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Summary Report

on the

Heat Treatment of Stockless Anchors

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ABSTRACT

Coupons and test castings of suitable dimensions to represent a section of a heavy anchor shank were heat treated by ten different procedures. One lot of castings was made from each of three very similar heats of modified Class B steel. In each lot, a prolonged anneal was used as a control treatment.

Methods of sampling, description of testing procedure, data, interpretation of results, conclusions, and recommendations are given.

It was found that prolonged annealing can be replaced by several shorter treatments. Although not recommended for adoption as a specification at present, quenching and tempering give the most desirable physical properties. For expediency and satisfactory physical properties, a single normalizing and tempering treatment is suggested as the most logical treatment.

AUTHORIZATION

1. The problem was authorized by Bureau of Ships Letter S-26-2 (3692) of 7 April 1942.

STATEMENT OF PROBLEM

2. Navy specification, 6A2a, requires that stockless anchors be given an annealing treatment involving a time cycle of 72 hours, regardless of the weight of the anchor. Such a treatment is unduly long and does not produce optimum physical properties. The object of this investigation, therefore, was to develop a suitable heat treatment which would be shorter and equally or more effective than the specified treatment.

KNOWN FACTS BEARING ON THE PROBLEM

3. Some of the work in connection with this investigation has been previously reported in references (1) and (2). Reference (1) contains an account of information available in the literature and of preliminary experimental work as well as the results obtained from coupons and test castings corresponding to sections of heavy anchor shanks. Reference (2) contains further results obtained from coupons and test castings. Although not directly connected with this problem, reference (3) reports the investigation of two failed Danforth Anchors. Improper heat treatment of one of these anchors was a factor contributing to its original failure.

4. From the results of the previous work several conclusions may be drawn:

(a) Prolonged annealing is less effective in promoting optimum physical properties than any of several much shorter treatments.

(b) Heating rates up to 400°F. per hour do not seem to be harmful in uniform sections of relatively mild steel such as is used in anchors.

(c) Long soaking at austenitizing temperatures is unnecessary. Satisfactory results are obtainable from periods shorter than the commercially conventional "one hour per inch of section" if proper precautions are taken. (It is to be noted that one hour per inch of section amounts to considerably less, even for the most massive anchors, than the 30 hours at temperatures given by Specification 6A2a.)

(d) Accelerated cooling rates from austenitizing temperatures, followed by suitable tempering, produce the most desirable microstructure and thereby the best combinations of strength, ductility and notched-bar impact resistance.

(e) Double treatments appear to be more effective than single treatments although the data are not sufficiently complete to warrant a positive statement. (This matter is clarified by the third series of experiments described in this report.)

5. At conferences with metallurgists at the Norfolk Navy Yard and with representatives of the foundry industry, it was emphasized that war-time difficulties involved in the acquisition of new equipment which would be required for high temperature treatments and liquid quenching would prevent many foundries, otherwise in a position to manufacture anchors for the Navy, from bidding on anchor contracts. For example, most heat treating furnaces in current use are not designed to operate above 1650°F. or 1700°F. and a good many foundry heat treating departments are not equipped for liquid quenching. Furthermore, batch heating is conducive to rather large temperature gradients throughout a charge and unless adequate pyrometric equipment is used to insure that all castings have reached the desired temperature and have been held for the proper time, holding at heat treating temperatures for minimum times might be a dangerous practice.

EXPERIMENTAL PROCEDURE

6. Test castings and coupons for the experimental work were made of basic electric steels, the compositions of which are given in Table 1. Photographs of the two types of coupons and of a test casting, which were taken before removal of gates and risers, are shown as Plates 1 and 2. The final dimensions of the test castings were 10 x 10 x 20 inches, being of sufficient cross-section to approximate a heavy anchor shank and long enough to eliminate end effects from solidification and heat treatment.

7. In order to answer the questions implied in paragraph 4 and to comply with the restrictions imposed by paragraph 5, a new series of heat treatments was applied to six test castings and corresponding coupons. These treatments are Nos. 7 through 12 listed below. The previous treatments, discussed in detail in the other reports dealing with this investigation, are also listed by their original numbers, 1 through 6.

Heat R

Treatment No. 1

1800°F., 6 hours, AC to 950°F.
1650°F., 3 hours, AC to 900°F.
1300°F., 3 hours, FC to 950°F., AC
Total time involved - 36 hours

Treatment No. 2

1700°F., 4½ hours, AC to 900°F.
1300°F., 3 hours, FC to 720°F., AC
Total time involved - 32 hours

Treatment No. 3

1600°F., 25 hours, FC to 865°F.
(Heating time, 15 hours; cooling
time, 24 hours)
Total time involved - 64 hours

Heat S

Treatment No. 4

1800°F., 5 hours, AC to 750°F.
1650°F., 2 hours, WQ
1230°F., 4 Hours, AC
Total time involved - 22 hours

Treatment No. 5

1800°F., 2 hours, AC to 750°F.
1230°F., 4 hours, AC
Total time involved - 13 hours

Treatment No. 6

Same as No. 3

Heat T

Treatment No. 7

1650°F., 10 hours, AC to 800°F.
1250°F., 10 hours, AC
Total time involved - 28 hours

Treatment No. 8

1650°F., 2-1/2 hours, AC to 800°F.
1250°F., 2-1/2 hours, AC
Total time involved - 13 hours

Treatment No. 9

1800°F., 10 hours, AC to 800°F.
1650°F., 10 hours, AC to 800°F.
1250°F., 10 hours, AC
Total time involved - 43 hours

Treatment No. 10

2000°F., 10 hours, AC to 800°F.
1650°F., 10 hours, AC to 800°F.
1250°F., 10 hours, AC
Total time involved - 44 hours

Treatment No. 11

1650°F., 10 hours, AC to 800°F.
1650°F., 10 hours, AC to 800°F.
1250°F., 10 hours, AC
Total time involved - 42 hours

Treatment No. 12

Same as No. 3 and No. 6

NOTE: AC - Air Cooled, FC - Furnace Cooled, WQ - Water Quenched
Total time stated includes that of heating,
holding, cooling and manipulation.

8. It is to be noted that the last six heat treatments, except No. 12 which is the control treatment, were based upon normalizing from 1650 F. and tempering at 1250 F. With all treatments except No. 8, in which one quarter hour per inch of section was used, holding times were one hour per inch of section; otherwise No. 8 was the same as No. 7. In treatments No. 9 and No. 10 preliminary austenitizing treatments were given at 1800 F. and 2000 F. respectively to obtain comparable data for determining the advisability of higher temperature treatments when and if they become more generally possible.

9. The test castings were sectioned as shown by the line sketch of Plate 3. Sections A and C were then sawed into specimen blanks as detailed in Plate 4 and the half-inch sections, D, were used for hardness surveys and deep-etching. Plate 5 illustrates the method by which the coupons were sampled.

DISCUSSION OF RESULTS

10. Inasmuch as three different heats of steel were used in the investigation, it is not possible to compare physical properties directly. Examination of the tensile strength data, Table 2, for the control treatments, No. 3, No. 6 and No. 12 (all identical), at the center and at the corners of the test castings as well as in the coupons, shows Heat S to have greater strength than Heat R and Heat R to have greater strength than Heat T. The maximum variation for any particular position in castings or coupons is about 10%. Such variation can be accounted for by the differences in chemical composition, Table 1.

11. By further study of the tensile strength data as a whole, it can be observed that, except for treatment No. 4 which forms a class by itself, in any particular location in castings or coupons, the maximum variation for all treatments is only about 10%. Considering treatments 7 through 12, the maximum variation is only 5%. Similarly the variation is of a smaller order in the other individual heats if Treatment No. 4 is taken as an exception. When factors, necessary to convert tensile

strength for the control treatments to some common base such as 70,000 PSI at one position in the test casting, are applied to other values for different treatments in the same heat it becomes obvious that all treatments except No. 4 give results almost within the range of experimental error. Table 2a gives the converted values.

