desired total deformation values.

Until creep frames are needed for the aluminum alloy tests, creep exposures to give 2 percent total deformation at 100 hours will be continued for 17-7PH.

Tension-impact tests with both alloys are scheduled to be initiated during the coming work period. Compression tests will be delayed until the completion of the extensometer fixture.

REFERENCES

1. Gluck, Voorhees, Freeman, "First Progress Report to Materials Laboratory, WADC," on Contract AF 33(616)-3368, "Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals" - page 2 - 4.

2. Armco Steel Corp. , Product Data Bulletin on Armco 17-7PH Steel, March 1, 1954.

3. ref 1 - pages 8 - 9.

4. Muhlenbruch, "A Tension-Impact Test for Sheet Materials" A.S.T.M. Bulletin No. 196, page 43, February 1954.

5. ref 1 - page 11.

6. ref 1 - page 10.

7. Brisbane "Mechanical Properties of 17-7PH Stainless Steel" WADC Technical Note 56 - 169, page 7, April 12, 1956.

8. Hanlon, Salvaggi, Guarnieri "Intermittant Stressing and Heating of Aircraft Structural Metals" Bi-monthly Progress Report to Air Research and Development Command, Contract AF 33(616)-2226, page 7, June 30, 1955.

9. ref 1 - page 4.

Table 1

Example Calculation of Effective Gage Lengths for Strip Specimens

		Gage Length for Creep at 800°F				Elastic Gage Length	
(a) Distance from Shoulder inches	(b) Spec. Widths inches	(c) Stress psi	(d) Creep Rate ΔL+ ΔR/hr	(e) Avg. Creep Rate per .050"	(f) Avg. Creep (e) / Creep at Center per .050"	(g) Rel. Area of Interval	(h) Area in GS / (g) x Length of Interval
0	1.0050	55,400	0.025			1.005	.0255
0.050	0.9236	60,300	0.066	0.0455	0.001	.924	.0274
0.100	0.8466	65,800	0.095	0.0805	.002	.847	.0299
0.150	0.7790	71,500	0.210	0.1525	.004	.779	.0326
0.200	0.7210	77,300	0.470	0.340	.008	.721	.0351
0.250	0.6707	83,100	1.1	0.785	.019	.671	.0377
0.300	0.6278	88,800	2.2	1.65	.039	.628	.0403
0.350	0.5916	94,200	4.8	3.50	.083	.592	.0428
0.400	0.5622	99,000	9.5	7.15	.170	.562	.0450
0.450	0.5387	103,500	17.0	13.25	.316	.539	.0470
0.500	0.5208	107,000	27.0	22.0	.524	.521	.0485
0.550	0.5094	109,400	38.0	32.5	.774	.509	.0498
					Sum ~~1.340~~ 1.940		Sum .4616 = .46
Center	0.5064	110,000	42.0	---		.506	

PLASTIC CASE - 800°F

Effective Length 2 fillets = 2(1.940)(.050)
= 0.194"

Shank Length = pin-pin minus shoulder-shoulder
= 4.82 - 3.55 = 1.27

Equivalent Length of Shank:

$$1.27 \frac{(\text{Creep Rate in Shank})}{(\text{Creep Rate at Center})} = 1.27 \frac{(.025)}{(42)} = .0008''$$

Total Equivalent Length: Shank plus Fillets

.0008 + 0.194 = 0.195"

ELASTIC CASE

Effective Length 2 fillets = 2(.46)= .92"

Shank Length = 1.27"

Equivalent Shank Length:

$$1.27 \frac{(\text{Gage Section Area})}{(\text{Shank Area})} = 1.27 \frac{(.506)}{(1.005)} = .63''$$

Total Equivalent Length: Shank plus Fillets

= .92 + .63 = 1.55"

EFFECTIVE GAGE LENGTH = SHOULDER TO SHOULDER - ACTUAL FILLET + (EFFECTIVE SHANK PLUS FILLETS)

$EGL_{800°F} = SS - 2(.55) + .195$

$= SS - .905''$

$EGL_{elastic} = SS - 2(.55) + 1.55$

$= SS + .45''$

Similarly

$EGL_{(600°F)} = SS - 1.01''$

$EGL_{(900°F)} = SS - 0.83''$

Table 2

Room Temperature Tensile Data

17-7PH Alloy (TH 1050 Condition)

Spec. Loc.	Ult. Tensile (psi)	0.2% Yield Strength (psi)	Elongation (% in 2 in)	Reduction of Area (%)	$E \times 10^6$ psi	Hardness (R"C")
1C-T1	212,000	208,000	4.2	16.9	29.0	43.9
1L-T1	209,000	196,000	6.0	13.9	28.8	42.8
1L-T2	214,000	196,000	5.5	14.3	29.0	43.5
1L-T3	216,000	210,000	5.6	9.8	28.7	43.8
1L-T4	215,000	208,000	4.5	13.4	28.6	44.9
1U-T2	211,000	207,000	4.0	17.9	28.6	43.4
Average	212,833	204,160	5.0	14.4	28.8	43.7
2J-T3	197,000	186,000	9.0	19.4	27.6	43.4
2N-T3	187,000	173,500	8.8	21.7	29.3	42.3
Average	192,000	179,750	8.9	20.6	28.4	42.8
3G-T1	201,000	195,500	7.8	18.7	28.2	45.1
3Q-T1	202,000	195,000	7.2	20.8	29.2	44.3
Average	201,500	195,250	7.5	19.8	28.7	44.7
Avg. of 10 Tests	206,400	197,500	6.3	16.7	28.7	43.7
Avg. of Sheet Avg.	203,100	193,050	7.1	18.2	28.6	43.7
Properties Reported by Armco Steel Corp. (ref 2)						
Typical	200,000	185,000	9.0			43
Minimum	180,000	150,000	6.0			

