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BORON AND TITANIUM ADDITIONS TO "17-22-A"V STEEL

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BORON AND TITANIUM ADDITIONS TO "17-22-A"V STEEL

A previous investigation (Report 243) had suggested that titanium and boron when added separately to "17-22-A"V steel could improve creep-rupture properties at temperatures of up to 1100°F to a remarkable extent. In the investigation being reported both elements were added simultaneously to heats with carbon contents ranging from 0.10 to 0.26 percent. The manganese contents were in the range of 0.52 to 0.65 percent. "A" induction heats and "O" arc furnace heats were made, rolled to barstock or forged to discs, heat treated and machined to specimens by The Timken Roller Bearing Company. A range of heat treatments were used. Evaluations were primarily based on rupture tests at 1100°F. Three materials were tested at 1200°F as well.

CONCLUSIONS

Rupture test properties at 1100°F were considerably improved over those of "17-22-A"V steel by the addition of boron and titanium. Both strength and ductility were improved. Two of three arc furnace heats gave test results as either barstock or forgings which agreed well with the properties of induction heats. They were, in fact, considerably better.

One of the arc furnace heats, however, had comparatively poor properties as barstock. Forgings from the heat compared quite well with the other heats.

Evidently unidentified factors in chemical composition or prior history of working had a considerable effect on properties. Limited data indicated that the nitrogen content of the arc heat with the lowest properties was similar to that of the induction heats with the high comparative properties.

The properties of the arc furnace heats were as good as or better than the properties of the induction heats, unlike the results obtained from heats with only boron added (Report 243). This suggested that the titanium protected the boron in the arc furnace heats.

Isothermal transformation did not improve properties of the arc heat with the lower properties. Oil quenching forgings improved ductility but not strength for the one heat investigated.

In all cases strength increased and ductility decreased with increasing temperature of heat treatment. This seemed to be associated with solution of TiC particles in the microstructures. The properties of radial and tangential specimens were not excessively different.

Very low carbon (0.10 percent) resulted in soft material with low rupture strength for 100 hours. Only single survey tests did not indicate whether or not properties would compare better at prolonged time periods. The heat also had high boron and titanium.

TEST MATERIAL

Tensile specimens 0.505 inches in diameter were supplied by The Timken Roller Bearing Company from six heats of modified "17-22-A"V steel having the following reported chemical compositions:

Heat No.	C (%)	Mn (%)	P (%)	S (%)	Si (%)	Cr (%)	Ni (%)	Mo (%)	V (%)	B (%)	Ti (%)	N (%)
A134	.20	.57	.015	.033	.79	1.84	.24	.49	.77	.0036	.33	.012
A135	.25	.52	.015	.031	.79	1.70	.16	.51	.77	.0092	.43	.010
A73	.10	.54	.017	.026	.75	1.30	-	.53	.28	.042	.67	-
02392	.26	.61	.018	.017	.58	1.49	.29	.48	.71	.0028	.35	.011
02629	.21	.63	.010	.012	.64	1.49	.33	.53	.70	.0026	.32	-
02630	.24	.65	.012	.014	.63	1.47	.27	.49	.71	.0022	.37	-

The "A" heats were 300 pound induction heats and the "O" heats 2,000 pound arc furnace heats.

The specimens supplied from the induction heats were machined from heat treated 1 inch barstock. Specimens from the electric arc furnace heats were machined from both 1 inch diameter heat treated barstock and heat treated upset pancake forgings.

Parts of each of the arc furnace heats were forged at 2100°F to 7 inch square billets. The billet from Heat 02392 was then upset forged into 15 inch diameter by four inch thick pancakes and Heats 02629 and 02630 to 15½ inch diameter by three inch thick pancakes.

The pancake forgings were sectioned and sampled as indicated in Figure 1 for Heat 02392 and in Figure 2 for Heats 02629 and 02630.

The heat treatments used together with the reported hardness values are presented in Table 1. The room temperature mechanical properties as reported by The Timken Roller Bearing Company are presented in Table 2. For rupture tests where the stress exceeded 40,000 psi the diameter of the gage section of the specimens were reduced to bring the load requirements within the capacity of the rupture units.

RESULTS AND DISCUSSION

The preliminary portions of this investigation were conducted on specimens made from barstock from induction furnace heats. The composition of the most promising heats was then duplicated in larger arc melted "O" furnace heats. Both barstock and forgings were made from these latter heats.

The stress-rupture data obtained from the differest materials in their various conditions are shown in Table 3. The stress-rupture time curves derived from these data are presented in Figures 3, 4 and 5. The indicated rupture strengths for 100 and 1000 hours at 1100°F for the heats are shown in Table 4 together with the indicated ductilities in these time periods.

Induction Furnace Heats

Examination of the data from induction furnace heats (Figure 3 and Table 4) indicated the following effects from adding boron plus titanium to "17-22-A"V steel on rupture properties at 1100°F:

1. The heats with carbon contents of 0.20 and 0.25 (A134 and A135) had higher indicated strengths than "17-22-A"V steel.
2. Heat A73 with 0.10 percent carbon was much weaker. The carbon was too low to develop the hardness associated with the high strengths of Heats A134 and A135 or regular "17-22-A"V steel. Only single tests were conducted so that there was no way of estimating what the comparative long time strengths might be.
3. Increasing the temperature of heat treatment raised rupture strength but reduced ductility. The ductility was similar to "17-22-A"V steel for Heats A134 and A135 when heat treated at 1950°F, with substantially high rupture strengths. When heat treated at 1800°F the ductility was higher but the strengths were only on the high side of the range for "17-22-A"V steel.
4. Heat A73 had substantially higher rupture strength when the temperature of heat treatment was raised to 2100°F from 1950°F. Ductility was reduced but was still high compared to the harder materials from the higher carbon heats.
5. Boron plus titanium did not raise the rupture strength in comparison with Heat A127 made only with boron. Ductility may have been higher.

Comparative data (Report 243) for adding only titanium to "17-22-A"V steel are not available. When added to "17-22-A"S steel it increased strength and ductility to a remarkable extent. To obtain the high strength it was, however, necessary to heat treat at 1950°-2050°F.

Evidently when titanium was added it was necessary to use higher temperatures of heat treatment to dissolve TiC. The solution of TiC was required before the necessary hardness could be obtained. The solution of TiC apparently also led to increased rupture strengths as well (see Report 243). The increased strength from the high temperature heat treatments of the heats with boron and titanium presumably was therefore due to the solution of TiC.

The microstructure of the boron plus titanium heats (Plates 1, 2 and 3) indicated that titanium prevented coarsening of the grain size and bainitic structure resulting from heat treatment at 1950°F. The micro-structure of the 0.10 percent carbon Heat A73 appeared to be made up of ferrite plus titanium carbonitrides when heat treated at 1950°F. Raising the temperature of heat treatment to 2100°F induced some bainite to form for the test conditions evaluated. Both the low carbon content and the presence of titanium apparently restricted hardening and thereby restricted strength.

Maintaining the V/C ratio of the 0.10 percent carbon heat (A73) at 2.8 did not cause high strengths to be devloped at 100 hours. A proper ratio, however, could still be very effective for prolonged service although tests were not run to determine if this did occur. The boron content was also comparatively very high at 0.042 percent. The titanium level was also high at 0.67 percent.

Arc Furnace Heats

Data were obtained from rupture tests at 1100°F on samples from three heats (Heats 02392, 02629 and 02630). All three heats had very similar chemical compositions (page 2). The results for tests at 1100°F (Figures 4 and 5 and Table 4) are summarized in Figure 6. Pertinent points in the data are:

1. The rupture strengths of the arc furnace heats were high in comparison to "17-22-A"V steel. The differential increased markedly with the temperature of heat treatment of the boron plus titanium heats.
2. The barstock from the arc furnace heats had substantially higher strengths than the barstock from the induction furnace heats (Figure 6), except for Heat 02392. The strengths were similar to those for the boron-containing induction Heat A127. The heats did not undergo the reduction in strength observed for arc furnace heats with only boron added (Report 243).
3. The forgings had strengths similar to the barstock from the same heat for 100 hours. At 1000 hours the forgings tended to be lower in strength.

4. Isothermal transformation of barstock did not seem effective in raising the strength of Heat 02392 barstock. The same was true for oil quenching forgings and it may have reduced strength. Both may have improved ductility.

5. The forgings exhibited better ductility than the barstock in Heat 02392. This was also true for the other two heats.

6. In all cases raising the temperature of heat treatment raised the rupture strength and reduced the elongation (Figure 6 and Table 4).

7. In general radial specimens from the forgings had higher strength than those taken tangentially.

8. Microstructures (Plates 4 through 11):

   (a) All of the Heat 02392 barstock tended to have a distinct "grain" structure. This was exaggerated in the isothermally transformed barstock (Plates 4 and 5). Presumably this type of structure was responsible for the comparatively low strength and especially ductility. Plate 5, showing the microstructure of the isothermally transformed materials, emphasizes the wide differences in structure with similar hardness values which can exist in the alloy.

   (b) The forgings from Heat 02392 had the bainitic structures (Plates 6 and 7) associated with high strength in this alloy. The forging normalized from 1850°F had a very coarse grain structure (Plate 7). This presumably caused low ductility.

   (c) The oil quenched forgings had a tempered bainitic type structure (Plate 8) which has been associated with good strength and ductility in this alloy. The ductility was good. Rupture strengths were, however, somewhat low, suggesting that tempered martensite was present in the microstructure.

   (d) Heats 02629 and 02630 had the tempered bainitic structures (Plates 9, 10 and 11) associated with high strength and ductility in the alloy. The exception was the barstock from Heat 02630 normalized from 1850°F (Plate 10). It had the distinct "grain structure" associated with low ductility in the alloy. The forgings had finer tempered bainitic structures than the barstock.

9. The reason for the comparatively low properties of Heat 02392 in relation to the other two arc furnace heats is not known. The limited information available suggests that there exists a considerable difference in transformation characteristics among the heats. The reason for this difference is uncertain. The data also suggest that variables in the conditions of working were involved since barstock was so much poorer than forgings for Heat 02392. Heat 02392 had a nitrogen content similar to that of the induction heats (see page 2). This suggests that some other factor was involved.

These data furthermore do not indicate the reasons why the properties of the arc heats compared so favorably with those of the induction heats while they were so inferior where only boron was added (see Report 243). Possibly the titanium "protected" the boron in some way.

RUPTURE TESTS AT 1200°F

Very limited testing at 1200°F indicates that boron plus titanium can increase strength at 1200°F (Table 4). Specimens from induction Heat A134 had substantially higher strength than "17-22-A"V steel. The specimens from barstock from arc furnace Heat 02392 were no stronger than "17-22-A"V steel. This barstock, however, seemed unduly weak at 1100°F in comparison to other arc furnace heats or to forgings from the same heat. It is therefore possible that boron plus titanium can be beneficial.

The data suggest that boron plus titanium also improve ductility at longer times in the rupture tests.

In accordance with most data for quenched Cr-Mo-V steel, the oil quenched forging from Heat 02392 (Figure 4) was low in rupture strength.

TABLE 1

Heat Treatments used for Boron and Titanium Modified "17-22-A"V Steel

Heat No.	Material	Heat Treatment	BHN
A134	Barstock	Normalized from 1800°F+6hours at 1200°F	311/321
A134	Barstock	Normalized from 1950°F+6hours at 1250°F	302/311
A135	Barstock	Normalized from 1800°F+6hours at 1200°F	311/321
A135	Barstock	Normalized from 1950°F+6hours at 1250°F	293/311
A73	Barstock	Normalized from 1950°F+6hours at 1200°F	128
A73	Barstock	Renormalized from 2100°F+6hours at 1100°F	217/228
02392	Barstock	Normalized from 1800°F+6hours at 1200°F	352/363
02392	Barstock	Normalized from 1950°F+6hours at 1250°F	331/341
02392	Barstock	Austenitized at 1850°F, cooled to and held for 6 hours at 1225°F	321/331
02392	Barstock	Austenitized at 1950°F, cooled to and held for 6 hours at 1225°F	341
02392	Forging[(a)]	Normalized from 1800°F+11hours at 1200°F	311/321
02392	Forging	Normalized from 1850°F+6hours at 1200°F	277/311
02392	Forging	Oil quenched from 1800°F+6hours at 1200°F	293/311
02629	Barstock	Normalized from 1750°F+6hours at 1200°F	321
02629	Barstock	Normalized from 1850°F+6hours at 1200°F	321
02629	Forging[(b)]	Normalized from 1850°F+6hours at 1200°F	302/321
02630	Barstock	Normalized from 1750°F+6hours at 1200°F	341
02630	Barstock	Normalized from 1850°F+6hours at 1200°F	331/341
02630	Forging[(b)]	Normalized from 1850°F+6hours at 1200°F	311/331

(a) - Forging originally normalized from 1800°F, then a quarter section was renormalized and tempered as indicated.

