FIFTH PROGRESS REPORT

on

EFFECT OF LONG-TIME CREEP ON STRUCTURAL SHEET MATERIALS

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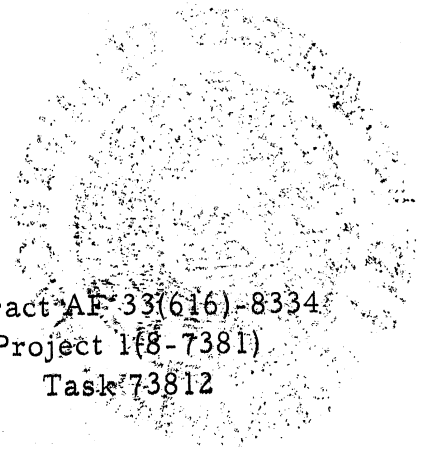

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INTRODUCTION

This research program was initiated for the purpose of obtaining data on the influence of long-time exposure at 550°F on the mechanical properties of AM350 sheet material. The data obtained in the present program is to be used in the evaluation of the alloy for possible use in the construction of a trisonic transport airplane. It is anticipated that the principles developed in this investigation regarding the influence of exposure on the strength properties of AM350 alloy can be extended to other alloys of a similar type.

AM350 material in both the SCT and the CRT conditions is being exposed under a stress of 67,000 psi. This stress was selected on the basis of being representative of the most probable design stress for the aircraft. Exposure times of 2000, 5000, 12,000, and 30,000 hours at 550°F have been incorporated into the research program to determine the influence of time of exposure on mechanical properties. In addition, a limited number of tests have been included to evaluate the possibility of using shorter-duration higher temperature exposures to predict changes in mechanical properties to be expected during a service life of 30,000 hours.

The nature of this program is such that rather long time periods exist between those times when new data can be reported. As a result of this scheduling, the present report will consist of a statement of the objectives of the program, the results obtained to date, and the present status of the research.

EXPERIMENTAL PROGRAM

Test Materials and Procedures

The AM350 sheet material tested in this program was obtained from a single consumable-electrode melted heat produced by the Allegheny-Ludlum Steel Corporation. This material, Heat No. 23327, had the following reported chemical composition:

C	Si	Mn	Cr	Ni	Mo	N	P	S
.084	.21	.65	16.50	4.29	2.94	.10	.009	.007

Thirteen sheets, each 12 inches wide by 24 inches long, of 0.025 inch thick material were received after having been cold worked 20 percent. Longitudinal specimen blanks from three of these sheets were tempered to the CRT condition by a three hour treatment at 850°F prior to specimen machining.

A similar number of the cold worked sheets were returned to the producer where they were cut into panels 12 inches wide by 8 inches long. These panels were annealed at 1950°F, pickled, conditioned for 5 to 10 minutes at 1710°F and air cooled.

Specimen blanks from five of the panels were sampled in the longitudinal direction at the University of Michigan. Conversion to the SCT condition was accomplished by cooling to -100°F for 3 hours followed by tempering at 850°F for 3 hours, all prior to specimen preparation.

Special furnaces were designed and constructed to uniformly heat the wide double gage length specimen shown at the bottom of Figure 1. The SCT panels were too short to be machined into this type of specimen and are, therefore, being exposed as single specimens. At the start of the exposure the specimens were loaded by

means of pins inserted through holes at the ends of the specimen. Creep readings are being taken from the smooth section of the specimen shown at the top of Figure 1. No creep readings are being taken on the specimens of the type shown at the bottom of this figure.

After exposure, a tensile test is conducted at room temperature on one of the test sections of the double specimen exposed to creep. The remaining section can then be used for a test at either room temperature or 550°F as the need may arise. Special adapters pull against the shoulder fillets to avoid stressing at the second gage section of the double specimen during tensile testing of the first.

Superficial hardness measurements were taken from most specimens prior to exposure. Hardness values after exposure are to be reported for the two conditions where readings after the exposure can be taken in the region of uniform exposure stress without affecting subsequent tensile tests: (a) wide unnotched specimens, with hardness readings in the gage section, but not in the plane of the notch, and (b) unstressed exposure for which hardness readings are to be taken in the specimen shoulders.

