SECOND PROGRESS REPORT

TO

MATERIALS LABORATORY, AIR MATERIEL COMMAND

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 Second Progress Report covering an investigation being carried out under Air Force Contract Number: AF33(038)-13496 (Expenditure Order Number: 605-227 SR-7), for the time period from 1 April 1951 to 30 June 1951.

This investigation is to study the high-temperature properties of four low-alloy steels in the form of J-33 jet-engine disks. A concurrent investigation of the high-temperature properties of the isothermal products of transformation of each steel is being carried out to correlate with results to be obtained for the disks.

To date, none of the disks has arrived, but notice has been received that the disks have been forged and heat treated, and that they will be shipped to the University some time in July.

Creep tests are now in progress on specimens (both normalized + tempered to 300 Brinell, and oil quenched + tempered to 300 Brinell) of steels 4340, 17-22A(S) and H-40.

Bar stock of steels 4340, 17-22A(S), H-40 and C-422 has been supplied gratis for the work on isothermal transformation. Using these materials, the following results have been obtained from creep tests at 1100° F on normalized structures tempered to 280-320 Brinell hardness:

Steel	Stress to Cause One Percent Total Deformation in 1000 Hours at 1100° F (psi)
4340**	4,250
17-22A(S)*	20,000 (approximately)
H-40*	30,000 (approximately)

**Creep tests completed
*Creep tests in progress

Because of the poor strength of 4340 at 1100° F, it was decided to conduct limited testing at 1100° F and to proceed with more extensive creep testing at 1000° F.

Additional tempering data for 4340 and 17-22A(S) have been obtained. The time-temperature-transformation curve for H-40 has been partially outlined and partial tempering data for H-40 have been obtained.

INTRODUCTION

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

The investigation, as outlined in the first Progress Report dated 31 March 1951, may be divided in two phases, namely:

A. Disk Investigation

(1) Determination of the effect of heat treatment upon the high-temperature properties of four low-alloy steels in the form of J-33 jet engine disks. The four alloys to be tested are 4340, 17-22A(S), H-40 and Crucible 422.

(2) Determination out to 1000 hours for each steel of design curves 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.

B. Isothermal Transformation Investigation

(1) Determination of the creep and rupture characteristics of the products of isothermal transformation of the four steels. This work is being done on bar stock to correlate with the results obtained from the work on the disks and to help explain

the properties of the disks after various heat treatments.

PROCEDURE AND PROPOSED TESTING CONDITIONS

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

TEST MATERIALS

The Crucible Steel Company of America has supplied, without charge, hot-rolled bar stock of H-40 and C-422 to be used for the isothermal transformation studies. These steels are from the same heats as used for the disk billets.

The Timken Roller Bearing Company has furnished, also without charge, hot-rolled bar stock of 4340 and 17-22A(S) for use in isothermal-transformation studies of these steels. The actual chemical analyses of the disk-billet stock are not yet available, but the actual analyses of the bar stock supplied are as follows:

Type Steel	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Ni (%)	Mo (%)	Va (%)	W (%)	Cu (%)	Heat Number
4340	0.40	0.70	0.30	0.02	0.019	0.78	1.75	0.26	-	-	0.12	19053
17-22A(S)	0.30	0.63	0.60	0.016	0.018	1.25	0.25	0.52	0.25	-	0.10	24797
H-40	0.29	0.48	0.26	0.012	0.018	3.05	0.49	0.49	0.85	0.55	0.15	K-2509
C-422	0.23	0.81	0.16	0.011	0.022	13.19	0.65	1.03	0.25	0.84	-	W-3561

The specified heat treatments for the disks have been outlined previously, (see Progress Report dated 31 March 1951).

RESULTS

The results obtained to date in the investigation of the creep-rupture properties of the products of isothermal transformation are presented separately for each steel.

4340 STEEL

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

Treatment	Brinell Hardness
As normalized 1 hour at 1750° F	390
As oil quenched from 1750° F	585
Austenitize 1 hour at 1750° F + 10 hours at 1240° F (Upper Pearlite)	207
Austenitize 1 hour at 1750° F + 111 hours at 1050° F (Lower Pearlite)	281
Austenitize 1 hour at 1750° F + 28 hours at 850° F (Upper Bainite)	315
Austenitize 1 hour at 1750° F + 1-1/2 hours at 650° F (Lower Bainite)	431

The tempering behaviors of the normalized and of the oil-quenched structures have been reported previously. Figures 1-3 show the tempering behaviors of the lower-pearlite, upper-bainite and lower-bainite structures.

The first criterion used in evaluating the high-temperature properties of different microstructures for each steel was the stress to cause one percent total deformation in 1000 hours at 1100° F. The stress which caused one percent total deformation for the normalized structure, tempered to a hardness of 300 Brinell was used for initial testing of the other structures.

For 4340 steel this stress was found to be 4,250 psi. Table I shows the creep data obtained to date from creep tests run on various microstructures of 4340.

In figures 4 and 5 are plotted stress vs. time for specified total deformations, and stress vs. total deformation at specified times for the normalized structures of 4340 steel tempered to an approximate hardness of 300 Brinell. Figure 6 shows a plot of stress vs. creep rate obtained for this normalized and tempered structure.

Incomplete results from a creep test in progress on 4340 material which has

been oil quenched and tempered to a hardness of 300 Brinell shows this structure to be markedly inferior to the normalized and tempered structure at the same hardness level.

Because of the low stress (4,250 psi) to cause one percent total deformation of the normalized and tempered structure at 1100° F, it has been decided to conduct limited testing at 1100° F and more extensive testing at 1000° F.

Photomicrographs of the normalized and tempered structure before and after creep testing at 1100° F under a stress of 4000 psi are shown in figures 7 and 8.

17-22A(S) STEEL

The hardness values obtained after normalizing and after oil quenching 17-22A(S) steel were as follows:

Treatment	Brinell Hardness
Normalize one hour at 1750° F	361
Oil quench from 1750° F	524

The tempering behaviors of these structures are shown in figures 9 and 10.

Results from creep tests on this steel show that the stress to cause one percent total deformation in 1000 hours at 1100° F for the normalized structure, tempered to a hardness of about 300 Brinell, is approximately 20,000 psi. A creep test in progress on the oil quenched structure, tempered to a hardness of approximately 300 Brinell, shows that this material is markedly inferior to the normalized plus tempered structure.

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

Stress-time-total deformation curves are shown in figures 11 and 12, while figure 13 shows a plot of stress vs. creep rate for this steel in the normalized plus tempered condition.

Photomicrographs of the normalized plus tempered structure before and after creep testing at 1100° F under a stress of 17,000 psi are shown in figures 14 and 15.

H-40 STEEL

The hardness values obtained after normalizing and after oil quenching H-40 steel were as follows:

Treatment	Brinell Hardness
Normalize one hour at 1950° F	435
Oil quench from 1950° F	522

The tempering behaviors of these structures are shown in figures 16 and 17.

Results from creep tests now in progress on H-40 steel indicate that the stress to cause one percent total deformation in 1000 hours at 1100° F for the normalized structure, tempered to a Brinell hardness of 300 will be approximately 30,000 psi.

Creep data obtained to date from tests on normalized plus tempered structures of H-40 are included in Table I. Stress-time-deformation curves, plotted from data obtained to date, are shown in figures 18 and 19.

Work is now in progress on the determination of the time-temperature-transformation curve for H-40.

C-422 STEEL

To date, no work has been done with this steel.

FUTURE WORK

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

Concurrent testing is planned for all four disk materials as soon as they are received.

TABLE I.

CREEP DATA

Steel	Heat Treatment	BHN	Test Temp. (°F)	Stress	Time in Progress (Hrs)	Minimum Creep Rate %/1000 Hrs	Percent Total Deformation at Indicated Time Pericds 300 Hrs	500 Hrs	1000 Hrs	Time in Hours for Specified Total Deformations 0.1%	0.2%	0.5%	1.0%
4340	N. 1750°F + 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	-
	" " "	299	1100	6,000	1050*	2.4	1.04	1.57	3.07	8	26	101	286
	0.Q. + 10 Hr at 1100°F	309	1100	4,500	450	-	1.14	-	-	6	23	103	258
	N. 1750°F + 1 Hr at 1100°F	303	1000	15,000	250	-	-	-	-	2	25	196	-
17-22A(S)	N. 1750°F + 10 Hrs at 1200°F	302	1100	10,000	1056*	0.16	0.26	0.31	0.38	33	138	-	-
	" " "	291	1100	14,000	1150*	0.3	0.22	0.28	0.44	47	230	1220[B]	-
	" " "	317	1100	17,000	1036*	0.45	0.25	0.34	0.58	11	175	857	-
	" " "	311	1100	20,000	100	-	-	-	-	1	45	-	-
	0.Q. + 1 Hr at 1300° F	306	1100	20,000	560	1.86	0.84	1.49	-	A	46	140	364
H-40	N.1950°F + 18 Hrs at 1200°F	320	1100	27,500	536	-	0.42	0.55	-	A	38	430	-
	" " "	316	1100	31,000	536	-	0.53	0.75	-	A	7	274	-
	" " "	312	1100	34,000	270**	1.48	-	-	-	A	5	162	-

*Completed Creep Tests
**Broke in Fillet at 270 Hours
A - Reached 0.1% Deformation on Loading
B - Extrapolated Value

