THIRD PROGRESS REPORT

TO

MATERIALS LABORATORY, WRIGHT AIR DEVELOPMENT CENTER

DEPARTMENT OF THE AIR FORCE

ON

FOUR LOW-ALLOY STEELS FOR ROTOR DISKS OF GAS TURBINES IN JET ENGINES

By

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IN JET ENGINES

SUMMARY

This report is the Third Progress Report on an investigation being carried out for the Materials Laboratory, Wright Air Development Center, Department of the Air Force. The time period covered is from 1 July 1951 to 30 September 1951. Air Force Contract Number: AF33(038)-13496 (Expenditure Order Number: 605-227 SR-7) authorizes the investigation.

The investigation is to study the high-temperature properties of four low-alloy steels, 4340, 17-22A(S), H40, and C-422, in the form of forged J-33 jet engine disks. A concurrent investigation of the high-temperature properties of the products of isothermal transformation of each steel is being carried out utilizing bar stock. The results of the structural studies are to be correlated with the results to be obtained from the disks.

The jet-engine disks were received from Canton Drop Forge and Manufacturing Company on 27 July 1951. Four of the disks (the oil-quenched and interrupted-quenched disks of 4340 and 17-22A(S)) have been split and the center slabs cut out. Hard spots in the C-422 alloy disks were encountered. The slabs have been magnafluxed and macroetched and found to be sound. Also, a hardness survey has been made on each center slab.

The results obtained to date from creep-rupture tests in the investigation of the properties of the products of isothermal transformation are as follows:

Steel	Heat Treatment	BHN	Test Temp. (°F)	Stress to Cause 1% Total Deformation in 1000 Hrs. (psi)
4340	N.1750°F+ T. 1 Hr. at 1100°F	292/311	1100	4,250
"	N.1750°F+ T. 1 Hr. at 1100°F	301/303	1000	13,300
17-22A(S)	N.1750°F+ T. 10 Hrs at 1200°F	291/317	1100	19,000
H-40	N.1950°F+ T. 18 Hrs at 1200°F	312/320	1100	27,800
C-422	N.1900°F+ T. 24 Hrs at 1200°F	299/306	1100	28,700

For 4340 steel, the upper-bainite structure was the only structure which showed a significantly higher creep strength than the normalized structure. This was true at both 1000° and 1100° F. The oil-quenched, upper-pearlite, lower-pearlite, and lower-bainite structures possessed creep strengths which were either approximately equal to or lower than that of the normalized structure.

For 17-22A(S) steel, the oil-quenched, upper-pearlite, lower-pearlite, and lower-bainite structures all had lower creep strengths than the normalized structure. To date, the upper-bainite structure has not been tested.

For H-40 steel, results to date show the normalized structure to be stronger than the oil quenched structure.

For C-422 steel, results to date show the normalized structure and oil-quenched structure to have similar creep strengths.

Additional tempering data for 17-22A(S), H-40, and C-422 have been obtained. The time-temperature-transformation curve for H-40 has been outlined, and work is in progress on the time-temperature-transformation curve for C-422.

INTRODUCTION

This report covers the progress made between 1 July 1951 and 30 September 1951 on an investigation of the high-temperature properties of four ferritic alloys in the form of forged rotor disks for gas turbines in jet engines.

The purpose of this investigation is twofold, namely:

A. To determine the effect of heat treatment upon the high-temperature properties of four low-alloy steels in the form of contour forged J-33 jet engine disks. The steels to be investigated are 4340, 17-22A(S), H-40, and C-422.

As a further clarification of the effect of heat treatment upon the high-temperature properties of these steels, a concurrent study of the creep-rupture properties of the products of isothermal transformation of each of these steels is being carried out, utilizing bar stock.

B. To establish design curves out to 1000 hours, for each steel, showing stress vs. time for (1) rupture, (2) start of third-stage creep, and (3) total deformations of 1.0, 0.5, 0.2, and 0.1 percent. These design curves are to be established at 1100° F and two other temperatures for the heat treatment which gives the best practical properties.

PROCEDURE AND PROPOSED TESTING CONDITIONS

The procedure and proposed testing conditions to be used in this investigation were outlined on pages 3, and 6 - 9 of the first Progress Report.

A plan for sectioning the disks and a detailed outline of the proposed testing to be carried out was submitted by the University to Wright Field shortly after the disks were received. Wright Field approved these proposals as they are presented below.

The plan for sectioning the disks is shown in figures 1 and 2. The detailed outline of the testing to be carried out on the disks is as follows:

A. The stub shaft and boss will be cut off of each disk.

B. A slab (1, 2, and 3) will be cut from the center of each disk and used for:

1. A Brinell hardness survey.

2. Macroetching and magnaflux examination.

3. Room temperature tensile tests on specimens 1W, 1X, 2W, 2X, 2Y, and 2Z.

C. Conduct sufficient tests on specimens 4W, 4X, 4Y, 4Z, 6W, 6X, 6Y, and 6Z from each disk to establish the stress-rupture time curve and the stress for 1% total deformation in 1000 hours at 1100° F.

D. Send quarter section to W. Brown, Lewis Flight Propulsion Laboratory of the NACA.

E. Review data from (B) and (C) and recommend the heat treated disk of the most practical interest for each alloy. On agreement as to the most practical heat treatment, the disk will be used for complete testing, and the following additional tests will be made:

1. Short-time tensile tests at 1100° F and two other temperatures to be agreed upon using specimens 1Y, 1Z, 3W, 3X, 3Y, 3Z, 14X, 14Y, and 14Z.

2. Creep and rupture tests using specimens from 7, 8, 9, 10, 11, 12, and 13 as necessary to determine the design curves for the material at the rim. Checks will be made to see if there is a difference between surface and center specimens.

3. Single check creep-rupture tests on tangential specimens using stresses selected to produce fracture in 1000 hours at each test temperature.

4. All specimens used will be 0.505-inch diameter with a 2-inch gage length. Check rupture tests will be run on 0.250-inch diameter specimens taken radially and as near the rim as possible in one case and the center in the other to determine the variation in properties.

TEST MATERIALS

The chemical analyses reported for the disks are as follows:

Steel	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Ni (%)	Va (%)	Mo (%)	W (%)	Cu (%)	Heat No.
4340	0.40	0.76	0.29	0.01	0.015	0.74	1.91	-	0.50	-	-	656601
17-22A(S)	0.30	0.57	0.60	0.018	0.019	1.22	0.23	0.24	0.49	-	0.13	38516
H-40	0.29	0.48	0.26	0.012	0.018	3.05	0.49	0.85	0.49	0.55	-	K-2509
C-422	0.23	0.81	0.16	0.011	0.012	13.9	0.65	0.25	1.03	0.84	-	W-3561

The Canton Drop Forge and Manufacturing Company reported that the disks were given the following heat treatments with resulting surface hardness values as shown:

4340 STEEL

Surface Brinell Hardness Rim	Hub		Treatment
285	285	#1	First treatment - N. 1750°F + 2 Hrs at 1200°F Second treatment - N. 1750°F
255	255	#2	As forged
302	285	#3	First treatment - O.Q. from 1750°F + 8 Hrs at 1200°F Second treatment - O.Q. from 1550°F + tempered at 1050°F
302	293	#4	Water quench from 1750°F until black, then withdrawn until glow returned. This was repeated until the glow did not return upon withdrawal. Transferred to furnace at 700°F for 8 Hrs + 2 Hrs at 1200°F

NOTE: Second treatments were used because the first treatments produced hardness values lower than a hardness specification of 280 to 320 Brinell.

17-22A(S) STEEL

Surface Brinell Hardness Rim	Hub		Treatment
302	285	#1	N. 1750°F + 2 Hrs at 1200°F
293	277	#2	As forged
302	302	#3	O.Q. from 1750°F + 8 Hrs at 1200°F
341	331	#4	First treatment - interrupted quench from 1750°F (same treatment as 4340, #4) Second treatment - 2 Hrs at 1200°F. This second treatment was required because the initial hardness of 399 Brinell was too high.

Surface Brinell Hardness Rim	Hub	Treatment
		H-40 STEEL
341	341	#1 First treatment - N. 1950°F + 2 Hrs at 1200°F Second treatment - Retempered at 1200°F
363	363	#2 As forged
341	352	#3 First treatment - O.Q. from 1950°F + 8 Hrs at 1200°F Second treatment - Retempered at 1200°F
341	331	#4 First treatment - Interrupted quench from 1950°F (same treatment as 4340, #4) Second treatment - Retempered at 1200°F

NOTE: The additional tempering of the second treatments was required because the first treatments resulted in too high hardness values (#1 - 429/444 BHN, #3 - 415 BHN, #4 - 363/389 BHN).

Rim	Hub	Treatment
		C-422 STEEL
321	331	#1 N. 1900°F + 2 Hrs at 1200°F
321	388	#2 As forged
285	321	#3 As forged
285	285	#4 O. Q. from 1900°F + 8 Hrs at 1200°F

Disks numbered 1, 3, and 4 of each steel were shipped to the University.

RESULTS

The results obtained to date are presented separately for each steel under (1) disk investigation, and (2) investigation of the properties of the products of isothermal transformation.

1. Disk Investigation

4340 STEEL

The center slab has been cut from the oil-quenched disk and the interrupted-quenched disk. Both slabs were magnafluxed and macroetched and found to be sound. Brinell hardness surveys have been taken on both slabs, and these are shown in figures 3 and 4. The oil-quenched disk had a Brinell hardness range of 260 to

320. The principal hardness ranges were 260 to 280 near the center and 280 to 310 towards the edges. The interrupted-quenched disk had a Brinell hardness range of 272 to 342, although most of the hardness values were from 280 to 300.

17-22A(S) STEEL

The center slab has been cut from the oil-quenched disk and the interrupted-quenched disk. Both slabs were magnafluxed and macroetched and found to be sound. Brinell hardness surveys were taken on both slabs, and these are shown in figures 5 and 6. The oil-quenched disk had a Brinell hardness range of 285 to 343, although most of the hardness values were between 300 to 325. The interrupted-quenched disk had a Brinell hardness range of 302 to 350.

H-40 AND C-422 STEELS

To date, no work has been done on these disks, except that hard spots in the interior of the C-422 disks stopped the sectioning for preparation of samples.

2. Investigation of the Properties of the Products of Isothermal Transformation

4340 STEEL

The first criterion used in evaluating the high temperature properties of the different microstructures for each steel was the stress to cause one percent total deformation in 1000 hours at 1100°F. Because of the poor strength of 4340 at 1100°F, testing at 1000°F was initiated. The results obtained to date are as follows:

Structure	BHN	Test Temp. (°F)	Stress to Cause 1% Total Deformation in 1000 Hours (psi)
Norm. + T. 1 Hr at 1100°F	292/311	1100	4,250
Norm. + T. 1 Hr at 1100°F	301/303	1000	13,300
O.Q. + T. 10 Hrs at 1100°F	309	1100	less than 4,250

Structure	BHN	Test Temp. (°F)	Stress to Cause 1% Total Deformation in 1000 Hours (psi)
O.Q. + T. 10 Hrs at 1100°F	306	1000	less than 13,300
Lower Pearlite	275	1100	" " 4,250
Lower Pearlite	270	1000	" " 13,300
Upper Bainite	319	1100	greater than 4,250
Upper Bainite	322	1000	" " 13,300
Lower Bainite + T. 1-1/4 Hrs at 1100° F	301	1100	less than 4,250
Lower Bainite + T. 1-1/4 Hrs at 1100° F	294	1000	about 13,300
Upper Pearlite	219	1000	about 13,300

Because of the low strengths of the various structures of 4340, creep testing was limited to only one test for each structure other than the normalized structure and the upper bainitic structure. The upper bainitic structure was the only structure showing a significantly higher creep strength as compared to the normalized structure. The upper pearlitic structure was not tested at 1100° F because of its low hardness.

