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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 covers progress under Contract AF33(616)-3368 for the period from February 10, 1957 to May 25, 1957 on a study of the effect of prior-creep on the short-time mechanical properties of some aircraft structural metals. Materials presently under study include C-110M titanium alloy and 17-7PH (TH1050 condition) precipitation-hardening stainless steel.

During the period covered by this report the draft Summary Report covering the first year of the contract was approved and was reproduced for distribution.

Experimental work accomplished during this period included the establishment of base properties in tension and compression for 17-7PH at 800° and 900°F and for C-110M at 650°, 700°, and 800°F. Room temperature tension-impact tests were run on C-110M. Creep tests aimed at establishing total deformation curves for C-110M were completed at 700 and 800°F and are almost complete at 650°F.

Tensile tests of C-110M following unstressed exposure reveal little change in properties beyond a reduction in yield strength after 800°F exposure. Tensile tests at room temperature of discontinued creep specimens of C-110M revealed increases in strength up to 20% after 700°F prior creep.

The effects of prior creep on the room temperature tensile properties of 17-7PH have been determined over a wide range of prior deformations. Increased amounts of prior creep raised the subsequent tensile and yield strength at each of the test temperatures. Deformations above 1 percent had adverse effects on ductility. Scatter in the data will necessitate replicate testing before exact trends can be established.

Improvements in the tension-impact test procedures have been considered and a method for recording stress-strain curves during such tests is under development.

INTRODUCTION

This report, the sixth progress report to be issued under Air Force Contract AF33(616)-3368 and the first to be issued under Supplement 1(57-850) to the contract, covers the period from February 10, 1957 to May 25, 1957.

The purpose of the investigation is to study the effects of elevated temperature prior creep-exposure on the subsequent mechanical properties of three aircraft structural sheet alloys.

The materials and temperatures under study include:

1. Aluminum alloy 2024-T86 at 350°, 400°, and 500°F
2. Titanium alloy C110M at 650°, 700°, and 800°F
3. Stainless steel 17-7PH (TH1050 condition) at 600°, 800°, and 900°F.

The first phase of the contract involved study of the aluminum alloy and survey work on the stainless steel. The results of that investigation are contained in WADC Technical Report 57-150, pre-print copies of which will be available in June, 1957.

Both stressed and unstressed exposure tests are being conducted for times of 10, 50, or 100 hours. Stressed exposures are carried out at the nominal stresses to give 0.5, 1.0, 2.0, and 3.0 percent total deformation in the specified time period. The total deformation is defined as all deformation, elastic and plastic, that occurs during the application of the load and during the creep of the specimen at the testing stress and temperature. By fixing stress, temperature and time, it is necessary to accept whatever total deformation is obtained. Properties are correlated with respect to actual deformation.

After the specified exposure, the following properties are evaluated at both room temperature and the temperature of prior exposure; short-time tensile properties; short-time compression properties; tension-impact strength; and also hardness determinations at room temperature. Where significant effects are noted, metallurgical studies will be employed to explain their cause.

The stresses for the nominal exposure conditions are determined from curves of stress versus time for the specified total deformation, established for each material at each temperature of interest.

The properties of the exposed material are compared with the properties of the unexposed material which are established through from 7 to 10 tests of samples chosen randomly from the various sheets of material. In many cases, replicate exposure tests are run in order to ensure generality of the results.

As specified in the contract, the test materials were procured as approximately 0.064-inch thick sheets. The testing direction was dictated by the desire to test each material in its nominally weaker direction. The aluminum and stainless steel are tested crosswise to the sheet rolling direction, while the titanium alloy is tested parallel to the sheet rolling direction.

The aluminum and titanium alloys are tested as furnished by the manufacturer, the aluminum alloy was cold-worked and artificially aged and the titanium alloy hot-rolled and annealed. The stainless steel was heat treated to the TH 1050 condition at the University. This treatment is one of double aging, first at 1400°F and then at 1050°F.

Test Materials and Specimen Preparation

A complete discussion of the test materials and the specimen preparation is contained in the First Summary Report, WADC TR 57-150.

The materials as received conformed to their nominal composition limits. The 17-7PH alloy is a precipitation hardening stainless steel containing 16-18 percent chromium, 6.5-7.75 percent nickel, 0.75-1.5 percent aluminum, and 1 percent manganese. It was received in the annealed condition and heat treated to the TH 1050 condition as mentioned previously.

The titanium alloy C-110M is a binary alloy containing 7-9 percent manganese.

The aluminum alloy, 2024-T86, tested under the first phase of the contract contained3.8-4.9 percent copper, 0.3-0.9 percent manganese, and 1.2-1.8 percent magnesium.

Sheet sampling procedures were developed for each material in order to ensure randomness of the test results. Each specimen was given a code number denoting the individual sheet from which it came and the position within the sheet. A modular, repeating sampling system was applied to each sheet. The specimen number code identifies sheet number, module number, and position with the module--in that order.

Exposure specimens were so designed that the specimens for the subsequent tension, compression, and tension-impact tests could be machined from them with minimum difficulty. The specimens were milled to rough dimensions and then the shoulder radii and gage sections were ground to the finished dimensions.

Test Equipment and Procedures

A discussion of the test equipment and procedures developed in the first year of the contract was presented in the Summary Report and will not be repeated here.

In the period covered by this report, work was initiated on modification and extension of the previously-developed tension-impact test procedure. The work included the improvement of the elevated temperature test procedure and the development of equipment for recording stress-strain data during tension-impact tests.

The original plan for tension impact testing at elevated temperatures contemplated heating the specimen while it was attached to the pendulum head. A furnace was adapted to allow heating the specimen, its gripping assembly, and the impact striker while all were in the vertical position prior to release of the pendulum latch. Unfortunately, the combination of the high thermal conductivity of the aluminum specimens and the large unheated mass of the pendulum head caused a large temperature difference over the length of the specimen gage section. The heating elements of the furnace did not permit compensation for this difference.

As an expedient the tests of the aluminum alloy were conducted by heating the specimen assembly in a separate furnace and then attaching it to the pendulum head while it was hot. Compensation was made for the necessary time delay and fairly consistent values of impact energy were obtained once the operator had gained proficiency in handling the hot specimen assembly while wearing asbestos gloves.

Nevertheless, it was felt that improvement of this procedure was desirable. Present plans contemplate the building of a small furnace of the split type that will just fit around the specimen grips. Heating is to be accomplished with tubular heating elements with provision for both fixed and sliding elements in the annulus of the furnace. Temperature distribution is to be achieved by varying the longitudinal position of the sliding elements. In this way, heating of the specimen could be done while it was attached to the pendulum.

The elements were on order for the greater part of the report period and only recently received. Consequently construction of the furnace is just under way.