Table 3

Rupture and Total Deformation Data

17-7PH Alloy (TH 1050 Condition)

Spec. Loc.	Test Temp (°F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in)	Reduction of Area (%)	Hardness after test (R"C")	Loading Def. %	Time to Reach Indicated Total Deformation (hours) 0.5%	1.0%	2.0%	3.0%
1K-T5	600	180,000	0.1	4.0	13.1	44.4	--	---	---	---	---
1K-T2		180,000	on load	4.0	0	42.3	--	---	---	---	---
1U-T1		175,000	15.1	10.0	17.5	45.5	.80	---	.05	1.6	4.1
1C-T3		170,000	11.9	7.0	15.0	44.7	.75	---	.4	2.5	5.7
1G-T1		170,000	42.6	9.0	20.5	45.8	.72	---	4.0	4.6	12.0
1L-T6		165,000	98.8	12.5	20.5	44.3	.69	---	0.6	17.5	32.0
1C-T5		160,000	661.2	16.5	26.0	47.7	.64	---	8.5	71.0	152.0
2E-T1		150,000	in progress				.59	---	46.0	330.0	
2E-T5		125,000	in progress				approx .30	approx 1000			
1G-T5	800	105,000	37.3	22.0	37.0	46.3	.47	.05	0.3	0.8	1.3
3A-T6		100,000	61±3	43.0	44.0	46.8	.41	0.1	1.9	6.4	10.2
1U-T3		100,000	107±5	32.0	44.0	46.0	.41	0.1	2.3	8.5	16.0
1C-T4		95,000	179.1	26.0	36.5	47.2	.38	0.4	4.0	14.0	25.5
1U-T4		90,000	555.6	37.5	48.5	48.2	.35	0.5	8.0	29.0	52.0
1Q-T25		70,000	in progress				.26	7.0	90.0	850.0	---
1U-T5	900	75,000	19.8	31.0	46.5	46.9	.32	0.10	1.0	2.9	4.6
1K-T4		70,000	29.1	28.0	49.0	46.1	.29	0.20	1.2	3.4	5.7
1K-T6		70,000	56.7	38.5	52.8	45.9	.30	0.25	1.4	4.6	7.7
1L-T5		70,000	24.5	29.8	48.6	45.6	.31	0.15	0.8	2.4	4.3
1C-T2		70,000	28.4	32.2	47.2	46.8	.30	0.17	1.1	3.2	5.2
1K-T3		60,000	152.2	33.0	65.0	45.7	.26	0.8	4.4	13.5	24.4
1G-T4		55,000	323.6	43.0	51.0	46.8	.24	1.5	5.0	23.0	45.5
1C-T2		50,000	699.1	40.0	49.5	46.4	.21	4.0	17.0	76.0	134.0

Table 4

Estimated Stresses for Given Total Deformations

17-7PH Alloy (TH 1050 Condition)

Temp (°F)	Total Deformation (%)	Stress (psi) to reach stated total deformation in following time periods Time - hours 10 hrs	 50 hrs	 100hrs
600	0.5	--	--	--
	1.0	159,000	150,000	(146,000)
	2.0	167,000	161,000	157,000
	3.0	170,000	164,000	161,000
800	0.5	(73,000)	(63,000)	(59,000)
	1.0	88,000	(76,000)	(70,000)
	2.0	98,000	86,000	81,000
	3.0	102,000	90,000	85,000
900	0.5	(42,000)	--	--
	1.0	53,000	(40,000)	46,000
	2.0	63,000	51,000	49,000
	3.0	68,000	56,000	51,000

(   ) extrapolated

Table 5

Effect of Exposure on Room Temperature Tensile Properties

17-7PH Alloy (TH 1050 Condition)

Spec. Loc.	Temp (°F)	Stress (psi)	Time (hr)	Total Def. (%)	Ult. Tensile (psi)	0.2% offset Yield (psi)	Elongation (% - 2 in)	Reduction of Area (%)	E x 10^6 psi	Hardness R"C"
2E-T4	600	None	10	None	192,000	183,000	8.5	20.0	30.2	40.9
3P-T3	"	"	"	"	209,000	203,000	6.5	19.7	30.4	43.4
				Average	200,500	193,000	7.5	19.8	30.3	42.2
1P-T21	600	None	50	None	193,000	186,000	10.5	18.3	30.4	42.0
3L-T5	"	"	"	"	187,000	180,000	9.0	22.6	31.2	41.6
				Average	190,000	183,000	9.8	20.5	30.8	41.8
2N-T4	600	None	100	None	192,500	184,200	8.0	18.4	29.4	42.5
3A-T1	"	"	"	"	212,000	206,000	7.5	19.4	28.8	45.8
				Average	197,250	195,100	7.8	18.9	29.1	44.2
2N-T1	600	157,000	100.5	1.89	223,000	(223,000)	1.5	13.7	29.4	45.3
3H-T1	800	None	10	None	201,000	195,000	7.5	18.7	30.8	43.8
2R-T3	"	"	"	"	192,000	187,000	5.0	16.9	29.8	41.9
				Average	196,500	191,000	6.2	17.8	30.3	42.8
2S-T2	800	None	50	None	218,000	213,000	4.9	15.1	31.2	43.6
1Q-T23	"	"	"	"	220,000	215,000	6.0	17.9	30.4	45.5
				Average	219,000	214,000	5.4	16.5	30.8	44.6
3G-T6	800	None	100	None	222,000	216,000	4.0	17.9	29.8	47.4
2N-T2	"	"	"	"	222,500	216,000	5.0	17.3	30.2	48.2
				Average	222,250	216,000	4.5	17.6	30.0	47.8
3P-T1	800	81,000	102.6	2.12	232,000	229,000	3.5	12.1	29.9	46.7
2S-T6	"	"	102.1	1.88	227,000	222,000	4.2	15.8	30.2	46.7
			Average	2.0	229,500	225,500	3.8	14.0	30.1	46.7
1P-T23	900	None	10	None	205,500	200,000	6.5	17.2	30.2	43.1
3A-T5	"	"	"	"	206,500	201,000	5.0	18.2	30.8	44.2
				Average	206,000	200,500	5.8	17.7	30.5	43.6
2S-T1	900	None	50	None	230,000	224,000	3.5	14.1	30.9	46.2
3H-T6	"	"	"	"	234,000	228,500	5.0	13.7	30.6	47.0
				Average	232,000	226,500	4.2	13.9	30.8	46.6
3P-T6	900	None	100	None	222,000	215,000	4.5	8.4	30.4	46.2
2N-T5	"	"	"	"	220,000	213,000	6.0	17.1	78.8	47.0
				Average	221,000	214,000	5.2	12.8	29.6	46.6
					As treated properties - average of sheet averages					
Sheets 1, 2, and 3					203,100	193,050	7.1	18.2	28.6	43.7

