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Heat Treatment of Stockless Anchors

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ABSTRACT

Three 10 x 10 x 20 inch blocks which approximate the average section of large stockless anchors were cast of Class B steel, which is at the present time used in the manufacture of anchors. One casting was annealed according to existing specifications and the other two were given shorter heat treatments. It was found that the present heat treating time of 64 hours could be reduced about one-half by using a different heat treatment and that better physical properties throughout the test castings could be obtained.

Micrographs and macrographs, density measurements, and the results of low temperature impact tests are also presented.

AUTHORIZATION

1. The problem was authorized by Bureau of Ships letter S26-2(3692) of 7 April 1942.

STATEMENT OF PROBLEM

2. The object of this work was to develop a heat treatment for stockless anchors ranging in size up to 30,000 pounds which would be shorter than the heat treatment used at present and which would produce as good or better physical properties in the metal.

KNOWN FACTS BEARING ON THE PROBLEM

3. The heat treatment used at present for stockless anchors weighing over 10,000 pounds is as follows:

Time to raise to annealing temperature	15 hrs.
Hold at annealing temperature (1575 to 1675°F)	25 hrs.
Time to cool from annealing temperature	24 hrs.
Total	64 hrs.

This seems an unnecessarily long heat treatment, especially in time of war when heat treating facilities are at a premium. These specifications were written in 1913 and since that time much has been learned about the heat treatment of large steel castings.

4. The long time prescribed by specification 6A2a for heating castings to the annealing temperature was probably due to the early belief that the surface of a large casting rapidly reached the temperature of the furnace while the center remained cold. Conversely it was believed that in air cooling from a high temperature, the surface reached the temperature of the atmosphere very fast and might be black while the interior of the casting was still red hot. If this were true cracking or tearing would result from the tremendous stresses set up in large sections due to temperature gradients, and slow heating and cooling would be necessary to obviate this condition. The fact is, however, that steel is a very excellent heat conductor and there is surprisingly little temperature lag between the center and surface of a casting on rapid heating and cooling, so no trouble should arise from cracking due to thermal stresses in uniform sections.

5. At the Naval Research Laboratory a four inch diameter cast steel bar into which thermocouples were inserted to various depths was placed in a furnace at 1250°F and the temperature recorded at intervals. It was found that the whole casting reached the furnace temperature at about the same time and at no time was there a temperature difference between the center and the surface of the casting of over 50°F. When the casting reached the furnace temperature it was removed from the furnace and allowed to cool in air, and again it was found that the casting cooled almost uniformly throughout with about the same temperature difference prevailing between the center and surface on cooling as on heating.

6. For larger sections cooled from higher temperatures there is still only a comparatively small difference. Plate 12 shows the cooling curves for the surface and axis of a 12 inch diameter cylinder cooled in air at 65°F from a temperature of 1800°F. These curves were plotted from heat transfer formulas (5) and approximate the most drastic cooling which would be encountered in the test castings used in this work. At no time was the temperature difference between the axis and surface over 100°F. With temperature gradients of this small order existing in a casting, especially a casting made of mild steel and of fairly uniform section as an anchor shank, there is very little disposition toward cracking.

7. The annealing time of 25 hours required under present specifications promotes grain growth instead of grain refinement, and the slow cooling thru the critical zone causes the formation of large pearlite and ferrite areas, a condition which is not conducive to toughness. The long annealing time produces some homogeniety in the casting, but this could be more quickly accomplished by using a higher temperature. C. E. Sims (1) has pointed out that for every 100° increase in the annealing temperature above 1650°F, the time at temperature could be reduced by one-half to obtain the same effect. He based this conclusion on the commonly accepted belief that one hour per inch of the largest section of the casting at 1650°F produced satisfactory homogeniety.

8. Merton (1) believes that the only way that the physical properties of the steel in massive sections can be made to approach those of test coupons is to soak the casting at 2000°F for 2 hours per inch of cross section, then to normalize from above the critical to refine the grains, and finally to temper. He is of the opinion that the production of high quality castings of large cross section is aided by keeping the silicon content low and pouring as cold as possible. He advocates a soaking pit treatment for castings similar to that which rolling mills use for ingots.

9. Lorenz (1) found that in some cases a high temperature soaking treatment improved the physical properties of large sections and in other cases it did not. Because of his inconsistent results he concluded that design, and gating and feeding influenced physical properties as much as heat treatment.

10. Briggs and Gezelius (4) studied the effect of mass on sections as large as 8 x 8 inches and found that strength and ductility at the center of cast sections decreased as the section size increased. They used as their standard heat treatment an anneal at 1650°F for one hour per inch of cross section. They found no benefit from a high temperature anneal, but they held their specimens at these temperatures for only a very short time and did not follow the high temperature anneal with a grain refining treatment. They concluded that the decrease in mechanical properties at the center of large sections was caused by microstructure, carbon segregation, and a decrease in density. In contradiction to Merton they found that pouring temperature has no influence on the physical properties and that silicon segregation was not of sufficient magnitude to have much effect. It was pointed out in the discussion of Briggs and Gezelius' paper by both Phillips and Gagnebin that .03 to .05 percent of aluminum would cause a very serious drop in the ductility

of acid made steel, especially in large sections. This was reported by Sims and Dahle [6] to be due to the lowering of the oxygen content to a value such that the solubility of MnS is increased, thereby causing it to precipitate late in solidification in an eutectic-like pattern around the boundaries of the freezing dendrites. Higher additions of aluminum, above this critical percentage, result in the formation of aluminum sulfide (Al_2S_3) which decreases the maganese sulfide solubility causing it to precipitate early, consequently possessing enough time to form globules, a state in which the ductility is not affected.

11. Many metallurgists have observed that the values obtained from test coupons must not be taken as indicative of the properties of the casting itself, but merely as a basis for estimating those properties when considered in conjunction with section size, heat treatment, and metal density. The test coupon should be used only as an indication of the quality of the metal from which it is made.

METHODS USED IN TESTING

12. Three rectangular castings 10 x 10 x 20 inches were made at the Washington Navy Yard of Class B basic steel. Six test coupons, three of each of the types shown in the photograph of Plate 1, were also cast from the same ladle. Since a 10 x 10 inch cross section approximates the average dimension of a very large anchor, castings of this size were used in obtaining the results reported herein. A photograph of one of the large castings with the gate and riser intact is shown in Plate 2. A complete analysis of the steel used is given in Table 11 and it will be noticed that there is an excess of residual chromium and nickel present.

13. Each of the large castings, accompanied by one of each type of test coupon was given a different heat treatment. The logs of the three heat treatments are given below and are shown graphically in Plate 13.

Log of Treatment Sample No. 1

Temperature	Time consumed-hrs.	Operation
315°F		Furnace on
1800°F	3 3/4	At temperature
1800°F	6	6 hrs. at temperature. Sample out cooling in air.
950°F	1	Sample recharged. Furnace on.
1650°F	3 1/4	At temperature
1650°F	3	At temperature. 3 hrs. Furnace off
900°F	1	Recharged. Furnace on.
1290°F	2 1/2	At temperature
1300°F	3	3 hrs. at temperature. Furnace off. Sample cooling in furnace
980°F	8 1/2	Cooling in furnace. Furnace door partly open.
950°F	4	Sample removed from furnace.
Total	36	

Log of Treatment Sample No. 2

Temperature	Time consumed-hrs.	Operation
140°F		Furnace on
1690°F	5 1/2	At temperature
1695°F	4 1/3	4 hrs. 20 minutes at temperature. Sample removed, cooled in air.
900°F	1 1/6	Recharged. Furnace on.
1295°F	3	At temperature
1300°F	3	3 hrs. at temperature. Furnace off.
720°F	15	Sample removed from furnace.
	32	

Log of Treatment Sample No. 3

Temperature	Time consumed-hrs.	Operation
		Furnace on. Heating rate 100°F/hr.
1600°F	15	15 hours to reach temperature.
1605°F	25	25 hours at temperature. Furnace off.
865°F	24	24 hours to cool. Sample removed from furnace.
Total	64	

14. Heat treatment 1 consisted of a 6 hour homogenizing treatment at 1800°F, a normalizing treatment from 1650°F after holding for 3 hours, followed by a 3 hour temper at 1300°F and a furnace cool for stress relief. Heat treatment 2 consisted of a normalize from 1700°F after 4 1/2 hours, followed by the same stress relieving temper as in heat treatment 1. Heat treatment 3 is the one stipulated in present specifications consisting of slowly heating to the annealing temperature of 1600°F, holding for 25 hours and then slowly cooling. The temperatures were measured by means of chromel-alumel thermocouples with their hot junctions inserted to a depth of one inch in the large castings.