Table I shows the creep data obtained to date from creep tests run on various microstructures of 4340.

Figure 7 shows a plot of stress vs. time for specified total deformations for the normalized structure tempered to an approximate hardness of 300 Brinell and creep tested at 1000° F.

17-22A(S) STEEL

The hardness values obtained for various heat treatments are as follows:

Treatment	Brinell Hardness
As normalized 1 hour at 1750°F	361
As oil quenched from 1750°F	524

Treatment	Brinell Hardness
Austenitize 1 hour at 1750°F + 1-1/2 hours at 1350°F (Upper Pearlite)	315
Austenitize 1 hour at 1750°F + 10 hours at 1150°F (Lower Pearlite)	375
Austenitize 1 hour at 1750°F + 2 hours at 900°F (Upper Bainite)	466
Austenitize 1 hour at 1750°F + 5 minutes at 700°F (Lower Bainite)	365

The hardness values obtained for the bainitic structures are being investigated in order to determine why the upper bainite is harder than the lower bainite.

The tempering behaviors of the normalized and oil-quenched structures have been reported previously. Figures 8 to 11 show the tempering behaviors of the lower-bainite, upper-pearlite, lower-pearlite, and upper-bainite structures.

The results obtained to date from creep-rupture tests at 1100°F are as follows:

Structure	BHN		Stress to Cause 1% Total Deformation in 1000 Hours (psi)
Norm. + T. 10 Hrs at 1200°F	291/317		19,000
O.Q. + T. 1 Hr at 1300°F	302/306		15,000
Upper Pearlite	309/313	less than	19,000
Lower Pearlite + T. 12 Hrs at 1200°F	291/313	" "	19,000
Lower Bainite + T. 12 Hrs at 1200°F	302/303	" "	19,000

The creep data obtained to date from tests run on various microstructures of 17-22A(S) are included in table II.

Figure 12 shows a plot of stress vs. time for specified total deformations for the normalized structure tempered to an approximate hardness of 300 Brinell and creep tested at 1100°F.

H-40 STEEL

The time-temperature-transformation curve for H-40 has been outlined and is shown in figure 13. Results obtained in determining this curve indicate that the only microstructures which can be developed by isothermal treatment are upper and lower bainite. Holding for time periods out to 24 hours at temperatures above 900°F results in the appearance of a very small amount of a dark-etching material in the grain boundaries of the matrix material. This dark-etching material could not be identified, even after examining it at a magnification of 2000 diameters. Other than this, there were no signs of any transformation of the austenite.

The hardness values obtained for various heat treatments are as follows:

Treatment	Brinell Hardness
Normalize 1 hour at 1950°F	435
Oil quench from 1950°F	522
Austenitize 1 hour at 1950°F + 10 hours at 750°F (Upper Bainite)	481
Austenitize 1 hour at 1950°F + 1/2 hour at 600°F (Lower Bainite)	417

The hardness values obtained for the bainitic structures are being investigated in order to determine why the upper bainite is harder than the lower bainite.

The tempering behaviors of the normalized and oil-quenched structures have been reported previously. Figures 14 and 15 show the tempering behavior of the two bainite structures.

The following results have been obtained from creep tests run at 1100°F:

Structure	BHN	Stress to Cause 1 Percent Total Deformation in 1000 Hours (psi)
Norm. + T. 18 hours at 1200°F	312/320	27,800
O.Q. + T. 12 hours at 1200°F	321/323	23,300

Creep data obtained to date are included in table III.

Figure 16 shows a plot of stress vs. time for specified total deformations for the normalized structure, tempered to a hardness of approximately 300 Brinell.

C-422 STEEL

The hardness values obtained after normalizing and oil quenching C-422 Steel were as follows:

Treatment	Brinell Hardness
Normalize 1 hour at 1900°F	484
Oil Quench from 1900°F	494

The tempering behaviors of these structures are shown in figures 17 and 18.

The stress to cause one percent total deformation in 1000 hours at 1100°F is 28,700 psi for the normalized structure tempered to a Brinell hardness of 299/306. Creep data obtained to date are included in table IV. This data indicates that the oil quenched and normalized structures, when tempered to a hardness of about 300 Brinell, have similar creep properties.

Figure 19 is a plot of stress vs. time for specified total deformation for the normalized structure tempered to a Brinell hardness of 300.

Work is now in progress on the determination of the time-temperature-transformation curve for C-422.

FUTURE WORK

Creep-rupture testing, for determination of the heat-treated disk with the most practical properties, will be initiated as soon as test units are available.

The program on the bar stock is to be continued to define the relationship between microstructure and creep-rupture properties.

TABLE I.

CREEP PROPERTIES OF 4340 STEEL AT 1000° F AND 1100° F

Heat Treatment	BHN	Test Temp. (°F)	Stress (psi)	Time in Progress (Hrs)	Minimum Creep Rate (%/1000 Hrs)	Percent Total Deformation at Indicated Time Periods			Time in Hours for Specified Total Deformations			
						300 Hrs	500 Hrs	1000 Hrs	0.1%	0.2%	0.5%	1.0%
N.1750°F+T. 1 Hr. at 1100°F	292	1100	2,000	1056*	0.22	0.2	0.27	0.38	86	302	-	-
" " " " "	311	1100	4,000	1056*	0.52	0.37	0.51	0.78	18	95	484	1416[b]
" " " " "	299	1100	6,000	1050*	2.4	1.04	1.57	3.07	8	26	101	286
O.Q. + T. 10 Hrs. at 1100°F	309	1100	4,500	1050*	3.16	1.14	1.71	2.96	5	22	104	258
Aust. 1750°F + 111 Hrs. at 1050°F - (Lower Pearlite)	275	1100	4,250	470	-	1.37	-	-	9	21	90	217
Aust. 1750°F + 28 Hrs. at 850°F - (Upper Bainite)	319	1100	4,500	1012*	0.48	0.28	0.47	0.72	17	78	552	1585[b]
Aust. 1750°F + 1½ Hrs. at 650°F + T. 1¼ Hrs. at 1100°F (Lower Bainite)	301	1100	4,500	1012*	1.72	0.76	1.12	2.0	3	19	156	436
N.1750°F + T. 1 Hr. at 1100°F	301	1000	12,000	1000*	0.37	0.31	0.39	0.58	12	114	802	2150[b]
" " " " "	303	1000	15,000	1134*	1.45	0.63	0.9	1.83	2	25	196	556
O.Q. + T. 10 Hrs. at 1100°F	306	1000	13,000	1026*	1.15	0.54	0.81	1.74	3	27	248	628
Aust. 1750°F + 10 Hrs. at 1240°F (Upper Pearlite)	219	1000	13,000	1103*	0.57	0.35	0.48	0.77	6	63	528	1400[b]
Aust. 1750°F + 111 Hrs. at 1050°F (Lower Pearlite)	270	1000	13,000	350	-	2.0	-	-	2	6	46	141
Aust. 1750°F + 28 Hrs. at 850°F (Upper Bainite)	322	1000	13,000	1074*	0.24	0.27	0.33	0.47	5	91	1130[b]	-
Aust. 1750°F + 1½ Hrs. at 650°F + T. 1¼ Hrs. at 1100°F (Lower Bainite)	294	1000	13,000	810	-	0.5	0.64	-	2	32	300	-

*Completed Creep Test.

[b]Extrapolated Value.

TABLE II

CREEP PROPERTIES OF 17-22A(S) STEEL AT 1100°F

Heat Treatment	BHN	Stress (psi)	Time in Progress (Hrs)	Minimum Creep Rate (%/1000 Hrs)	Percent Total Deformation at Indicated Time Periods 300 Hrs	500 Hrs	1000 Hrs	Time in Hours for Specified Total Deformations 0.1%	0.2%	0.5%	1.0%
N.1750°F + T. 12 Hrs. at 1200°F	302	10,000	1056*	0.16	0.26	0.31	0.38	32	138	-	-
" " " " "	291	14,000	1150*	0.3	0.22	0.28	0.44	48	230	1204[b]	-
" " " " "	317	17,000	1036*	0.45	0.25	0.34	0.58	14	177	857	1970[b]
" " " " "	311	20,000	773[c]	0.86	0.43	0.67	-	1	46	375	656
O.Q. + T. 1 Hr. at 1300°F	306	20,000	666[c]	1.86	0.84	1.49	-	1	13	139	345
" " " " "	302	15,000	1070*	0.85	0.39	0.52	0.99	2	48	470	1006
Aust. 1750°F + 1½ Hrs. at 1350°F (Upper Pearlite)	309	19,000	520	2.04	0.88	2.04	-	1	17	159	356
" " " " " "	313	15,000	140	-	-	-	-	14	112	-	-
Aust. 1750°F + 10 Hrs at 1150°F + T. 12 Hrs. at 1200°F (Lower Pearlite)	313	19,000	280	-	-	-	-	A	10	79	194
" " " " " " " " "	291	15,000	140	-	-	-	-	24	54	-	-
Aust. 1750°F + 5 Min. at 700°F + T. 12 Hrs. at 1200°F (Lower Bainite)	302	19,000	1040*	1.46	1.09	1.41	2.41	A	14	101	268
" " " " " " " "	303	14,000	820	-	0.35	0.45	-	22	67	621	-

*Completed Creep Test.

[b]Extrapolated Value.

[A]Reached 0.1% Deformation on Loading.

TABLE III

CREEP PROPERTIES OF H-40 STEEL AT 1100°F

Heat Treatment	BHN	Stress (psi)	Time in Progress (Hrs)	Minimum Creep Rate (%/1000 Hrs)	Percent Total Deformation at Indicated Time Periods 300 Hrs	500 Hrs	1000 Hrs	Time in Hours for Specified Total Deformations 0.1%	0.2%	0.5%	1.0%
N. 1950°F + T. 18 Hrs. at 1200°F	316	27,500	1132*	0.64	0.42	0.55	0.94	A	37	429	1054
" " " " "	320	31,000	720[c]	1.05	0.53	0.75	-	A	7	274	677
" " " " "	312	34,000	272[c]	1.48	-	-	-	A	5	161	-
O.Q. + T. 12 Hrs. at 1200°F	321	30,000	865[c]	2.37	1.06	1.85	-	A	2	94	279
" " " " "	323	24,000	880	0.83	0.5	0.66	-	A	23	300	862

TABLE IV

CREEP PROPERTIES OF C-422 STEEL AT 1100°F

Heat Treatment	BHN	Stress (psi)	Time in Progress (Hrs)	Minimum Creep Rate (%/1000 Hrs)	300 Hrs	500 Hrs	1000 Hrs	0.1%	0.2%	0.5%	1.0%
N. 1900°F + T. 24 Hrs. at 1200°F	306	30,000	920	0.88	0.67	0.82	-	A	3	112	690
" " " " "	299	35,000	819[c]	2.24	1.33	1.96	-	A	D	16	157
" " " " "	303	39,000	366[c]	6.28	3.0	-	-	A	D	9	46
O.Q. + T. 4 Hrs. at 1200°F	307	30,000	370	-	0.64	-	-	A	1	133	-

*Completed Creep Test.

