ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICH.

SIXTH PROGRESS REPORT

TO

MATERIALS LABORATORY

WRIGHT AIR DEVELOPMENT CENTER

ON

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN MICROSTRUCTURE AND CREEP-RUPTURE PROPERTIES OF HEAT-RESISTANT ALLOYS

by

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Project 2460

Air Force Contract No. AF 33(616)-3239
Task No. 73512

September 15, 1957

INTRODUCTION

This report, the sixth quarterly progress report issued to the Materials Laboratory, Wright Air Development Center, under Air Force Contract No. AF 33(616)-3239, covers the period June 15, 1957 to September 15, 1957.

The general objective of this investigation is to determine what basic relationships exist between microstructure and creep-rupture properties of heat-resistant alloys. The current effort is to establish the principles necessary to utilize hot working as a means of producing structures which give maximum and predictable properties for service at elevated temperatures. The method being used is to vary the microstructure by controlled hot rolling and to determine which combination yields the best properties. Studies will then be made to establish the basic metallurgical principles involved. The alloys under study include three ferritic materials (SAE 4340, "17-22-A"S, and "17-22-A"V), a precipitation -- strengthened, austenitic alloy (A-286), and a commercially pure metal ("A" Nickel).

TEST MATERIALS

The alloys were supplied gratis by the following organizations: SAE 4340 from the Universal-Cyclops Steel Corporation, "17-22-A"S and "17-22-A"V from the Timken Roller Bearing Company, A-286 from the Allegheny-Ludlum Steel Corporation, and "A" Nickel from the International Nickel Company. The chemical analyses supplied by the producers were as follows:

Alloy	C	Mn	Si	Cr	Ni	Mo	V	Fe	Other
SAE 4340 (Ht D-14064)	0.40	0.80	0.27	0.82	1.67	0.32	----	Base	----
"17-22-A"S (Ht 10420)	0.29	0.61	0.67	1.30	0.18	0.47	0.26	Base	----
"17-22-A"V (Ht 11833)	0.29	0.70	0.71	1.43	0.31	0.51	0.81	Base	----
A-286 (Ht 21030)	0.06	1.35	0.47	14.58	25.3	1.38	0.21	Base	2.00 Ti 0.17 Al
"A" Nickel (Ht N9500A)	0.06	0.27	0.06	----	99.46(Ni+Co)		----	0.09	0.03 Cu 0.008 S

PROCEDURE

The general procedure adopted for this investigation consists of the following sequence of operations: (1) hot working each material isothermally and non-isothermally over a systematic range of temperatures and reductions; (2) heat treating the heat-treatable alloys with standard treatments; (3) evaluating the creep and rupture properties of each alloy at appropriate temperatures, and (4) correlating the properties with the structures as observed with electron and ordinary-light microscopy and x-ray studies.

Hot rolling was chosen as the mode of hot working to employ because it is a common commercial process and it offers good laboratory control of the temperature and amount of reduction. The temperatures for rolling A-286 alloy and "A" Nickel were selected at and below the minimum temperature for partial simultaneous recrystallization. It is in this temperature range that working is thought most likely to affect properties since variable amounts of strain hardening and substructures can be introduced into the material.

Rolling under isothermal conditions at elevated temperatures was approximated by using a maximum of two quick passes for each reduction. The maximum reduction for A-286 and "A" Nickel in two passes at 1700° and 1400°F, respectively, was about 37 percent because of the limited power of the mill. To study the influence of rolling on a falling-temperature cycle, several reductions in the range of 12 to 60 percent were made using 3, 4, 5 or 6 passes depending on the reduction. No reheats were used for either the isothermal or the non-isothermal rolling. The specific rolling conditions used for A-286 alloy and "A" Nickel are presented in Table I and Table II, respectively.

The creep-rupture properties are being evaluated primarily by comparisons of rupture times or minimum creep rates under identical test conditions. For measuring the creep resistance of "A" Nickel at 800°F, however, the stress to produce a given creep rate is being established because a single-stress type survey cannot cover the very wide range in properties produced by rolling. The creep and rupture properties for A-286 alloy and "A" Nickel are being evaluated as follows:

Alloy	Test Temperature (°F)	Test Stress (psi)	Index of Strength
A-286	1200	65,000	Time to Rupture
	1200	35,000	Minimum Creep Rate
	1350	40,000	Time to Rupture
"A" Nickel	800	Variable	Stress to Produce Minimum Creep Rate of 1% per 10,000 hours
	1100	20,000	Time to Rupture
	1100	11,000	Minimum Creep Rate

A-286 alloy was solution treated and aged after rolling; the "A" Nickel was tested in the as-rolled condition.

RESULTS AND DISCUSSION

The correlation of microstructures with properties is of major importance in this investigation. Since this aspect of the work has only recently been started (Figures 1 and 2), this report will consist primarily of the presentation of the creep and rupture data obtained to date.

A-286 Alloy

The originally planned rupture tests at 1200°F and 65,000 psi and at 1350°F and 40,000 psi are complete. The data are presented in Table I and Figures 3 through 6. It is apparent from these data that both temperature of heating and amount of reduction had significant effects on rupture strength. This is highly significant in view of the fact that all bars were given the same heat treatment after rolling.

The effect of thermal history was also observed in the ductility at fracture. Values of percent elongation for zero reduction by rolling ranged from 13.6 to 2.7 for tests at 1200°F and from 49.1 to 2.7 for tests at 1350°F.

Property differences between material rolled isothermally and non-isothermally were rather small.

"A" Nickel

Rupture data at 1100°F and 20,000 psi are complete for "A" Nickel rolled isothermally and non-isothermally (Table II and Figures 7 and 8). Creep data at 1100°F and 11,000 psi are nearly complete (Figures 9 and 10). For each rolling temperature the rupture strength rose sharply with the amount of reduction until recrystallization occurred either during rolling or during testing. The creep data showed the same general behavior, except that the peaks in strength tended to occur at lower reductions.

In general, ductility at rupture decreased with increasing rupture time.

Some differences between the effects of isothermal and falling-temperature rolling are evident in Figures 7 through 10, but they cannot be properly evaluated until the structural studies are complete.

FUTURE WORK

Work planned for the immediate future includes:

1. Analysis of the microstructures of A-286 alloy and "A" Nickel before and after testing and correlation of the structures with the properties.

2. Continuation of creep testing of A-286 alloy and "A" Nickel specimens already machined.

3. Hot rolling and testing of ferritic materials.

4. Measurement of bar temperatures at critical points in the rolling cycles.

CONSTANT STRAIN RATE MACHINE

The proposed design of a constant-strain-rate, high-temperature tension testing machine will be submitted early in October, 1957, for study by the Materials Laboratory, WADC.

TABLE I

ROLLING CONDITIONS AND RUPTURE, CREEP, AND TOTAL DEFORMATION DATA FOR A-286 ALLOY ROLLED ISOTHERMALLY AND NON-ISOTHERMALLY WITH NO REHEATS

Rolling Conditions			Rupture, Creep, and Total Deformation Data											
Temperature (°F)[a]	Reduction of Area (%)	Number of Passes	Temperature (°F)	Stress (psi)	Time to Rupture (hrs)	Elongation (% in 4D)	Reduction of Area (%)	Deformation on Loading (%)	Minimum Creep Rate (% per hr)	Time to Reach Indicated Total Deformation (hrs) 0.2%	0.5%	1.0%	2.0%	5.0%
80	0.0	0	1200	65,000	19.1	13.6	17.6	0.421	0.860	b	0.8	6.0 g	--	--
			1200	45,000	399.9	11.8	11.0	0.229	0.00348	b	80.0	145.0	204.0	310.0
			1200	35,000	c									
			1350	40,000	14.1	49.1	48.4	0.285	0.680	b	0.3	1.0	2.1	5.0
	9.4	3	1200	65,000	27.1	10.9	15.2	0.346	0.055	b	2.9	8.5	13.0 g	--
			1200	45,000	463.8	10.9	11.0	0.272	0.00164	b	96.0	196.0	263.0	374.0
			1200	35,000										
			1350	40,000	17.2	41.8	52.0	0.268	d	b	d	d	d	d
	19.7	5	1200	65,000	29.9	9.1	13.8	0.348	0.0264	b	4.0	9.5	15.0	25.0
			1200	45,000	413.2	10.0	11.0	0.232	0.0022	b	95.0	171.0	236.0	339.0
			1200	35,000										
			1350	40,000	16.3±3.0	52.7	49.1	0.328	0.875	b	0.3	0.8	2.0	4.7
	28.8	7	1200	65,000	31.0	13.6	16.0	0.352	0.0455	b	3.0	9.0	14.0	23.0
			1200	45,000	397.6	13.6	15.2	0.215	0.00296	b	80.0	142.0	204.0	305.0 g
			1200	35,000										
			1350	40,000	19.9	49.1	52.5	0.278	d	b	d	d	d	d
	39.5	9	1200	65,000	20.7	10.0	13.8	0.318	d	b	d	d	d	d
			1200	45,000	420.7	11.0	11.4	0.256	0.00280	b	71.0	145.0	216.0	334.0
			1200	35,000										
			1350	40,000	15.2	47.3	46.0	0.259	0.736	b	0.5	1.1	2.5	5.5
1700	0.0	0	1200	65,000	30.5	10.0	9.8	0.295	0.720	b	3.0	9.0	14.0	24.0
			1200	45,000	462.9	11.2	11.9	0.247	0.00420	b	48.0	142.0	220.0	340.0
			1200	35,000										
			1350	40,000	18.9	39.1	47.5	0.236	0.356	b	0.4	2.0	4.5	8.5
	3.9	1	1200	65,000	38.5	16.3	13.3	0.371	0.0356	b	3.0	13.5	22.0	31.0
			1200	35,000	> 886.2	--	--	0.221	0.000866	b	275.0	570.0	~930.0 g	--
			1350	40,000	21.0	37.2	43.9	0.262	0.228	b	1.0	2.7	4.8	9.6
	8.4	2	1200	65,000	43.9	6.4	6.4	0.316	0.186	b	6.5	14.0	23.0	--
			1200	35,000										
			1350	40,000	32.4	34.5	34.0	0.293	0.130	b	1.5	4.2	7.2	14.4
	21.5	2	1200	65,000	22.6	7.4	9.1	0.584	d	b	b	d	d	d
			1200	35,000										
			1350	40,000	16.6	42.6	49.7	0.266	d	b	d	d	d	d
	31.7	2	1200	65,000	22.2	10.9	9.4	0.362	d	b	d	d	d	d
			1200	35,000										
			1350	40,000	14.2	32.7	52.3	0.331	d	b	d	d	d	d
	11.5	3	1200	65,000	31.1	7.3	9.4	0.400	d	b	d	d	d	d
			1200	35,000										
			1350	40,000	24.5	34.6	43.4	0.228	2.65	b	1.0	2.6	4.9	10.1
	17.7	3	1200	65,000	30.1	7.3	9.8	0.463	0.0472	b	0.4	9.0	14.5	26.3
			1200	35,000	> 887.2	--	--	0.110	0.000543	205.0	535.0	780.0	~1000.0 g	--
			1350	40,000	23.1	30.0	25.7	0.266	d	b	d	d	d	d
	37.6	5	1200	65,000	29.2	8.2	8.6	0.337	d	b	d	d	d	d
			1200	35,000										
			1350	40,000	20.3	46.3	44.5	0.285	d	b	d	d	d	d

