FOURTH 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 covers progress under Contract AF33(616)-3368 for the period from August 21, 1956 to October 20, 1956 on a study of the effects of prior creep on the short-time mechanical properties of three aircraft sheet metals. The materials under study are: 2024-T86 aluminum alloy; C-110M titanium alloy; and 17-7PH precipitation hardening stainless steel.

Delivery of all experimental materials has now been completed with the receipt of the C-110M titanium alloy.

Tests of room temperature tensile properties of 17-7PH after exposure to two percent total deformation in 100 hours in the range between 600° and 900°F indicate that the tensile and yield strengths are increased over the increase previously reported for unstressed exposure. The maximum effect occurs at 800-850°F. At temperatures from 600 to 750°F, stressed exposure resulted in a loss of ductility not commensurate with the effect on tensile strength.

The determination of the total deformation properties of the 2024-T86 alloy has been completed and the stressed exposure tests of this material are in progress. The data indicate that increasing time, temperature, and total deformation result in a decrease in tensile and yield strength. Tensile tests of the unexposed material are complete at 350° and 400°F. The effects of unstressed exposure on the room-temperature hardness and tensile-impact properties show a decrease in strength with time and temperature of exposure.

In this investigation it was decided to fix the time, temperature, and stress of testing. Thus, deformation obtained must be accepted realizing that it might vary somewhat from the nominally specified value. Test stresses are determined from curves of stress versus time for a given total deformation, established for each material at each testing temperature.

The generality of the results was ensured by running replicate tests on two random samples for each exposure condition and by establishing the value of the normal properties of the material from 9 or 10 samples chosen randomly from the various sheets of material.

All the materials were procured as approximately 0.064-inch thick sheet. The aluminum and stainless steel alloys were specified to be tested in the direction crosswise to the sheet rolling direction, while the titanium alloy is to be tested parallel to the rolling direction.

The aluminum and titanium alloys are to be tested in the conditions as received from the manufacturers. The titanium alloy was furnished as hot rolled and annealed, while the 2024-T86 aluminum alloy was cold worked and artificially aged by the manufacturer. The stainless steel, 17-7PH is being tested in the TH 1050 condition, a double aging treatment at 1400°F and then 1050°F, which is performed at the University.

The current contract places emphasis of testing effort on evaluation of the aluminum alloy.

In the case of the stainless steel, a survey is being made of the effects of prior creep to 2 percent total deformation in 100 hours on the room-temperature tensile properties. These exposures are being carried out at 50°F temperature intervals between 600° and 900°F.

TEST MATERIALS

During the period covered by this report the C-110M titanium alloy was received, completing the delivery of all test materials ordered on this contract. The specifications follow:

C-110M Titanium Alloy

Eleven sheets of annealed C-110M titanium alloy were received from the Rem-Cru Titanium Corporation. The sheet dimensions were 0.064 inches thick by 30/36 inches wide by 60/90 inches long. The material was all from heat number A1172600. The chemical analysis furnished by the producer follows:

Element	Percent (by weight)
Manganese	7.9
Carbon	.10
Nitrogen	.02
Hydrogen	.0093
Titanium	balance

SPECIMEN PREPARATION

The sampling procedure used for the preparation of specimens for this investigation was designed to randomize the test results with respect to both sheet-to-sheet variations and the variations within an individual sheet. Since the as-received sheet sizes of the materials differed, the physical details of the sampling schemes differed, although the principle of selection was the same.

For each material three sheets were arbitrarily selected. Each sheet was divided into panels about 5 inches wide, and the panels themselves subdivided into 1-inch wide specimen blanks. Within the panel, the specimen blanks were so arranged that material was sampled from different locations across the panel width. Thus, the sampling pattern with respect to the width of the sheet repeated itself every 5 inches over the length of the sheet. Each specimen was labeled with a code number indicating sheet number, panel number, and specimen position within the panel.

Reference to Figure 1 in the case of the 2024-T86 aluminum alloy and to Figures 2 and 3 in the case of the 17-7PH alloy makes it possible to establish the location of any of the test specimens cited in the section of Results.

The dimensions of the various test specimens used are indicated in Figure 4. The specimens for mechanical tests were designed so that they could be cut from creep specimens following the desired exposure. For the exposure itself, the width of the gage section of the creep specimen was machined 0.030 inches oversize in order that after subsequent remachining the tests would measure the properties of the sheet material itself and not include the particular edge effects, if any, associated with the exposure of the specimen.

In the period covered by this report, evaluation of a notched tension-impact specimen was initiated. The dimensions of the proposed specimen are indicated in Figure 5. The specimen was designed to be machined from a creep-exposure specimen.

The notched tension-impact specimen was prepared to the major dimensions using standard procedures. Following this, a flat-bottomed V-groove was ground into each edge of the specimen. During this operation the specimen was held in a special fixture so that the location of the notches could be accurately controlled. Next, the center of each flat was nicked with a sharp grinding wheel. Finally, the nicked flat was lapped to the final width and root radius using a lapping compound and a phosphor bronze wire whose radius was slightly under the final radius desired for the notch. For the notch prepared to the dimensions indicated in Figure 5 the theoretical stress concentration factor, K_t, is equal to 1.65.

TEST EQUIPMENT AND PROCEDURES

Equipment used for creep-exposures, tensile tests and tension-impact tests was discussed in the first two progress reports. In the period covered by this report the compression test fixture which was described in the third report was modified slightly and the extensometer system for tension and compression tests was rebuilt. In addition, the furnace for elevated-temperature tests was operated successfully.

Compression Test Equipment

The original design of the compression test fixture, adapted from that of Flanigan et al (1), consisted of a base, a pair of adjustable guide blocks and a loading ram. The original guide blocks were smooth surfaced. During the initial tests of this unit it was found to be an art to obtain reproducible stress-strain curves with respect to both slope and proportional limit.

A report on compression testing techniques from the Titanium Metallurgical Laboratory at Batelle Memorial Institute (2) led to modification of the compression guide blocks. The results of Kotchanik et al were cited to show that values of compressive modulus (slope of the stress strain curve) were independent of supporting force when the guide blocks contained off-set grooves. Accordingly, a set of grooves off-set from each other were machined into the surface of the guide blocks. These are shown in Figure 6.

The second modification of the equipment was essentially procedural. According to Kotchanik et al the compressive yield strength was found to have a critical relationship to the supporting force. Consequently, the use of a torque wrench was introduced in tightening the guide blocks preparatory to running the tests. In this way, a moderate and consistent supporting force of from 2 to 4-inch pounds could be easily used for all tests.

These modifications of the compression test equipment, together with the use of the redesigned extensometer system, simplified the task of obtaining compression test stress-strain data.

Extensometer System

The original design of the extensometer system for compression tests and elevated-temperature tensile tests was a rod and tube assembly fastened to the edges of the specimen gage section by tungsten carbide-tipped screws. In this design (3) the extension was transmitted from one side of the specimen only and was sensitive to whether or not the sides of the specimen were parallel and to the axiality of the load application. The relative motion of the rod and tube was picked up by a microformer-type strain gage and recorded automatically.

After initial experience with this equipment the desirability of an averaging-type extensometer was recognized and the system accordingly modified. The modified system retains the rod and tube principle but transmits the deformation of the specimen through an averaging linkage.

The system as set up for a compression test is shown in Figure 7. The motion of the two gage screw assemblies is transmitted by sets of flat extensometer bars. At the lower ends of these bars are two cross pieces--one attached to a rod and the other containing a tube. The ends of the cross pieces are grooved to fit a pin brazed to the lower end of the extensometer bar. This acts in much the same manner as a knife edge. A spring maintains the seat of the pin in the cross piece. Finally, the microformer pickup is attached to the rod and tube. The details of the lower end assembly are shown in Figure 8.

Also essential to this system is the open frame that forms the base for the compression test set-up and which is drilled and tapped at each end so that it can be included in the specimen gripping assembly for tensile tests. The purpose of this frame is to permit the attachment of the microformer to the rod and tube on the center line of the compression or tension axis.

This system had been successfully used for obtaining stress-strain curves at room temperature in both tension and compression and at elevated temperature in tension. The extensometer was checked by comparing stress-strain curves obtained with it at room temperature against those in which the microformer was attached directly to the specimen. The results showed excellent agreement.

Elevated-Temperature Tensile Tests

The elevated-temperature tensile tests have been run in a wire-wound resistance furnace with a 5-inch diameter core having sufficient clearance for the extensometer assembly.

Difficulties in obtaining temperature distribution over the specimen gage length are minimized through the use of a slotted transite shield placed over the top opening after the specimen holding assembly is inserted. In addition, the furnace windings were designed to provide a closer spacing at the bottom of the furnace than at the top to compensate for differences in heat loss.

With reasonable care a temperature distribution of 2 - 3°F over the 2-inch gage section was found possible at temperatures of 350° to 500°F. At higher temperatures, preliminary tests indicate that it may be necessary to shunt a portion of the winding. However, the establishment of proper temperature distribution should not prove unduly difficult.

RESULTS AND DISCUSSION

Stressed Exposure Tests---17-7PH Alloy

By mutual agreement between the University and WADC the first phase of the evaluation of the 17-7PH alloy was a survey of the effects on the room-temperature tensile properties of elevated temperature stressed exposure to two percent total deformation in 100 hours. The exposure temperatures were fixed at 50°F increments between 600° and 900°F.

The results of this study are summarized in Table 1 together with comparative data for samples given unstressed exposure for the same time period. A plot of tensile strength, yield strength, elongation, and hardness (all taken at room temperature) versus exposure temperature for stressed or unstressed exposure is presented in Figure 9. At least two tests were run for each condition.

The effects of both stressed or unstressed exposure were to raise the tensile and yield strengths over the as-treated value. The stressed exposure raised the strength to a greater extent than did the unstressed exposure, with the maximum effect for both occurring at about 850°F. The strengthening effect of stressed exposure over unstressed exposure appears to be greater in the case of the yield strength than for tensile strength.

The effects of the exposures on the hardness and elongation were contrary to the trends indicated by the tensile and yield strengths. At the lower end of the range of exposure temperature the elongation was greatly reduced by stressed exposure. At 800°F the elongation of the unstressed samples also showed some reduction, and the elongations for both types of exposures tended to converge thereafter.