12. The results of hardness surveys, made by taking Brinell readings diagonally across sections sawed from the 10 x 10 x 20 inch test castings, are shown in graphical form as Plate 6.

13. Yield point data (Table 3) were determined by drop-of-the-beam method. In Table 3a are the ratios of yield to tensile strength. Treatment No. 4 is outstanding by such a comparison. In general, the double treatments are superior to single treatments for a high yield to tensile ratio although the difference is not significantly large.

14. With a very few minor exceptions, the prolonged annealing treatments resulted in lower values for the reduction of area (Table 4) and percent elongation (Table 5) than did the other treatments.

15. The results obtained from cold bend tests, Table 6, are erratic and no definite correlation can be made with static ductility as obtained from corresponding tensile bars. The most significant observation from these data is that all specimens obtained from coupons, regardless of the thermal treatment, bent well above 135 degrees without evidence of cracking, while specimens from the castings did not.

16. From Table 7 which shows the Izod impact resistance, it is obvious that quenching and tempering promote high notched-bar impact resistance even though the treatment is applied to 10 x 10 inch sections of steel having negligible hardenability. It is difficult to explain why the results from Treatment No. 2 are considerably lower than those from Treatment No. 3 and to a less degree why Treatment No. 7 should give somewhat lower values than Treatment No. 8 or Treatment No. 12. However, there is no reason to believe that even the lowest impact value recorded would decrease the servicability of an anchor.

17. Although low temperature notched bar impact-testing cannot be considered conclusive as a method of predicting metal behaviour when subjected to shock-loading at low temperatures, it does indicate a trend. The data presented as Table 8 leaves little to choose from except for Treatment No. 4 which again shows superiority.

18. Photomicrographs of specimens removed from center and corners of all test castings are reproduced as Plates 7 through 18. On the basis of fine grain-size and good distribution of ferrite and pearlite, Treatment No. 4 is the most beneficial. Treatments Nos. 11 and 1 follow in that order. Considering microstructures for only the final six treatments, No. 11 is preferred to Nos. 9 and 10 between which it is difficult to choose. Nos. 9 and 10 are more desirable than Nos. 7 and 8 which resemble each other closely. Treatment No. 12, the prolonged anneal, results in the least desirable microstructure.

19. The type and occurrence of non-metallics in the three heats were very much the same. There was no evidence of stringers or eutectic inclusions of a harmful nature. Representative photomicrographs of two unetched samples are reproduced on Plate 19.

20. Transverse cross-sections from all test castings were deep etched as a means of locating porosity or low density areas. Every casting appeared to be internally sound. A typical photomicrograph is reproduced as Plate 20. Density determinations were made at corner and center of one of the castings and no significant difference was found. Results are recorded in reference (1).

21. The specifications for steel castings are commonly expressed in terms of physical properties developed in coupons which are poured from the same ladle of metal as the castings. However, results from coupons are not necessarily the same as those which would be obtained from their corresponding castings since differences in section size affect as-cast structure and reaction to heat treatment. Thus, it is desirable to maintain as nearly a constant relationship as possible between the properties in the coupons and in the castings. It has been frequently noticed at the Naval Research Laboratory that the Type A coupon, which is used widely, varies considerably in reduction of area from top to bottom as is evident from the data of Table 4. Such variation makes the relationship between coupon and casting doubtful. In the Type B coupons, the projections which are used as test blanks solidify under exactly the same conditions and variations are reduced to a minimum. For that reason, it is felt that the Type B coupon or one similar to it should be more generally adopted.

CONCLUSIONS

22. Of the ten treatments used in this study, quenching and tempering developed optimum physical properties. However, restrictions imposed by limited equipment prevent wide use of such a treatment at present.

23. Since quenching and tempering are not possible, double normalizing and tempering result in the best over-all physical properties and microstructure.

24. Preliminary austenitizing at 1800°F. or 2000°F. followed by normalizing from 1650°F. and tempering at 1250°F. apparently offer no advantages over double normalizing from 1650°F. and tempering at 1250°F.

25. Holding at heat treating temperatures for one hour per inch of maximum section provides a reasonable factor of safety for heat treating times.

26. Notwithstanding the slightly better physical properties obtained by double normalizing and tempering, the difference is probably not large enough to overbalance the economy and simplicity of the single treatment.

RECOMMENDATIONS

27. It is recommended that a suitable number of anchors in various size ranges be given the following heat treatment:

Heat to 1650°F. at a rate not to exceed 400°F. per hour.
Hold at 1650°F. for one hour per inch of maximum section.
Air cool to 800°F.

Heat to 1250°F. at a rate not to exceed 400°F. per hour.
Hold at 1250°F. for one hour per inch of maximum section.

These anchors should then be proof tested. If they prove to be of equal or better quality than anchors treated according to Navy Department Specification 6A2a, the experimental work of this investigation will be substantiated and interim specifications should be written to take advantage of the economy offered by such a treatment.

28. Although the restrictions with regard to liquid quenching apply to anchors in the heavier weight classes, there is no reason why simple, improvised, small-scale quenching equipment could not be used for the quenching of light anchors. It is, therefore, recommended that quenching and tempering be considered for light anchors.

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TABLE 1

Chemical Composition of the Steels Used, PSI

	<u>P E R C E N T</u>		
	<u>Heat R</u>	<u>Heat S</u>	<u>Heat T</u>
Carbon	0.24	0.27	0.24
Manganese	0.66	0.63	0.56
Silicon	0.44	0.43	0.40
Sulphur	0.016	0.012	0.017
Phosphorus	0.031	0.030	0.036
Copper	0.21	0.17	0.15
Nickel	0.75	0.73	0.79
Chromium	0.22	0.19	0.15

TABLE 2

Effect of Heat Treatments upon Tensile Strength.

Treatment No.	10x10x20 Inch Castings		Coupons			
	Center	Corners	Top, A	Bottom, A	B	
Heat R	1	70,000	76,000	75,700	76,500	76,000
	2	67,000	76,000	76,250	76,250	75,500
	3	68,000	78,650	77,500	77,500	77,500
Heat S	4	77,250	84,500	88,000	87,000	93,875
	5	72,500	80,250	79,250	78,750	79,750
	6	72,500	79,350	78,000	79,000	79,375
Heat T	7	68,875	72,415	73,250	73,500	72,690
	8	67,460	74,585	74,750	74,750	74,050
	9	67,170	72,585	73,125	72,500	72,810
	10	66,750	72,420	72,875	72,125	71,875
	11	66,375	71,875	73,625	73,750	73,190
	12	65,165	71,665	72,125	73,000	73,060

TABLE 2a

Effect of Heat Treatment Upon Tensile Strength as Calculated
To a Base of 70,000 PSI for Control Treatments.