TABLE I (concluded)

ROLLING CONDITIONS AND RUPTURE, CREEP, AND TOTAL DEFORMATION DATA FOR A-286 ALLOY ROLLED ISOTHERMALLY AND NON-ISOTHERMALLY WITH NO REHEATS

Rolling Conditions			Rupture, Creep, and Total Deformation Data											
Temperature (°F)[a]	Reduction of Area (%)	Number of Passes	Temperature (°F)	Stress (psi)	Time to Rupture (hrs)	Elongation (% in 4D)	Reduction of Area (%)	Deformation on Loading (%)	Minimum Creep Rate (% per hr)	Time to Reach Indicated Total Deformation (hrs) 0.2%	0.5%	1.0%	2.0%	5.0%
1950	0.0	0	1200	65,000	127.2	6.4	4.8	0.323	0.00440	b	34.0	77.0	103.0	--
			1200	45,000	>1200.5	--	--	0.257	0.000068 e	b	1130.0	--	--	--
			1200	35,000										
			1350	40,000	102.2	18.2	22.6	0.233	0.00570	b	28.0	55.0	71.0	87.0
	3.9	1	1200	65,000	143.2	4.5	5.6	0.383	0.00250	b	47.0	96.0	118.0	--
			1200	45,000	>1203.2	--	--	0.212	0.000098	b	840.0	--	--	--
			1200	35,000										
			1350	40,000	66.3	23.6	24.9	0.238	0.0154	b	3.5	26.0	36.0	--
	9.7	2	1200	65,000	127.4	6.2	8.3	0.360	0.0046	b	30.0	69.0	93.0	125.0 g
			1200	35,000										
			1350	40,000	48.9	20.0	26.2	0.223	0.0242	b	7.0	14.0	23.0	--
	17.9	2	1200	65,000	159.0	5.5	7.9	0.330	0.00170	b	60.0	73.0	117.0	165.0
			1200	35,000										
			1350	40,000	53.7	19.4	27.0	0.227	0.0508	b	5.0	14.0	23.0	34.0
	23.5	2	1200	65,000	53.9	7.3	14.9							
			1200	35,000										
			1350	40,000	42.1	32.7	37.2							
	34.2	2	1200	65,000	78.5±2.0	9.1	12.8							
			1200	35,000										
			1350	40,000	42.2	30.9	45.6							
	12.2	3	1200	65,000	100.2	7.3	7.9	0.350	0.00360	b	26.0	49.0	66.0	93.0 g
			1200	35,000										
			1350	40,000	48.9	20.0	25.7	0.181	0.0428	~5.0	7.5	13.5	20.0	--
	18.8	3	1200	65,000	112.3	11.8	9.9	0.388	0.0041	b	21.0	53.0	73.0	--
			1200	35,000										
			1350	40,000	49.3	24.6	33.4	0.248	0.0708	b	2.5	9.5	18.0	31.0
	38.7	5	1200	65,000	62.1	10.0	8.6	0.390	0.0116	b	6.0	19.0	31.0	--
			1200	35,000										
			1350	40,000	32.1	39.1	47.3	0.179	d	<1.0	d	d	d	d
2200	0.0	0	1200	65,000	41.2	2.7	5.6	0.431	0.0246	b	0.4	14.4	--	--
			1200	35,000	>1318.3	--	--	0.416		b				
			1350	40,000	128.1	2.7	2.0	0.284	0.00266	b	70.0	107.0	--	--
	5.4	1	1200	65,000	80.7	2.7	4.8	0.398	0.00568	b	11.0	53.0	78.0 g	--
			1200	35,000										
			1350	40,000	72.4	8.0	10.3	0.170	0.0100 e	6.5	21.0	31.0	44.0	66.0
	10.4	2	1200	65,000	91.5	2.7	4.0	0.350	0.00383	b	31.0	61.0	--	--
			1200	35,000										
			1350	40,000	50.8	8.2	8.7	0.303	0.0244	b	7.5	17.0	26.5	43.0
	26.2	2	1200	65,000	97.0	3.6	7.1							
			1200	35,000										
			1350	40,000	78.4	10.9	14.4							
	26.1	2	1200	65,000	130.4	3.6	6.8							
			1200	35,000										
			1350	40,000	78.4	11.8	15.4							
	35.1	2	1200	65,000	121.9	4.5	8.6							
			1200	35,000										
			1350	40,000	66.1	13.6	16.7							
	14.5	3	1200	65,000	125.8	4.5	4.8	0.429	0.00207	b	29.0	84.0	113.0	--
			1200	35,000										
			1350	40,000	62.2	7.3	9.8	0.217	0.0180	b	11.0	20.0	31.0	54.0
	20.8	3	1200	65,000	132.2	4.5	6.0	d	0.00210	b	d	d	d	--
			1200	35,000										
			1350	40,000	66.6	9.1	12.7	0.283	0.0130	b	13.0	25.0	36.0	56.0
	39.8	5	1200	65,000	186.2	4.5	5.2	0.378	0.00178 e	b	67.0	108.0	148.0	--
			1200	35,000										
			1350	40,000	94.4	f	11.4	0.240		b	23.0	38.0	59.0	85.0

> "Greater than." (Indicates in the "Time to Rupture" column the time at which the test was discontinued.)
>> "Much greater than."
< "Less than."
~ "Approximately."
a Initial temperature; no reheats were used.
b Indicated deformation exceeded upon application of load.
c Blank spaces in table indicate data are not yet available.
d Value unknown or uncertain because of either insufficient or faulty data.
e This rate of creep was preceded by an initial, brief period of either zero or negative creep.
f Calculation impossible because a piece of the gage section was lost.
g Value obtained by extrapolation or interpolation.

TABLE II

ROLLING CONDITIONS AND RUPTURE, CREEP, AND TOTAL DEFORMATION DATA FOR "A" NICKEL ROLLED ISOTHERMALLY AND NON-ISOTHERMALLY WITH NO REHEATS