Table 6

Room Temperature Tension Impact Test Data

17-7PH Alloy (TH 1050 Condition)

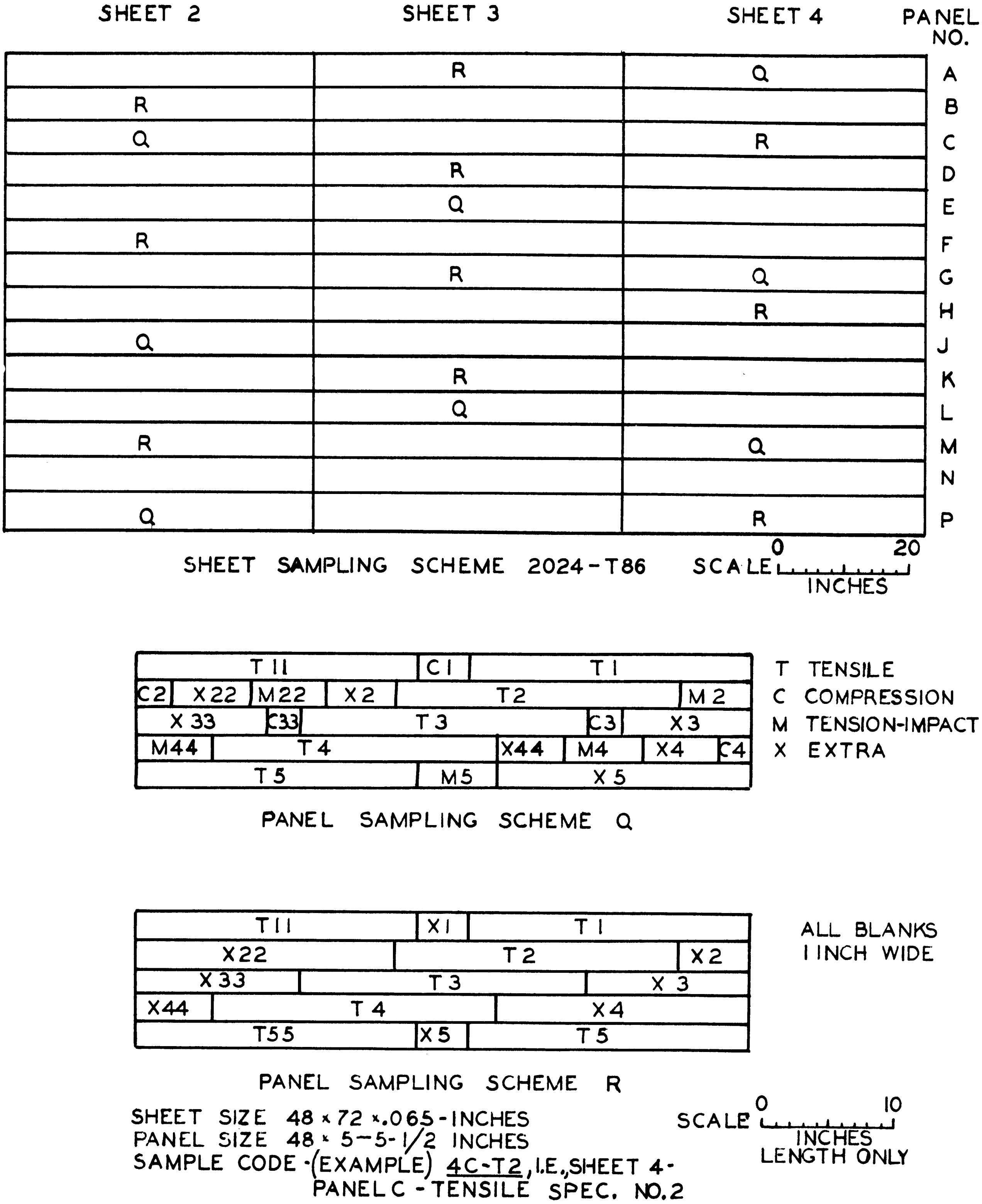
Spec. Loc.	Energy Absorbed ft-lb	Elongation (% - 2 in)
1C-M5	35	2.5
1C-M6	37	4.0
Average	36	3.2
2J-M1	48	4.0
2J-M2	41	3.0
Average	44.5	3.5
3L-M2	52	5.6
3L-M5	52	5.6
Average	52	5.6
Grand Average	44.1	4.1

Table 7

Room Temperature Tensile Data

2024-T86 Aluminum Alloy

Spec. Loc.	Ult. Tensile (psi)	0.2% Yield Strength (psi)	Elongation (% in 2 in)	Reduction of Area (%)	$E \times 10^6$ psi
2P-T5	75,000	70,100	10.2	12.9	10.7
3E-T1	74,500	69,400	8.0	19.0	10.4
4A-T5	75,200	70,000	8.0	8.6	10.7



