SECOND PROGRESS REPORT

on

EFFECT OF LONG-TIME CREEP ON STRUCTURAL SHEET MATERIALS

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INTRODUCTION

The contract originally specified exposure of AM350 sheet in the CRT and SCT conditions for 30,000 hours under the stress causing 0.5 percent creep deformation at 550°F in that time period. As shown in the First Progress Report, preliminary creep tests indicated that the stress required to produce this amount of creep would well exceed the yield strength. Even then, most of the creep would occur during the first few hours of testing.

With 0.5 percent creep established as an unsatisfactory exposure criterion, the program was re-evaluated with technical representatives of ASD. The objectives were changed to obtain the most information possible regarding changes in mechanical properties as a result of prolonged exposure under stress at 550°F. With de-emphasis of high-sensitivity creep measurements on the specimens during exposure, a considerable increase was possible in the number of specimens which could be exposed. The experimental program detailed in the next section was developed to furnish types of data now deemed most useful in evaluating materials for the construction of a Mach 3 transport airplane. The exposure stress of 67,000 psi was selected as representative of the most probable design stress for that type of airplane. The program now provides for exposure time periods of 2000, 5000, and 12,000 hours at 550°F, as well as 30,000 hours, to show the effect of time of exposure. It also includes a minimum number of tests designed to study the possibility of using results from shorter-duration exposures to predict changes in properties to be expected during a service life of 30,000 hours.

REVISED EXPERIMENTAL PROGRAM

The exposure conditions and subsequent tensile tests now planned are given in Table 1 along with the status of the tests. It will be noted that testing at 550°F as well as room temperature has been added. This was done because data now available for alloys being considered for the Mach 3 airplane suggest that the properties at 550°F are more critical than those at room temperature. For this reason, it seemed desirable to add as much testing at 550°F as possible in the revised program.

Duplicate tests are planned at room temperature after exposure of unnotched and $K_t = 3$ specimens for 30,000 hours; but only single tests at 550°F. A fourth specimen is being left uncommitted, with the testing conditions to be determined after the other three specimens have been tested. For all other exposures, only single tensile tests after exposure are now planned. The omission of replicate specimens is recognized not to be desirable but seemed acceptable to obtain data for more different conditions. Deviations from general trends should be no more troublesome to interpret than deviations from the average of replicate tests.

The following sections indicate reasons for the choices of the actual exposure tests detailed in Table 1.

Effect of Exposure at 550°F for 30,000 Hours Under 67,000 psi

This will be measured by:

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

(b) the change in short time tensile strength of edge notched ($K_t = 3$) specimens at room temperature and 550°F after exposure with the notch present. This notch is intended to simulate the effect of a stress concentration present from design considerations.

(c) the change in ability to withstand a very sharp notch introduced during exposure. Unnotched specimens are being exposed. After exposure, ASTM sharp notches are 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 present originally in the airplane. It should be a severe test of changes during exposure in the important ability of the material to withstand sharp notches or cracks. A sharp notch present during exposure should undergo creep relaxation and thus provide a less severe test of changes in notch sensitivity than a notch introduced after exposure. The procedure adopted does not, however, test the possibility that a sharp notch might cause cracking during exposure.

Effect of Time at Exposure

In addition to the exposure for 30,000 hours, the revised program allows exposure of specimens for shorter times before tensile testing. This provides data for study of possible methods of extrapolating from short time exposures, and also provides interim factual data without waiting the full 30,000 hours for an indication of the effect of exposure.

Exposure times of 2000, 5000, and 12,000 hours will be used. Unnotched and notched (K_t = 3) specimens are to be exposed for 12,000 hours and then tensile tested at room temperature and 550°F. The 5000 and 2000 hour exposures include similar tests, plus two specimens in which sharp notches will be machined after exposure, prior to tensile testing at room temperature and 550°F.