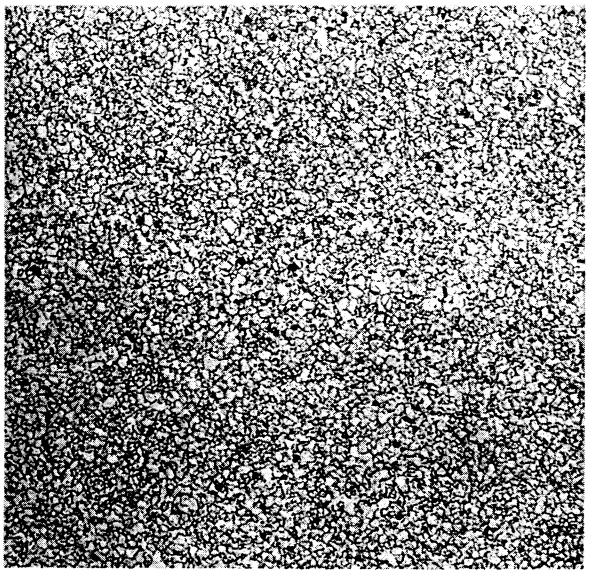
Rolling Conditions			Rupture, Creep, and Total Deformation Data								Time to Reach Indicated Total Deformation (hrs)				
Temperature (°F)[a]	Reduction of Area (%)	Number of Passes	Temperature (°F)	Stress (psi)	Time to Rupture (hrs)	Elongation (% in 4D)	Reduction of Area (%)	Deformation on Loading (%)	Minimum Creep Rate (% per hr)	0.2%	0.5%	1.0%	2.0%	5.0%
80	0.0	0	800	35,000	> 525.6	--	--	>5.00	0.00120	b	b	b	b	b
			800	32,000	> 525.4	--	--	>5.00	0.00106	b	b	b	b	b
			800	20,000	> 982.0	--	--	1.70	0.000420	b	b	b	15.0	>1000.0
			800	14,000	c									
			1100	20,000	25.1	61.6	74.8	3.46	2.34	b	b	b	b	< 1.0
			1100	17,000	102.1	51.8	52.8	1.92	d	b	b	b	d	d
			1100	14,000	359.0	29.1	30.7	0.908	0.0587	b	b	< 1.0	~2.0	23.0
			1100	11,000	2309.7	e	28.8	0.240	0.00827	b	< 1.0	12.0	50.0	240.0
			1100	8,000	>1079.6	--	--	0.110	0.00225	7.0	60.0	190.0	570.0	>1000.0
			1200	15,000	10.2	81.5	67.3							
	11.3	4	800											
			1100	20,000	187.9	23.6	31.0	0.117	0.00700	~2.0	32.0	71.0	107.0	152.0
			1100	11,000	>1348.7	--	--	0.055	0.000118	140.0	>1000.0	--	--	--
	16.5	6	800											
			1100	20,000	269.9	27.8	31.5	0.112	0.00735	~2.0	33.0	85.0	145.0	219.0
			1100	11,000	>1153.0	--	--	0.054	0.000117	215.0	>1000.0	--	--	--
	20.5	6	800											
			1100	20,000	470.5	20.9	29.8	0.141	0.00512	10.0	62.0	136.0	250.0	392.0
			1100	11,000	>1296.0	--	--	0.035	0.000063	650.0	>>1000.0	--	--	--
	35.5	8	800											
			1100	20,000	442.1	30.0	42.1	0.100	0.00624	9.0	50.0	130.0	223.0	329.0
			1100	11,000	> 863.0	--	--	0.057	0.000960	60.0	330.0	550.0	745.0	--
	61.2	12	800											
			1100	20,000	56.3	53.7	86.5	0.109	0.0628 d	~1.0	6.0	12.0	18.0	26.0
			1100	11,000	> 428.8	--	--	0.049	0.0297	12.0	27.0	50.0	80.0	170.0
1400	4.7	2	800											
			1100	20,000	43.9	40.0	58.1	0.171	0.40 d	< 1.0	< 1.0	2.0	4.5	--
			1100	11,000	> 861.1	--	--	0.081	0.000680	55.0	300.0	880.0 g	--	--
	9.7	2	800	20,000	> 934.5	--	--	0.105	0.0000225	>1000.0	--	--	--	--
			1100	20,000	110.9	41.8	54.5	0.172	0.0710	< 1.0	4.0	11.0	21.0	45.0
			1100	11,000	> 838.3	--	--	0.059	0.000315	120.0	780.0	>1000.0	--	--
	14.7	2	800											
			1100	20,000	240.0	30.0	40.8	0.104	0.0119	~1.0	25.0	54.0	90.0	150.0
			1100	11,000	> 742.0	--	--	0.081	0.000277	90.0	1000.0 g	--	--	--
	26.1	2	800											
			1100	20,000	335.4	20.0	33.0	0.144	0.0114	~1.0	14.0	60.0	120.0	237.0
			1100	11,000	>1108.8	--	--	0.077	0.00022	20.0	750.0	>1000.0	--	--
	36.1	2	800											
			1100	20,000	627.2	30.9	56.1							
			1100	11,000	> 886.8	--	--	0.047	0.000448	105.0	710.0	~2000.0 g	--	--
	19.5	3	800											
			1100	20,000	265.0	30.0	40.8	0.142	0.0127	2.0	24.0	56.0	97.0	162.0
			1100	11,000	>1227.9	--	--	0.091	0.000056	170.0	>1000.0	--	--	--
	33.8	4	800											
			1100	20,000	647.8	22.7	41.7	0.114	0.0093	< 1.0	17.0	60.0	143.0	340.0
			1100	11,000	>1136.9	--	--	0.072	0.000148	70.0	1000.0	>>1000.0	--	--
	58.7	6	800											
			1100	20,000	379.8	36.4	76.4	0.129	0.00352	~3.0	68.0	152.0	233.0	324.0
			1100	11,000	> 676.2	--	--	0.089	0.000726	45.0	380.0	600.0	--	--
1600	0.0	0	800	16,000	> 721.4	--	--	0.708	0.000294	b	b	600.0	>1000.0	--
			1100	20,000	30.5±0.5	46.4	53.0	3.47	0.480	b	b	b	b	< 1.0
			1100	11,000	> 982.0	--	--	0.436	0.00845	b	< 1.0	8.0	45.0	235.0
	5.3	2	800	20,000	> 937.3	--	--	0.174	0.000178	10.0	~1300.0 g	--	--	--
			1100	20,000	71.3	40.7	49.5	3.90	0.218	b	b	b	b	~1.0
			1100	11,000	> 863.5	--	--	0.089	0.000990	65.0	335.0	830.0	>1000.0	--
	9.9	2	800	24,000	> 725.1	--	--	0.396	0.000195	b	410.0	>1000.0	--	--
			1100	20,000	125.2	38.2	51.0	0.108	0.0735	< 1.0	~5.0	11.0	22.0	56.0
			1100	11,000	>1084.1	--	--	0.061	0.000250	220.0	1100.0 g	--	--	--
	15.2	2	800											
			1100	20,000	142.3	38.2	52.0	0.148	0.0487	< 1.0	~3.0	10.0	28.0	67.0
			1100	11,000	>1368.7	--	--	0.061	0.000273	160.0	740.0	~2000.0 g	--	--

TABLE II (concluded)

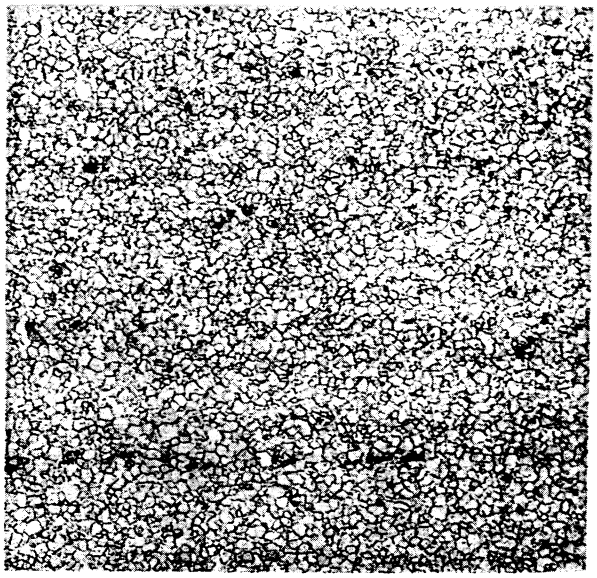
ROLLING CONDITIONS AND RUPTURE, CREEP, AND TOTAL DEFORMATION DATA FOR "A" NICKEL ROLLED ISOTHERMALLY AND NON-ISOTHERMALLY WITH NO REHEATS

Rolling Conditions			Rupture, Creep, and Total Deformation							Time to Reach Indicated Total Deformation (hrs)				
Temperature (°F)[a]	Reduction of Area (%)	Number of Passes	Temperature (°F)	Stress (psi)	Time to Rupture (hrs)	Elongation (% in 4D)	Reduction of Area (%)	Deformation on Loading (%)	Minimum Creep Rate (% per hr)	0.2%	0.5%	1.0%	2.0%	5.0%
1600	26.7	2	800											
			1100	20,000	521.8	29.1	35.2	0.096	0.00862	6.0	40.0	95.0	188.0	360.0
			1100	11,000	>1320.0	--	--	0.052	0.000227	105.0	1030.0	>2000.0	--	--
	36.8	2	800											
			1100	20,000	463.7	28.2	39.6	0.076	0.0088	4.0	30.0	85.0	175.0	329.0
			1100	11,000										
	20.3	3	800	28,000	>1036.1	--	--	0.205	0.000182	b	~1200.0 g	--	--	--
			1100	20,000	180.9	28.2	56.7	0.117	0.0248	~1.0	13.0	33.0	63.0	118.0
			1100	11,000	>1083.7	--	--	0.095	0.000231	30.0	740.0	>1000.0	--	--
	34.4	4	800	40,900	>1052.5	--	--	0.698	0.000415	b	b	205.0	>1000.0	--
			1100	20,000	663.6	27.3	42.0	0.106	0.00476	~3.0	50.0	130.0	255.0	480.0
			1100	11,000	>1203.6	--	--	0.048	0.000091	330.0	>1000.0	--	--	--
	59.1	6	800	61,900	0.4	36.5	72.9	1.58	d	b	b	b	< 0.1	--
			800											
			1100	20,000	1030.4	16.4	53.6	0.088	0.00179	15.0	145.0	420.0	720.0	960.0
			1100	11,000	>1057.8	--	--	0.060	0.000107	145.0	>1000.0	--	--	--
1800	0.0	0	800	15,000	> 886.0	--	--	0.832	0.00079	b	b	570.0	>>1000.0	--
			1100	20,000	19.5	50.9	62.9	4.50	1.30	b	b	b	b	0.03
			1100	11,000	>1173.5	--	--	0.109	0.0087	~1.0	10.0	25.0	70.0	280.0
	5.8	2	800											
			1100	20,000	72.8	43.4	49.1	1.06	0.190	b	b	b	< 1.0	~4.0
			1100	11,000	> 702.0	--	--	0.082	0.00129	55.0	230.0	610.0	~1500.0 g	--
	10.8	2	800											
			1100	20,000	69.9	47.3	64.3	0.988	0.282	b	b	< 1.0	~1.0	7.0
			1100	11,000	> 702.0	--	--	0.078	0.00121	55.0	240.0	650.0	~1600.0 g	--
	15.7	2	800											
			1100	20,000	93.3	48.2	63.7	0.786	0.180	b	b	< 1.0	~1.0	8.0
			1100	11,000	> 843.0	--	--	0.073	0.00092	65.0	295.0	785.0	--	--
	27.3	2	800											
			1100	20,000	58.7	43.6	59.7	1.04	0.254	b	b	b	~1.0	7.0
			1100	11,000	> 988.2	--	--	0.084	0.000355	60.0	620.0	~2000.0 g	--	--
	37.5	2	800											
			1100	20,000	109.0±0.9	41.8	62.7	0.771	0.160	b	b	< 1.0	4.0	19.0
			1100	11,000	> 886.9	--	--	0.190	0.00306	~1.0	40.0	180.0	525.0	~1500.0 g
	20.7	3	800											
			1100	20,000	75.2±1.5	53.6	63.9	0.438	0.0222	b	< 0.4	0.4	1.5	13.0
			1100	11,000	>1010.6	--	--	0.092	0.00049	35.0	460.0	~1500.0 g	--	--
	35.2	4	800											
			1100	20,000	214.3	27.3	48.6	0.145	0.0174	~2.0	15.0	38.0	73.0	132.0
			1100	11,000	> 701.4	--	--	0.087	0.000298	135.0	1050.0 g	--	--	--
	59.3	6	800											
			1100	20,000	1028.3	e	33.4	0.137	0.00208	~5.0	115.0	350.0	660.0	935.0
			1100	11,000	> 917.8	--	--	0.078	0.000099	525.0	>1000.0	--	--	--