[c] Broke at This Time.

[A] Reached 0.1% Deformation on Loading.

[D] Reached 0.2% Deformation on Loading.

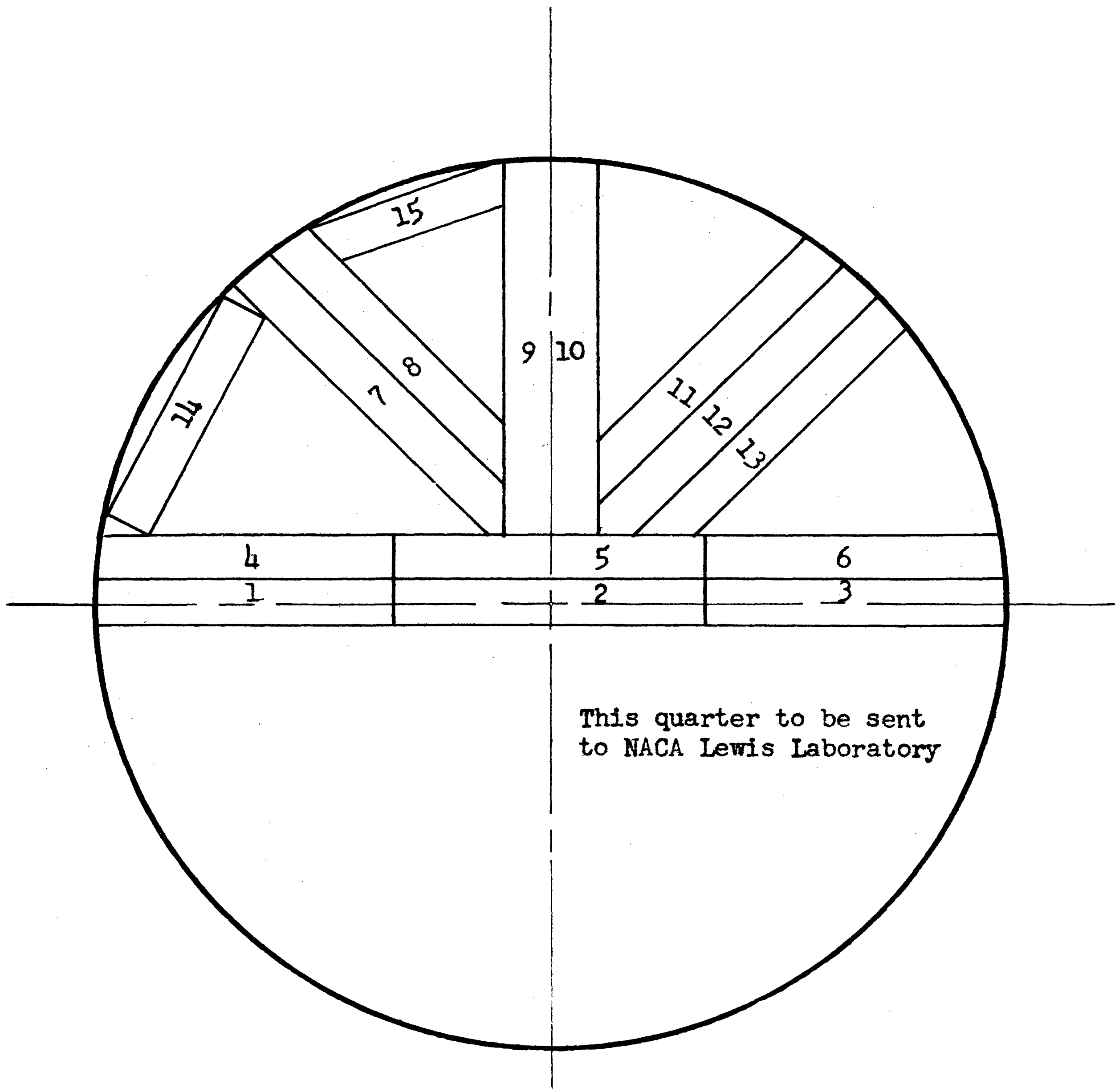


Figure 1. - Proposed Method for Sectioning Disks to be Investigated under Project M903.

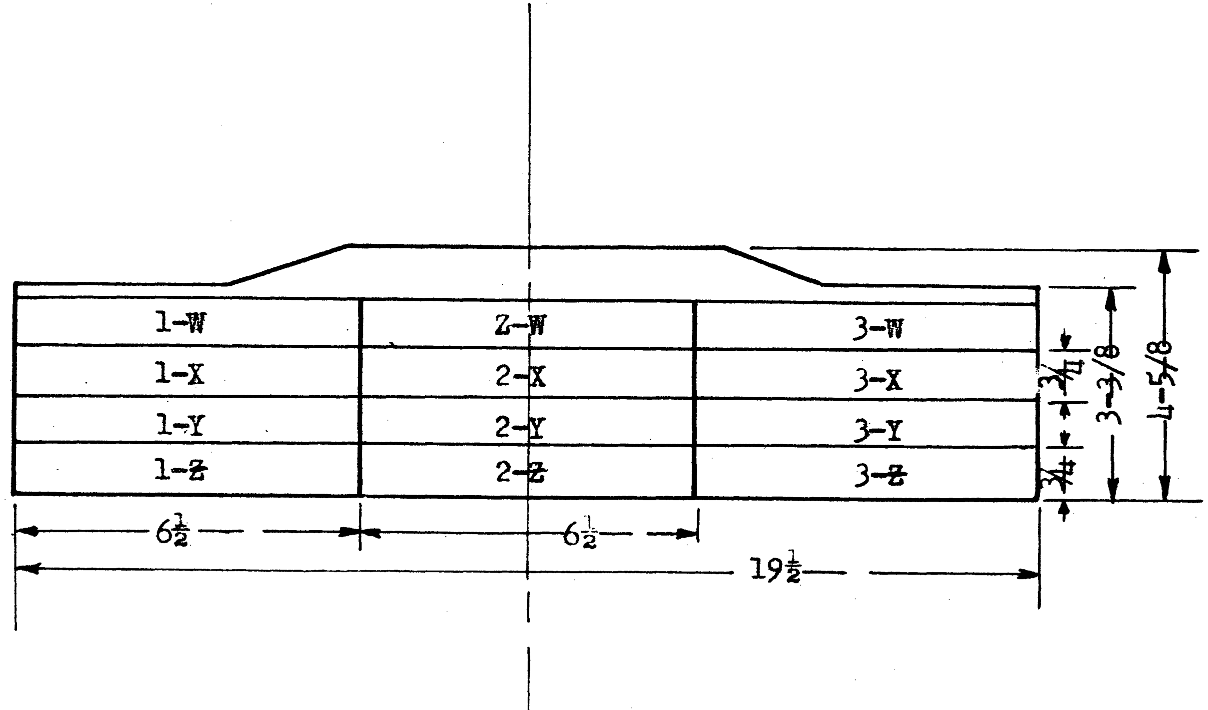
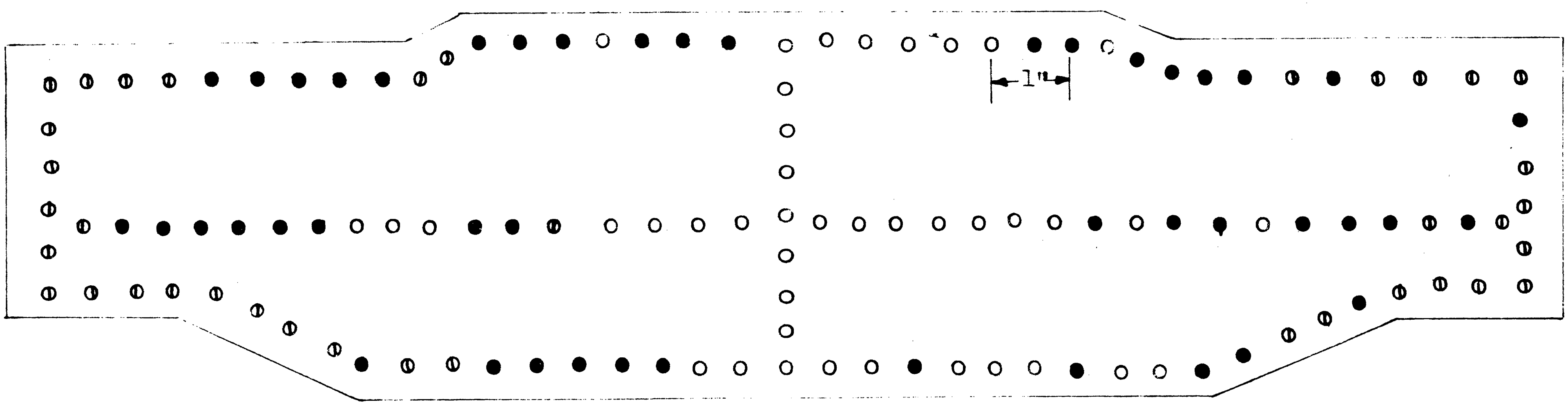


Figure 2. - Cross-Section View of Center of Disk.



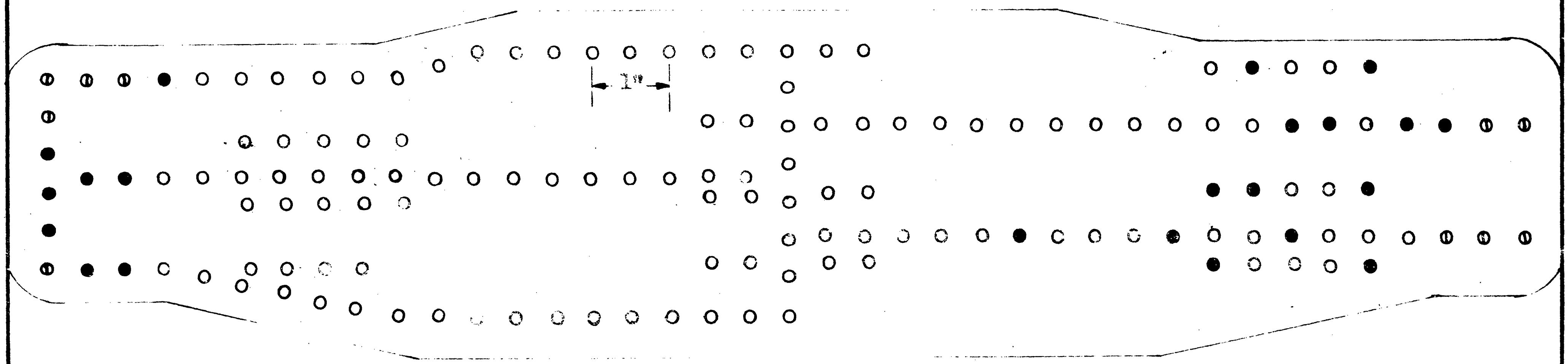
○ = 260-280 Brinell Hardness

● = 281-300 " "

⊕ = 301-320 " "

Heat Treatment: First treatment - O.Q. from 1750°F + 8 Hrs. at 1200°F.
Second treatment - O.Q. from 1550°F + tempered at 1050°F.