Effect of Stress During Exposure

A very limited study of the effect of stress during exposure was made possible by including a few specimens in the exposure furnaces with no stress applied. Exposure times of 30,000, 12,000, and 5000 hours will be covered. Tensile tests at room temperature and 550°F are planned.

"Accelerated" Exposures

Table 1 lists some tensile tests to be carried out after prior creep under 67,000 psi stress, but at 600-700°F. Results are to be analyzed to determine if effects of prolonged exposure can be predicted from shorter exposures at higher temperatures. Emphasis is on changes in properties of unnotched specimens, but a few specimens are included in which sharp edge notches will be added after the creep exposure.

Times of 2000 hours at 600°, 200 hours at 650°, and 20 hours at 700°F were selected to produce changes in subsequent tensile properties roughly the same as would 30,000 hours at 550°F under the 67,000 psi stress. The mechanisms by which exposure to creep should cause any changes in mechanical properties were reasoned to involve reactions of the type obeying the Arrhenius rate equation. Then the rate of property change ($\dot{p}$) at constant stress may be expressed in terms of the gas control R, and a constant A and an energy E which are independent of temperature:

$$\dot{p} = A\, e^{-(E/RT)}$$

Defined, in terms of the inverse of $\dot{p}$, the time t at absolute temperature T for a given degree of property change becomes:

$$t = \frac{C}{\dot{p}} = \left(\frac{C}{A}\right) e^{E/RT} = A'\, e^{E/RT}.$$

Converting to common logarithms and rearranging,

$$T (-\log A' + \log t) = E/2.3R = \text{Constant at constant stress.}$$

For creep rupture of many alloys, -log A' is about 20. If this value and the above reasoning apply, times at 600°, 650°, and 700°F corresponding to 30,000 hours at 550°F are, respectively, about 2090, 190, and 20 hours. The 200 hour exposures at 700°F were included to allow for an actual value of -log A' of 15 or less.

Other Tests

Besides these tests, the following data will be obtained:

1) Creep measurements during exposure will be made on unnotched specimens except for two cases. When two unnotched specimens are exposed in tandem, creep will be measured only on one of the two. Creep measurements will not be made on wide specimens to be notched after exposure.

2) Hardness will be measured on the shoulder section of specimens before exposure, and of specimens after unstressed exposure. Measurements after stressed exposure will be limited to the wide specimens that are to receive sharp edge notches after creep exposure.

3) Selected specimens will be examined microscopically after exposure.

TEST MATERIAL AND PROCEDURES

All test specimens were sampled with their length in the direction of rolling of AM350 sheet from consumable-electrode melted Heat No. 23327, which 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

Specially-designed long furnaces were made to uniformly heat two specimens

in tandem. The specimens being used are shown in Figure 1. The SCT material panels are too small to make the double gage length wide specimen shown at the bottom of Figure 1 and is, therefore, to be exposed as single specimens. During exposure, the specimens are loaded by pins inserted through the holes at the ends of the specimens. Creep readings are made on the unnotched part of the specimens shown at the top of Figure 1. No creep readings are being taken on the wide specimens shown at the bottom of Figure 1.

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 tests at either room temperature or 550°F as the need may be. Special adapters pull against the shoulder fillets to avoid stressing the second gage section of the double specimen during tensile testing of the first.

Rockwell "45N" superficial hardness measurements were taken for most specimens prior to the start of exposures. Hardness values after exposure are to be reported only 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 at the location to be notched, and (b) unstressed exposure for which hardness readings may be taken in the specimen shoulders.

PRESENT STATUS OF THE PROGRAM

Table 1 shows the status of the tests. All of the 30,000 hour exposures have been started. Most of the 5000 hour and part of the 2000 hour exposures are in progress. Some of the "accelerated" exposures at 600°, 650°, and 700°F have been started, with part of them now completed. The 12,000 hour exposures will be started in the units made available by the completion of the 5000 hour exposures. The remaining exposures for 2000, 200, and 20 hours must await completion of those now in progress.