Treatment No.	10x10x20 Inch Castings		Coupons			
	Center	Corners	Top, A	Bottom, A	B	
Heat R	1	62,300	67,640	67,370	68,090	67,640
Factor	2	59,630	67,640	67,865	67,860	67,200
0,89002	3	60,520	70,000	68,975	68,975	68,975
Heat S	4	68,150	74,540	77,630	76,750	82,810
Factor	5	63,960	70,800	69,910	69,470	70,350
0,88217	6	63,960	70,000	68,810	69,690	70,020
	7	67,275	70,730	71,550	71,790	71,000
Heat T	8	65,890	72,850	73,010	73,010	72,330
Factor	9	65,610	70,900	71,430	70,820	71,120
0,97677	10	65,200	70,740	71,180	70,450	70,200
	11	64,830	70,200	71,910	72,040	71,490
	12	63,650	70,000	70,450	71,300	71,360

TABLE 3

Effect of Heat Treatments Upon Yield Point, PSI

Treatment	No.	10x10x20 Inch Castings		Coupons		
		Center	Corners	Top, A	Bottom, A	B
Heat R	1	45,000	49,000	51,700	52,250	50,500
	2	43,750	45,900	48,850	48,850	48,850
	3	40,500	43,800	44,500	46,000	47,500
Heat S	4	50,650	58,300	63,000	62,250	71,100
	5	41,900	47,600	48,500	48,750	48,250
	6	39,650	45,200	44,000	44,250	44,500
Heat T	7	42,200	44,000	48,000	47,500	44,000
	8	41,500	41,625	46,375	47,500	46,250
	9	45,960	44,625	47,500	49,250	47,750
	10	45,500	43,670	47,125	47,125	45,940
	11	42,875	46,040	49,000	50,500	48,190
	12	37,915	39,625	42,625	43,250	41,625

TABLE 3a

Effect of Heat Treatments Upon Ratio
of Yield Strength to Tensile Strength

Treatment	No.	10x10x20 Inch Castings		Coupons		
		Center	Corners	Top, A	Bottom, A	B
Heat R	1	.64	.64	.68	.68	.66
	2	.65	.60	.64	.64	.65
	3	.60	.56	.57	.59	.61
Heat S	4	.66	.69	.72	.72	.76
	5	.58	.59	.61	.62	.61
	6	.55	.57	.56	.56	.56
Heat T	7	.61	.61	.66	.65	.61
	8	.66	.66	.62	.64	.62
	9	.68	.61	.65	.68	.66
	10	.68	.60	.65	.65	.64
	11	.65	.64	.67	.68	.66
	12	.58	.55	.59	.59	.57

TABLE 4

Effect of Heat Treatments Upon Percent Reduction of Area

Treatment	No.	10x10x20 Inch Castings		Coupons		
		Center	Corners	Top, A	Bottom, A	B
Heat R	1	18.1	35.8	35.0	51.7	57.4
	2	14.5	37.0	32.5	54.9	58.2
	3	18.1	38.5	25.1	41.3	45.2
Heat S	4	21.0	47.0	40.0	57.0	63.0
	5	20.0	31.0	31.0	48.0	55.0
	6	24.0	31.0	33.0	39.0	44.0
Heat T	7	24.7	36.7	39.4	51.9	57.5
	8	20.7	34.3	51.7	51.9	57.6
	9	23.2	39.2	42.6	51.2	59.9
	10	19.9	33.1	38.5	56.6	59.4
	11	21.5	36.3	33.1	38.3	60.7
	12	19.8	32.7	33.5	40.5	50.5

TABLE 5

Effect of Heat Treatments Upon Percent Elongation in 2 Inches.

Treatment	No.	10x10x20 Inch Castings		Coupons		
		Center	Corners	Top, A	Bottom, A	B
Heat R	1	16.4	26.8	25.8	29.7	32.4
	2	9.4	25.8	22.7	29.7	32.0
	3	10.9	26.5	25.0	28.9	28.9
Heat S	4	13.0	26.0	23.4	28.9	28.0
	5	15.0	23.0	23.4	28.9	30.0
	6	19.0	20.0	24.2	25.0	27.0
Heat T	7	16.0	25.1	29.0	30.7	31.7
	8	12.8	23.9	26.9	30.7	30.5
	9	13.1	28.0	28.5	28.8	31.5
	10	13.6	26.5	27.3	31.5	31.0
	11	14.8	24.6	21.5	24.5	31.8
	12	11.4	24.8	23.0	26.6	29.2

TABLE 6

Effect of Heat Treatments Upon Cold Bend Properties.

Treatment No.	10 x 10 x 20 Inch Castings				Coupons - B		
	Surface		Center		Max. Load Lbs.	Angle of Bend Deg.	
	Max. Load lbs.	Angle of Bend Deg.	Max. Load Lbs.	Angle of Bend Deg.			
Heat R	1	7,600	95	7,400	95	7,900	135
	2	7,600	75	7,100	65	8,000	135
	3	7,600	70	7,400	75	8,000	135
Heat S	4	8,300	84	7,750	71	8,600	135
	5	7,550	66	7,350	63	8,000	135
	6	7,800	70	7,400	68	8,100	135
Heat T	7	7,030	77	6,660	84	7,505	135
	8	7,305	115	7,080	85	7,455	135
	9	7,245	97	7,120	83	7,525	135
	10	7,185	121	6,950	94	7,240	135
	11	7,235	135	7,085	94	7,470	135
	12	7,740	107	6,975	75	7,530	135

TABLE 7

Effect of Heat Treatments Upon Izod Impact Resistance, Ft.-lb.

Treatment	No.	10x10x20 Inch Castings		Coupons	
		Center	Corners	A	B
Heat R	1	31.5	30.0	34.0	35.0
	2	22.0	20.5	25.5	27.0
	3	32.0	31.0	34.0	37.5
Heat S	4	51.0	64.0	81.0	79.0
	5	40.0	32.0	35.0	33.0
	6	37.0	27.0	32.0	30.0
Heat T	7	28.0	31.0	43.8	34.8
	8	34.8	36.0	42.4	41.5
	9	37.1	32.3	46.3	42.0
	10	34.8	33.3	42.1	39.3
	11	40.9	35.0	44.0	42.0
	12.	38.0	35.3	41.6	38.3

TABLE 8

Effect of Heat Treatments Upon Charpy (Keyhole) Impact Resistance, Ft.-Lb., at Indicated Temperatures.

Location of Sample in 10x10x20 Inch Casting	°F. Test Temp.	Heat R			Heat S			Heat T					
		1	2	3	4	5	6	7	8	9	10	11	12
Center, Block	70	22	19	20	33	27	24	22	23	25	22	26	22
	32	19*	16*	19*	27	20	20	20	19	21	23	22	19
	0				29	22	16	16	13	16	18	21	20
	-20				20	12	16	13	18	12	15	18	12
	-40				16	12	10	9	12	12	11	13	11
Surface, Block	70	20	17	16	37	22	20	22	20	24	21	26	24
	32	18*	14*	15*	28	17	18	16	20	24	21	20	22
	0				30	18	13	17	16	19	18	19	19
	-20				26	13	13	15	14	10	14	18	10
	-40				15	16	6	12	12	18	13	11	15
Coupon B	70	25	19	21	46	27	20	27	29	30	26	29	23
	32				36	22	19	26	19	26	25	27	21
	0				30	21	16	22	22	21	24	25	23
	-20				26	18	13	11	16	18	16	14	10
	-40				25	11	11	8	17	21	20	18	11

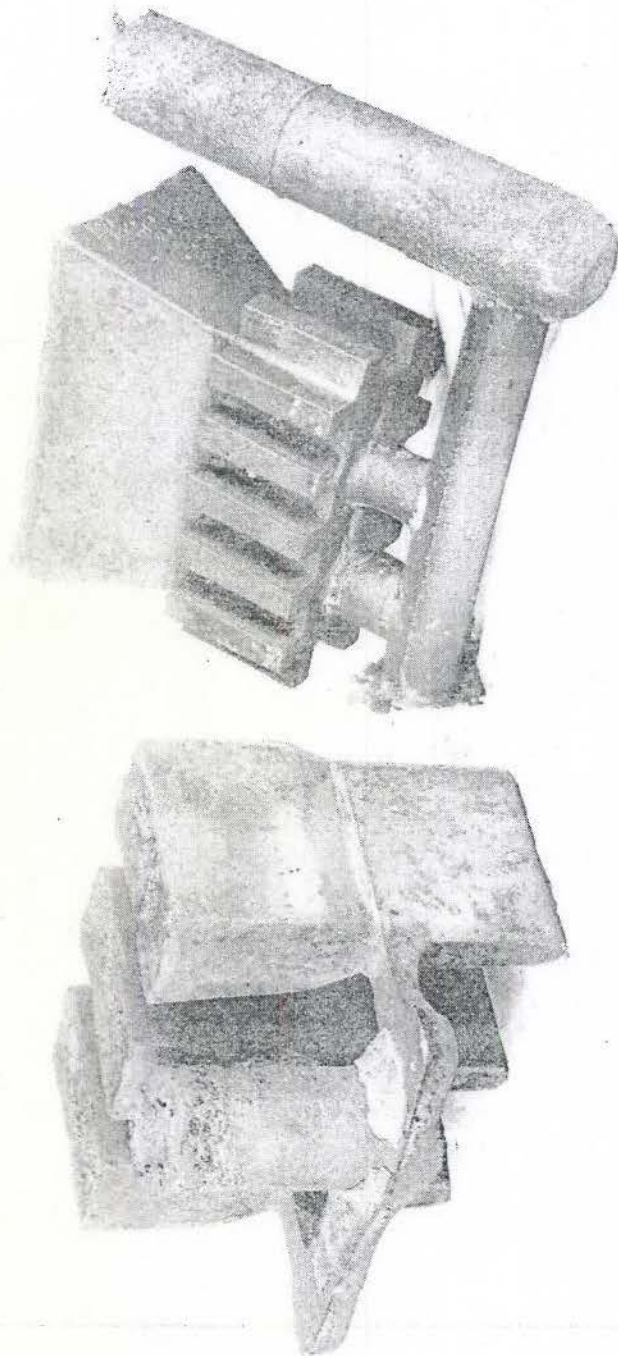
(*) - Testing Temperature, 35°F.