(b) - The upset pancakes from these heats were forged from 7 inch squares hot rolled at 2150°F. After upsetting the pancake forgings were equalized at 1800°F, cooled in sand and heat treated as indicated.

TABLE 2

Room Temperature Mechanical Properties Reported by The Timken Roller Bearing Company for Boron and Titanium Modified "17-22-A"V Steel

Heat No.	Material	Specimen Direction	Heat Treatment (°F)	Yield Strength 0.2% Offset (psi)	Tensile Strength (psi)	Elong. (% in 2 ins)	Red. of Area (%)	Izod Impact (ft.-lbs.)
A134	Barstock	-	N1800+T1200	134,500	147,500	17.0	57.5	-
A134	Barstock	-	N1800+T1200	139,250	150,000	15.5	57.1	-
A134	Barstock	-	N1950+T1250	136,500	151,500	15.5	55.6	-
A134	Barstock	-	N1950+T1250	137,000	152,500	15.0	54.8	-
A135	Barstock	-	N1800+T1200	132,500	144,250	16.5	56.0	-
A135	Barstock	-	N1800+T1200	135,750	145,250	16.0	55.0	-
A135	Barstock	-	N1950+T1250	139,000	151,250	15.0	53.6	-
A135	Barstock	-	N1950+T1250	137,000	150,000	16.0	53.5	-
02629	Forging	R	N1850+T1200	140,750	151,000	13.0	39.1	4-4-4-½
02629	Forging	R	N1850+T1200	135,625	147,750	12.5	33.8	-
02629	Forging	Ta	N1850+T1200	141,250	149,000	2.0(a)	2.8 (a)	5-4-4
02629	Forging	Ta	N1850+T1200	140,000	152,500	9.5	28.8	-
02630	Forging	R	N1850+T1200	141,750	154,250	14.0	44.9	4-3-4
02630	Forging	R	N1850+T1200	138,750	149,250	11.0	32.5	-
02630	Forging	Ta	N1850+T1200	141,625	154,625	12.0	35.1	3-4-4
02630	Forging	Ta	N1850+T1200	143,125	155,250	10.5	25.5	-

(a) - Severe non-metallic inclusions responsible for low ductility

R - Radial specimen

Ta - Tangential specimen

TABLE 3

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

Heat Treatment (a)	Specimen Direction	Temp. (°F)	Stress (psi)	Rupture Time (hours)	Elong. (% in 2 ins)	Red. of Area (%)
		Heat A134 - Barstock				
N1800+T1200	-	1100	50,000	137	13.5	68.5
N1800+T1200	-	1100	40,000	1070	21.0	68.5
N1950+T1250	-	1100	60,000	86	10.0	43.0
N1950+T1250	-	1100	50,000	803	4.5	9.5
N1950+T1250	-	1100	40,000	3472	3.5	7.5
N1950+T1250	-	1200	30,000	228	6.0	(a)
N1950+T1250	-	1200	25,000	454	11.0	31.0
		Heat A135 - Barstock				
N1800+T1200	-	1100	45,000	260	24.0	61.5
N1800+T1200	-	1100	40,000	499	25.0	61.5
N1950+T1250	-	1100	55,000	236	12.0	48.0
N1950+T1250	-	1100	40,000	2177	9.5	36.0
		Heat A73 - Barstock				
N1950+T1200	-	1100	25,000	36	34.0	86.0
N2100+T1100	-	1100	35,000	209	18.0	81.0
		Heat 02392 - Barstock				
N1800+T1200	-	1100	55,000	67	1.5	3.5
N1800+T1200	-	1100	49,000	140	1.5	4.0
N1800+T1200	-	1100	40,000	597	3.0	4.5
N1800+T1200	-	1200	30,000	86	8.5	13.5
N1800+T1200	-	1200	20,000	268	14.5	34.0
N1950+T1250	-	1100	55,000	130	3.0	3.5
N1950+T1250	-	1100	43,000	597(b)	3.0	5.5
N1950+T1250	-	1200	30,000	146	4.5	11.0
N1950+T1250	-	1200	20,000	723	7.5	12.0

continued . . .

TABLE 3 continued

Heat Treatment (a)	Specimen Direction	Temp. (°F)	Stress (psi)	Rupture Time (hours)	Elong. (% in 2 ins)	Red. of Area (%)
Aus1850-Iso1225	-	1100	52,000	41.5	8.5	17.5
Aus1850-Iso1225	-	1100	40,000	408	8.0	10.5
Aus1850-Iso1225	-	1200	30,000	81	22.5	43.0
Aus1950-Iso1225	-	1100	50,000	140	2.0	6.5
Aus1950-Iso1225	-	1200	20,000	466	16.0	23.0
		Heat 02392 - Pancake Forging				
N1800+T1200	R	1100	55,000	61	9.0	34.0
N1800+T1200	R	1100	45,000	268	11.5	27.0
N1800+T1200	Ta	1100	40,000	395	6.0	14.5
N1850+T1200	R	1100	55,000	34	5.0	23.5
N1850+T1200	Ta	1100	50,000	292	2.5	4.5
N1850+T1200	R	1100	45,000	448	7.0	11.5
N1850+T1200	Ta	1100	44,000	740	1.5	7.0
OQ1800+T1200	R	1100	55,000	52	12.0	39.0
OQ1800+T1200	Ta	1100	55,000	45	17.5	52.5
OQ1800+T1200	R	1100	45,000	296	11.0	23.5
OQ1800+T1200	R	1100	40,000	515	8.5	27.0
OQ1800+T1200	Ta	1100	40,000	229	13.0	28.5
OQ1800+T1200	R	1200	20,000	169	17.0	38.0
OQ1800+T1200	Ta	1200	20,000	153	14.5	30.0
		Heat 02629 - Barstock				
N1750+T1200	-	1100	55,000	64.3	16.5	55.0
N1750+T1200	-	1100	45,000	239	19.5	68.5
N1750+T1200	-	1100	35,000	1198	20.5	65.5
N1850+T1200	-	1100	55,000	238	6.0	27.0
N1850+T1200	-	1100	50,000	488	4.5	24.0
N1850+T1200	-	1100	46,000	943	6.5	17.0
		Heat 02629 - Forging				
N1850+T1200	R	1100	60,000	90.3	19.5	69.0
N1850+T1200	R	1100	55,000	175	17.0	69.0
N1850+T1200	R	1100	52,000	754	15.5	66.0
N1850+T1200	Ta	1100	52,000	119	13.0	59.5
N1850+T1200	Ta	1100	46,000	330	22.0	69.0

continued . . .

TABLE 3 concluded

Heat Treatment (a)	Specimen Direction	Temp. (°F)	Stress (psi)	Rupture Time (hours)	Elong. (% in 2 ins)	Red. of Area (%)
		Heat 02630 - Barstock				
N1750+T1200	-	1100	55,000	47.7	25.0	69.5
N1750+T1200	-	1100	45,000	268	19.0	60.0
N1750+T1200	-	1100	38,000	540	19.5	62.0
N1750+T1200	-	1100	35,000	761	24.0	65.0
N1850+T1200	-	1100	55,000	189	3.0	8.0
N1850+T1200	-	1100	50,000	471	4.0	8.0
N1850+T1200	-	1100	46,000	967	5.5	8.0
		Heat 02630 - Pancake Forging				
N1850+T1200	R	1100	60,000	108	17.0	64.5
N1850+T1200	R	1100	52,000	348	13.5	63.0
N1850+T1200	Ta	1100	51,900	217	15.0	67.0
N1850+T1200	Ta	1100	50,000	244	17.5	69.0
N1850+T1200	R	1100	44,000	671	16.0	79.0
N1850+T1200	R	1100	38,000	1412	22.0	73.5
N1850+T1200	Ta	1100	38,000	867	20.0	74.0

(a) - All temperatures in °F

(b) - Broke in gage mark

R - Radial specimen

Ta - Tangential specimen

Aus - Austenitize

Iso - Isothermally transform

N - Normalize

OQ - Oil quench

T - Temper

TABLE IV

Rupture Strengths at 1100° and 1200°F for Boron and Titanium Modified "17-22-A"V Steel

Additions made to "17-22-A"V	Heat No.	Material	Heat Treatment Austenitized (°F)	Heat Treatment Tempered (°F)	BHN	Rupture Strength (psi) 100 hr.	Rupture Strength (psi) 1000 hr.	Rupture Test Elongation (%) 100 hr.	Rupture Test Elongation (%) 1000 hr.
				Rupture Properties at 1100°F					
"17-22-A"V + Ti + B Induction Heats									
36 ppm B - .33% Ti	A134	Barstock	1800	1200	311/321	52,000	40,000	14	21
36 ppm B - .33% Ti	A134	Barstock	1950	1250	302/311	59,000	49,000	10	4
92 ppm B - .43% Ti	A135	Barstock	1800	1200	311/321	(52,000)	35,000	-	25
92 ppm B - .43% Ti	A135	Barstock	1950	1250	293/311	(62,000)	45,000	-	10
420 ppm B - .67% Ti -	A73	Barstock	1950	1200	128	(21,000)	-	30	-
.10%C - 28% V	A73	Barstock	2100	1100	217/228	(39,000)	-	20	-
"17-22-A"V + Ti + B "O" Arc Furnace Heats									
28 ppm B - .35% Ti	02392	Barstock	1800	1200	352/363	52,000	37,000	1.5	3
28 ppm B - .35% Ti	02392	Barstock	1950	1250	331/341	57,000	40,000	3	3
28 ppm B - .35% Ti	02392	Barstock	1850	Iso 1225	321/331	47,000	(36,000)	8	8
28 ppm B - .35% Ti	02392	Barstock	1950	Iso 1225	341	52,000	-	2	-
28 ppm B - .35% Ti	02392	Forging (R)	1800	1200	311/321	51,000	(37,000)	9	12
28 ppm B - .35% Ti	02392	Forging (T)	1800	1200	311/321	-	(35,000)	-	6
28 ppm B - .35% Ti	02392	Forging (R)	1850	1200	277/311	50,000	42,000	5	7
28 ppm B - .35% Ti	02392	Forging (T)	1850	1200	277/311	-	42,000	-	1.5
28 ppm B - .35% Ti	02392	Forging (R)	(OQ) 1800	1200	293/311	51,000	35,000	12	8.5
28 ppm B - .35% Ti	02392	Forging (T)	(OQ) 1800	1200	293/311	47,000	(30,500)	17	-
26 ppm B - .32% Ti	02629	Barstock	1750	1200	321	51,000	36,000	16	20
26 ppm B - .32% Ti	02629	Barstock	1850	1200	321	(62,000)	46,000	-	6.5
26 ppm B - .32% Ti	02629	Forging (R)	1850	1200	302/321	59,000	50,000	20	15
26 ppm B - .32% Ti	02629	Forging (T)	1850	1200	302/321	53,000	(40,000)	13	-
22 ppm B - .37% Ti	02630	Barstock	1750	1200	341	50,000	32,500	(25)	24
22 ppm B - .37% Ti	02630	Barstock	1850	1200	331/341	(59,000)	46,000	(3)	6
22 ppm B - .37% Ti	02630	Forging (R)	1850	1200	311/331	62,000	40,000	17	(16/22)
22 ppm B - .37% Ti	02630	Forging (T)	1850	1200	311/331	(60,000)	37,000	15	(20)
Typical Values for "17-22-A"V Steel									
Experimental induction heat		Barstock				45,000/52,000	30,000/36,000	8	5
Production heats		Barstock	C and Mn high for hardenability			40,000/50,000	24,000/33,000	5	4
				Rupture Properties at 1200°F					
"17-22-A"V + Ti + B Induction Heat									
36 ppm B - .33% Ti	A134	Barstock	1950	1250	302/311	(37,000)	(21,000)	(6)	(11)
"17-22-A"V + Ti + B "O" Arc Furnace Heat									
28 ppm B - .35% Ti	02392	Barstock	1800	1200	352/363	28,000	(13,000)	8	-
28 ppm B - .35% Ti	02392	Barstock	1950	1250	331/341	33,000	18,500	4	(7)
28 ppm B - .35% Ti	02392	Barstock	1850	Iso 1225	321/331	-	-	22	-
28 ppm B - .35% Ti	02392	Barstock	1950	Iso 1225	341	16,000	16,000	-	15
28 ppm B - .35% Ti	02392	Forging (R)	(OQ) 1800	1200	293/311	22,000	-	17	-
28 ppm B - .35% Ti	02392	Forging (T)	(OQ) 1800	1200	293/311	22,000	-	15	-
Typical Values for "17-22-A"V Steel									
Production heats		Barstock	C and Mn high for hardenability			25,000/30,000	13,000/15,000	10	3.5

(a) - Data from Report 243
Iso - Isothermally transformed
(R) - Radial specimen
(T) - Tangential specimen
(OQ) - Oil quenched
ppm - Parts per million

