REPORT

ON

INFLUENCE OF VARIATIONS IN CHEMICAL COMPOSITION AND HEAT TREATMENT ON THE RUPTURE PROPERTIES OF COMMERCIAL HEATS OF "17-22-A"V STEEL

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INFLUENCE OF VARIATIONS IN CHEMICAL COMPOSITION AND HEAT TREATMENT ON THE RUPTURE PROPERTIES OF COMMERCIAL HEATS OF "17-22-A"V STEEL

Rupture tests were carried out on specimens from eight commercial heats of "17-22-A"V steel at 1100°F. A few tests were also run at 1200°F. A number of heat treatments were studied for heats which showed low and intermediate hardenability on both bar stock and large section sizes. All of the heats were tested as either specimens cut from bars inserted in large blocks or as specimens cut from large blocks to simulate heat treatment of disks for the gas turbines of jet engines. Variations in heat treatment on the low hardenability heats to determine ways to obtain both adequate hardness and rupture properties included increased normalizing, tempering, oil quenching, and double normalizing. Considerable experimenting was also done with an "isothermal treatment" which consisted ofmoving the specimens from the austenitizing furnace to a furnace at 1200° or 1225°F, holding for six hours, and air cooling without further tempering.

Heats having carbon below 0.26 percent and manganese below 0.70 percent showed low hardenability in comparison to those indicated by the experimental heats as discussed in the previous Reports 199 and 200. The previous work had indicated that best rupture properties were associated with normalizing from 1800°F and tempering for 6 hours at 1200°F. These treatments gave the hardness values (in the range of 300 to 340 Brinell) required for disks. The rupture strengths at 1100°F were also indicated to be above 50,000 psi for 100 hours and of the order of 35,000 psi for 1000 hours. After the low hardenability of the commercial heats was found, carbon was increased to 0.27-0.30 percent and manganese to 0.70-0.84 percent.

SUMMARY AND CONCLUSIONS

An extensive study of the relations of heat treatment and section size to rupture properties at 1100°F was carried out on commercially produced "17-22-A"V steel. A small amount of rupture testing was also done at 1200°F. In most cases, the number of rupture tests was very limited. However, appraisal of the rupture data indicated that the reported rupture properties, as based on wide experience with the test, are probably quite reliable. It must be recognized, however, that some uncertainties exist due to uncertainty of the shape of the stress - rupture time curves, possible specimen to specimen variation, and unrecognized errors in testing.

The data obtained indicated the following trends for response to heat treatment and rupture properties at 1100°F:

1. Stock from commercially produced heats did not have as high hardenability as the original experimental heats described in Reports 199 and 200. To obtain hardness values between 300 and 340 Brinell on direct normalizing from 1800° or 1850°F and tempering for 6 hours at 1200°F, it was found necessary to raise the carbon content to 0.27-0.30 percent and the manganese to 0.80-0.84 percent.

2. Hardness values in the range of 300-340 BHN were obtained on normalizing section sizes as thick as 6 inches from 1850°F, followed by a 6-hour temper at 1200°F, when the carbon and manganese were in the ranges given above.

3. The rupture strengths at 1100°F for the large sections which hardened properly when normalized from 1850°F were approximately 40,000 psi for 100 hours and 30,000 psi for 1000 hours with quite high elongation.

These values are somewhat lower than the corresponding values of 45,000 to 57,000 psi and 30,000 to 36,500 psi established for the experimental heats.

4. Increasing the normalizing temperature to 1950°F gave adequate hardness in the low hardenability heats (0.22-0.26 C and 0.56-0.62 Mn) in heavy section sizes. The rupture strengths approached those of the experimental heats and were above those of the high hardenability heats normalized from 1850°F. The data suggested, however, that rupture strengths decreased with increasing hardenability after a 1950°F normalize.

5. Increasing the cooling rate of low hardenability heats by oil quenching from 1850°F gave adequate hardness and a high level of rupture strength. One or two test points suggested, however, that care must be exercised to avoid martensite formation on liquid quenching, if rupture strengths are to be maintained at a high level.

6. Double normalizing the low hardenability heats increased hardenability and rupture strength at some sacrifice in elongation. The increase in hardenability, however, was not sufficient to obtain proper hardening on normalizing large sections from 1850°F.

7. Specimens produced by austenitizing and then transferring to a furnace at 1200° or 1225°F for 6 hours for "isothermal transformation" gave quite good rupture properties. They were, however, no better than those characteristic of material with proper direct normalizing and tempering.

8. The relationships of microstructure to rupture properties are not yet clear. In general, fine to medium grain size bainites have excellent rupture properties and adequate hardness. However, a rather wide range in structures with little variation in rupture properties was observed. The commercial heats did not have the sharp coarsening temperature between 1800° and 1850°F observed for the first experimental Heat A80. Low

hardenability heats were ferrite and pearlite when the hardness was low. On the other hand, the "isothermally transformed" specimens appeared to be ferrite and pearlite with high hardness and quite good rupture strength. As previously mentioned, there are indications that martensite should be avoided.

9. The use of higher levels of carbon and manganese together with an 1850°F normalize has apparently given adequate hardening from 1850°F with some sacrifice in rupture strength. The data suggest that lower carbon and manganese heats give better rupture strength with adequate hardenability on normalizing from 1950°F. The data suggest that the higher hardenability heats would not respond as well to the 1950°F treatment. It appears that further research on compositon, hardenability, and heat treatment is warranted. Apparently the difference in melting practice and/or hot working conditions between experimental and commercial heats influences the response to heat treatment.

The 1200°F rupture tests on material with proper response to heat treatment (as judged by 1100°F rupture properties) were limited to isothermal treatments. The results indicated that "17-22-A"V steel with proper response to heat treatment can be expected to have rupture strengths at 1200°F of the order of 28,000-30,000 psi for 100 hours and 13,000-15,000 psi for 1000 hours. Corresponding elongations should be of the order of 10 and 3-5 percent for the same time periods.

TEST MATERIALS

A number of machined 0.505-inch diameter tensile specimens from eight heats of "17-22-A"V steel were furnished for rupture testing at 1100° and 1200°F. They were reported to have the following analysis:

Chemical Composition (percent)

Heat No.	C	Mn	P	S	Si	Cr	Ni	Mo	V
25919	0.22	0.56	0.013	0.018	0.65	1.24	0.22	0.50	0.85
11625	0.26	0.62	0.016	0.014	0.68	1.34	0.34	0.51	0.77
11401	0.24	0.60	0.013	0.020	0.74	1.24	0.18	0.54	0.80
11574	0.27	0.84	0.017	0.013	0.66	1.34	0.32	0.51	0.80
11573	0.27	0.84	0.015	0.016	0.80	1.31	0.29	0.50	0.82
11504	0.28	0.86	0.016	0.015	0.70	1.30	0.30	0.50	0.80
11833	0.29	0.70	0.019	0.017	0.71	1.43	0.31	0.51	0.81
11704	0.30	0.79	0.013	0.015	0.70	1.40	0.32	0.50	0.83

The section sizes heat treated were bar stock, bar stock sealed in a 4-inch x 9-inch x 9-1/2-inch block, and various sizes of blocks. The heat treatments used were either a normalize, an oil quench, or an "isothermal transformation" at 1200° or 1225°F. Except for the isothermal transformations, all material was tempered for 6 hours at 1200° or 1225°F. The details of the heat treatments of the various section sizes and the resulting hardness data are presented in Table I.

Where the applied stresses for rupture testing were greater than 40,000 psi, the diameters were reduced to less than 0.505 inch in order to bring the load requirements within the capacity of the rupture units.

RESULTS

The rupture data obtained at 1100° and 1200°F for the various conditions of heat treatment are presented in Table II, the stress - rupture time curves in Figures 1 through 10, and the microstructures in Plates 1 through 21. The influence of various heat treating conditions on the elevated temperature properties of these individual heats of "17-22-A"V steel was as follows:

Influence of Heat Treatment on the Rupture Properties of Heat 25919

Both the response to heat treatment, as measured by hardness, and the rupture strengths and ductilities are summarized for Heat 25919 in the following tabulation:

Rupture Strength and Ductility of Heat 25919 at 1100°F

Heat Treatment	B H N	Rupture Strength (psi) 100-hr	Rupture Strength (psi) 1000-hr	Rupture Elongation (%) 100-hr	Rupture Elongation (%) 1000-hr
Bar Stock. N. 1800°F + 6 hrs at 1200°F	248/255	36,000	(26,500)	15	(5)
Bar Stock. N. 1850°F + 6 hrs at 1200°F	321/331	49,000	27,000	10	(3)
Bar Stock Sealed in Block. N. 1850°F + 6 hrs at 1200°F	207	32,000	29,000	40	(35)
Bar Stock Sealed in Block. N. 1950°F + 6 hrs at 1200°F	302	50,000	(37,500)	5	(1)
Bar Stock. N. 1950°F + N. 1800°F + 6 hrs at 1200°F	311	45,000	(32,000)	5	(1)
Bar Stock. N. 1950°F + N. 1850°F + 6 hrs at 1200°F	341	52,500	(34,500)	5	(1)
Bar Stock. N. 2100°F + N. 1800°F + 6 hrs at 1200°F	302	(>52,000)	(~26,000)	(4)	(1)
10" Square by 6" Section. N. 1950°F + 6 hrs at 1200°F (surface)	255/262	(47,000)	(32,000)	(11)	(2.!
10" Square by 6" Section. N. 1950°F + 6 hrs at 1200°F (quarter)	255/262	(45,000)	(30,000)	(12)	(2.5)
10" Square by 6" Section. O.Q. 1850°F + 6 hrs at 1200°F (surface)	341	(52,000)	(38,000)	4	(2)
10" Square by 6" Section. O.Q. 1850°F + 6 hrs at 1200°F (quarter)	331	49,000	37,000	5	(3)
10" Square by 6" Section. N. 1950°F + N. 1850°F + 6 hrs at 1200°F (quarter)	229/241	35,000	(29,000)	25	(15)

( ) - Brackets indicate extrapolated values.
N. - Normalize.
O.Q. - Oil Quench.

The data indicate that in heat treating bar stock from this heat it was necessary to raise the normalizing temperature from 1800° to 1850°F to obtain the desired hardness of approximately 300 Brinell after tempering. The increase in normalizing temperature to 1850°F resulted in a substantial increase in rupture strength for 100 hours at 1100°F with little change at 1000 hours and some decrease in elongation, Figure 1A.

Sealing the bar stock in a 4 inch x 9 inch x 9-1/2 inch block, normalizing from 1850°F and tempering gave the low hardness of 207 Brinell. The 100-hour rupture strength at 1100°F was lowered from 49,000 psi for bar stock normalized at 1850°F to 32,000 psi for the block specimen normalized at the same temperature. However, the 1000-hour rupture strength of the block specimen was increased slightly to 29,000 psi and the elongation at fracture was increased to above 35 percent, Figure 1B. Raising the normalizing temperature for the block specimens to 1950°F and tempering resulted in the desired hardness level, together with an increase in the 100-hour and 1000-hour rupture strength at 1100°F to 50,000 and 37,500 psi, Figure 1B. The ductility, however, was lowered to approximatly 5 percent and 1 percent, respectively.