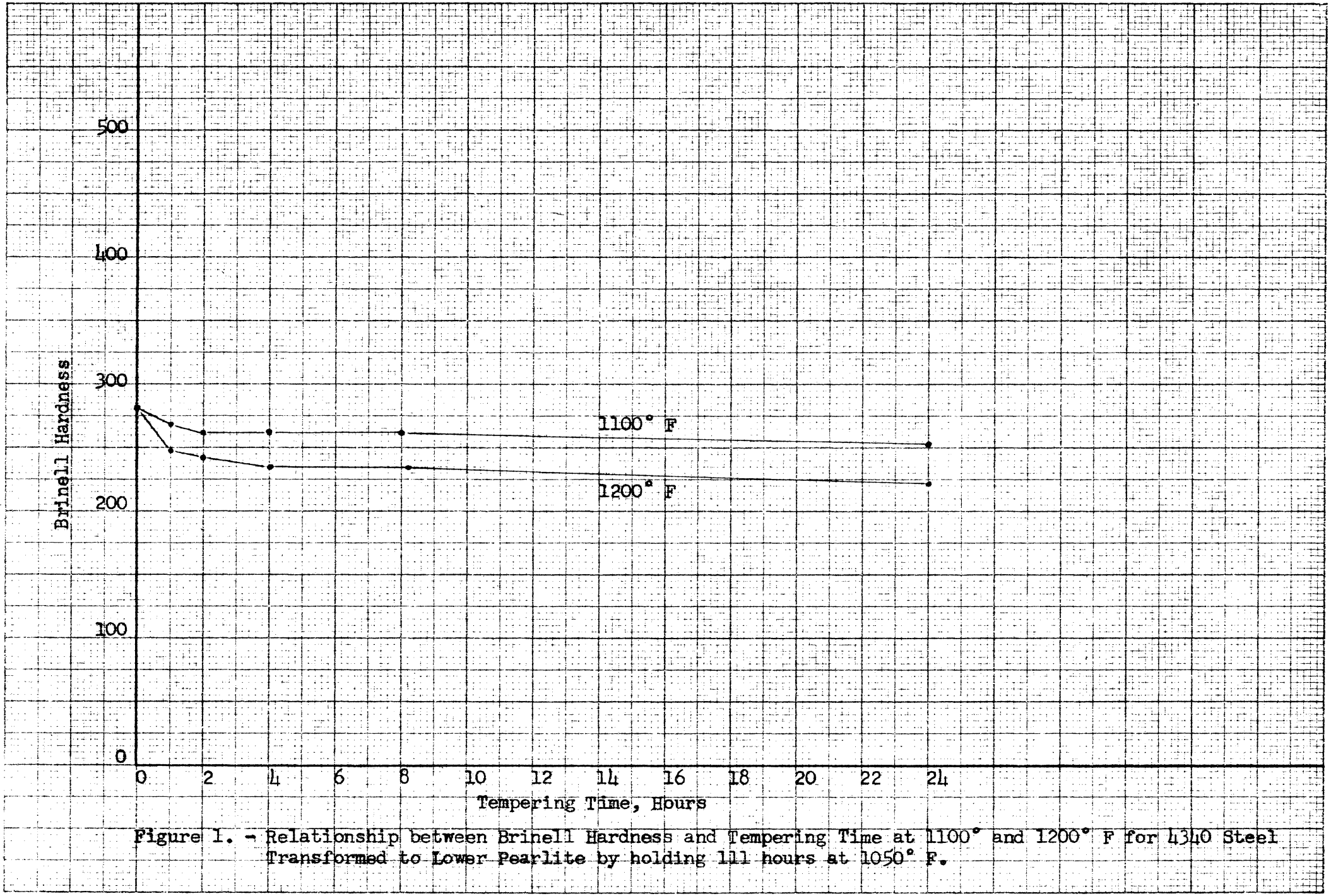

Figure 1. - Relationship between Brinell Hardness and Tempering Time at 1100° and 1200° F for 4340 Steel Transformed to Lower Pearlite by holding 111 hours at 1050° F.

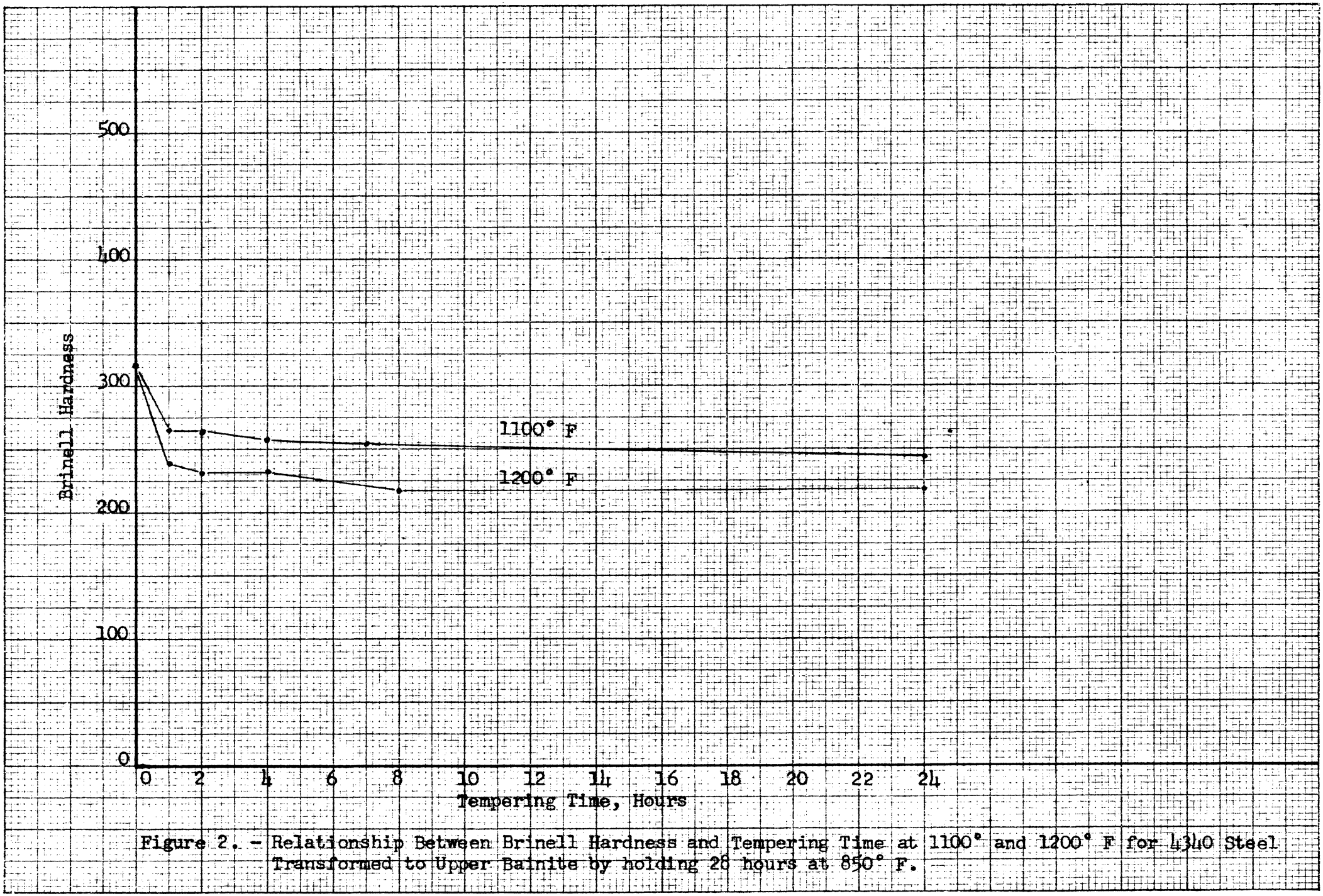

Figure 2. - Relationship Between Brinell Hardness and Tempering Time at 1100° and 1200° F for 4340 Steel Transformed to Upper Bainite by holding 28 hours at 850° F.