Influence of Stressed Exposure at 550°F

The effect of exposure at 550°F for 30,000 hours under a stress of 67,000 psi will be measured by:

(a) The change in the short-time tensile properties at room temperature and 550°F of unnotched strip specimens.

(b) The change in the short time tensile strength of edge notched (K_t = 3) specimens at room temperature and at 550°F after

exposure with the notch present. This notch is intended to simulate the presence of an area of concentration in the material.

(c) The change in ability to withstand a very sharp notch introduced after exposure. Unnotched specimens are being exposed. After exposure, ASTM sharp edge notches will be machined into the specimens, and tensile tests conducted at room temperature and at 550°F. This procedure was selected on the basis that sharp notches and cracks should not be originally present in the airplane. This should constitute a severe test of changes during exposure in the ability of the material to withstand sharp notches or cracks. A sharp notch present during exposure should cause creep relaxation and thereby should provide a less severe test of changes in notch sensitivity than a notch introduced after exposure.

Effect of Exposure Time

In addition to the exposure for 30,000 hours, exposures for shorter times prior to tensile testing will provide data for study of possible methods of extrapolating from short time exposures, and also will provide factual interim data without the necessity of waiting 30,000 hours for an indication of the influence of exposure. Exposure times of 2000, 5000, and 12,000 hours are being used. Unnotched and notched (K_t = 3) specimens are being exposed for 12,000 hours. At the completion of the exposure the specimens will be tensile tested at room temperature and at 550°F. The 5000 and 2000 hour exposures included similar tests, plus two specimens in which sharp notches were machined after exposure and prior to tensile testing at room temperature and 550°F.

Effect of Stress During Exposure

A very limited study of the influence of stress during exposure is being made by the inclusion of a few specimens in the exposure furnaces which have no applied stress. Exposure times of 30,000, 12,000, and 5000 hours are being evaluated, with subsequent tensile tests to be conducted at room temperature.

Accelerated Exposure

Mechanical property changes induced by exposure to elevated temperatures should involve reactions of the type obeying the Arrhenius rate equation. If this is true, then it should be possible to use shorter-duration higher temperature exposures to predict changes in mechanical properties to be expected during a service life of 30,000 hours at 550°F. In order to test this hypothesis the Arrhenius rate equation was used to select exposure times at 600°F, 650°F, and 700°F which should induce equivalent mechanical property changes to those expected in 30,000 hours at 550°F. The corresponding times selected were 2000 hours at 600°F, 200 hours at 650°F, and 20 hours at 700°F In addition, tests were run for 200 hours at 700°F to allow for the possibility that the rate constant selected for the Arrhenius equation was different from that expected.

PRESENT STATUS OF THE PROGRAM

The 2000 and 5000 hour exposures of the AM350 sheet material have been finished and the tensile tests of the exposed samples completed. In addition, the accelerated exposures at 600°F, 650°F, and 700°F have been run and the tensile tests of these samples completed. The results of these tests are reported in Table I.

The 12,000-hour and 30,000-hour exposures are now in progress. The status of these exposures is shown in Table II. The 12,000-hour exposures should be completed in January, 1964 and the 30,000-hour exposures approximately a year and one-half later.

RESULTS TO DATE

The AM350 sheet materials do not appear to be subject to creep at 550°F under a stress of 67,000 psi. During the first 14,000 hours of exposure, measurements indicate that the total amount of creep has been less than 0.01 percent. It is doubtful that the creep which has occurred to date is of any significance.

The results of the completed tensile tests along with the hardness data are reported in Table I. In Figure 2, the ultimate tensile strengths at 550°F and at room temperature of the three different types of specimens, together with the elongations for the unnotched specimens, are plotted as a function of exposure time at 550°F.

The following trends have been revealed by study of the data obtained thus far in the investigation. These trends have been divided into two categories, (1) properties of the unexposed material, and (2) properties of the material as influenced by exposure.

Properties of the Unexposed Material

(1) The alloy in the SCT condition is slightly weaker than the alloy in the CRT condition at room temperature, however, at 550°F it is considerably stronger.

(2) The notches of intermediate acuity (K_t = 3) raised the net-section strength at 550°F and at room temperature for the alloy in the SCT condition. The alloy in the CRT condition also exhibited an increase in notch strength at 550°F, however, at room temperature there was very little influence of notches of intermediate acuity on the net-section strength of the material.