Double normalizing the bar stock initially at 1950°F and then at 1800° or 1850°F and tempering resulted in higher hardness and rupture strength at 1100°F than did the bar stock receiving only a single 1800° or 1850°F normalizing treatment prior to tempering, Figure 1C. The ductility at fracture of the double normalized material was low at both 100 and 1000 hours. The higher renormalizing temperature of 1850°F gave higher strength. However, increasing the initial normalizing temperature to 2100°F only reduced 1000-hour strength.

The large 10-inch square by 6-inch sections did not harden to the required 300 BHN even at the high normalizing temperature of 1950°F.

Increasing the cooling rate by oilquenching from 1850°F and tempering produced a hardness of 331 to 341 Brinell, higher 1000-hour rupture strength at 1100°F of 37,000 to 38,000 psi with a ductility of approximately 2 percent, Figure 1D. Double normalizing the large section, first from 1950°F, then from 1850°F, followed by tempering did not improve on the hardness or rupture strength, but did result in higher ductility as least for the quarter section. The two rupture tests run on the surface section gave erratic results.

The bar stock normalized from 1800° and 1850°F and tempered, Plates 1A and 1B, had similar structures of fine grained ferrite containing small areas of dark etching transformation products. Some unreported work undertaken to establish the effect of heat treatment on the microstructure of this heat indicated that the dark etching constituent seen after normalizing from 1800°F was tempered martensite, whereas that seen after normalizing from 1850°F was tempered bainite.

When the bar stock was normalized in the large block from 1850°F and tempered, Plate 2A, fine pearlite formed instead of bainite. Increasing the normalizing temperature to 1950°F, Plate 2B, produced an increase in grain size with a structure which was not as easily interpreted. The dark etching constituent appeared to be tempered bainite. However, the ferrite grains appeared to differ from the 1850°F treatment in that an acicular pattern was present in the ferrite which could only be resolved with difficulty.

Normalizing bar stock at 1950°F prior to normalizing at 1800° or 1850°F, Plates 3A and 3B, apparently increased the tendency for bainite to form. The unreported work previously mentioned indicated that double normalizing resulted in an increased amount of bainite. Furthermore, the amount of bainite present increased with an increase in the second normalizing temperature.

Normalizing from 2100°F before normalizing at 1800°F resulted in a coarse grain, almost completely bainitic structure, Plate 4.

The strucutre of the samples from the 10-inch square by 6-inch thick blocks is difficult to explain. The microsections examined were taken from the ends of the tensile specimens submitted and therefore may not be representative of the material in the gage sections. It appears that:

(a) The 1950°F normalized surface section apparently consisted of coarse grained tempered bainite, Plate 5A. Renormalizing from 1850°F eliminated the duplex grain structure of Plate 5A to give more uniform finer grained ferrite, Plate 6A, together with lesser amounts of the same type of bainite found after normalizing from 1950°F. The reason for the low hardness of the surface sections in view of the structure is not evident.

The quarter sections of the normalized blocks had an intermediate ferrite grain size and contained small patches of fine pearlite, Plates 5B and 6B.

(b) The 10-inch square by 6-inch thick block, oil quenched from 1850°F and tempered, Plates 7A and 7B, appears to have an entirely acicular tempered bainitic structure. The high hardness, the high rupture strength at 1100°F, and the low ductility at fracture seem to be consistent with the structure.

Influence of Heat Treatment on the Rupture Properties of Heat 11625

The response to heat treatment of Heat 11625, as measured by hardness and rupture properties, at 1100° and 1200°F is summarized in the following tabulation:

Rupture Strength and Ductility of Heat 11625

Heat Treatment	B H N	Rupture Strength (psi)		Rupture Elongation (%)	
		100-hr	1000-hr	100-hr	1000-hr
1100°F					
Bar Stock (round). N. 1800°F + 6 hrs at 1200°F	331	(38,000)	--	(>10)	--
Bar Stock (round) Sealed in Block. N. 1850°F + 6 hrs at 1200°F	277/285	40,000	(31,500)	15	(<10)
Bar Stock (round) Sealed in Block. N. 1950°F + 6 hrs at 1200°F	352	50,000	(33,500)	5	(<4)
Bar Stock (round). Aus. 1850°F, cooled to and held for 6 hrs at 1200°F *	270/294	45,000	(38,000)	25	(<15)
Bar Stock (round). Aus. 1850°F, cooled to and held for 6 hrs at 1200°F *	285/311	44,000	34,500	8	(<4)
Bar Stock (round). Aus. 1950°F, cooled to and held for 6 hrs at 1225°F	321	(55,500)	33,500	5	(<2)
Bar Stock (round). Aus. 1800°F, Reaus. 1900°F, cooled to and held for 6 hrs at 1200°F	286/294	49,000	(36,500)	10	(<7)
1200°F					
Bar Stock. N. 1800°F + hrs at 1200°F	331	21,000	10,000	25	15
Bar Stock. Aus. 1850°F, cooled to and held for 6 hrs at 1200°F	285/311	28,500	15,000	10	5
Bar Stock. Aus. 1950°F, cooled to and held for 6 hrs at 1200°F	321	35,000	(15,500)	4	(<3)

Rupture Strength and Ductility of Heat 11625 (Cont.)

Heat Treatment	B H N	Rupture Strength (psi)		Rupture Elongation (%)	
		100-hr	1000-hr	100-hr	1000-hr
Bar Stock. Aus. 1800°F, Reaus. 1900°F, cooled to and held for 6 hrs at 1200°F	286/294	28,000	(17,000)	10	(10)

* - Duplicate sets of specimens.
N. - Normalized from.
Aus. - Austenitized at.

The only single normalizing treatment given bar stock from Heat 11625 was 1800°F resulting, after tempering, in a Brinell hardness of 331 which was at the desired hardness level. Two rupture tests at 1100°F were run at a stress of 33,000 psi, resulting in rupture times of 259 to 268 hours, Figure 2A, and elongations of about 10 percent.

Rupture testing the 1800°F treated bar stock at 1200°F resulted in 100-hour and 1000-hour rupture strengths of 21,000 psi and 10,000 psi, and elongations at fracture of 25 percent and 15 percent respectively, Figure 2A.

Increasing the normalizing temperature of the bar stock sealed in block from 1850° to 1950°F raised the hardness to 352 BHN. The rupture strength was also increased and elongation at fracture lowered, Figure 2B.

In addition, bar stock was austenitized at various temperatures, cooled to and held at 1200° or 1225°F in an attempt to more nearly duplicate the cooling rates obtained in large section sizes. The stress - rupture time curves for these treatments are shown in Figure 2C. These so called "isothermal transformation" treatments appeared to result in higher rupture strengths and about the same elongations at 1100°F as were obtained for block specimens when normalized from the same austenitizing temperatures and tempered.

In general, raising the austenitizing temperature of the isothermally transformed materials appeared to increase the slope of the stress - rupture time curve at 1100°F so that the 100-hour rupture strength was increased and 1000-hour strength decreased.

The rupture tests at 1200°F, Figure 2D, indicated that the isothermally treated specimens as at 1100°F had the higher rupture strength.

The structure of Heat 11625 when normalized from 1800°F and tempered as bar stock consisted of a uniform fine grained ferrite and tempered bainite, Plate 8, as compared to the ferrite and tempered martinsite found in Heat 25919, Plate 1A, for the same heat treatment.

Sealing the bar stock in a block, normalizing at 1850°F and tempering, resulted in a coarser structure of ferrite and tempered bainite, Plate 9A, than was obtained for the bar stock normalized from 1800°F, Plate 8. The 1950°F block normalized and tempered specimens, Plate 9B, had a considerably increased amount of tempered bainite but no appreciable difference in grain size, in comparison to the block specimens normalized at 1850°F.

The material isothermally transformed from the various initial austenitizing temperatures resulted in structures primarily of ferrite and pearlite.

(a) Two sets of specimens were submitted at different times, one code 1850 and the other X, after having received the same isothermal heat treatment at 1850°F. The microstructures of both sets consisted of ferrite and fine pearlite, Plates 10A and 10B. However, the material coded X had somewhat larger ferrite grains and pearlitic areas.

(b) The material austenitized twice, once at 1800°F and then at 1900°F followed by transformation at 1200°F, Plate 11A, appeared to have a structure similar to that of the material transformed at 1200°F after austenitizing from 1850°F, Plate 10A.

(c) Transforming at 1225°F after austenitizing at 1950°F caused an appreciable coarsening of the structure, Plate 11B.

Influence of Heat Treatment on the Rupture Properties of Heat 11401

The conditions of treatment of Heat 11401, together with the resulting hardness values and the rupture properties at 1100°F, are summarized in the following tabulation:

Rupture Strength and Ductility of Heat 11401 at 1100°F

Heat Treatment	B H N	Rupture Strength (psi)		Rupture Elongation (%)	
		100-hr	1000-hr	100-hr	1000-hr
Bar Stock Sealed in Block. N. 1850°F + 6 hrs at 1200°F	229	36,000	31,500	30	15
Bar Stock Sealed in Block. N. 1950°F + 6 hrs at 1200°F	311	52,000	37,000	8	4
8" Round x 6" Block. O.Q. 1850°F + 6 hrs at 1200°F (surface)	341	50,000	(27,000)	3.5	(1)
8" Round x 6" Block. O.Q. 1850°F + 6 hrs at 1200°F (quarter)	341	45,000	(33,000)	3	(3)
Bar Stock. Aus. 1850°F and Isothermally Transformed at 1200°F	269/277	37,000	29,000	25	10

The normalizing temperature of 1850°F was too low to adequately harden the block specimen, whereas the 1950°F normalizing temperature hardened the bar stock sealed in the block.

Increasing the normalizing temperature from 1850° to 1950°F increased the rupture strength of the block treated bar stock at both 100 and 1000 hours, Figure 3A.

The elongation of the fractured specimens treated from 1850°F remained high even out to 1000 hours. The elongation of the material treated at 1950°F, though lower than that of the 1850°F material, was not unusually low for the alloy.

Oil quenching the 8-inch round by 6-inch block from 1850°F and tempering resulted in high hardness, 341 BHN, at least at the quarter section. Rupture strength was high at 100 hours and for 1000 hours at the quarter section. Surface specimens had low 1000-hour strength. Elongations were low in both cases. Bar stock in a block normalized from 1850°F and tempered did not adequately harden as previously discussed.

Isothermal transformation of bar stock at 1200°F after austenitizing at 1850°F gave a low hardness of 269/277 Brinell. The 100-hour rupture strength was somewhat higher than that of the block specimens, but lower than the oil quenched quarter section, Figure 3B. The ductility remained high. The 1000-hour strength, however, was low.

The structure of the block specimen normalized from 1850°F and tempered consisted of fine grained ferrite, together with small amounts of what appears to be pearlite, Plate 12A.

Raising the normalizing temperature of the block specimens to 1950°F and tempering resulted in a ferritic - tempered bainitic structure that exhibited mixed fine and coarse grains, Plate 12B. The same pattern in the ferrite was noted for Heat 25919 in the same condition, Plate 2B.

Oil quenching of the 8-inch round by 6-inch long section from 1850°F and tempering resulted in the structure shown in Plates 13A and 13B. There appears to be little difference between the structures of the surface and quarter specimens, both appeared to be tempered bainite, although possibly the surface section was tempered martensite.

The isothermally transformed structure, Plate 14, consisted of fine uniform ferrite grains and carbides. There was very little evidence of the areas of pearlite that were so pronounced in Heat 11625 treated from the various austenitizing temperatures, Plates 10 and 11.