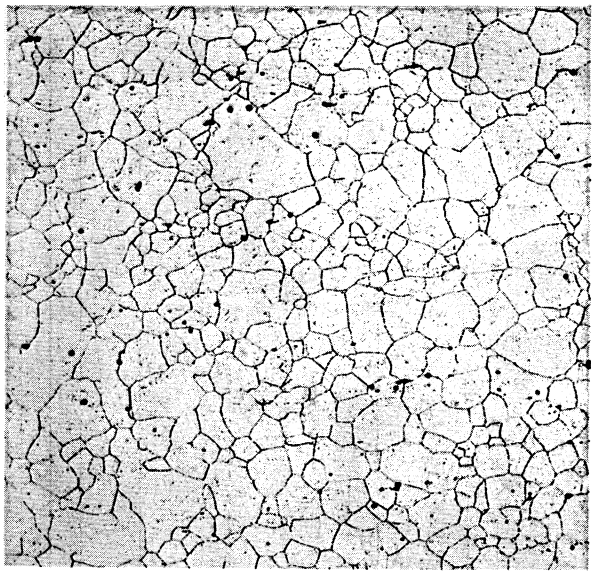
> "Greater than." (Indicates in the "Time to Rupture" column the time at which the test was discontinued.)
>> "Much greater than."
< "Less than."
~ "Approximately."
a Initial temperature; no reheats were used.
b Indicated deformation exceeded upon application of load.
c Blank spaces in table indicate data are not yet available.
d Value unknown or uncertain because of insufficient time-elongation data.
e Calculation impossible because a piece of the gage section was lost.
g Value obtained by extrapolation or interpolation.



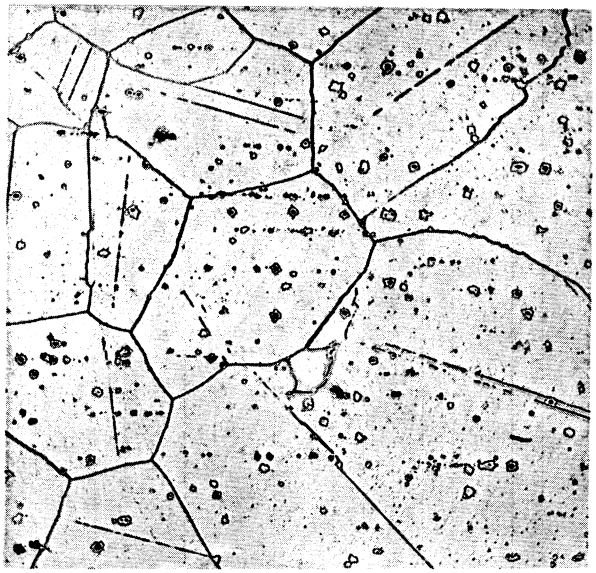
(a) Solution Treated and Aged.



(b) 45 Minutes at 1700°F, Air Cooled + Solution Treated and Aged.



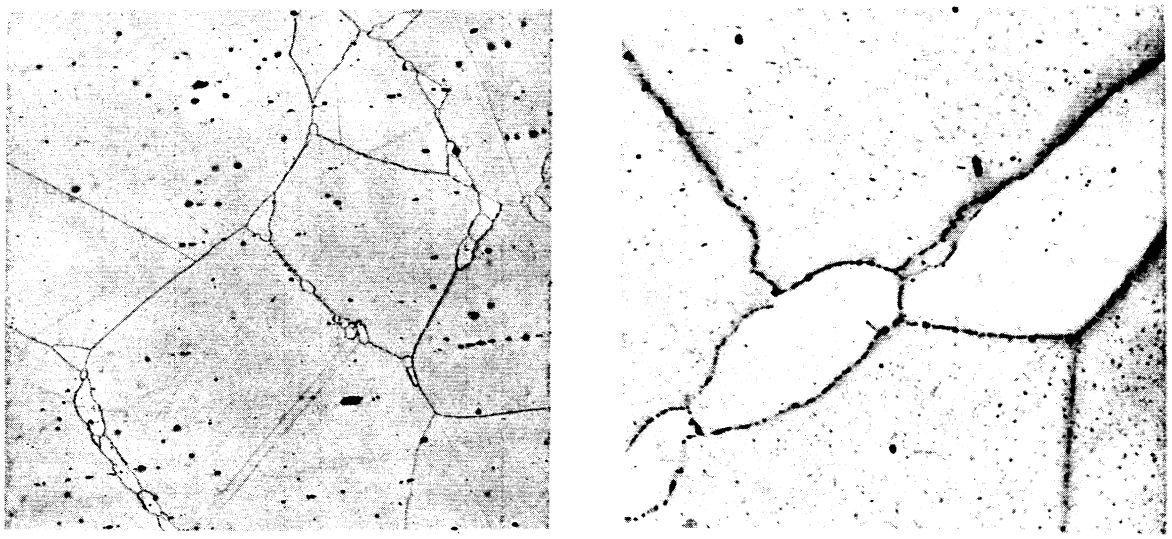
(c) 45 Minutes at 1950°F, Air Cooled + Solution Treated and Aged.



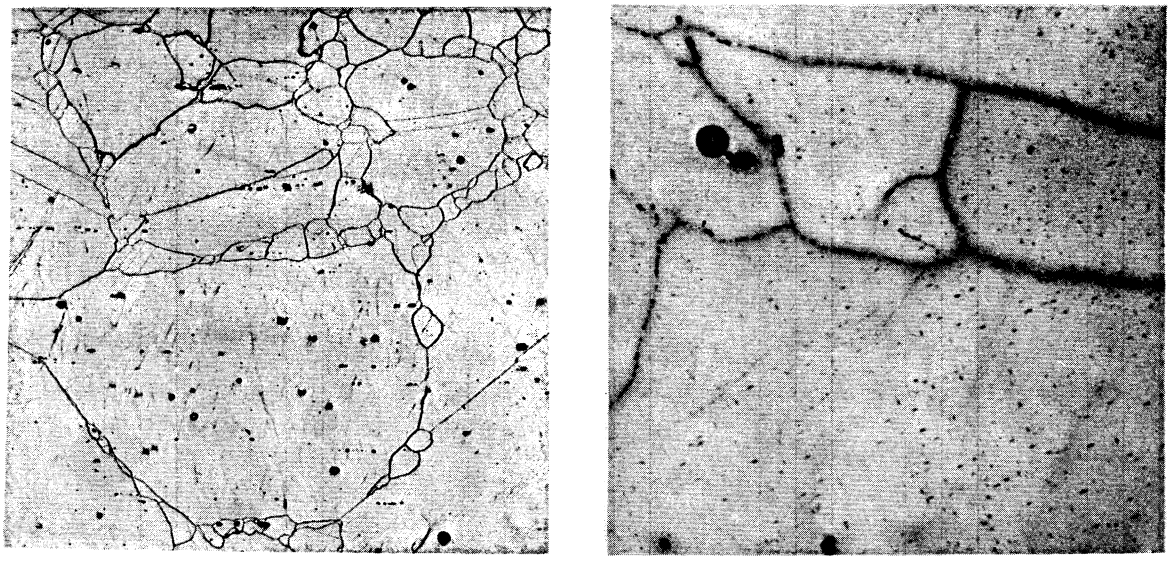
(d) 45 Minutes at 2200°F, Air Cooled + Solution Treated and Aged.

Figure 1. - Microstructure of A-286 Alloy Solution Treated 1 Hour at 1650°F and Aged 16 Hours at 1325°F with (a) No Prior Heating, (b) Prior Heating to 1700°F, (c) Prior Heating to 1950°F, and (d) Prior Heating to 2200°F. Magnification X100D.