(3) Sharp edge notches reduced the net-section strength of the SCT material at 550°F by approximately 35,000 psi. The alloy in the CRT condition had approximately the same net-section strength as the unnotched material at both room temperature and at 550°F.

Properties of the Alloy as Influenced by Exposure

(1) In both the CRT and the SCT conditions the strength properties of the material have not been significantly changed as the result of stressed or unstressed exposure at 550°F for 2000 or 5000 hours.

(2) A slightly but consistently lower elongation after 5000 hours of exposure than after 2000 hours suggests that a reaction could be occurring during exposure which causes a continuing loss of ductility with prolongation of exposure.

(3) The accelerated, equivalent time exposures carried out at 600°F, 650°F, and 700°F caused no appreciable changes in the strength properties or in the elongation of the AM350 sheet material in either the SCT or the CRT condition.

(4) The yield strength and hardness data reported in Table I show that little change occurred in either property as the result of exposure at 550°F. The only exception to this was an apparent drop in yield strength at room temperature from 179 to 159 ksi for the SCT material exposed for 5000 hours without stress. The results to be obtained from the 12,000 hour exposures should give an indication of whether or not this apparent drop in yield strength was actually the result of exposure.

Table I

RESULTS OF TENSILE TESTS FOR AM350 SHEET

Exposure Conditions			Test	Subsequent Tests on Unnotched Specimens							Notched (K_t = 3)	[a]Sharp Edge Notches		
Temp.	Stress	Time	Temp	P.L.	Offset Yield Strengths (ksi)			Tensile	Elongation (%)		Tensile Strength	Rockwell "45N" Hardness		Tensile
(°F)	(ksi)	(hrs)	(°F)	(ksi)	0.02%	0.1%	0.2%	Strength(ksi)	Per 2"	Per 0.5"	(ksi)	Before Exp.	After Exp.	Strength (ksi)
CRT Condition														
None			Room	93	122	168	185.5	218.5	28	--	225.5	51	--	214
None			Room	100	126	165	191	217	16.5	--	---	51.5	--	215.1
None			Room	110	137	171.5	182	224.2	23.5	--	---	---	--	---
550	40	2000	Room	89	107	155	178	212.5	21	34	---	---	--	---
550	67	2000	Room	---	---	---	[b](178)	221.8	22	--	220	52	51.5	212
550	90	2000	Room	119	142.5	154.5	186	221.4	16.5	--	---	---	--	---
550	150	2000	Room	(145)	174	198	(208)	221.1	19.5	--	---	---	--	---
550	0	5000	Room	120	140.5	170	178.5	219	20	--	---	---	--	---
550	67	5000	Room	150	174	182	185.5	222.2	19	--	223.8	53.5	51.5	213
600	67	2000	Room	114	139	168	181	217.8	17	28	---	---	--	---
700	67	200	Room	(70)	111	158	183	215.8		--	---	52.5	52	211.4
700	67	200	Room	---	---	---	---	---	--	--	---	52	51	209.8
None			550	95	120	144	153	169	4	--	185	50.5	--	172.1
None			550	96	115	143	153	168.8	4.5	--	---	50.5	--	166.8
550	0	2000	550	89	112.5	135.5	147.5	171.2	4	10	---	---	--	---
550	67	2000	550	85	105	132	141	163.5	2	6	178.2	52	--	160
550	67	5000	550	110	126	144	151	168.6	2	--	181.8	53.5	51.5	170.5
600	67	2000	550	92	113	141	153	172	5	--	175.7			
650	67	200	550	85	101	139	154	170.8	4	8	---	---	--	---
700	67	20	550	80	97	130	145	170.7	4	6	---	---	--	---
700	67	200	550	95	104	140	152.5	188	4.5	--	---	52	51	[c](>151)
700	67	200	550	103	117	139	150.5	171.2	4	8	---	52.5	52	172
SCT Condition														
None			Room	113	143	170	185.3	214.9	17	32	241.5	---	--	216
None			Room	119	139	165	178	213.1	12	26	---	---	--	208.3
None			Room	105	129	162	176	214	16.5	32	---	---	--	---
550	67	2000	Room	---	---	---	---	---	--	--	238.8	---	--	196.5
550	67	2236	Room	123	146.8	170	179	212	18	--	237.5	---	--	---
550	0	5000	Room	90	103	136	159	214.5	14	--	---	---	--	---
550	67	5000	Room	120	137	163	176	216	13.3	--	238.5	---	--	209.4
700	67	200	Room	---	---	---	---	---	--	--	---	53.5	52	208.8
None			550	70	89	119	135	193.6	5	12	210	---	--	159.3
None			550	80	98	126.9	141	194.4	6.5	12	---	---	--	159
550	67	2000	550	95	113.5	138	150	195.9	8.5	16	---	54.5	55	159.2
550	0	2236	550	70	92.3	125.5	142	199.5	7.5	--	---	---	--	---
550	67	2236	550	80	106	132	147.5	199	7.5	--	206.1	---	--	---
550	67	5000	550	110	114	134	145	193.5	4.5	--	208	---	--	161.5
600	67	2000	550	81	101	132	145.5	198.5	5.5	--	---	---	--	---
650	67	200	550	75	95	122	140	195.8	6	12	---	---	--	---
700	67	20	550	87	101	131	146	200.3	5.5	--	---	53.5	51	163
700	67	200	550	96	118	141	151.5	201.2	6	--	---	---	--	---