Influence of Heat Treatment on the Rupture Properties of Heat 11574

Three conditions of heat treatment were used on Heat 11574. The rupture data obtained at 1100° and 1200°F for these treatments are plotted in the stress - rupture time curves of Figure 4. The response to the treatments investigated as measured by hardness and rupture properties at 1100° and 1200°F are presented in the following tabulation:

Rupture Strength and Ductility of Heat 11574

Heat Treatment	B H N	Rupture Strength (psi) 100-hr	Rupture Strength (psi) 1000-hr	Rupture Elongation (%) 100-hr	Rupture Elongation (%) 1000-hr
	1100°F				
Bar Stock Sealed in Block. N. 1850°F + 6 hrs at 1200°F	341	44,000	--	20	--
Bar Stock. Aus. 1850°F, cooled to and held for 6 hrs at 1200°F	293/311	41,500	(28,000)	10	(5)
4" x 9" x 9-1/2" Block. Aus. 1950°F, cooled to and held for 6 hrs at 1225°F	277/285	41,000	(32,000)	10	(4)
	1200°F				
4" x 9" x 9-1/2" Block. Aus. 1950°F, cooled to and held for 6 hrs at 1225°F	277/285	(31,000)	(13,000)	(10)	(5)

The rupture tests run on this heat were for the most part of too short a duration to permit more than an estimated extrapolation of the data.

Of the three heat treatments, the bar stock sealed in the block, normalized from 1850°F and tempered at 1200°F, had the highest 100-hour rupture strength, 44,000 psi, at 1100°F. The bar stock austenitized at 1850°F and transformed at 1200°F resulted in very little if any decrease in rupture strength. Austenitizing bar stock in a block from 1950°F and transforming at 1225°F resulted in approximately the same 100-hour strength. However, extrapolation of the rupture data from the isothermally transformed materials indicated a higher 1000-hour rupture strength for the 1950°F austenitized and isothermally transformed block specimen than for the 1850°F austenitized bar stock and isothermally transformed block.

The 1200°F rupture strength of the 1950°F isothermally transformed material was slightly lower than that of Heat 11625 austenitized at the same temperature. The difference, however, may have been caused by the difference in section size treated. Heat 11625 was heat treated as bar stock, whereas Heat 11574 was heat treated as a large block.

All of the fractured specimens at both 1100° and 1200°F appeared to be sufficiently ductile.

The microstructure of bar stock from Heat 11574 normalized from 1850°F and tempered while sealed in a block, Plate 15, consisted of tempered bainite and some fine grained ferrite. Austenitizing of Heat 11574 at 1850°F and transforming at 1200°F resulted in the formation of ferrite and rather large areas of uniformly distributed tempered pearlite, Plate 16A. Raising the austenitizing temperature to 1950°F and isothermally transforming a large block at 1225°F caused an even greater increase in the ferrite grain size, Plate 16B. Pearlite was present in very large coarse stringers.

Influence of Heat Treatment on the Rupture Properties of Heat 11573

The rupture strength of Heat 11573 in its three conditions of heat treatment was established out to a time period of 100 hours. The stress - rupture time curves for these are shown in Figure 5 and the 100-hour rupture strength and elongation values in the following tabulation:

Rupture Strength and Ductility of Heat 11573 at 1100°F

Heat Treatment	B H N	Rupture Strength (psi) 100-hr	Rupture Elongation (%) 100-hr
Bar Stock Sealed in a Block. N. 1850°F + 6 hrs at 1200°F	285	42,000	15
Bar Stock Sealed in a Block. N. 1950°F + 6 hrs at 1200°F	341	(45,000)	(5)
Bar Stock Austenitized at 1850°F, cooled to and held for 6 hrs at 1200°F	277/285	39,000	10

The single rupture test run on the material sealed in a block, normalized from 1950°F and tempered, indicated a slightly higher 100-hour rupture strength at 1100°F than was obtained for the 1850°F block normalized material -- approximately 45,000 psi, as compared to 42,000 psi. The isothermally transformed bar stock, though having the same hardness as the 1850°F treated block specimen, had slightly lower strength.

The lowest ductility was obtained for the block specimens treated from 1950°F.

The microstructure of the block specimen normalized from 1850°F and tempered, Plate 17A, consisted of uniform grains of ferrite and some tempered bainite, a structure very similar to that obtained for Heat 11401, Plate 12A. A coarser non uniform structure of ferrite and of more acicular tempered bainite, Plate 17B, was formed after normalizing from 1950°F and tempering. In addition, the structure normalized at the higher temperature appeared to contain less undissolved carbides.

The isothermally transformed structure, Plate 18, consisted of ferrite grains and stringers of a pearlitic like structure. The pearlite stringers were more pronounced and the grain size less uniform than that of Heat 11625 in the same condition, Plates 10A and 10B.

Rupture Properties of Heat 11504, Heat 11833, and Heat 11704 at 1100°F

These three heats were rupture tested in only one or two conditions of heat treatment. The stress - rupture time curves for these heats are shown in Figures 6 and 7. The rupture strengths and elongation values are shown in the following tabulation:

Rupture Strength and Ductility of Heat 11504, Heat 11833, and Heat 11704 at 1100°F

Heat Treatment	B H N	Rupture Strength (psi)		Rupture Elongation (%)	
		100-hr	1000-hr	100-hr	1000-hr
Heat 11504					
Bar Stock Sealed in a Block. N. 1850°F + 6 hrs at 1200°F	341	--	(25,000)	--	(4)
Bar Stock. Aus. 1850°F, cooled to and held for 6 hrs at 1200°F	321/352	(49,000)	(32,000)	(5)	(3)
Heat 11833					
Bar Stock Sealed in a Block. N. 1850°F + 6 hrs at 1250°F	311	39,000	(30,000)	25	(15)
Heat 11704					
Bar Stock Sealed in a Block N. 1850°F + 6 hrs at 1250°F	341	42,000	(30,000)	(5)	(4)

The bar stock from these three heats sealed in a block, normalized from 1850°F and tempered, all hardened to more than 300 BHN. Extrapolation of the stress - rupture time curves gave 1000-hour rupture strengths at 1100°F of 25,000 to 30,000 psi, values on the low side for the expected strength of the alloy.

Isothermally transforming bar stock from Heat 11504 resulted in higher 1000-hour rupture strength than that obtained for the block normalized specimens. The steeper slope of the stress-rupture curve (Figure 6) for the block normalized specimens from Heat 11504 indicate a greater 100-hour rupture strength.

The bar stock from Heat 11504 normalized from 1850°F and tempered in a block had a structure of ferrite and tempered acicular bainite, Plate 19A. The bainite appeared to be more acicular and the grain size larger than that obtained for Heat 11574, Plate 15.

Isothermal transformation at 1200°F after austenitizing at 1850°F resulted in a mixed grain size, Plate 19B. The microstructure was essentially ferrite and pearlite, very similar to that of Heat 11574, Plate 16B, and Heat 11573, Plate 18.

Heat 11833 normalized in a block at 1850°F and tempered had a rather fine ferrite grain size. The microstructure consistedof ferrite and tempered bainite, Plate 20.

Heat 11704 appeared to be very coarse grained, Plate 21, after block normalizing from 1850°F. The photomicrograph indicates that the structure is predominantly an acicular, tempered bainitic structure containing very little, if any, primary ferrite grains.

DISCUSSION

Two previous reports, Numbers 199 and 200, presented the first data in the development of "17-22-A"V steel. In both cases, one-inch round bar stock from Heat A80 and 2 x 22-inch disks from Heat 02359 hardened sufficiently well on normalizing from 1800°F to give Brinell hardness values in excess of 300 BHN. In the series of tests covered by this report, lack of adequate hardening for certain of the heats was encountered.

Comparison of the chemical composition with hardness values indicates that increased carbon and manganese were associated with hardness values of 300 BHN or higher. Heat 25919 with 0.22 C - 0.56 Mn and Heat 11401 with 0.24 C - 0.60 Mn would not harden on normalizing from 1800°F, even as one-inch round bar stock. Heat 11625 with 0.26 C and 0.62 Mn had intermediate hardenability. The other heats with 0.27-0.30 C and 0.70-0.86 Mn hardened satisfactorily. The lack of hardenability was somewhat unexpected in that the two heats involved in Reports 199 and 200 had low carbon and/or manganese (Heat A80: 0.22 C - 0.84 Mn, and Heat 02359: 0.25 C - 0.56 Mn). It seems evident, however, the carbon in excess of 0.25 percent and manganese above 0.70 percent are necessary to give adequate hardenability on normalizing commercially produced material, particularly in heavy sections.

The tests carried out for Report 199 indicated that the best combination of rupture strength and ductility was obtained when the bar stock was normalized from 1800°F and tempered for 6 hours at 1200°F. The data on disks for Report 200 seemed to bear this out, although some difficulty in obtaining sufficient tempering at 1200°F was encountered. A review of the hardness data for the present report in Table I indicates that a shift was made to 1850°F for the normalizing temperature when difficulty was encountered with the low hardenability heats. This normalizing temperature was maintained after the hardenability had been improved by increasing carbon and manganese.

In the case of Heat 25919, increasing the normalizing temperature to 1850°F did harden bar stock, but not large size pieces or bars inserted in large blocks. The large sizes would not harden for Heat 11401, and Heat 11625 was somewhat soft. In each case, increasing the normalizing temperature to 1950°F did give adequate hardening. Oil quenching from 1850°F also hardened sufficiently in the case of Heats 25919 and 11401.

The influence of heat treatments on the rupture properties at 1100°F is summarized by Table III. These data indicate that:

1. When normalized from 1800° or 1850°F, the commercial heats had lower rupture strength and, in most cases, higher ductility than the original Heats A80 and 02359 (N. 1800°F), whether or not they hardened to 300 BHN or higher. (See Figure 8.)

2. When bars from low hardenability Heats 25919, 11401, and 11625 were normalized from 1950°F in 4-inch x 9-inch x 9-1/2-inch blocks, the rupture properties approached the high values originally obtained for "17-22-A"V steel (Heats A80 and 02359). The one high hardenability heat (Heat 11573) tested apparently tended to have strength on the low side, as is shown by Figure 9. It should be noted that when the low hardenability Heat 25919 was normalized from 1950°F as a 6-inch thick block, the hardness and rupture strengths were somewhat low. Apparently the hardenability was inadequate for a 6-inch section.

3. Specimens normalized in blocks from 1850°F, Figure 8, indicate that low hardenability reduced short time strengths with this treatment, but that by 500 hours there was little difference. One high harden-

ability heat (Heat 11504), however, had a very steep rupture curve or erratic test behavior. This raises the possibility that for some heats (or certain prior working conditions) 1850°F may be too high a temperature for best rupture properties.

4. The high strength of the low hardenability heats after normalizing from 1950°F in blocks probably should not be extended to high hardenability heats without further checking. Figure 9 indicates a decrease in strength with increasing hardenability.

5. The microstructures of the specimens do not yield too definite information on the hardness and rupture properties. Low hardness seems to be associated with ferrite and pearlite. At high hardness levels, however, the structures have less apparent relation to the properties. In comparison to Heat A80, normalized from 1800°F, there seems to be no reason why Heat 25919 had low strength when normalized from 1850°F as bar stock because their structures appeared almost identical. The high hardenability heats had a rather wide range in structures on normalizing from 1850°F in blocks with rather similar rupture properties. While Heat 11504 did have a different structure than the others, it seems premature to attribute its different rupture characteristics to that cuase in view of the wide variations in the others with similar rupture properties.