TABLE 9

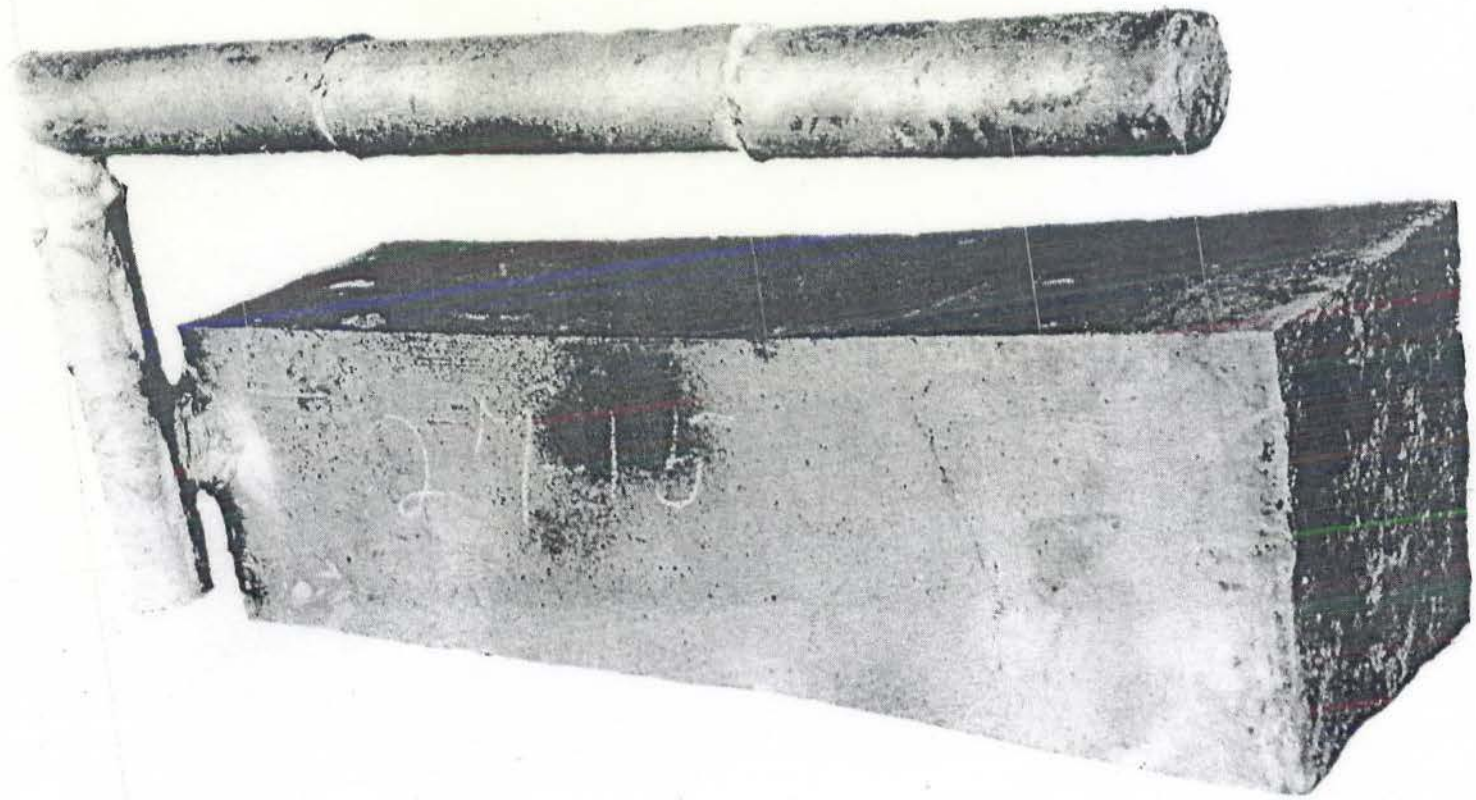
Critical Points* of Samples Taken from 10 x 10 x 20 Inch Castings

	Heat R		Heat S		Heat T	
	<u>Center</u>	<u>Corner</u>	<u>Center</u>	<u>Corner</u>	<u>Center</u>	<u>Corner</u>
AC ₁	1375°F.	1380°F.	1365°F.	1375°F.	1365°F.	1365°F.
AC ₃	1540°F.	1540°F.	1535°F.	1520°F.	1530°F.	1520°F.
AR ₃	1375°F.	1380°F.	1390°F.	1365°F.	1400°F.	1380°F.
AR ₁	1205°F.	1190°F.	1195°F.	1195°F.	1195°F.	1180°F.

(*) - Determined dilatometrically at heating and cooling rates of approximately 40°F. per minute,