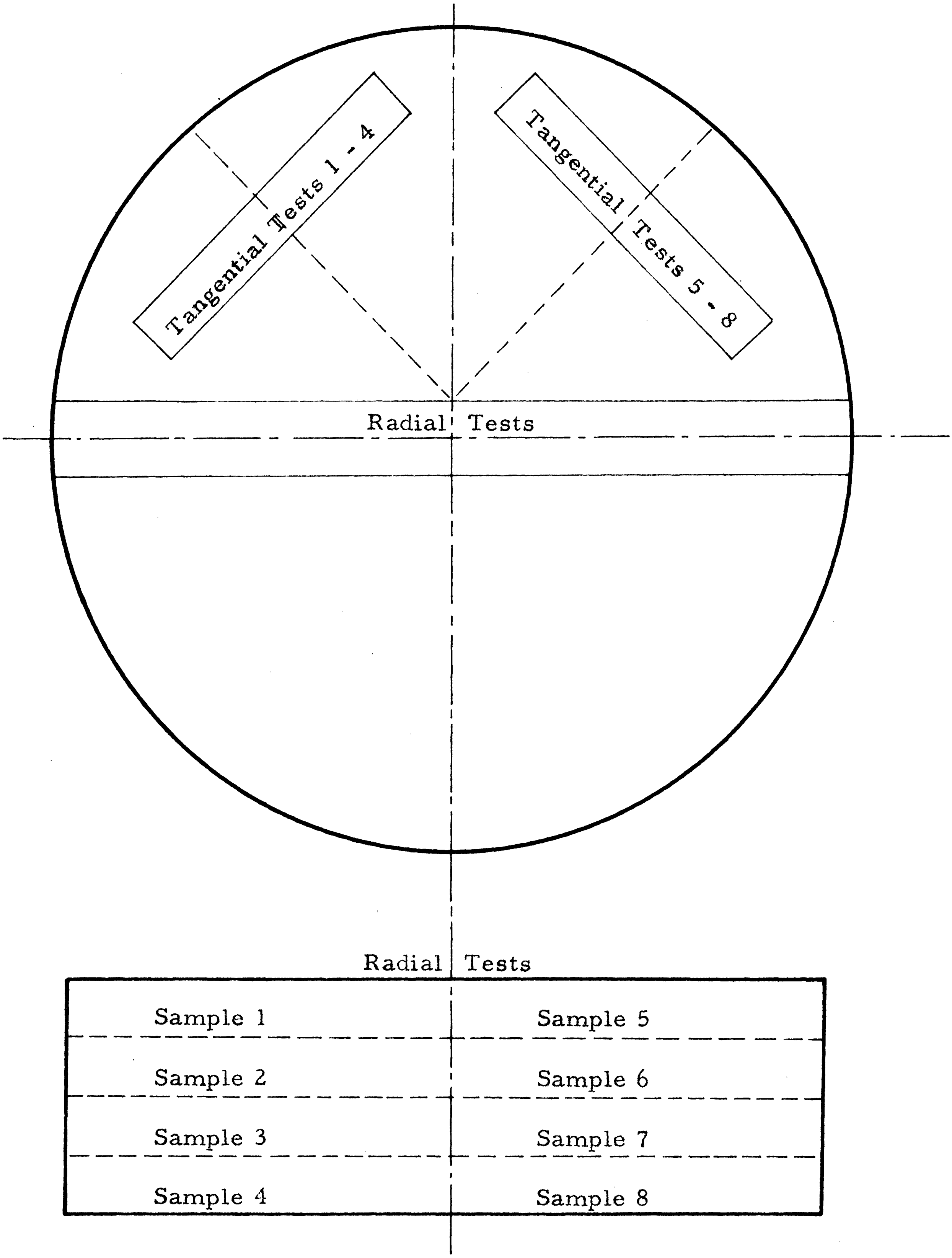


Figure 1. Sketch to show Location of Test Specimens in 15-inch Diameter by 4-inch thick Forgings from Heat 02392.

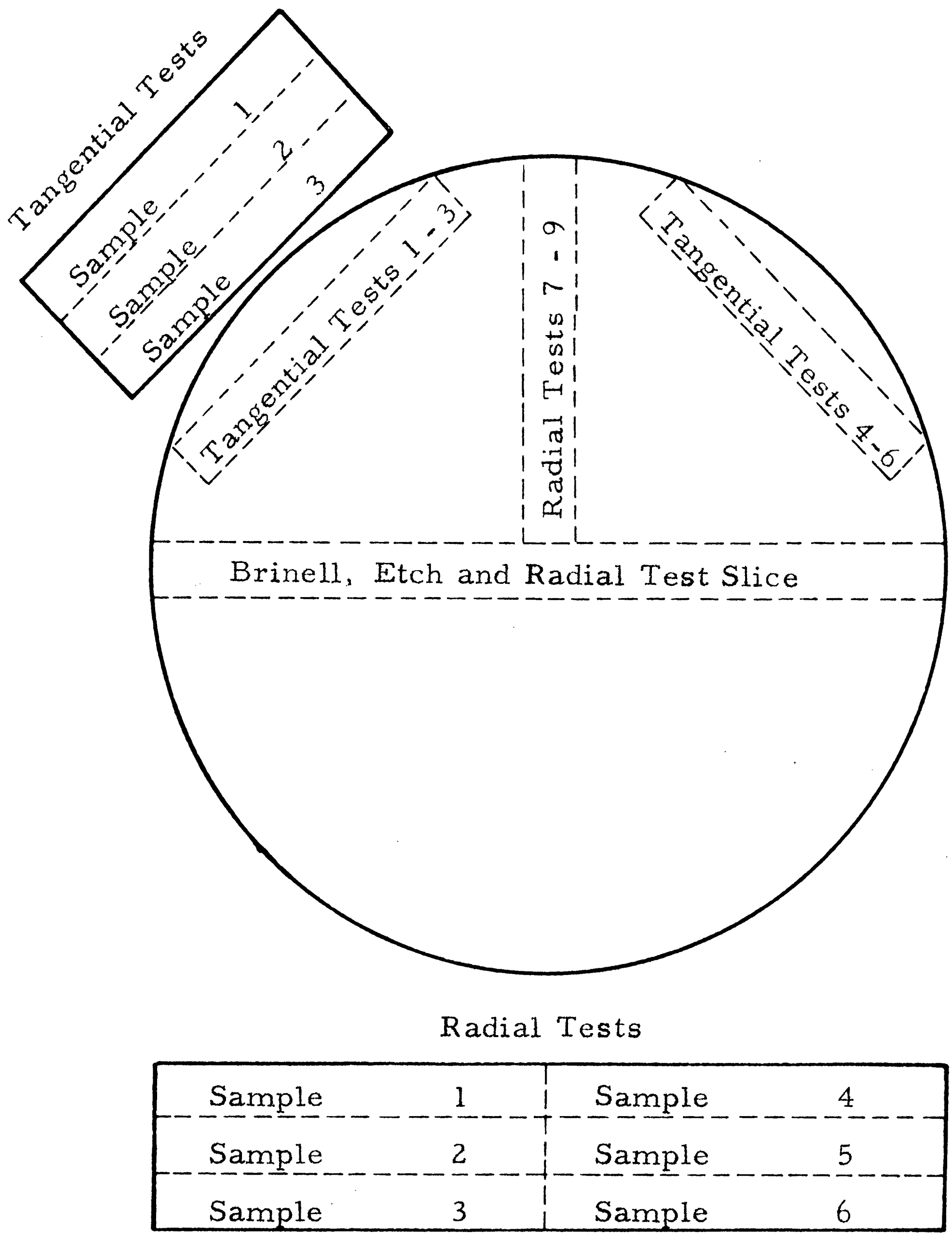


Figure 2. Sketch to show Location of Test Specimens in 15½-inch Diameter by 3-inch thick Forgings from Heats 02629 and 02630.

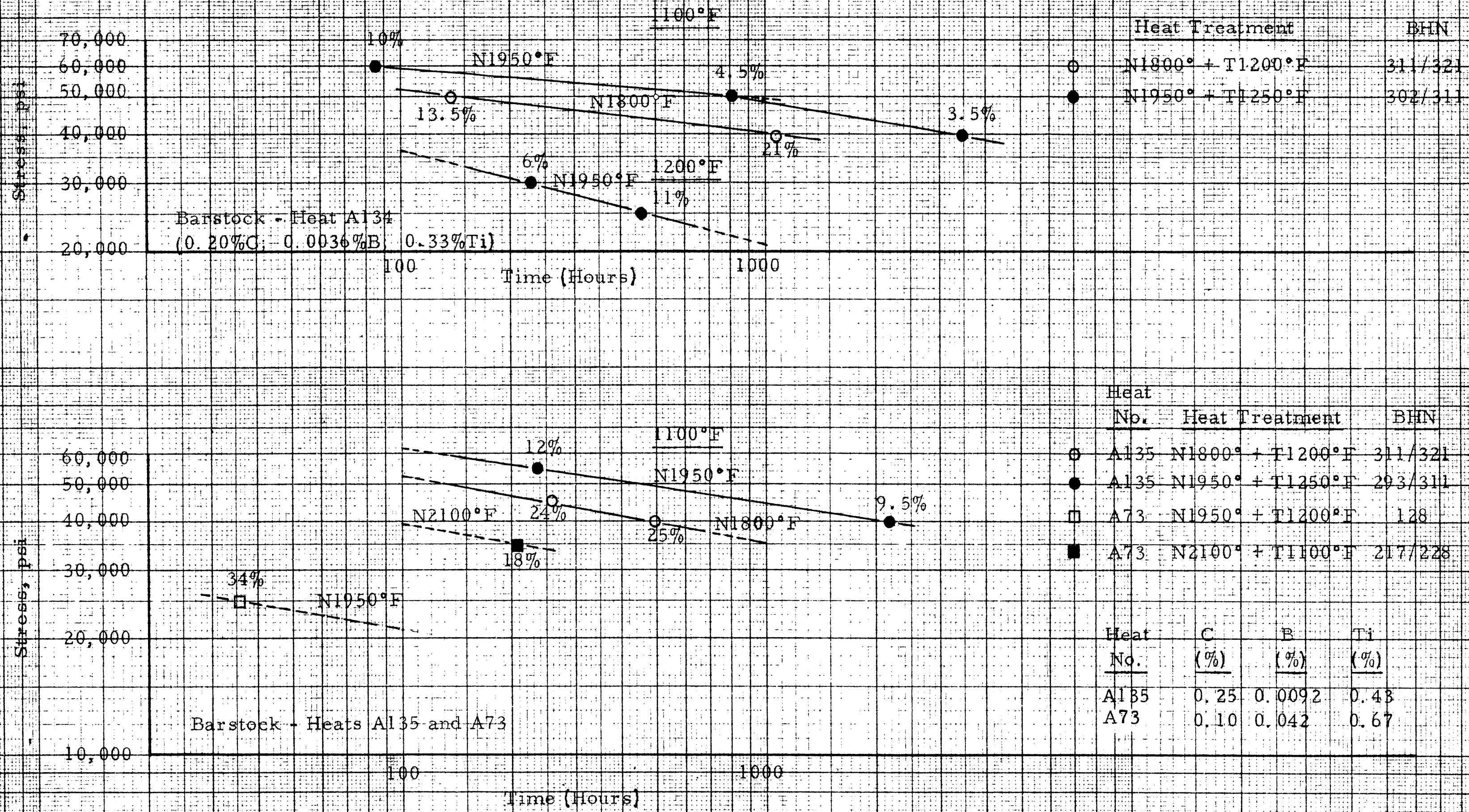


Figure 3. Stress-Rupture Time Curves at 1100° and 1200°F for "17-22-A"V Steel with Boron and Titanium. Barstock from Heats A134, A135 and A73 heat treated as indicated.