6. Heat A80 underwent coarsening between 1800° and 1850°F. The commercial heats did not show this sharp coarsening temperature.

7. Normalizing from 1950°F in blocks produced bainitic structures and similar grain sizes in all four heats. The lower strength high hardenability Heat 11573 appeared to have a somewhat different arrangement of the bainite with a tendency for more very fine grains.

8. It appears that as yet it is almost impossible to correlate rupture properties with microstructure. Fine grained bainitic structures

tend to have high strength. However, some heats can have definitely bainitic structures, such as Heat 11704 normalized from 1850°F in a block (Plate 21), without attaining the high levels of strength which the analysis can develop. Some other factor not readily apparent in the microstructure must be operating to influence properties

Oil Quenching and Double Normalizing

Oil quenching large blocks from the low hardenability Heats 25919 and 11401 from 1850°F brought up both the hardness and rupture strength with somewhat low elongation. (See Table III.) Thus it appears that increasing the cooling rate to obtain hardness is effective in low hardenability heats. It should be recognized, however, that the surface specimens from Heat 11401 had somewhat low strength, apparently due to martensite formation. Thus, in the use of liquid quenches care should probably be exercised to avoid quenches rapid enough to form martensite. Judging from the microstructures, the cooling rate should be selected to produce bainite structures.

Because low rupture strength and hardenability may have been due to difficulty in dissolving vanadium carbides, double normalizing treatments were tried on Heat 25919. The results obtained are summarized in Table IV. The double normalizing was effective in one-inch rounds in increasing both hardness and rupture strength by causing bainitic structures to form. Furthermore, it increased rupture strength to a high level even when the hardness had been sufficiently high, but the rupture strength low, after a single normalize from 1850°F. It was detrimental to rupture ductility, particularly at the longer time periods. In bar stock, a first normalize at 1950°F seemed to be better than 2100°F, possibly because the resulting bainite was too coarse.

Double normalizing from 1950°F and then at 1850°F was not sufficiently effective in increasing the hardenability of Heat 25919 to obtain adequate hardening in a 6-inch section. The microstructures, Plate 6, show that only the surface developed bainite. This accounts for the low strength of the quarter section specimens. Surface specimens gave erratic results, probably because the bainitic structure was rather shallow.

Isothermal Transformation

The hardness and rupture properties at 1100°F are summarized in Table V and Figure 10 for specimens prepared by austenitizing and then transferring directly to a furance at 1200° or 1225°F for 6 hours, followed by air cooling without further tempering. In general, these data do not indicate any particular advantage to this process. In most cases, the hardness was somewhat low. In those cases where the hardness was over 300 BHN, the strengths were little or no better than was obtained on direct transformation.

There is a lack of comparative data for bar stock from the same heat with a simple normalize so that direct comparison of the effect of the isothermal treatment cannot be made. It seems doubtful, however, that it was helpful in any case.

In all cases but Heat 11401, the treatment developed pearlite. Pearlite would be expected to form on direct cooling to 1200° or 1225°F, followed by a prolonged holding at those temperatures. Apparently the formation of pearlite did not deplete the remaining austenite in alloys; otherwise, the hardness would have been lower than that obtained.

Rupture Properties of "17-22-A"V Steel at 1200°F

The measured rupture properties at 1200°F, summarized by Table VI, suggest that the rupture strengths at 1200°F will be of the order of 28,000 to 30,000 psi for 100 hours and 13,000 to 15,000 psi for 1000 hours when the best response to heat treatment is obtained. The elongations at corresponding time periods apparently will be about 10 and 3 to 5 percent respectively. These estimates were derived by selecting the values in Table VI which corresponded to those which gave high values at 1100°F.

The data at 1200°F were obtained on "isothermally transformed" structures, except for those from Heat 11625 normalized from 1800°F. These latter specimens were low in strength at 1100°F, and it is assumed that the strength at 1200°F was also low. The isothermally transformed structures tended to have reasonably typical properties at 1100°F, and it is therefore assumed that their properties at 1200°F are near to those which might be expected for the alloy when proper response is obtained in direct transformation. It should be noted that elongations in the rupture tests at 1200°F are no better than those obtained at 1100°F, particularly at 1000 hours.

General Considerations

The review of the data indicates that increasing the hardenability of the "17-22-A"V analysis by increasing carbon and manganese and normalizing large sections from 1850°F resulted in somewhat lower strength than was established for the steel from experimental heats. The low hardenability heats, on the other hand, developed nearly the same properties as the experimental material, together with adequate hardness on normalizing from 1950°F. There appears to be a difference in response to heat treatment between the commercial and experimental heats. This may have been due to either or both melting practice and hot-working conditions. It suggests that further research on relations of composition and heat treatment using lower hardenability analysis might be useful in raising the general level of properties, providing higher heat treating temperatures were practical.

The possible influence of the rather limited number of tests should be recognized. The use of two tests to establish the rupture properties could be misleading, even though wide experience with the rupture test was applied in deriving rupture strengths. Uncertainties of the shape of the stress - rupture time curves, specimen to specimen variation and undetected testing errors are difficult to eliminate with so few tests. In most cases, however, the consistent nature of the data indicates that the general trends are reliable.

The analysis of the microstructures was hampered by all of the available structures, except those isothermally treated, having been tempered. In particular, it was difficult to tell whether initial structures were bainitic or martensitic. Likewise it was difficult to be sure of the difference between primary ferrite and highly tempered bainite.

TABLE I

Section Sizes, Heat Treatments, and Hardnesses of the "17-22-A"V Steels

Size Stock Heat Treated	Heat Treatment	B H N
	Heat 25919	
1" round	N 1800°F + 6 hrs at 1200°F	248/255
1" round	N 1850°F + 6 hrs at 1200°F	321/331
7/8" round	N 1850°F + 6 hrs at 1200°F in 4" x 9" x 9-1/2" block	207
7/8" round	N 1950°F + 6 hrs at 1200°F in 4" x 9" x 9-1/2" block	302
1" round	N 1950°F + N 1800°F + 6 hrs at 1200°F	311
1" round	N 1950°F + N 1850°F + 6 hrs at 1200°F	341
1" round	N 2100°F + N 1800°F + 6 hrs at 1200°F	302
10" square x 6"	N 1950°F + 6 hrs at 1200°F	255/262
10" square x 6"	N 1950°F + N 1850°F + 6 hrs at 1200°F	229/241
10" square x 6"	OQ 1850°F + 6 hrs at 1200°F	331/341
	Heat 11625	
1" round x 7"	N 1800°F + 6 hrs 1200°F	331
7/8" round	N 1850°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	277/285
7/8" round	N 1950°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	352
1" round x 7"	Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F	270/294
1" round x 7"	Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F	285/311
1" round x 7"	Austenitized 1950°F -- cooled to and held for 6 hrs at 1225°F	321
1" round x 7"	Austenitized 1800°F -- cooled to and held for 6 hrs at 1200°F -- Reaustenitized 1900°F -- cooled to and held for 6 hrs at 1200°F	286/294
	Heat 11401	
7/8" round	N 1850°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	229
7/8" round	N 1950°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	311
8" round x 6"	OQ 1850°F + 6 hrs 1200°F	341
1-1/2" square x 7"	Austentized 1850°F -- cooled to and held for 6 hrs at 1200°F	269/277
	Heat 11574	
7/8" round	N 1850°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	341
1-1/2" square x 7"	Austenitized 1850°F -- cooled to and held for 6 hours at 1200°F	293/311
4" x 9" x 9-1/2" block	Austenitized 1950°F -- cooled to and held for 6 hrs at 1225°F	277/285
	Heat 11573	
7/8" round	N 1850°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	285
7/8" round	N 1950°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	341
1-1/2" square x 7"	Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F	277/285
	Heat 11504	
7/8" round	N 1850°F + 6 hrs 1200°F in 4" x 9" x 9-1/2" block	341
1-1/2" square x 7"	Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F	321/352
	Heat 11833	
7/8" round	N 1850°F + 6 hrs at 1250°F in 4" x 9" x 9-1/2" block	311
	Heat 11704	
7/8" round	N 1850°F + 6 hrs at 1250°F in 4" x 9" x 9-1/2" block	341

TABLE II

Rupture Data for "17-22-A"V Steel at 1100° and 1200°F

Heat Treatment	Code No.	B H N	Temp (°F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Reduction of Area (%)
			Heat 25919				
N 1800°F + 6 hrs at 1200°F	1800	248/255	1100	49,600	10	36.5	72.5
				40,000	46.5	17.5	49.5
				30,000	406	9.0	16.3
N 1850°F + 6 hrs at 1200°F	1850	321/331	1100	50,400	85	12.0	15.6
				45,000	168	5.0	6.5
				40,000	303	7.0	8.5
				32,000	615	3.0 (a)	--
N 1850°F + 6 hrs at 1200°F (b)	A	207	1100	35,000	18	42.5	81.5
				30,000	377	36.5	49.6
N 1950°F + 6 hrs at 1200°F (b)	B	302	1100	50,000	102	5.0	5.7
				40,000	588	1.5 (h)	1.6
N 1950°F + N 1800°F + 6 hrs at 1200°F (i)	1	311	1100	50,000	48	7.5	12.3
				40,000	216	4.0	6.0
N 1950°F + N 1850°F + 6 hrs at 1200°F (i)	2	341	1100	50,000	124	4.5	6.7
				40,000	433	3.5	4.6
N 2100°F + N 1800°F + 6 hrs at 1200°F (i)	3	302	1100	50,000	186	3.0	2.9
				40,000	325	2.0 (h)	7.9
N 1950°F + 6 hrs at 1200°F (j)	BS (d)	255/262	1100	40,000	258	11.0	22.6
				34,000	693	2.5	1.6
	BQ (e)	255/262	1100	40,000	205	12.0	28.4
				34,000	527	3.5	6.9
N 1950°F + N 1850°F + 6 hrs at 1200°F (j)	CS (d)	229/241	1100	40,000	362	5.0	12.1
				35,000	185	22.0	57.0
	CQ (e)	229/241	1100	40,000	21	21.0	61.9
				30,000	657	17.0	25.4
OQ 1850°F + 6 hrs at 1200°F (j)	QS (d)	341	1100	50,000	138	3.5	6.9
				40,000	699	2.0	4.4
	QQ (e)	331	1100	50,000	81	6.5	7.9
				40,000	486	4.5	6.8
			Heat 11625				
N 1800°F + 6 hrs at 1200°F (f)	C	331	1100	33,000	259	10.0	19.6
				33,000	267	8.5	18.5
			1200	35,000	16	25.0	44.5
				28,000	35	21.5	41.0
				20,000	123	27.0	37.0
				12,000	591	18.5	18.5
N 1850°F + 6 hrs at 1200°F (b)	A	277/285	1100	50,000	14	20.0	65.5
				35,000	381	13.0	36.8
N 1950°F + 6 hrs at 1200°F (b)	B	352	1100	50,000	110	4.5	4.0
				40,000	365	4.1	10.2
Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F (f)	1850	270/294	1100	50,000	20	33.5	60.0
				40,000	623	15.0	20.5
	X	285/311	1100	45,000	80	8.5 (h)	24.0
				37,000	521	4.5	9.5
			1200	25,000	156	7.0 (h)	21.0
				15,000	951	5.5	12.0
Austenitized 1950°F -- cooled to and held for 6 hrs at 1225°F (f)	Y	321	1100	48,000	207	3.5	4.0
				37,000	666	2.5	3.5
			1200	30,000	157	3.5	5.0
				20,000	484	3.5	4.5
Austenitized 1800°F -- cooled to and held for 6 hrs at 1200°F + Reaustenitized 1900°F -- cooled to and held for 6 hrs at 1200°F (f)	1900	286/294	1100	50,000	76	10.5	23.0
				40,000	460	7.5 (h)	11.0
			1200	30,000	72	11.0 (h)	22.5
				20,000	461	12.0	19.5