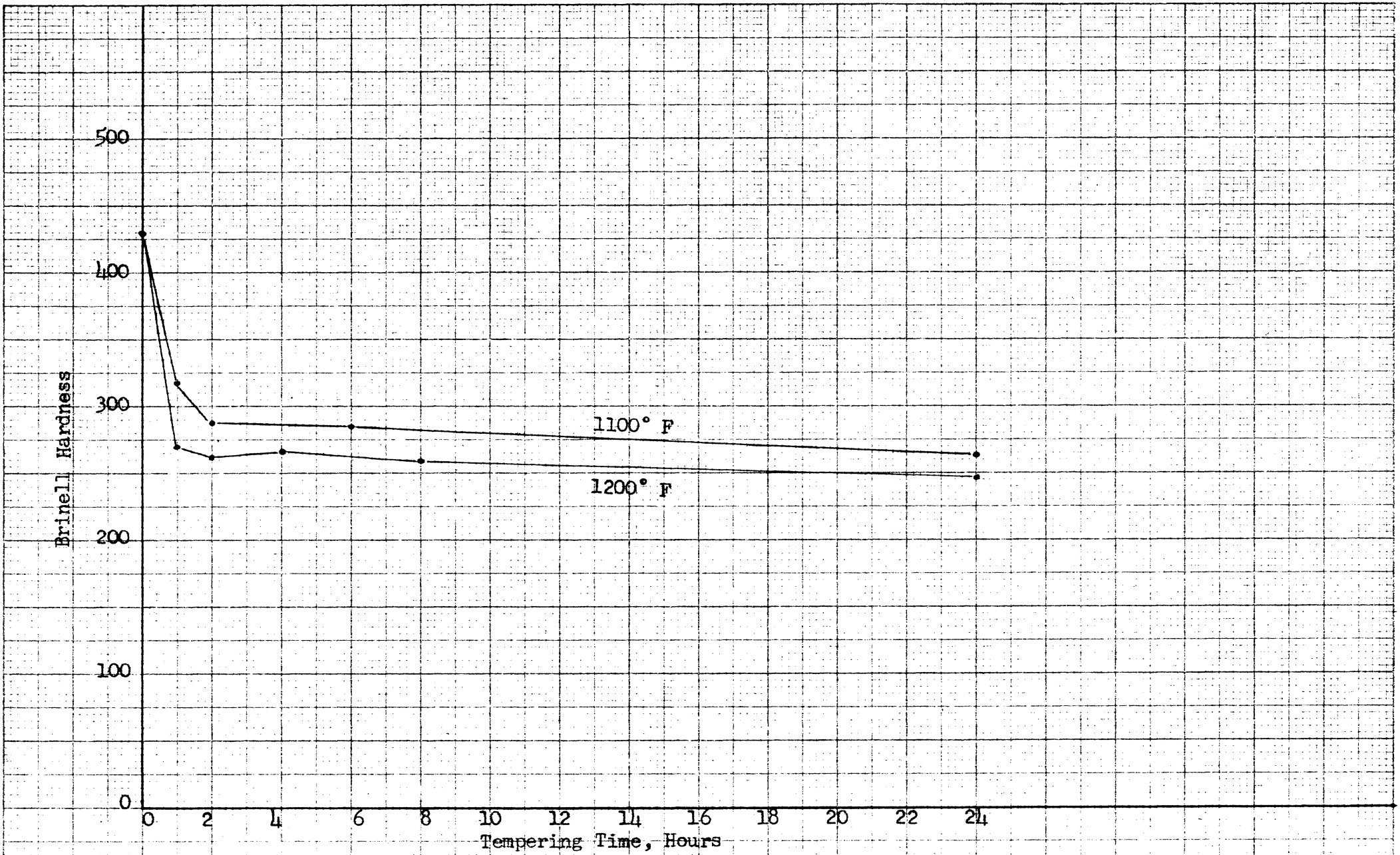

Figure 3. - Relationship between Brinell Hardness and Tempering Time at 1100° and 1200° F for 4340 Steel Transformed to Lower Bainite by holding 1.5 hours at 650° F.

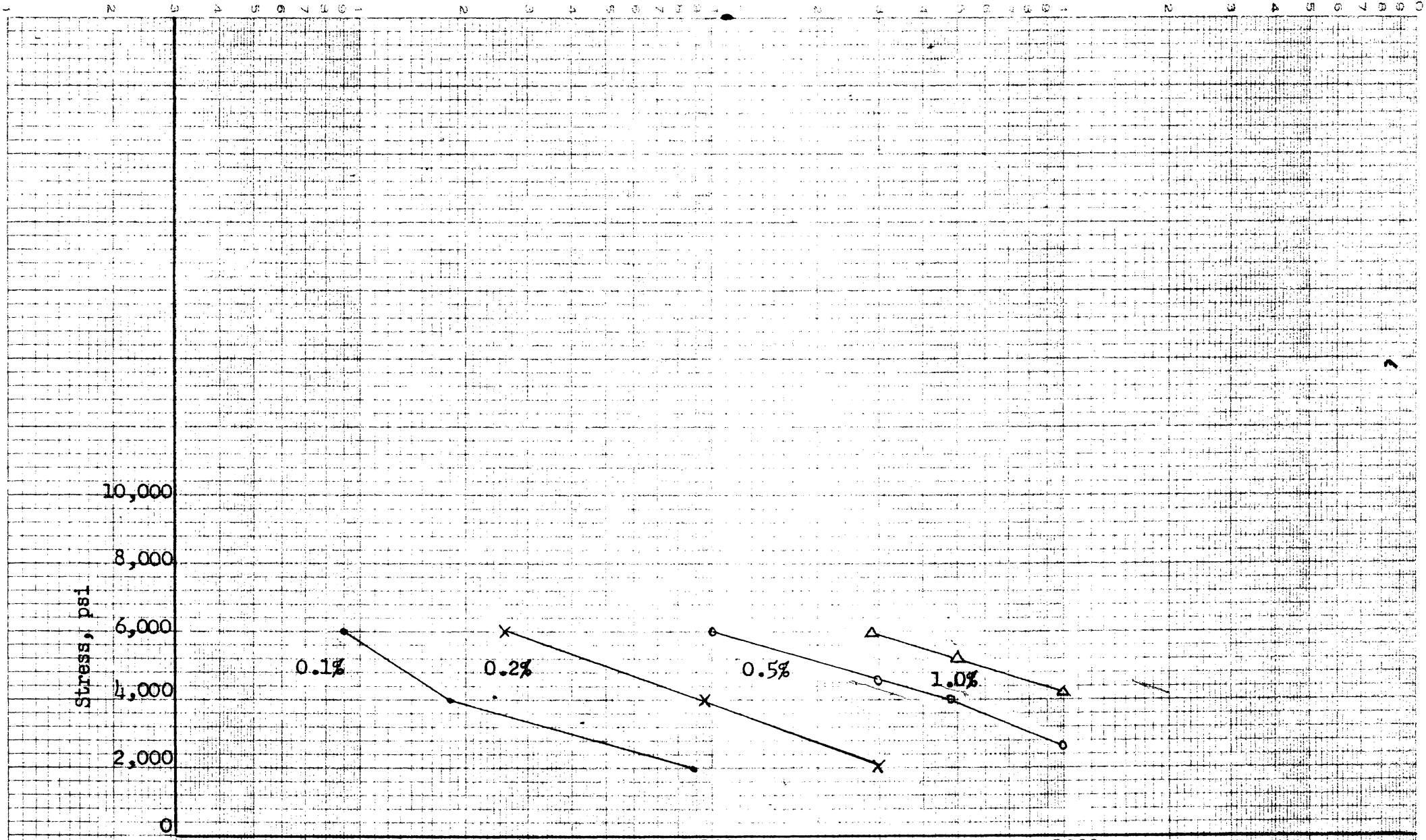

Figure 4. - Stress vs. Time for Specified Total Deformations at 1100° F for 4340 Steel Normalized 1 hour at 1750° F + 1 hour at 1100° F. Brinell Hardness 292 to 311.

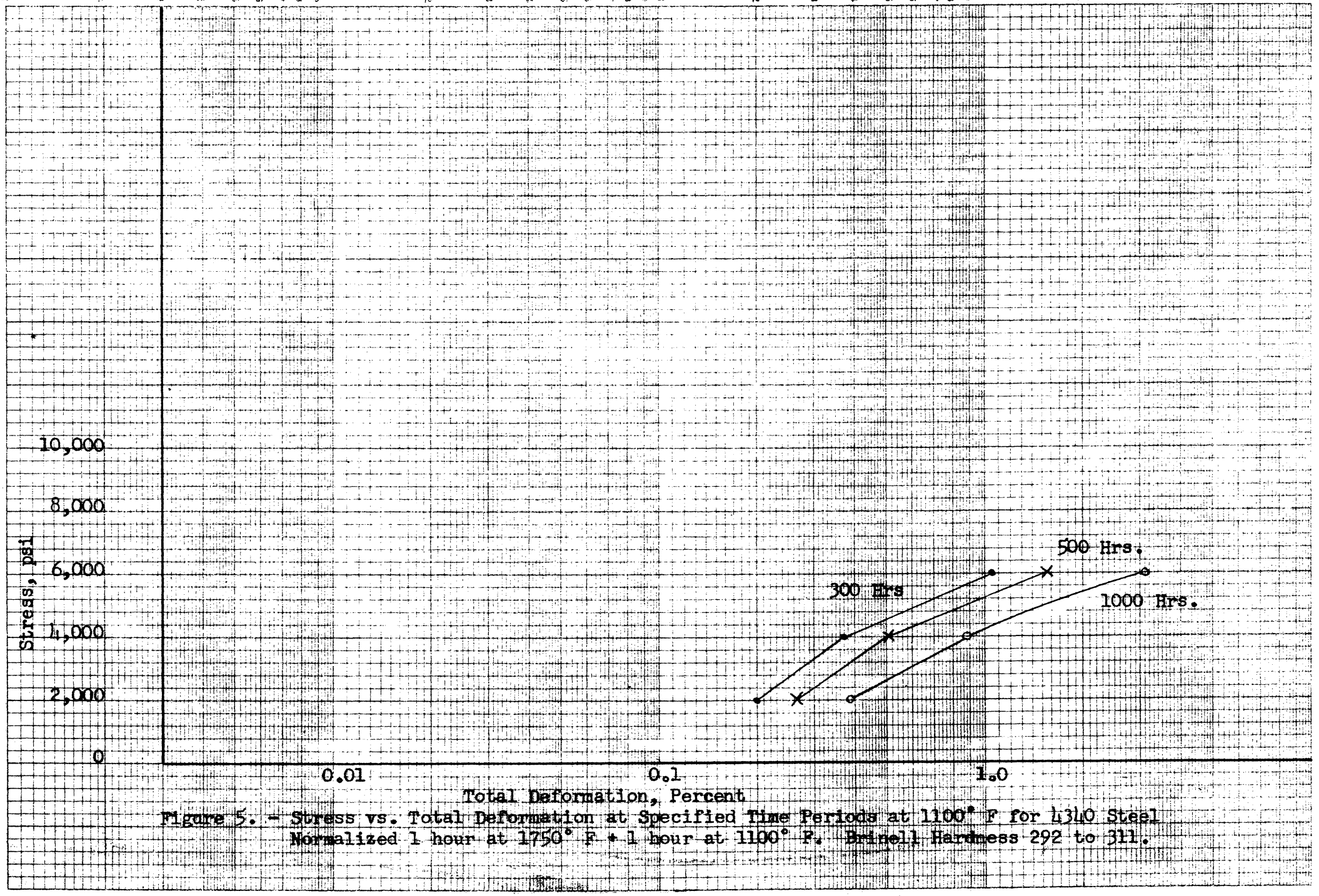

Figure 5. - Stress vs. Total Deformation at Specified Time Periods at 1100° F for 4340 Steel Normalized 1 hour at 1750° F + 1 hour at 1100° F. Brinell Hardness 292 to 311.