SHEET 2	SHEET 3	SHEET 4	PANEL NO.
	R	Q	A
R			B
Q		R	C
	R		D
	Q		E
R			F
	R	Q	G
		R	H
Q			J
	R		K
	Q		L
R		Q	M
			N
Q		R	P

SHEET SAMPLING SCHEME 2024-T86

T TENSILE
C COMPRESSION
M TENSION-IMPACT
X EXTRA

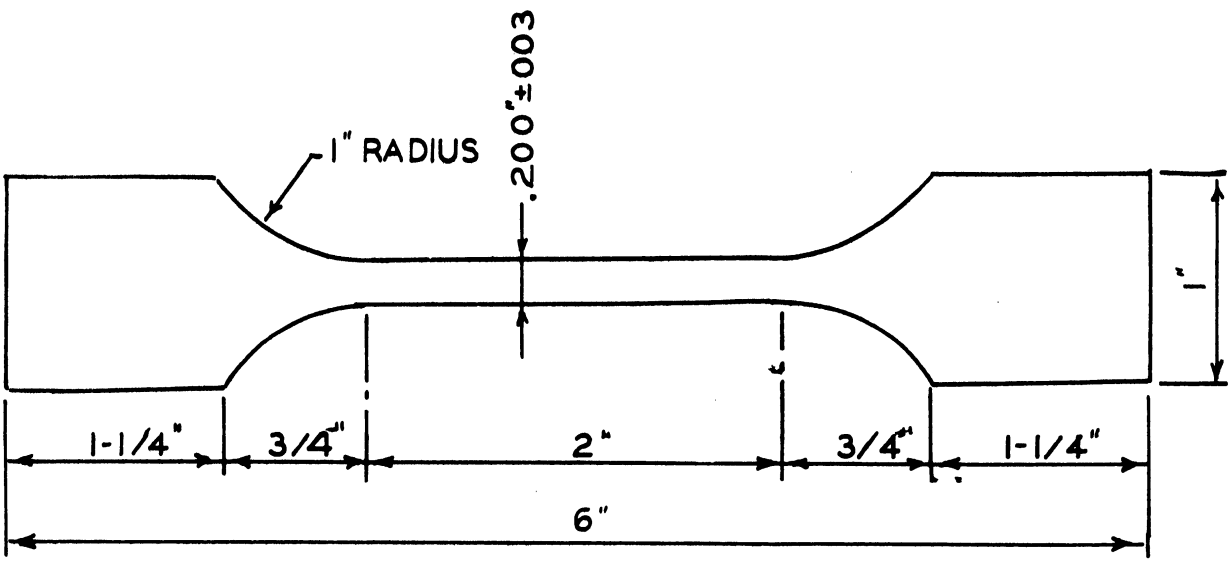
PANEL SAMPLING SCHEME Q

ALL BLANKS
1 INCH WIDE

PANEL SAMPLING SCHEME R

SHEET SIZE 48 × 72 ×.065-INCHES
PANEL SIZE 48 × 5-5-1/2 INCHES
SAMPLE CODE -(EXAMPLE) 4C-T2, I.E., SHEET 4-PANEL C - TENSILE SPEC. NO.2

Figure 1. - Sampling Procedure for sheets of 2024-T86 aluminum alloy



SPECIMEN IS FULL SHEET THICKNESS - .064 INCHES

Figure 2. - Tension-impact specimen -- as modified from previous design

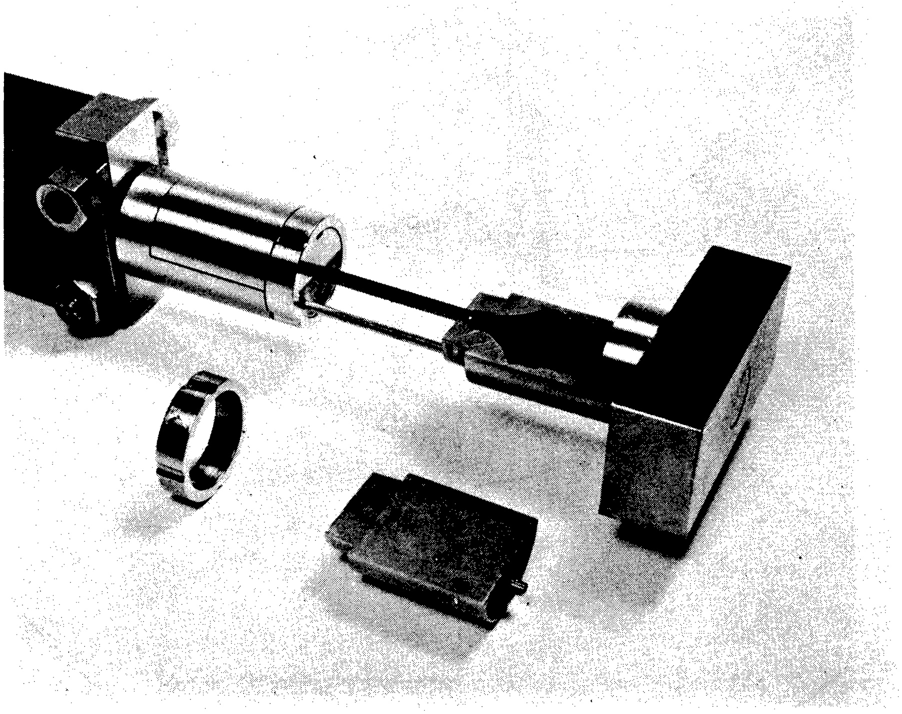


Figure 3. - Tension-impact specimen and gripping assembly. The plates at left fit over the impact machine pendulum head