TABLE II, Continued

Heat Treatment	Code No.	B H N	Temp (°F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Reduction of Area (%)
				Heat 11401			
N 1850°F + 6 hrs at 1200°F (b)	A	229	1100	37,500	59	34.0	71.5
				32,500	628	16.0	38.4
N 1950°F + 6 hrs at 1200°F (b)	B	311	1100	50,000	138	7.5	10.1
				40,000	596	4.5	8.2
OQ 1850°F + 6 hrs at 1200°F (c)	QS (d)	341	1100	50,000	102	3.5	5.2
				40,000	236	2.0	3.0
	QQ (e)	341	1100	50,000	44	2.7 (a)	--
				40,000	253	2.8	2.2
Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F (f)	--	269/277	1100	45,000	19.3	27.5	74.5
				30,000	804	11.0	19.0
				Heat 11574			
N 1850°F + 6 hrs at 1200°F (b)	A	341	1100	55,000	8.4	27.5	66.7
				45,000	76	21.0	41.3
Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F (f)	--	293/311	1100	45,000	65	11.5	22.5
				36,000	250	5.0	3.5
Austenitized 1950°F -- cooled to and held for 6 hrs at 1200°F (g) (e)	--	277/285	1100	45,000	41	10.0 (k)	30.0
				34,000	538	4.0 (k)	5.0
			1200	25,000	175	8.0 (k)	8.0
				17,000	474	5.0 (k)	7.0
				Heat 11573			
N 1850°F + 6 hrs at 1200°F (b)	A	285	1100	55,000	11	12.5	41.5
				45,000	58	17.0	17.4
N 1950°F + 6 hrs at 1200°F (b)	B	341	1100	40,000	233	4.0	9.9
Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F (f)	--	277/285	1100	45,000	27.5	25.0	48.5
				37,000	206	8.0	19.0
				Heat 11504			
N 1850°F + 6 hrs at 1200°F (b)	A	341	1100	50,000	218	5.0	13.0
				40,000	352	6.0	17.0
Austenitized 1850°F -- cooled to and held for 6 hrs at 1200°F (f)	--	321/352	1100	45,000	167	5.0	8.0
				37,000	488	3.0	3.0
				Heat 11833			
N 1850°F + 6 hrs at 1250°F (b)	A	311	1100	40,000	82	26.0	47.9
				34,000	351	18.5	28.5
				Heat 11704			
N 1850°F + 6 hrs at 1250°F (b)	A	341	1100	40,000	133	5.0	15.6
				34,000	436	4.5	4.5

(a) Broke in fillet.
(b) Bar stock treated in 4" x 9" x 9-1/2" block.
(c) 8"-round x 6" section heat treated.
(d) Specimens taken from surface section.
(e) Specimens taken from quarter section.
(f) 1-1/2" round or square x 7" section heat treated.
(g) 4" x 9" x 9-1/2" section heat treated.
(h) Broke in gage mark.
(i) 1"-round bar stock.
(j) 10"-square x 6" section.
(k) % in 1 inch.

TABLE III

Summarized Rupture Properties at 1100°F

for Single Heat Treatments of Eight Heats of "17-22-A"V Steel

Heat No.	Brinell Hardness	Rupture Strength (psi)		Rupture Elongation (%)	
		100-hr	1000-hr	100-hr	1000-hr
1-inch round. N. 1800°F + 6 hrs at 1200°F					
A80[a]	302/311	(57,000)	35,000	--	4
25919	248/255	36,000	(26,500)	15	(5)
11625	331	(38,000)	--	(>10)	--
2-inch by 22-inch diameter disk. N. 1800°F + 6 hrs at 1225°F					
02359[b]	302/337	45,000/ 53,000	30,000/ 36,500	5/ 8.5	3/ 6
1-inch round. N. 1850°F + 6 hrs at 1200°F					
A80[c]	331/341	(>40,000)	--	(brittle)	--
25919	321/331	49,000	27,000	10	(3)
7/8-inch round in a 4" x 9" x 9-1/2" block. N. 1850°F + 6 hrs at 1200°F					
25919	207	32,000	29,000	40	(35)
11625	277/285	40,000	(31,500)	15	(>10)
11401	229	36,000	31,500	30	15
11574	341	44,000	--	20	--
11573	285	42,000	--	15	--
11504	341	--	(25,000)	--	(4)
11833[d]	311	39,000	(30,000)	25	(15)
11704[d]	341	42,000	(30,000)	(5)	(4)
Bar Stock. N. 1950°F + Tempered					
A80	363	38,000	27,000	(brittle)	--
Bar Stock in a 4" x 9" x 9-1/2" block. N. 1950°F + Tempered					
25919	302	50,000	(37,500)	5	(1)
11625	352	50,000	(33,500)	5	(<4)
11401	311	52,000	37,000	8	4
11573	341	(45,000)	--	(5)	--

TABLE III, Cont.

Heat No.	Brinell Hardness	Rupture Strength (psi) 100-hr	1000-hr	Rupture Elongation (%) 100-hr	1000-hr
		Block 10" sq. x 6" thick. N. 1950°F + Tempered			
25919	255/262	(45,000)/ (47,000)	(30,000)/ (32,000)	(11)/ (12)	(2.5)
		Oil Quenched 1850°F + Tempered			
		(10" square x 6")			
25919	331/341	49,000/ (52,000)	37,000/ (38,000)	4/ 5	(2)/ (3)
		(8" round x 6")			
11401	341	45,000/ 50,000	(27,000)/ (33,000)	3/ 3.5	(1)/ (3)

(a) Report No. 199.
(b) Report No. 200.
(c) Tempered at 1225°F.
(d) Tempered at 1250°F.

TABLE IV

Influence of Double Normalizing on the Hardness and Rupture Properties

at 1100°F for Low Hardenability Heat 25919 of "17-22-A"V Steel

Section Size	Normalizing Temp (°F)		Brinell Hardness	Rupture Strength (psi)		Rupture Elongation (%)	
	First	Second		100-hr	1000-hr	100-hr	1000-hr
1" round	--	1800	248/255	36,000	(26,500)	15	(5)
	1950	1800	311	45,000	(32,000)	5	(1)
	2100	1800	302	(>52,000)	(~26,000)	(4)	(1)
1" round	--	1850	321/331	49,000	27,000	10	(3)
	1950	1850	341	52,500	(34,500)	5	(1)
10" Sq. x 6" (quarter section)	1950	1850	229/241	35,000	(29,000)	25	(15)

TABLE V

Summarized Hardness and Rupture Properties at 1100°F

for "17-22-A"V Steel "Isothermally" Transformed

Heat No.	Section Size	Austenitizing Temp (°F)	Transformation Temp (°F)	Brinell Hardness	Rupture Strength (psi)		Rupture Elongation (%)	
					100-hr	1000-hr	100-hr	1000-hr
11625	1" round	1850	1200	270/294	45,000	(38,000)	25	(<15)
		1850	1200	285/311	44,000	34,500	8	(<4)
		1950	1225	321	(55,000)	33,500	5	(<2)
		1800 + 1900	1200	286/294	49,000	(36,000)	10	(<7)
11401	1-1/2" square	1850	1200	269/277	37,000	29,000	25	10
11574	1-1/2" square	1850	1200	293/311	41,500	(28,000)	10	(5)
	4" x 9" x 9-1/2" block	1950	1225	277/285	41,000	(32,000)	10	(4)
11573	1-1/2" square	1850	1200	277/285	39,000	--	10	--
11504	1-1/2" square	1850	1200	321/352	(49,000)	(32,000)	(5)	(3)

TABLE VI

Rupture Data at 1200°F for "17-22-A"V Steel

Heat No.	Section Size	Treatment	Brinell Hardness	Rupture Strength (psi)		Rupture Elongation (%	
				100-hr	1000-hr	100-hr	1000-hr
11625	Bar Stock	N. 1800°F + 6 hrs at 1200°F	331	21,000	10,000	25	15
		Aus. 1850°F - cooled to 1200°F and held for 6 hrs	285/311	28,500	15,000	10	5
		Aus. 1950°F - cooled to 1200°F and held for 6 hrs	321	35,000	(15,500)	4	(<3)
		Aus. 1800°F + Reaus. 1900°F - cooled to 1200°F and held for 6 hrs	286/294	28,000	(17,000)	10	(10)
11574	4" x 9" x 9-1/2" Blook	Aus. 1950°F - cooled to 1225°F and held for 6	277/285	(31,000)	(13,000)	(10)	(5)