Other effort has been devoted to developing procedures for recording room-temperature stress-strain curves in tension-impact testing. The method contemplated utilizes electrical strain gages arranged in a nominally balanced Wheatstone Bridge configuration. A voltage is applied across one diagonal of the bridge and a deformation of the sensing element causes an output across the other diagonal of the bridge. Two circuits are to be used. One bridge is to be used for stress measurements. To accomplish this, a tension link of square cross-section was machined from 17-22 AV steel, a material with a high proportional limit, and the strain gages applied to this in the form of a temperature compensating bridge circuit. The link was designed to attach between the impact holding jaws and the pendulum head. The anticipated stresses fall well within the elastic range of the tension link and thus the knowledge of the electrical characteristics of the bridge and the elastic modulus of the link allow conversion of the deformation of the link to the load on the specimen.

The deformation of the tension-impact specimen is to be measured by two strain gages attached to opposite sides of the specimen gage section and wired in series to an external bridge circuit, the other three legs of which are constructed of similar strain gages. This type of gage mounting eliminates the extraneous effects of any bending since one gage is in compression and the other in tension should bending occur. The net output is that due to pure tension.

Initial tests of the equipment have been conducted with a tensile machine. A Moseley X-Y Recorder has been used to record stress-strain curves. Input voltages to the bridge circuits are supplied by mercury dry cells which are noted for their constant voltage. The initial tests have been directed toward the establishment of the circuitry and the reconciliation of the actual output voltages with those computed from the bridge characteristics, gage factors, the input voltages, and the modulii of the materials under consideration. Fair results have been obtained.

In actual tension-impact testing it is anticipated that the strain rates encountered will be beyond the range of pen travel speed of the X-Y Recorder. The use of recording oscilloscopic equipment is anticipated for these tests.

RESULTS AND DISCUSSION

Base Properties of 17-7PH

Tensile and compression tests at 600°, 800°, and 900°F were completed on samples of 17-7PH stainless steel in the TH 1050 condition. The purpose of these tests was to establish the base properties of the as-treated material prior to creep-exposure. The elevated temperature tensile data are summarized in Table 1 and the compression test data are summarized in Table 2. The average room temperature properties previously determined for this material are included in each table. Figure 1 presents a plot of the tensile properties and compression yield strength versus test temperature.

Tensile test results at 800° and 900°F show somewhat less scatter within individual sheets than did the 600°F data, however, the agreement in average properties from sheet to sheet is about the same for all test temperatures. The drop in strength with temperature was about the same for the ultimate tensile and yield strengths, however, the compressive yield strength showed a somewhat greater temperature dependence over the range from 600° to 900°F.

A small drop in tensile test elongation from that at room temperature was found at 600°F, while at 800° and 900°F the elongation showed a substantial increase. The reduction of area data included in Table 1 show a similar trend.

At both room temperature and 600°F, the compression yield strength was appreciably higher than the ultimate tensile and tensile yield strength. The greater temperature dependency of the compression strength reduced its value to about that of the tensile strength at 800° and 900°F.

Modulus values included in Tables 1 and 2 were computed from the slopes of the stress-strain curves recorded for each test. No consistent difference appears to be evident between the tension and compression modulus at the various test temperatures.

Effect of Unstressed Exposure on Elevated Temperature Tensile Properties of 17-7PH

The results of tensile tests conducted at 600°F on samples of 17-7PH (TH 1050 condition) given various unstressed exposures at 600°F are presented in Table 3. Exposure times of 10, 50, or 100 hours were used.

The data are incomplete since the duplicate specimens exposed at each condition have not yet been tested. The available results indicate that exposure caused a drop in the tensile and yield strength and a slight increase in ductility. The apparent minimum strength for 50 hours exposure may be due to testing scatter and should not be taken seriously until the results of the additional tests are available.

Effect of Prior Creep on Tensile Properties of 17-7PH

The results presently available on the effects of prior creep on the tensile properties of 17-7PH (TH 1050 condition) are presented in Table 4. These results include a fairly complete coverage of the temperatures, times, and deformations as they affect room temperature properties and some sparse data on the elevated temperature properties. Inasmuch as replicate tests are planned for many of these conditions, no plots have been prepared from these data. Examination of the results shows inconsistencies in the tensile and yield strengths that are probably due to testing and material scatter. It is difficult to establish exact trends for changes in strength properties from these initial data. Cursory examination indicates that increased amounts of prior creep tend to raise the room temperature tensile and yield strength, following exposure at each of the test temperatures. Prior deformations above 1 percent appear to reduce the ductility of the material by appreciable amounts. This is especially noticeable at 600° and 800°F.

The elevated temperature test data suggest that there may be a maximum in the relation between strength and prior deformation, however, the ductility properties do not appear to be seriously affected.

Base Properties of C110M

Tests to determine the base properties of C-110M titanium alloy at 650°, 700° and 800°F were completed for the tensile properties and compression properties. The room temperature tension-impact properties have also been determined. The tensile test data are summarized in Table 5, the compression test data in Table 6, and the tension-impact data in Table 7. A plot of the effect of test temperature on the tensile and compressive properties is presented in Figure 2.

The tensile data show good consistency both within individual sheets and between sheets. An almost linear drop in tensile and yield strength with temperature was noted over the range studied. A slight decrease in ductility was observed at 650° and 700° over the room temperature value and a sharp increase in ductility was found at 800°F.

The compression yield strength dropped similar to the tensile strength between room temperature and 650°F, however, the decrease with temperature leveled off at 700° and 800°F. In contrast to the data for the 17-7PH stainless steel, the compression yield strength was substantially lower than the tensile yield strength.

The modulus values showed a moderate decrease with increasing test temperature. The compression modulus values were not noticeably different than the tensile modulii.

The room temperature tension-impact data in Table 7 show good agreement when compared on the basis of sheet averages. Individual tests within sheets exhibited scatter, particularly in the case of sheet 2.

Effect of Unstressed Exposure on Tensile Properties of C110M

Samples of C110M have been exposed at 650°, 700°, or 800° for 10, 50, or 100 hours and then tensile tested at either room temperature or the temperature of prior exposure. At least one room temperature test has been completed for each exposure condition and subsequent tests at 650° and 800°F have also been performed. The results of these tests are summarized in Table 8 and the data are plotted in Figure 3. Replicate tests are planned for several conditions in order to check the results.

As Figure 3 indicates, the unstressed exposure had negligible effect on the room temperature tensile strength, while the room temperature yield strength was only noticeably affected by prior exposure at 800°F.

The tensile and yield strengths at 650°F were also little affected by prior exposure. The 800°F tensile strength showed a slight increase with exposure time, while the 800°F yield strength dropped for exposures up to 50 hours and then recovered at 100 hours--but not back to its original value.

As mentioned above, further testing is contemplated to confirm these results, however, it appears that unstressed exposure had little serious effect other than a possible reduction of yield strength after 800°F exposure.

The ductility data in Table 8 showed no significant effects following unstressed exposure.

Creep Tests of C110M

Creep tests have been run on specimens of C110M at 650°, 700° and 800°F in order to establish the curves of stress versus time for given total deformations, to be used for selection of stresses for creep-exposure tests.