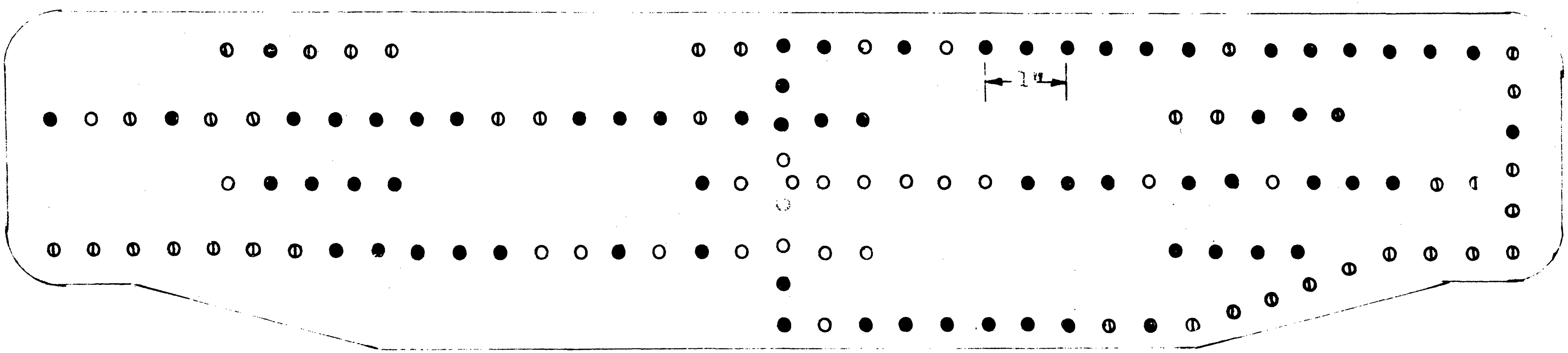
Figure 3. - Brinell hardness survey on center section (1-2-3) of disk #3 of 4340 steel.



○ = 280-300 Brinell Hardness
● = 301-320 " "
⦶ = 321-340 " "

Heat Treatment: Water quench from 1750°F until black, then withdrawn until glow returned. This was repeated until the glow did not return upon withdrawal. Transferred to furnace at 700°F for 8 Hrs. + 2 Hrs. at 1200°F.

Figure 4. - Brinell hardness survey on center section (1-2-3) of disk #4 of 4340 steel.



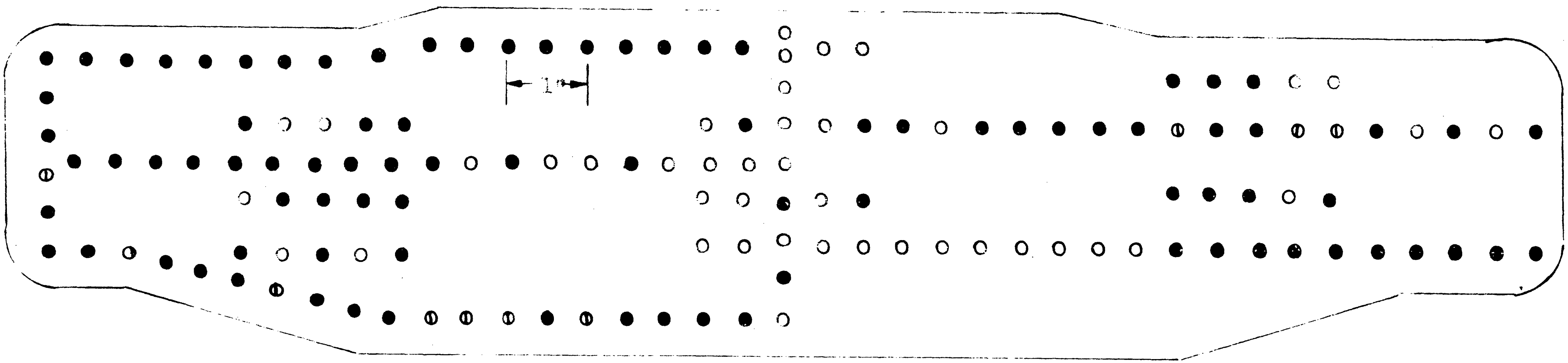
○ = 280-300 Brinell Hardness

● = 301-320 " "

⊖ = 321-340 " "

Heat treatment: O. Q. from 1750°F + 8 Hrs. at 1200°F.

Figure 5. - Brinell hardness survey on center section (1-2-3) of disk #3 of 17-22A(S) steel.



o = 301-320 Brinell Hardness

● = 321-340 " "

⊖ = 341-360 " "

Heat treatment: Interrupted-quench from 1750°F (same treatment as 4340, #4).

Figure 6. - Brinell hardness survey on center section (1-2-3) of disk #4 of 17-22A(S) steel.

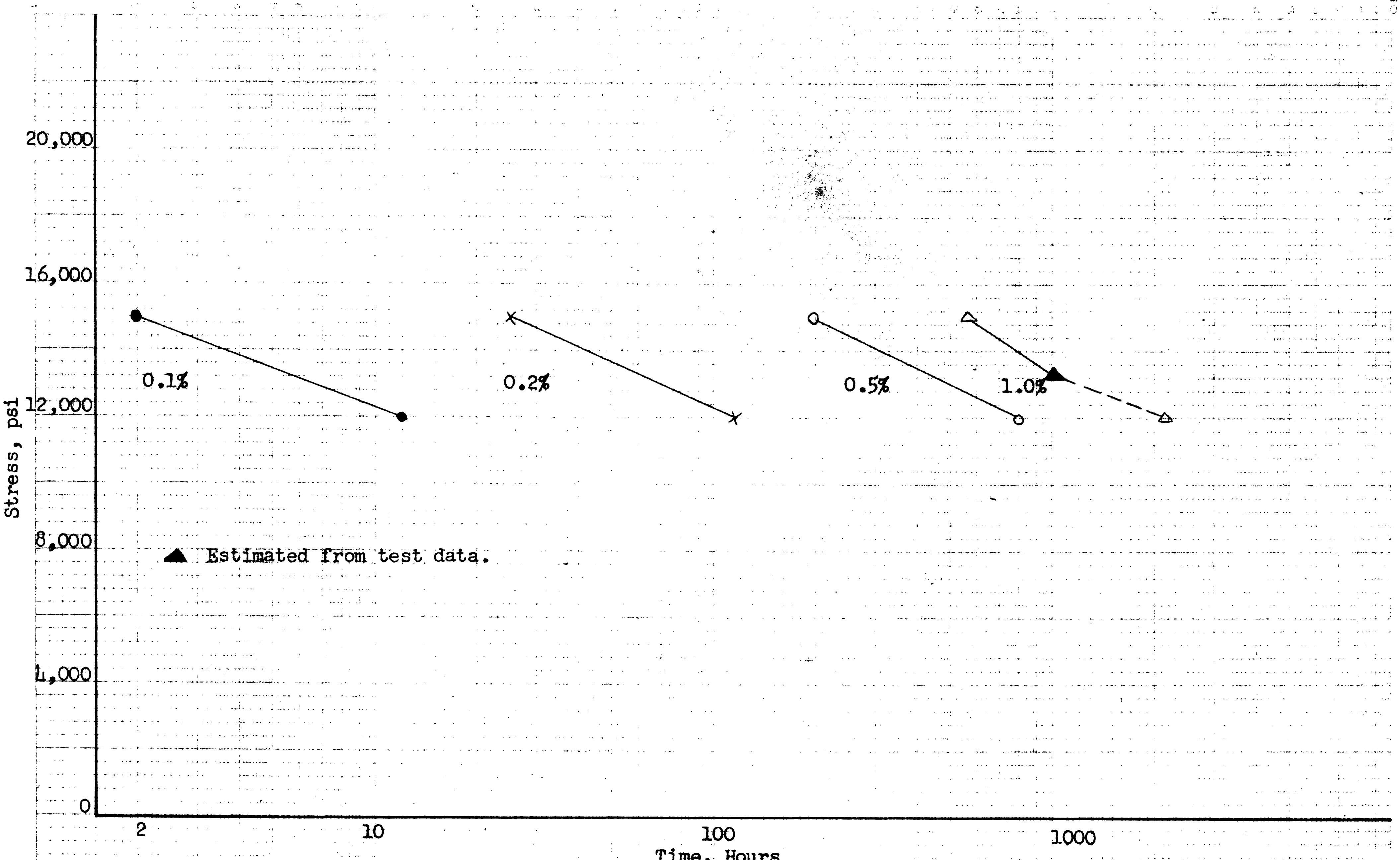


Figure 7. - Stress vs. Time for Indicated Total Deformations at 1000° F for 4340 Steel Normalized 1 Hour at 1750° F + 1 Hour at 1100° F. Brinell Hardness 301 to 303.

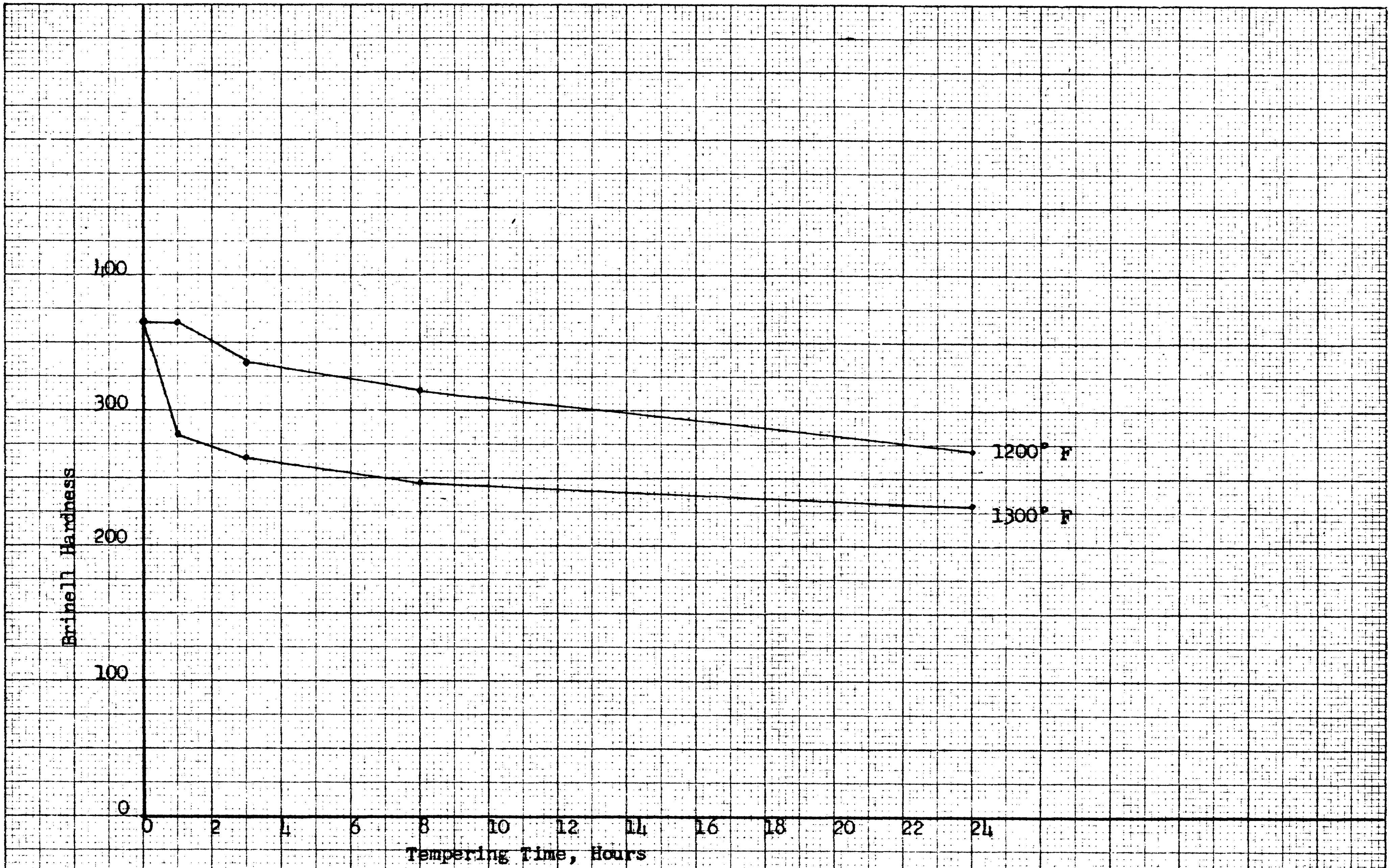


Figure 8. - Relationship between Brinell Hardness and Tempering Time at 1200° F and 1300° F for 17-22A(S) Steel Transformed to Lower Bainite by Holding for 5 Minutes at 700° F.