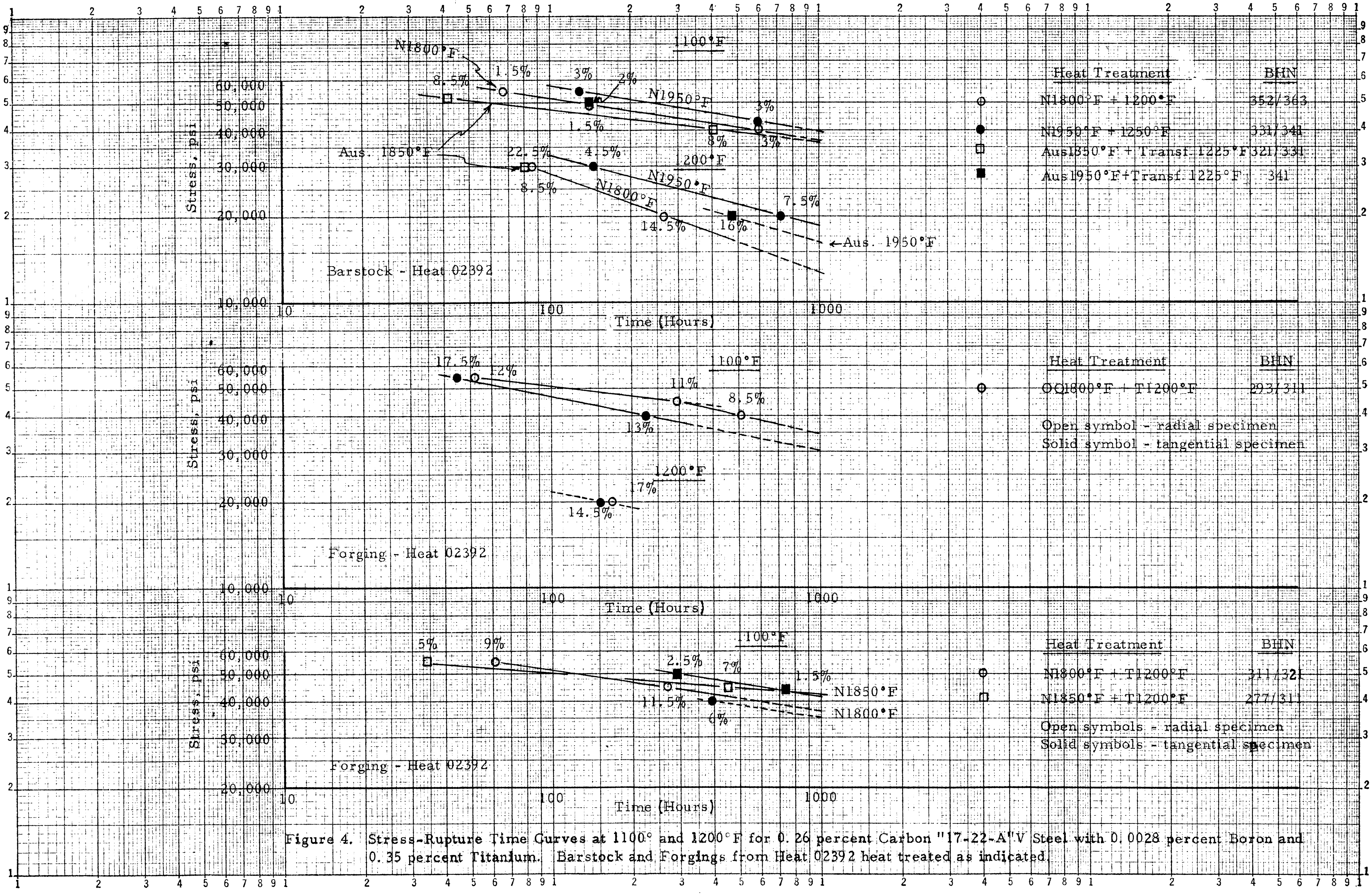


Figure 4. Stress-Rupture Time Curves at 1100° and 1200°F for 0.26 percent Carbon "17-22-A"V Steel with 0.0028 percent Boron and 0.35 percent Titanium. Barstock and Forgings from Heat 02392 heat treated as indicated.

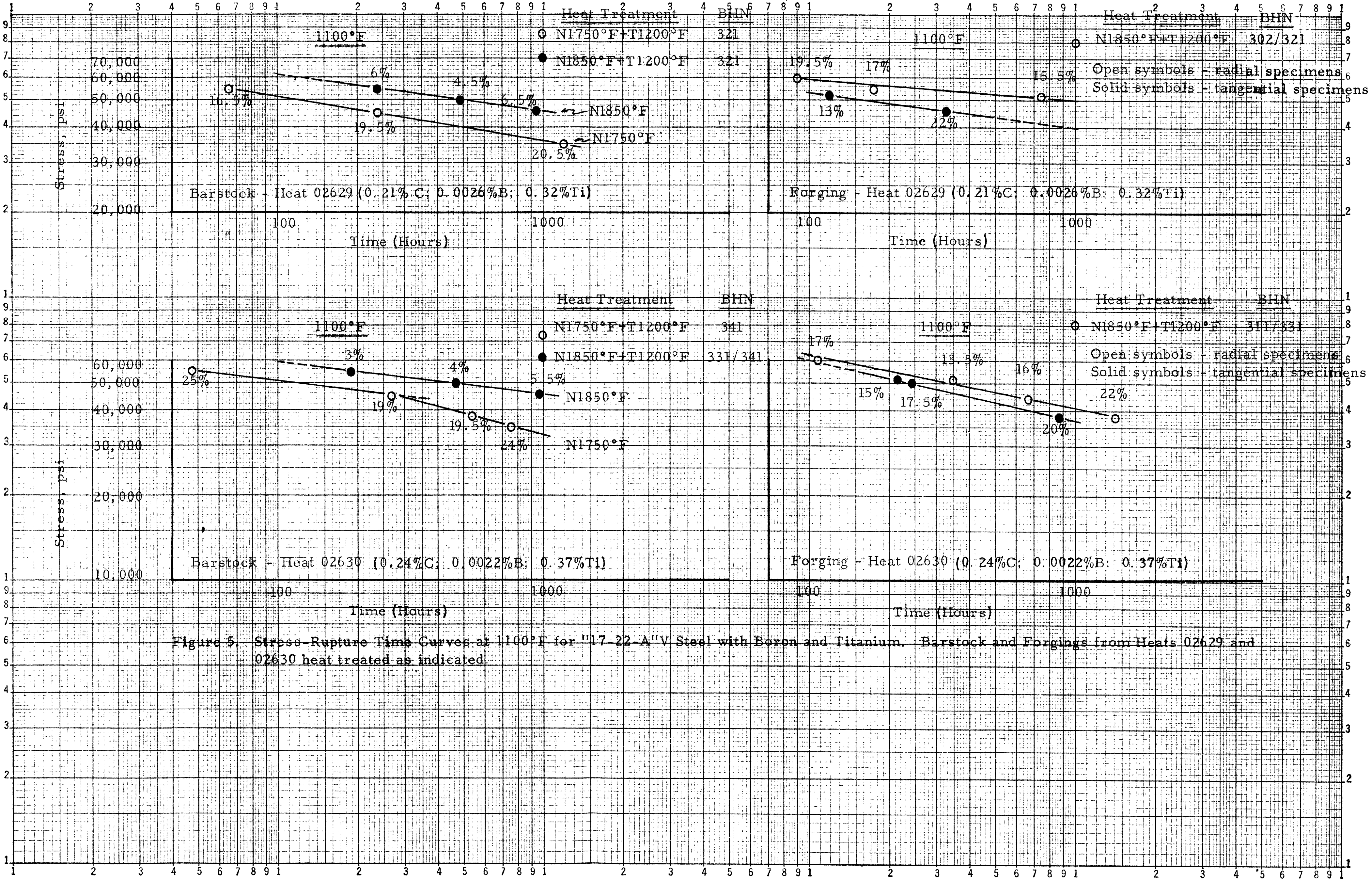


Figure 5. Stress-Rupture Time Curves at 1100°F for "17-22-A"V Steel with Boron and Titanium. Barstock and Forgings from Heats 02629 and 02630 heat treated as indicated.

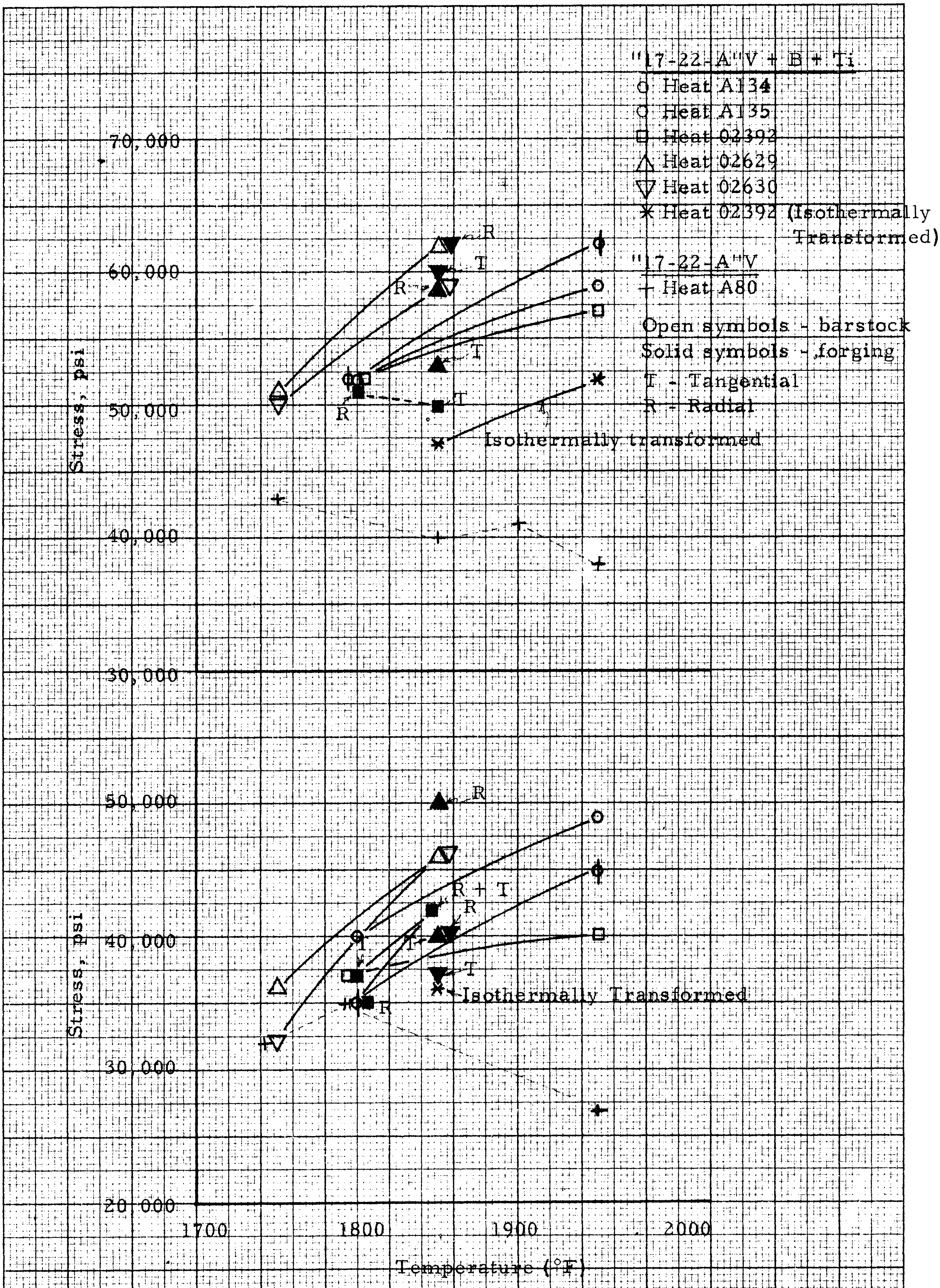
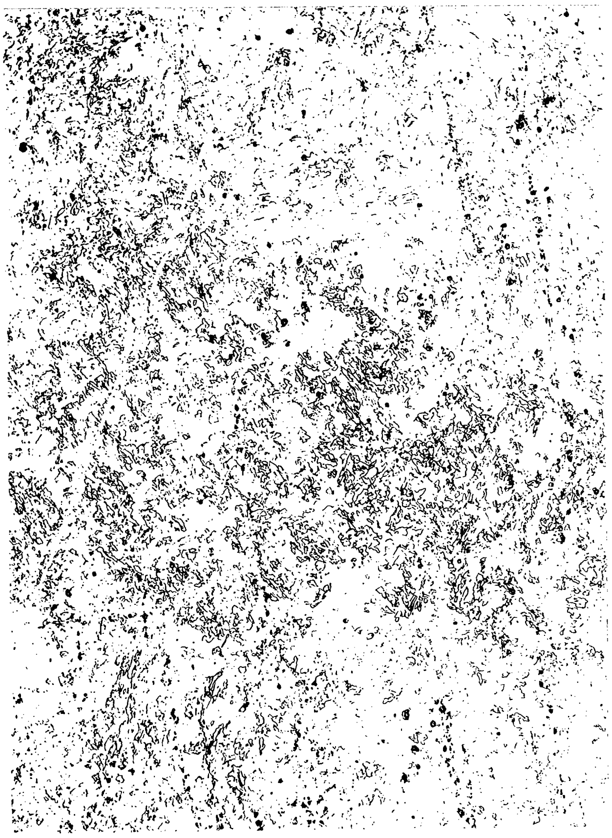
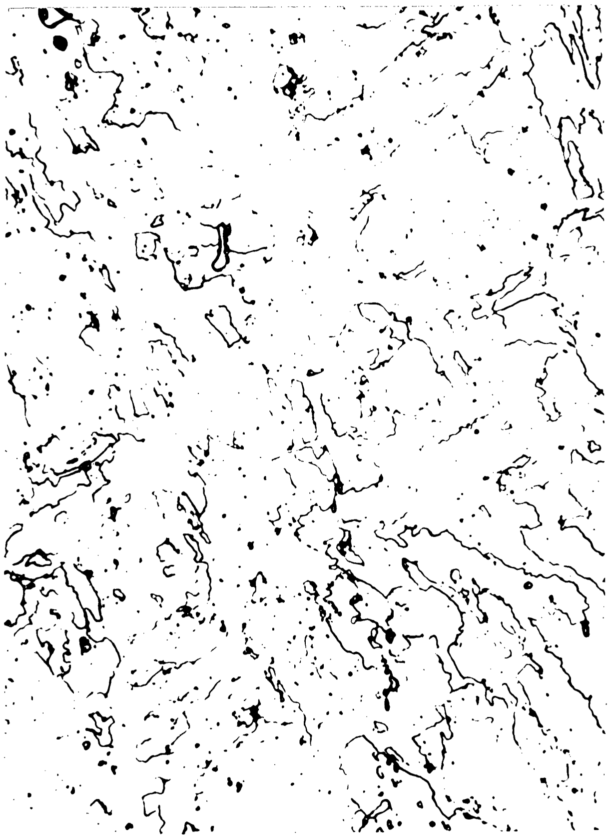


Figure 6. Effect of Temperature of Heat Treatment on the Rupture Strength at 1100°F of Barstock and Forgings from five Heats of "17-22-A"V+ Titanium and Boron Steel.