The results of tests conducted to data are summarized in Table 9 and plotted in Figure 4. None of the tests were run to rupture, the test being discontinued once the limit of useful information had been reached. The discontinued creep specimens were then tensile tested and the total test time, final deformation, and subsequent tensile properties for each specimen have been included in Table 9. This tabulation gives an idea of the relative amount of property change that might be expected from controlled-condition stressed exposure tests.

Curves of 0.5, 1, 2, and 3 percent total deformation from 10 to 100 hours have been established with fairly good success at 700°and 800°F. (See Fig. 4) At 650°F, only the 0.5 and 1.0 percent curves have been tentatively established. Following the loading deformation, the creep of this alloy at 650°F is very slow. The scatter in test points has been relatively slight with the exception of some high stress tests at 650° and 700°F. Further testing is contemplated at 650°F.

The subsequent room temperature tensile properties of these samples show instances of increased tensile and yield strength following prior creep. This was most noticeable for the 700°F samples. The increase in strength was moderate and was accompanied by some decrease in ductility. In a few cases an apparent slight decrease in strength was noted, however, this may be due to testing scatter. What appears to be a very severe loss in yield strength was noted for the sample tested after almost 1300 hours at 800°F. Generally, the increased strength was within about 15 percent of the base value.

FUTURE WORK

Work planned for the near future includes the following:

1. Preliminary copies of the Summary Report, WADC TR 57-150, will be distributed as soon as they are received from the printer.

2. The establishment of total deformation properties of C-110M at 650°F will be completed.

3. The furnace for tension-impact testing will be constructed and the development of strain-strain recording equipment will be continued.

4. Replicate stressed exposure tests of 17-7PH will be run to allow establishment of trends in the changes in room temperature properties. Testing of elevated temperature properties will be continued. Primary emphasis will be placed on evaluation of 17-7PH.

5. The evaluation of the effects of prior creep on compression properties will be initiated.

TABLE 1

ELEVATED TEMPERATURE TENSILE TEST DATA

17-7PH (TH 1050 CONDITION) AS TREATED

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)
room	Average	203,100	193,050	7.1	18.2	28.6
600	1G-T3	179,600	168,500	4.0	12.6	28.1
	1P-T22	175,300	169,500	5.8	17.2	28.2
	1P-T26	163,600	158,900	5.0	15.0	27.9
	Average	172,833	165,633	4.9	14.9	28.1
	2E-T2	183,000	168,700	4.5	16.1	29.3
	2J-T4	156,900	148,000	5.2	14.8	27.4
	2S-T4	186,900	179,000	5.2	16.1	27.2
	Average	175,600	165,233	5.0	15.7	28.0
	3A-T3	157,100	147,900	2.5	16.4	29.4
	3P-T3	186,000	178,600	6.2	15.2	27.9
	3P-T4	159,200	150,000	4.5	12.5	28.6
	Average	167,433	158,833	4.4	14.7	28.6
	Average - 9 tests	171,989	163,233	4.8	15.1	28.2
800	1P-T25	150,000	136,000	13.7	30.6	27.6
	2E-T3	148,000	138,000	15.5	28.8	26.0
	2J-T2	153,000	146,000	11.0	21.0	23.7
	2R-T4	148,000	138,000	10.8	26.8	23.6
	Average	149,667	140,667	12.4	25.5	24.4
	3F-T5	148,000	138,000	12.8	29.2	23.0
	3P-T2	147,000	137,000	9.5	27.9	24.8
	3B-T6	140,000	132,000	9.3	23.5	22.2
	Average	145,000	135,667	10.5	26.9	23.3
	Average - 3 sheets	148,223	137,444	12.2	27.6	25.1
900	1K-T1	118,200	109,100	17.5	38.6	20.9
	1Q-T24	123,000	111,000	21.3	39.2	21.7
	Average	120,800	110,500	18.4	38.9	21.3
	2J-T1	125,000	112,000	32.3	43.0	21.6
	2S-T5	129,000	118,000	11.5	35.5	21.4
	Average	127,000	115,000	21.9	39.2	21.5
	3B-T7	117,300	109,000	17.5	38.6	21.0
	3L-T3	121,500	109,000	16.5	41.0	22.2
	3Q-T2	123,000	112,000	20.5	38.3	22.5
	Average	120,600	111,000	18.2	39.3	21.9
	Average - 3 sheets	122,800	112,133	19.8	39.1	21.6

TABLE 2

ELEVATED TEMPERATURE COMPRESSION TEST DATA

17-7PH (TH 1050 CONDITION) AS TREATED

Test Temp (°F)	Spec. No.	0.2% offset Yield Strength (psi)	Modulus, E 10^6 (psi)
room	Average	220,777	29.8
600	1U-X2	184,000	25.6
	1T-X44	182,000	26.2
	Average	183,000	25.9
	2C-X2	190,000	25.8
	2T-X2	190,000	25.8
	Average	190,000	25.8
	3D-X2	181,000	26.2
	3R-X44	187,500	26.2
	3K-X2	184,000	26.2
	Average	184,167	26.2
	Average - 3 sheets	185,723	26.0
800	1D-X44	146,000	24.4
	1N-X44	149,000	24.4
	1U-X44	148,000	24.4
	Average	147,667	24.4
	2U-X44	144,000	24.7
	2G-X2	144,000	24.7
	2A-X44	146,000	23.8
	Average	144,667	24.4
	3K-X44	146,200	25.4
	3T-X44	147,000	24.4
	3D-X44	151,000	24.8
	Average	148,067	24.9
	Average - 3 sheets	146,800	24.6
900	1N-X2	107,000	23.0
	1T-X3	112,000	23.1
	1T-X2	114,000	23.1
	Average	111,000	23.1
	2C-X44	110,000	23.0
	2U-X2	117,500	23.5
	2L-X2	119,000	22.6
	Average	115,500	23.0
	3D-X3	112,000	23.2
	3R-X2	115,500	23.0
	3T-X2	118,000	23.2
	Average	115,133	23.1
	Average - 3 sheets	113,877	23.1

TABLE 3

EFFECT OF UNSTRESSED EXPOSURE AT 600°F ON SUBSEQUENT 600°F TENSILE PROPERTIES OF 17-7PH (TH 1050 CONDITION)

Exposure Temp (°F)	Exposure Time (hr)	Test Temp (°F)	Spec. No.	Ult. Tensile (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus E x 10^6 (psi)
600	nil	600	average	171,989	163,233	4.8	15.1	28.2
600	10	600	1D-T3	159,000	151,000	5.5	15.2	25.4
	50	600	2U-T3	148,000	139,500	6.5	19.6	26.0
	100	600	2U-T6	161,000	153,000	5.0	18.3	25.8

Note: Additional specimen exposed for each condition but not yet tested.