a) Exposed unnotched. Sharp edge notches added before tensile test.
b) By "drop of needle"; extensometer erratic
c) Specimen shoulder tore; no fracture at the notch.

Table II

STATUS OF EXPOSURE TESTS

12,000 - Hour Exposures at 550°F

Specimen Code	Specimen Type[a]	Alloy Condition[b]	Date Started	Accumulated Time to Date (Hrs.)	Estimated Completion	Stress (psi)
C-7	U	SCT	8/29/62	9528	1/11/64	None
D-2	U	SCT	9/ 6/62	9336	1/19/64	None
D-3	U	SCT	9/ 6/62	9336	1/19/64	67,000
D-5	U	SCT	9/ 6/62	9336	1/19/64	67,000
34	U	CRT	8/29/62	9528	1/11/64	None
45	U	CRT	8/29/62	9528	1/11/64	67,000
46	U	CRT	8/29/62	9528	1/11/64	67,000
43	U	CRT	9/ 6/62	9336	1/19/64	None
D-2	N	SCT	9/ 6/62	9336	1/19/64	None
D-3	N	SCT	9/ 6/62	9336	1/19/64	67,000
D-5	N	SCT	9/ 6/62	9336	1/19/64	67,000
45	N	CRT	8/29/62	9528	1/11/64	67,000
46	N	CRT	8/29/62	9528	1/11/64	67,000
43	N	CRT	8/29/62	9528	1/11/64	None
30,000 - Hour Exposures at 550°F						
E-6	W	SCT	2/13/62	14256	7/17/65	67,000
E-7	W	SCT	2/13/62	14256	7/17/65	67,000
E-4	U	SCT	2/24/62	13992	7/28/65	67,000
C-6	U	SCT	2/24/62	13992	7/28/65	None
E-1	U	SCT	2/ 9/62	14352	7/13/65	67,000
C-3	U	SCT	2/ 9/62	14352	7/13/63	None
C-1	U	SCT	5/ 3/62	12360	10/4 /65	67,000
E-2	U	SCT	5/ 3/62	12360	10/ 4 /65	67,000
D-4	U	SCT	5/ 3/62	12360	10/ 4/65	None
37	W	CRT	2/17/62	14160	7/21/65	67,000
55	U	CRT	2/13/62	14256	7/17/65	None
36	U	CRT	2/24/62	13992	7/28/65	67,000
56	U	CRT	2/17/62	14160	7/21/65	None
32	U	CRT	1/23/62	14760	6/26/65	67,000
52	U	CRT	1/23/62	14760	6/26/65	67,000
53	U	CRT	1/23/62	14760	6/26/65	None
41	U	CRT	2/ 9/62	14352	7/13/65	67,000
E-4	N	SCT	2/24/62	13992	7/28/65	67,000
E-1	N	SCT	2/ 9/62	14352	7/13/65	67,000
C-1	N	SCT	5/ 3/62	12360	10/ 4/65	67,000
E-2	N	SCT	5/ 3/62	12360	10/ 4/65	67,000
36	N	CRT	2/24/62	13992	7/28/65	67,000
32	N	CRT	1/23/62	14760	6/26/65	67,000
52	N	CRT	1/23/62	14760	6/26/65	67,000
41	N	CRT	2/ 9/62	14352	7/13/65	67,000

a) U = Unnotched, 0.350-inch gage width; N = Notched, K_t = 3; W = Wide unnotched during exposure, sharp edge notches for tensile tests.