RESULTS TO DATE

All tests completed to date are listed in Tables 2 and 3. The following tabulation has been prepared to summarize the ultimate strength data. Where more than one test was conducted, averaged values were tabulated.

	Room Temperature				550°F			
	CRT		SCT		CRT		SCT	
	Ultimate Strength (psi)	N/S Ratio	Ultimate Strength (psi)	N/S Ratio	Ultimate Strength (psi)	N/S Ratio	Ultimate Strength (psi)	N/S Ratio
Original Unexposed Condition								
Unnotched	219,900		214,000		168,500		194,000	
$K_t = 3$	225,500	1.02	241,500	1.13	185,000	1.1	210,000	1.08
Sharp Notch	214,500	0.98	212,150	0.99	169,450	1.05	159,150	0.82
Exposed 550°F - 2000 hours								
40,000 psi (Unnotched)	215,500							
90,000 psi (Unnotched)	221,400							
150,000 psi (Unnotched)	221,100							
Exposed 600°F - 67,000 psi								
2000 hours (Unnotched)					172,000		198,500	
Exposed 650°F - 67,000 psi								
200 hours (Unnotched)					170,800		195,800	
Exposed 700°F - 67,000 psi								
20 hours (Unnotched)					170,700		200,300	
200 hours (Unnotched)					188,000		201,200	
200 hours (Sharp Notch added after Exposure)	209,800	0.96	208,800	0.98	--		163,000	0.84

These data show the following:

1) The SCT material is slightly weaker than the CRT at room temperature, but considerably stronger at 550°F.

2) The K_t = 3 notches raised net section strengths at both room temperature and 550°F.

3) Sharp notches did not significantly change strengths except for a significant reduction of the SCT material at 550°F.

4) The three specimens exposed under three different stresses at 550°F for 2000 hours did not show significant change in strength, as was previously reported.

5) The exposures carried out to date at 600°, 650°, and 700°F did not appreciably change properties except possibly in one case. The CRT specimen exposed for 200 hours at 700°F and subsequently tensile tested at 550°F had an ultimate strength which could be significantly higher than unexposed material and, therefore, indicative of a change.

The following tabulation summarizes the yield strengths and elongation values from the tests to date on unnotched specimens:

	0.2% Offset Y.S. (psi)		Elongation (% in 2 in.)	
	CRT	SCT	CRT	SCT
		Room Temperature		
Unexposed	186,200	179,800	16-28	12-17
Exposed 550°F - 2000 hours				
40,000 psi	178,000		21	
90,000 psi	186,000		16.5	
150,000 psi	(208,000)		19.5	
		550°F		
Unexposed	153,250	138,000	4	5.5
Exposed 600°F - 67,000 psi				
2000 hours	153,000	145,500	5	5.5
Exposed 650°F - 67,000 psi				
200 hours	154,000	140,000	4	6
Exposed 700°F - 67,000 psi				
20 hours	145,000	146,000	4	5.5
200 hours	152,500	151,500	4.5	6

The following comments are derived from these data:

1) The SCT condition had lower yield strength prior to exposure than the CRT condition, with the difference being quite large at 550°F and only slight at room temperature. There was little difference in elongation between the two conditions.

2) Yield strength and, particularly, elongation were lower at 550°F than at room temperature.

3) The yield strength of the CRT condition did not change as a result of exposure under the conditions tested to date. The possible exception was an increase as a result of exposure for 2000 hours at 550°F under 150,000 psi (the yield strength).

4) The yield strength of the SCT condition at 550°F appeared to increase slightly with increasing temperature of prior exposure.

5) No significant changes in elongation resulted from the exposures. Tables 2 and 3 include some elongation values for a gage length of 0.5 inch. This was done to show whether or not the materials exhibited marked local necking at the point of fracture. This practice was initiated by request after some of the tests had been completed. Values for the 0.5-inch gage length will not be available for most of the early tests.