TABLE I

EFFECT OF ELEVATED TEMPERATURE STRESSED EXPOSURE ON SUBSEQUENT TENSILE PROPERTIES OF 17-7PH (TH 1050 CONDITION)

Nominal Exposure Conditions				Actual Exposure Conditions					Subsequent Room Temperature Properties					
Temp (°F)	Time (hr)	Total Def. (%)	Spec. No.	Time (hr)	Stress (psi)	Load Def. (%)	Creep Def. (%)	Total Def. (%)	Ult. Tensile Strength (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus, E 10^6 (psi)	Hardness R"C"
600	10	0.5	2U-T5	10.0	118,000	0.43	0.02	0.45	186,500	179,000	5.5	20.5	29.6	41.1
	10	1.0	3D-T6	10.0	159,000	0.69	0.35	1.04	210,000	210,000	4.0	16.3	29.7	45.0
	10	2.0	1D-T6	10.0	167,000	0.77	0.99	1.76	211,000	211,000	2.3	13.3	28.0	43.3
			2T-T5	--	167,000	rupture on load.		--	--	--	--	--	--	--
	10	3.0	2Q-T4	10.2	173,000	0.98	1.53	2.51	227,000	227,000	2.0	11.2	28.5	44.7
			3R-T6		173,000	rupture at 6.5 hours		--	--	--	--	--	--	--
	50	0.5	1D-T5	50.1	116,000	0.43	0.06	0.49	205,000	195,000	7.0	16.7	30.0	45.1
	50	1.0	3K-T2	50.0	150,000	0.54	0.32	0.86	205,000	205,000	3.2	13.8	29.2	44.2
	50	2.0	2A-T3	--	160,000	rupture on load		--	--	--	--	--	--	--
	50	3.0	3T-T5	50.0	164,000	0.63	1.18	1.81	216,000	216,000	2.2	10.5	29.9	44.0
	100	0.5	3D-T1	100.0	114,500	0.39	0.05	0.44	191,500	186,000	9.8	17.2	29.6	45.0
	100	1.0	1D-T4	99.9	146,000	0.55	0.31	0.86	218,000	218,000	3.0	10.7	29.2	42.9
	100	2.0	2N-T1	100.5	157,000	0.60	1.28	1.88	223,000	223,000	1.5	13.7	29.4	--
			3Q-T7	104.9	157,000	--	--	3.84	209,000	--	2.0	8.6	30.3	41.1
			3H-T4	--	157,000	rupture at 17.8 hours		--	--	--	--	--	--	--
			1P-T24	99.9	157,000	--	--	5.30	217,500	188,500	2.0	5.8	28.9	42.8
	100	3.0	2C-T1	100.0	161,000	0.74	3.68	4.42	218,000	218,000	1.8	6.3	29.0	43.9
800	10	0.5	3K-T6	10.2	70,000	0.29	0.13	0.52	212,000	206,500	4.3	13.1	29.8	42.6
	10	1.0	2G-T5	10.2	88,000	0.36	0.68	1.04	191,500	188,000	6.5	16.6	30.2	41.1
	10	2.0	1J-T6	10.0	98,000	0.35	1.86	2.21	208,000	207,000	3.5	16.5	28.4	45.5
	10	3.0	3R-T5	10.0	101,000	0.42	2.08	2.55	234,000	222,000	3.0	14.2	30.2	48.7
	50	0.5	1N-T1	50.0	62,000	0.23	0.15	0.98	187,000	174,000	9.5	17.0	29.4	42.3
	50	1.0	2A-T1	50.0	75,000	0.32	0.64	0.96	221,000	207,000	9.5	16.6	29.5	47.4
	50	2.0	3R-T2	50.0	86,000	0.35	1.43	1.78	172,000	171,000	3.0	16.4	29.2	45.0
	50	3.0	1J-T4	50.1	91,000	0.33	2.77	3.10	216,000	212,000	3.5	17.0	29.6	46.9
	100	0.5	3P-T5	100.0	59,000	0.23	0.15	0.48	208,000	204,000	3.8	17.6	30.3	--
	100	1.0	3H-T5	100.0	70,000	0.27	0.62	0.89	220,000	215,000	3.5	14.0	32.1	--
	100	2.0	3P-T1	102.6	81,000	0.31	1.81	2.12	223,000	229,000	3.5	12.1	29.9	46.7
			2S-T6	102.1	81,000	0.32	1.56	1.88	227,000	222,000	4.2	15.8	30.2	46.7
	100	3.0	3L-T2	100.0	85,000	0.32	2.13	2.45	218,000	214,000	2.2	20.2	30.1	--
900	10	0.5	2L-T6	10.1	46,000	0.21	0.36	0.57	228,000	218,000	2.2	3.6	30.3	46.3
	10	1.0	1J-T2	10.1	55,000	0.24	0.89	1.13	215,000	207,000	4.0	15.2	29.9	44.0
	10	2.0	3K-T1	10.0	62,000	0.28	2.03	2.31	221,500	219,000	3.5	12.7	29.4	47.0
	10	3.0	1N-T6	10.1	68,000	0.27	3.09	3.36	201,000	195,000	4.8	17.6	29.2	43.1
	50	0.5	2U-T4	50.0	40,000	0.17	0.45	0.62	235,000	228,000	7.0	9.8	30.0	48.4
	50	1.0	2A-T2	50.0	48,500	0.20	0.91	1.11	200,000	191,500	9.8	18.0	29.4	44.3
	50	2.0	1D-T2	49.9	54,000	0.29	1.48	1.77	205,000	197,000	6.8	17.0	29.2	47.5
	50	3.0	3R-T1	50.0	56,000	0.25	2.15	2.40	195,000	189,000	8.0	19.6	30.0	43.0
	100	0.5	3G-T5	100.0	37,000	0.14	0.33	0.47	204,000	196,000	4.5	17.6	29.2	--
	100	1.0	3A-T4	100.0	46,000	--	--	0.94	228,000	220,000	4.5	14.4	30.1	46.0
			2R-T1	100.0	49,000	0.19	1.36	1.55	214,000	209,000	6.5	16.7	29.9	45.3
	100	2.0	3G-T2	100.1	50,000	0.22	1.82	2.04	224,000	219,000	4.0	15.2	29.7	46.8
			1Q-T22	100.0	50,000	0.20	2.13	2.33	235,000	230,000	4.0	13.1	30.0	48.1
	100	3.0	3Q-T4	100.0	52,000	0.23	2.07	2.30	221,000	219,000	5.0	14.9	31.0	--
									Subsequent 800°F Properties					
800	100	1.0	2T-T6	99.9	70,000	0.26	0.57	0.83	149,000	140,000	16.8	27.7	22.6	47.6
	100	2.0	3T-T1	100.0	81,000	0.32	1.76	2.08	144,000	137,000	14.8	28.8	23.3	46.5
									Subsequent 900°F Properties					
900	100	0.5	1D-T1	100.2	37,000	0.16	0.43	0.59	132,000	119,000	17.8	28.4	23.0	45.6
	10	3.0	2G-T6	10.1	68,000	0.31	2.49	2.80	125,000	117,000	14.5	31.3	21.3	43.9