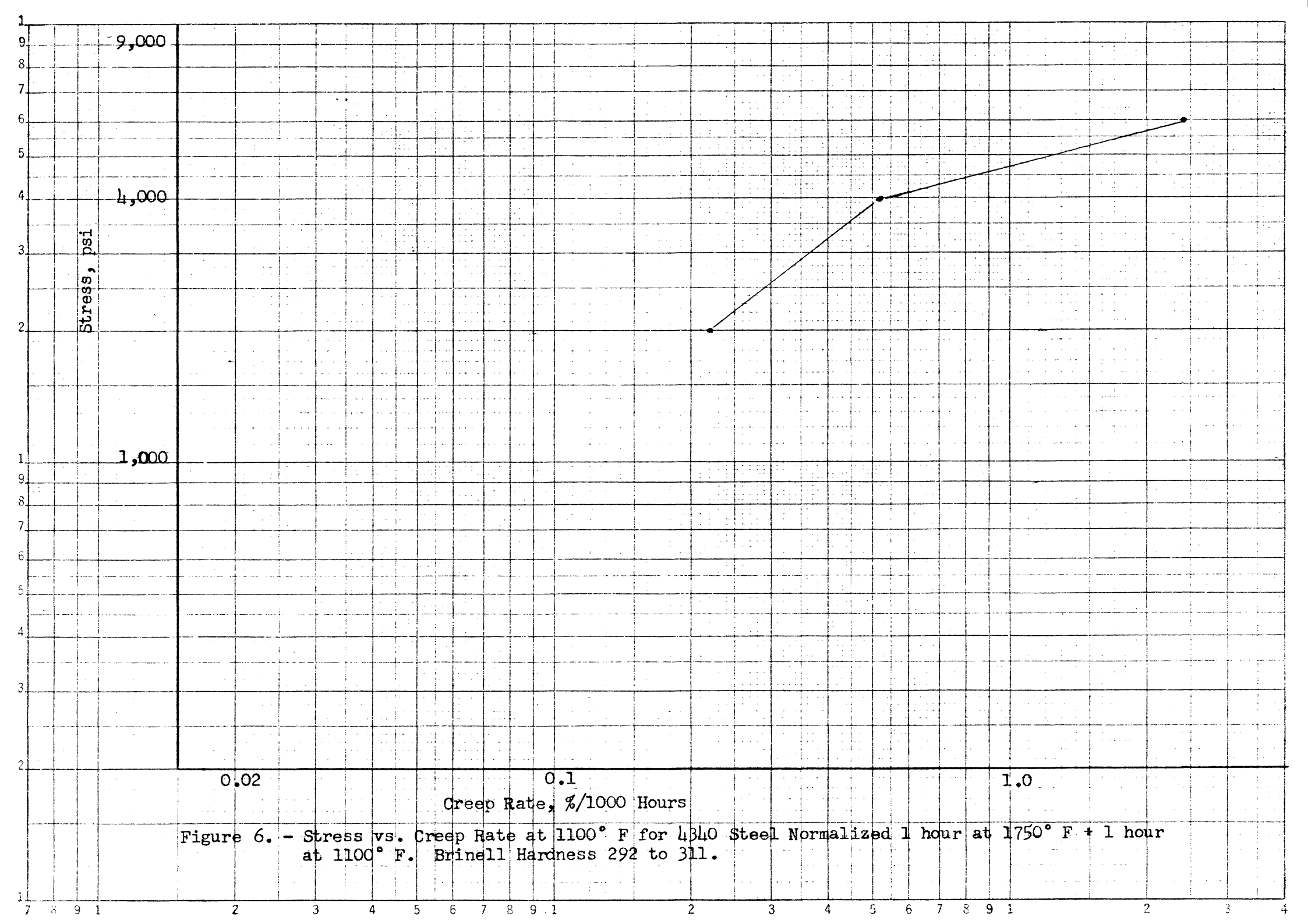

Figure 6. - Stress vs. Creep Rate at 1100° F for 4340 Steel Normalized 1 hour at 1750° F + 1 hour at 1100° F. Brinell Hardness 292 to 311.

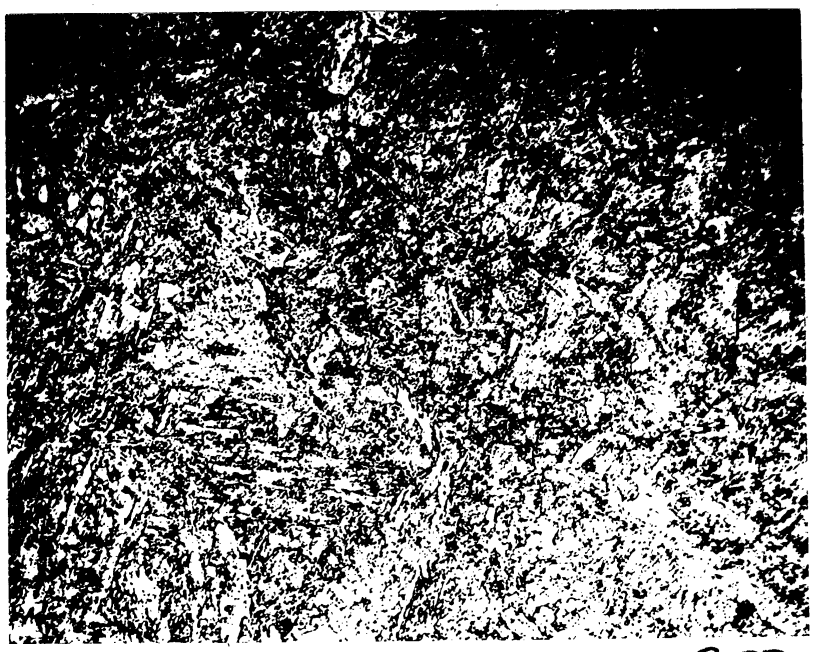

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Figure 7. - 4340 Steel Normalized 1 hour at 1750° F + 1 hour at 1100° F. (X500).

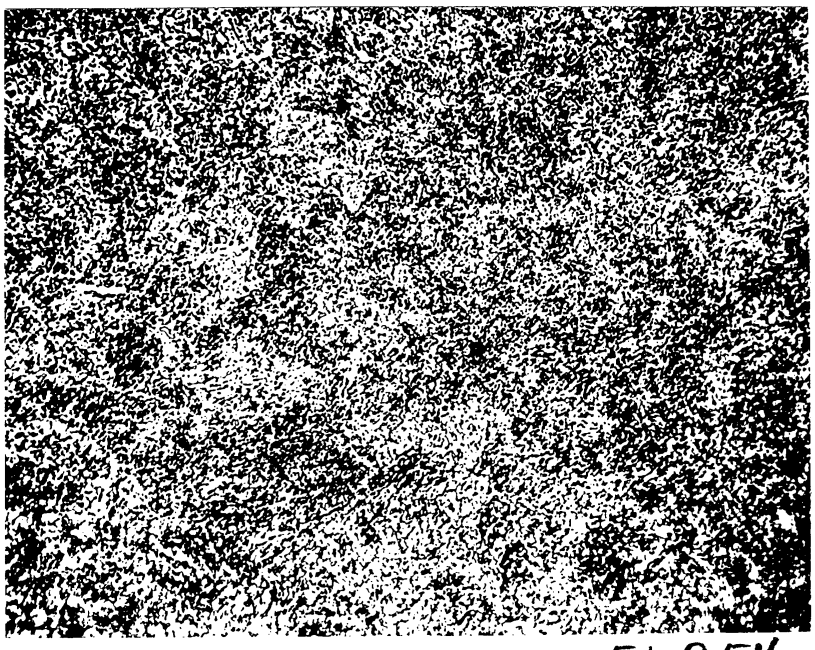

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Figure 8. - 4340 Steel Normalized 1 hour at 1750° F + 1 hour at 1100° F; Creep Tested at 1100° F and 4000 psi for 1056 hours. (X500).