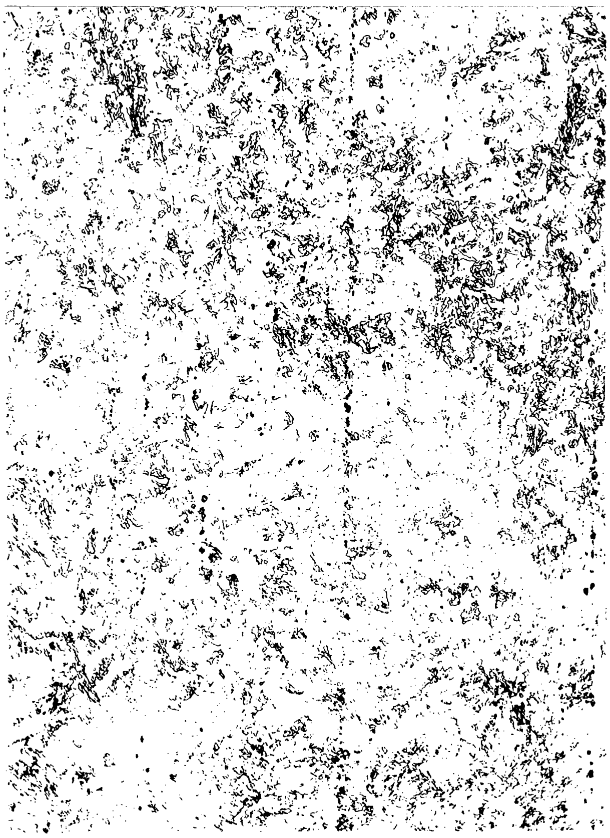


X100D

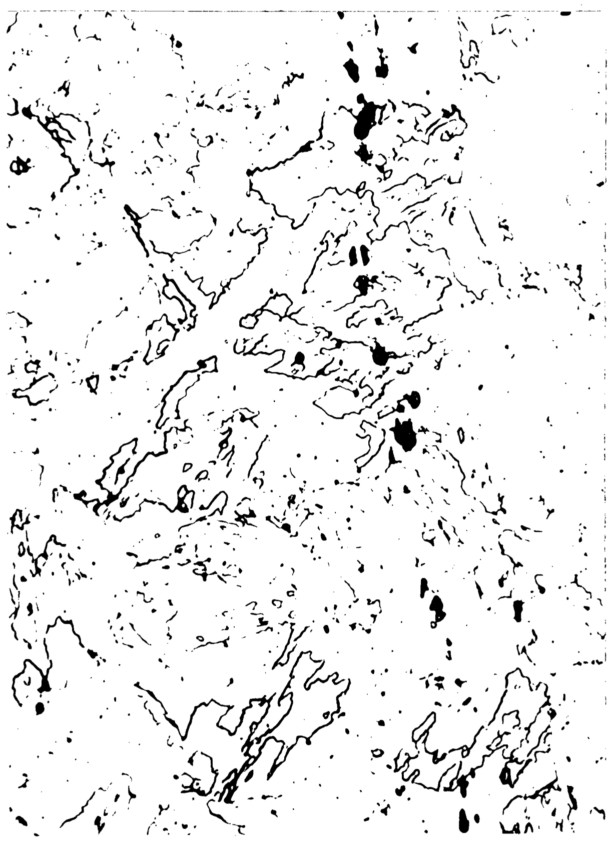


X1000D

A. Normalized 1800°F, tempered for 6 hours at 1200°F to 311/321 BHN.



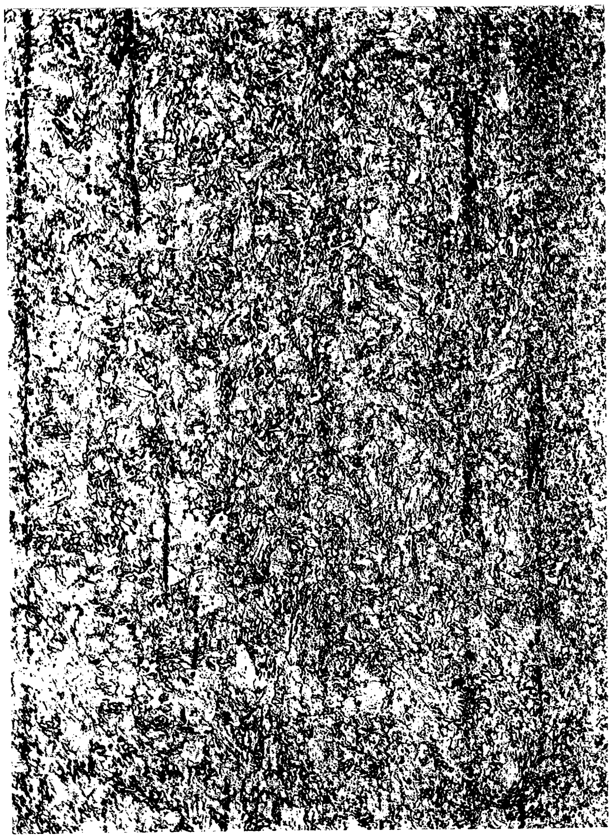
X100D



X1000D

B. Normalized 1950°F, tempered for 6 hours at 1250°F to 302/311 BHN.

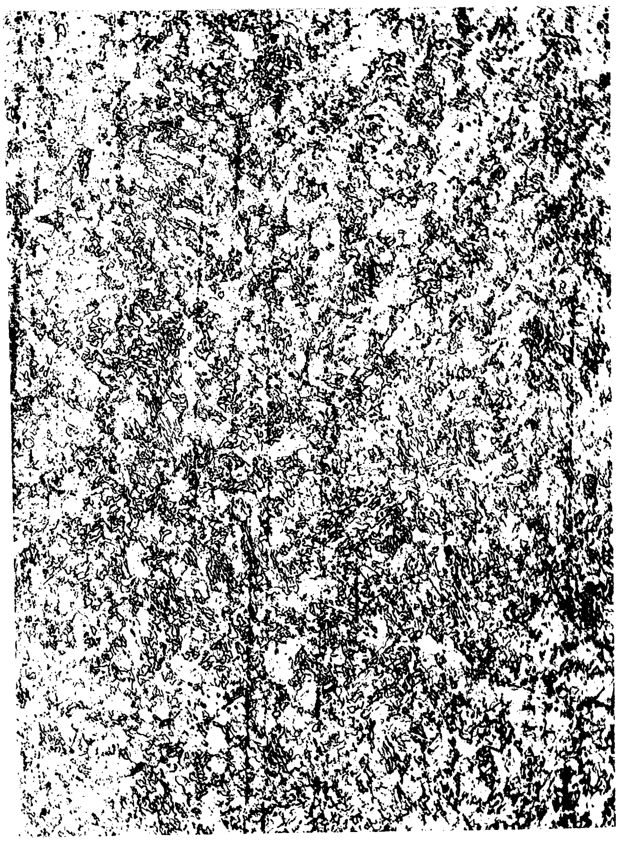
Plate No. 1. Original microstructure of 0.20 percent Carbon "17-22-A"V + 0.0036 percent Boron + 0.33 percent Titanium Steel, Heat A134. Barstock heat treated as indicated.



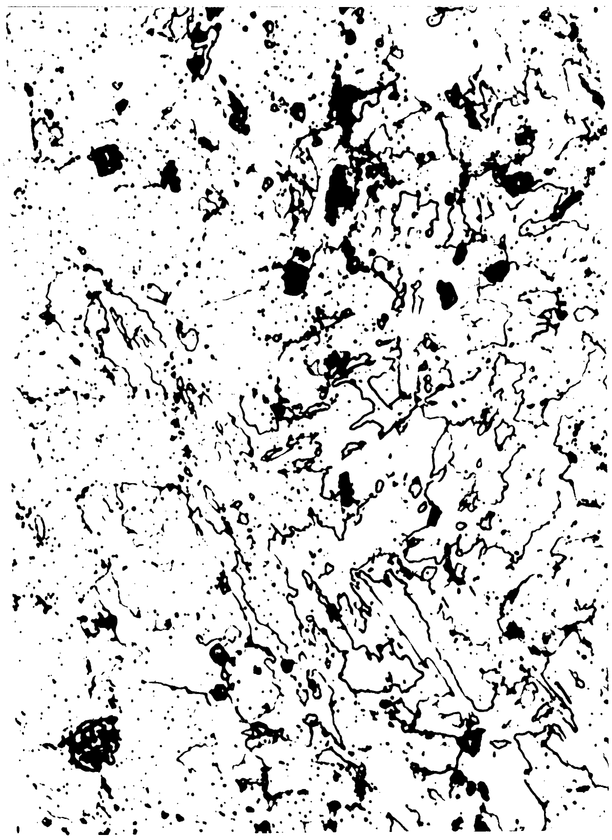
X100D

X1000D

A. Normalized 1800°F, tempered for 6 hours at 1200°F to 311/321 BHN.



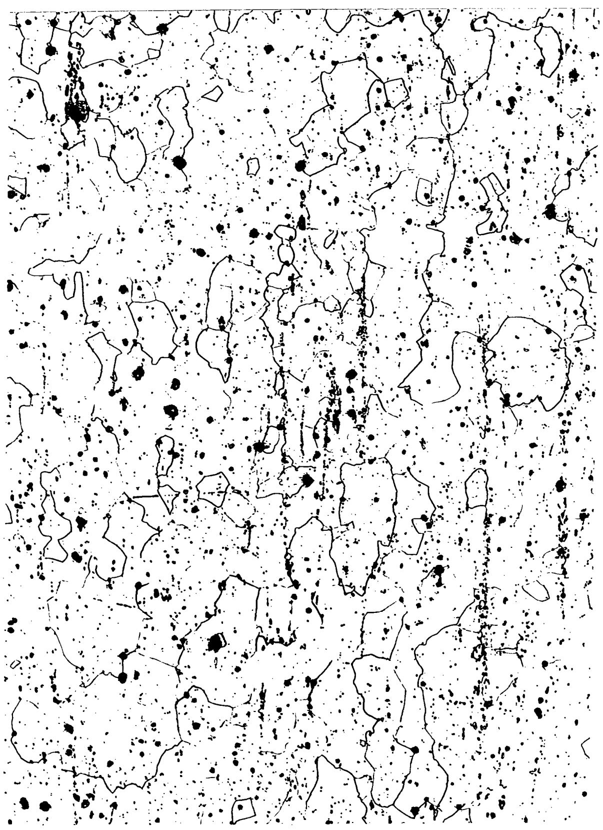
X100D



X1000D

B. Normalized 1950°F, tempered for 6 hours at 1250°F to 293/311 BHN.

Plate No. 2. Original microstructure of 0.25 percent Carbon "17-22-A"V + 0.0092 percent Boron + 0.43 percent Titanium Steel, Heat A135. Barstock heat treated as indicated.



X100D

X1000D

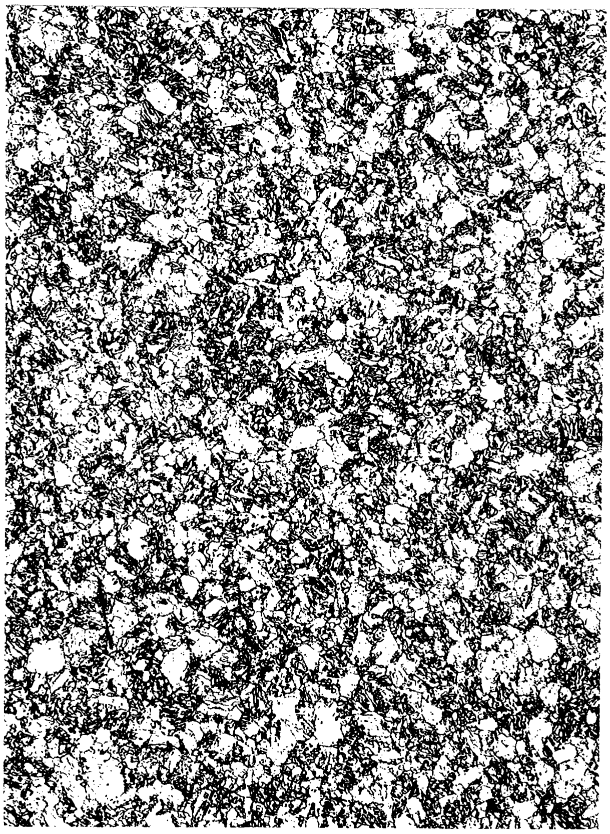
A. Normalized 1950°F, tempered for 6 hours at 1200°F to 128 BHN.