TABLE 5

TENSILE TEST DATA FOR

C110M AS PRODUCED

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)
room	1A-9T	145,000	140,000	22.0	35.2	16.8
	1AB-17T	144,000	139,000	24.0	32.4	16.0
	1C-13T	152,000	144,000	21.5	30.2	16.8
	Average	147,000	141,000	23.5	32.6	16.5
	2C-5T	146,000	144,000	22.3	29.6	16.8
	2C-20T	147,000	143,000	21.7	31.6	16.4
	2A-28T	146,000	142,000	20.5	32.0	16.9
	Average	146,333	143,000	21.5	31.1	16.7
	3C-20T	146,000	142,000	22.7	26.4	15.8
	3A-13T	147,000	145,000	21.5	30.8	16.4
	3A-34T	151,000	147,000	22.5	33.3	16.6
	Average	148,000	144,667	22.2	30.1	16.3
	Average - 9 tests	146,211	142,889	22.4	31.3	16.5
650	1C-24T	108,000	92,000	19.5	28.0	13.4
	1A-32T	109,000	95,000	21.0	33.3	13.8
	1C-9T	107,000	--	15.1	31.6	13.6
	Average	108,000	93,500	18.5	31.0	13.5
	2A-24T	112,000	97,000	14.5	29.0	13.6
	2C-13T	111,000	97,000	17.5	24.7	13.5
	2A-5T	112,000	94,500	16.0	24.0	13.9
	Average	111,667	96,167	16.0	25.9	13.7
	3C-9T	114,000	100,000	17.0	21.6	13.8
	3C-34T	111,000	96,700	17.7	26.6	13.0
	3A-1T	112,000	98,600	16.7	24.8	13.6
	Average	112,333	98,433	17.1	24.3	13.5
	Average - 9 tests	110,667	96,033	17.2	27.1	13.6
700	1C-1T	94,900	83,500	17.2	36.4	12.3
	1A-13T	106,000	91,000	19.0	34.1	13.7
	1A-28T	105,000	92,700	21.2	31.4	13.6
	Average	101,967	89,067	19.1	33.9	13.2
	2C-36T	107,000	95,700	16.1	32.7	13.6
	2C-24T	107,000	91,400	17.0	32.8	13.3
	2AB-17T	106,000	91,500	15.8	29.6	13.5
	Average	106,667	92,867	16.3	31.8	13.5
	3C-17T	107,000	97,500	16.0	32.4	12.8
	3A-24T	109,000	96,700	18.7	29.2	13.4
	3A-9T	108,000	94,000	19.0	28.0	12.7
	Average	108,000	96,067	17.9	29.9	13.0
	Average - 9 tests	105,545	92,667	17.8	31.9	13.2
800	1C-28T	90,000	83,000	39.7	51.0	11.8
	1C-17T	90,000	85,000	25.4	47.3	11.8
	1A-20T	90,600	82,000	29.0	49.5	12.0
	Average	90,200	83,333	31.4	49.3	11.9
	2A-9T	91,000	79,700	30.0	48.7	12.0
	2A-36T	93,000	84,500	46.5	51.0	12.3
	2C-28T	93,200	85,500	32.0	49.7	11.3
	Average	92,400	83,233	36.2	49.8	11.9
	3C-1T	95,000	84,800	24.7	45.3	11.2
	3C-28T	95,300	85,700	30.8	47.2	11.1
	3A-20T	94,000	87,000	21.3	43.4	11.2
	Average	94,766	85,833	25.6	45.3	11.2
	Average - 9 tests	92,455	84,133	31.1	48.1	11.7

TABLE 6

COMPRESSION TEST DATA

FOR C110M AS PRODUCED

Test Temp (°F)	Spec. No.	0.2% offset Yield Strength (psi)	Compression Modulus, E 10^6 (psi)
room	1C-24C	108,000	15.8
	1A-5C	107,000	16.2
	1A-13C	108,000	16.0
	Average	107,667	16.0
	2C-24C	107,000	16.7
	2C-9C	109,000	15.9
	2A-28C	105,000	16.4
	Average	107,000	16.3
	3A-24C	108,000	16.0
	3C-32C	110,000	16.4
	3A-9C	111,000	16.1
	Average	109,667	16.2
	Average - 9 tests	108,111	16.2
650	1A-24C	63,000	12.9
	1C-32C	58,400	12.6
	1C-5C	57,600	12.8
	Average	59,667	12.8
	2C-28C	58,400	12.9
	2A-9C	55,800	13.2
	2A-5C	68,400	13.2
	Average	60,800	13.1
	3A-13C	58,600	13.2
	3C-24C	71,000	13.3
	3C-5C	57,800	12.8
	Average	62,400	13.1
	Average - 9 tests	61,000	13.0
700	1A-28C	57,900	12.7
	1C-13C	53,800	12.5
	1A-9C	55,400	12.3
	Average	55,700	12.5
	2C-13C	60,600	12.9
	2A-24C	--	12.5
	2C-5C	59,400	12.5
	Average	60,000	12.6
	3A-32C	54,600	12.7
	3C-28C	59,000	12.5
	3C-6C	--	12.4
	Average	56,800	12.5
	Average - 7 tests	57,243	12.5
800	1C-28C	53,900	11.8
	1C-9C	55,100	11.8
	1A-32C	53,800	11.6
	Average	54,300	11.7
	2C-32C	62,500	12.0
	2A-32C	55,400	11.7
	2A-13C	55,600	11.9
	Average	57,800	11.9
	3A-28C	59,800	12.1
	3C-13C	--	--
	3A-5C	54,600	11.7
	Average	57,200	11.9
	Average - 8 tests	56,337	11.8

TABLE 7

SMOOTH-BAR TENSION-IMPACT TEST DATA AT ROOM TEMPERATURE FOR C110M AS PRODUCED

Spec. No.	Tension-Impact Strength (ft - lb)
1A 5M	48
1A 13M	50
1C 24M	69
Average	55.6
2A-28M	67
2C-5M2	64
2C-9M	37
Average	56.0
3A-9M	50
3A-24M	62
3C-28M	58
Average - 9 tests	56.1