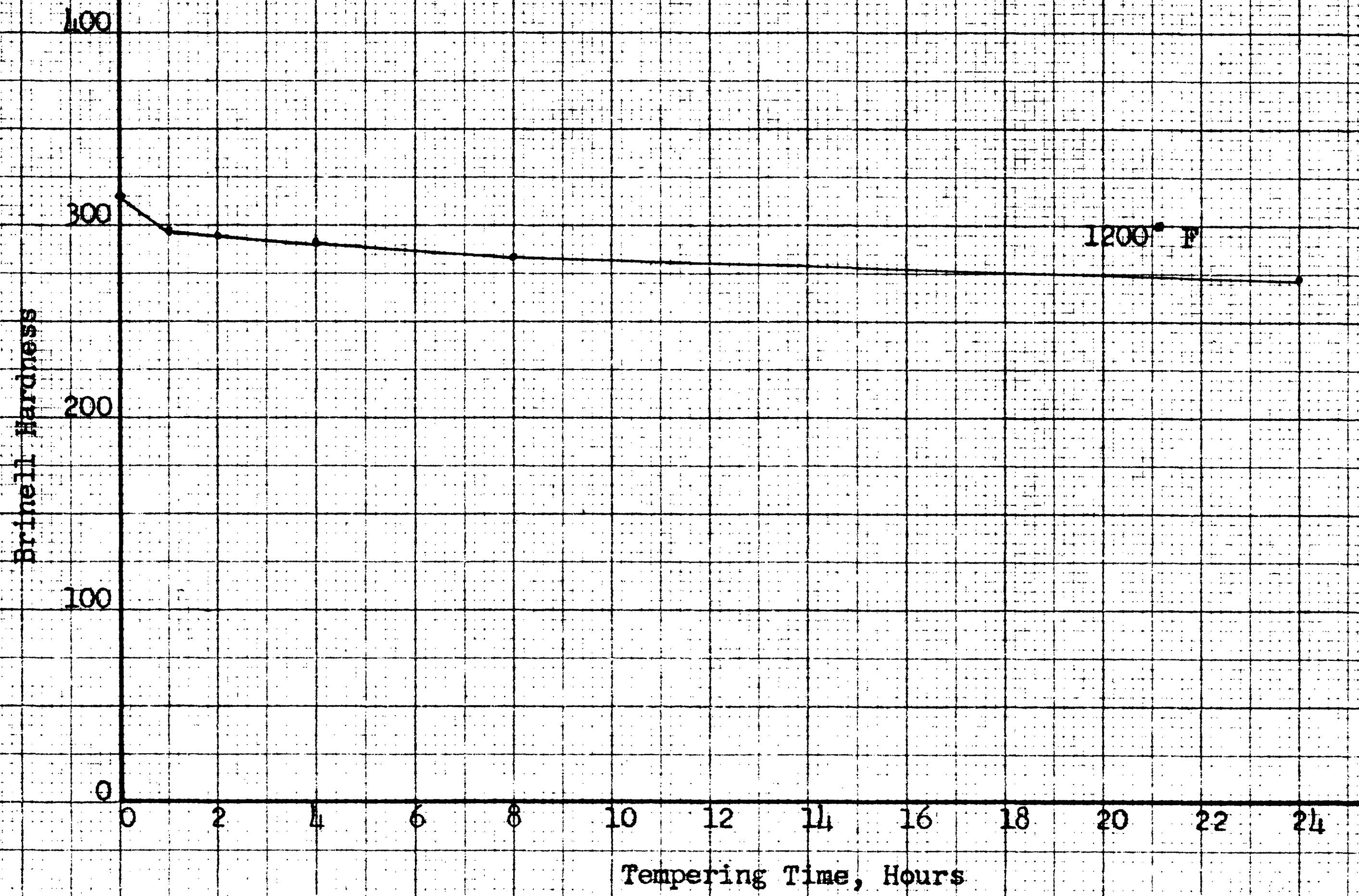


Figure 9. - Relationship between Brinell Hardness and Tempering Time at 1200° F for 17-22A(S) Steel Transformed to Upper Pearlite by Holding 1-1/2 Hours at 1300° F.

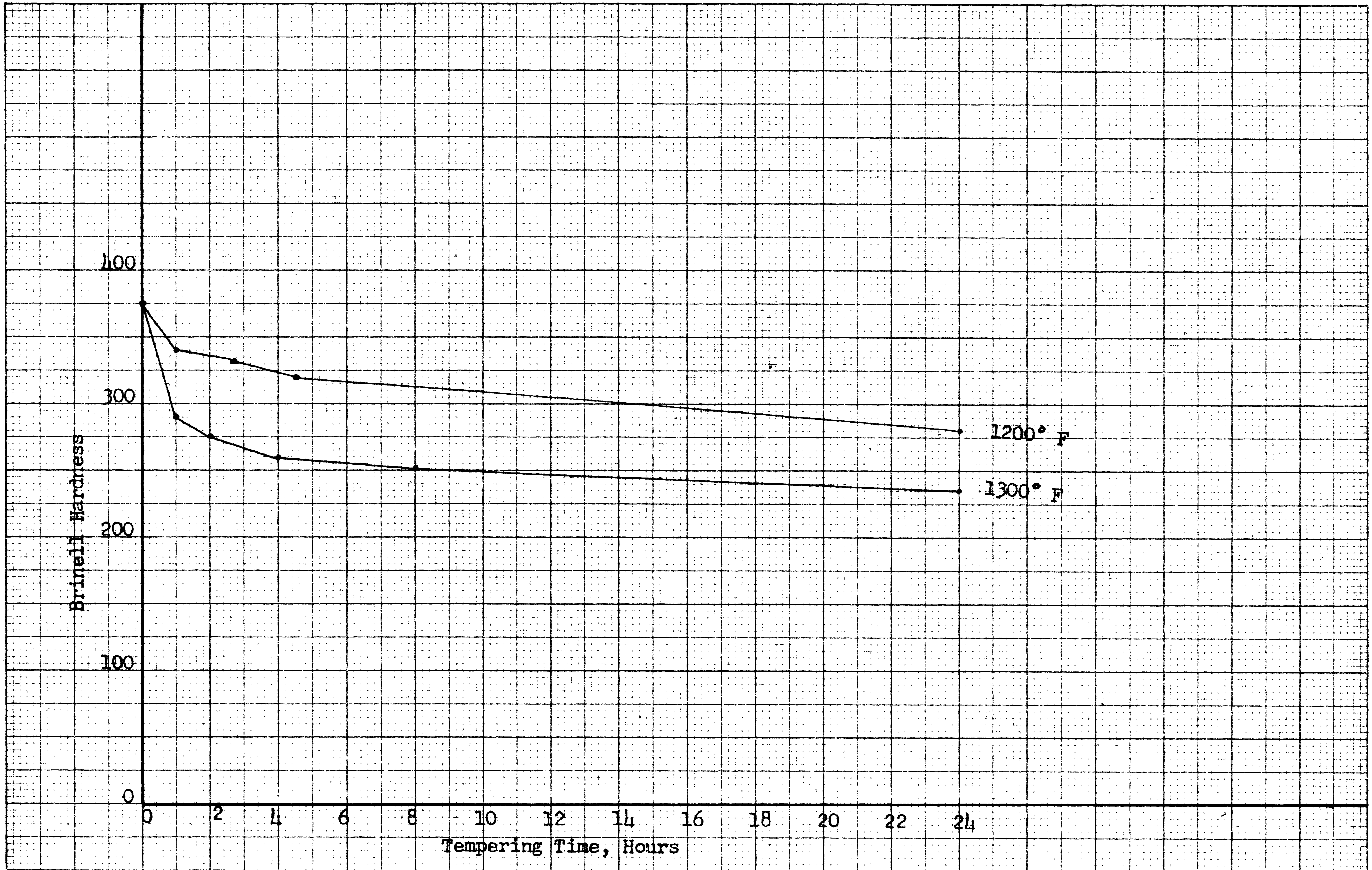


Figure 10. - Relationship between Brinell Hardness and Tempering Time at 1200° F and 1300° F for 17-22A(S) Steel Transformed to Lower Pearlite by Holding 10 Hours at 1150° F.