The final hardness for samples given stressed exposure tended to be slightly lower than the hardnesses of the unstressed samples with the exception of the tests at 900°F. This was contrary to the normal expectation that increased hardness would accompany the higher tensile and yield strengths of the stressed samples.

The most significant results of this survey appear to be the following:

1. Stressed or unstressed exposures between 600° and 900°F tend to raise the tensile and yield strengths.

2. The effect of stressed exposure is greater than that for unstressed exposure--particularly in reducing the spread between the tensile and yield strengths.

3. The temperature of maximum effect is about 800-850°F.

4. At the lower end of the temperature range, i.e. 600°-750°F, stressed exposure greatly reduced the room-temperature ductility.

Attention is called to the variability of total deformation obtained for substantially identical exposure conditions at 600°F. At the lower temperatures of exposure particularly, much of the total deformation is obtained upon loading or shortly thereafter. Another way of stating this would be to say that the proportion of creep deformation comprising the total deformation increases as the exposure temperature is increased.

It would appear valuable eventually to extend the testing to temperatures below 600°F in order to better define any adverse effects of stressed exposure on ductility. In addition, the data should be analyzed in terms of the relative components making up the total deformation.

Compression Tests--17-7PH Alloy

The results of nine compression tests run at room temperature on samples of 17-7PH alloy (TH 1050 condition) are summarized in Table 2. The data presented are the 0.2 percent offset yield strength and the compression modulus computed from the slope of the stress-strain curve. Also included in Table 2 are the average values of the tensile yield strength and modulus as previously reported for samples from the same sheets of material.

The values of compressive yield strength show fair consistency and the scatter between tests was no greater than the scatter previously encountered in tensile tests of the same material. Both the compression yield and modulus are greater than those obtained in tension, with the compression yield about 12-13 percent higher. This compares favorably with the data of the Armco Steel Corporation (4) which indicate the compressive yield to be about 110 percent of the tensile yield. The increase in modulus was of the order of 4-5 percent.

Notched Tension-Impact Tests---17-7PH Alloy

In the period covered by this report, studies were initiated on a notched bar tension-impact test to supplement the smooth-bar test previously reported (5).

As discussed in the section on Specimen Preparation (page 4), notched samples were prepared having a theoretical stress concentration factor, K_t, of 1.65.

The results of tests using these samples are summarized in Table 3 together with the smooth-bar data. It should be noted that the gage section width of the smooth-bar samples was 0.200 inches, while the root width of the notch was 0.250 inches. Thus, the cross-sectional area of the specimens did not strictly correspond.

The notched bar tests showed a much greater scatter than did the tests run on smooth bars. The comparison of the average values of energy absorbed shows that in both cases Sheet 1 had the lowest value. However, Sheet 2 was intermediate in the case of smooth bars while Sheet 3 was intermediate in the case of notched bars.

Based on the averages of all tests, the effect of notching the bars was to reduce significantly the amount of energy absorbed in tension-impact. It is possible that the scatter of the notched bars results may be due to slight (and probably unaccountable) differences in the notches themselves.

Elevated-TemperatureTensile Tests---2024-T86 Alloy

The results of tensile tests at 350°, 400°, and 500°F on the 2024-T86 alloy are summarized in Table 4. Nine tests, three from each sheet, have been run at 350° and 400°, while three have been completed so far at 500°F. The purpose of these tests is to establish the normal scatter in properties of the unexposed material at each temperature. The results appear to be quite consistent and the differences between sheets are no greater than the differences within an individual sheet.

At the elevated temperatures, the strengths were lowered and the spread between the tensile and yield strengths was decreased from that at room temperature. At room temperature the yield strength was about 5,000 psi lower than the tensile strength, while the spread had decreased to approximately 1,500 psi at the temperatures tested. The elongations and reductions of area showed only a moderate increase over the room temperature values for tests up to 500°F.

Effect of Unstressed Exposure on 2024-T86

The third progress report (6) presented data on the effects of unstressed exposure on the room-temperature tensile properties of 2024-T86 aluminum alloy. These tests run for 10, 50, or 100 hours at 350°, 400°, or 500°F showed that increasing time and temperature of exposure resulted in decreased tensile and yield strengths, although, the effect on ductility was not significant.

Hardness test results are now available on these specimens and the data are summarized in Table 5 and plotted in Figure 10. In addition, tension-impact tests at room temperature (with smooth specimens) have been run on specimens given the same exposures to time and temperature in the absence of stress. These data are also summarized in Table 5 and plotted in Figure 10.

The effect of the unstressed exposures on the hardness of this alloy followed the same course as did the tensile and yield strengths; that is, a decrease with increasing time and temperature.

The tension-impact data on the average appear to be consistent with the other results for 10 and 50 hours exposure at the three temperatures, however, the results of the 100-hour exposures are somewhat confusing. Perhaps some of this can be traced to the scatter between duplicate tests of the same condition. This is particularly evident for the 350°F exposure samples. It would appear that the smooth-bar tension-impact test may not be as sensitive to the effect of exposures as are the other tests employed.

Total-Deformation Tests---2024-T86 Alloy

The creep-rupture tests at 350°, 400°, and 500°F have been completed on the 2024-T86 alloy. The purpose of these tests was to establish the curves of stress versus time to reach the total deformations specified for the stressed-exposure tests in this investigation.

The test data are summarized in Table 6 and plotted in Figure 11.

The curves of stress versus rupture time for this material appear to be consistent with the uniformity of the material as revealed by the short-time tests of mechanical properties. The low values of elongation at rupture suggested that some difficulty might be encountered in obtaining the higher amounts of total deformation desired---2.0 and 3.0 percent in 100 hours. This was indeed the case. The curves for 0.5 and 1.0 percent total deformation were established without too much difficulty at all three temperatures, however, 2.0 percent appears to be a practical limit for deformation at 350° and 400°F. Even this requires stresses to within 1000 psi of the rupture strength and examination of Figure 11 reveals the difficulty of stress selection inherent in trying to reach 2.0 and 3.0 percent deformations in 10, 50, or 100 hours. For the time being, the attainment of 3.0 percent total deformation has been ruled out at 350° and 400°F.

Stressed-Exposure Tests---2024-T86 Alloy

Results of the stressed exposure tests completed to date on the 2024-T86 alloy are presented in Table 7. The data included are the effects of stressed exposure on the room-temperature tensile properties. The data for unstressed exposures are also included for comparative purposes.

The effects on room-temperature tensile strength of various amounts of total deformation for the time periods and temperatures considered are presented in Figure 12. As this plot indicates, the effects of exposure become more severe as the time, temperature, and amount of deformation are increased. For times of 10 hours at both 350° and 400° there was a slight decrease in tensile strength for exposures of up to 2 percent total deformation. Fifty and 100 hours at these temperatures appeared to result in a greater effect although the data are as yet incomplete. However, the effects of 10-hours exposure at 500°F are large, and 50 and 100-hours exposure to stress result in a severe loss of strength.

The effects of these exposures on the yield strength and hardness appear to fall in line with the effects noted on tensile strength, while the effects on ductility are inconclusive.

Further detailed discussion of the effects of stressed exposure will be deferred to the next report.

FUTURE WORK

During the next work period the emphasis of the investigation will be devoted to the completion of the testing program on the 2024-T86 alloy. This will include all categories of tests in the testing program. In addition, the evaluation of the notched tensile-impact test on the 17-7PH alloy will be continued.

The draft copy of a summary report is scheduled to be submitted during January.

REFERENCES

1. Flanigan, Tedsen, Dorn "Compressive Properties of Aluminum Alloy Sheet At Elevated Temperatures," Proceedings A. S. T. M., Vol. 46, pages 951-967, (1946).

2. Hyler, "An Evaluation of Compression-Testing Technique for Determining Elevated Temperature Properties of Titanium Sheet," Titanium Metallurgical Laboratory, Battelle Memorial Institute, TML Report No. 43, pages 21, A-13 (June 8, 1956).

3. Gluck, Voorhees, Freeman, "Third Progress Report to Materials Laboratory, WADC on Contract AF33(616)-3368, "Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals," page 7, Figure 6.

4. Armco Steel Corporation, Product Data Bulletin on Armco 17-7PH Steel, March 1, 1954.

5. Gluck, Voorhees, Freeman, "Second Progress Report to Materials Laboratory, WADC on Contract AF33(616)-3368, "Effect of Prior Creep on Mechanical Properties of Aircraft Structural Metals," Table 6.

6. Ref. 3 - pages 11, 12, Figure 9.

Table 1

Effect of Stressed or Unstressed Exposure on Room Temperature Tensile Properties of

17-7PH Alloy (TH 1050 Condition)

Spec. Loc.	Exposure Conditions: Temp (°F)	Stress (psi)	Time (hr)	Total Def. (%)	Room Temperature Tensile Properties: Ult. Tensile Strength (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 in.)	Reduction of Area (%)	E 10^6 psi	Hardness R"C"
Average Properties - 3 sheets - As treated					203,000	193,050	7.1	18.2	28.6	43.7
2N-T4	600	none	100	none	192,500	184,200	8.0	18.4	29.4	42.5
3A-T1	600	none	100		212,000	206,000	7.5	19.4	29.8	45.8
				Average	202,250	195,100	7.8	18.9	29.1	45.3
2N-T1	600	157,000	100.5	1.89	223,000	(223,000)	1.5	13.7	29.4	45.3
3Q-T7	600	157,000	104.5	3.82	209,000	--	2.0	8.6	30.3	41.1
1P-T24	600	157,000	99.9	5.30(?)	217,500	(188,500)	2.0	5.8	28.9	42.8
			Average	3.67(?)	216,500	(205,750)	1.8	9.7	29.5	43.1
2S-T3	650	137,000	105.0	1.87	215,000	215,000	2.5	12.5	30.4	43.5
3B-T4	650	137,000	100.1	2.71	206,000	206,000	2.5	14.0	31.8	41.7
			Average	2.29	210,500	210,500	2.5	13.2	31.1	42.6
2R-T6	700	118,000	100.2	1.82	211,000	210,000	4.0	17.7	29.6	42.8
3G-T3	700	118,000	100.7	1.60	218,500	218,000	3.0	16.0	30.8	44.9
			Average	1.71	214,750	214,000	3.5	16.8	30.2	43.8
2R-T2	700	120,000	100.1	2.54	219,000	218,000	2.2	13.7	30.6	44.0
3Q-T6*	700	120,000	100.1	1.95	220,000	219,000	3.5	13.8	29.6	44.2
			Average	2.24	219,500	218,500	2.8	13.8	30.1	44.1
2J-T5	750	101,000	100.0	1.94	222,000	220,000	3.0	17.0	29.7	44.2
3B-T3	750	101,000	100.0	1.62	218,000	217,000	4.5	16.7	30.0	46.1
			Average	1.78	220,000	218,500	3.7	16.8	29.8	45.2
3G-T6	800	none	100.0	none	222,000	216,000	4.0	17.9	29.8	47.4
2N-T2	800	none	100.0	none	222,500	216,000	5.0	17.3	30.2	48.2
			Average	none	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	800	81,000	102.1	1.88	227,000	222,000	4.2	15.8	30.2	46.7
			Average	2.00	229,500	225,500	3.8	14.0	30.1	46.7
2R-T5	850	66,000	100.0	1.99	235,000	230,000	5.0	13.4	30.8	46.4
3H-T3	850	66,000	100.1	2.09	231,000	228,000	4.2	14.3	30.0	47.6
			Average	2.04	233,000	229,000	4.6	13.8	30.4	47.0
3P-T6	900	none	100.0	none	222,000	215,000	4.5	8.4	30.4	46.2
2N-T5	900	none	100.0	none	220,000	213,000	6.0	17.1	28.8	47.0
			Average	none	221,000	214,000	5.2	12.8	29.6	46.6
2R-T1	900	49,000	100.0	1.55	214,000	209,000	6.5	16.7	29.9	45.3
		50,000	100.0	2.04	224,000	219,000	4.0	15.2	29.7	46.8
		50,000	100.0	2.33	235,000	230,000	4.0	13.1	30.0	48.1
			Average	1.97	224,333	219,333	4.8	15.0	29.5	46.7