X100 X1000



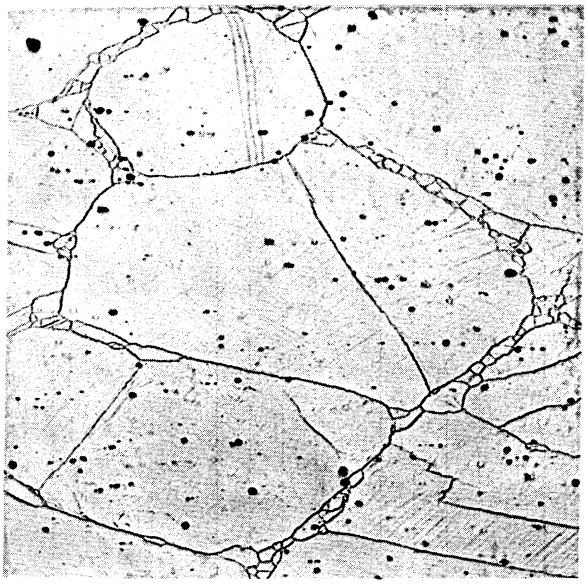
(a) Heated 45 Minutes at 2200°F, Hot Rolled 5.4 Percent in 1 Pass, Air Cooled + Solution Treated 1 Hour at 1650°F and Aged 16 Hours at 1325°F.

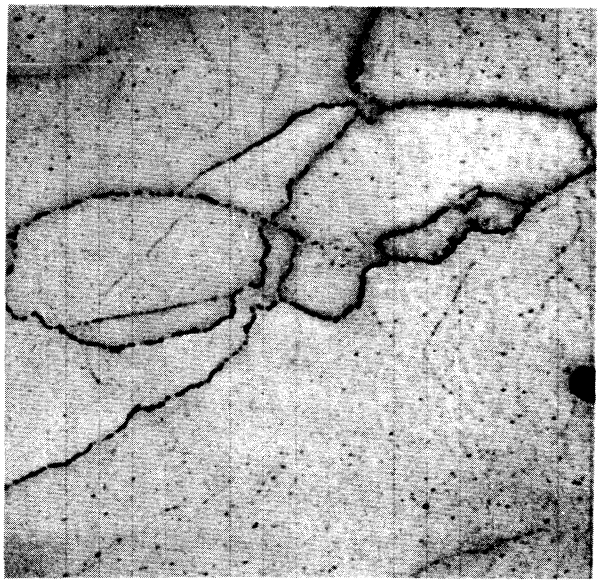


(b) Heated 45 Minutes at 2200°F, Hot Rolled 14.5 Percent in 3 Passes, Air Cooled + Solution Treated 1 Hour at 1650°F and Aged 16 Hours at 1325°F.

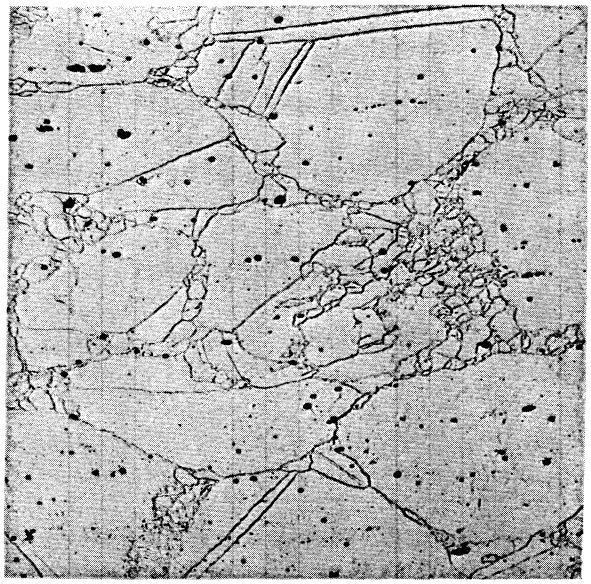
Figure 2. - A-286 Alloy Hot Rolled from 2200°F and Subsequently Solution Treated and Aged. The hot rolling was (a) 5.4 percent in 1 pass, (b) 14.5 percent in 3 passes, (c) 26.8 percent in 4 passes, and (d) 39.8 percent in 5 passes with no reheats.

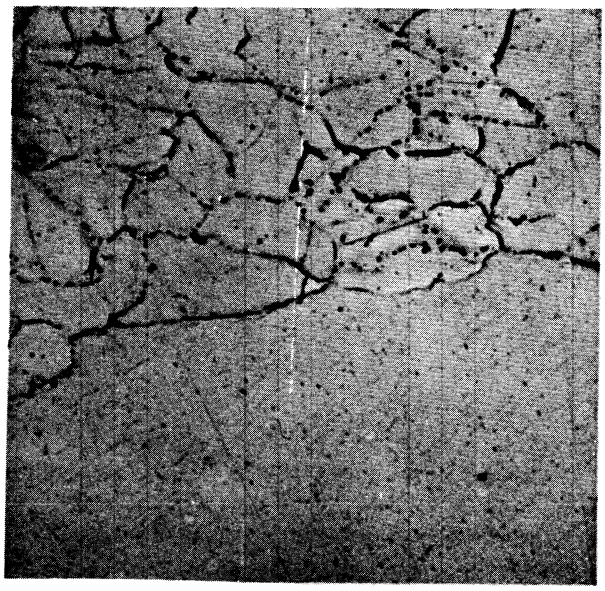
X100 X1000





(c) Heated 45 Minutes at 2200°F, Hot Rolled 26.8 Percent in 4 Passes, Air Cooled + Solution Treated 1 Hour at 1650°F and Aged 16 Hours at 1325°F.





(d) Heated 45 Minutes at 2200°F, Hot Rolled 39.8 Percent in 5 Passes, Air Cooled + Solution Treated 1 Hour at 1650°F and Aged 16 Hours at 1325°F.

Figure 2. - concluded.

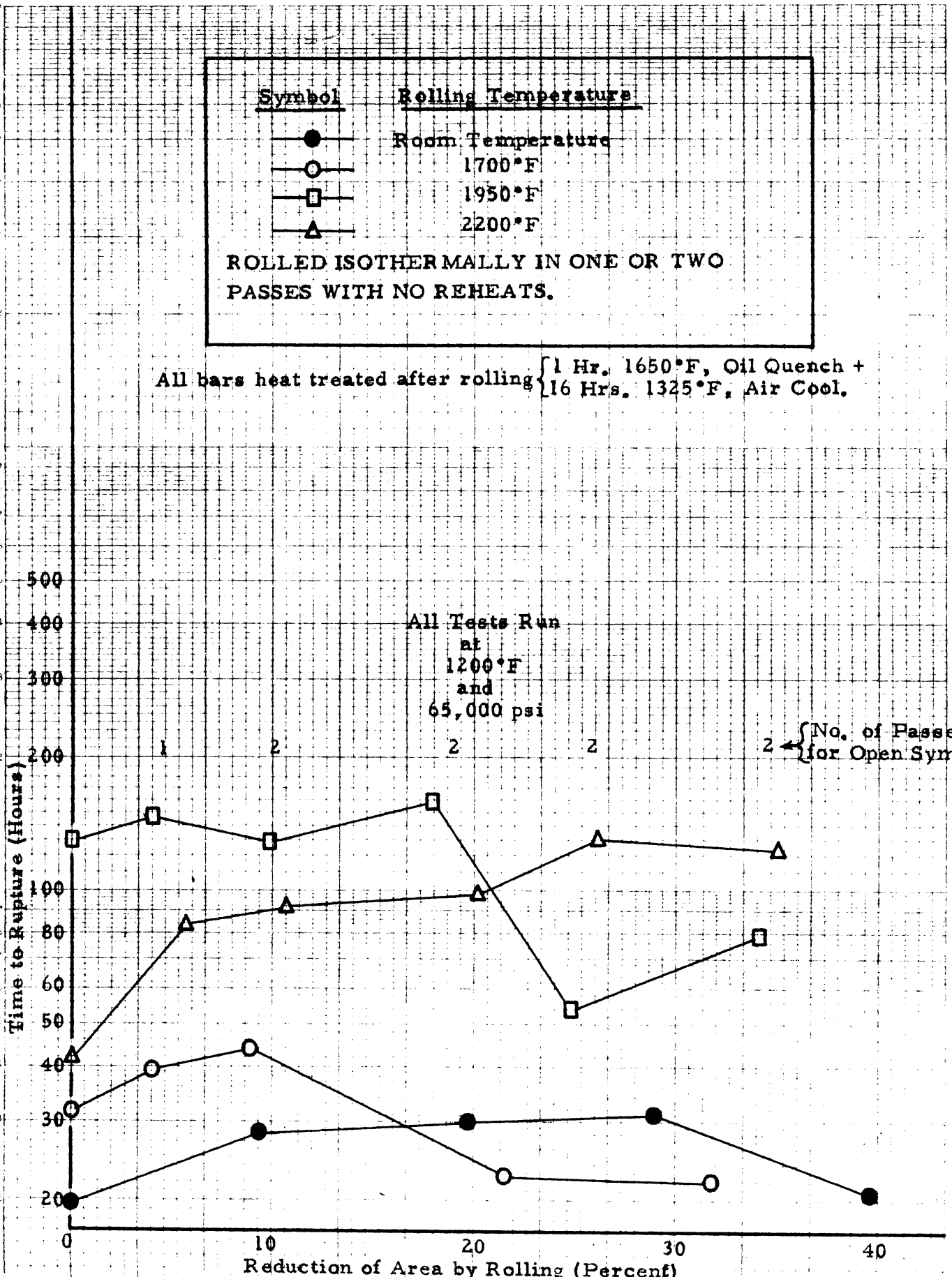


Figure 3. - Variation of Rupture Life with Isothermal Rolling Conditions for A-286 Alloy Tested at 1200°F and 65,000 psi.