Hardness values obtained to date show very little change, if any, from creep exposure.

Table 1

Outline and Status of the Revised Testing Program

a) Outline of Initial Exposures to Creep						Proposed Subsequent Tensile Tests				
				Date Started		Temperature			Date Completed	
Spec. Type	Stress (psi)	Temp. (°F)	Duration (hrs)	CRT	SCT	Room	550°F	b) Either	CRT	SCT
U	67,000	550	30,000	Jan. 62	Jan. 62	X			(Est: July 65)	
U	67,000	550	30,000	Feb. 62	Feb. 62	X				
U	67,000	550	30,000	Jan. 62	Jan. 62		X			
U	67,000	550	30,000	Feb. 62	Feb. 62			X		
N	67,000	550	30,000	Jan. 62	Jan. 62	X				
N	67,000	550	30,000	Feb. 62	Feb. 62	X				
N	67,000	550	30,000	Jan. 62	Jan. 62		X			
N	67,000	550	30,000	Feb. 62	Feb. 62			X		
W	67,000	550	30,000	Feb. 62	Feb. 62	X				
W	67,000	550	30,000	Feb. 62	Feb. 62		X			
U	None	550	30,000	Jan. 62	Jan. 62	X				
U	None	550	30,000	Feb. 62	Feb. 62	X				
U	None	550	30,000	Feb. 62	Feb. 62		X			
U	67,000	550	12,000			X				
U	67,000	550	12,000				X			
N	67,000	550	12,000			X				
N	67,000	550	12,000				X			
U	None	550	12,000			X				
U	None	550	12,000				X			
U	67,000	550	5,000	Feb. 62	Jan. 62	X			(Est: Sept. 62)	
U	67,000	550	5,000	Feb. 62	Jan. 62		X			
N	67,000	550	5,000	Feb. 62	Jan. 62	X				
N	67,000	550	5,000	Feb. 62	Jan. 62		X			
W	67,000	550	5,000	Feb. 62		X				
W	67,000	550	5,000	Feb. 62			X			
U	None	550	5,000	Feb. 62	Jan. 62			X		

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) Temperature of these tensile tests is to be selected after other results become available.

Table 1 (Concluded)

Outline and Status of the Revised Testing Program

a) Outline of Initial Exposures to Creep						Proposed Subsequent Tensile Tests			
Spec. Type	Stress (psi)	Temp. (°F)	Duration (hrs)	Date Started CRT	Date Started SCT	Temperature Room	Temperature 550°F	Date Completed CRT	Date Completed SCT
U	67,000	550	2,000			X			
U	67,000	550	2,000	Mar. 62	Mar. 62		X		
N	67,000	550	2,000			X			
N	67,000	550	2,000				X		
W	67,000	550	2,000	Feb. 62		X			
W	67,000	550	2,000	Feb. 62			X		
U	67,000	600	2,000			X			
U	67,000	600	2,000	Dec. 61	Dec. 61		X	Mar. 62	Mar. 62
U	67,000	650	200			X			
U	67,000	650	200	Dec. 61	Dec. 61		X	Mar. 62	Mar. 62
U	67,000	700	200			X			
U	67,000	700	200	Jan. 62	Jan. 62		X	Mar. 62	Mar. 62
W	67,000	700	200	Feb. 62	Feb. 62	X		Mar. 62	Mar. 62
W	67,000	700	200		Feb. 62		X		Mar. 62
U	67,000	700	20			X			
U	67,000	700	20	Dec. 61	Dec. 61		X	Mar. 62	Mar. 62