* gage section not remachined before tensile test

Table 2

Room Temperature Compression Test Data

17-7PH Alloy (TH 1050 Condition)

Spec. Loc.		0.2% offset Compression Yield Strength (psi)	Compression Modulus 10^6 psi
1C-C44		242,000	29.5
1C-C4		235,000	30.1
1C-C22		228,000	29.6
1U-C4		226,000	29.6
	Average	232,750	29.7
2J-C44		195,000	29.6
2E-C2		206,000	30.1
	Average	200,500	29.8
3L-C6		205,000	29.8
3L-C4		234,000	29.6
3L-C44		216,000	30.3
	Average	218,333	29.6
Average 9 tests		220,777	29.8
Average of sheet averages		217,194	29.8
		Tension Yield	**Tension Modulus**
Average of sheet 1		204,160	28.8
Average of sheet 2		179,750	28.4
Average of sheet 3		195,250	28.7
Average of 3 sheets		193,050	28.6

Table 3

Notched Bar and Smooth Bar Tension-Impact Data at Room Temperature

17-7PH Alloy (TH 1050 Condition)

Specimen		Notch Bar Energy Absorbed (ft-lb)		Smooth Bar Energy Absorbed (ft-lb)
1G-M5		32	1C-M5	35
1G-M2		8	1C-M6	37
1U-M2		16	1C-M1	45
1U-M4		12		
	Average	17	Average	39
2E-M6		36	2J-M1	48
2N-M4		45	2J-M2	41
2N-M5		9	2E-M1	62
	Average	30	Average	50.3
3F-M5		36	3L-M2	52
3F-M6		49	3L-M5	52
3L-M1		46	3F-M4	33
	Average	47	Average	45.6
Average 10 tests		28.9	Average 9 tests	45.0
Average sheet averages		31.3	Average sheets	45.0

Note: Notched Specimens 0.250 inch wide at minimum section. Theoretical stress concentration factor, $K_t = 1.65$.

Smooth Specimens 0.200 inch wide in gauge section.

Table 4

Elevated Temperature Tensile Data

2024-T86 Alloy

Test Temp °F	Specimen	Ult. Tensile Strength (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 in.)	Reduction of Area (%)	Elastic Modulus 10^6 psi
350	2B-T55	57,100	55,700	9.5	15.9	10.5
	2F-T3	58,300	56,400	9.8	20.6	10.2
	2M-T2	59,400	58,500	8.5	17.9	10.5
	Average	58,267	56,867	9.3	18.1	10.4
	3A-T11	56,900	55,500	9.5	20.3	10.6
	3G-T3	58,100	56,900	9.0	19.1	10.0
	3K-T2	57,500	56,700	10.0	20.0	9.9
	Average	57,500	56,367	9.5	19.8	10.2
	4C-T11	56,800	55,600	7.0	13.1	10.6
	4H-X11	58,500	56,900	9.5	18.2	9.8
	4Q-T1	58,100	56,900	9.5	17.4	10.3
	Average	57,800	56,467	8.7	16.2	10.2
Average 9 tests		57,854	56,456	9.2	18.0	10.3
400	2D-T11	51,800	50,000	9.5	19.2	9.5
	2F-T5	52,100	50,300	8.5	16.6	9.3
	2M-T3	54,900	53,000	9.5	21.9	9.8
	Average	52,933	51,100	9.2	19.2	9.5
	3A-T2	54,600	52,300	10.8	20.4	9.0
	3G-T1	51,700	50,000	9.0	19.6	9.4
	3K-T1	51,700	49,600	8.0	18.6	9.3
	Average	52,667	50,633	9.3	19.5	9.2

Table 4 (continued)

Test Temp °F	Specimen	Ult. Tensile Strength (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 in.)	Reduction of Area (%)	Elastic Modulus 10^6 psi
400	4C-T55	51,400	49,500	7.0	(9.0)*	9.3
	4N-T2	52,300	50,700	10.0	18.3	9.1
	4P-T3	54,400	53,900	8.8	18.8	9.5
	Average	52,700	51,700	8.6	18.6	9.3
Average 9 tests		52,784	51,033	9.0	19.2	9.4
500	2D-T4	37,600	35,200	9.5	23.9	7.3
	2H-T3	38,900	38,000	9.5	21.6	7.7
	2M-T11	43,200	42,000	9.0	19.3	7.9
	Average	39,900	38,400	9.3	21.6	7.6
Room Temp.	Average	75,690	70,560	7.8	11.9	10.8

* omitted from average - broke at gage point

Effect of Unstressed Exposure on Room Temperature Hardness and Tension-Impact Properties

2024-T86 Alloy

Exposure Temp °F	Exposure Time hr	Hardness after Exposure: Spec. No.	Hardness after Exposure: Hardness Rockwell B	Tension-Impact Properties (Smooth Bar): Spec. No.	Energy Absorbed (ft-lb)	Elongation (%/2 in.)	Reduction of Area (%)
Unexposed		Average	80.3	Average	18.2	5.8	11.2
350	10	2J-T1	79.3	4A-X3	15	3.0	7.9
	10	4A-T2	80.7	3E-X22	21	5.0	9.9
		Average	80.0	Average	18	4.0	8.9
	50	2P-T1	77.8	4M-X4	17	5.0	11.4
	50	4G-T3	77.2	2C-X22	19	6.0	9.4
		Average	77.5	Average	18	5.5	10.4
	100	2P-T3	75.8	3L-X4	10	6.0	8.5
	100	4M-T1	75.8	2C-X4	16	6.0	6.1
		Average	75.8	Average	13	6.0	7.3
400	10	2P-T2	75.8	4M-X3	18	6.5	8.6
	10	4G-T1	74.7	2J-X4	17	6.0	11.6
		Average	75.2	Average	17.5	6.2	9.1
	50	3E-T4	72.0	4A-X4	11	8.0	13.0
	50	4M-T2	71.3	3E-X33	21	6.5	7.7
		Average	71.6	Average	16.0	7.2	10.3
	100	2C-T3	68.2	2J-X22	18	9.0	12.7
	100	3L-T1	68.7	4M-X33	19	7.5	9.2
		Average	68.4	Average	18.5	8.2	10.9

Table 5 (continued)

Exposure Temp °F	Exposure Time hr	Hardness after Exposure		Tension-Impact Properties (Smooth Bars)			
		Spec. No.	Hardness Rockwell B	Spec. No.	Energy Absorbed (ft-lb)	Elongation (%/2 in.)	Reduction of Area(%)
500	10	2P-T11	65.3	4G-X22	13	5.5	10.2
	10	3E-T3	66.8	3E-X4	14	6.0	11.0
		Average	66.0	Average	13.5	5.8	10.6
	50	2C-T4	68.0	4G-X4	11	4.0	11.5
	50	4G-T4	66.1	2P-X33	14	4.5	9.2
		Average	67.0	Average	12.5	4.2	10.4
	100	3L-T4	54.3	2P-X4	15	6.0	13.8
	100	4A-T3	54.7	3L-X22	14	6.0	13.9
		Average	54.5	Average	14.5	6.0	13.8

Table 6

Rupture and Total Deformation Data

2024-T86 Aluminum Alloy

Spec. Loc.	Test Temp °F	Stress (psi)	Rupture Time hrs	Elongation (%/2 in.)	Reduction of Area (%)	Loading Def. %	Time to Reach Indicated Total Deformation hrs			
							0.5%	1.0%	2.0%	3.0%
2B-T5	350	46,000	20.4	6.0	8.8	.51	--	approx. 7		
3L-T11		45,000	24.5	4.2	9.2	.47	.08	--	--	--
4A-T4		40,000	82.3	4.5	6.7	.42	1.0	40.0	71.0	--
3E-T5		37,500	171.3	3.0	4.6	.38	6.5	76.0	approx 7	--
2C-T1		35,000	481.2	2.8	4.1	.37	19.5	256.0	--	--
4M-T4		32,000	460.5	2.0	5.1	.32	31.5	310.0	--	--
2F-T11		30,000	(742.5)[b]	--	--	.32	46.0	554.0	--	--
2P-T4	400	40,000	6.6	7.0	14.4	.46	0.3	--	--	--
3D-T3		37,500	19.2	5.0	8.1	.41	0.5	8.1	18 (est)	--
4M-T11		35,000	28.1	2.0	1.6	.41	1.2	15.0	--	--
3E-T11		30,000	(51.5)[a]	1.5	4.6	.32	4.0	32.0	--	--
2C-T5		30,000	83.1	4.0	6.6	.33	4.0	43.5	76.5	--
2J-T5		25,000	360.6	3.5	6.2	.29	23.0	169.0	354.0	--
4G-T5		20,000	(1127.8)[b]	--	--	.21	160.0	825.0	--	
3L-T2	500	25,000	1.7	7.0	20.4	.34	.06	.51	1.05	1.5
2J-T2		20,000	8.6 ± 1	10.5	22.0	.26	1.1	4.0	--	--
4G-T11		20,000	7.1 ± 1.5	11.0	27.4	.27	0.6	2.6	--	--
2J-T11		19,000	22.8	9.2	13.1	.22	2.4	7.9	--	--
2C-T11		15,000	113.1	9.2	16.3	.16	11.1	42.4	--	--
4A-T1		14,000	66.6	9.3	19.1	.18	8.4	26.0	45.8	60 (est)
3D-T5		14,000	104.5	8.8	13.6	.17	11.5	40.0	73.5	85 (est)
4A-T11		10,000	461.0	8.7	19.4	.13	74.0	184.0	378.0	438.0