15. After heat treatment was completed, each 10 x 10 x 20 inch casting was sawed into four sections A, B, C, and D as shown in Plate 3. Four cold bend specimens were sawed from section A as shown in Plate 4, two specimens from the center and two near the surface of the casting. The 1 1/4 inch section marked B was cut into tensile, Charpy, and Izod blanks as shown in Plate 4. The 4 1/2 inch section C of Plate 3 was also cut into blanks for tensile and impact specimens so that the properties in a longitudinal direction could be determined. The half inch section D of Plate 3 was machined and ground and used for a hardness survey and also for etch tests. Tensile, cold bend, and impact specimens were obtained from the coupons as shown in Plate 5.

16. All tensile specimens used were 0.505 inch diameter shoulder grip specimens with a two inch gage length and were broken under a rate of loading of 10,000 pounds per minute. The drop of beam was used to obtain the yield point. The Charpy specimens were the keyhole type and the Izod specimens were the conventional V-notch type, but had only two notches instead of the usual three.

DATA OBTAINED

17. The method chosen to show a comparison between the three heat treatments was to compare each of the several properties tested both by selecting the heat treatment which gave the best values at each position in the large test castings and also by averaging the values obtained for all positions in each casting. Included in these tables are the values of specimens sectioned from the two test coupons. For specimens trepanned from more than one similar position in the test casting, which was the case in all but the center specimens, the results are averaged.

18. A Brinell hardness survey was made on each of the half inch sections cut from the test casting. Fifteen impressions were made on each section from one corner diagonally across to the opposite corner and at all points on all three plates the hardness was 140 Brinell. Thus all heat treatments left the castings in the same condition of hardness which was about the lowest possible with this steel.

19. Tables 1 thru 8 show the results of other physical properties tested. From Table 2 it can be seen that the same tensile strengths were obtained with all heat treatments. However Table 1 shows that the highest yield strengths were obtained from specimens trepanned from block 1 which was homogenized at 1800°F. This superiority was evident in all positions in the blocks and the average yield strength of block 1 was 5,500 psi higher than in block 3 which was annealed according to specifications. The yield strength of block 2, normalized and drawn, was midway between the other two.

20. Tables 3 and 4 show that block 1 also has the best ductility as measured by elongation and reduction of area, with block 3 second best. The higher ductility of block 1 is more in evidence in the cold bend tests, the results of which are listed in Table 5. The angle of fracture of specimens obtained from block 1 is 95 degrees but only about 70 degrees for the other two blocks. The effect of mass on physical properties is most pronounced on the ductility tests. Throughout Tables 1 to 8 it can be seen that for each value tested the test coupon has better properties than does the block with which it was heat treated, but this difference is most apparent in the tables showing elongation, reduction of area, and cold bend results. Block 1, for example, has an average elongation of 18.3 percent while specimens obtained from coupon B have an elongation of 32.4 percent, or almost twice as much. The difference in reduction of area values is still greater, with block 1 having an average of 23.2 percent while the reduction of area value of specimens obtained from coupon B treated with block 1 is 57.4 percent. The cold bend specimens taken from coupon B did not fracture even after being bent through 160 degrees while specimens sectioned from the large test blocks failed to even approach the 120 degrees required in specifications before fracture. This is another proof that results of specimens removed from coupons should not be taken as other than relative to the properties of the castings poured from the same metal.

21. The results of the Izod impact tests are listed in Table 6 and show that block 3 which was annealed, and block 1 which was homogenized, normalized and drawn, were about equal in Izod impact resistance, while the normalized and drawn block 2 was about 30 percent less than blocks 1 and 3 . This great difference does not show up in the Charpy keyhole tests, the results of which are tabulated in Table 7. The Charpy keyhole tests showed no significant difference in the 3 blocks.

22. Since both the Charpy and the Izod tests give an indication of impact resistance, it would be expected that there would be a relationship between the two. Work in progress at this laboratory on impact tests in connection with welds may disclose an explanation for this anomaly. A number of the Charpy specimens broken at the temperature of 35°F showed approximately 4 ft. lbs. lower impact resistance than at room temperature. These results are given in Table 8.

23. Photomicrographs from various points in the large test castings showed that the structure was uniform throughout each block; but there was a marked difference in the structure brought about by each heat treatment. Plates 6, 7, and 8 are photomicrographs of the corners and centers of each casting and show both the uniformity of structure in each casting and the difference brought about by heat treatment. Test block 1 which was homogenized, normalized and tempered has the finest ferrite and pearlite grains; test casting 2 has a somewhat coarser structure; while the annealed casting, 3, has exceedingly large ferrite and pearlite areas. Thus from the standpoint of carbon dispersion, heat treatment 1 is to be preferred and heat treatment 3 is the least desirable. Micrographic studies of specimens taken from coupons A and B showed a slightly finer structure than was found in the large test castings with which they were heat treated but the difference was too little to merit inclusion of the pictures.

24. Strength and ductility of each of the three test blocks is lowest at the center and highest at the surface. This condition is always found in massive sections and is variously attributed to differences in metal density, variations in cooling rates, centerline shrinkage, or sulphur, phosphorus, silicon, carbon, or aluminum segregation. None of these causes seem to apply here as the analyses, Table 10, showed no significant segregation; a boiling 50 percent HCL etch disclosed no centerline porosity, Plate 9; and density measurements, Table 9, showed only a negligible difference between the edge and center of the block. It is entirely possible that a micro-analysis would show up segregation of phosphorus since the properties of the steels become poorer as the solidification rate becomes slower and slow solidification is conducive to dendritic, or phosphorus, segregation. Sulphur evidently is not responsible for this condition as a sulphur print, Plate 10, taken diagonally across a section of one of the large test castings shows uniform sulphur distribution.

25. It is of interest to note that the elongation and reduction of area of the specimens taken from the bottom of test coupon A are much greater than in those taken from the top. In the 3 test coupons of this type used there was a difference in elongation of at least 4 percent and of reduction of area of at least 16 percent between the top and bottom. Such a variation in results should preclude the use of this type coupon.

26. Inclusion studies were made on all microspecimens before etching and there were no signs of stringers or inclusion concentrations of a type which would impair ductility. Plate 11 shows photomicrographs of typical inclusions found.

27. The section etched with hot HCL for 30 minutes, Plate 9, shows hairline cracks running from the surface to the interior, but these are characteristic of acid etched plates and cast no reflection on the integrity of the steel. The corroded surface was machined from one of these plates and it was then magnafluxed. No evidence of cracking was apparent.

28. The ductility of all three test blocks as measured by elongation, reduction of area, and cold bend tests is below coupon values required for class B steels. Although it was found that an homogenizing treatment improved ductility, a still greater improvement should be obtainable by more drastic heat treatment. For this reason more test castings are being made and will be subjected to other heat treatments in an endeavor to improve the ductility.

CONCLUSIONS

29. Casting 1 which was homogenized at 1800°F, normalized from 1650°F, and drawn at 1300°F showed consistently better physical properties than did casting 3 which was annealed at 1600°F in accordance with present specifications.

30. Test casting 2 which was normalized from 1700°F and drawn at 1300°F showed physical properties which were about equal to those obtained in the block treated as per existing specifications.

31. The time required for heat treatment 1 was 36 hours and for heat treatment 2, 32 hours, while the currently used heat treatment 3 required 64 hours. The substitution of heat treatment 1, which proved superior, for the time consuming anneal now used would enable heat treating furnaces to be used to greater advantage and would also lead to better properties.

32. More work will be required before final specifications can be written. A second set of 3 large castings and 6 test coupons have been ordered upon which further studies will be conducted.

RECOMMENDATIONS

33. It is recommended that heat treatment 1, as described in this report, be considered for use as an interim specification for heat treating stockless anchors to replace existing Navy specification 6A2a if present furnaces are properly equipped for use at the higher temperatures.