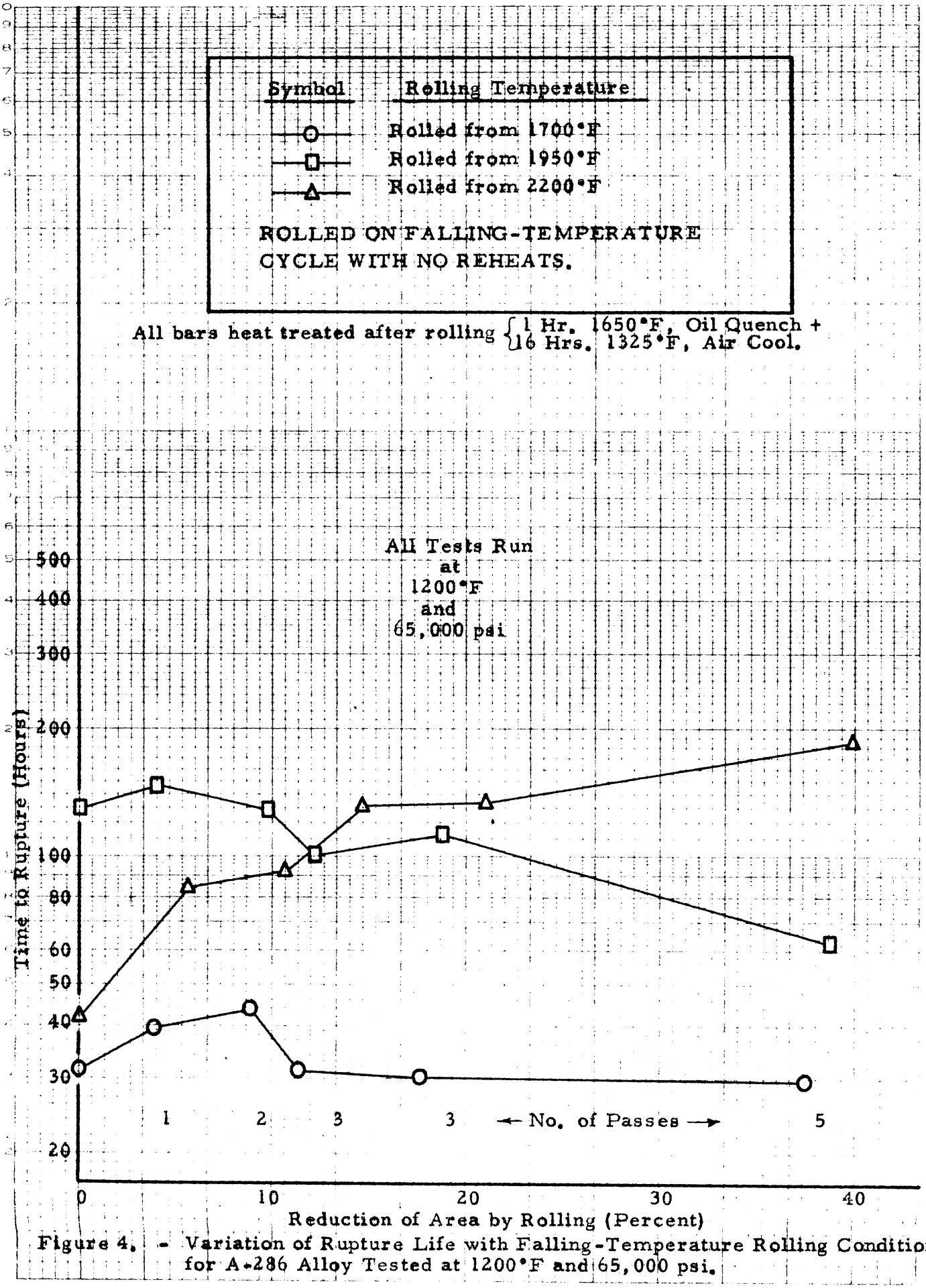


Figure 4. - Variation of Rupture Life with Falling-Temperature Rolling Conditions for A-286 Alloy Tested at 1200°F and 65,000 psi.

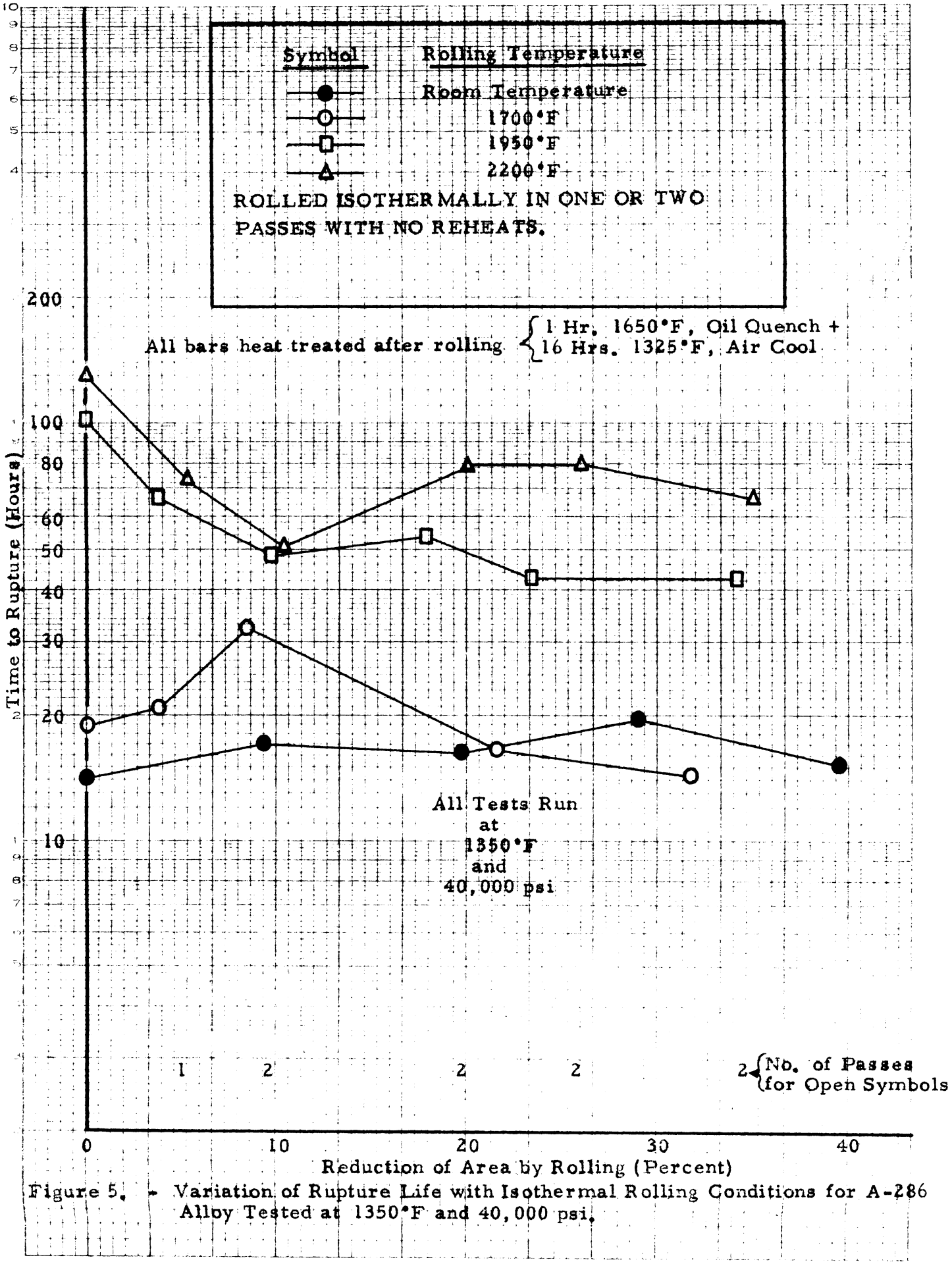


Figure 5. - Variation of Rupture Life with Isothermal Rolling Conditions for A-286 Alloy Tested at 1350°F and 40,000 psi.