b) CRT = Cold rolled 20 percent plus three hours at 850°F
SCT = Annealed at 1950°F, conditioned for 10 minutes at 1710°F, A.C., held three hours at -100°F and tempered three hours at 850°F

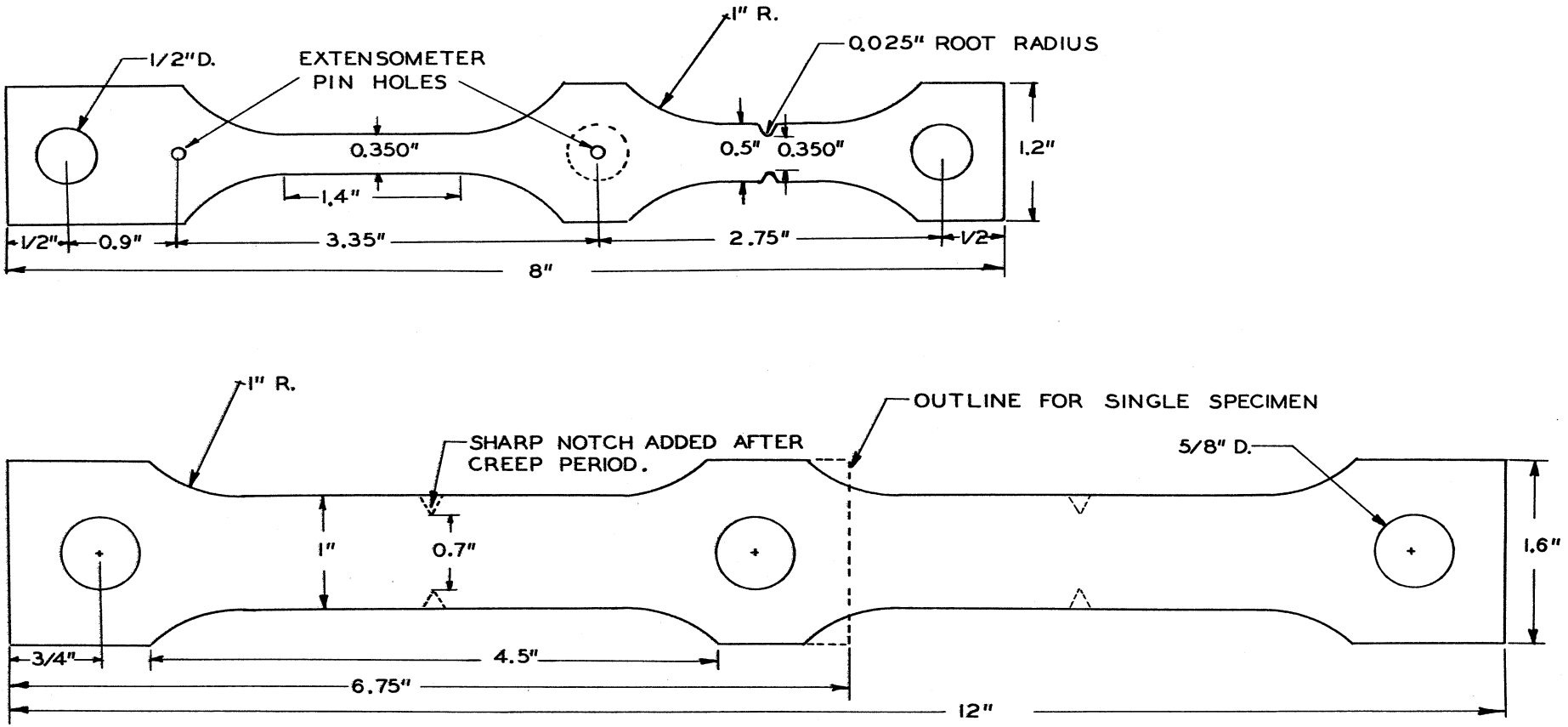

Figure 1 - Specimen for Long-Time Creep and Subsequent Tensile Testing.