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

Table 2

Results of Tensile Tests for AM350 Sheet in the CRT Condition

Exposure Conditions			Hardness (Rockwell "45N")		Subsequent Tensile Properties							
Temp. (°F)	Stress (psi)	Duration (hrs)	Before Exp.	After Exp.	Temp. (°F)	Proportional Limit (psi)	Offset Yield Strengths (psi) 0.02%	0.1%	0.2%	Tensile Strength (psi)	Elong. (%) Per 2"	Per 0.5"
					Unnotched Specimens							
(No Prior Exposure)			48.5		Room	93,000	122,000	168,000	185,500	218,500	28	
(No Prior Exposure)			49		Room	100,000	126,000	165,000	191,000	217,000	16.5	
(No Prior Exposure)			51		Room	110,000	137,000	171,500	182,000	224,200	23.5	
550	40,000	2000			Room	89,000	107,000	155,000	178,000	212,500	21	34
550	90,000	2000			Room	119,000	142,500	154,500	186,000	221,400	16.5	
550	150,000	2000			Room	(145,000)	174,000	198,000	(208,000)	221,100	19.5	
(No Prior Exposure)			49.5		550	95,000	120,000	144,000	153,000	169,000	4	
(No Prior Exposure)			50		550	96,000	115,000	143,000	153,500	168,800	4.5	
600	67,000	2000			550	92,000	113,000	141,000	153,000	172,000	5	
650	67,000	200			550	85,000	101,000	139,000	154,000	170,800	4	8
700	67,000	20			550	80,000	97,000	130,000	145,000	170,700	4	6
700	67,000	200	52		550	95,000	104,000	140,000	152,500	188,000	4.5	
					Notched Specimens (K_t = 3)							
(No Prior Exposure)			49		Room					225,500		
(No Prior Exposure)			49		550					185,000		
					Exposed Unnotched; Sharp Edge Notches Added Before Tensile Test							
(No Prior Exposure)			51		Room					214,000		
(No Prior Exposure)			51.5		Room					215,100		
700	67,000	200	52	51	Room					209,800		
(No Prior Exposure)			50.5		550					172,100		
(No Prior Exposure)			50.5		550					166,800		
700	67,000	200	52	51	550					a)(>151,000)		

a) Specimen shoulder tore; no fracture at the notch.

Table 3

Results of Tensile Tests for AM350 Sheet in the SCT Condition

Exposure Conditions			Hardness (Rockwell "45N")		Subsequent Tensile Properties							
Temp. (°F)	Stress (psi)	Duration (hrs)	Before Exp.	After Exp.	Temp. (°F)	Proportional Limit (psi)	Offset Yield Strengths (psi) 0.02%	0.1%	0.2%	Tensile Strength (psi)	Elong. (%) Per 2"	Per 0.5"
					Unnotched Specimens							
(No Prior Exposure)					Room	113,000	143,000	170,000	185,300	214,900	17	32
(No Prior Exposure)			52.5		Room	119,000	139,000	165,000	178,000	213,100	12	26
(No Prior Exposure)			52.5		Room	105,000	129,000	162,000	176,000	214,000	16.5	32
(No Prior Exposure)					550	70,000	89,000	119,000	135,000	193,600	5	12
(No Prior Exposure)					550	80,000	98,000	126,900	141,000	194,400	6.5	12
600	67,000	2000			550	81,000	101,000	132,000	145,500	198,500	5.5	
650	67,000	200			550	75,000	95,000	122,000	140,000	195,800	6	12
700	67,000	20			550	87,000	101,000	131,000	146,000	200,300	5.5	
700	67,000	200			550	96,000	118,000	141,000	151,500	201,200	6	
					Notched Specimens (K_t = 3)							
(No Prior Exposure)					Room					241,500		
(No Prior Exposure)					550					210,000		
					Exposed Unnotched; Sharp Edge Notches Added Before Tensile Test							
(No Prior Exposure)					Room					216,000		
(No Prior Exposure)					Room					208,300		
700	67,000	200	53.5	52	Room					208,800		
(No Prior Exposure)					550					159,300		
(No Prior Exposure)					550					159,000		
700	67,000	200	53.5	51	550					163,000		