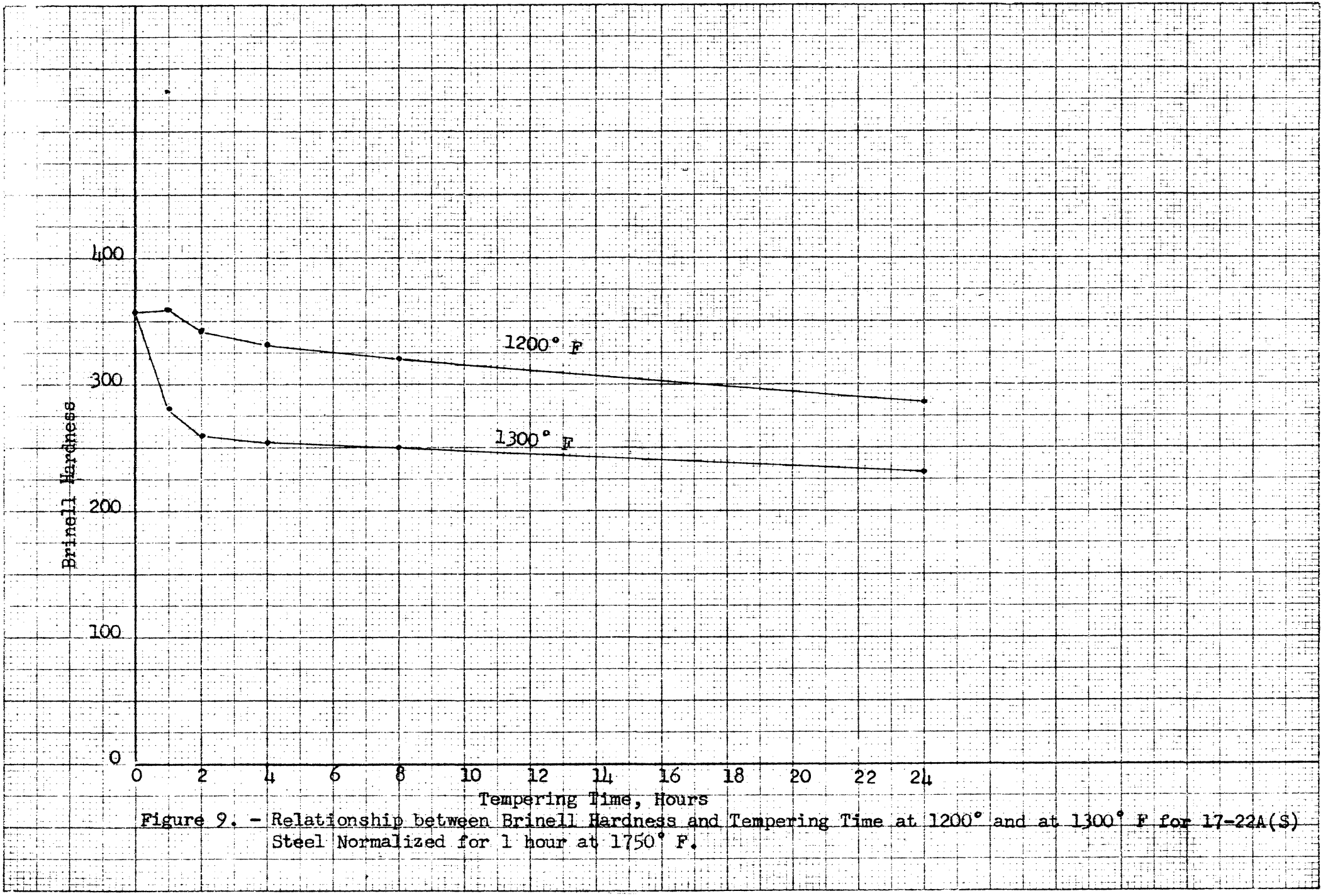

Figure 9. - Relationship between Brinell Hardness and Tempering Time at 1200° and at 1300° F for 17-22A(S) Steel Normalized for 1 hour at 1750° F.

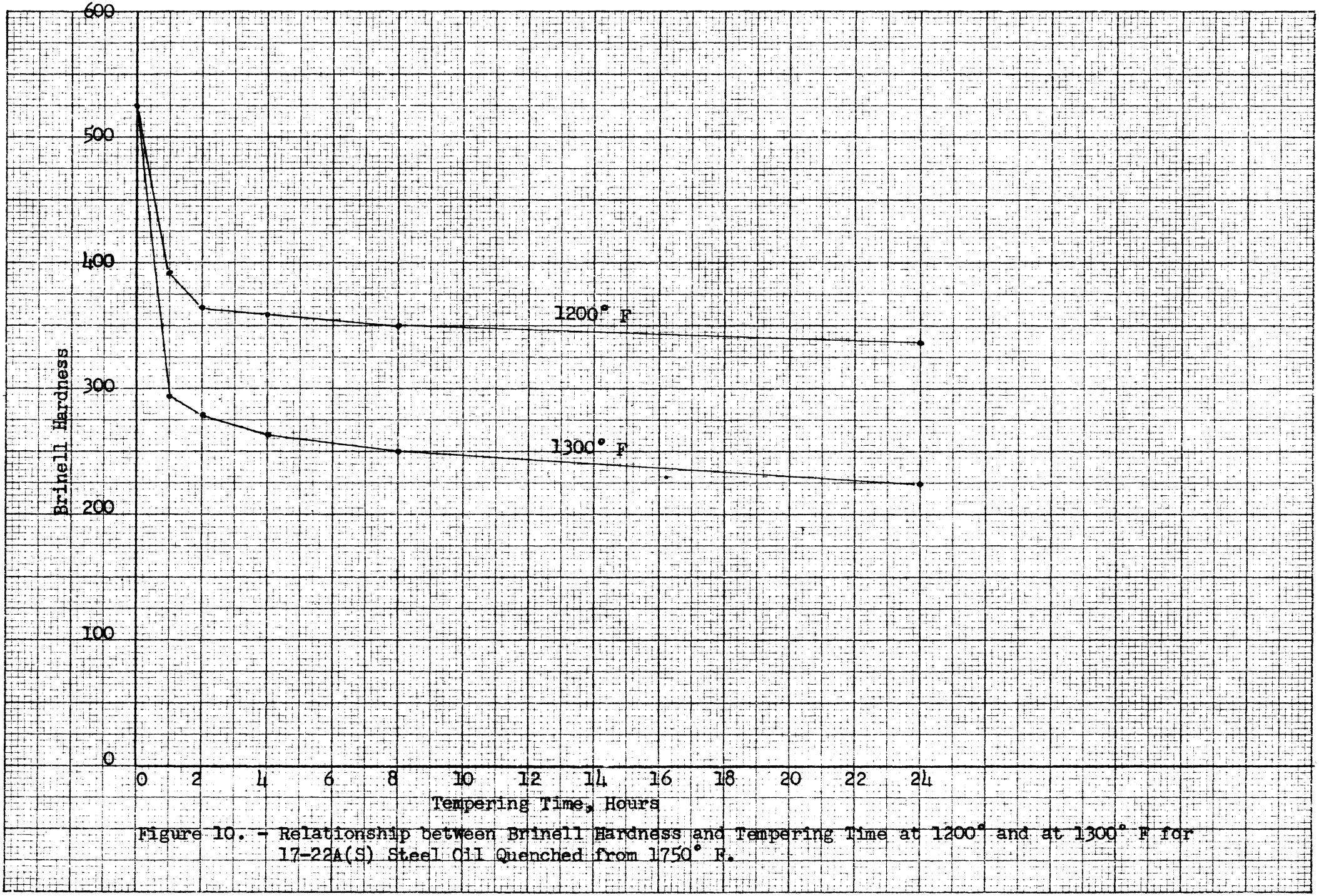

Figure 10. - Relationship between Brinell Hardness and Tempering Time at 1200° and at 1300° F for 17-22A(S) Steel Oil Quenched from 1750° F.

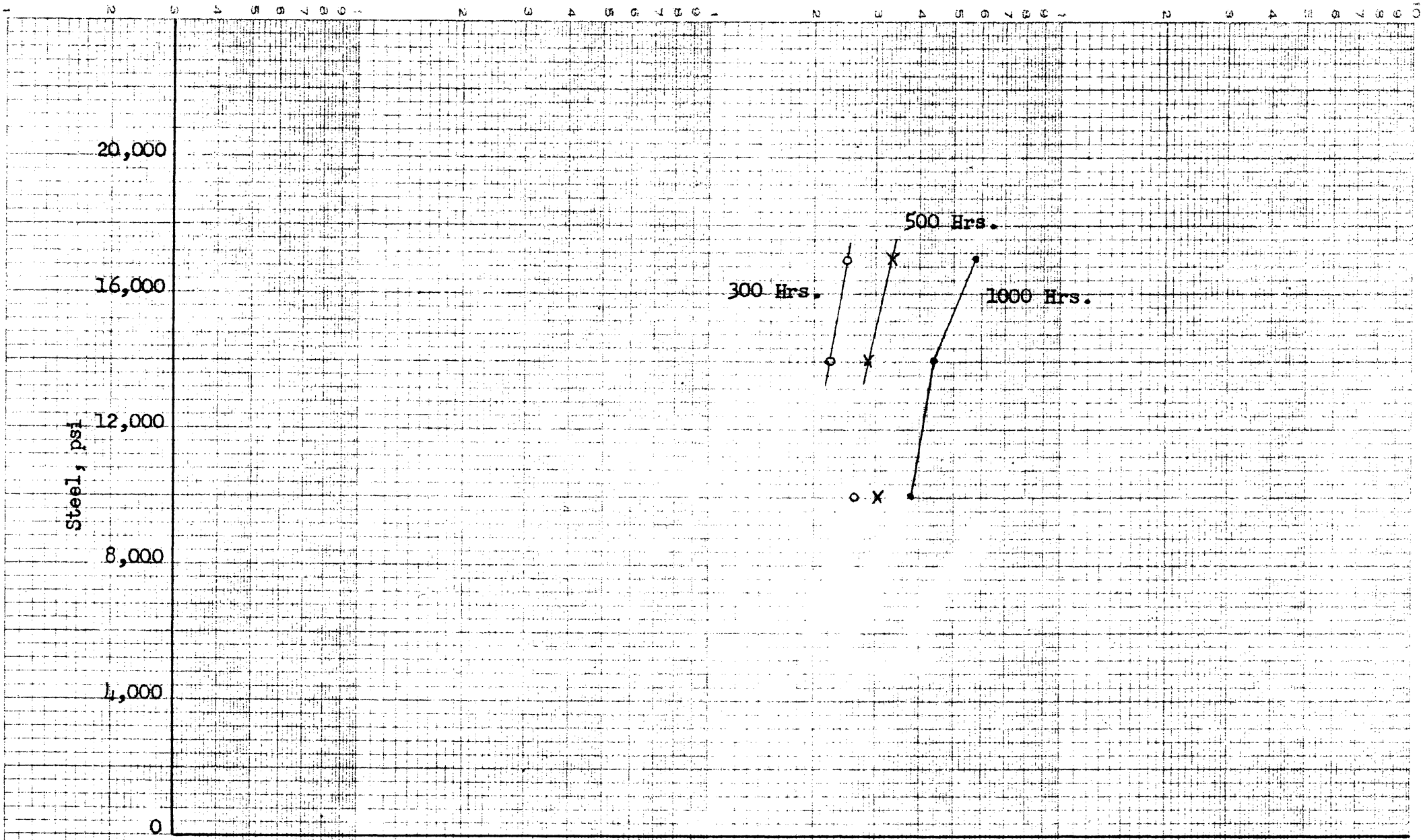

Figure 11. - Stress vs. Total Deformation at Specified Time Periods at 1100° F for 17-22A(S) Steel Normalized 1 hour at 1750° F + 10 hours at 1200° F. Brinell Hardness 291 to 317.