TABLE 8

EFFECT OF UNSTRESSED EXPOSURE ON SUBSEQUENT

TENSILE PROPERTIES OF C110M

Exposure Conditions			Subsequent Tensile Properties						
Temp (°F)	Time (hr)	Spec. No.	Test Temp (°F)	Ult. Tensile Strength (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus, E 10^6, psi	Hardness R"C"
650	10	2A-31A	room	144,000	136,000	25.3	31.4	15.1	35.3
	50	1C-26C	room	147,500	140,700	23.3	35.6	15.4	37.2
	100	2A-21A	room	143,400	136,800	24.0	32.2	15.5	35.8
	10	3C-11C	650	112,700	94,900	20.5	26.0	13.7	35.4
	50	2A-B21	650	111,500	94,500	17.5	27.6	12.9	34.5
	100	2A-B7	650	114,000	97,000	22.5	26.3	12.9	35.8
700	10	1C-D15	room	143,000	140,000	23.8	34.0	15.4	39.1
	50	2C-21C	room	149,000	137,500	23.0	33.2	16.1	35.8
	100	1A-3A	room	146,500	140,000	19.5	32.0	15.4	38.5
800	10	1A-15A	room	146,000	133,000	24.0	35.7	15.1	35.1
	50	1C-D3	room	144,000	129,000	23.3	31.8	15.0	34.9
	100	2C-D31	room	147,000	125,000	19.3	29.2	15.7	34.1
	10	3A-B33	800	91,600	74,400	22.3	48.6	11.3	34.7
	50	2A-B31	800	92,200	68,000	23.5	45.0	11.4	32.8
	100	3A-18A	800	96,500	78,200	29.5	43.4	11.2	---

TABLE 9

TOTAL DEFORMATION DATA AND RETAINED TENSILE PROPERTIES

AT ROOM TEMPERATURE FOR CREEP TESTS OF C110M

Test Temp (°F)	Spec. No.	Stress (psi)	Loading Deformation (%)	Time to Reach Indicated Total Deformation (hrs) 0.5%	1.0%	2.0%	3.0%	Test Time (hrs)	Total Deformation (%)	Subsequent Room Temperature Tensile Properties: Ult. Tensile Strength (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 inches)	Reduction of Area (%)	Modulus, E 10^6 (psi)	Hardness R"C"
650	1C-32T	105,000	in progress	--	--	--	--	--	--	--	--	--	--	--	--
	3A-28T	95,000	0.84	--	13.5	125.5	--	166	2.63	165,000	160,000	12.2	23.9	15.9	39.0
	1A-36T	85,000	0.68	--	110	--	--	142	1.10	144,000	141,500	20.0	32.6	15.0	38.4
	2A-32T	75,000	0.60	--	125	--	--	142	1.05	164,000	159,000	14.5	22.8	16.8	--
	3C-5T	70,000	0.56	--	290	--	--	307	1.03	151,000	145,000	19.7	27.9	15.4	--
	1A-5T	60,000	0.48	5	--	--	--	216	0.68	152,000	145,000	19.3	29.8	15.6	--
	2A-1T	55,000	0.42	66.5	--	--	--	142	0.53	146,000	140,000	15.8	31.2	15.8	36.1
700	3C-24T	90,000	0.86	--	0.4	12.9	25 *	51	5.0 *	--	--	--	--	--	--
	3AB-17T	80,000	0.65	--	22.2	47 *	68 *	71	3.1 *	164,000	158,000	13.0	22.0	15.2	39.2
	2A-13T	75,000	0.63	--	17	46	64	147	6.0 *	174,200	164,800	7.3	17.3	16.5	--
	2C-32T	65,000	0.52	--	41	94	127	143	3.49	170,000	151,000	16.8	26.0	16.1	--
	3A-5T	60,000	0.43	5	49	102	142	210	4.8 *	169,000	149,000	16.5	21.2	16.1	--
	1C-5T	50,000	0.36	28	108	220	--	242	2.18	167,000	151,000	15.7	25.6	16.9	--
	2C-9T	40,000	0.30	63	193	--	--	193	1.10	158,000	140,000	17.5	27.0	16.6	--
	1A-1T	35,000	0.21	110	--	--	--	139	0.58	149,000	134,000	18.0	27.4	15.5	--
800	3C-13T	35,000	0.30	1	3.2	7.6	12.2	46	6.60	151,000	140,000	19.3	25.2	15.9	--
	2A-20T	30,000	0.24	3	8.5	17.5	26	117	10 *	151,000	138,000	20.3	28.6	15.0	--
	1A-24T	25,000	0.18	4	11	27.5	46.5	123	6.40	158,000	137,000	24.0	31.4	17.2	--
	3C-32T	20,000	0.18	11	29	87	160	169	3.10	145,000	130,000	19.8	21.4	16.2	--
	3A-32T	15,000	0.07	20	64	314	--	358	2.11	143,000	125,000	23.0	25.2	15.2	33.2
	2C-1T	10,000	0.09	52.5	296	--	--	307	1.02	150,000	132,000	30.0	25.5	16.5	--
	1C-20T	5,000	0.05	1140	--	--	--	1292	0.52	135,000	67,700 (?)	23.8	33.5	16.3	35.9

* Estimate by extrapolation.