34. It is felt that Class B steel well made and properly heat treated is satisfactory for use in stockless anchors as designed at present. It is possible to obtain greatly improved properties by quenching and tempering, a procedure which is fully practical for smaller anchor shanks, such as those used on destroyers. If performance is particularly unsatisfactory on these smaller types it is recommended that consideration be given to a specification covering this type of treatment.

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TABLE 1

Effect of Heat Treatment on Yield Strength of Class B Steel

Position in 10" x 10" block			Heat Treatment			Best Properties from Heat treatment
			1	2	3	
A-	Center	longitudinal	45,000	43,750	40,500	1-2
B-	Midway between center and edge	"	46,425	43,750	41,400	1
C-	Edge, midway between corners	"	48,700	45,700	43,300	1
D-	Corners	"	49,000	45,900	43,800	1
X-	Center	transverse	46,600	44,000	40,550	1
Y-	Midway between center and edge	"	47,250	44,000	41,700	1
Z-	Edge	"	48,750	46,000	43,000	1
W-	Edge, right angles to Z	"	49,000	45,800	42,500	1
	Average Y.S. of blocks		47,590	44,860	42,090	1
N2-	Top, coupon A		51,700	48,850	44,500	1
N1-	Bottom, coupon A		52,250	48,850	46,000	1
R	Coupon B		50,500	48,850	47,500	no choice

TABLE 2

Effect of Heat Treatment on Tensile Strength of Class B Steel

	Position in 10" x 10" block		Heat Treatment 1	2	3	Best Properties from Heat Treatment
A-	Center	longitudinal	70,000	67,000	68,000	1
B-	Midway, between center and edge	"	71,000	71,250	71,350	no choice
C-	Edge, midway between corners	"	75,400	75,500	76,000	" "
D-	Corners	"	76,000	76,000	78,650	3
X-	Center	transverse	73,250	71,500	70,750	no choice
Y-	Midway, between center and edge	"	73,000	71,000	72,250	" "
Z-	Edge	"	76,500	75,000	75,000	" "
W-	Edge, right angles to Z	"	72,500	76,500	75,000	2-3
	Average T.S. of blocks		73,460	72,970	73,375	no choice
N2-	Top, coupon A		75,700	76,250	77,500	" "
N1-	Bottom, coupon A		76,500	76,250	77,500	" "
R-	Coupon B		76,000	75,500	77,500	" "

TABLE 3

Effect of Heat Treatment on Elongation of Class B Steel

	Position in 10" x 10" block		Heat treatment 1	2	3	Best Properties from Heat Treatment
A-	Center	longitudinal	16.4	9.4	10.9	1
B-	Midway between center and edge	"	15.9	13.3	15.3	1-3
C-	Edge, midway between corners	"	19.0	19.3	20.3	no choice
D-	Corners	"	26.8	25.8	26.5	" "
X-	Center	transverse	15.6	14.1	14.8	" "
Y-	Midway between center and edge	"	17.6	8.6	16.0	1-3
Z-	Edge	"	17.2	17.2	15.0	1-2
W-	Edge right angles to Z	"	17.5	14.5	15.6	1
	Average elongation of blocks		18.3	15.3	16.8	1
N2-	Top, coupon A		25.8	22.7	25.0	no choice
N1-	Bottom, coupon A		29.7	29.7	28.9	" "
R-	Coupon B		32.4	32.0	28.9	1-2

TABLE 4

Effect of Heat Treatment on Reduction of Area of Class B Steel

	Position in 10" x 10" block		Heat Treatment 1	Heat Treatment 2	Heat Treatment 3	Best Properties from Heat Treatment
A-	Center	longitudinal	18.1	14.5	18.1	1-3
B-	Midway between center and edge	"	22.0	24.2	17.8	1-2
C-	Edge, midway between corners	"	23.4	18.0	25.9	1-3
D-	Corner	"	35.8	37.0	38.5	no choice
X-	Center	transverse	15.9	18.8	18.1	2-3
Y-	Midway between center and edge	"	23.0	19.5	21.8	1
Z-	Edge	"	26.3	20.6	20.4	1
W-	Edge, right angle to Z	"	21.0	19.0	19.6	1
	Average R. A. of blocks		23.2	21.45	22.5	1-3
N2-	Top, coupon A		35.0	32.5	25.1	1-2
N1-	Bottom, coupon A		51.7	54.9	41.3	1-2
R-	Coupon B		57.4	58.2	45.2	1-2

TABLE 5

Effect of Heat Treatment on Cold Bend Properties of Class B Steel

Position in 10" x 10" block		Heat Treatment 1		Heat Treatment 2		Heat Treatment 3	
		Max load	Fracture	Max load	Fracture	Max load	Fracture
J-	Surface	7600 lb.	95°	7600 lb.	75°	7600 lb.	70°
K-	Center	7400	95°	7100	65°	7400	75°
	Average	7500	95°	7350	70°	7500	73°
R-	Coupon B	7900	over 160°	8000	over 160°	8000	over 160°

TABLE 6

Effect of Heat Treatment on Izod Impact Resistance of Class B Steel

	Position in 10" x 10" block		Heat Treatment 1	2	3	Best Properties from Heat Treatment
A-	Center	longitudinal	31 1/2	22	32	1-3
B-	Midway between center and edge	"	34	24	34	1-3
C-	Edge, midway between corners	"	30	20	31	1-3
D-	Corner	"	30	20 1/2	31	1-3
X-	Center	transverse	33	22	36 1/2	3
Y-	Midway between center and edge	"	32	23	34	1-3
Z-	Edge	"	27	20 1/2	27	1-3
W-	Edge, right angle to Z	"	26 1/2	21 1/2	29 1/2	3
	Average Izod value of blocks		30.5	21.75	31.9	1-3
N-	Coupon A		34	25 1/2	34	1-3
R-	Coupon B		35	27	37 1/2	1-3

TABLE 7

Effect of Heat Treatment on Charpy Keyhole Impact Resistance of Class B Steel

	Position in 10" x 10" block		Heat Treatment 1	2	3	Best Properties from Heat Treatment
A-	Center	longitudinal	22	19	20	1
B-	Midway between center and edge	"	21	23	19	2
C-	Edge, midway between corners	"	20	16 1/2	16	1
D-	Corner	"	21	19	20	no choice
X-	Center	transverse	22 1/2	20	22	1-3
Y-	Midway between center and edge	"	21	21	20 1/2	no choice
Z-	Edge	"	19 1/2	16 1/2	18	" "
W-	Edge, right angle to Z	"	18	20	16	" "
	Average Charpy values of Blocks		20.6	19.4	19.0	1
N-	Coupon A		25	26	25	no choice
R-	Coupon B		25	19	21	1

TABLE 8

Effect of Heat Treatment on Low Temperature* Charpy Keyhole Impact Resistance of Class B Steel

	Position in 10" x 10" block	Heat Treatment 1	2	3	Best Properties from Heat Treatment
L1-	Near center	19	16	18 1/2	1-3
L2-	Near surface	17 1/2	13	13 1/2	1
L3-	Near corner	15	16 1/2	15 1/2	no choice
B-	Midway between center and edge	18	14	14 1/2	1
C-	Edge, midway between corners	15	12	13	1
D-	Corner	19	13 1/2	17	1-3
	Average low temp. Charpy values of blocks	17.2	14.2	15.3	1

* Testing Temperature 35°F

TABLE 9

Effect of Mass and Position on Density of Class B Steel

Position	Density
Corner 10" x 10" x 20" block	7.822
Center 10" x 10" x 20" block	7.821
Corner coupon B	7.830

TABLE 10

Chemical Analysis at 3 points in 10 x 10 x 20 inch Test Casting

Center		Midway between Center and Corner		Corner	
C	.28%	C	.24%	C	.25%
Mn	.59%	Mn	.61%	Mn	.61%
Si	.43%	Si	.42%	Si	.43%
P	.029%	P	.03%	P	.033%
S	.015%	S	.014%	S	.017%