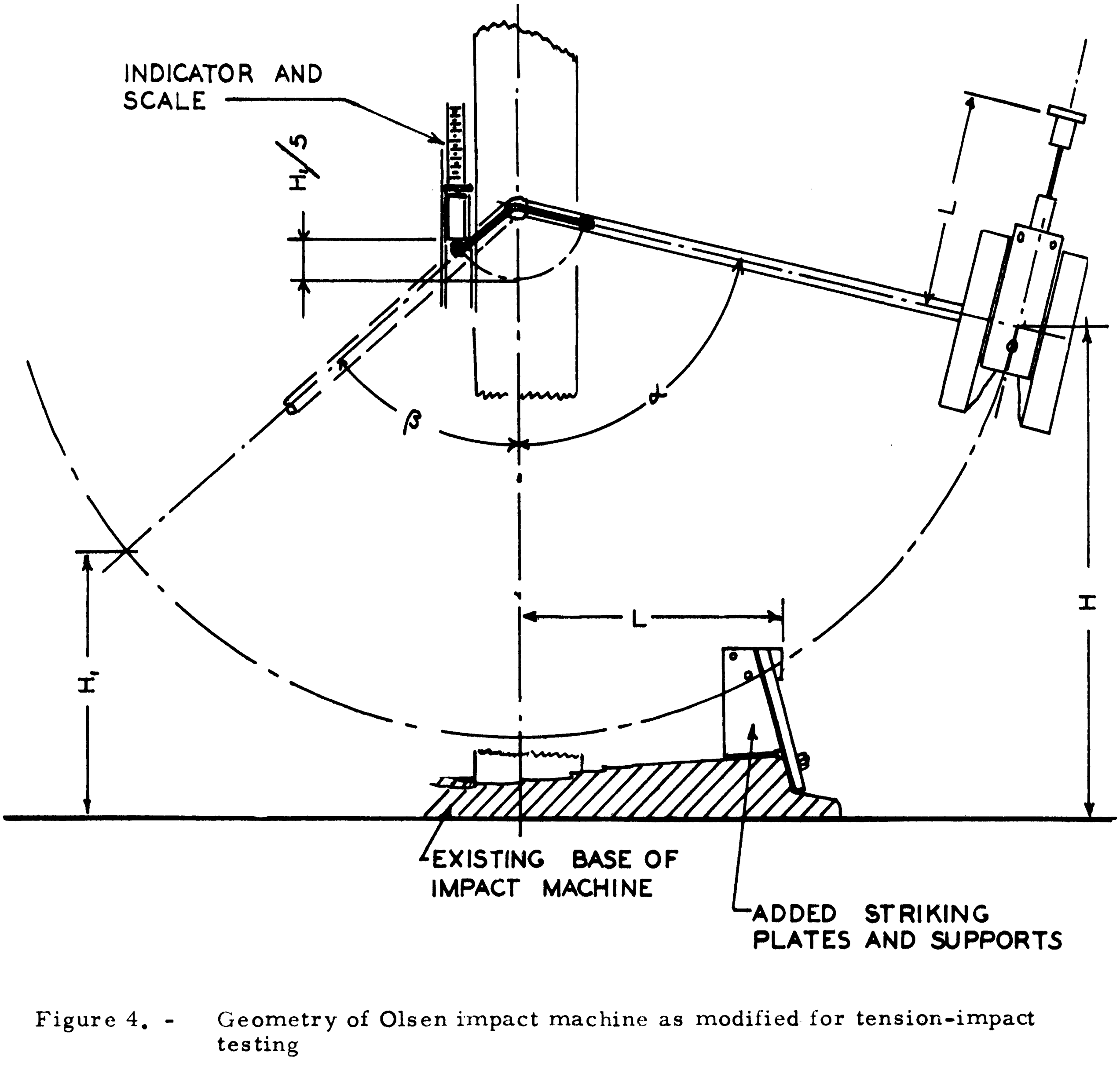


Figure 4. - Geometry of Olsen impact machine as modified for tension-impact testing