X100D

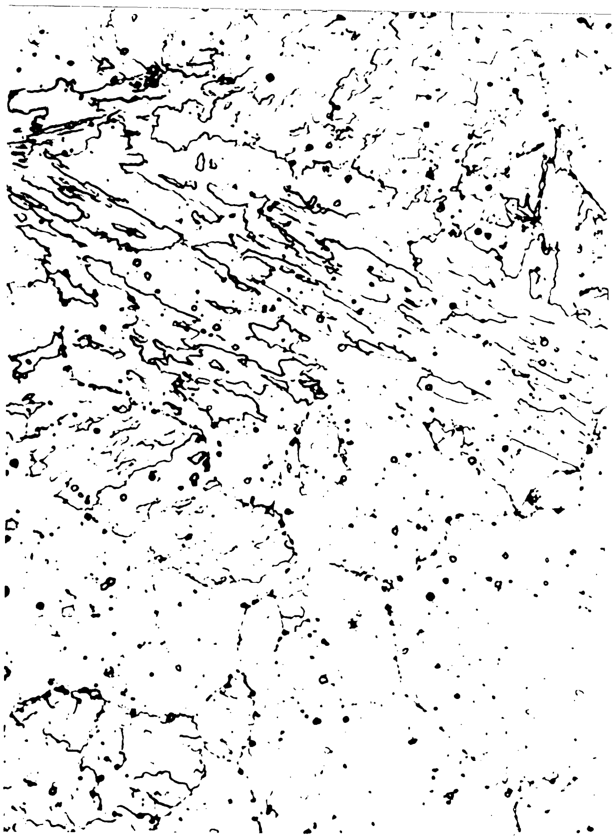
X1000D

B. Normalized 1950°F, tempered at 1200°F, renormalized 2100°F. tempered for 6 hours at 1100°F to 217/228 BHN.

Plate No. 3. Original microstructure of 0.10 percent Carbon "17-22-A"S + 0.042 percent Boron + 0.67 percent Titanium Steel, Heat A73. Barstock heat treated as indicated.

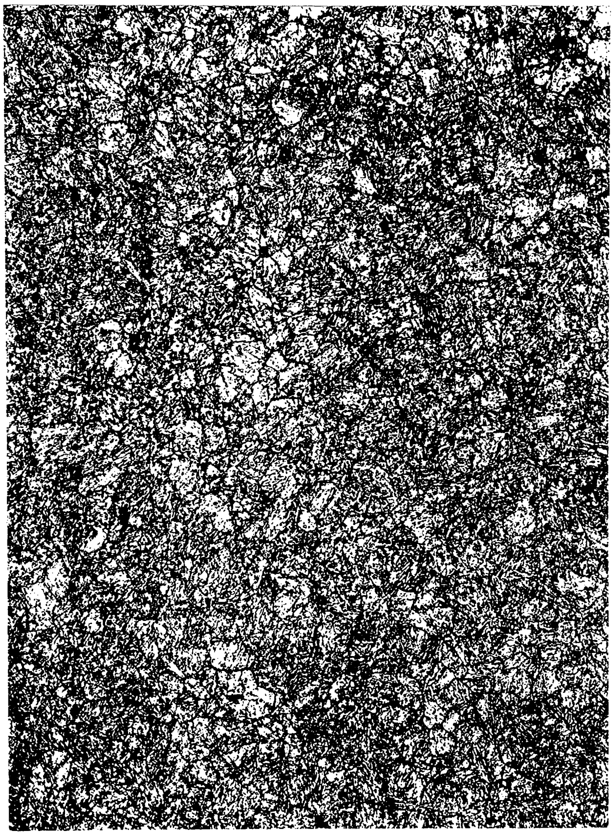


X100D

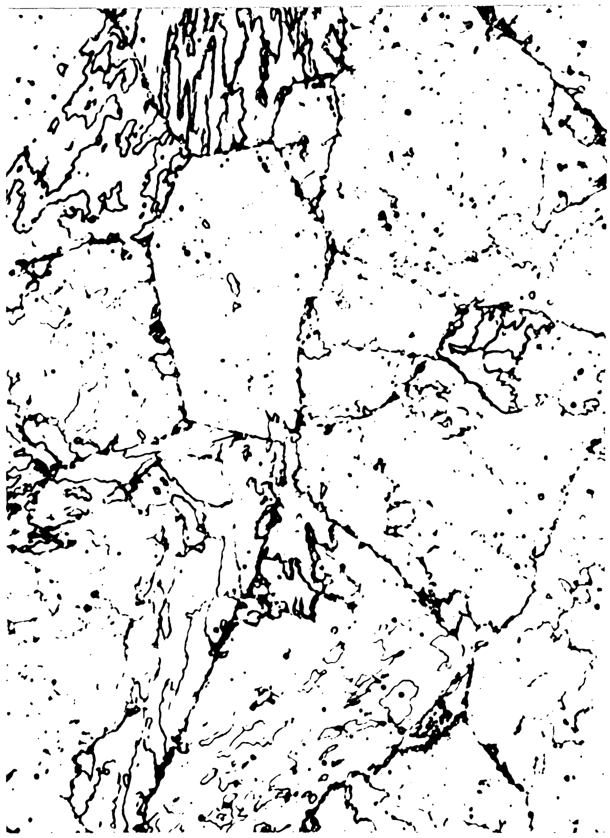


X1000D

A. Normalized 1800°F, tempered for 6 hours at 1200°F to 352/363 BHN.



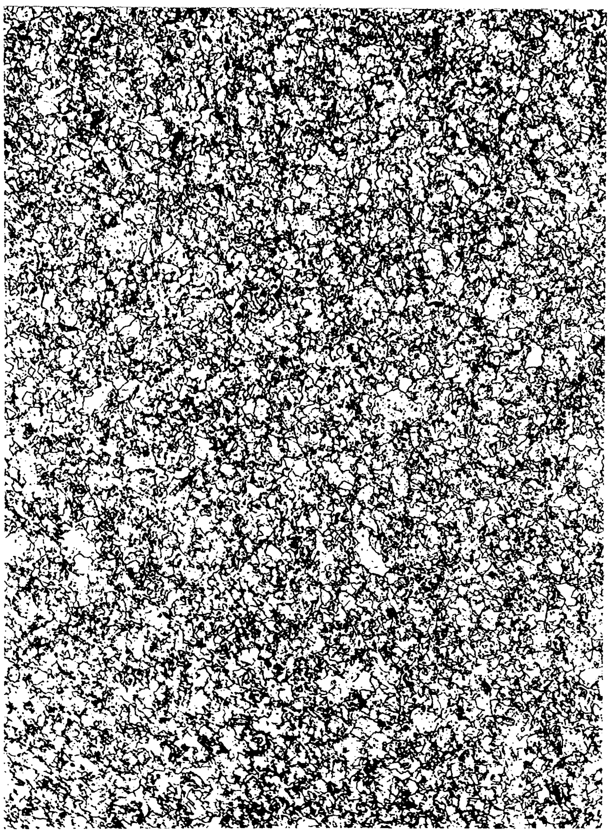
X100D



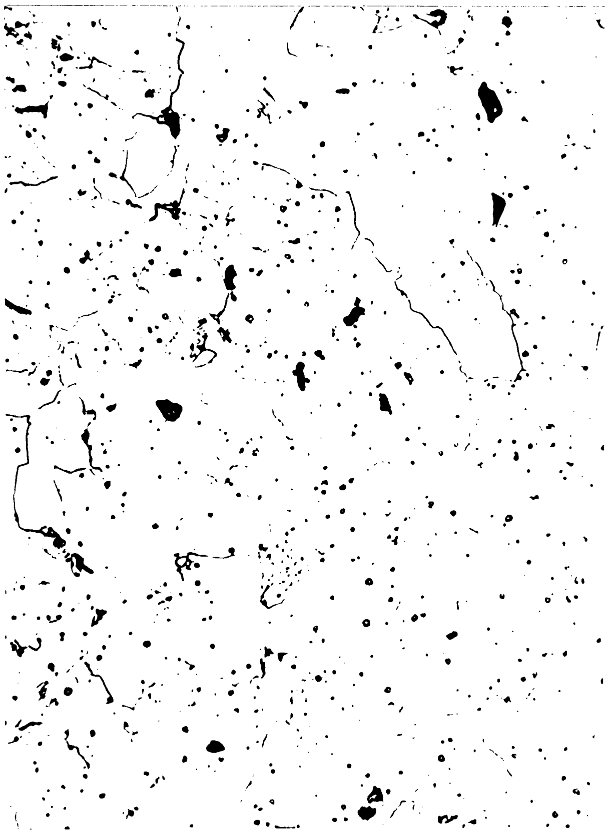
X1000D

B. Normalized 1950°F, tempered for 6 hours at 1250°F to 331/341 BHN.

Plate No. 4. Original microstructure of 0.26 percent Carbon "17-22-A"V + 0.0028 percent Boron + 0.35 percent Titanium Steel, Heat 02392. Barstock heat treated as indicated.