(a) failed at collar; collar on gage section in this instance

(b) Test discontinued without failure

Table 7

Effect of Stressed and Unstressed Exposure on Room Temperature Tensile Properties of

2024-T86 Alloy

Nominal Time	Spec. Loc.	Exposure Conditions: Temp °F	Stress (psi)	Actual Time hrs	Total Def. (%)	Room Temperature Tensile Properties: Ult. Tensile Strength (psi)	0.2% offset Yield Strength (psi)	Elongation (%/2 in.)	Reduction of Area (%)	E 10^6 psi	Hardness R"B"
	Average Properties - Unexposed					75,690	70,560	7.8	11.9	10.8	80.3
10 hr	2J-T1	350	none	10	none	74,900	69,000	7.5	9.2	10.9	79.3
	4A-T2	350	none	10	none	75,400	69,500	8.2	13.8	10.1	80.7
	Average	350	none	10	none	75,150	69,250	7.8	11.8	10.5	80.0
	4H-T5	350	36,000	10.1	0.52	74,800	68,600	8.5	13.8	10.7	78.2
	2F-T4	350	44,500	10.0	1.13	73,600	68,000	7.0	14.2	10.7	80.2
	3K-T11	350	47,000	10.1	1.62	74,300	69,200	10.0	12.6	10.8	79.3
50 hr	2P-T1	350	none	50	none	73,300	66,100	7.5	9.9	11.0	77.8
	4G-T3	350	none	50	none	74,500	65,900	7.5	8.1	10.8	77.2
	Average	350	none	50	none	73,900	66,000	7.5	9.0	10.9	77.5
	3G-T55	350	39,500	50.0	1.10	69,800	62,400	8.5	10.8	10.7	76.8
100 hr	2P-T3	350	none	100	none	71,600	63,500	7.5	11.1	10.8	75.8
	4M-T1	350	none	100	none	71,500	63,200	7.0	11.0	10.8	75.8
	Average	350	none	100	none	71,550	63,350	7.2	11.0	10.8	75.8
	4P-T4	350	37,500	100	1.13	71,700	62,900	8.5	10.8	10.7	76.8
	3K-T5	350	39,000	100.1	1.95	65,100	60,000	5.0	4.7	10.9	na
10 hr	2P-T2	400	none	10	none	71,600	63,900	6.5	15.3	11.0	75.8
	4G-T1	400	none	10	none	71,200	63,300	6.5	12.3	11.0	74.7
	Average	400	none	10	none	71,400	63,600	6.5	13.8	11.0	75.2
	2B-T1	400	28,000	10.0	.66	68,800	59,300	7.5	11.3	10.6	74.3
	4C-T3*	400	28,000	12.4	.82	70,500	60,900	8.0	14.8	10.5	76.1
	3D-T11	400	36,000	10.7	1.13	69,000	60,000	8.0	14.2	10.9	75.0
	4C-T4*	400	36,000	12.4	1.39	68,600	59,200	8.5	12.3	10.9	74.3
50 hr	3E-T4	400	none	50	none	67,000	56,900	7.5	12.9	11.0	72.0
	4M-T2	400	none	50	none	66,600	56,500	7.5	11.4	11.3	71.3
	Average	400	none	50	none	66,800	56,700	7.5	12.2	11.2	71.6
	4H-T1	400	23,000	50.0	.53	65,300	55,100	8.0	9.6	10.8	71.3
	3K-T3	400	23,000	50.3	.58	66,600	56,000	8.5	10.6	10.7	na
	Average	400	23,000	50.2	.56	65,650	55,550	8.2	10.1	10.8	
	3K-T55	400	29,000	50.1	.96	65,900	56,000	7.5	8.6	11.3	72.1
	2B-T4*	400	30,000	50.1	1.43	64,500	53,800	7.0	10.6	10.7	70.8
100 hr	2C-T3	400	none	100.0	none	64,500	53,800	7.5	12.1	10.7	68.2
	3L-T1	400	none	100.0	none	64,300	53,800	7.5	13.0	11.3	68.7
	Average	400	none	100.0	none	64,400	53,800	7.5	12.6	11.0	68.4
	3D-T4	400	21,000	100.0	.59	64,500	53,100	9.0	14.6	10.9	70.0
	4H-T55	400	21,000	100.2	.55	64,500	53,900	8.5	11.7	11.0	68.9
	Average	400	21,000	100.1	.57	64,500	53,500	8.8	13.7	11.0	69.5
	4H-T3	400	27,000	100.3	1.07	61,800	50,800	11.0	11.7	10.4	69.0
	3A-T5*	400	29,000	100.0	1.53	60,600	50,900	5.5	7.5	10.9	na
10 hr	2P-T11	500	none	10	none	62,500	50,100	7.0	10.0	10.6	65.3
	3E-T3	500	none	10	none	61,500	49,300	7.0	12.6	10.9	66.8
	Average	500	none	10	none	62,000	49,700	7.0	11.3	10.5	66.0
	2B-T3*	500	14,500	21.2	na	51,300	35,900	9.0	14.1	10.7	54.0
	4H-T4	500	18,000	10.0	na	48,900	33,400	8.0	13.9	10.7	50.3
50 hr	2C-T4	500	none	50	none	62,400	50,300	7.5	11.0	10.8	68.0
	4G-T4	500	none	50	none	59,900	48,500	7.0	11.7	10.6	66.1
	Average	500	none	50	none	61,150	49,400	7.2	10.8	10.7	67.0
	4P-T55	500	11,000	53.6	na	42,200	25,000	10.2	18.4	10.7	35.3
	3G-T2	500	14,000	50.3	1.59	46,100	29,400	10.0	15.7	10.6	na
100 hr	3L-T4	500	none	50.0	none	51,500	37,000	7.0	13.0	10.9	54.3
	4A-T3	500	none	50.0	none	52,100	38,800	6.5	13.6	10.6	54.7
	Average	500	none	50.0	none	51,800	37,900	6.8	13.3	10.8	54.5
	3D-T55	500	9,000	100.0	.62	44,400	28,200	9.8	17.5	10.7	na

* data included for comparative purposes; test conditions not otherwise applicable