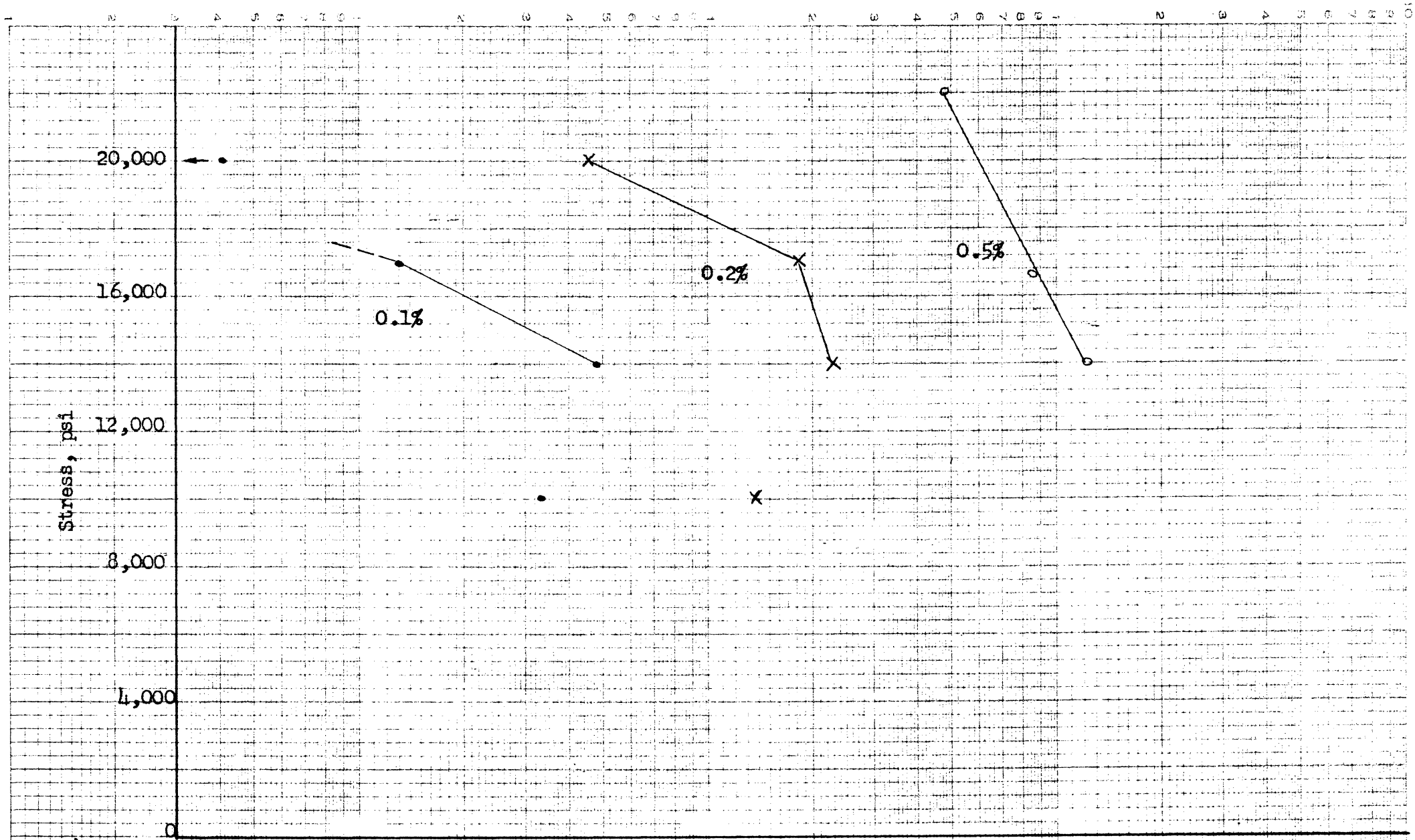

Figure 12. - Stress vs. Time for Indicated Total Deformations at 1100° F for 17-22A(S) Steel Normalized 1 hour at 1750° F + 10 hours at 1200° F. Brinell Hardness 291 to 317.

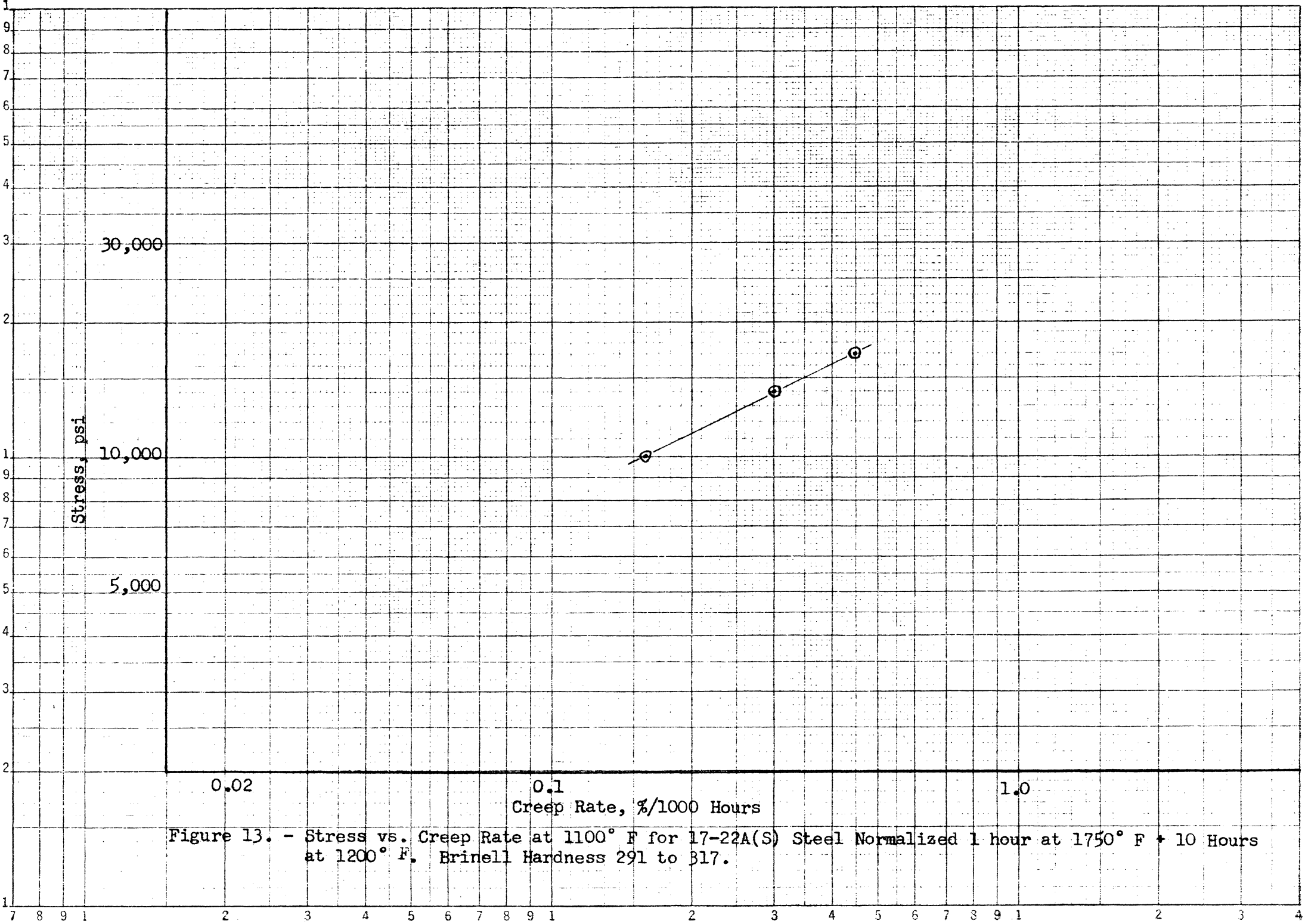

Figure 13. - Stress vs. Creep Rate at 1100° F for 17-22A(S) Steel Normalized 1 hour at 1750° F + 10 Hours at 1200° F. Brinell Hardness 291 to 317.