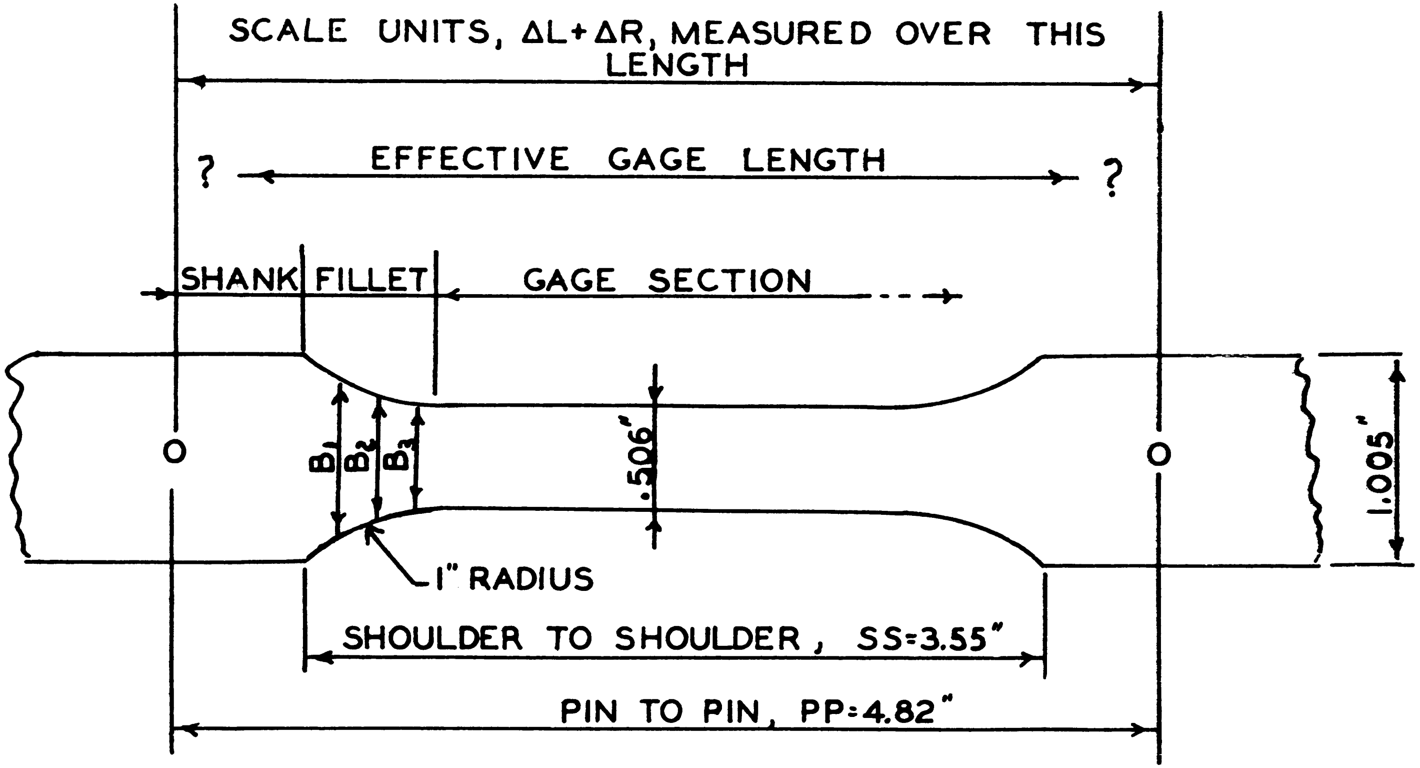


Figure 5. - Gage section of typical strip specimen for illustration of calculation of effective gage length

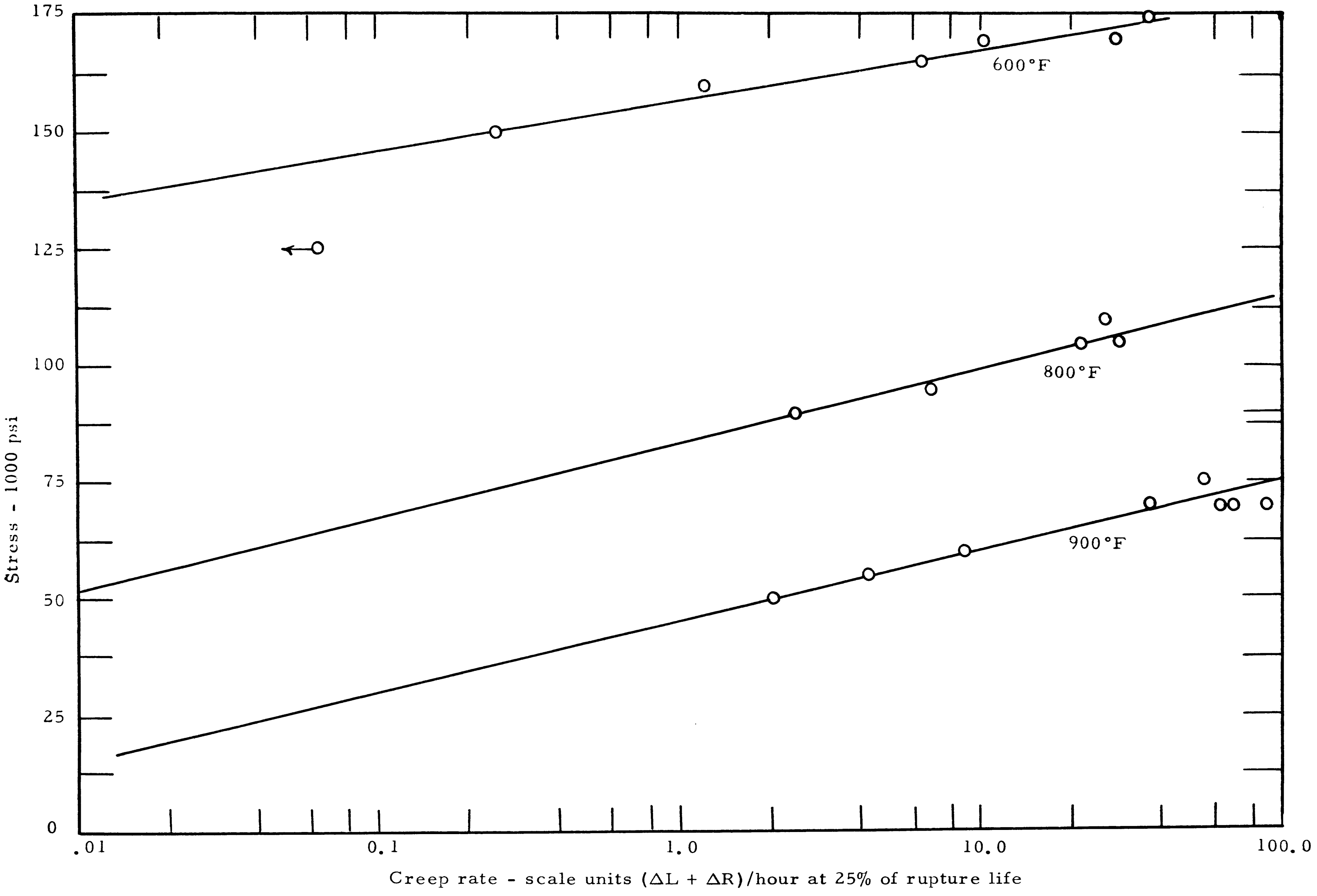


Figure 6. - Stress versus relative creep rate at 600°, 800°, 900°F for 17-7PH alloy in TH 1050 condition