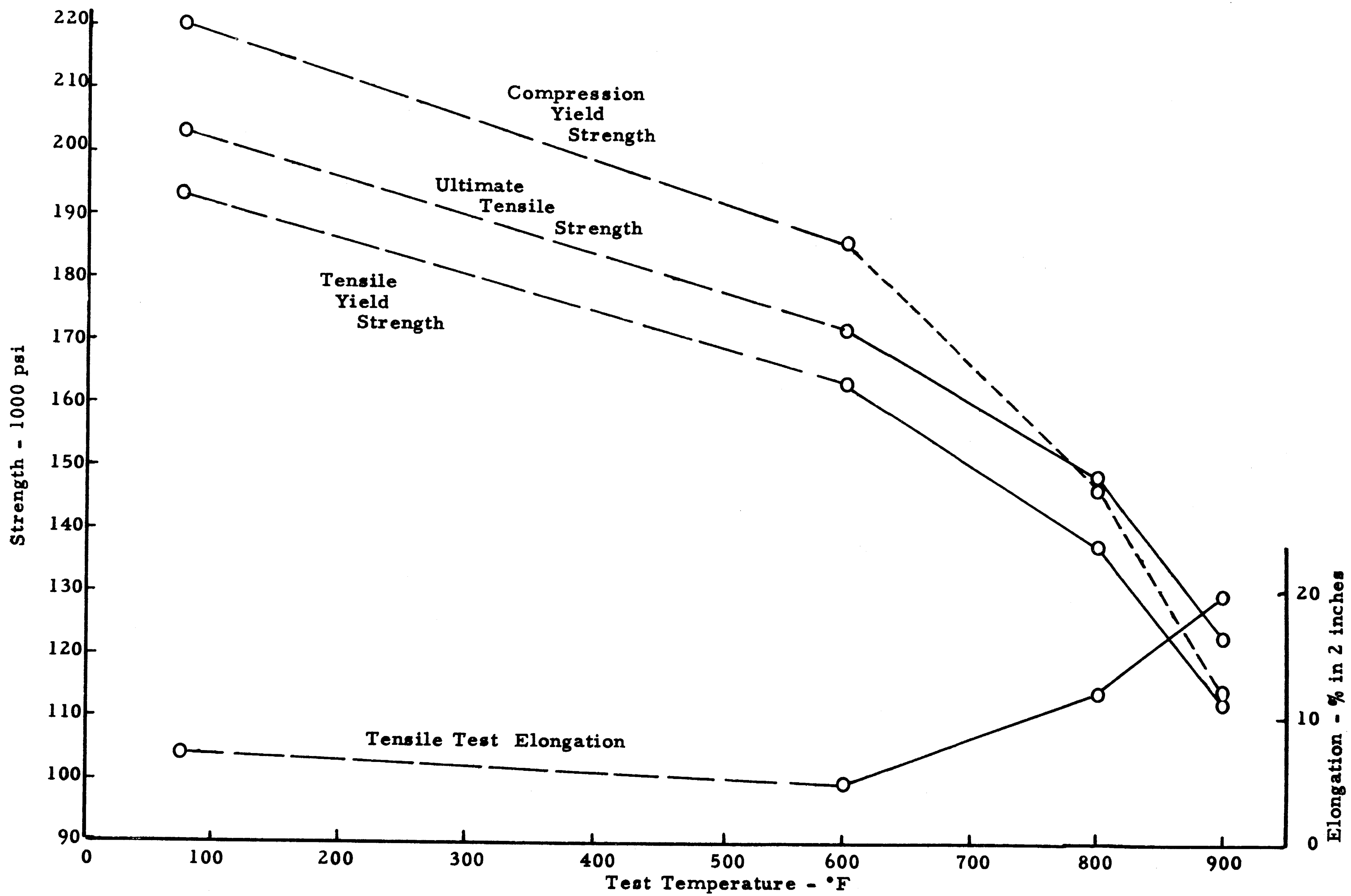

Figure 1. - Effect of Test Temperature on Tensile and Compressive Properties of 17-7PH (TH 1050 Condition) As Treated.

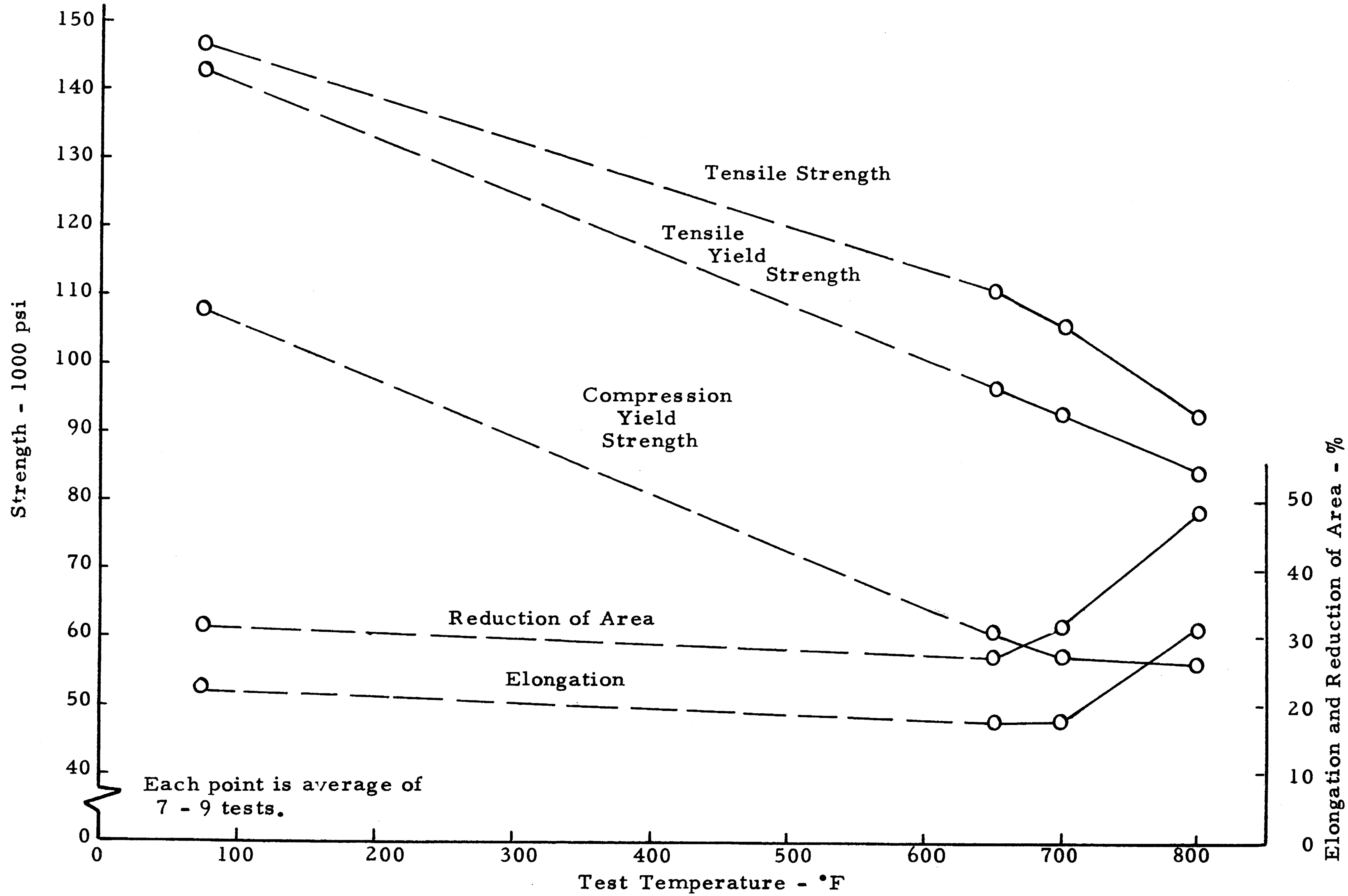

Figure 2. - Effect of Test Temperature on Mechanical Properties of Annealed C110M (As-Received).