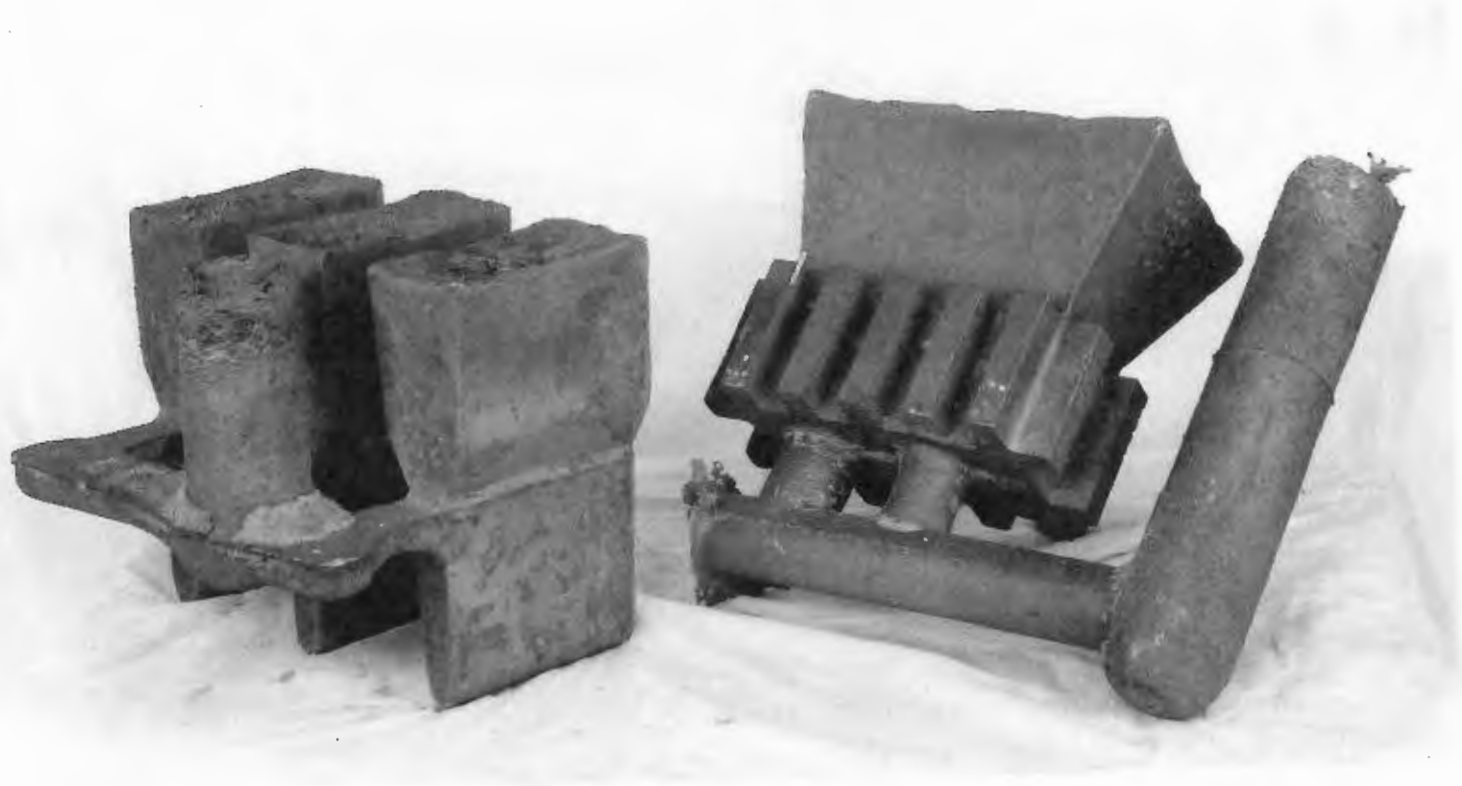
TABLE 11

Chemical Analysis of Steel Taken from Test Coupon

Test Coupon B

C	.24%	Cu	.21%
Mn	.66%	Mo	.08%
Si.	.44%	Ni	.75%
S	.016%	Cr	.22%
P	.031%	Al	.075%

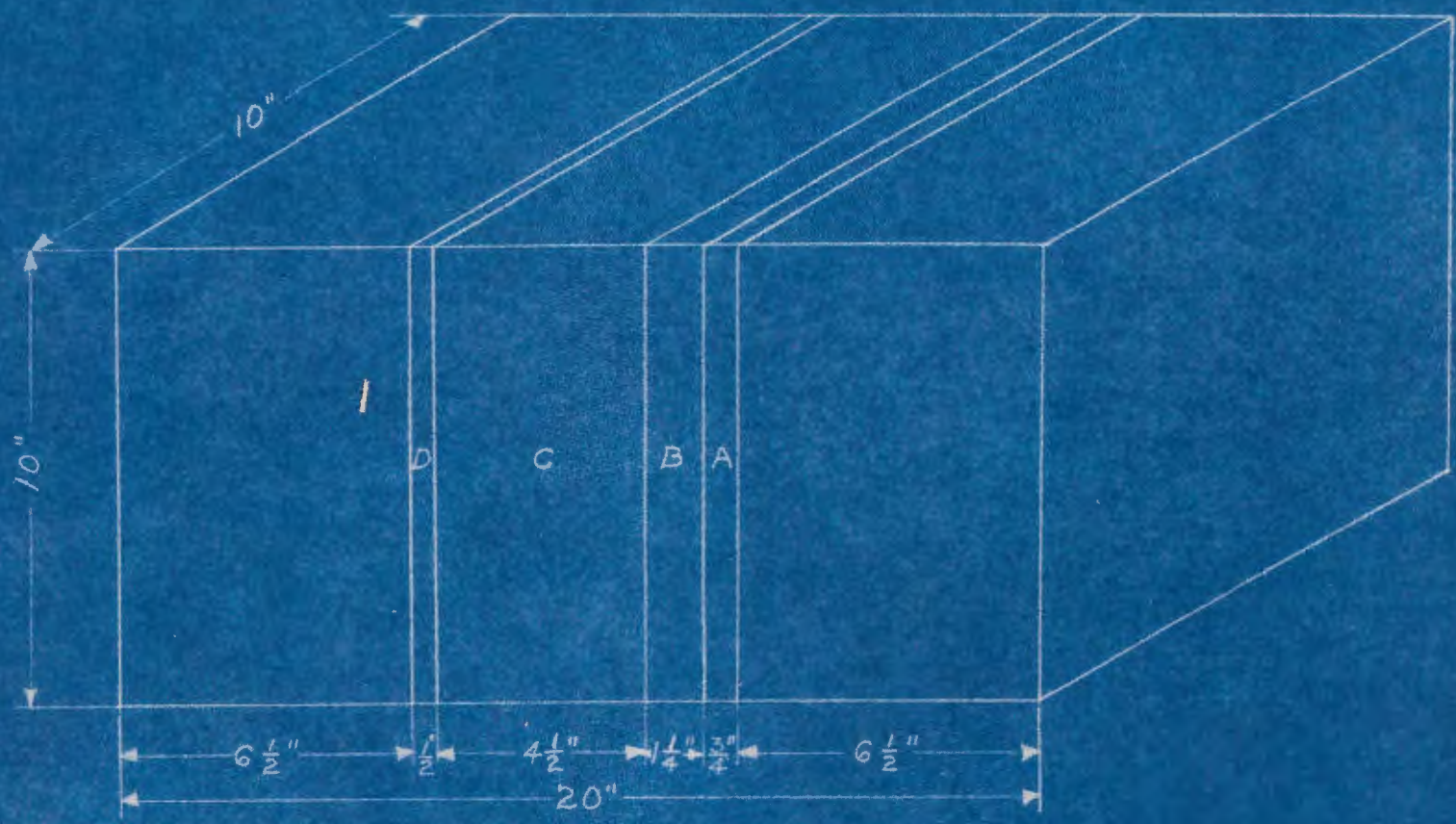
PLATE I



PHOTOGRAPH OF TEST COUPONS
TYPE A (LEFT) AND TYPE B (RIGHT)

PLATE 2

Photograph of the test casting before the removal of the gate and riser.