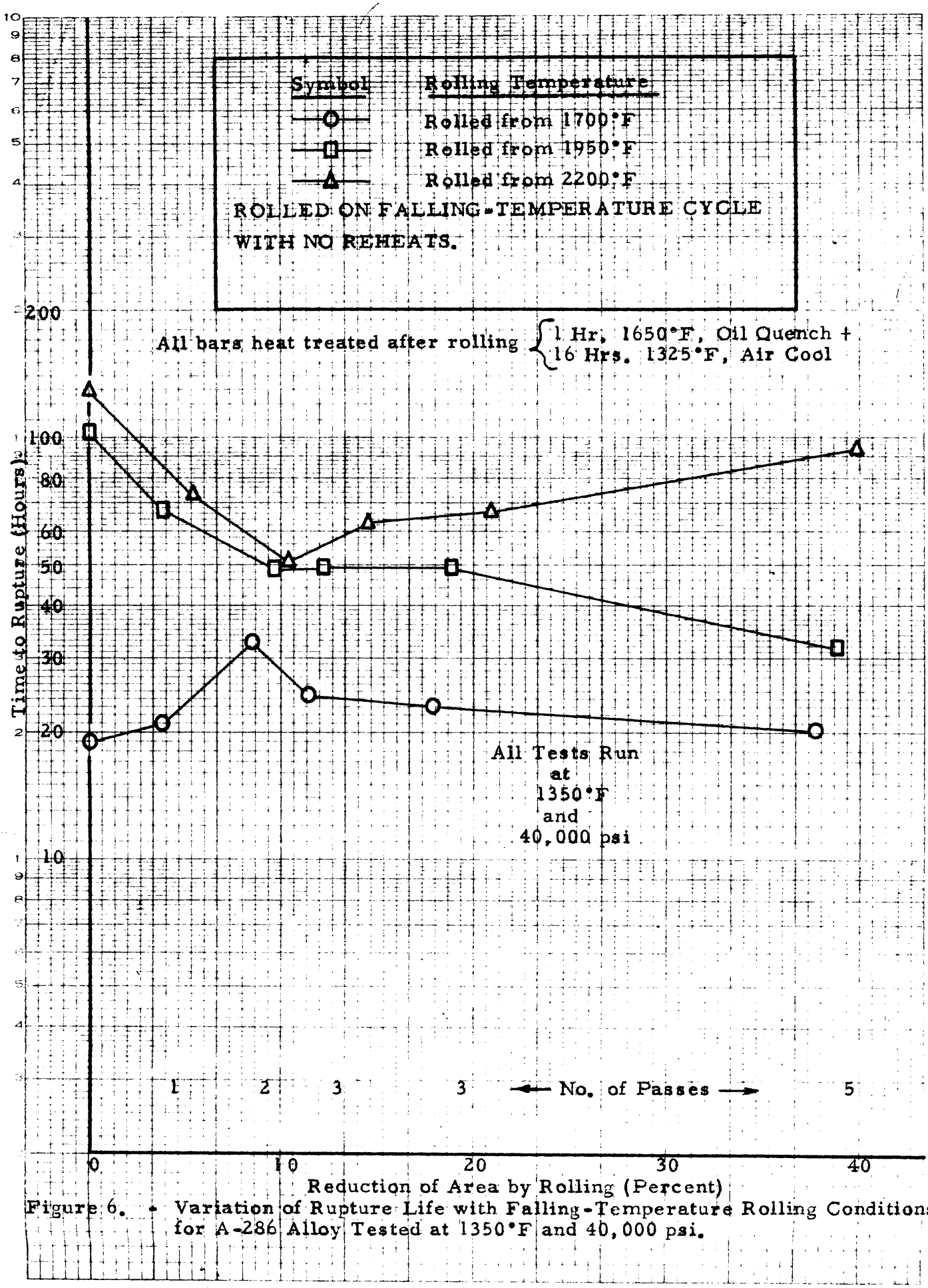


Figure 6. - Variation of Rupture Life with Falling-Temperature Rolling Conditions for A-286 Alloy Tested at 1350°F and 40,000 psi.

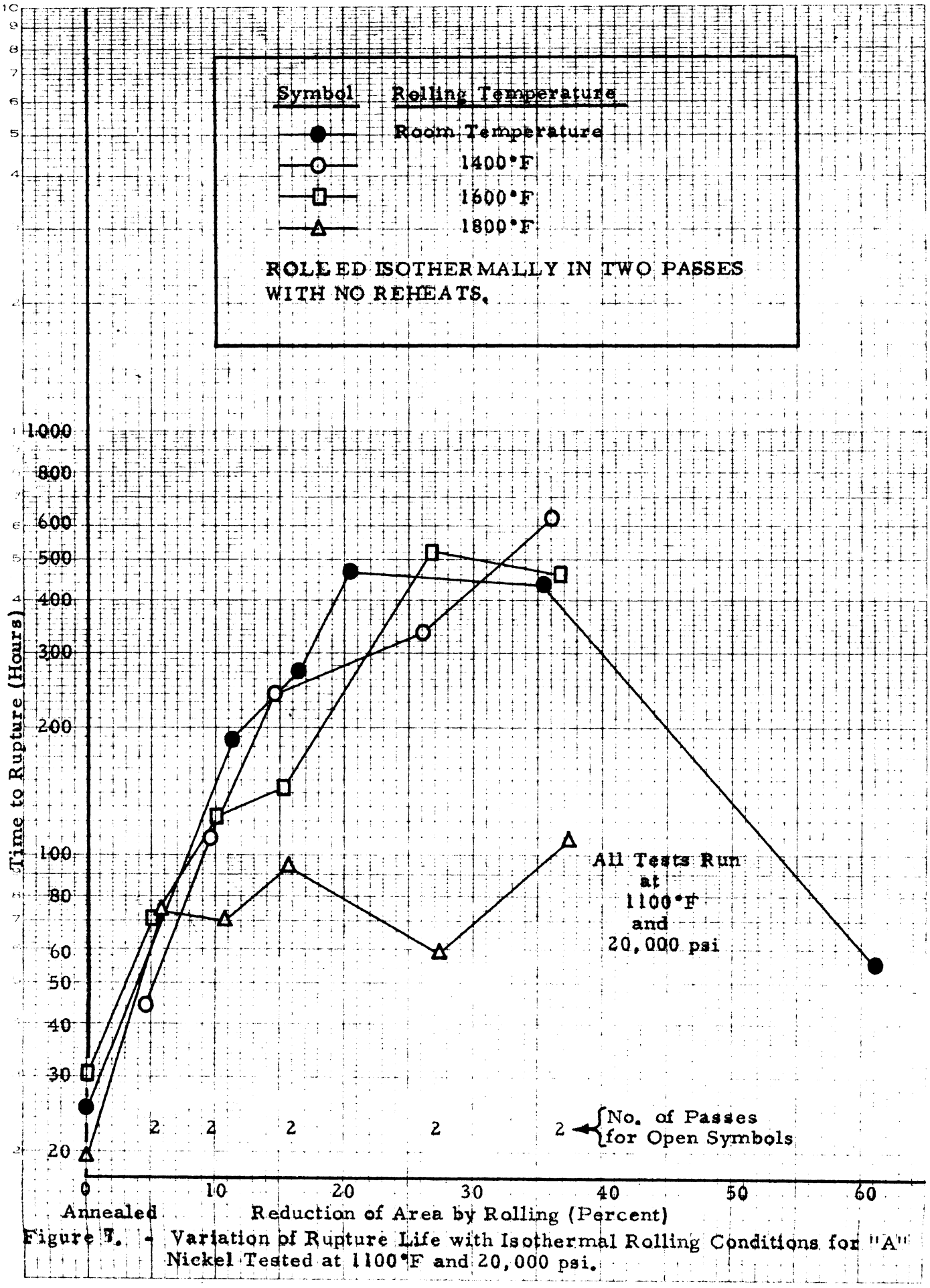


Figure 7. - Variation of Rupture Life with Isothermal Rolling Conditions for "A" Nickel Tested at 1100°F and 20,000 psi.