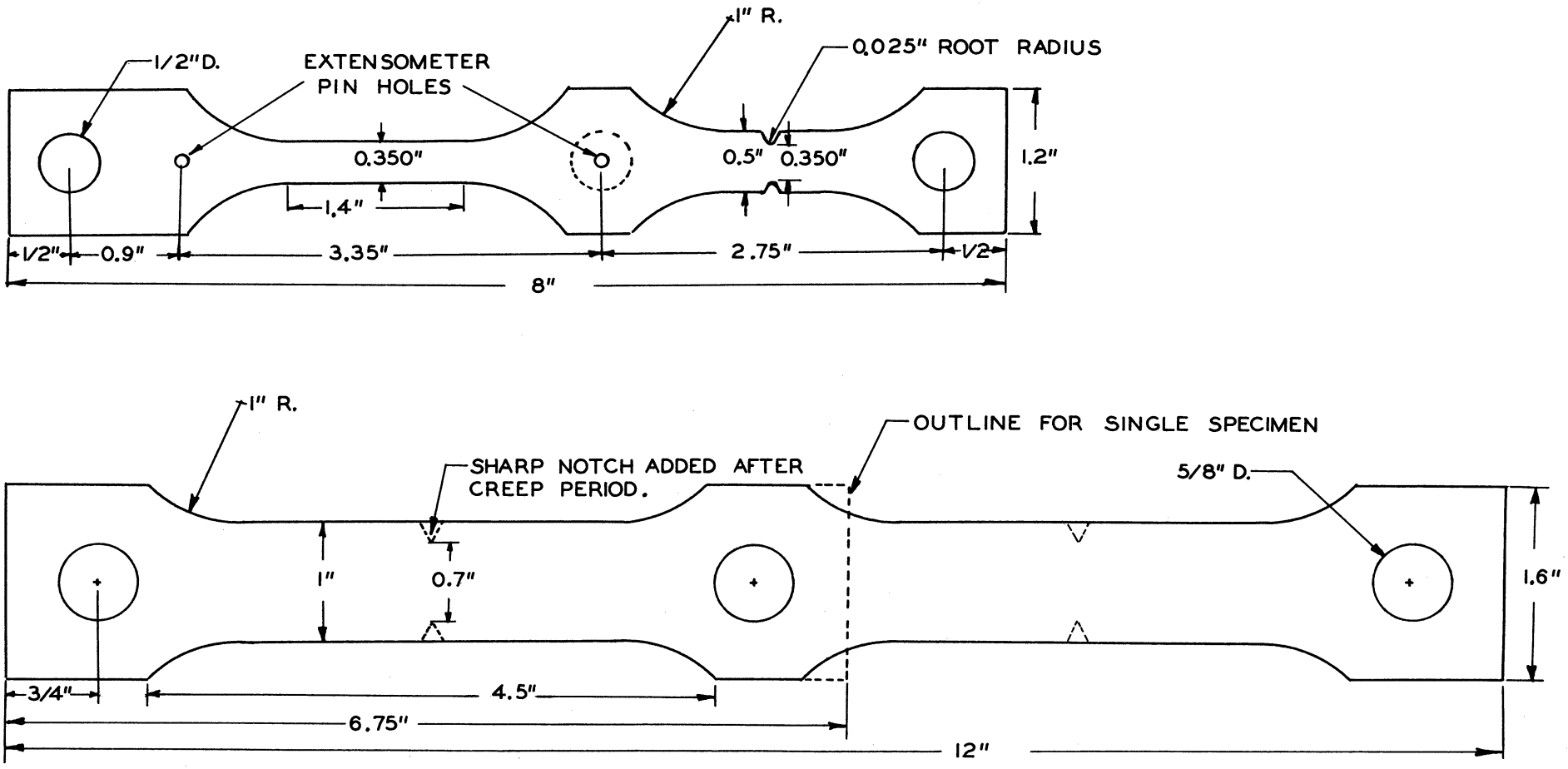

Figure 1 - Specimen for Long-Time Creep and Subsequent Tensile Testing.