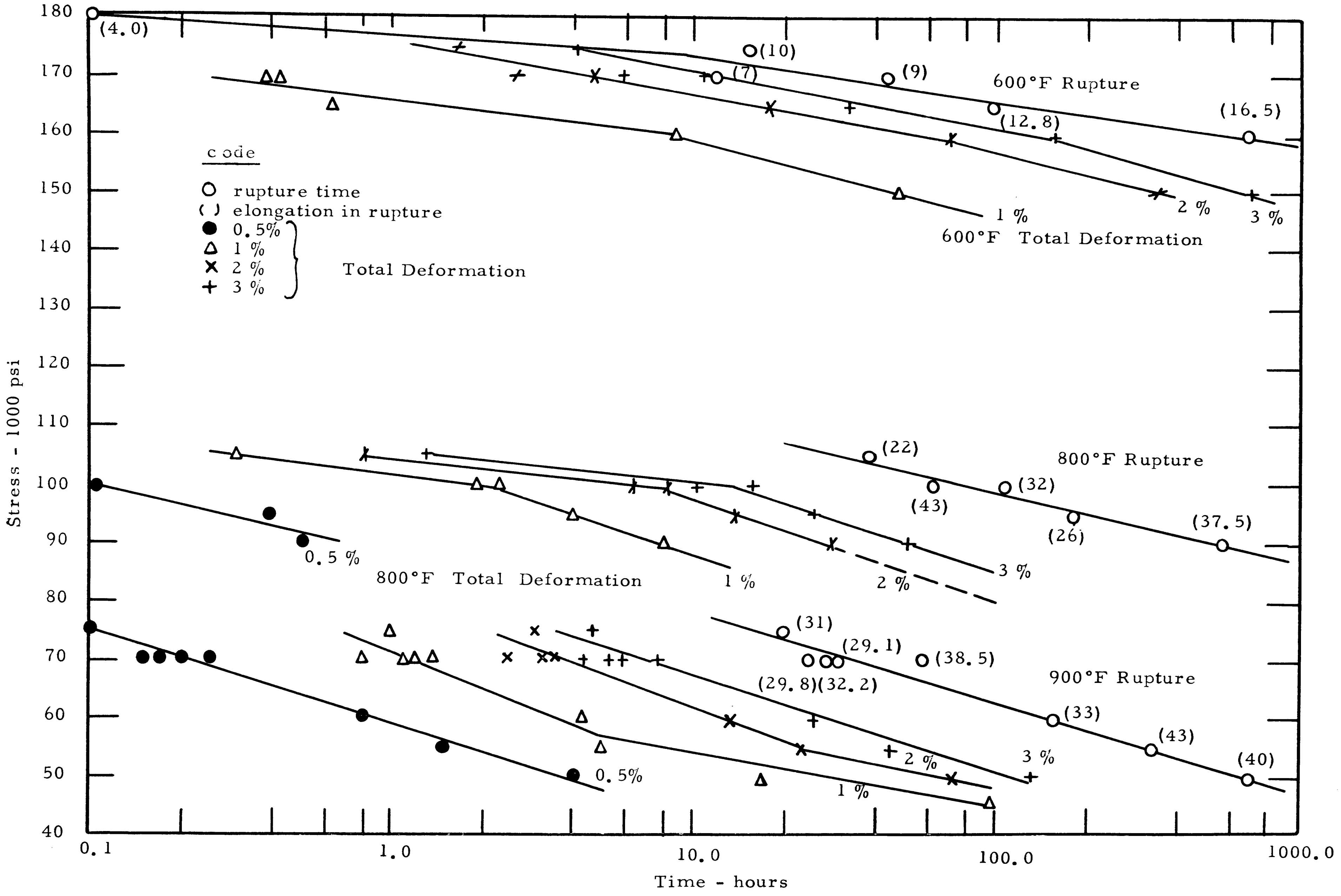


Figure 7. - Time for rupture and specified total deformations versus stress for 17-7PH alloy in TH 1050 condition