na - not yet available

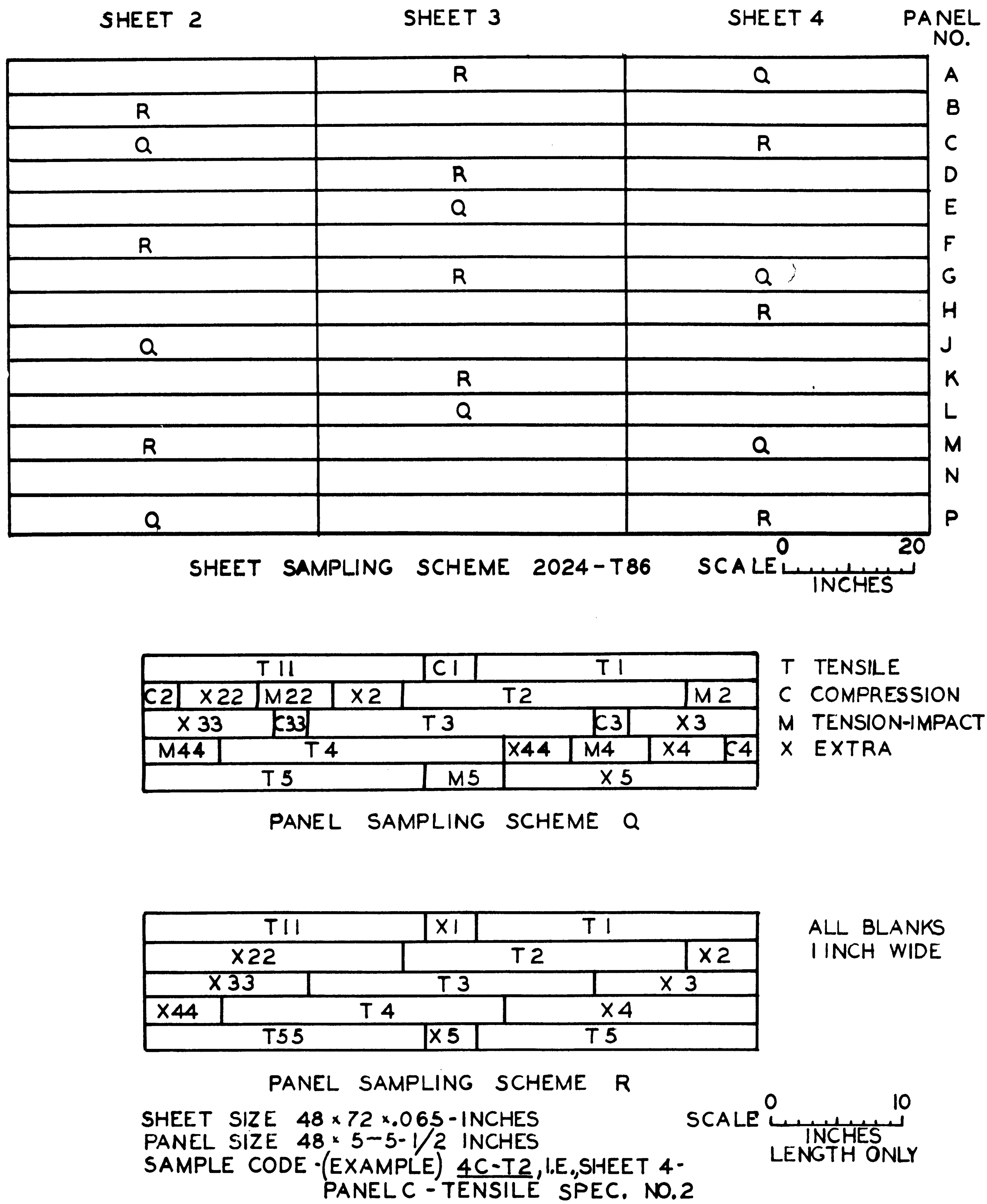
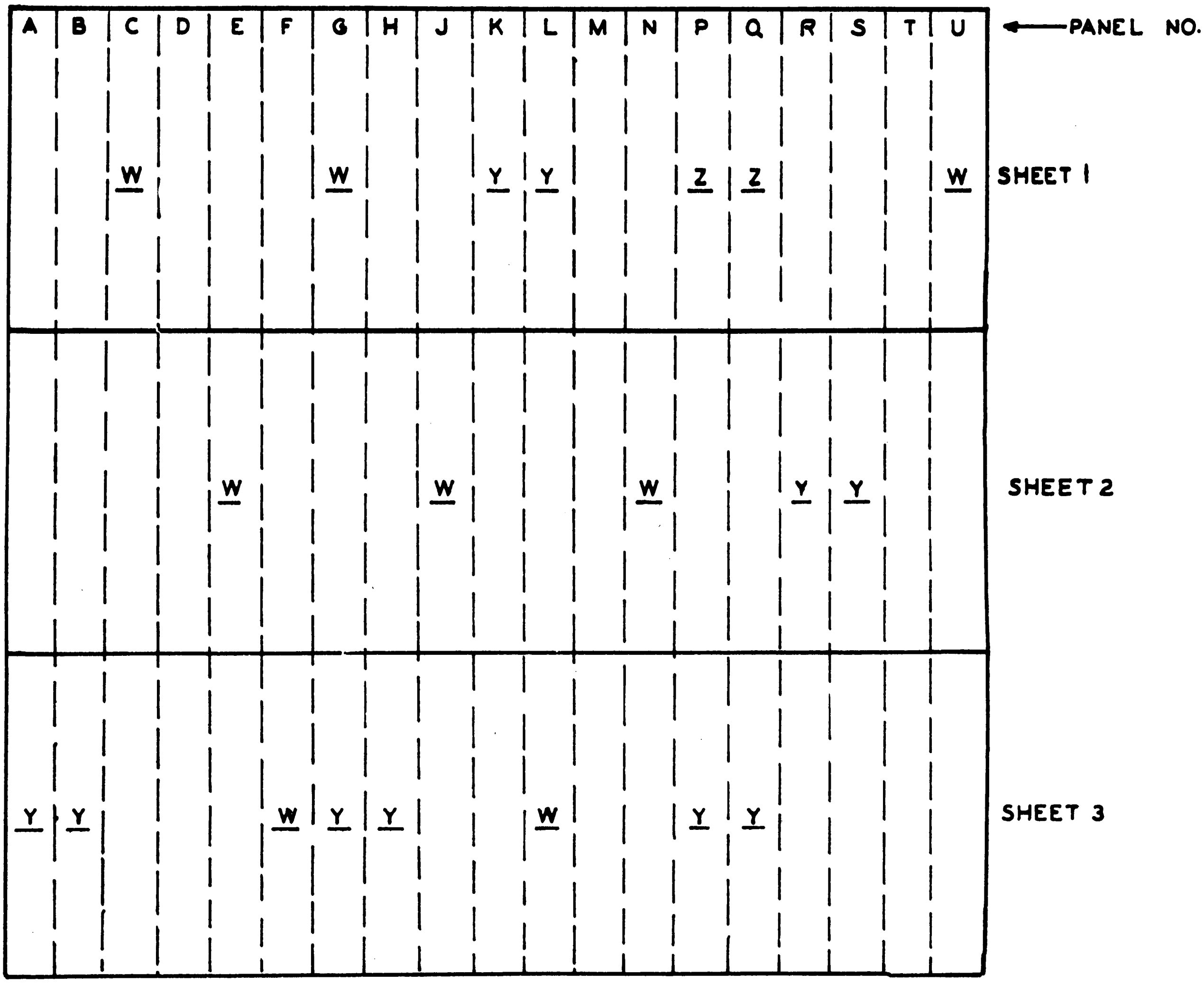
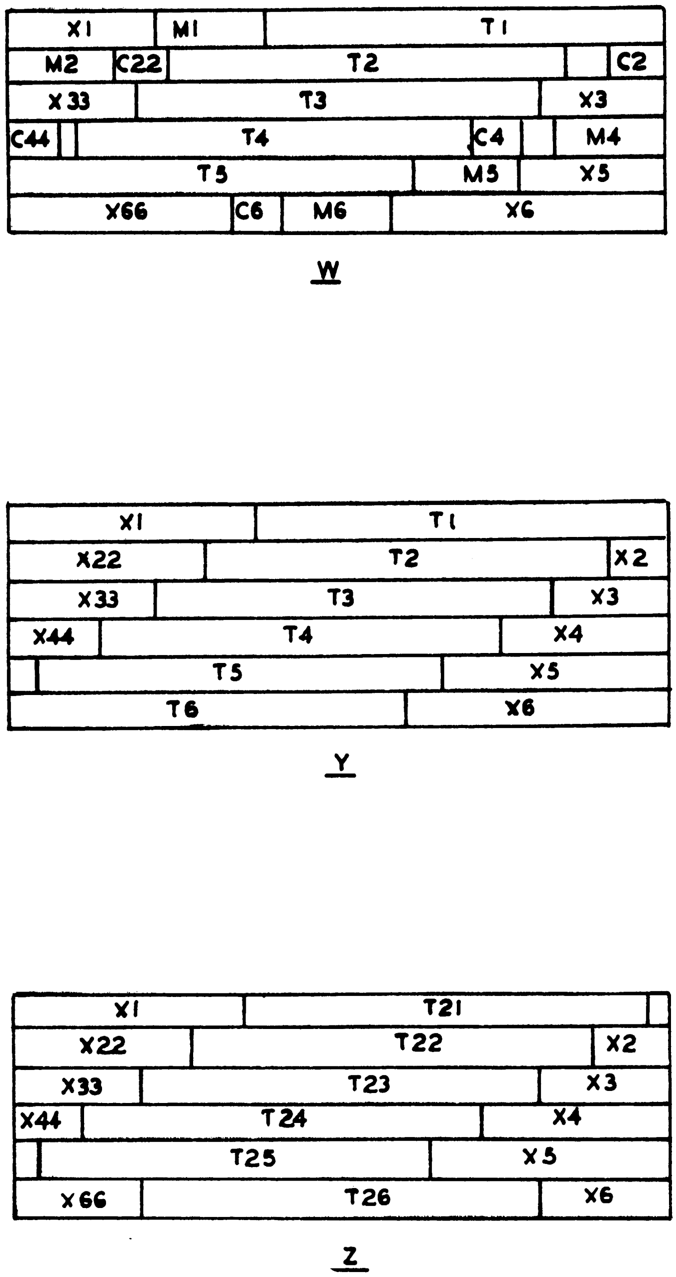


Figure 1. - Sampling Procedure for sheets of 2024-T86 aluminum alloy



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: W, Y, or Z (see Figure 3)

Figure 2. - Panel sampling scheme for sheets of 17-7PH stainless steel sheet



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

SCALE: 0 10
INCHES
(LENGTH ONLY)
ALL BLANKS 1 INCH WIDE

Figure 3. - Specimen blank sampling schemes for panels of 17-7PH stainless steel sheet

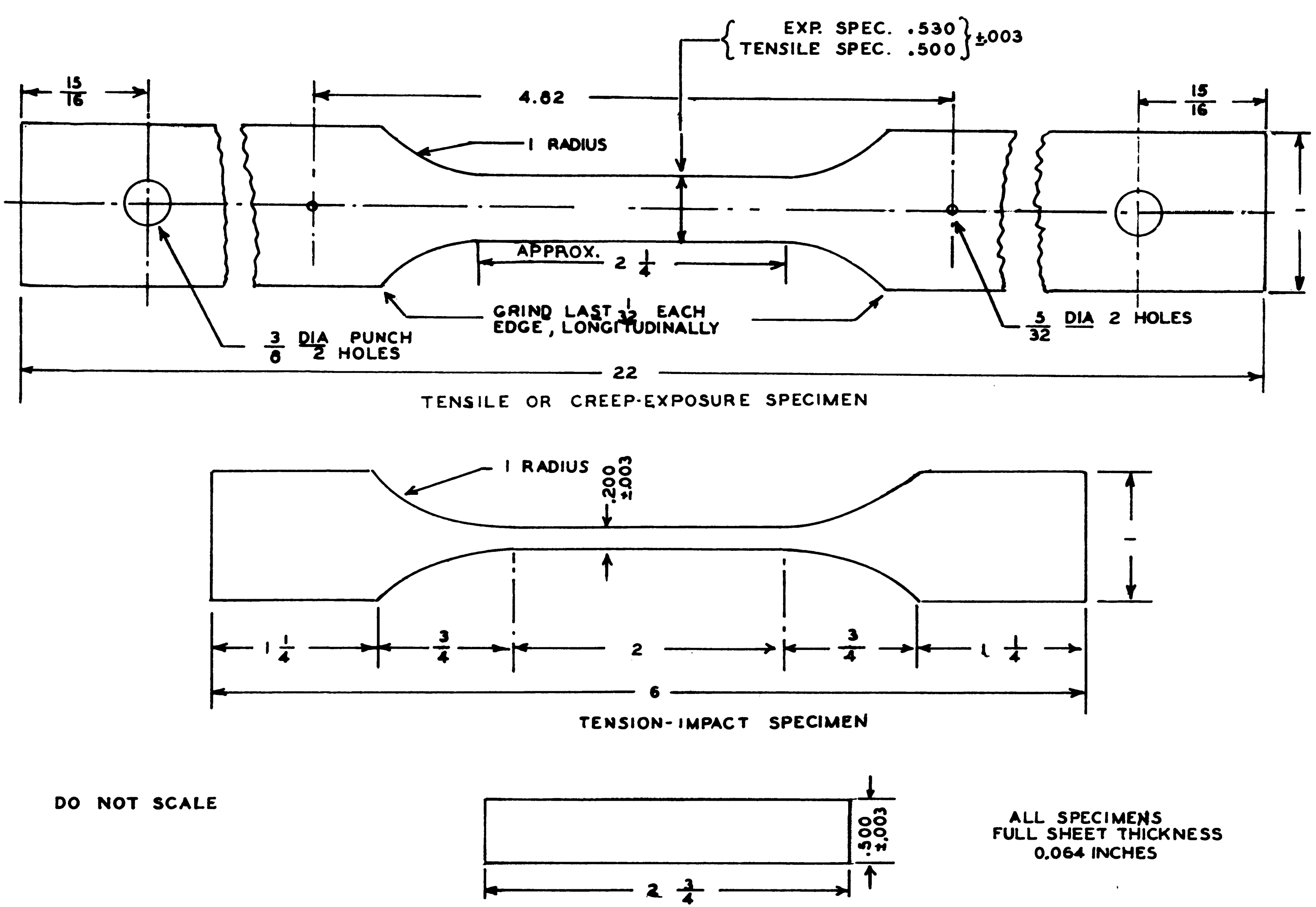


Figure 4. - Details of Test Specimens (Tension-Impact and Compression Specimens Designed to be Cut from Creep Specimens after Exposure).