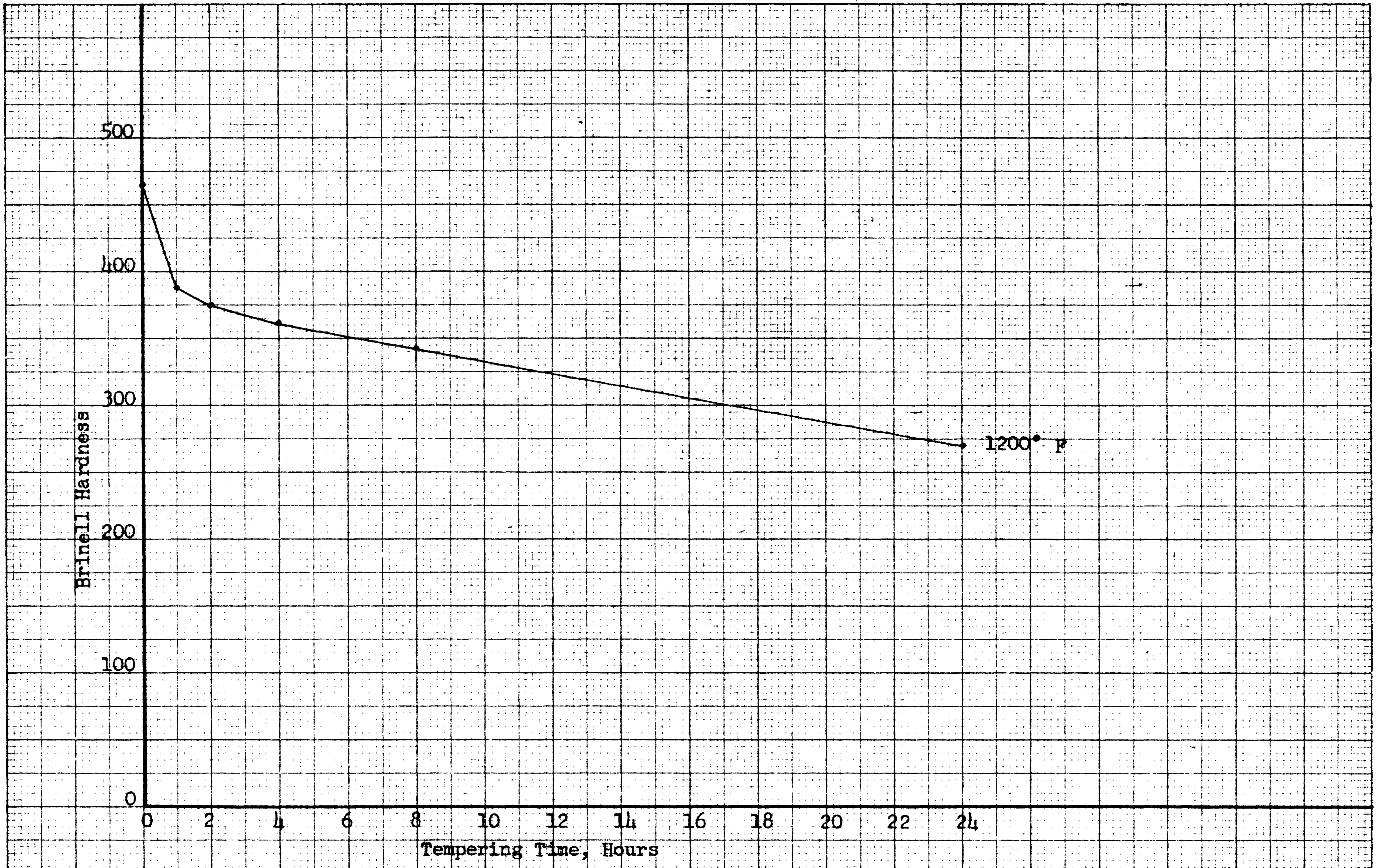


Figure 11. - Relationship between Brinell Hardness and Tempering Time at 1200° F for 17-22A(S) Steel Transformed to Upper Bainite by Holding for 2 Hours at 900° F.

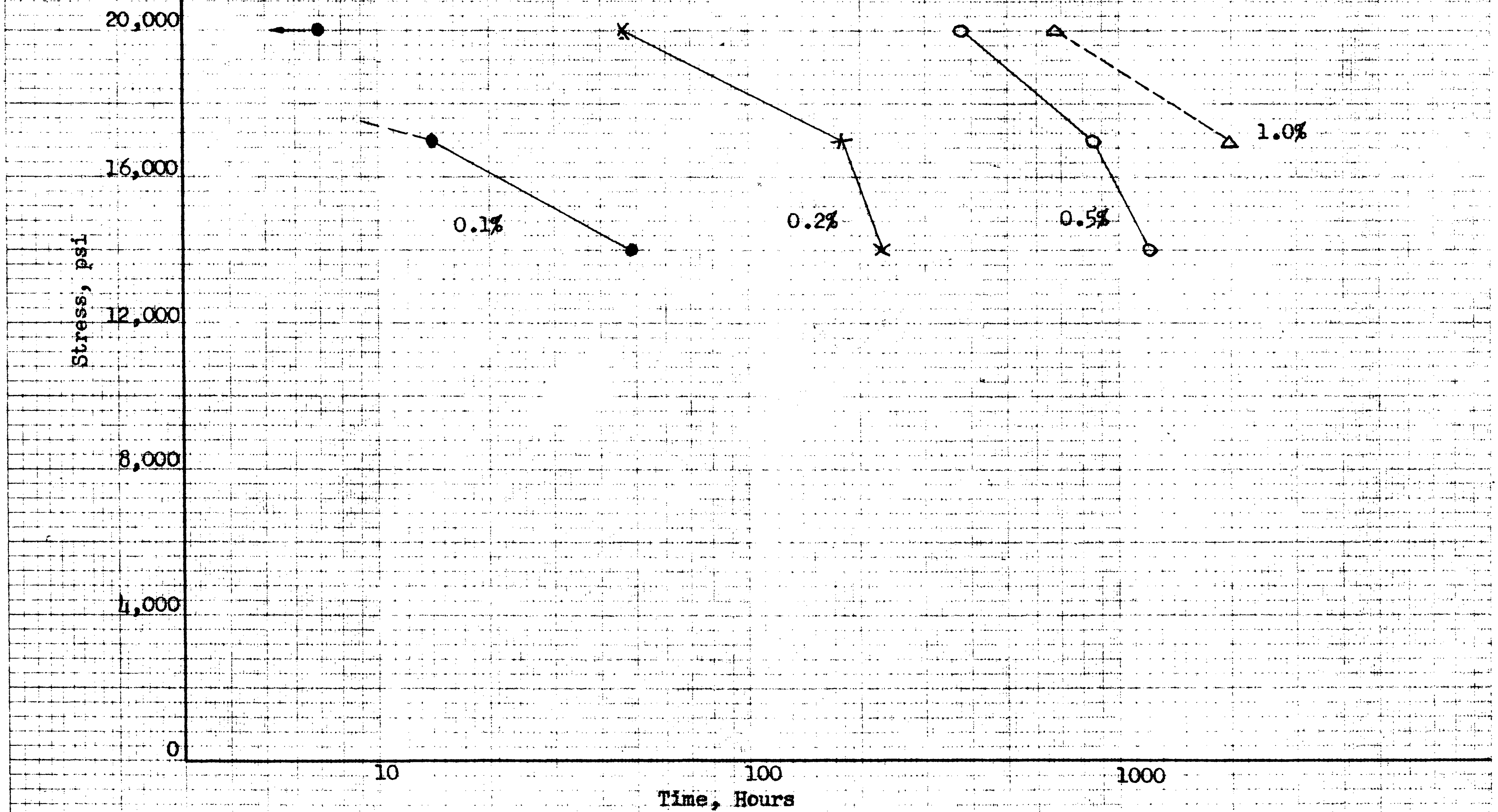


Figure 12. - Stress vs. Time for Indicated Total Deformations at 1100° F for 17-22A(S) Steel Normalized 1 Hour at 1750° F + 10 Hours at 1200° F. Brinell Hardness 291 to 317.

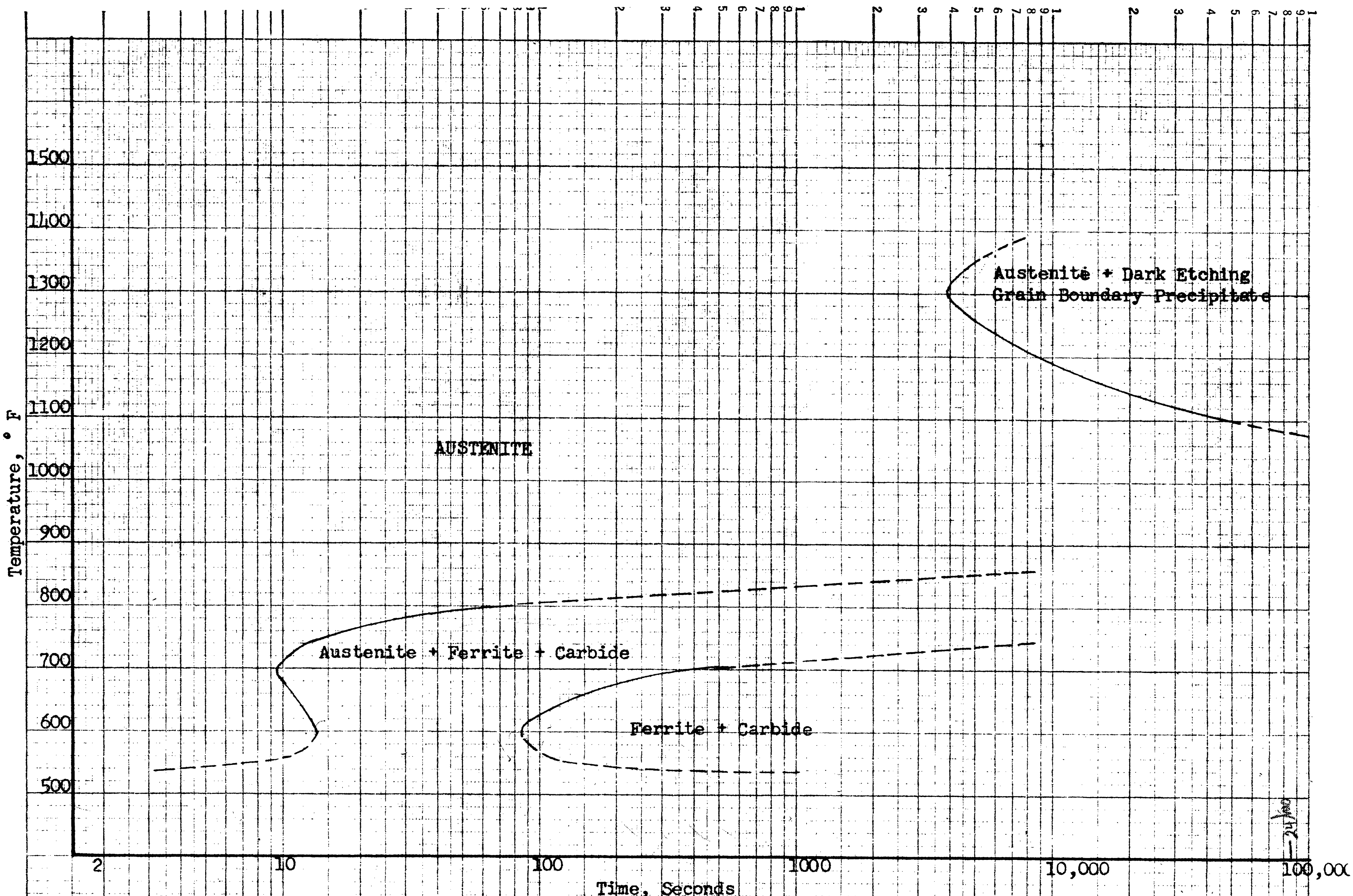


Figure 13. - Time-Temperature-Transformation Curve for H-40, Austenitized at 1950°F, Grain Size #6-7.