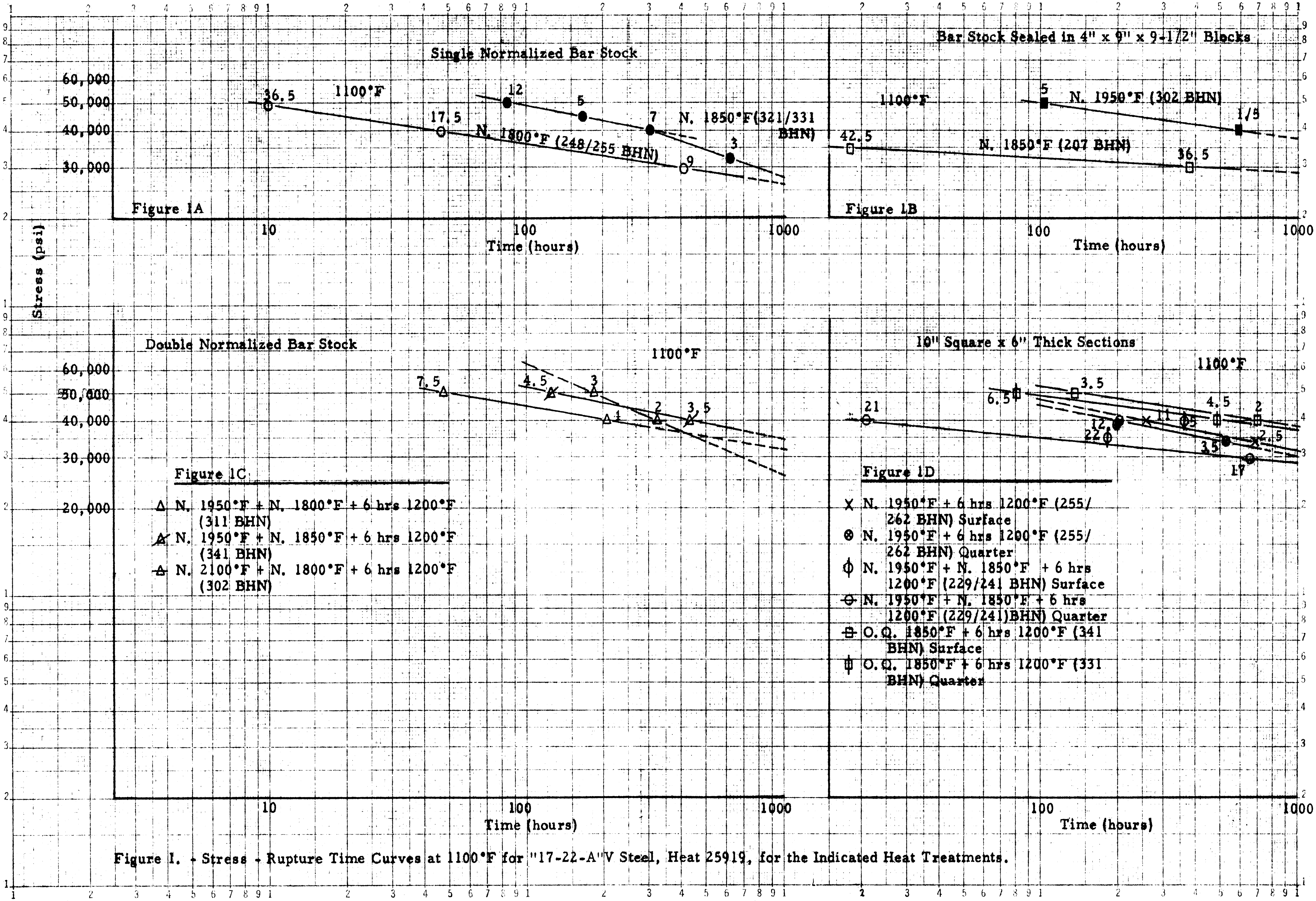

Figure I. - Stress - Rupture Time Curves at 1100°F for "17-22-A"V Steel, Heat 25919, for the Indicated Heat Treatments.

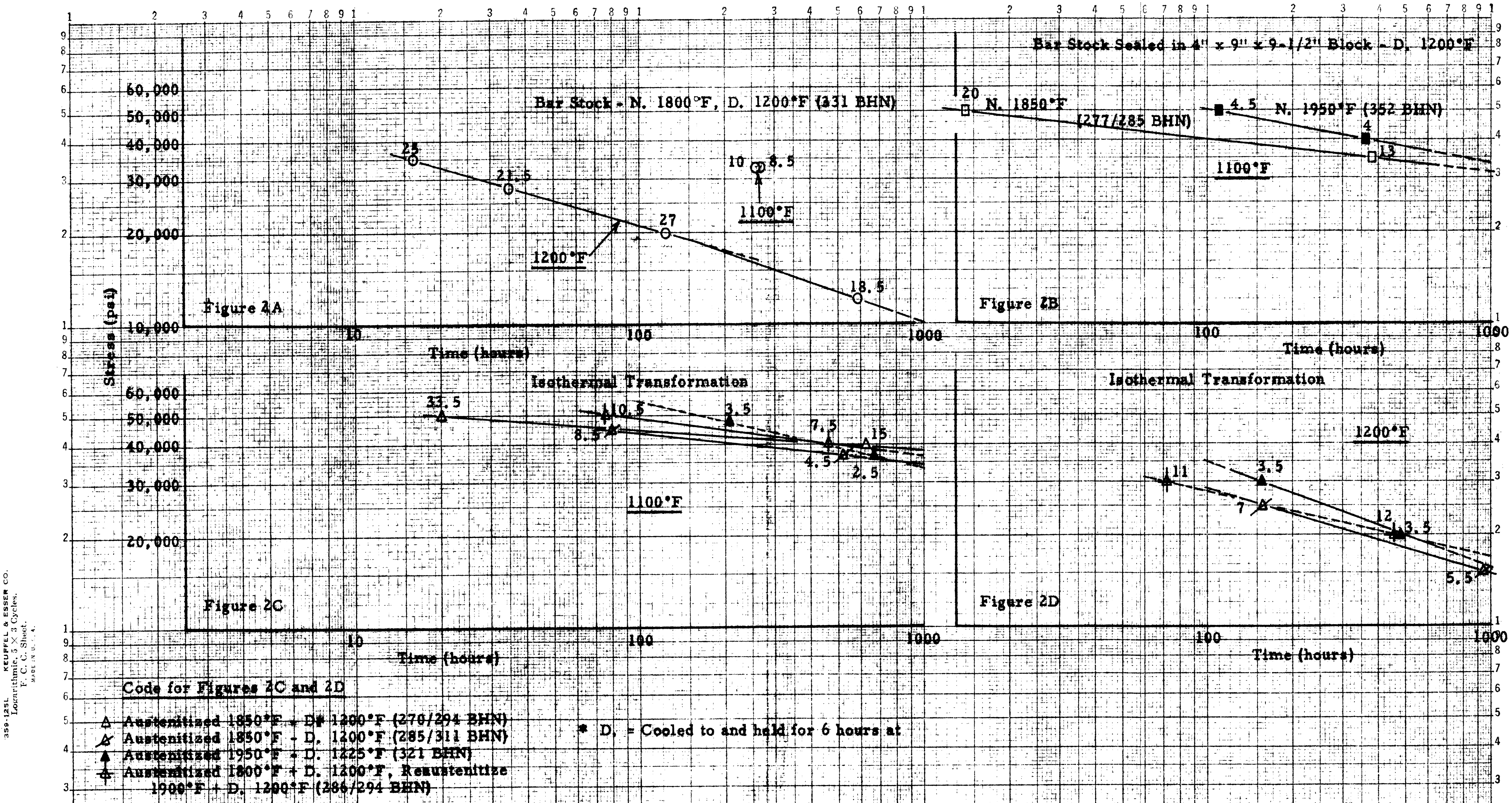

Figure 2. - Stress - Rupture Time Curves at 1100° and 1200°F for "17-22-A"V Steel, Heat 11625. Heat treated as indicated. Hardness data enclosed in brackets.

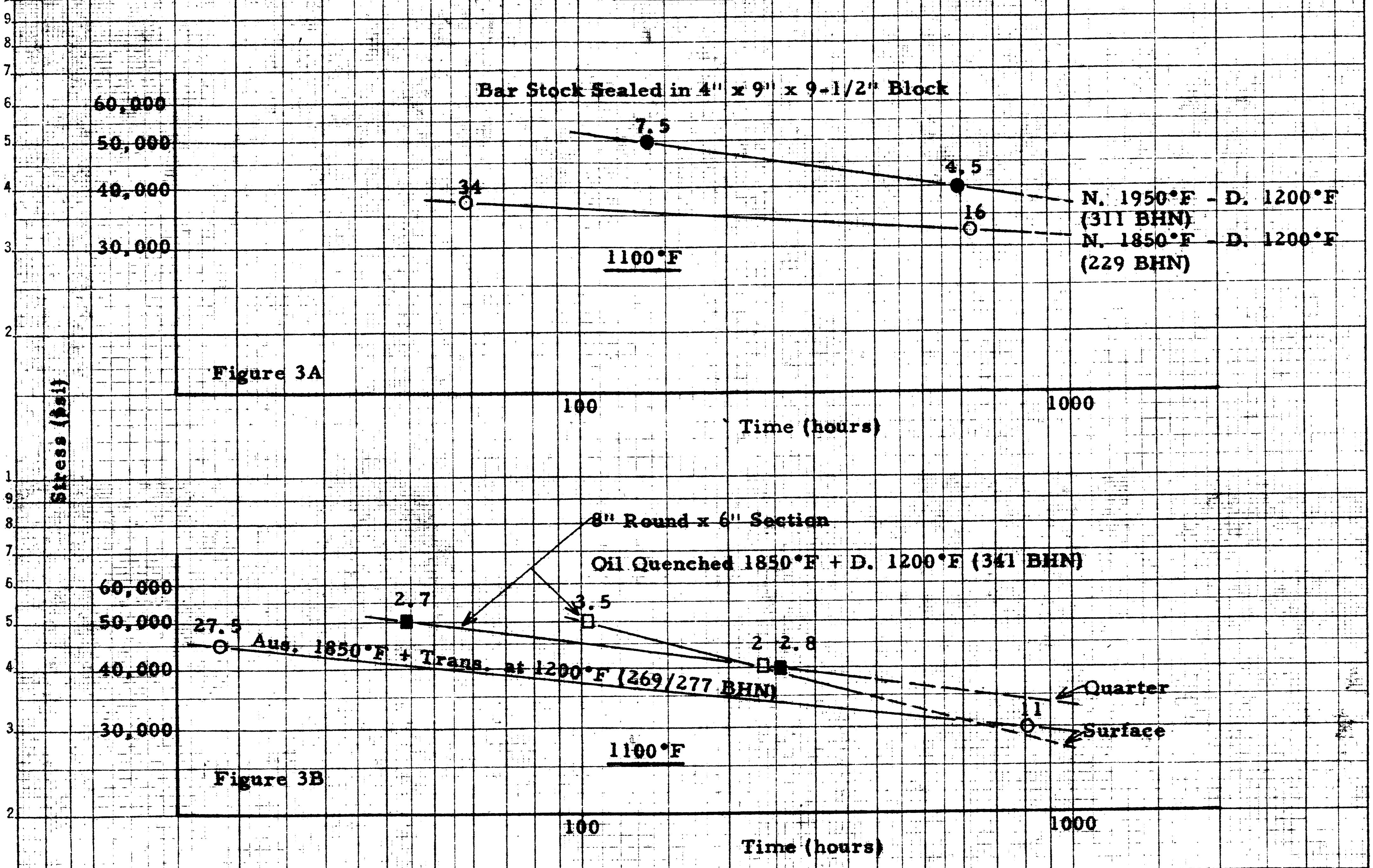

Figure 3. - Stress - Rupture Time Curves at 1100°F for "17-22-A"V Steel, Heat 11401. Heat treated as indicated.