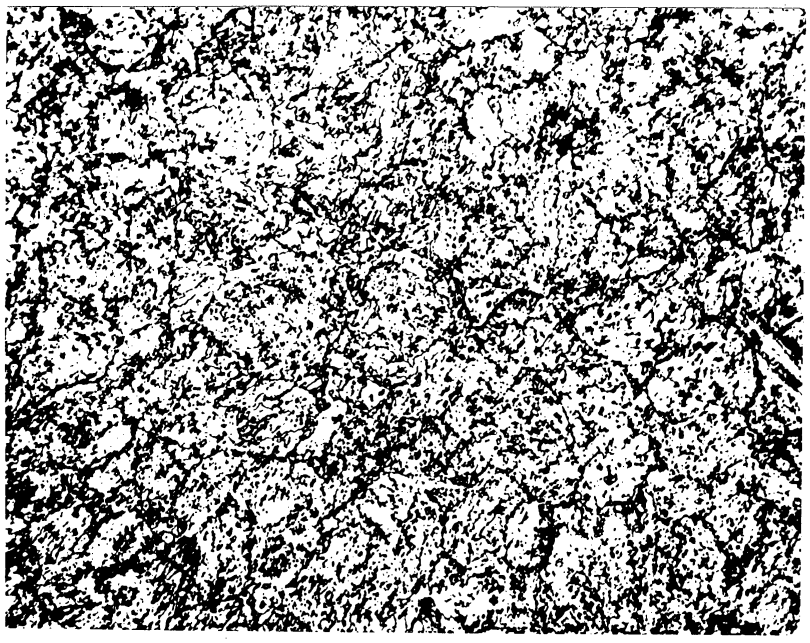

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Figure 14. - 17-22A(S) Steel Normalized 1 hour at 1750° F + 10 hours at 1200° F. (X500).

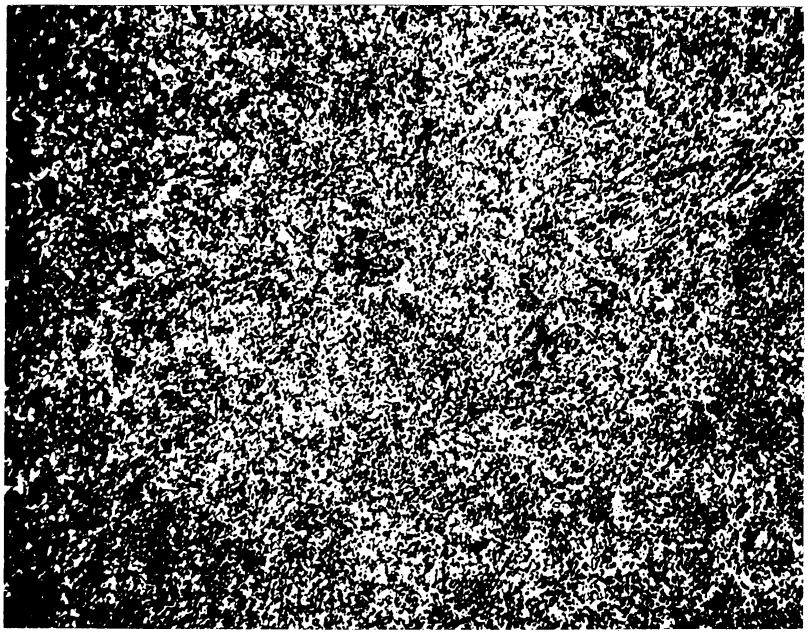

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Figure 15. - 17-22A(S) Steel Normalized 1 hour at 1750° F + 10 hours at 1200° F; Creep Tested at 1100° F and 17,000 psi for 1036 hours. (X500).

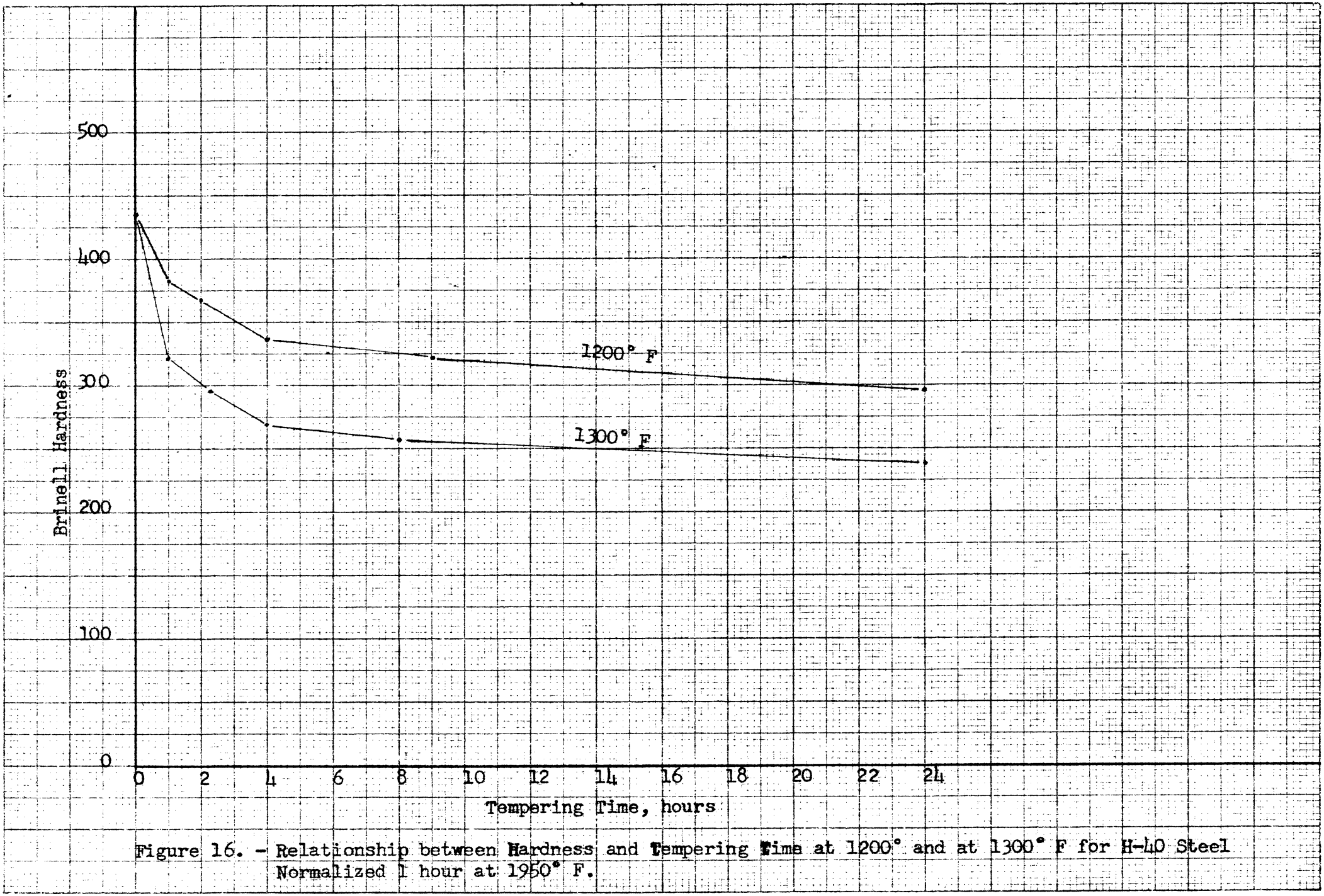

Figure 16. - Relationship between Hardness and Tempering Time at 1200° and at 1300° F for H-40 Steel Normalized 1 hour at 1950° F.