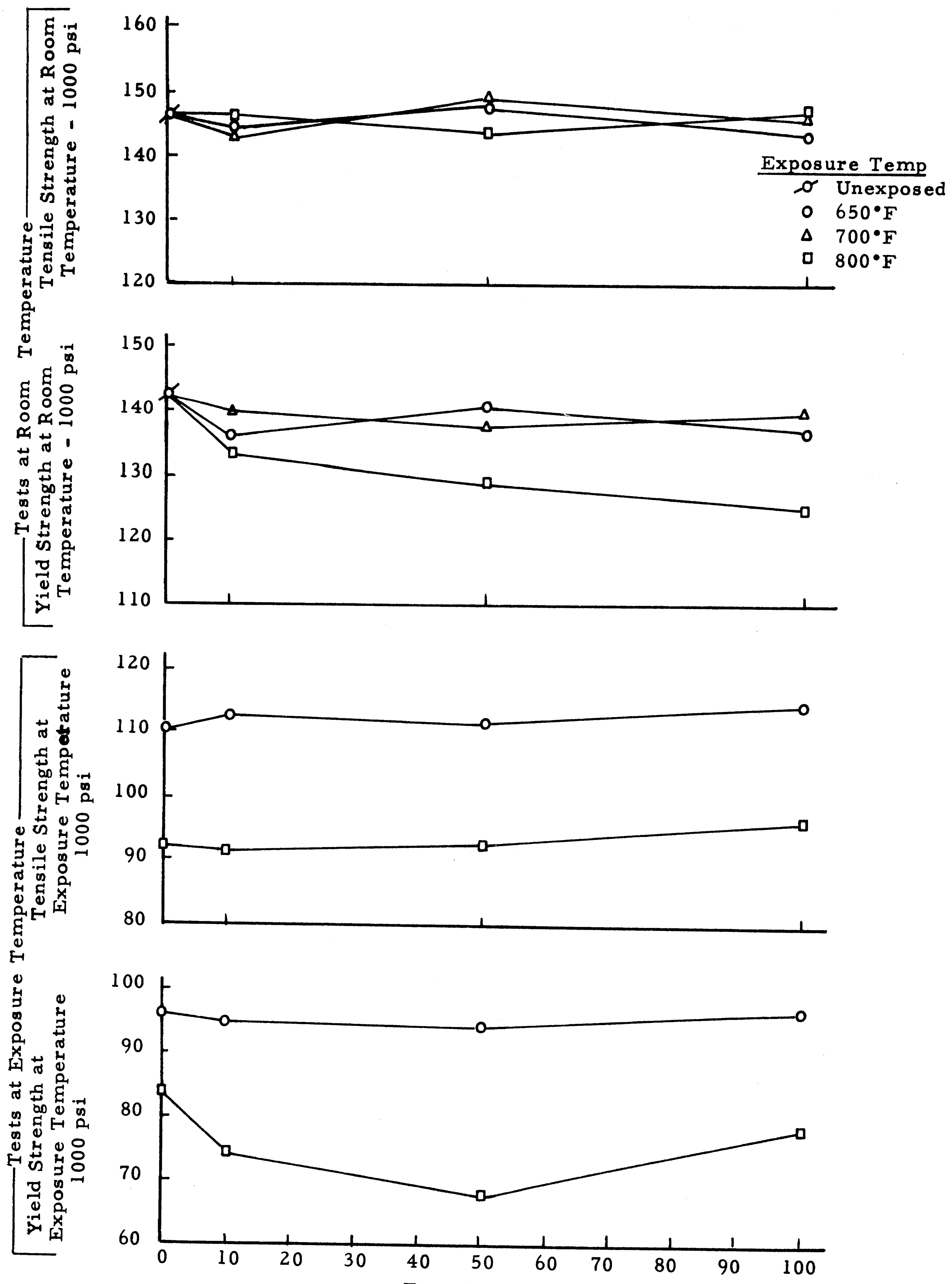

Figure 3. - Effect of Elevated Temperature Unstressed Exposure on Tensile Properties of C110M at Room Temperature or Exposure Temperature.

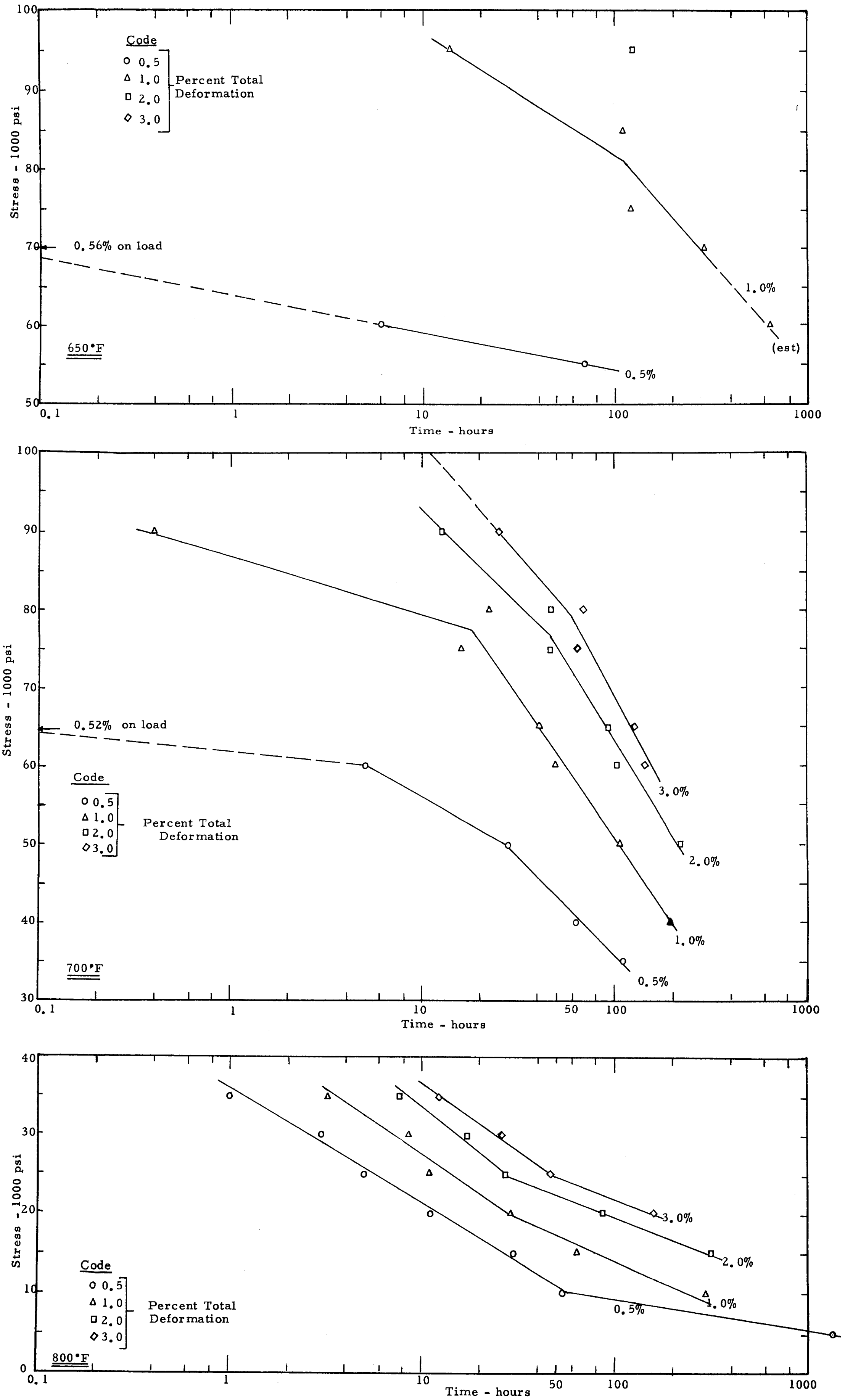

Figure 4. - Stress Versus Time to Reach Indicated Total Deformation for C110M at 650°, 700° and 800°F.