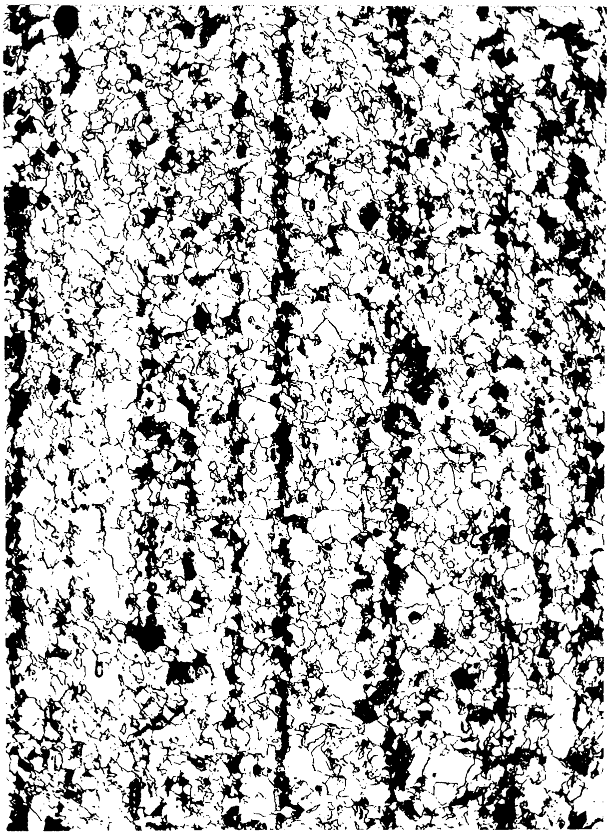


X100D



X1000D

A. Austenitized 1850°F, cooled to and held for 6 hours at 1225°F to 321/331 BHN.

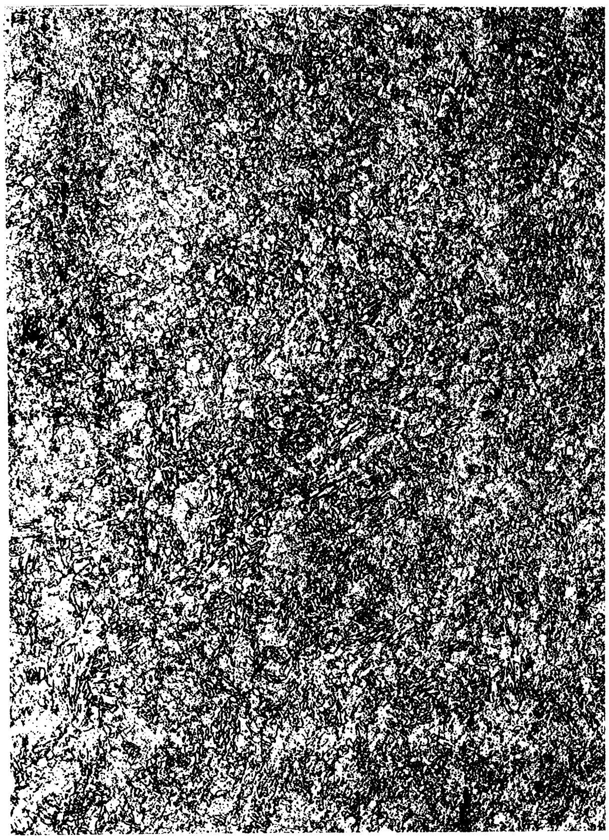


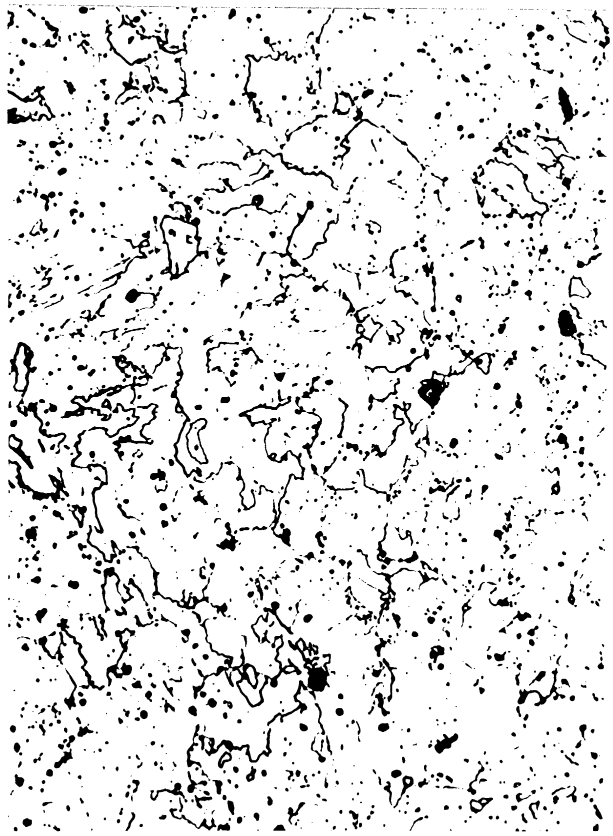
X100D

X1000D

B. Austenitized 1950°F, cooled to and held for 6 hours at 1225°F to 341 BHN.

Plate No. 5. Original microstructure of 0.26 percent Carbon "17-22-A"V + 0.0028 percent Boron + 0.35 percent Titanium Steel, Heat 02392. Barstock heat treated as indicated.

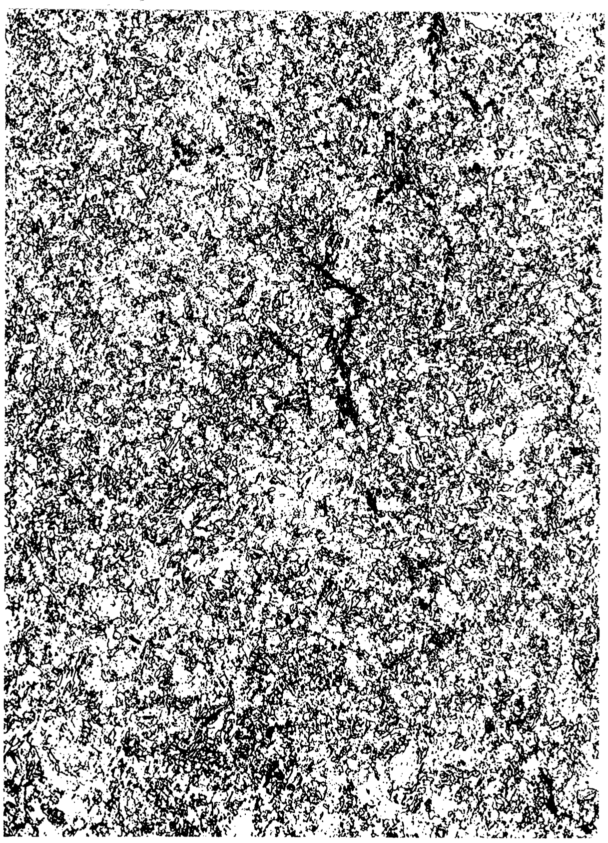


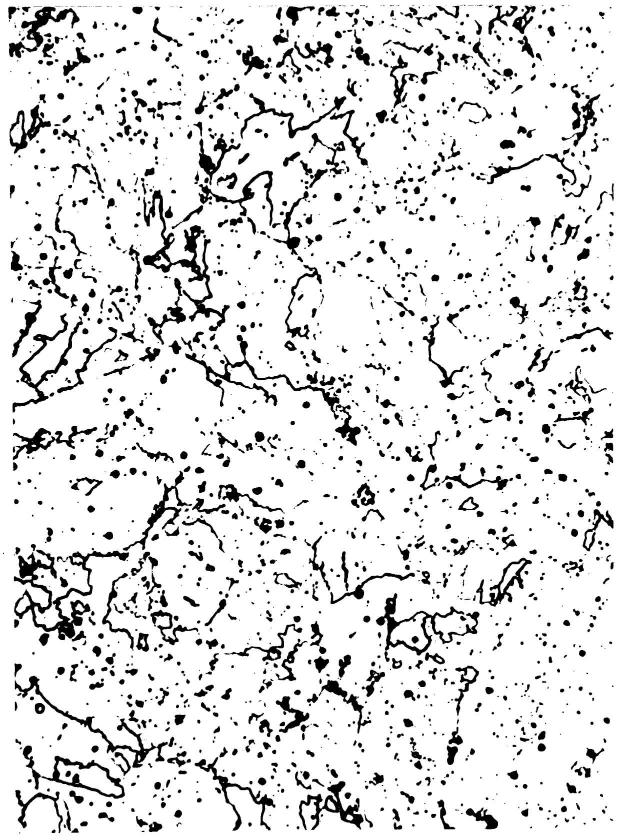


X100D

X1000D

A. Radial specimen.





X100D

X1000D

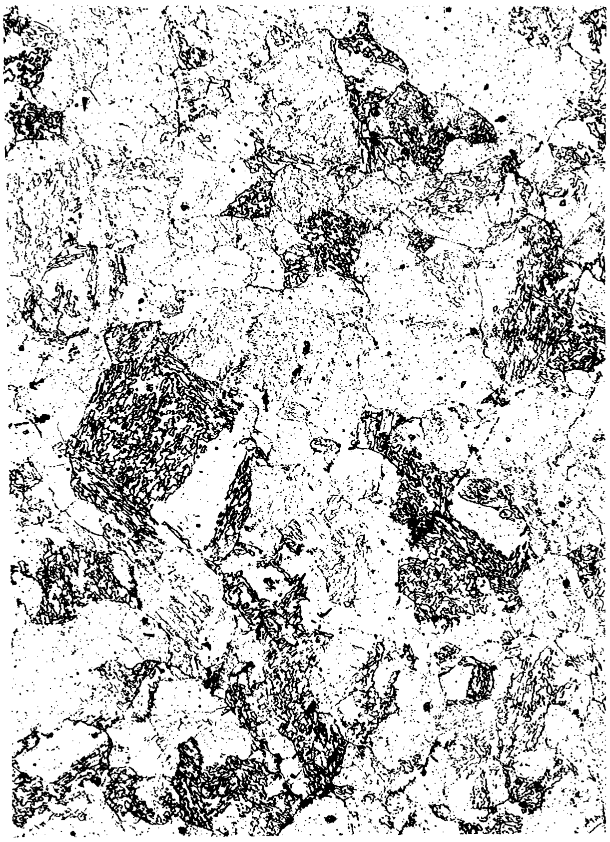
B. Tangential specimen.

Plate No. 6. Original microstructure of 0.26 percent Carbon "17-22-A"V + 0.0028 percent Boron + 0.35 percent Titanium Steel, Heat 02392. Forging normalized from 1800°F and tempered for 11 hours at 1200°F to 311/321 BHN.

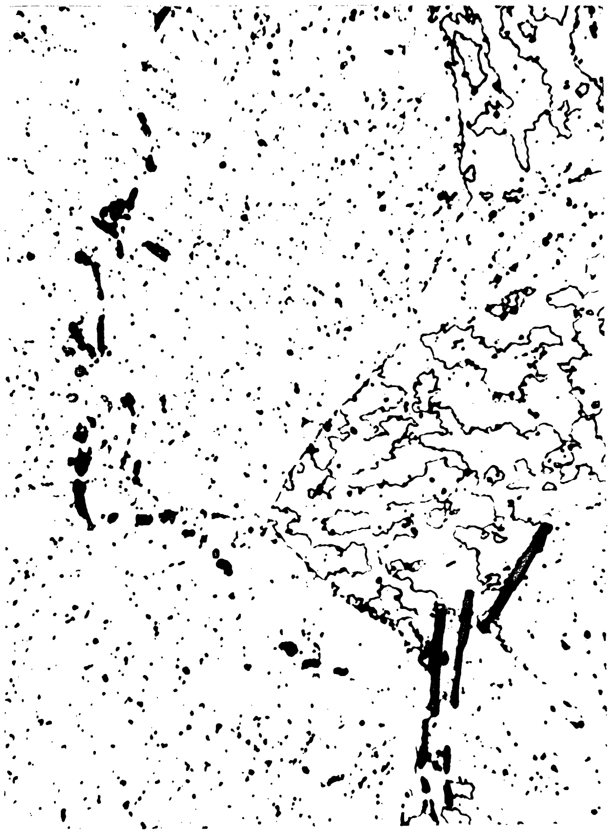
X100D

X1000D

A. Radial specimen.



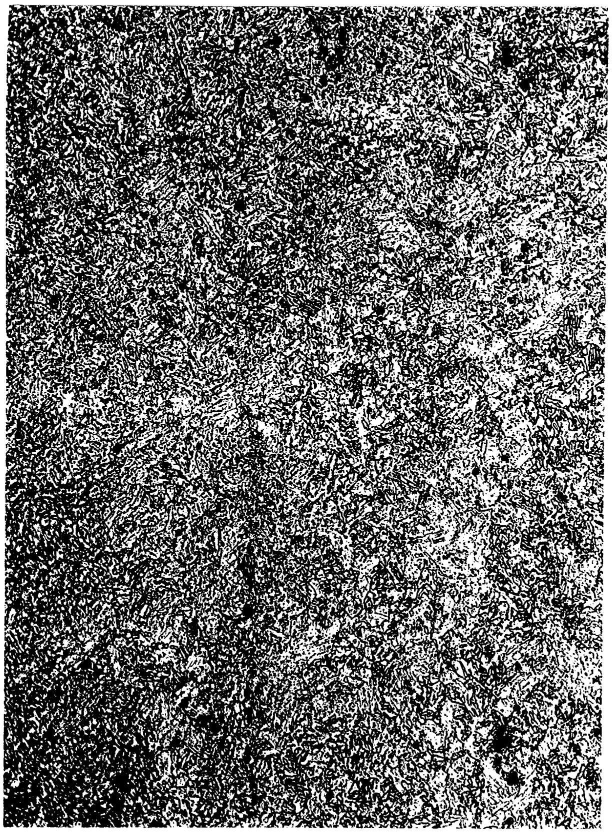
X100D



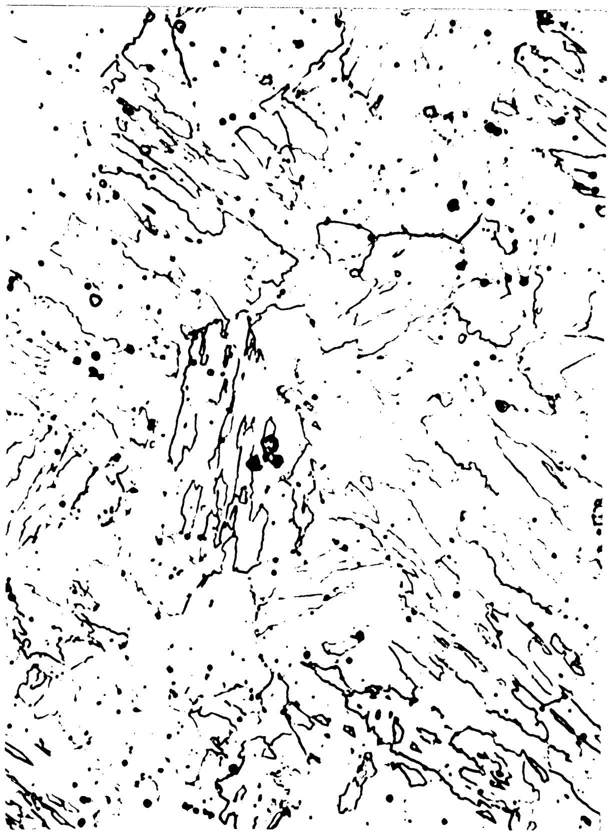
X1000D

B. Tangential specimen.

Plate No. 7. Original microstructure of 0.26 percent Carbon "17-22-A"V + 0.0028 percent Boron + 0.35 percent Titanium Steel, Heat 02392. 15 inch diameter by 4 inch thick upset pancake forging normalized from 1850°F, tempered for 6 hours at 1200°F to 277/311 BHN.