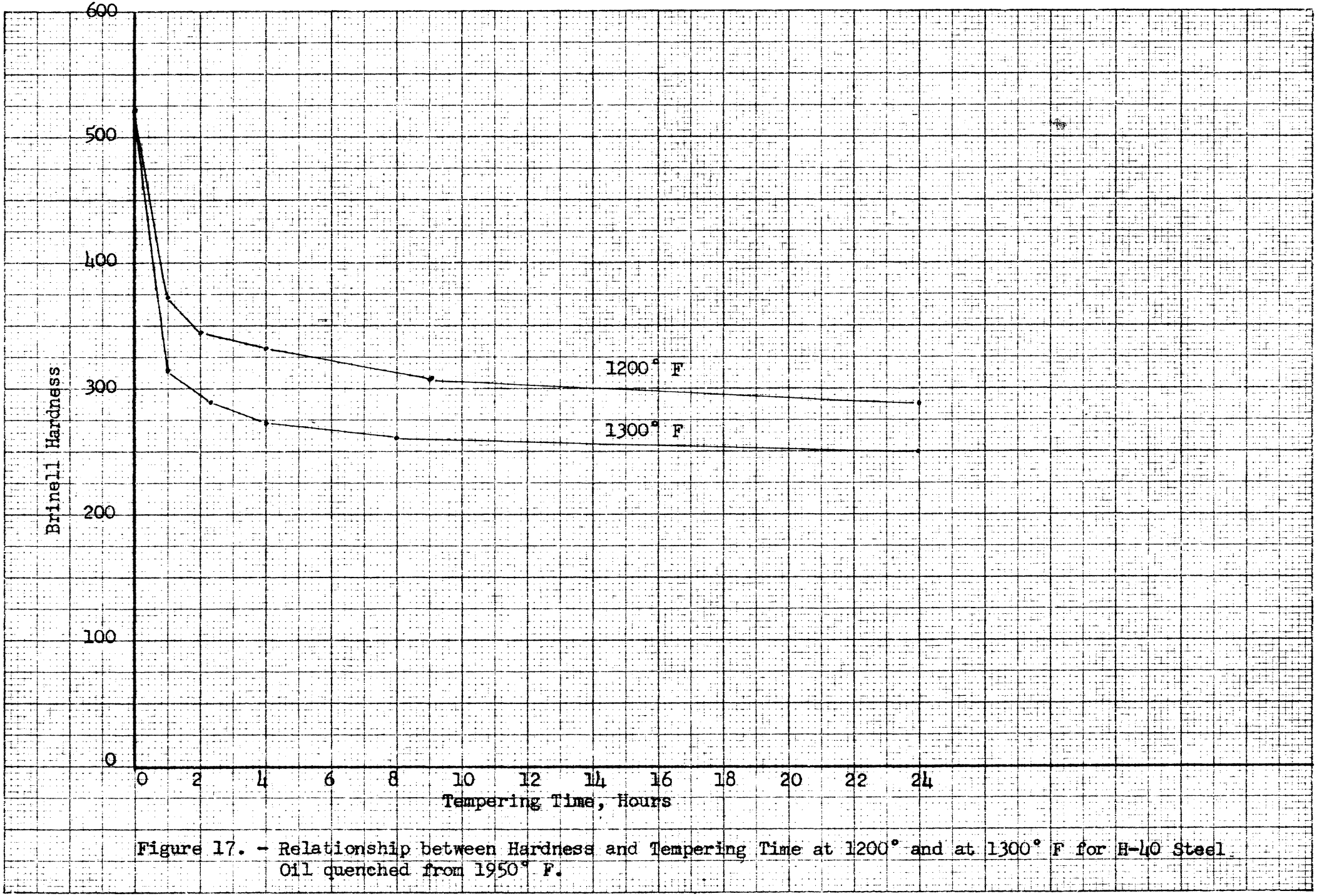

Figure 17. - Relationship between Hardness and Tempering Time at 1200° and at 1300° F for H-40 Steel Oil quenched from 1950° F.

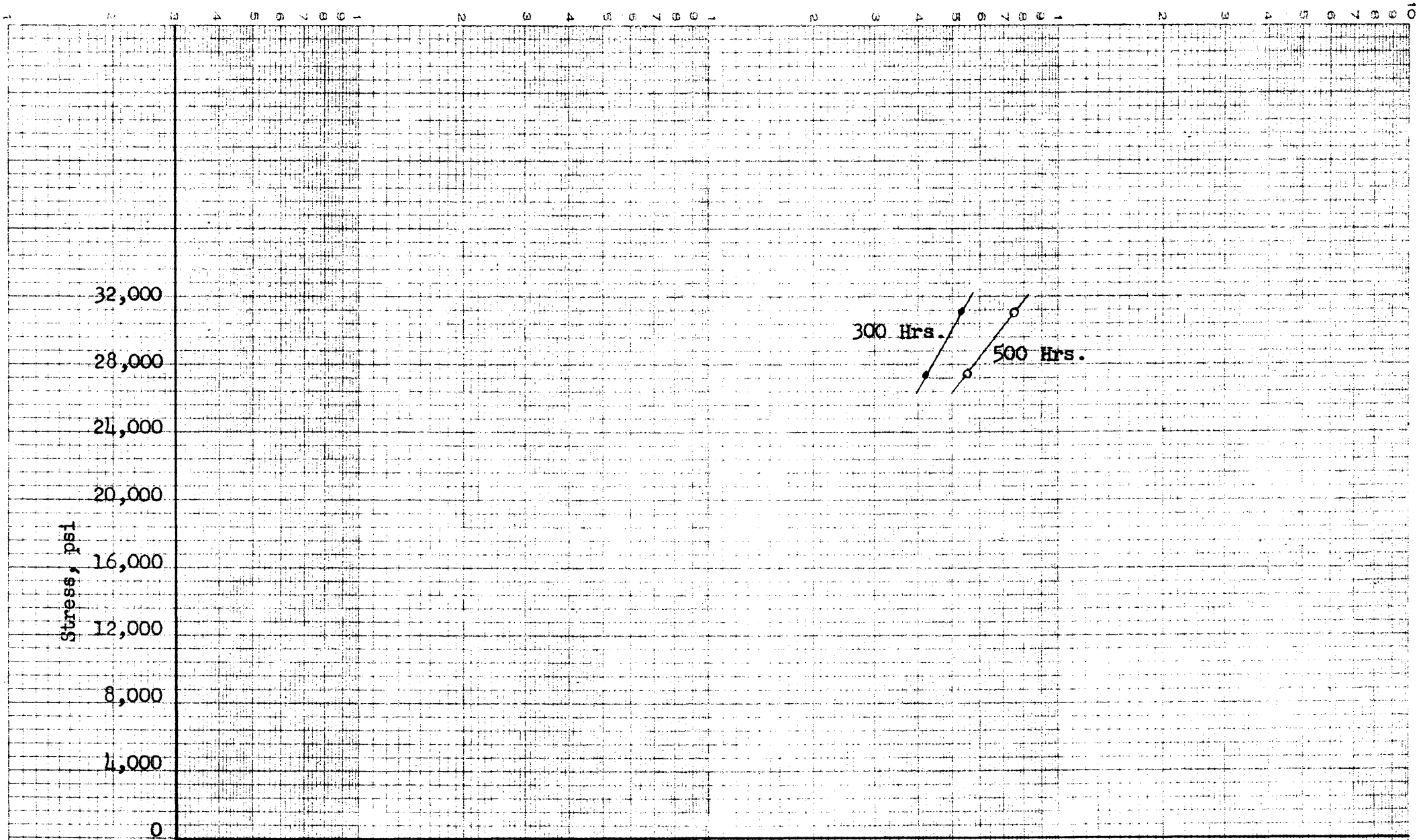

Figure 18. - Stress v. Total Deformation at 1100° F for Specified Time Periods for H-40 Steel Normalized 1 Hour at 1950° F + 10 Hours at 1200° F. Brinell Hardness 312 to 320.

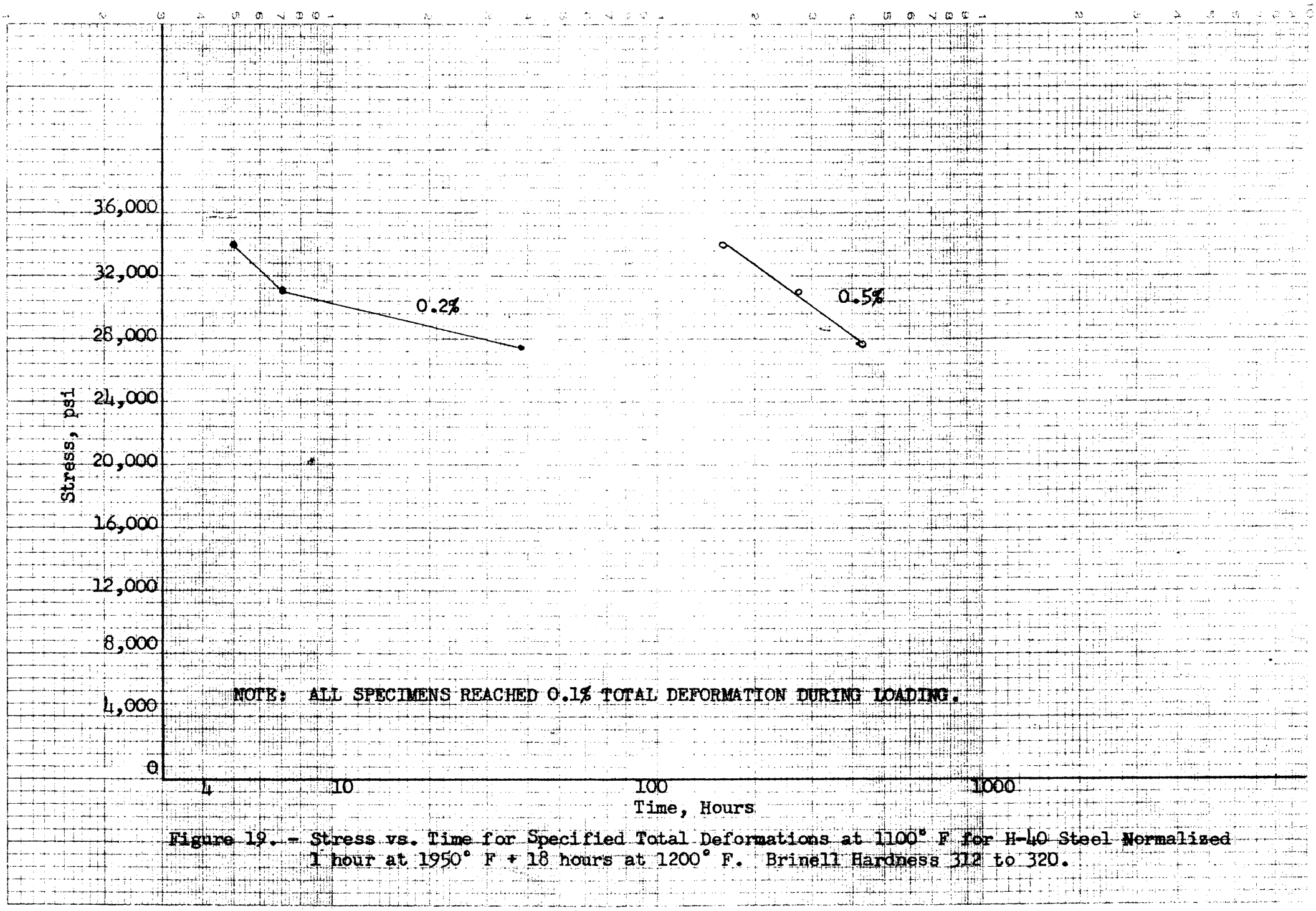

Figure 19. - Stress vs. Time for Specified Total Deformations at 1100° F for H-40 Steel Normalized 1 hour at 1950° F + 18 hours at 1200° F. Brinell Hardness 312 to 320.