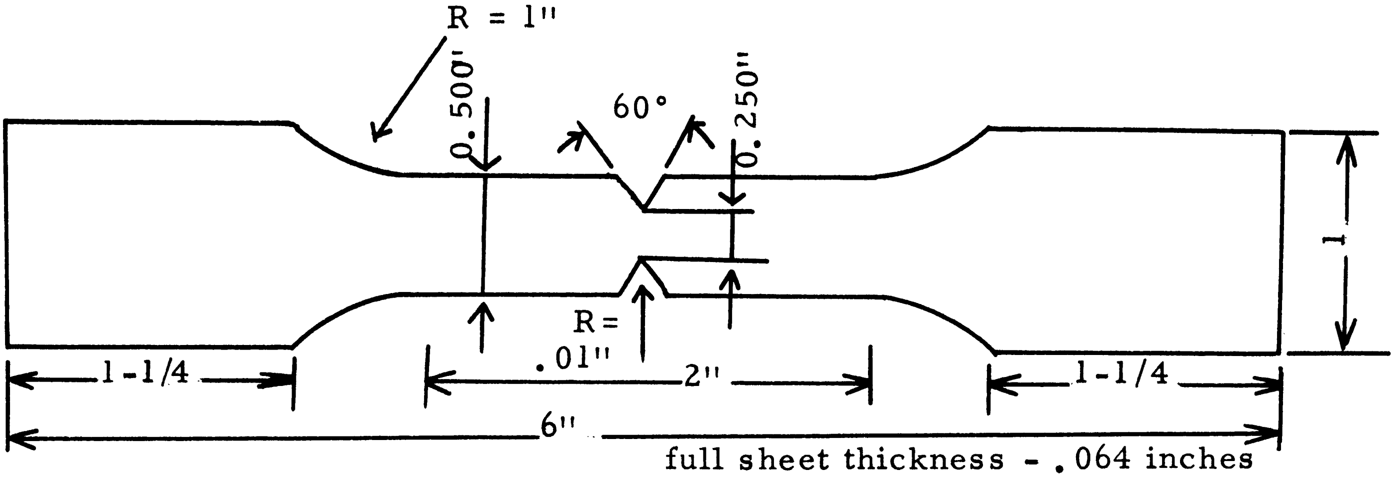


Figure 5. - Design of notched tension-impact specimen

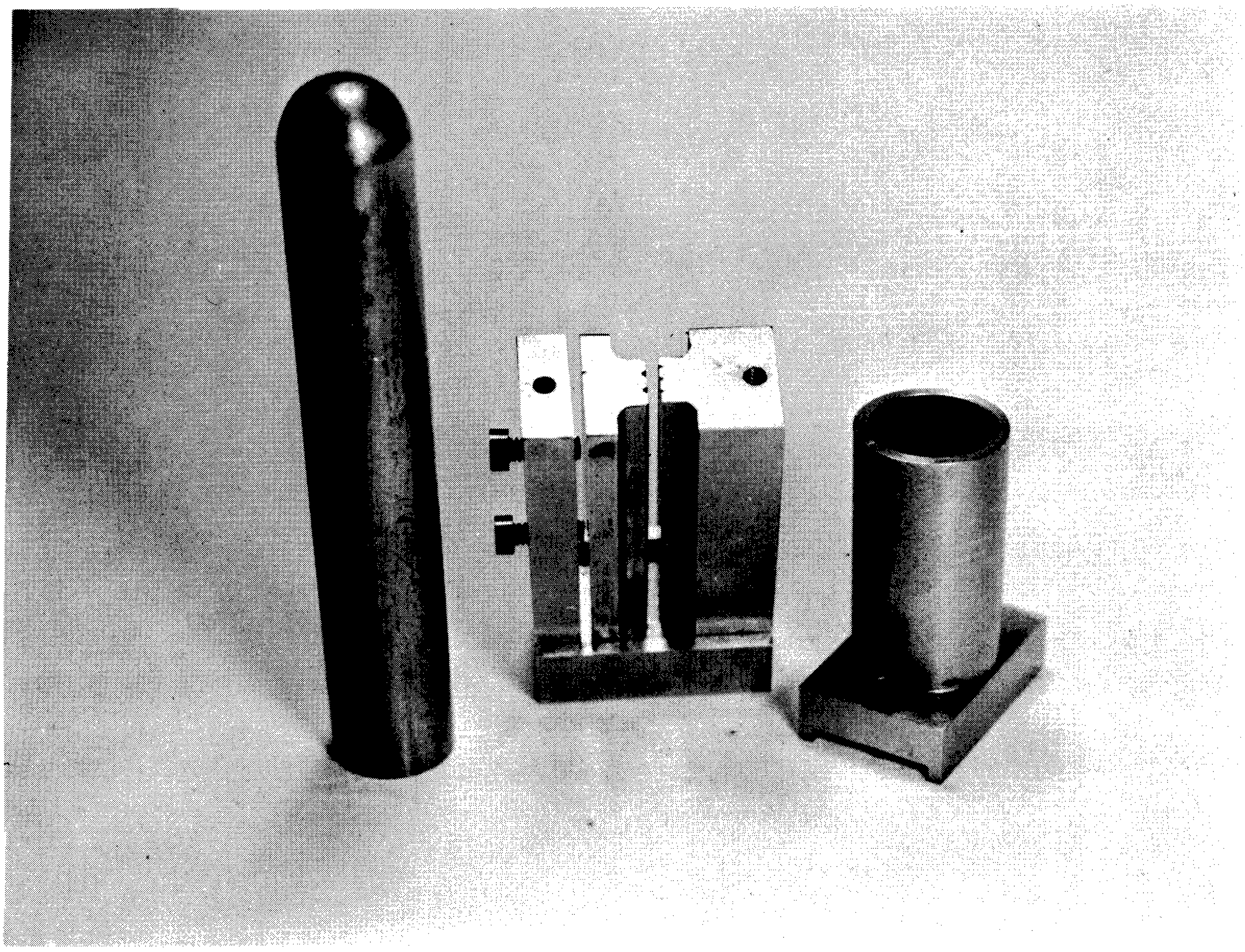


Figure 6. - Revised compression fixture showing off-set grooves in guide blocks.

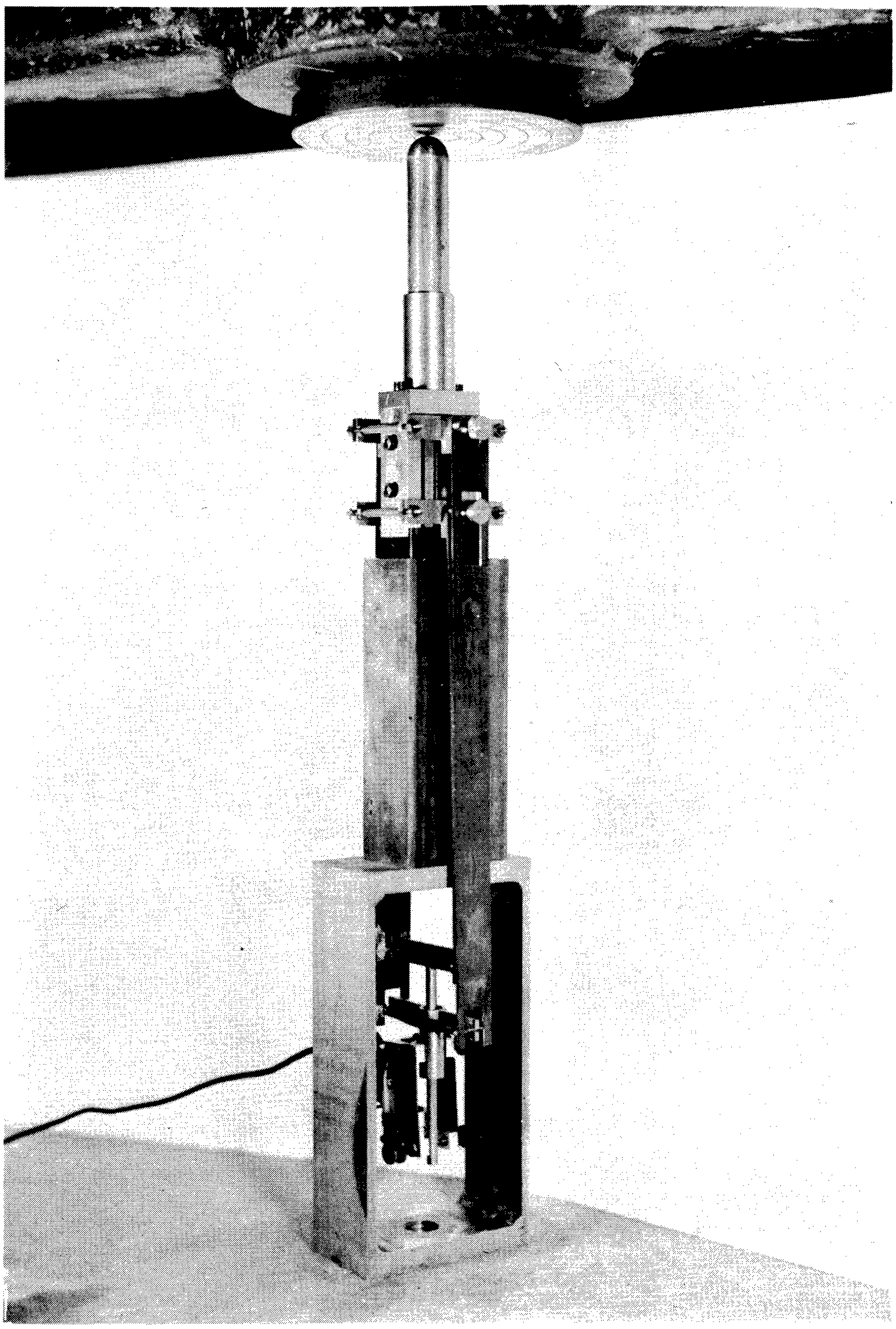


Figure 7. - Revised extensometer system employing averaging linkage, as assembled for compression testing.