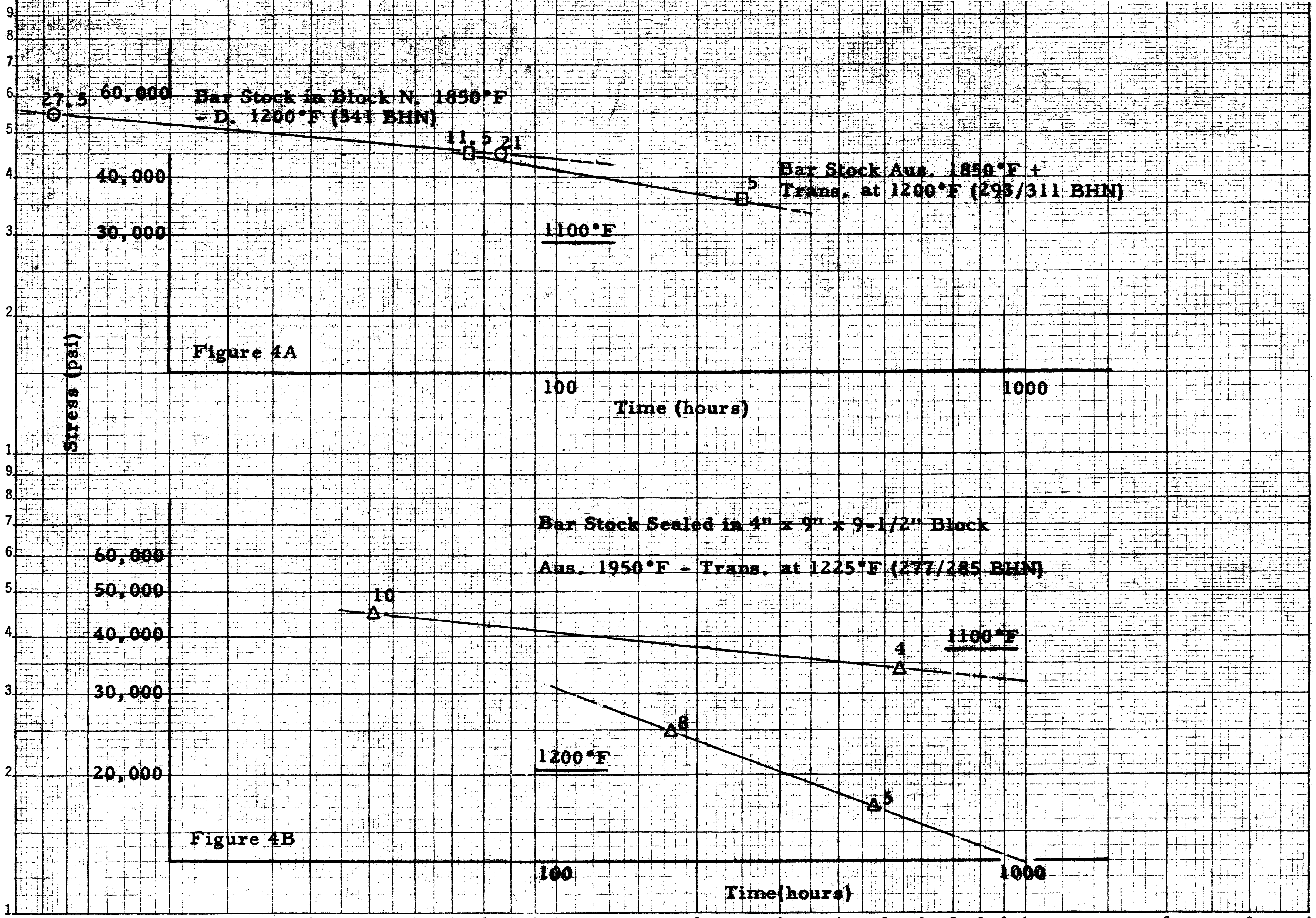

Figure 4. - Stress - Rupture Time Curves at 1100° and 1200°F for "17-22-A"V Steel, Heat 11574. Heat Treated as Indicated.

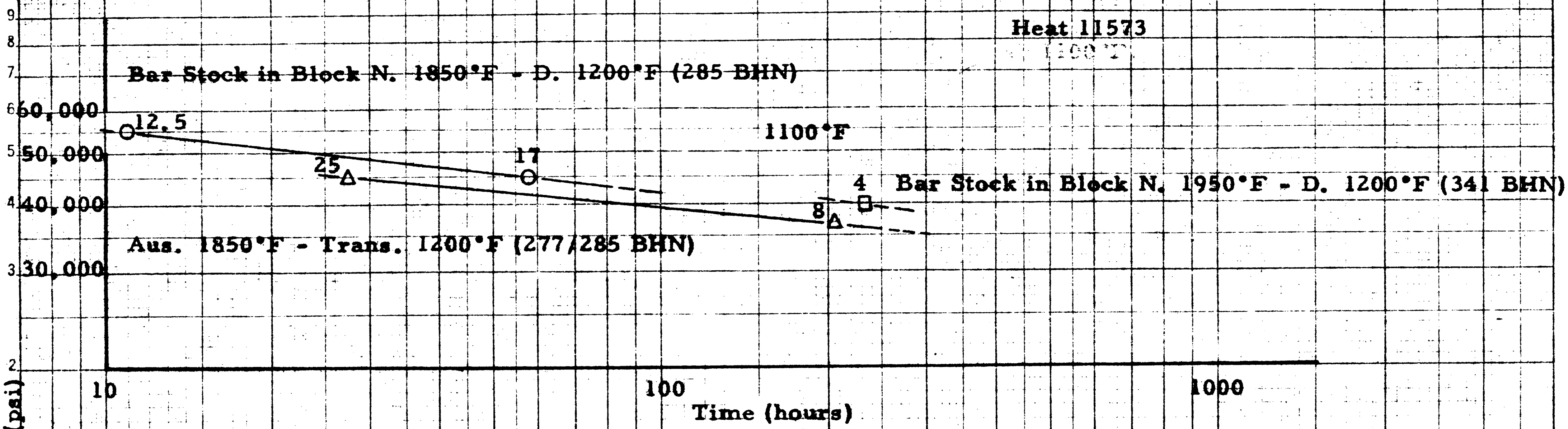

Figure 5. - Stress - Rupture Time Curves at 1100°F for "17-22-A"V Steel, Heat 11573. Heat treated as indicated.

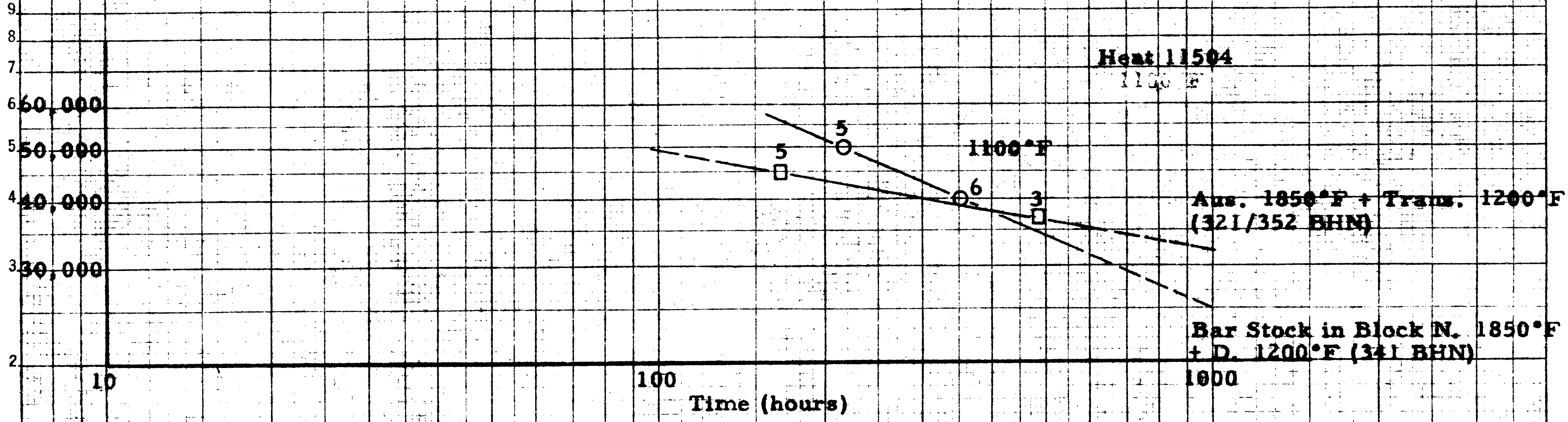

Figure 6. - Stress - Rupture Time Curves at 1100°F for "17-22-A"V Steel, Heat 11504. Heat treated as indicated.

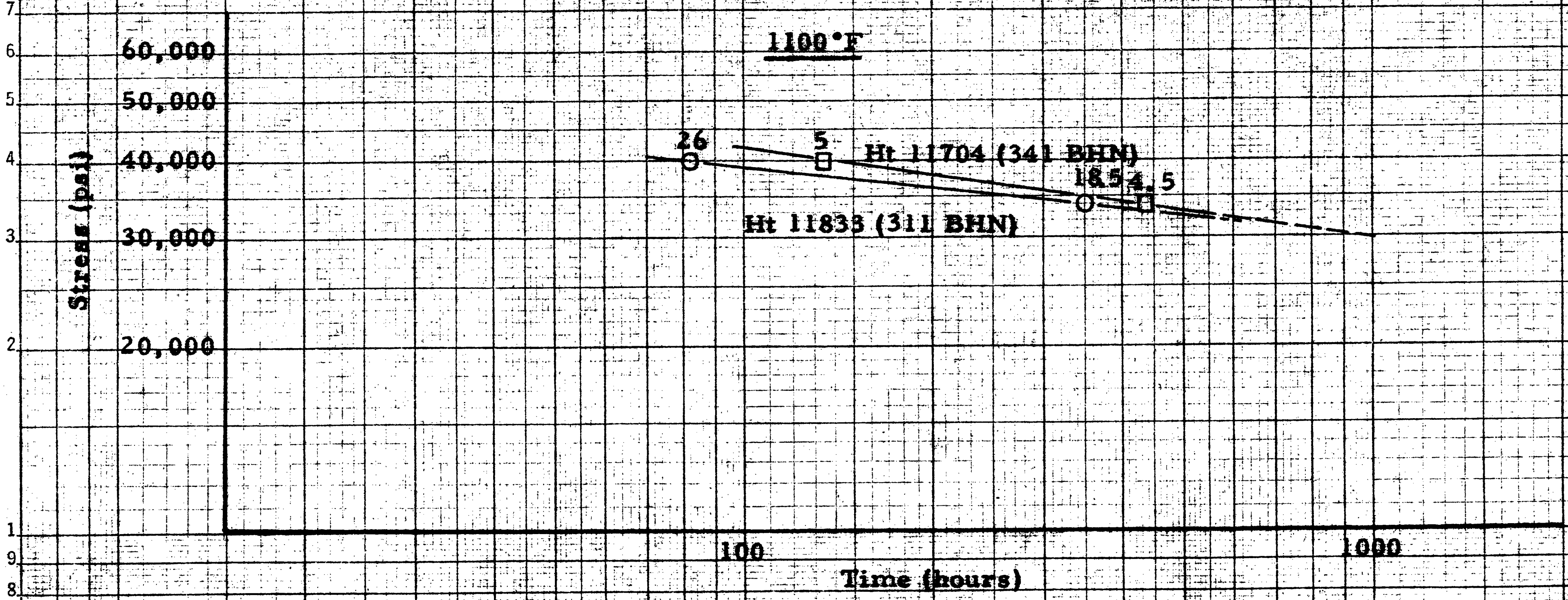

Figure 7. - Stress - Rupture Time Curves at 1100°F for "17-22-A"V Steels, Heats 11833 and 11704. Bar stock sealed in 4" x 9" x 9-1/2" block normalized from 1850°F and drawn for 6 hours at 1250°F to the indicated hardness level.