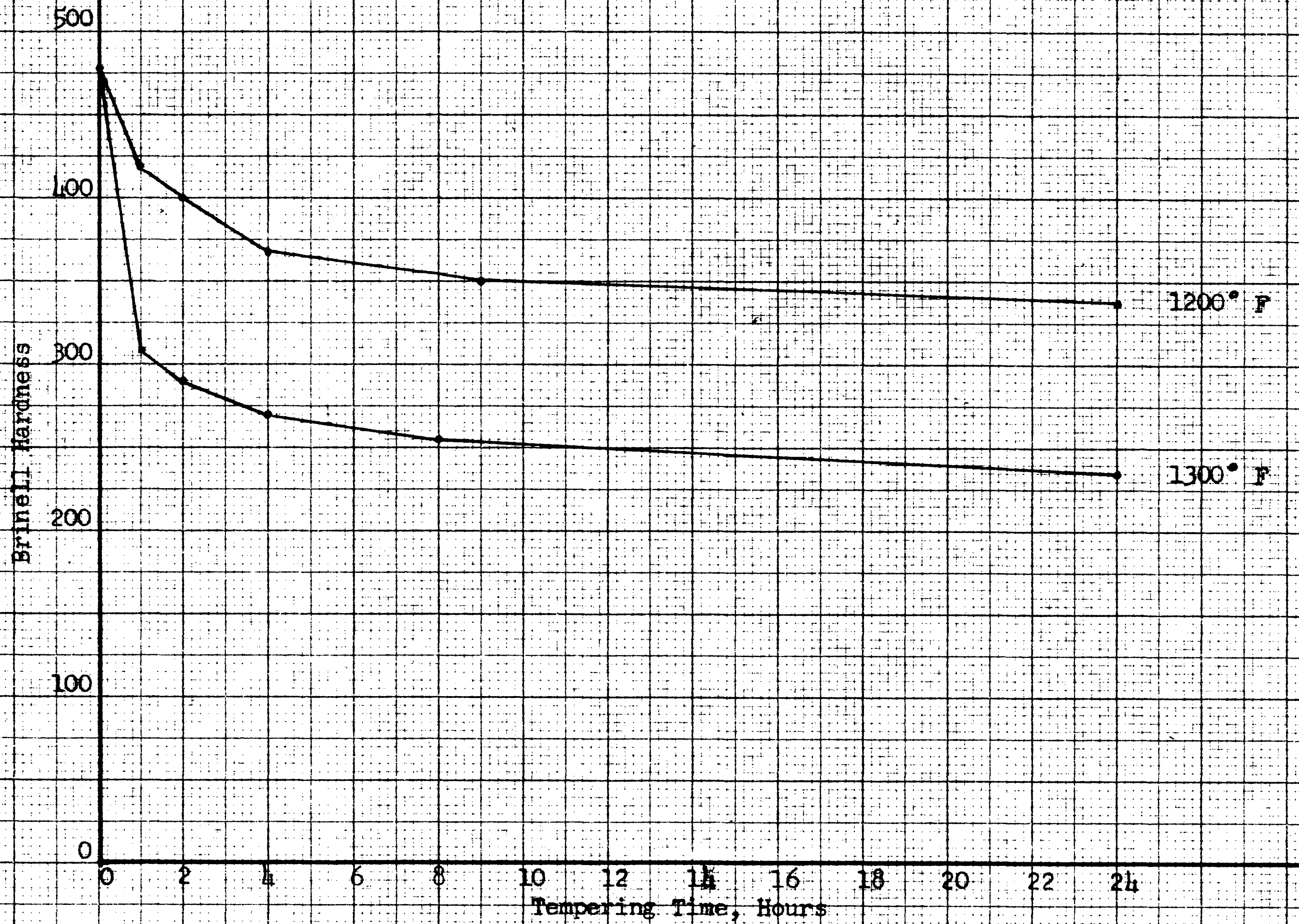


Figure 14. - Relationship between Brinell Hardness and Tempering Time at 1200° F and 1300° F for H-40 Steel Transformed to Upper Bainite by Holding 10 Hours at 750° F.

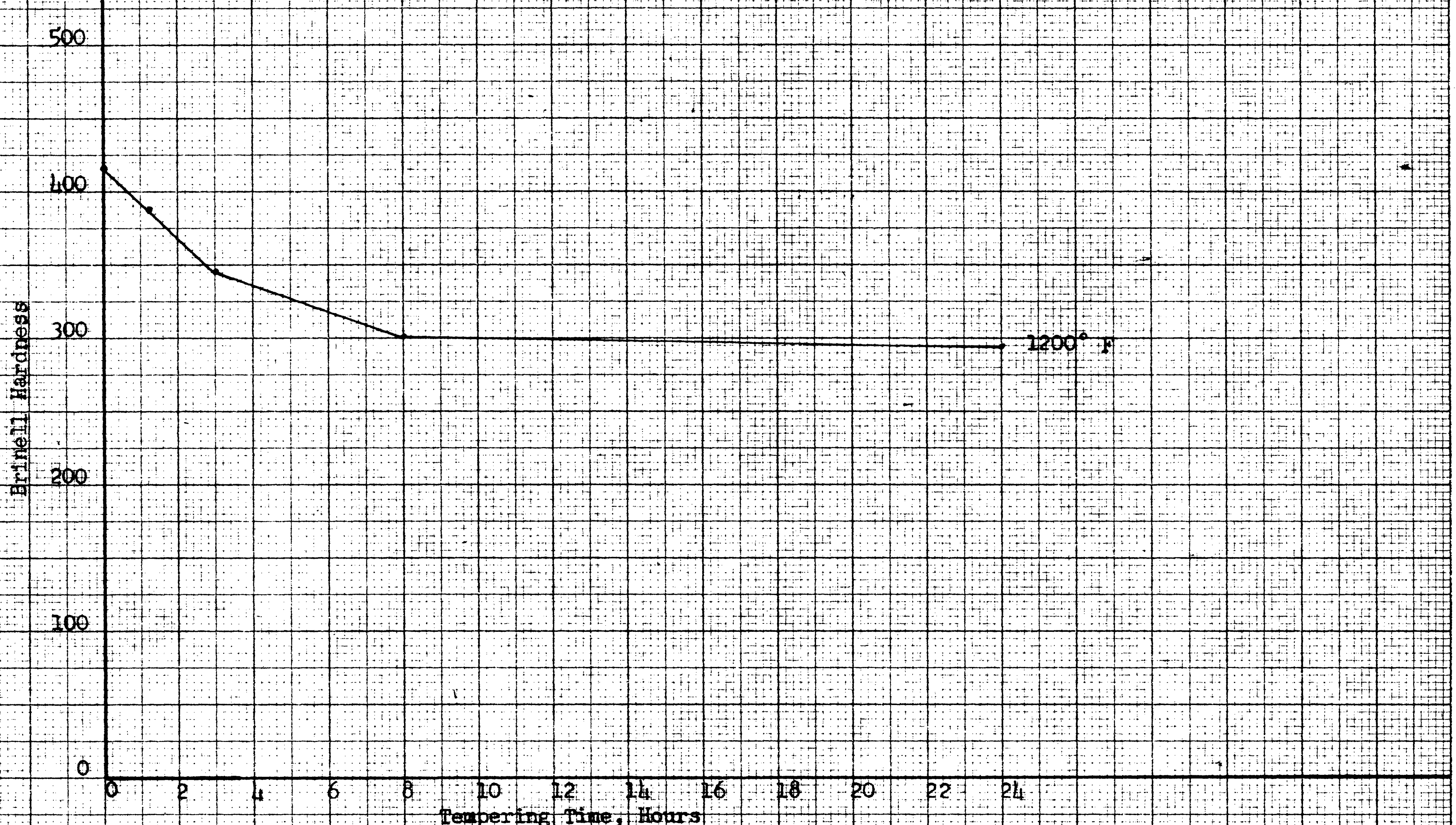


Figure 15. - Relationship between Brinell Hardness and Tempering Time at 1200° F for H-40 Steel Transformed to Lower Bainite by Holding 1/2 Hour at 600° F.

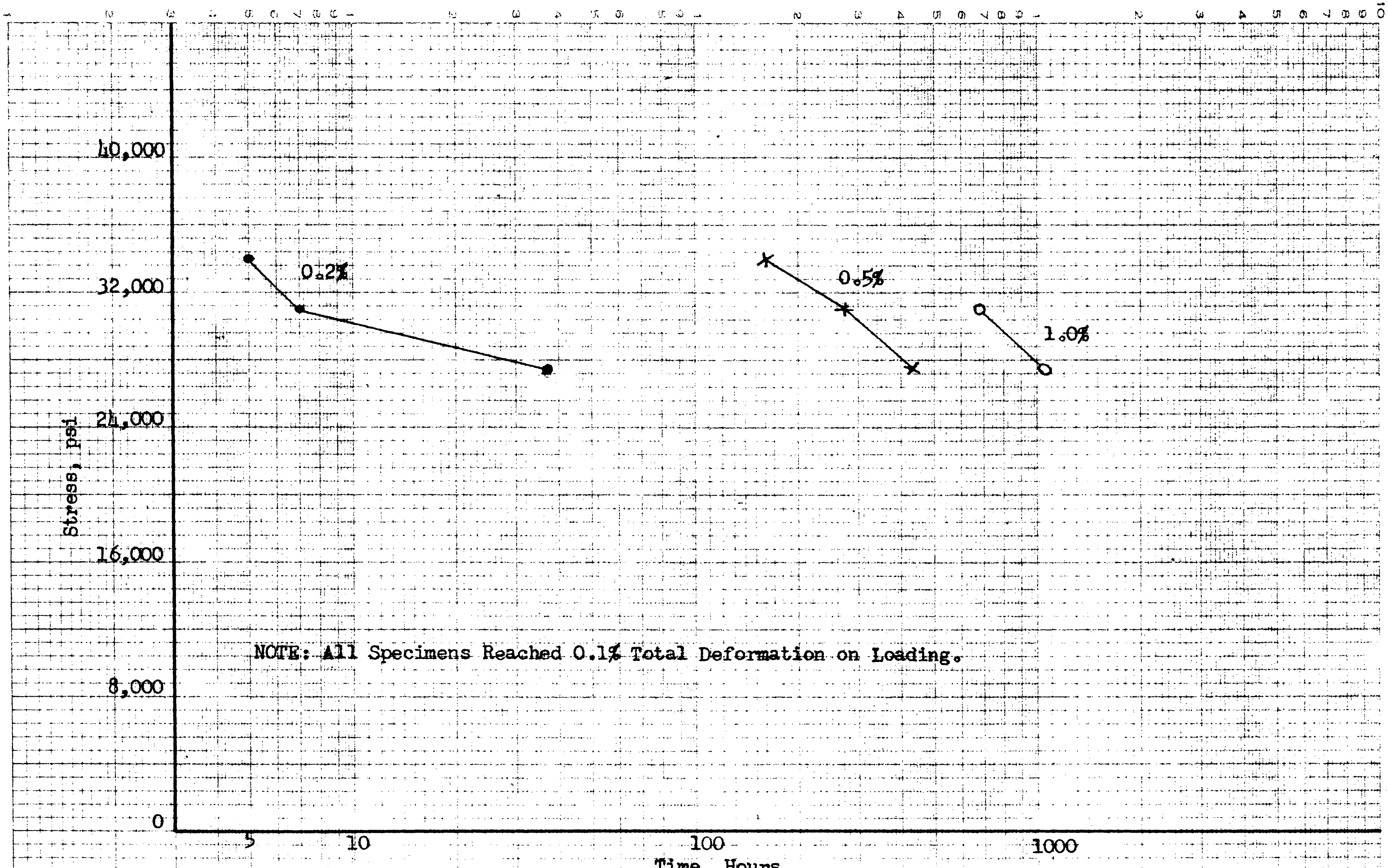


Figure 16. - Stress vs. Time for Indicated Total Deformations at 1100° F for H-40 Steel Normalized 1 Hour at 1950° F + 18 Hours at 1200° F. Brinell Hardness 312 to 320.