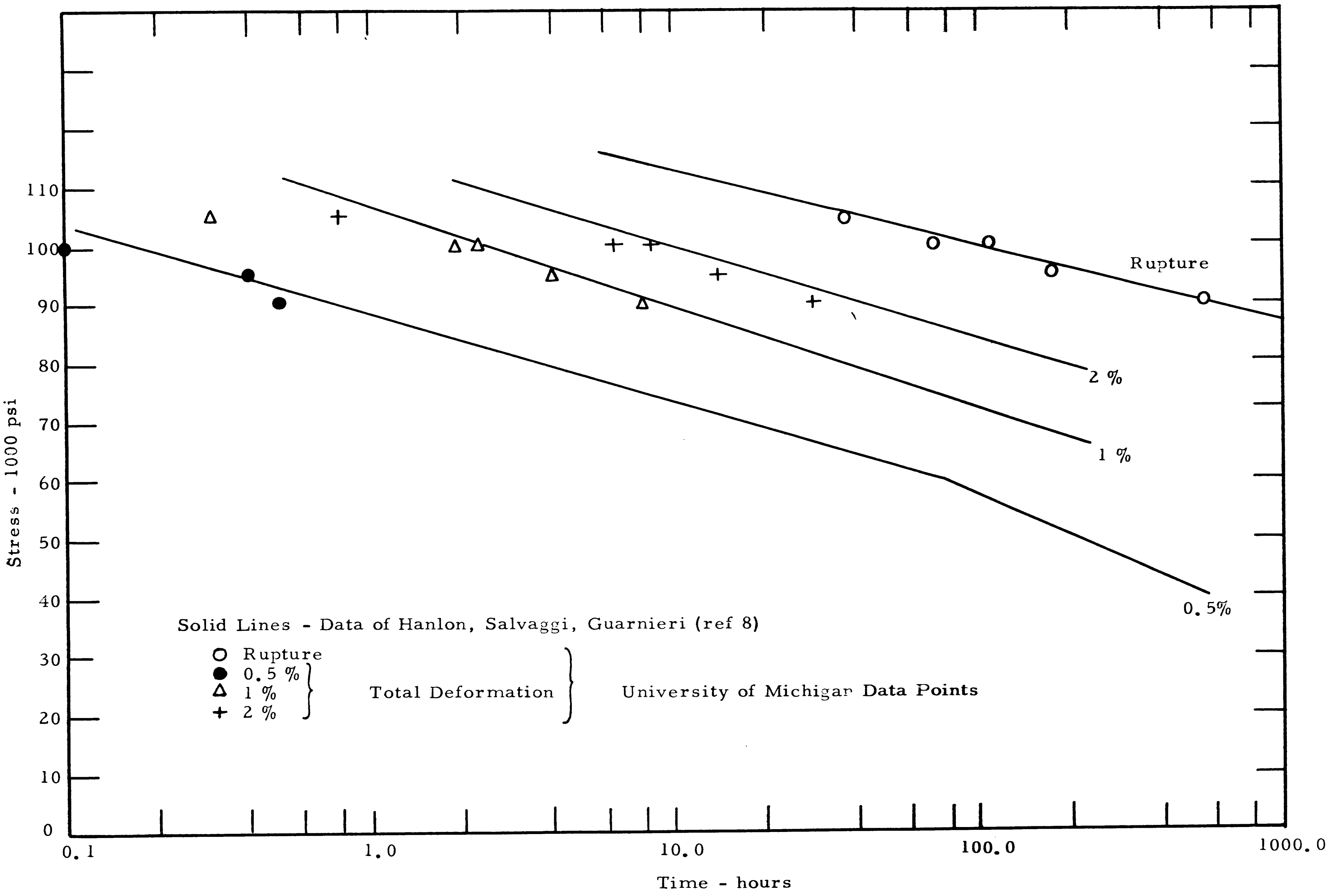


Figure 8. - Comparison of University of Michigan data points with rupture and total deformation curves of Hanlon, et al for 17-7PH at 800°F

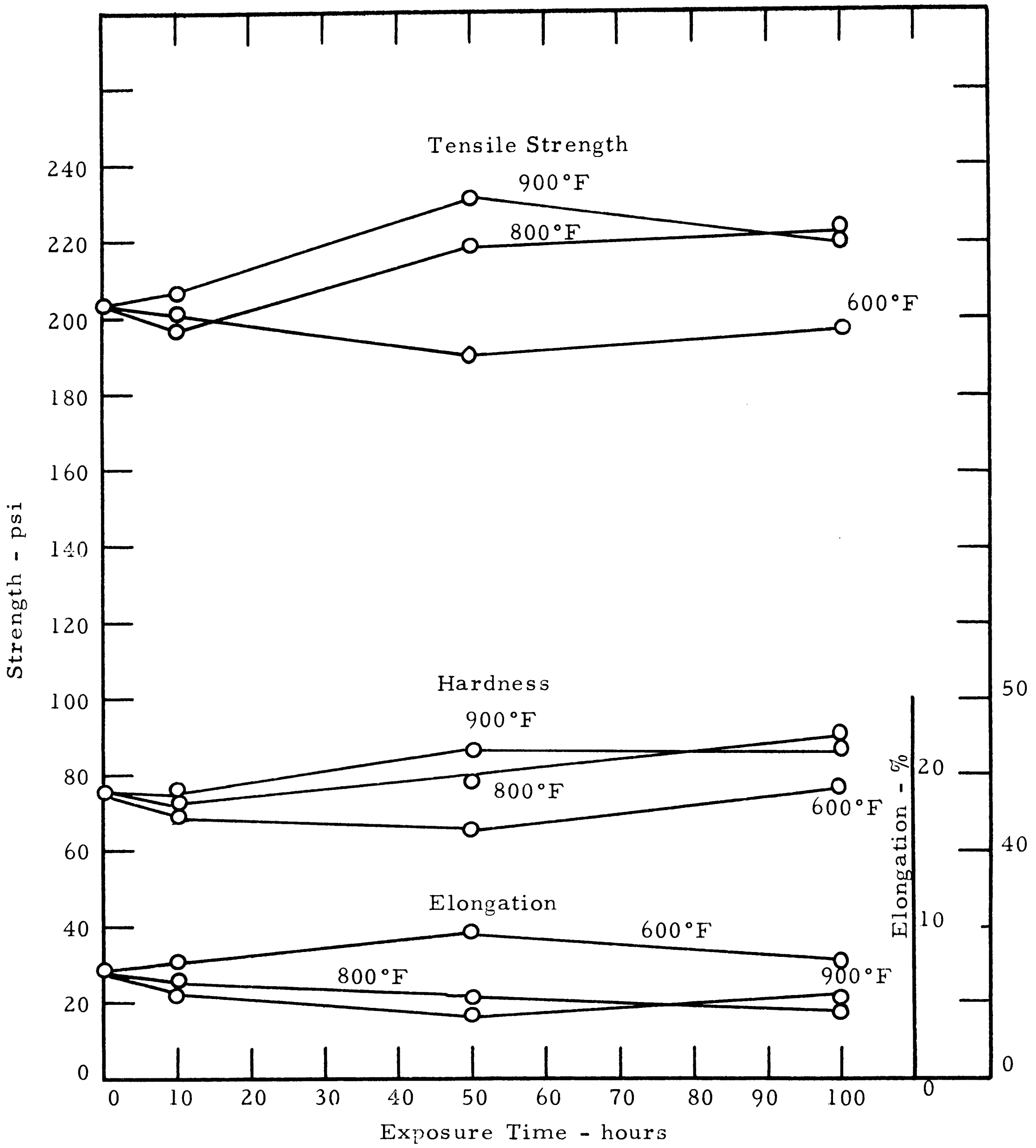


Figure 9. - Effect of unstressed exposure at indicated conditions on tensile strength, elongation, and hardness of 17-7PH alloy in TH 1050 condition