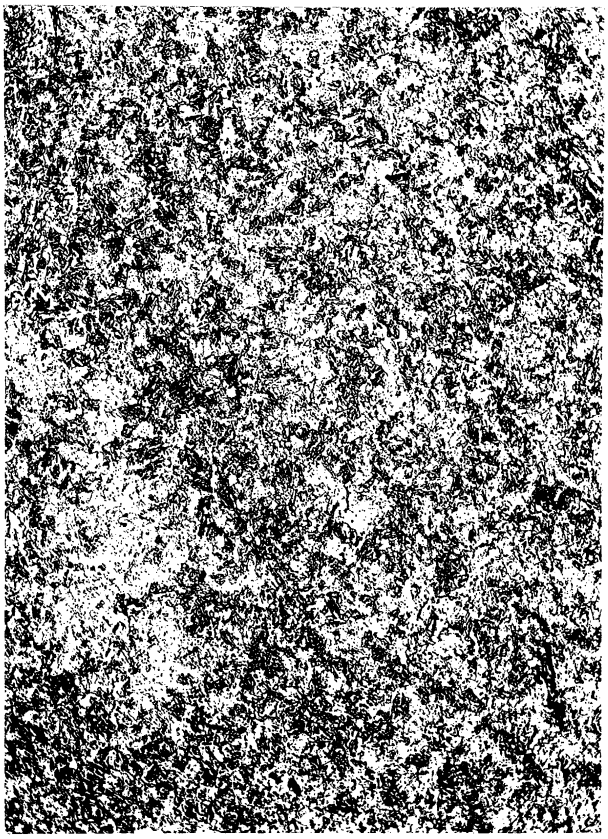


X100D



X1000D

A. Radial specimen.

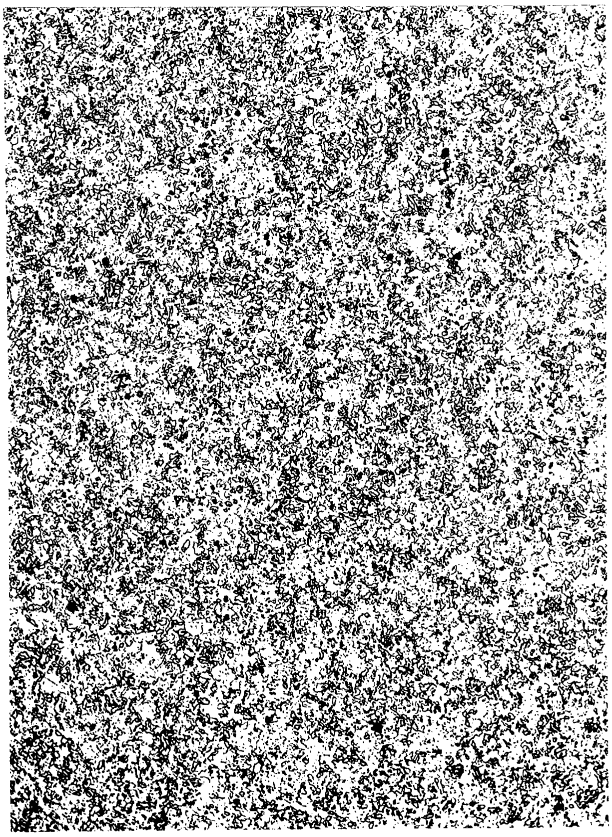


X100D

X1000D

B. Tangential specimen.

Plate No. 8. Original microstructure of 0.26 percent Carbon "17-22-A"V + 0.0028 percent Boron + 0.35 percent Titanium Steel, Heat 02392. 15 inch diameter by 4 inch thick upset pancake forging oil quenched from 1800°F, tempered for 6 hours at 1200°F to 293/311 BHN.



X100D

X1000D

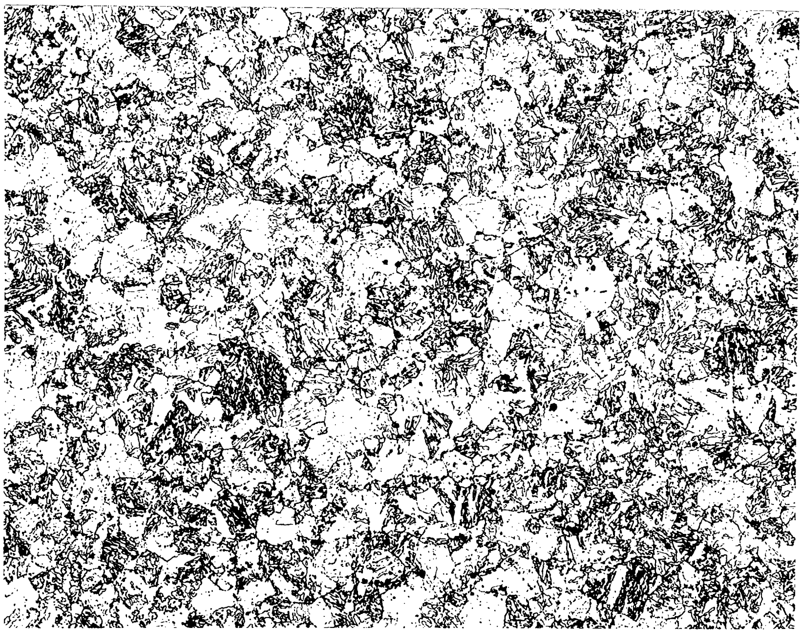
A. Normalized 1750°F, tempered for 6 hours at 1200°F to 321 BHN.

X100D

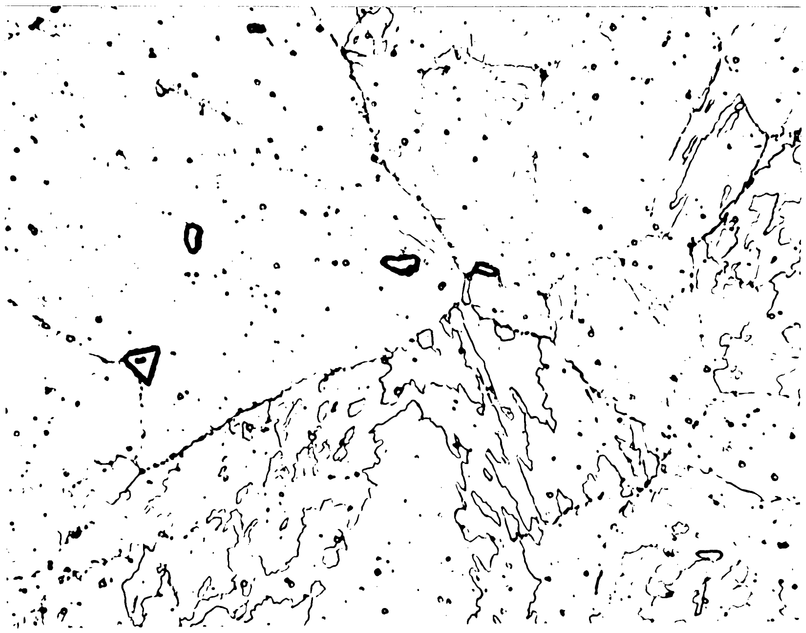
X1000D

B. Normalized 1850°F, tempered for 6 hours at 1200°F to 321 BHN.

Plate No. 9. Original microstructure of 0.21 percent Carbon "17-22-A"V + 0.0026 percent Boron + 0.32 percent Titanium Steel, Heat 02629. Barstock heat treated as indicated.

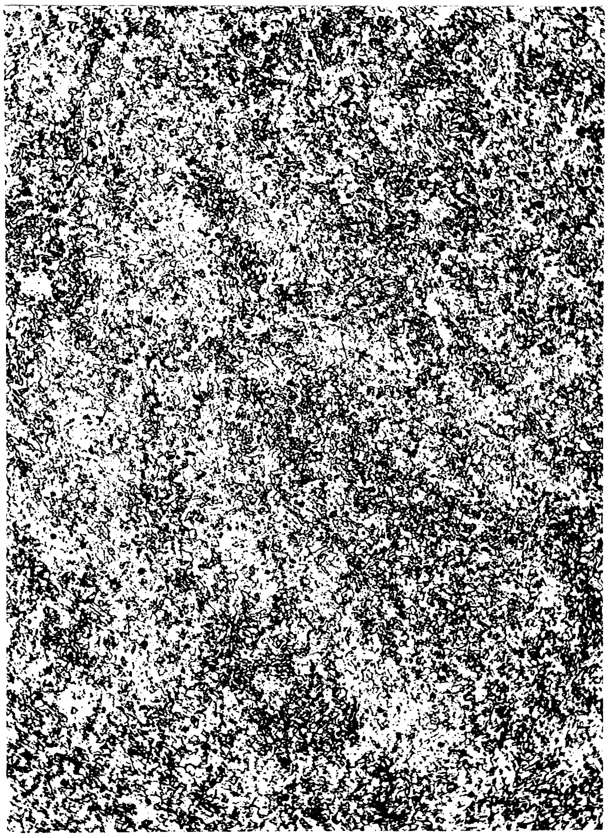


X100D



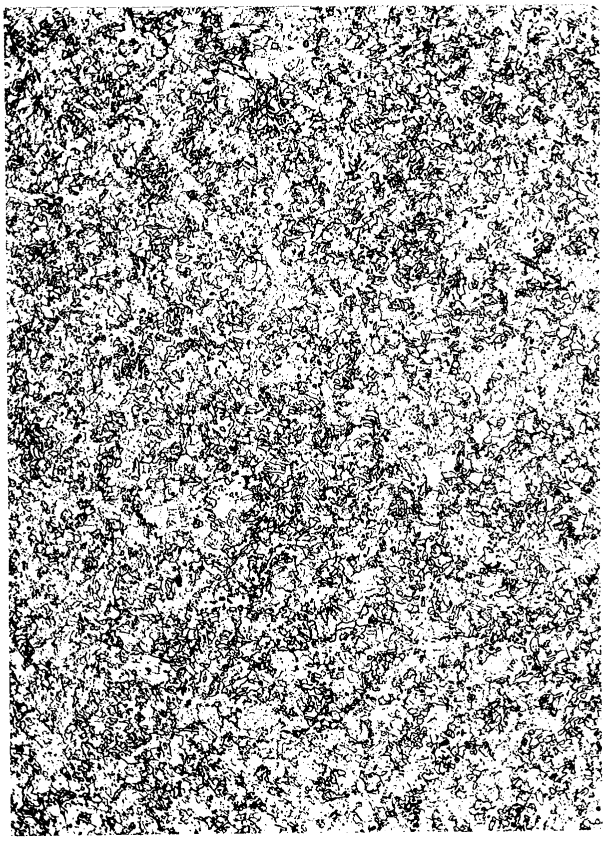
X1000D

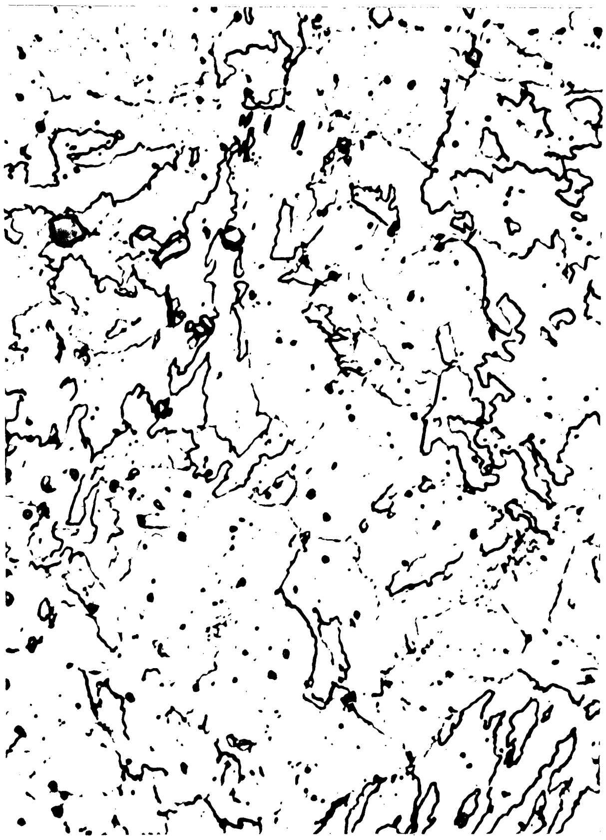
Plate No. 10. Original microstructure of 0.24 percent Carbon "17-22-A"V + 0.0022 percent Boron + 0.37 percent Titanium Steel, Heat 02630. Barstock normalized from 1850°F and tempered at 1200°F to 331/341 BHN.



X100D X1000D

A. Radial specimen from Heat 02629 - 302-321 BHN.





X100D X1000D

B. Radial specimen from Heat 02630 - 311/331 BHN.

Plate No. 11. Original microstructure of "17-22-A"V + Boron + Titanium Steel pancake forgings 15½ inches in diameter by 3 inches thick from the indicated heats. The forgings were normalized from 1850°F, tempered for 6 hours at 1200°F.