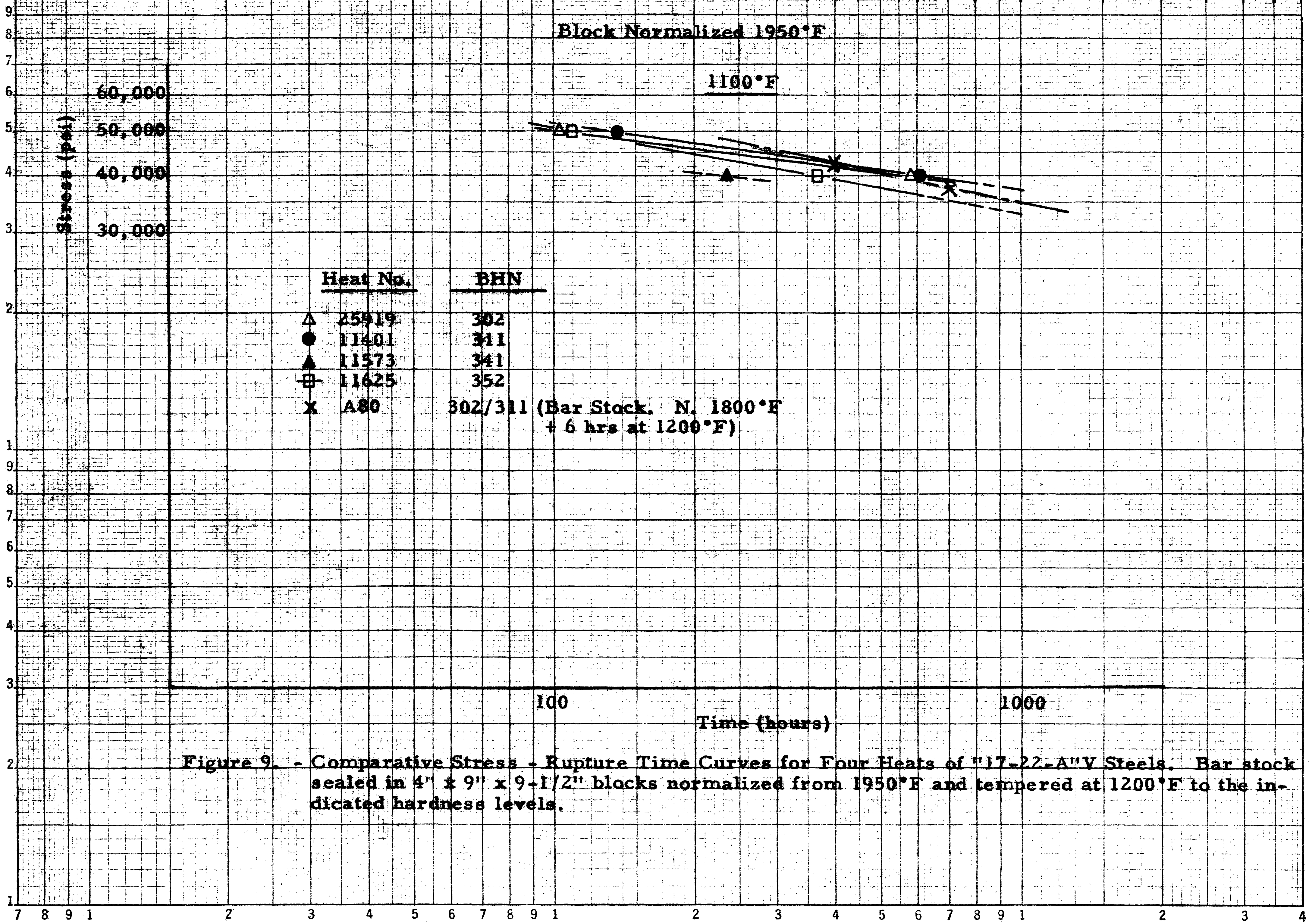

Figure 9. - Comparative Stress - Rupture Time Curves for Four Heats of "17-22-A"V Steels. Bar stock sealed in 4" x 9" x 9-1/2" blocks normalized from 1950°F and tempered at 1200°F to the indicated hardness levels.

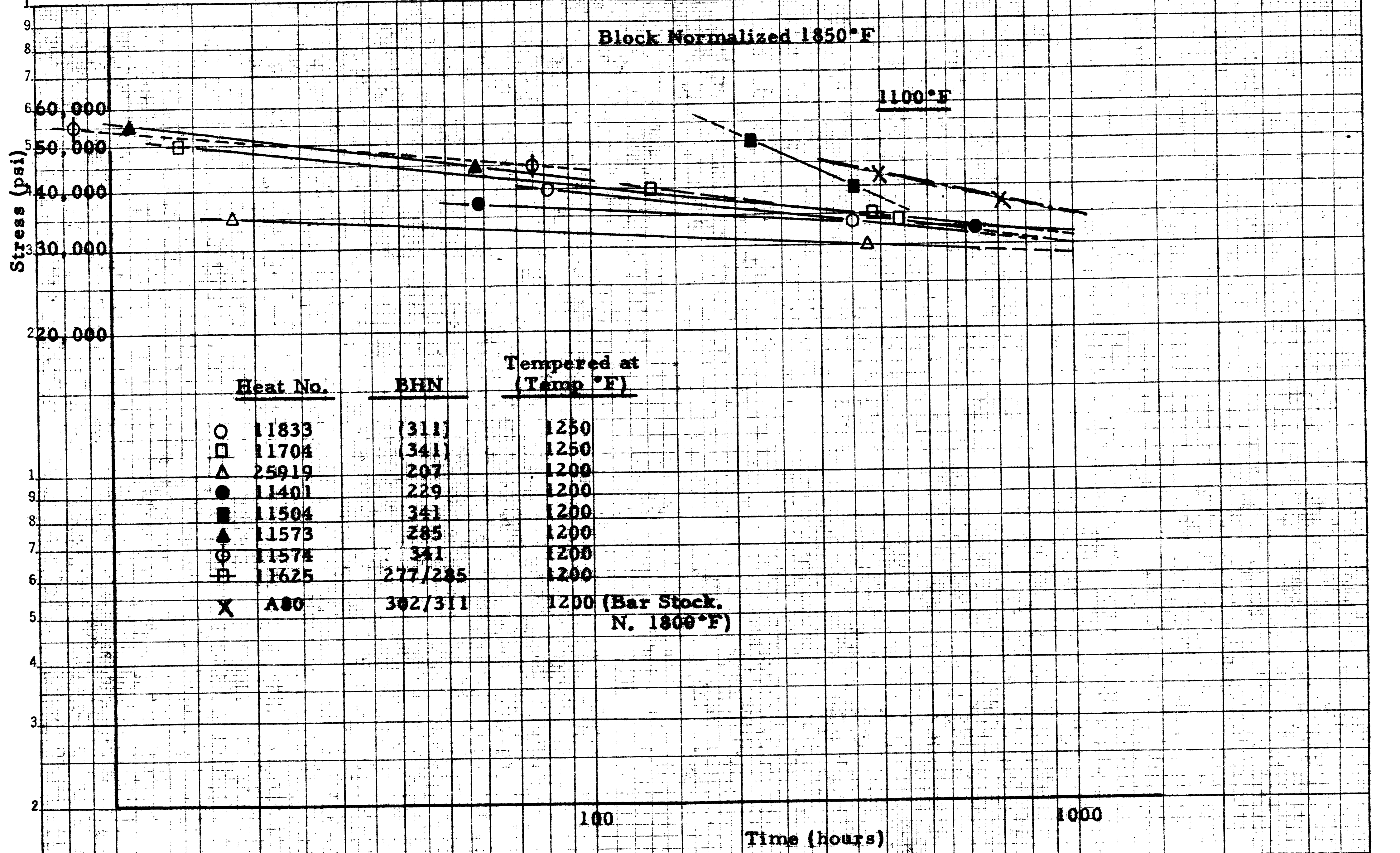

Figure 8. - Comparative Stress - Rupture Time Curves at 1100°F for Eight Heats of "17-22-A"V Steel. Bar stock sealed in 4" x 9" x 9-1/2" block normalized from 1850°F and tempered to the indicated hardness levels.

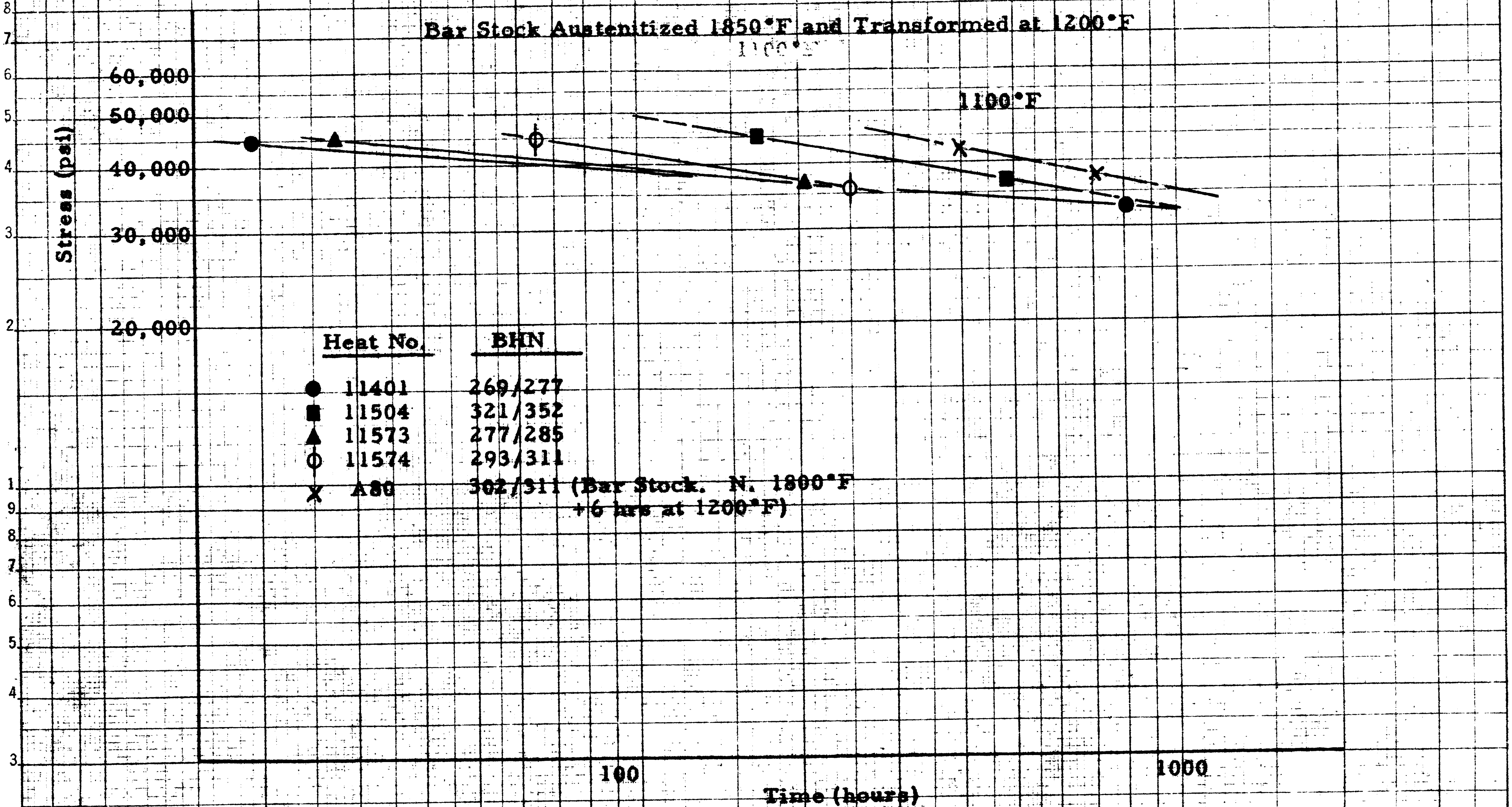

Figure 10. - Comparative Stress - Rupture Time Curves at 1100°F for Five Heats of "17-22-A"V Steels. 1-1/2" x 7" Bars Austenitized at 1850°F, cooled to and held at 1200°F for 6 hours.

21 Mounted Picture Pages follow here.

See ERI File copy.