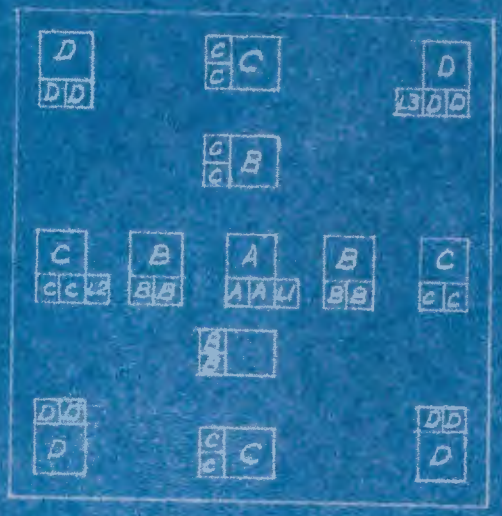


TEST CASTING SHOWING POSITIONS OF SECTIONS FROM WHICH TEST SPECIMENS WERE OBTAINED

PLATE 3

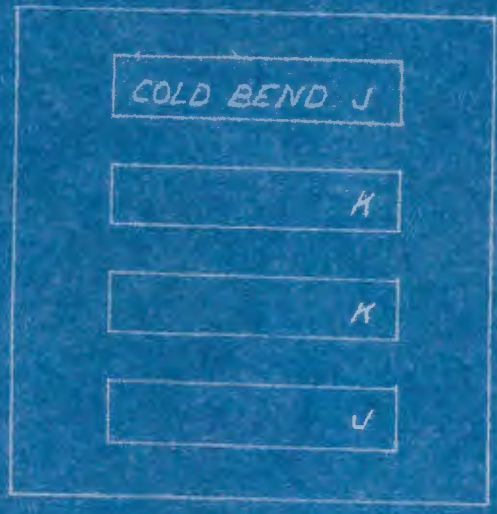
POSITION OF TEST BLANKS REMOVED FROM SECTION SHOWN IN PLATE 3

4½" SECTION C



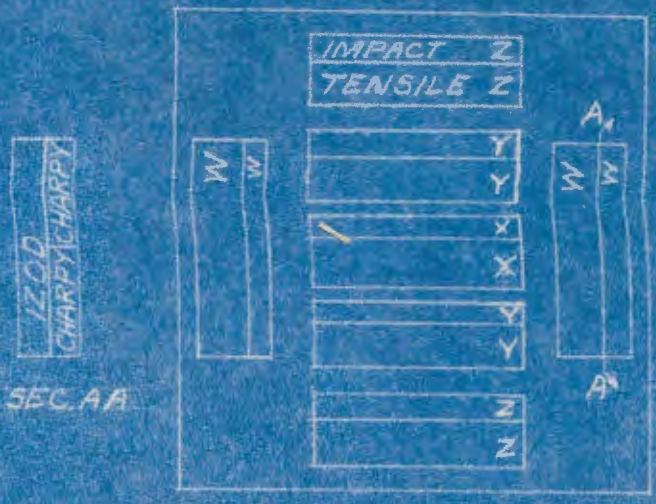
POSITION OF LONGITUDINAL TENSILE AND IMPACT SPECIMENS

¾" SECTION A



POSITION OF COLD BEND SPECIMENS

1¼" SECTION B

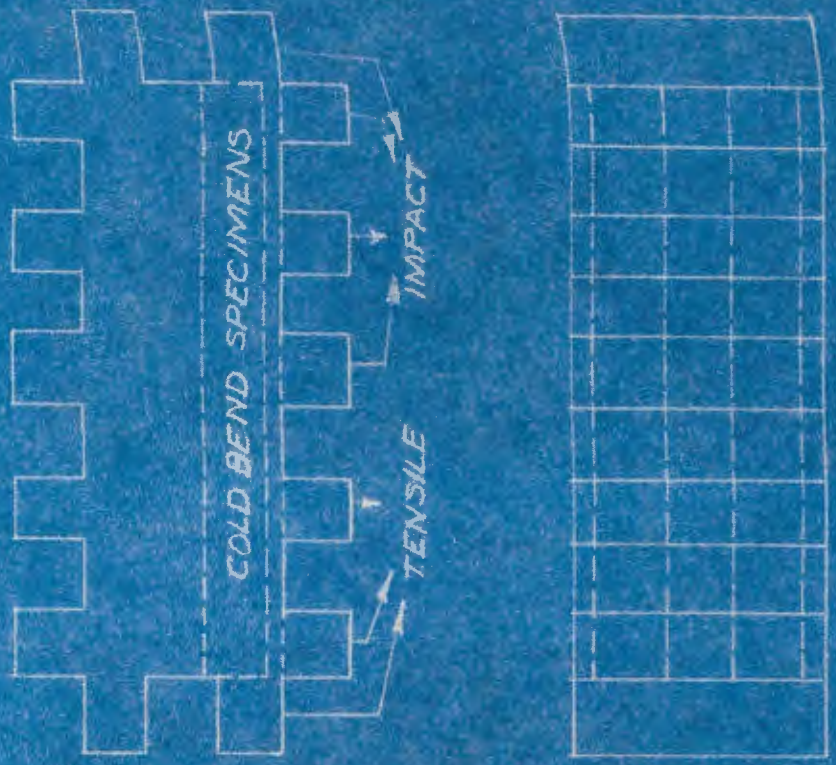


SEC. AA

POSITION OF TRANSVERSE TENSILE AND IMPACT SPECIMENS