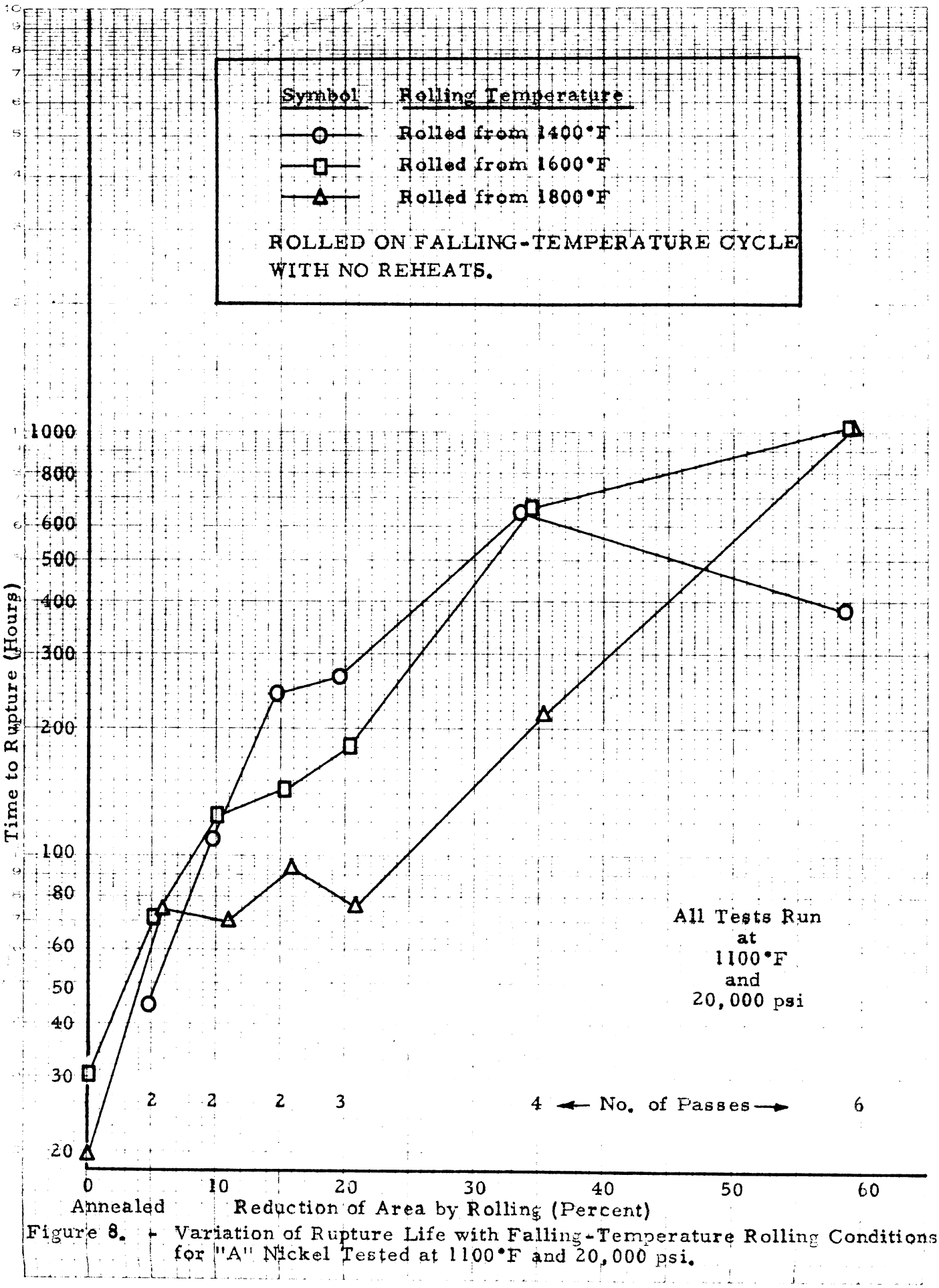


Figure 8. - Variation of Rupture Life with Falling-Temperature Rolling Conditions for "A" Nickel Tested at 1100°F and 20,000 psi.

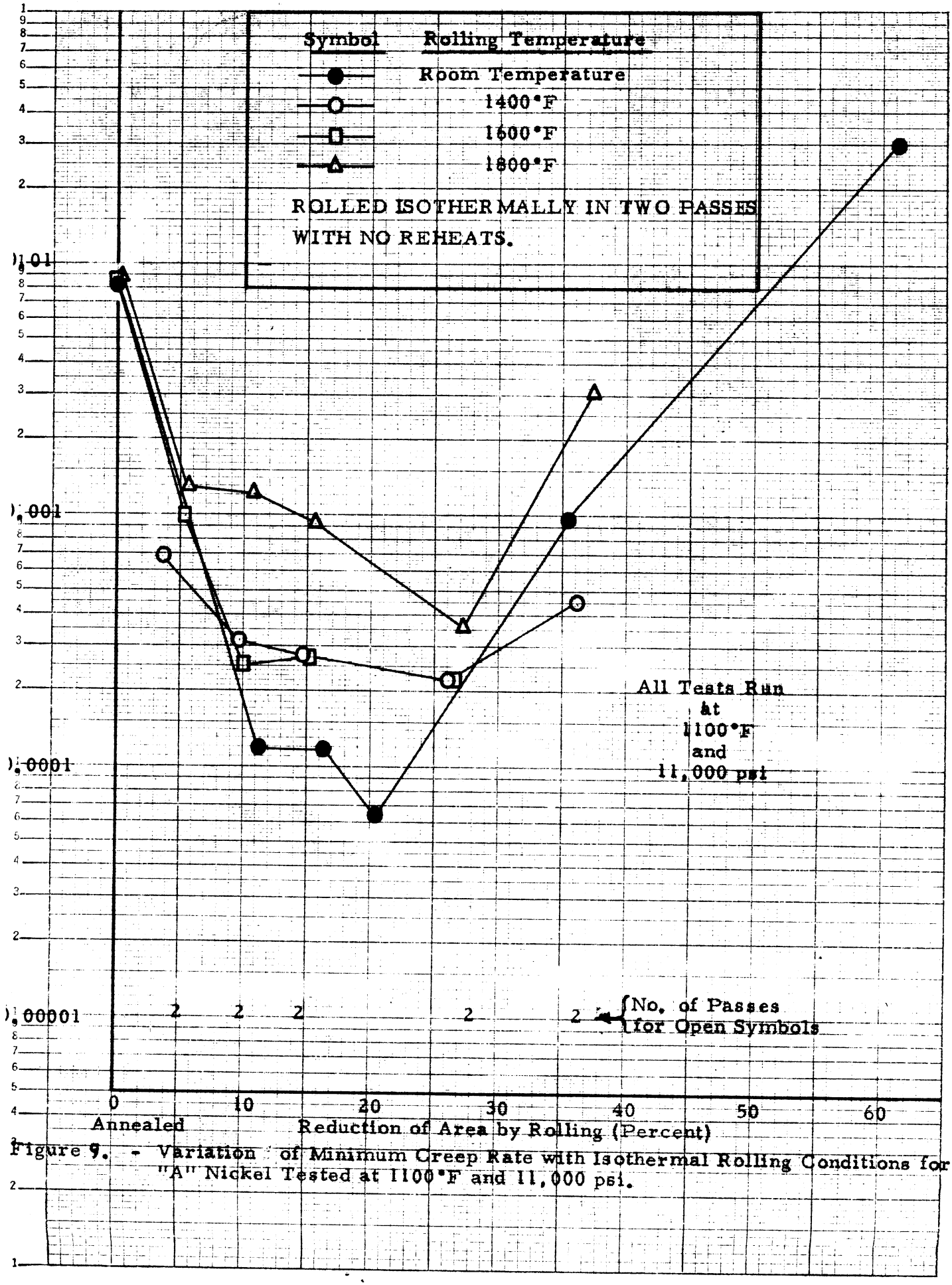


Figure 9. - Variation of Minimum Creep Rate with Isothermal Rolling Conditions for "A" Nickel Tested at 1100°F and 11,000 psi.

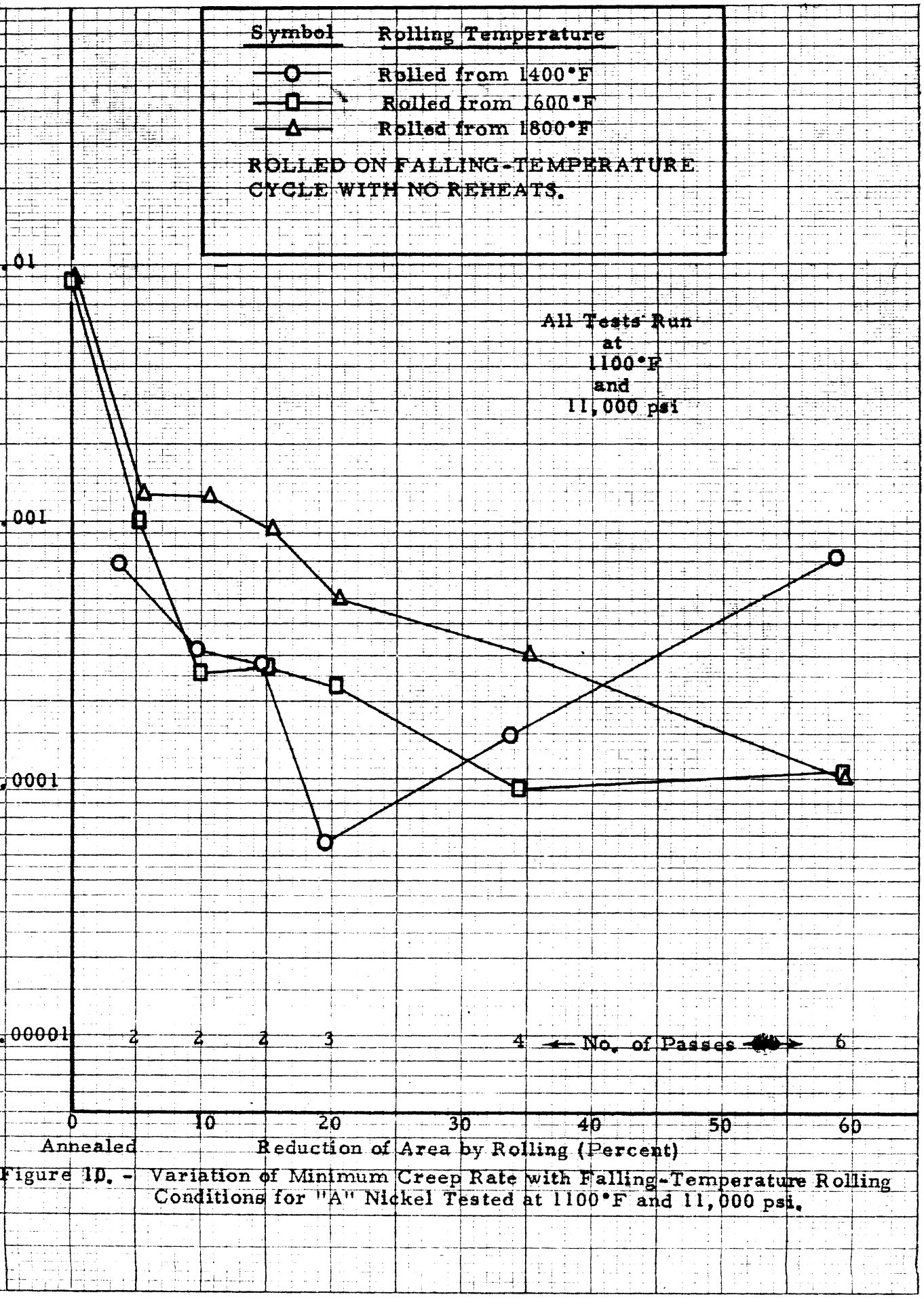


Figure 10. - Variation of Minimum Creep Rate with Falling-Temperature Rolling Conditions for "A" Nickel Tested at 1100°F and 11,000 psi.