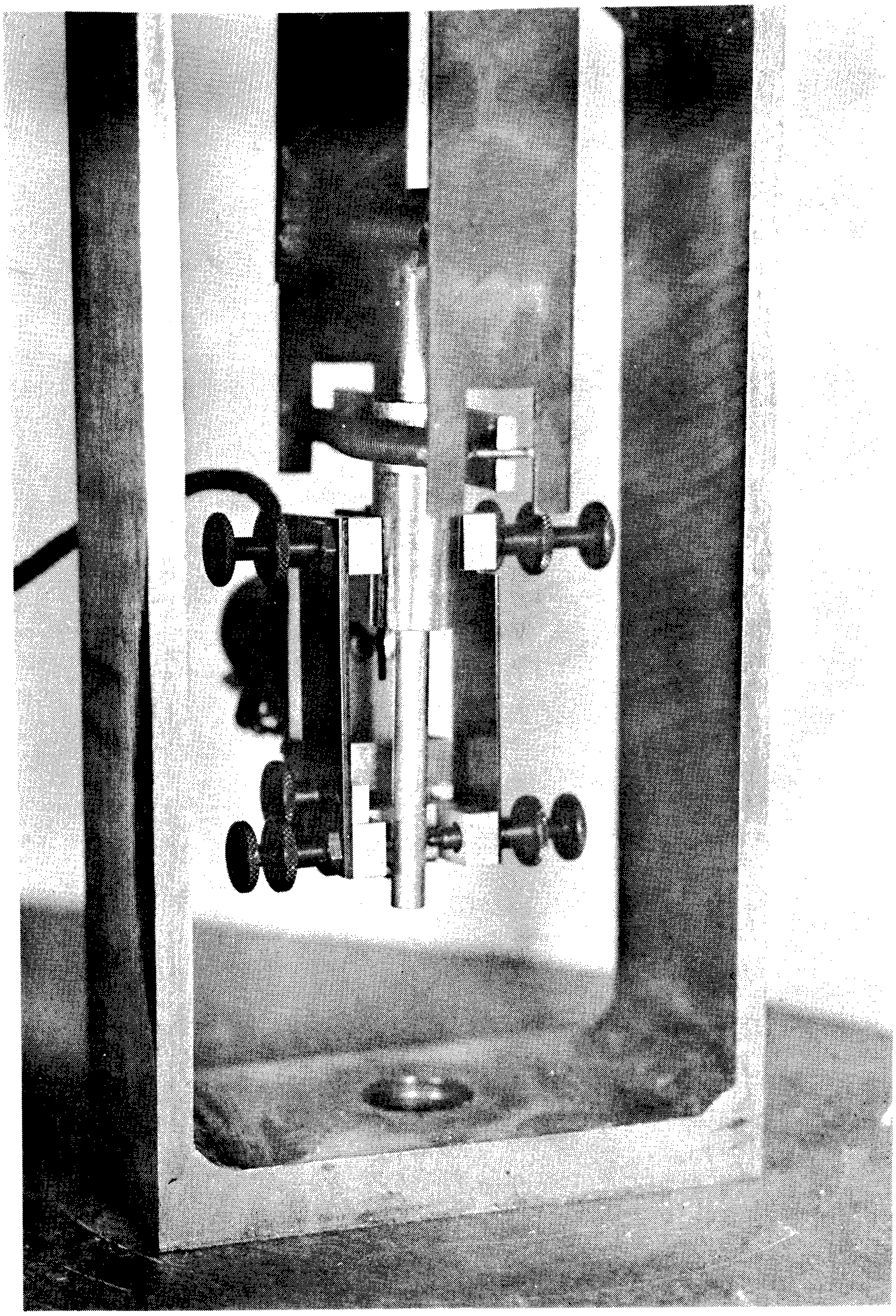


Figure 8. - Detail of lower end of revised extensometer system.

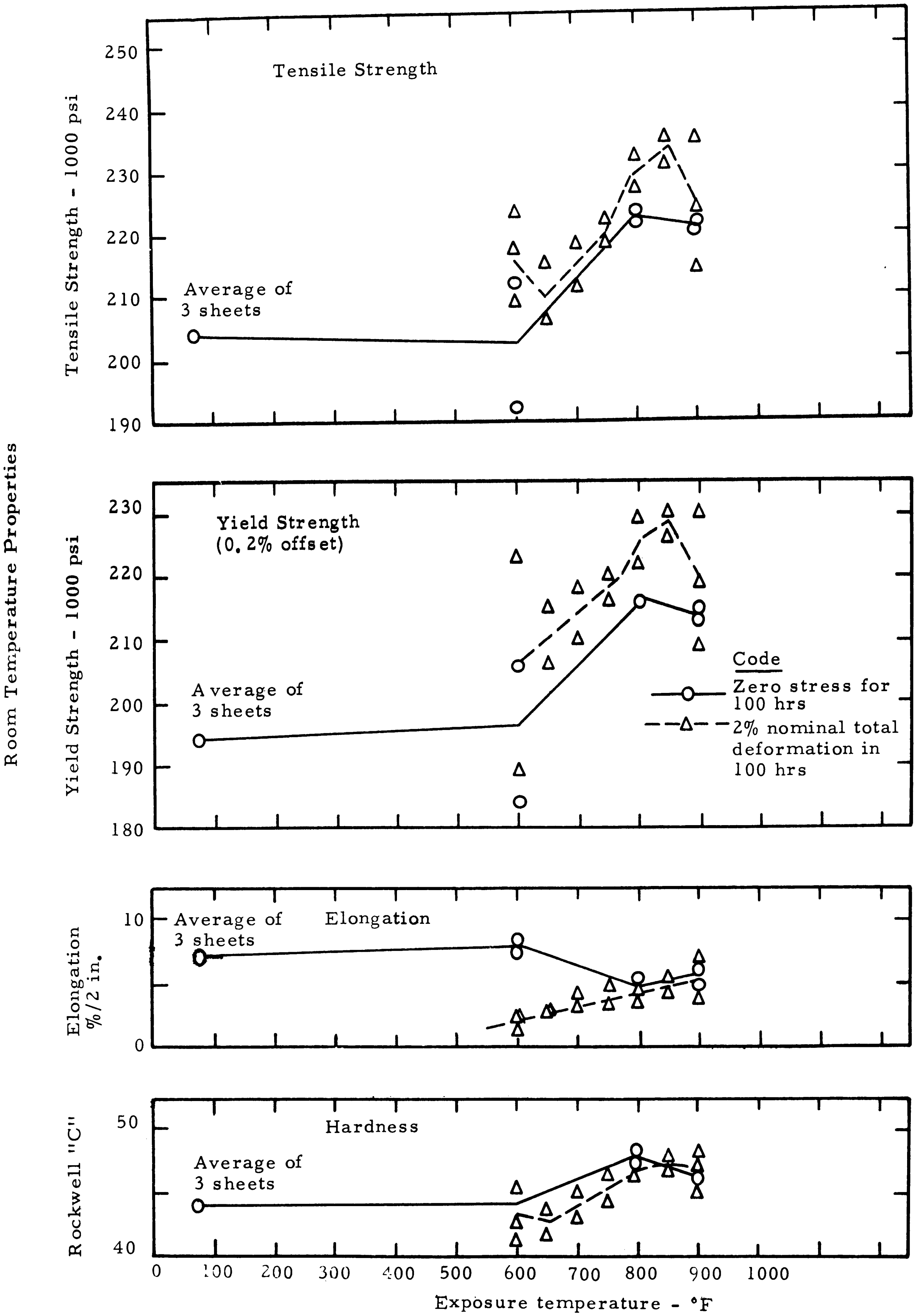


Figure 9. - Effects of 100 hours unstressed exposure or 100 hours stressed exposure to 2 percent total deformation at indicated temperatures on room temperature tensile properties of 17-7PH alloy (TH 1050 condition)