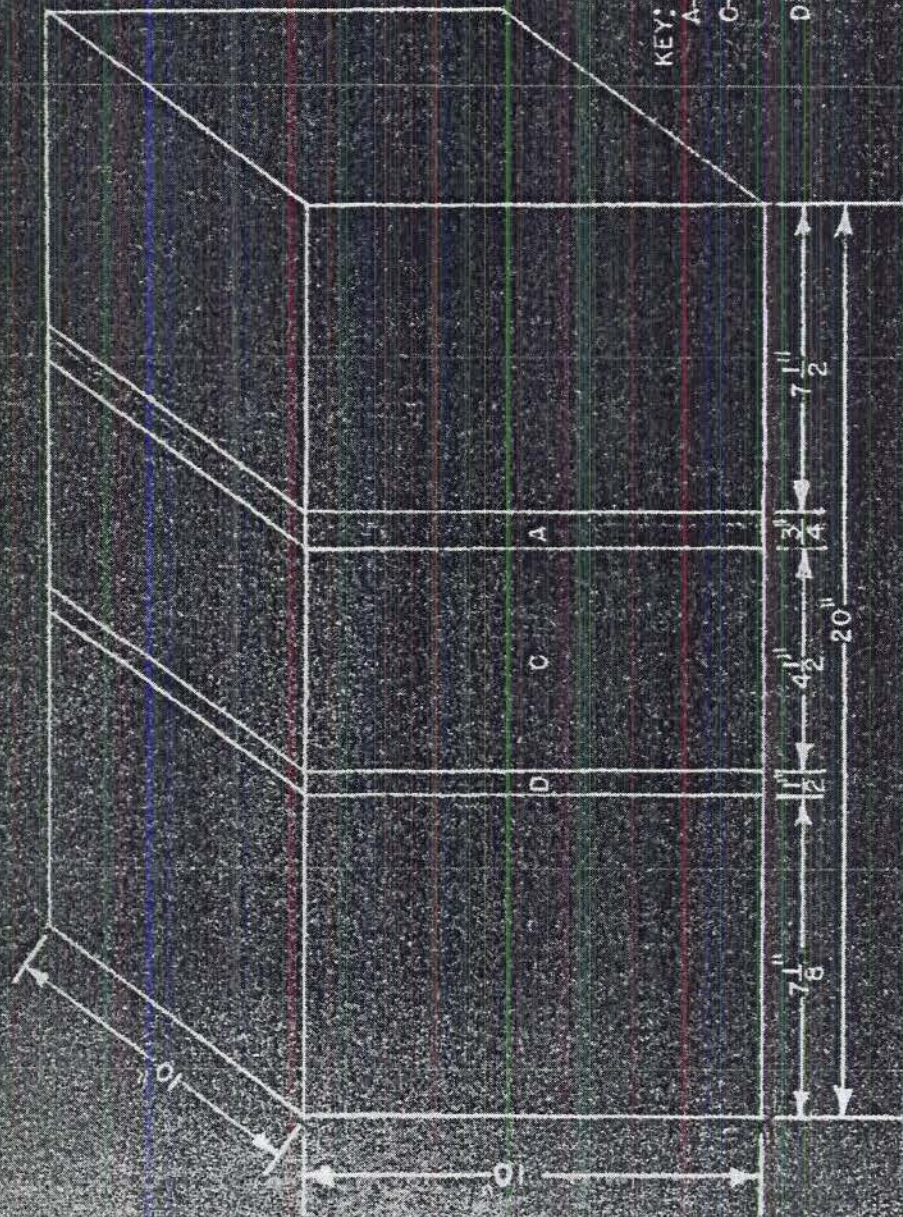


PHOTOGRAPH OF TEST COUPONS
TYPE A (LEFT) AND TYPE B (RIGHT)



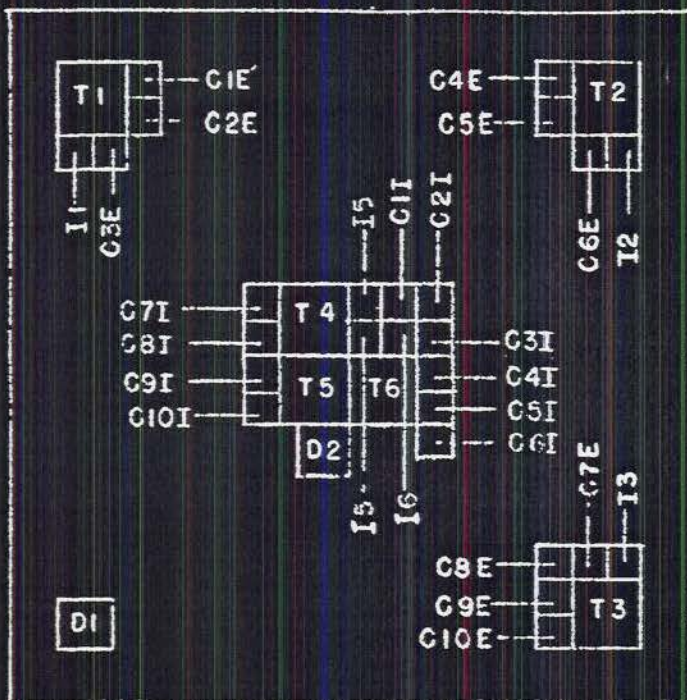
Photograph of the test casting before the removal
of the gate and riser.

PLATE 2



KEY:
 A—COLD BEND SPECIMAN
 C—LONGITUDINAL TENSILE
 AND IMPACT SPECIMENS
 D—BRINELL HARDNESS
 AND DEEP ETCHING
 SPECIMEN

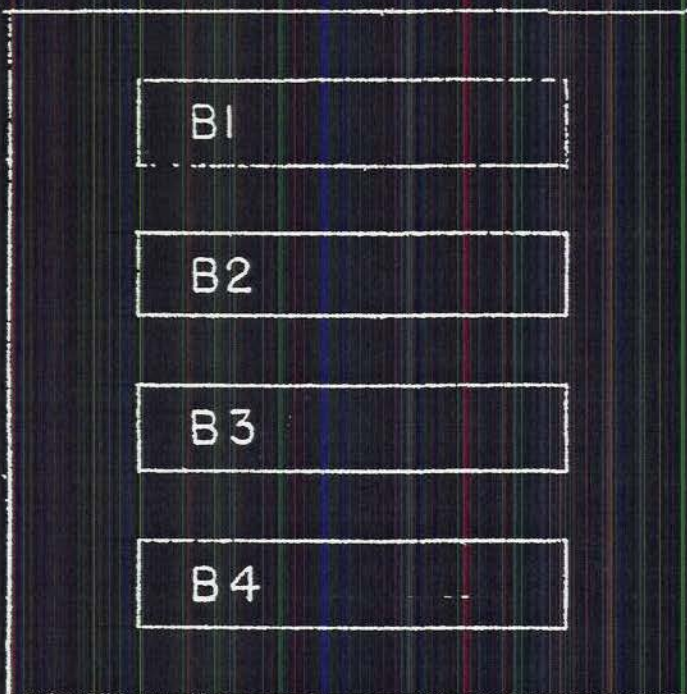
LINE SKETCH OF TEST CASTING SHOWING POSITIONS OF SECTIONS FROM WHICH TEST SPECIMENS WERE OBTAINED



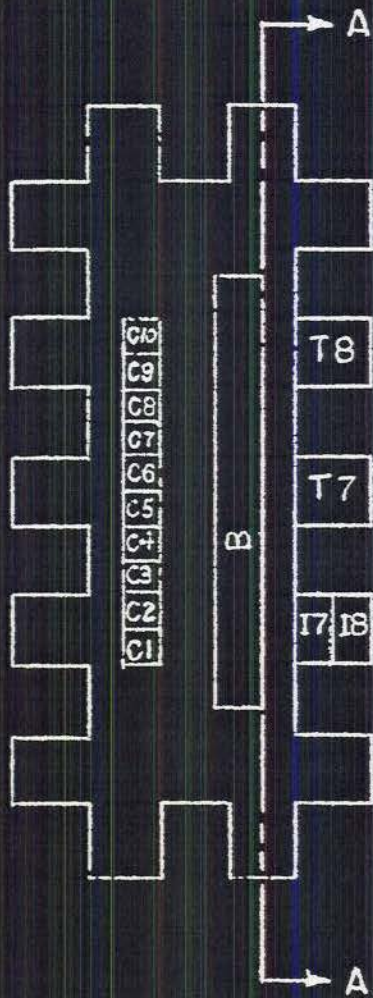
SECTION C

KEY:

- T = TENSILE BLANK
- I = IZOD BLANK
- C = CHARPY BLANK
- B = COLD BEND BLANK



SECTION A



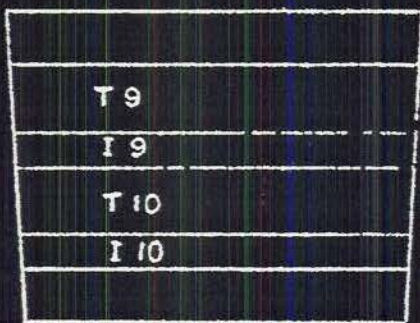
COUPON B



SECTION AA

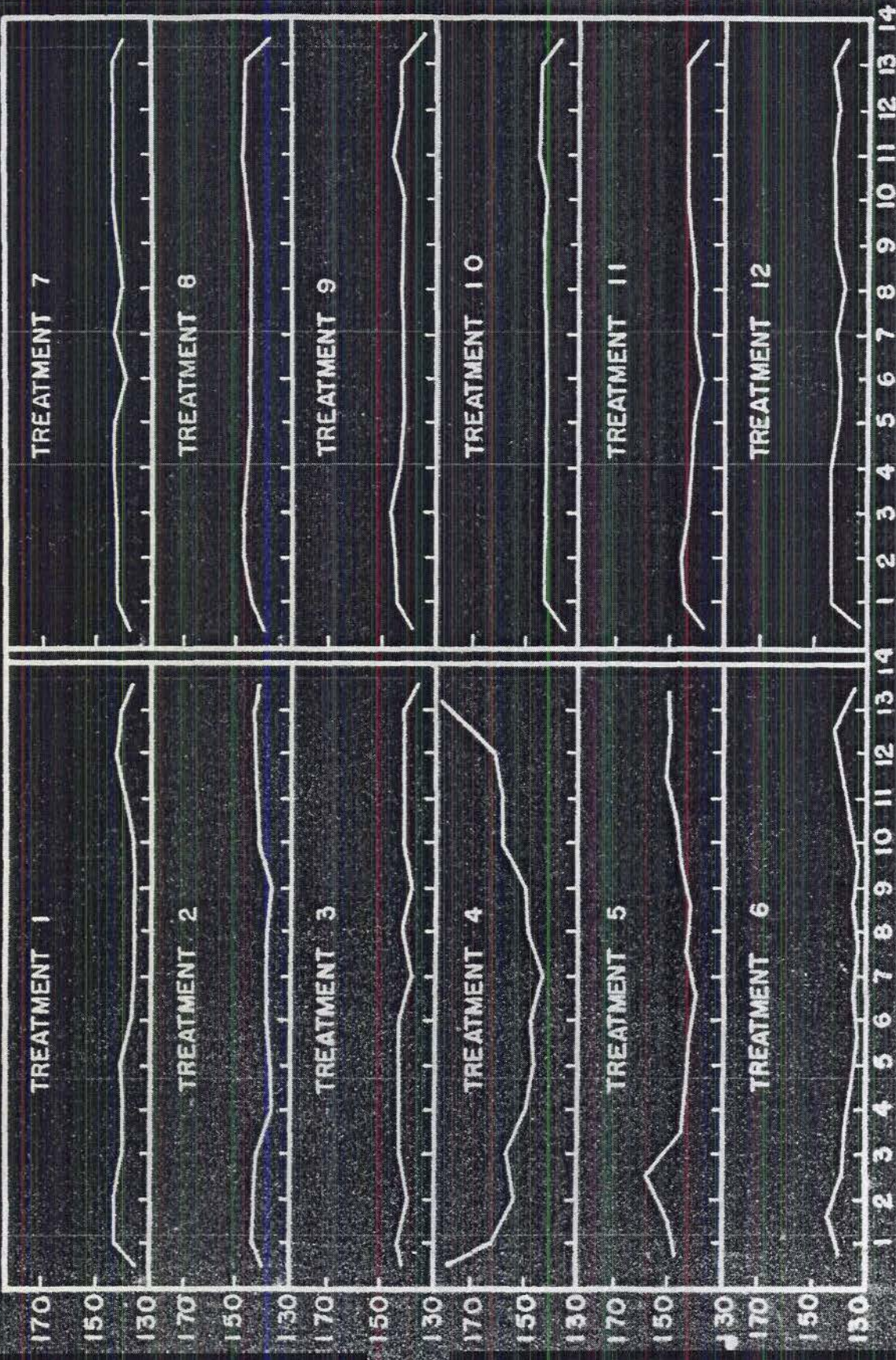
KEY:

- T = TENSILE BLANK
- I = IZOD BLANK
- C = CHARPY BLANK
- B = COLD BEND BLANK



COUPON A

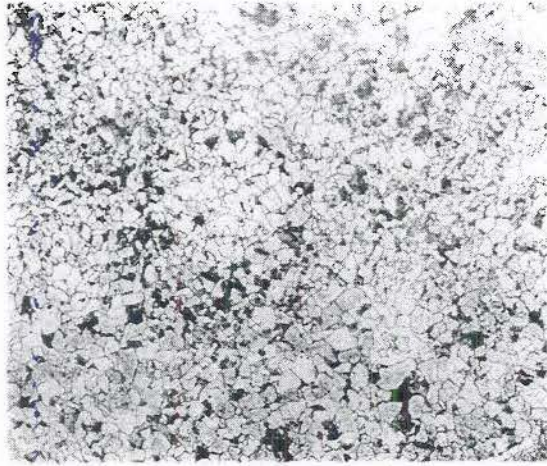




BRINELL HARDNESS ACROSS DIAGONAL OF 10X10X20 INCH CASTING FOR ALL HEAT TREATMENTS

NH 9

PLATE 6



1A CENTER 100X

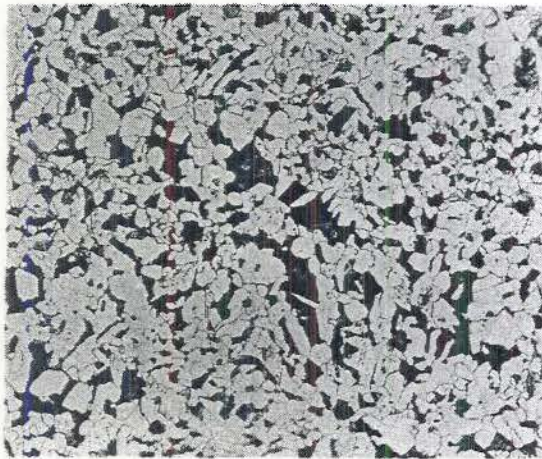


1D CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING OF #1 MIDWAY BETWEEN TOP & BOTTOM
AUSTENIZED 1800°F., 6 HOURS, NORMALIZED 1650°F., 3 HOURS
TEMPERED 1300°F., 3 HOURS

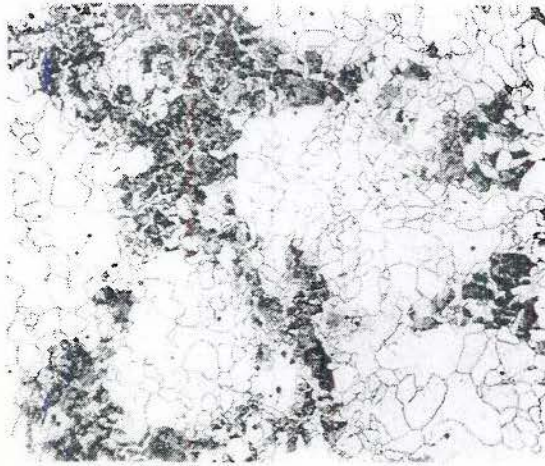


2A CENTER 100X



2D CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #2 MIDWAY BETWEEN TOP & BOTTOM
NORMALIZED 1700°F., 4 1/2 HOURS, TEMPERED 1300°F., 3 HOURS

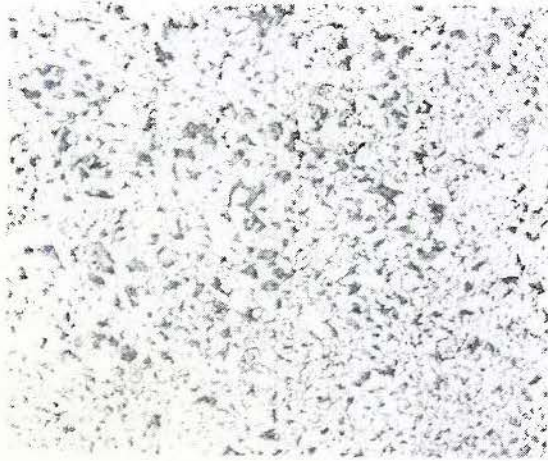


3A CENTER 100X

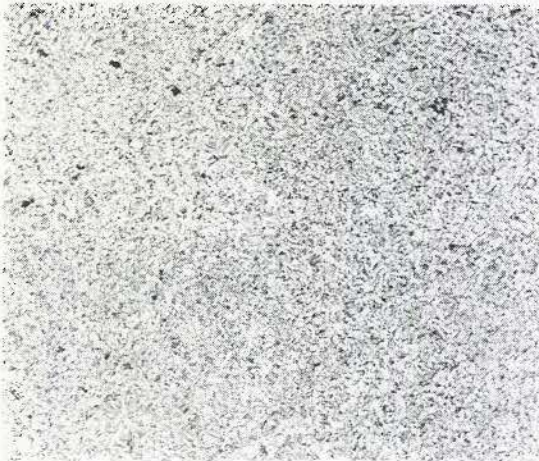


3D CENTER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #3 MIDWAY BETWEEN TOP & BOTTOM
ANNEALED 1600°F., 25 HOURS. (CONTROL TREATMENT, SAME
AS NO.6 AND NO.12.)