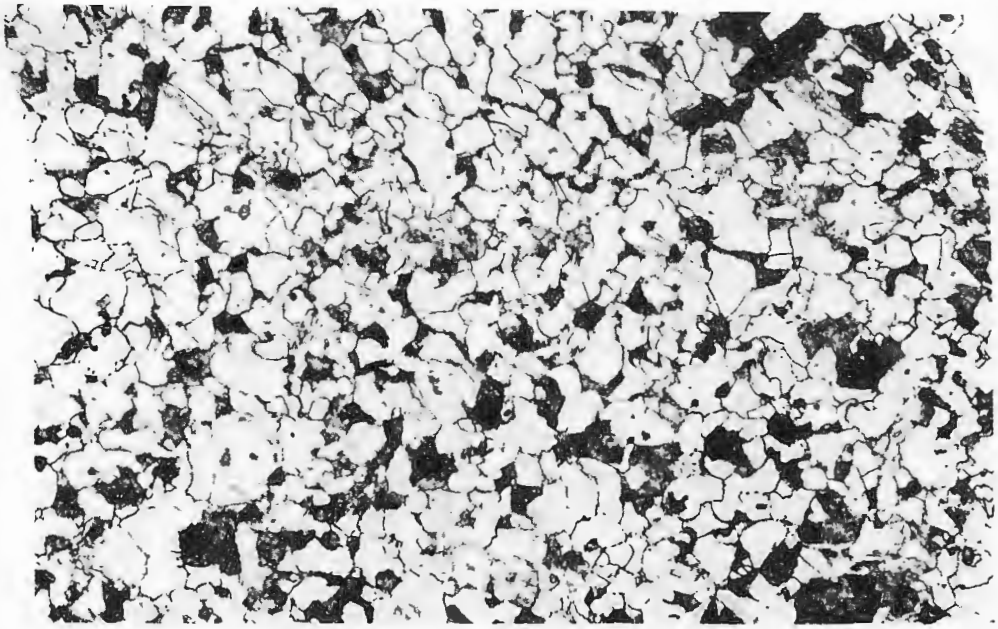
PLATE 4

TEST COUPON B
SHOWING POSITION OF TEST SPECIMENS

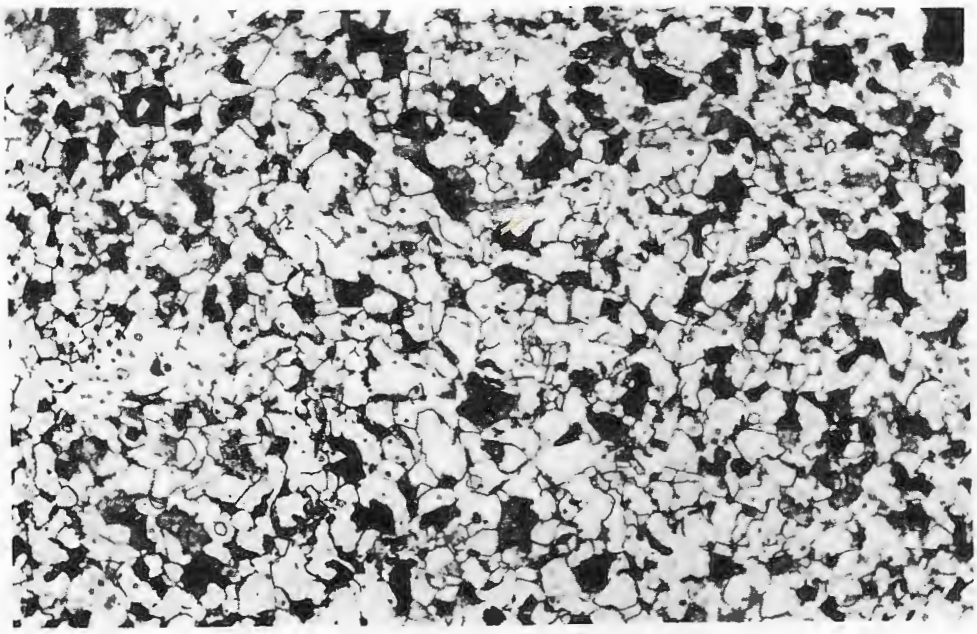


TEST COUPON A
SHOWING POSITION OF TEST SPECIMENS

PLATE 5



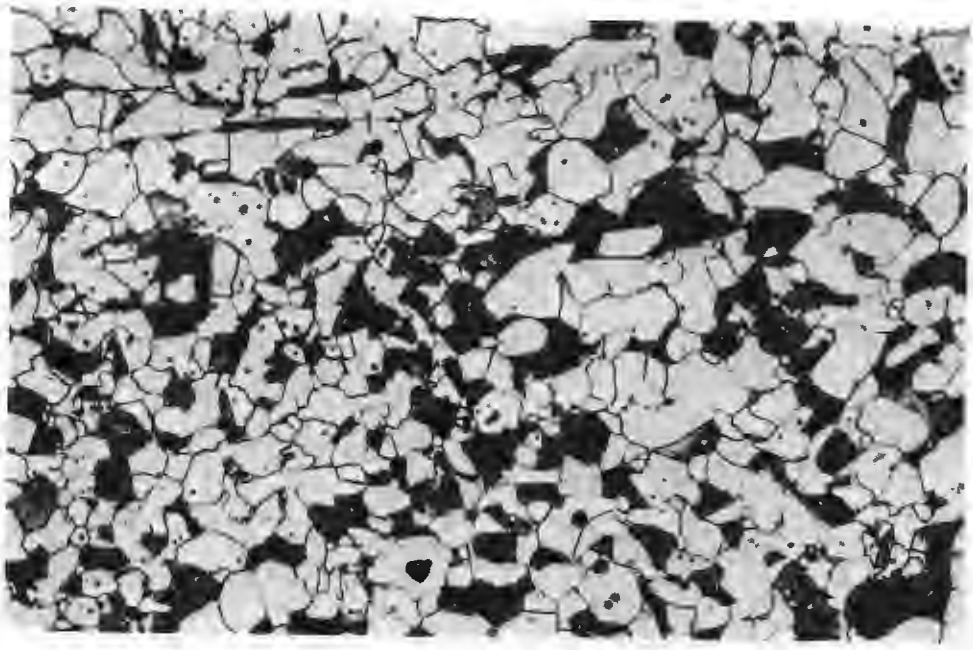
1A Center 200X



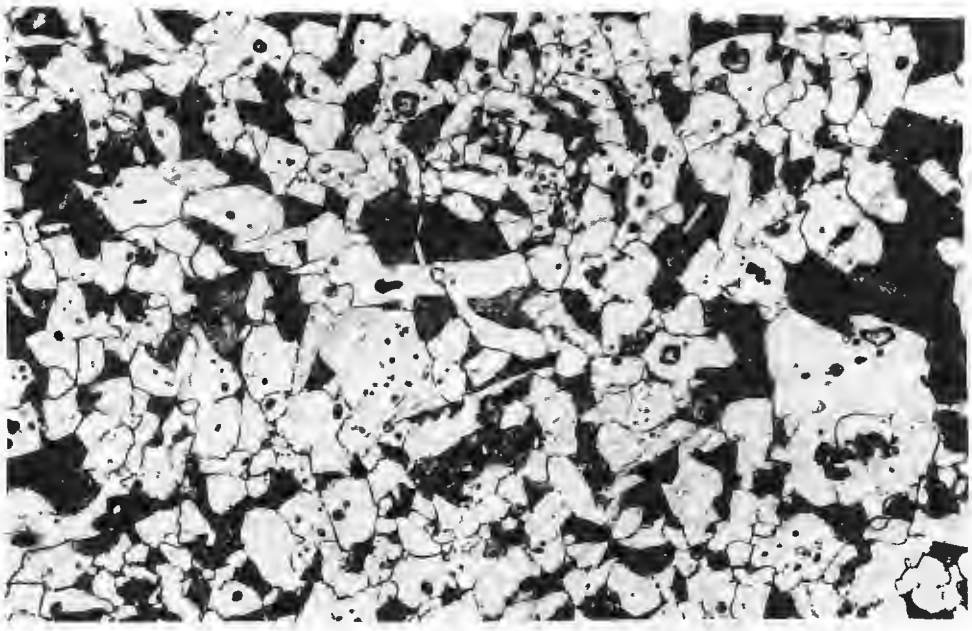
1D Corner 200X

Photomicrographs taken from a section of the 10x10x20 inch casting #1 midway between top and bottom.
Homogenized 1800°F., 6 hrs. Normalized 1650°F., 3 hrs.
Drawn 1300°F., 3 hrs.