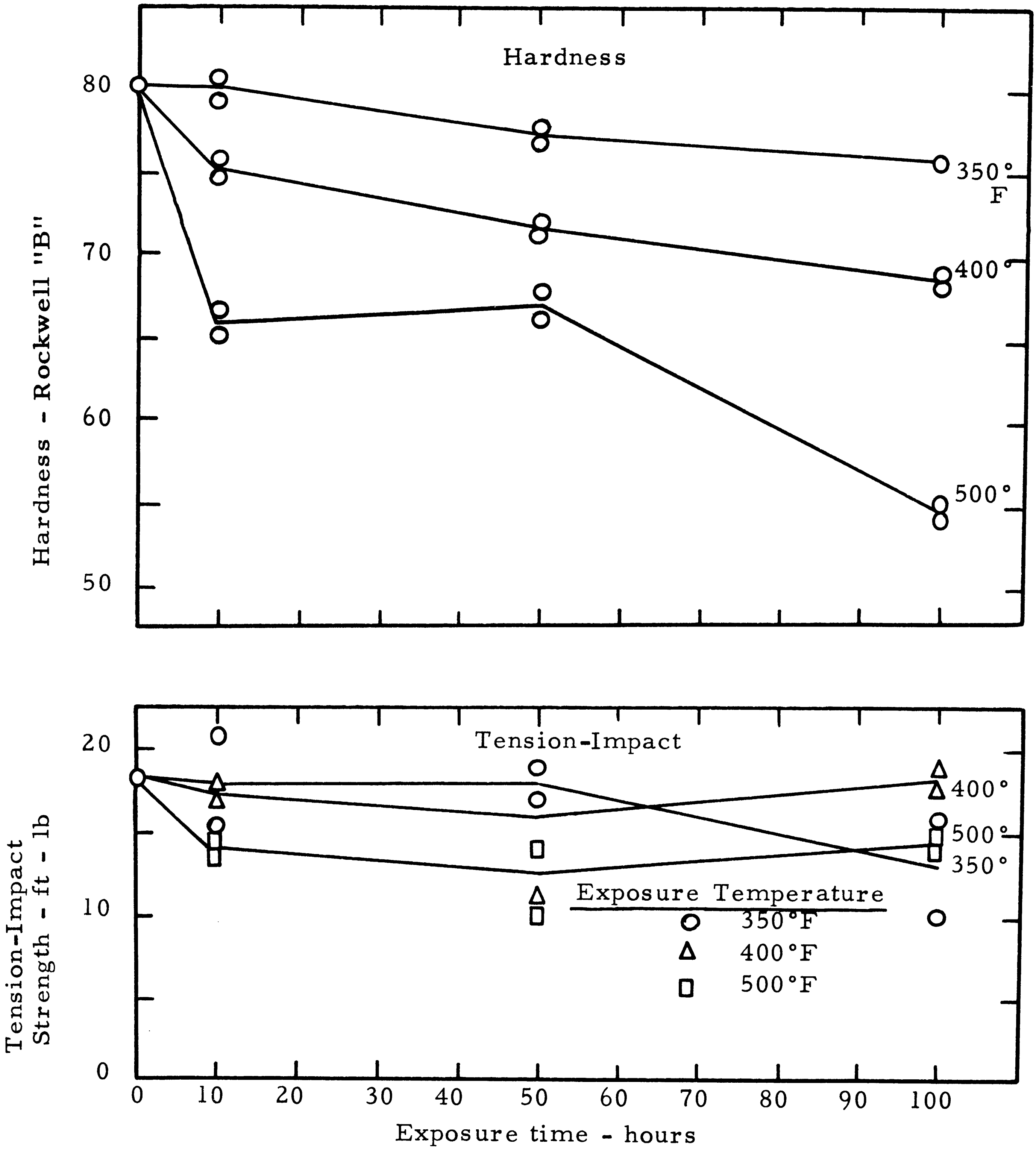


Figure 10. - Effect of unstressed exposure on hardness and room-temperature tension-impact strength of 2024-T86 alloy.

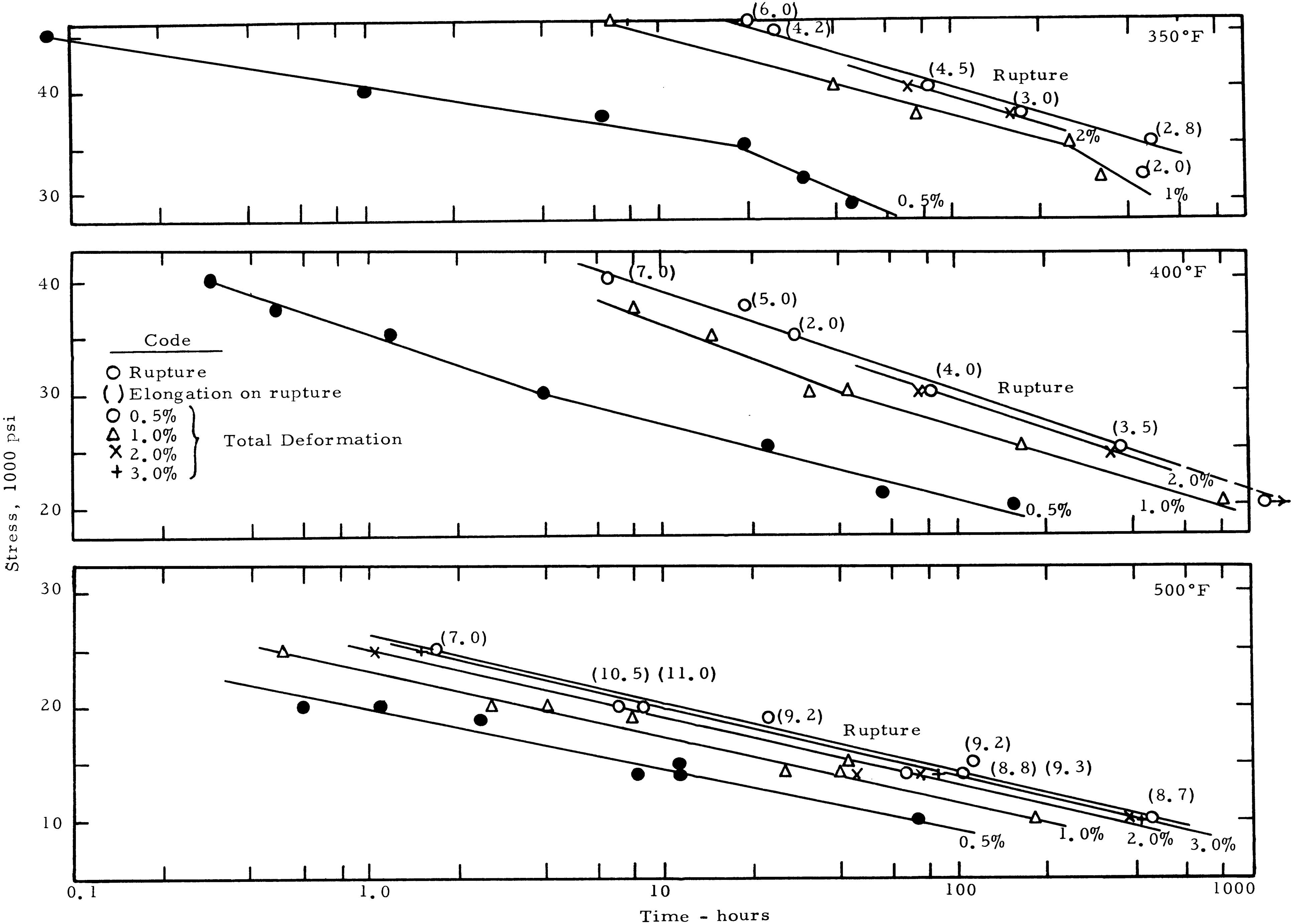


Figure 11. - Stress versus time for rupture and specified total deformations for 2024-T86 aluminum alloy at 350°, 400°, 500°F.

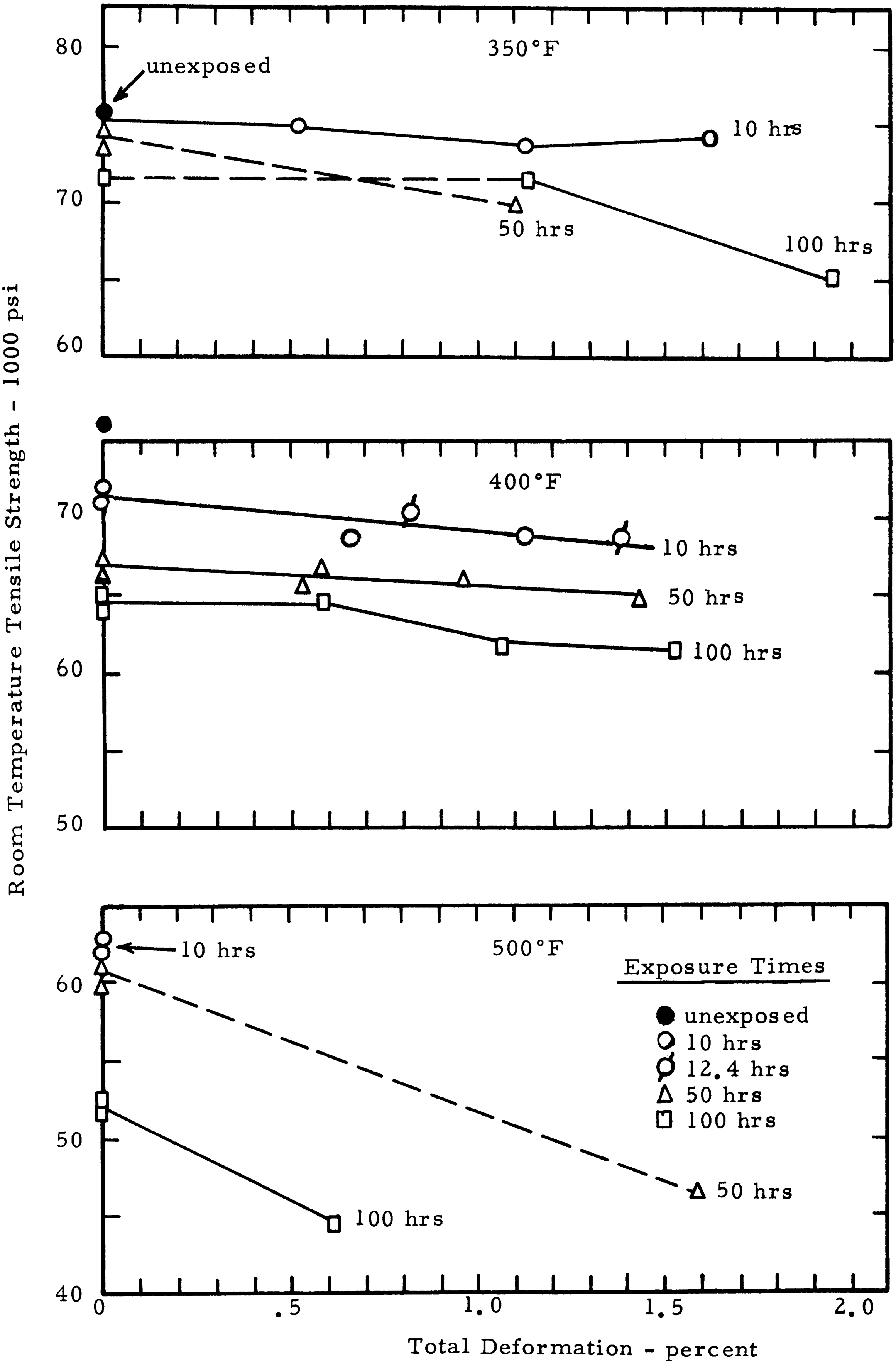


Figure 12. - Effect on room temperature tensile strength of 2024-T86 alloy from exposure to temperature and stress as indicated.