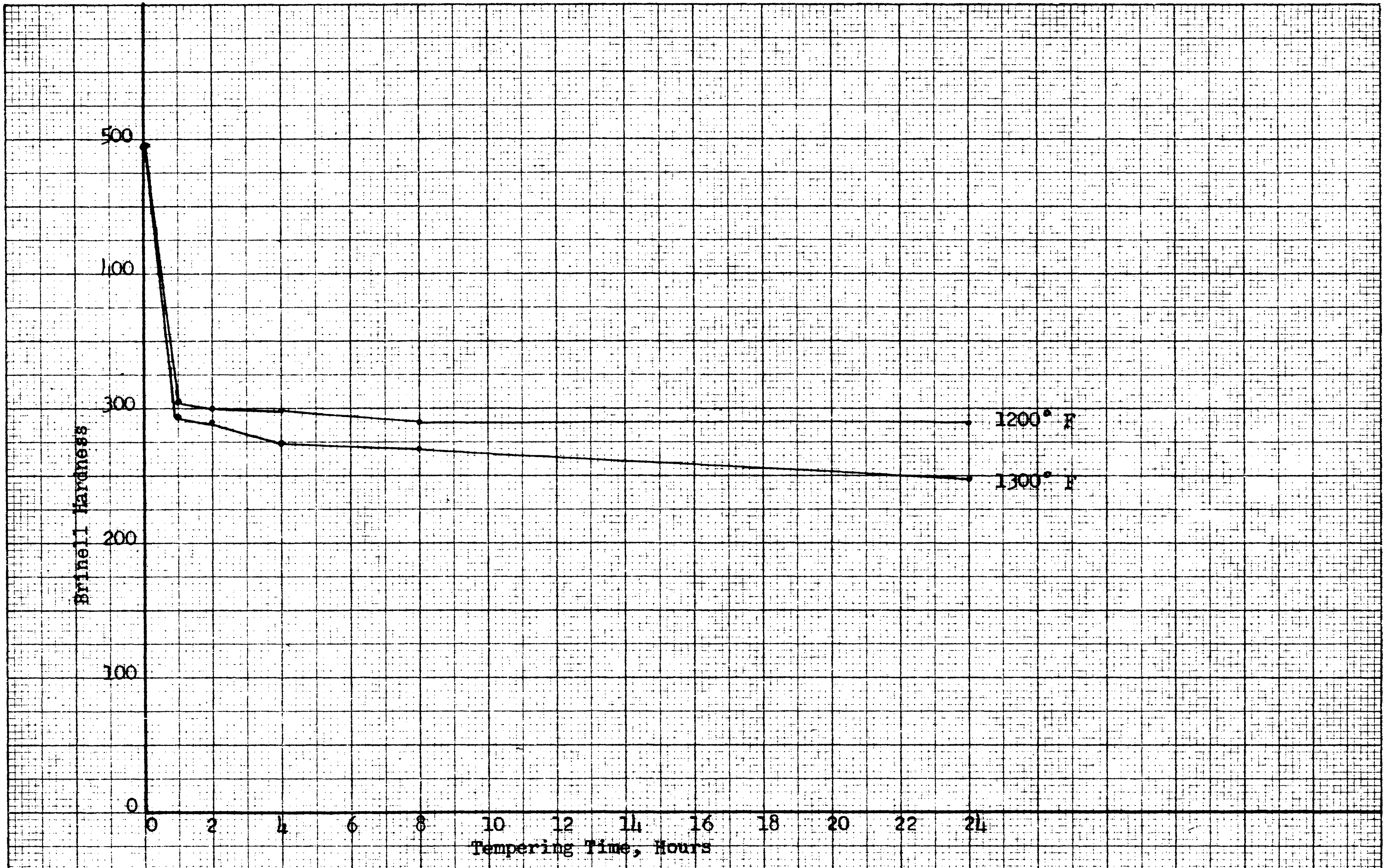


Figure 17. - Relationship between Brinell Hardness and Tempering Time at 1200° F and 1300° F for C-422 Steel Oil Quenched from 1900° F.

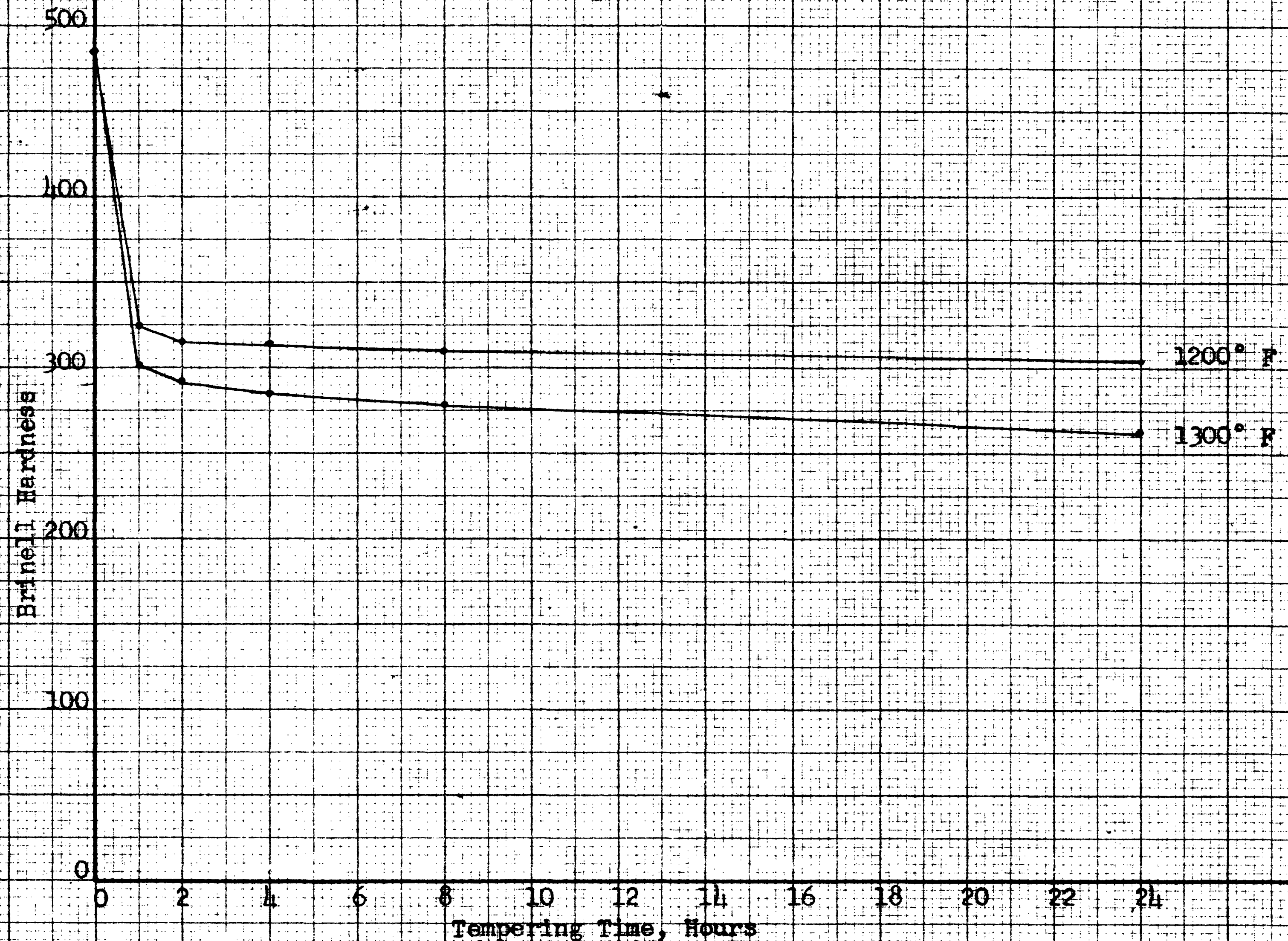


Figure 18. - Relationship between Brinell Hardness and Tempering Time at 1200° F and 1300° F for C-422 Steel Normalized 1 Hour at 1900° F.

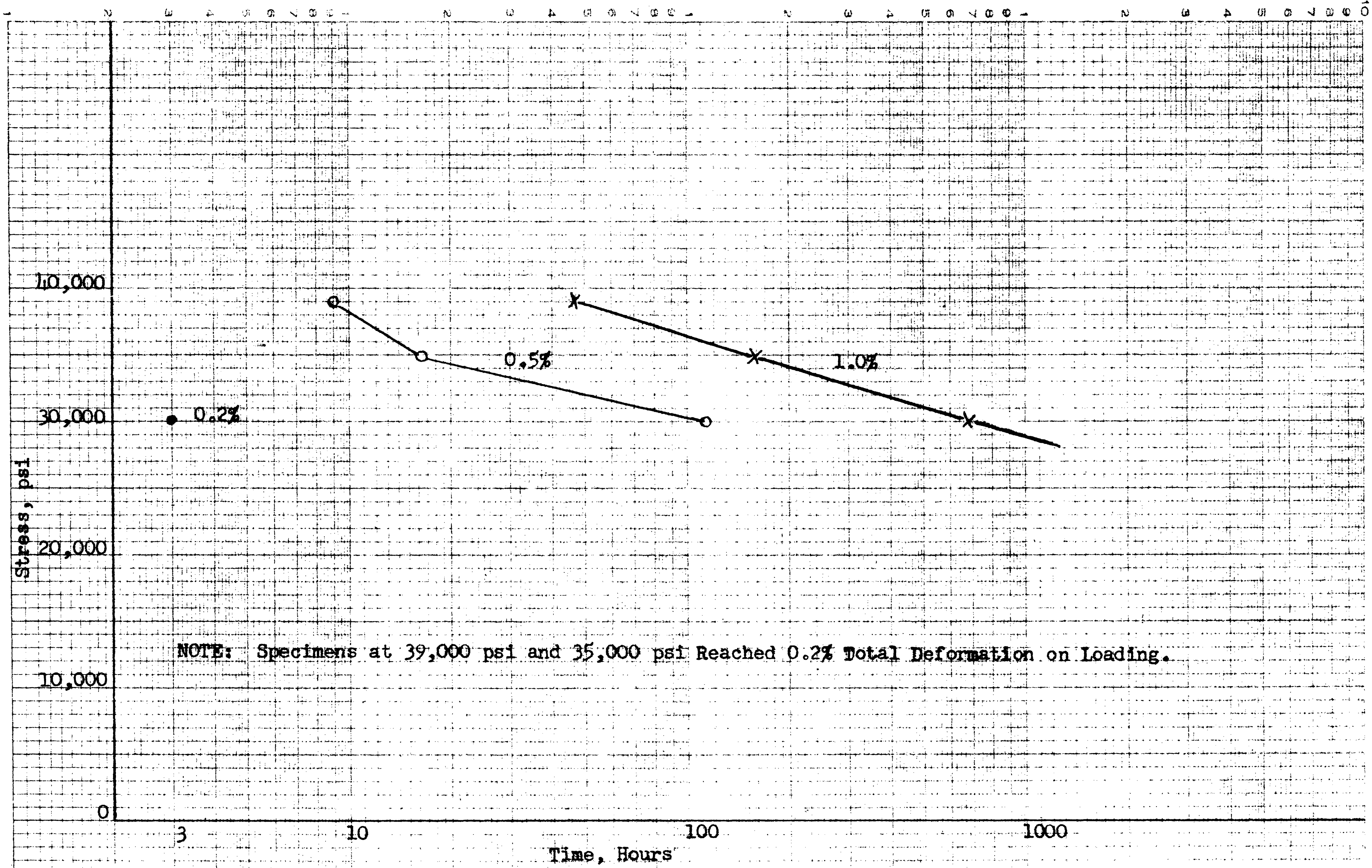


Figure 19. - Stress vs. Time for Indicated Total Deformations at 1100° F for C-422 Steel Normalized 1 Hour at 1900° F + 24 Hours at 1200° F. Brinell Hardness 299-306.