PLATE 6

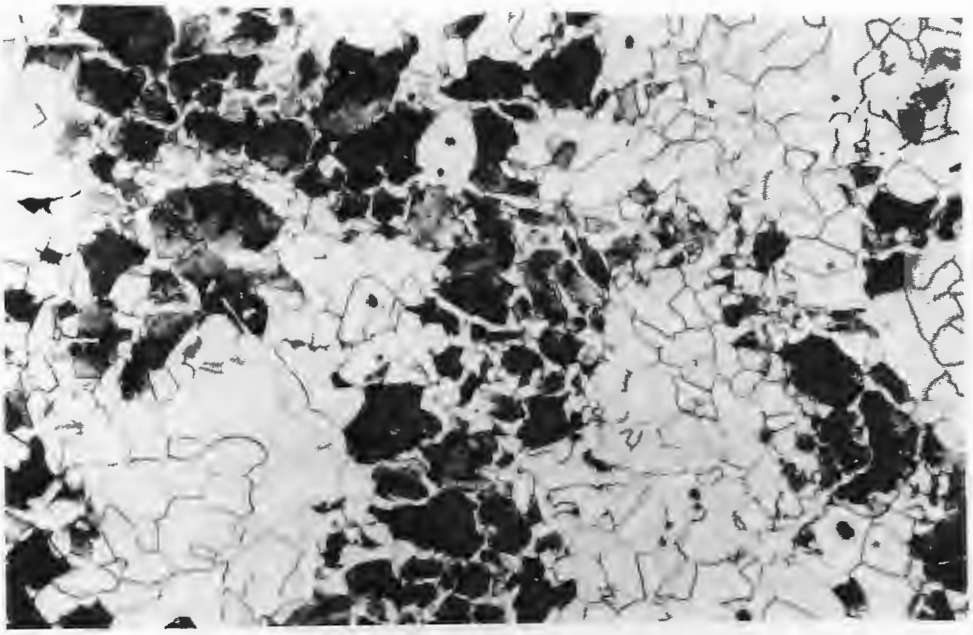


2A Center 200X

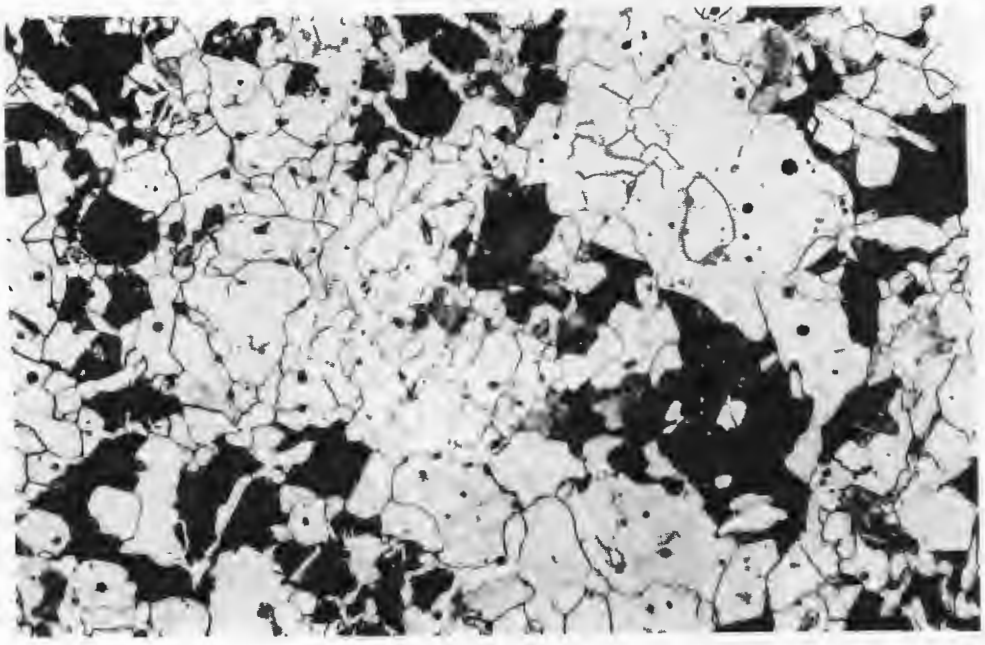


2D Corner 200X

Photomicrographs taken from a section of 10×10×20 inch casting #2 midway between top and bottom.
Normalized 1700°F.,4 1/2 hrs. Drawn 1300°F.,3 hrs.



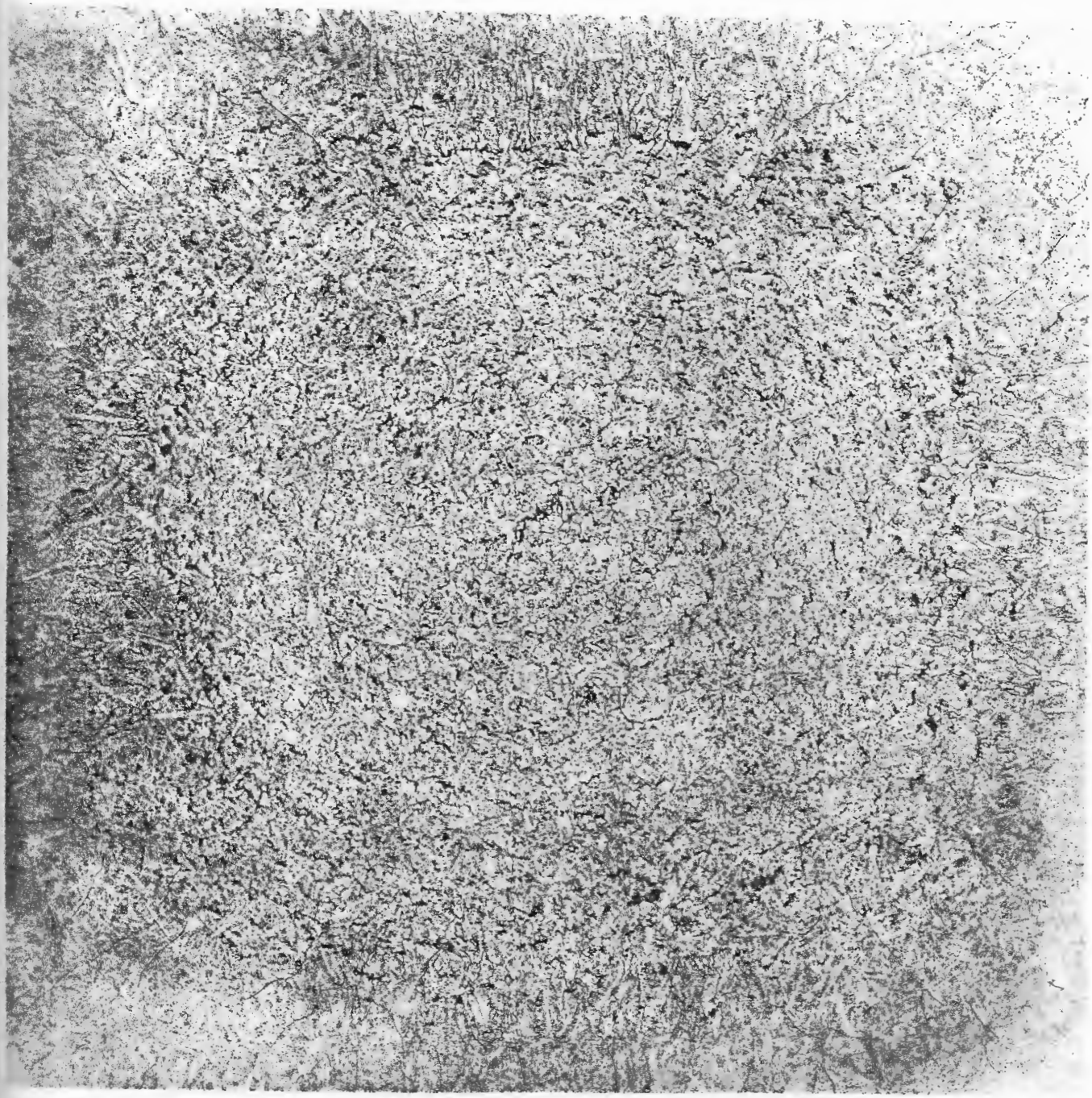
3A Center 200X



3D Corner 200X

Photomicrograph taken from a sector of 10x10x20 inch casting #3 midway between top and bottom.
Annealed 1600°F., 25 hrs.

PLATE 8

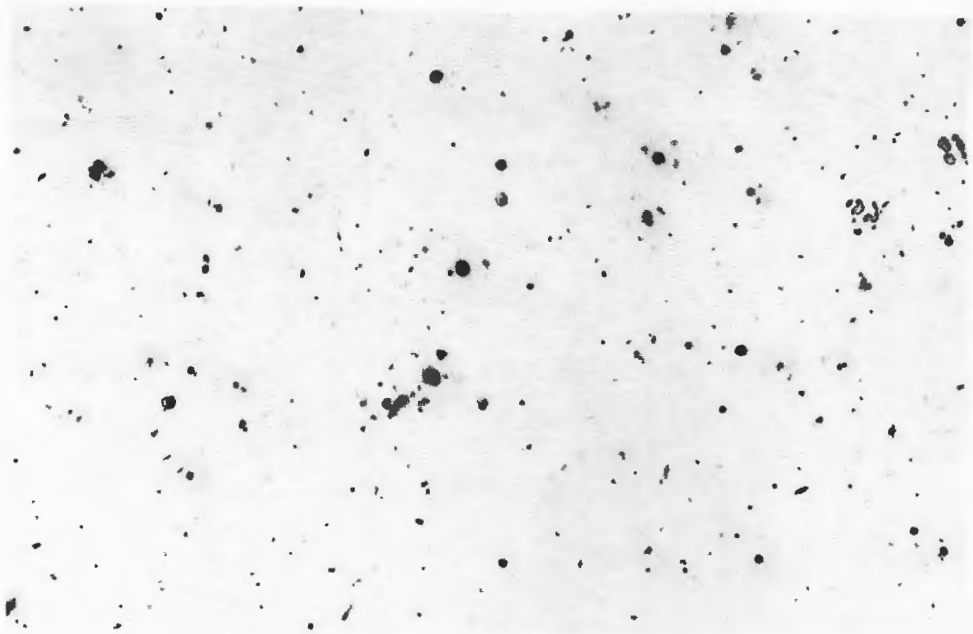


Macrostructure of cross section of test casting #2 etched with a boiling 50% HCL solution.