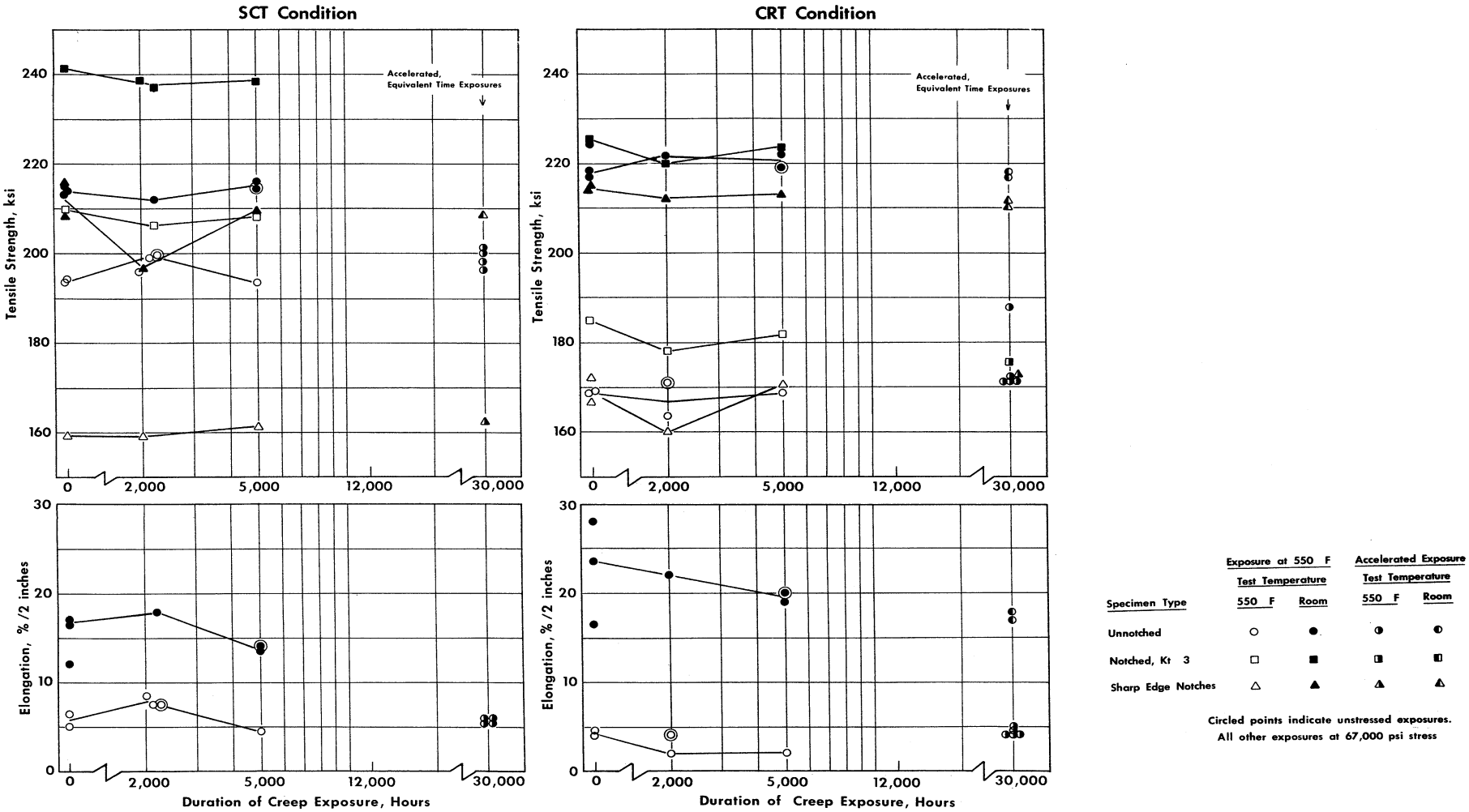

Figure 2 . Effect of Exposure at 550° on Tensile Strength and Ductility of Vacuum-Melted AM350 Sheet at 550° F and at Room Temperature. Predicted Strengths and Ductilities Based on the Results of Accelerated Tests Conducted at 600°, 650°, and 700° F Are Plotted at an Equivalent Exposure Time of 30,000 Hours.