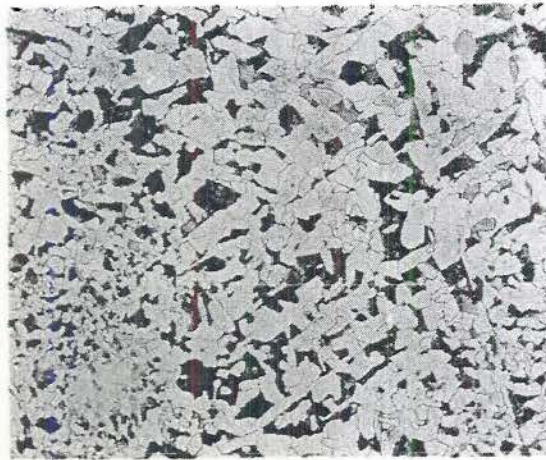


15T4 CENTER 100X



15T2 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #4 MIDWAY BETWEEN TOP & BOTTOM
AUSTENIZED 1800°F., 5 HOURS, WATER QUENCHED FROM 1650°F
2 HOURS, TEMPERED 1230°F., 4 HOURS



16T4 CENTER 100X

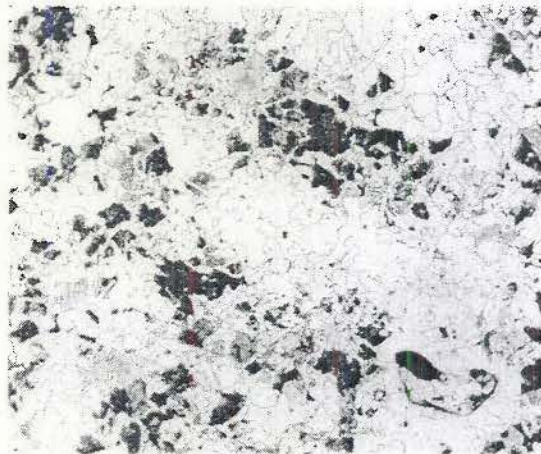


16T2 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #5 MIDWAY BETWEEN TOP & BOTTOM
NORMALIZED 1800°F., 5 HOURS, TEMPERED 1230°F., 4 HOURS



17T4 CENTER 100X



17T2 CENTER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #6 MIDWAY BETWEEN TOP & BOTTOM
ANNEALED 1600°F., 25 HOURS (CONTROL TREATMENT, SAME AS
NO. 3 AND NO. 12

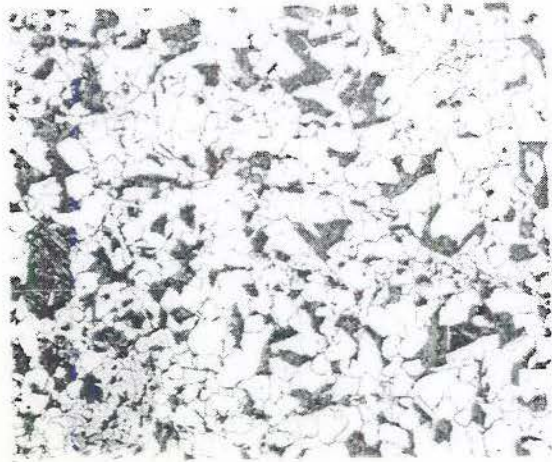


31T5 CENTER 100X

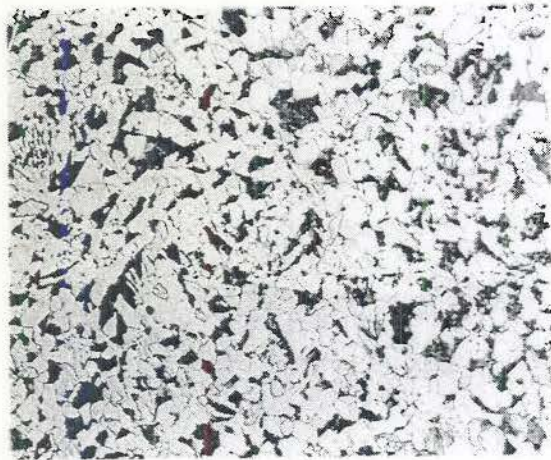


31T1 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #7 MIDWAY BETWEEN TOP & BOTTOM
NORMALIZED 1650°F., 10 HOURS, TEMPERED 1250°F., 10 HOURS.



41 T6 CENTER 100X

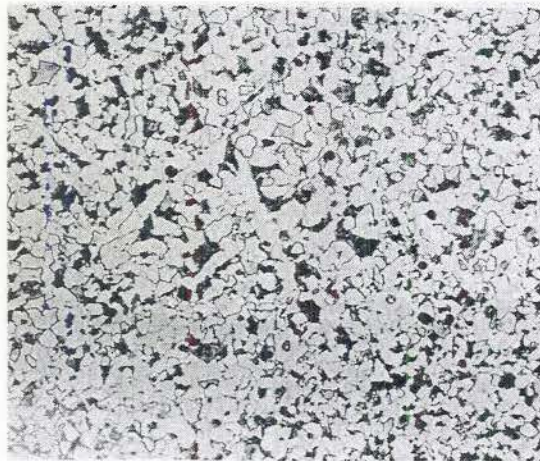


41T1 CORNER 100

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #8 MIDWAY BETWEEN TOP & BOTTOM
NORMALIZED 1650°F., 2 1/2 HOURS, TEMPERED 1250°F., 10 HOURS



51T6 CENTER 100X



51T1 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #9 MIDWAY BETWEEN TOP & BOTTOM
AUSTENIZED 1800°F., 10 HOURS, NORMALIZED 1650 °F.
10 HOURS, TEMPERED 1250 °F., 10 HOURS

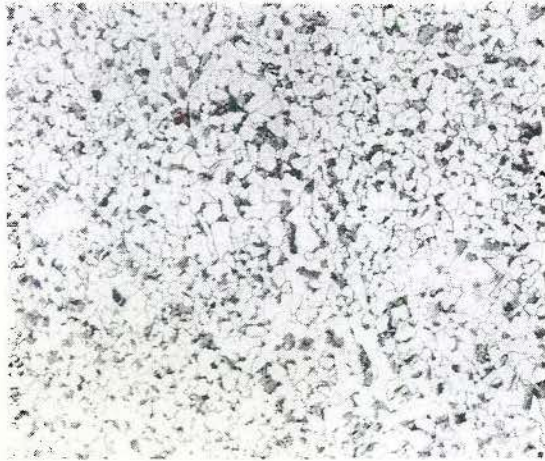


61T6 CENTER 100X

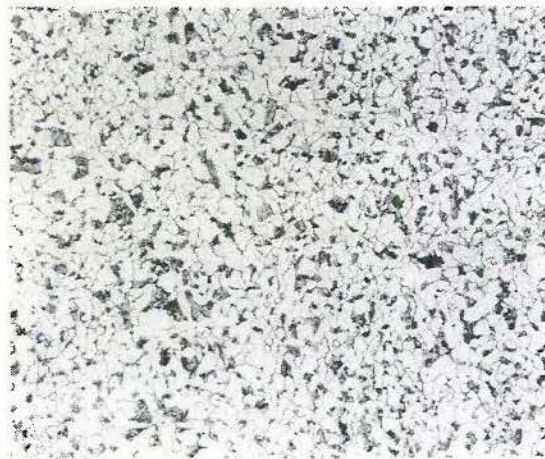


61T1 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10X 20 INCH CASTING #10 MIDWAY BETWEEN TOP & BOTTOM
AUSTENITIZED 2000°F., 10 HOURS, NORMALIZED 1650°F.,
10 HOURS, TEMPERED 1250°F., 10 HOURS