PLATE 9

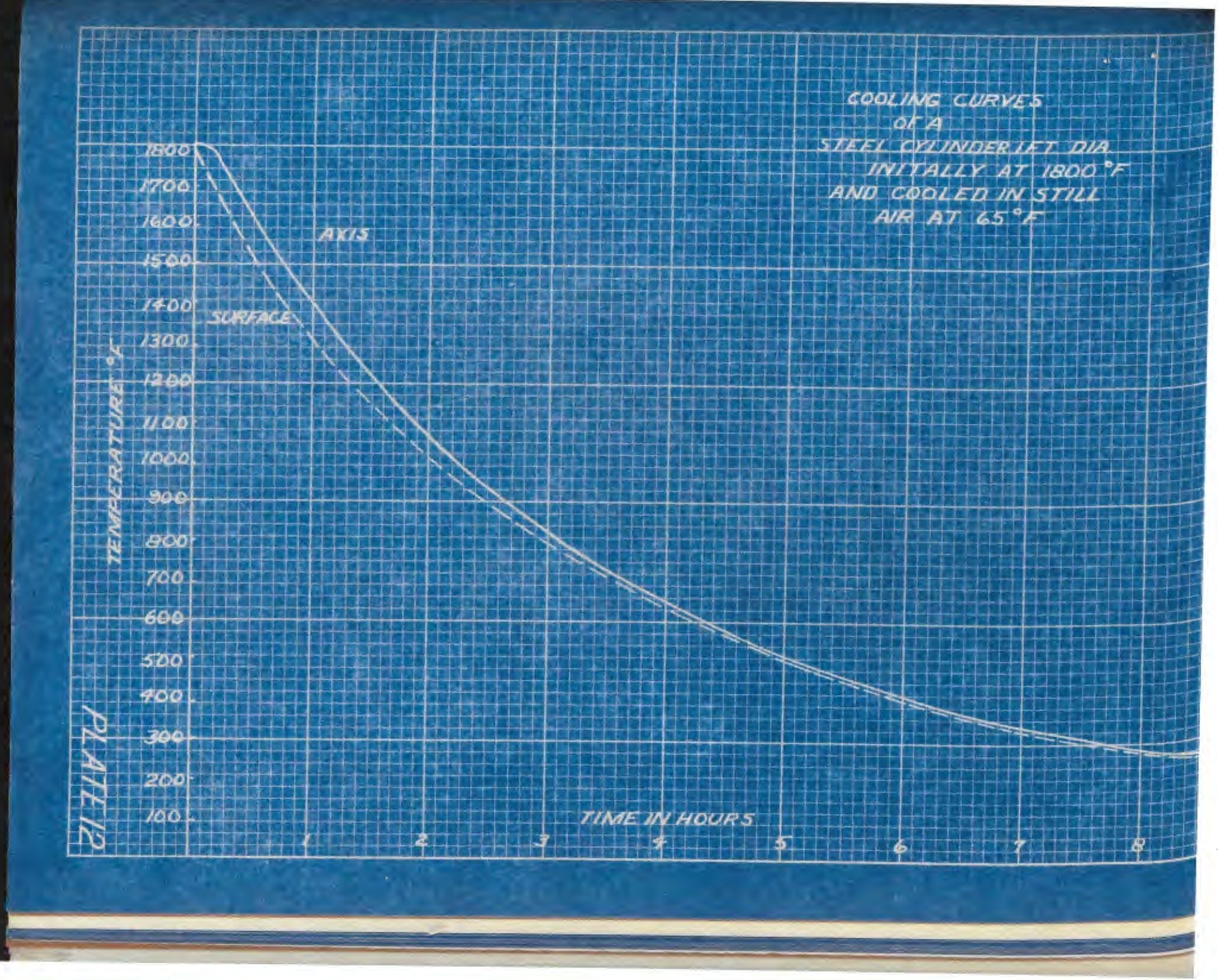
Sulphur Print of part of cross section of test casting #2.

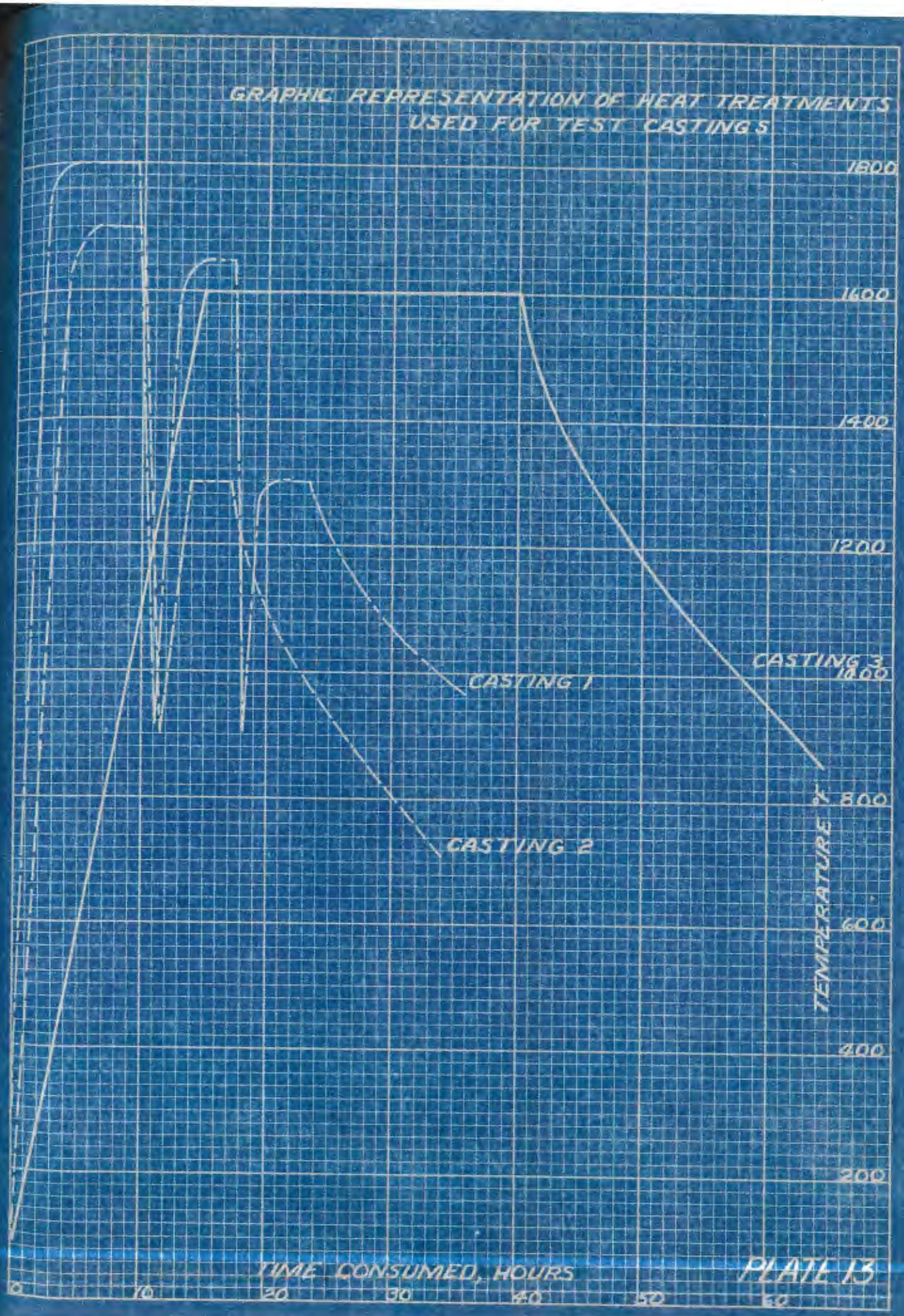
PLATE 10



Typical inclusions found in the test castings. 200X

PLATE 11


COOLING CURVES
OF A
STEEL CYLINDER 1 FT. DIA.
INITIALLY AT 1800 °F
AND COOLED IN STILL
AIR AT 65 °F
AXIS
SURFACE
TEMPERATURE °F
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
TIME IN HOURS
1
2
3
4
5
6
7
8


GRAPHIC REPRESENTATION OF HEAT TREATMENTS USED FOR TEST CASTINGS
1800
1600
1400
1200
1000
800
600
400
200
TEMPERATURE
CASTING 3
CASTING 1
CASTING 2
0
10
20
30
40
50
60
TIME CONSUMED, HOURS
PLATE 13