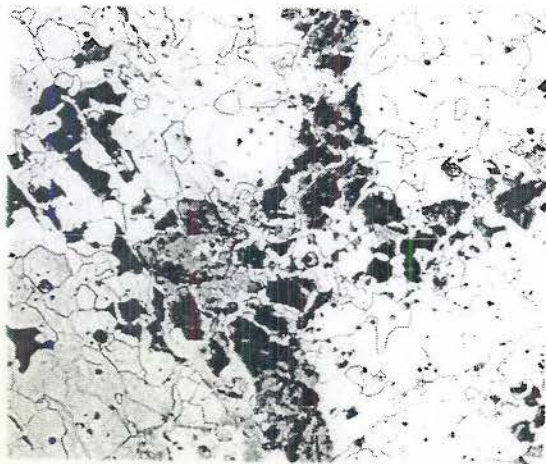


71T6 CENTER 100X



71T1 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #11 MIDWAY BETWEEN TOP & BOTTOM
NORMALIZED 1650°F., 10 HOURS, NORMALIZED 1650°F.,
10 HOURS TEMPERED 1250°F., 10 HOURS.

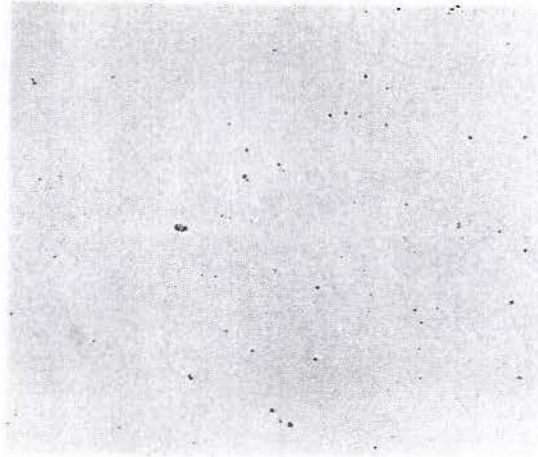


81T6 CENTER 100X

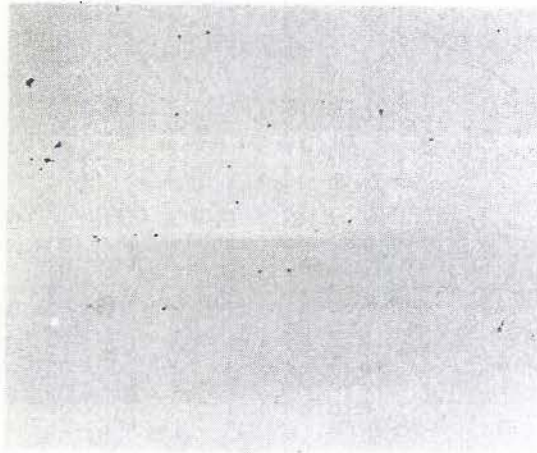


81T1 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #12 MIDWAY BETWEEN TOP & BOTTOM
ANNEALED 1600°F., 25 HOURS. (CONTROL TREATMENT, SAME AS
NO. 3 AND NO. 6)

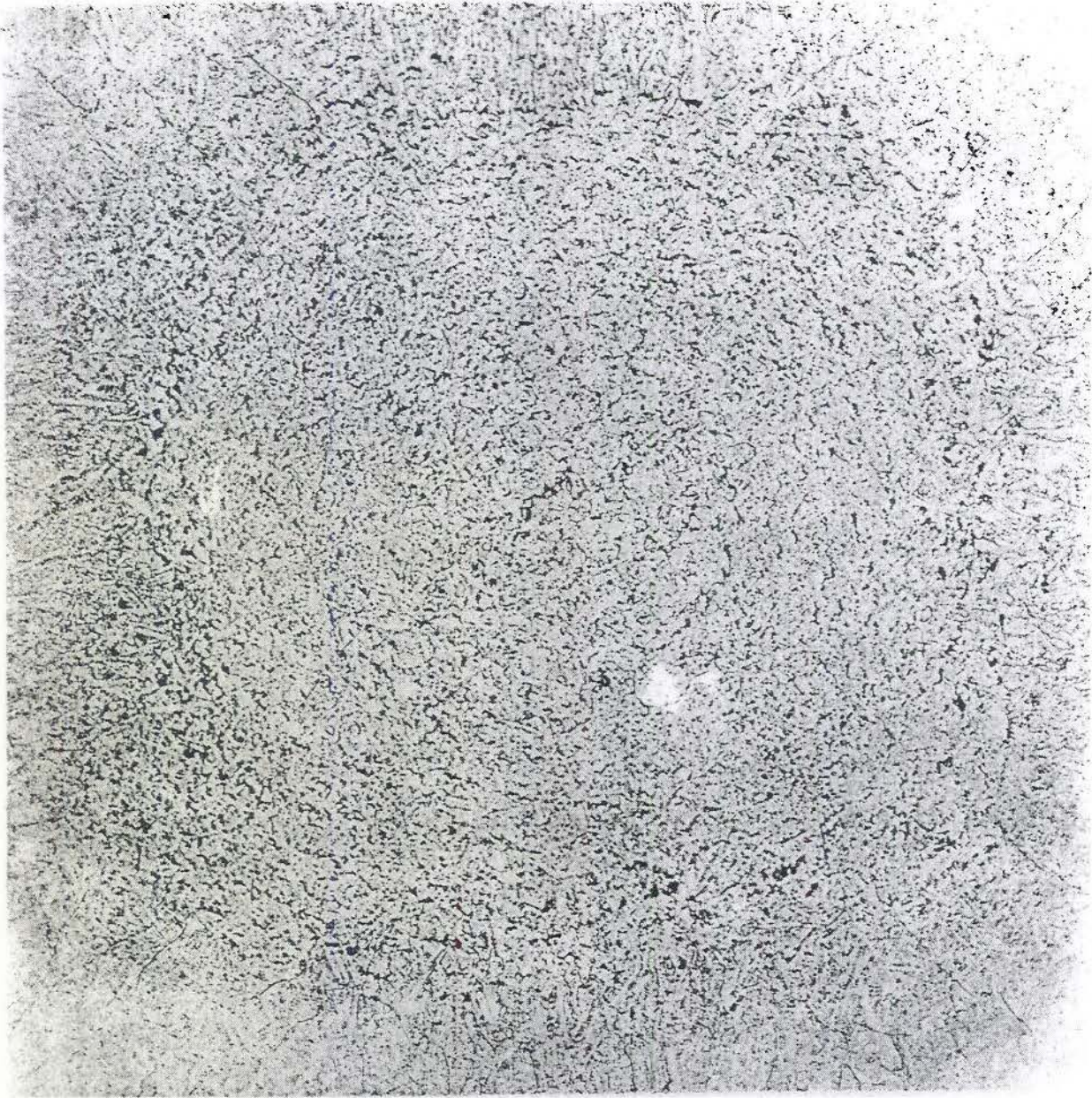


15T4 CENTER 100X



15T2 CORNER 100X

PHOTOMICROGRAPHS TAKEN FROM A SECTION OF THE
10 X 10 X 20 INCH CASTING #4 MIDWAY BETWEEN TOP & BOTTOM
UNETCHED TO SHOW REPRESENTATIVE OCCURENCE
AND DISTRIBUTION OF NON-METALLICS.



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