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HIGH-STRENGTH CAST STEEL FOR NAVY ANCHORS

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ABSTRACT

Exploitation of recent improvements in anchor design requires a cast steel which will have a yield strength in heavy sections of 80,000 psi without the use of liquid quenching or potentially scarce alloying additions.

Thirteen small preliminary heats were made to analyses which, on the basis of data available in the literature, indicated promise of meeting these requirements. Small specimens of these steels were tested after a heat treatment which simulated "a normalize and draw" of a 15-inch section. From these test results it was concluded that a manganese-molybdenum steel was the most practicable. Consequently, two 12x12x24 inch ingots of manganese-molybdenum steel were normalized and drawn, and mechanical properties of the surface and of the center were determined. Results indicated that the subject requirements could be realized in sections up to at least 12x12 inches.

PROBLEM STATUS

This report concludes the work on this problem, and unless otherwise advised by the Bureau the Laboratory will consider the problem closed one month from the mailing date of this report.

AUTHORIZATION

NRL Problem M01-21R

HIGH-STRENGTH CAST STEEL FOR NAVY ANCHORS

INTRODUCTION

The object of this work was to determine a steel analysis and heat treatment for Navy anchors which would give a yield strength of 80,000 psi minimum, without the use of potentially scarce materials or liquid quenching, and would have ductility as close as possible to 24 percent elongation and 35 percent R.A. in a tensile test and 120° bend in a slow bend test.

Prior to the last war, Navy cast-steel anchors were made in accordance with Navy Department Specification 49S1 Class B. The steel, which had a specified minimum yield strength of 30,000 psi, was entirely satisfactory for the then-current anchor designs.

During the last war, the need for anchors of higher holding power for a given anchor weight led to the development of the BuShips Light Weight Type (LWT) anchors. These LWT anchors were produced in accordance with BuShips specifications which required a cast steel of 40,000 psi minimum yield strength, one-third greater than the previously used 49S1 Class B material. The LWT anchors made of this higher-strength material have proved to be satisfactory.

In order to achieve still greater anchor efficiencies, BuShips now desires anchors of cast steel with a yield strength of at least 80,000 psi. Certain considerations of practicability preclude or impose restrictions upon some of the alloying elements and on heat-treatments which might be selected. These considerations are:

(a) Liquid quenching is undesirable for large anchors. Because of the large size of some anchors (up to 15 inches square) and the lack of adequate quenching facilities in most foundries, a composition which would necessitate quenching in order to meet mechanical property requirements could seriously interfere with procurement.

(b) Use of certain alloying elements should be avoided. Conservation measures will almost certainly be imposed during future emergencies. For this reason, the use of potentially scarce elements such as nickel, or chromium, should be avoided or minimized.

(c) Deviation from standard foundry practice should be minimum. In time of emergency, many foundries of variable experience, equipment, and skills are possible sources of anchors. For this reason, it is desirable to avoid, as far as is possible, any practices which might be difficult or unusual for the average foundry and which could, therefore, eliminate them as sources or reduce their production efficiency.

With liquid quenching eliminated as a practicable treatment for large anchors, the question of the relative merits of annealing and of normalizing becomes pertinent. With respect to economy, normalizing is preferred. With respect to mechanical properties, Taylor et al.,[1] working with anchor steel (49S1 Class B) in heavy sections (10 x 10 inches), showed a single normalize and draw to be better than an anneal and draw. Hawkes and Brown[2] confirmed this conclusion and pointed out that, in general, mechanical properties of cast steels improve with increases in the cooling rate.

Assuming a normalize and draw treatment to be the most practicable, the estimation of analyses which will meet the 80,000-psi yield strength requirement is made possible by relationships established by Gorsuch and Newhouse[3] between chemical analysis and the mechanical properties of steels after slow cooling rates.

TEST PROCEDURE

On the basis of data available and the restrictions mentioned above, compositions for thirteen preliminary heats were selected as shown by Table 1.[4] These steels were melted in a 100-pound high-frequency induction furnace. Raw materials consisted of Armco iron and commercial materials for alloy additions. Final deoxidation was made with aluminum in the proportion of 1½ pounds per ton of steel. The steels were poured into clover-leaf dry-sand coupon molds.

Coupons measuring approximately 1x1x6 inches were saw-cut from the castings and normalized at 1700°F. They were next treated in accordance with one of the following heat treatment cycles:

Treatment A (1) 1550° F for ½ hr.
(2) Air cool
(3) 930° F for 4 hrs.
(4) Air cool

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[1] Clark, K.L., "Summary Report on the Heat Treatment of Stockless Anchors," NRL Report No. M-2123, July 1943, Unclassified.

[2] Hawkes and Brown, "The Microstructure and Mechanical Properties of Cast Steels," Preprint No. 17, ASM 1948.

[3] Gorsuch, P.D. and Newhouse, D.L., "Calculation of Tensile Strength and Yield Point of Normalized and Annealed Steels from Chemical Composition," NRL Report M-2641, September 15, 1945, Unclassified.

[4] All tables are grouped at the end of this report.

Treatment B (1) 1550° F for ½ hr.
(2) Air cool
(3) 700° F for 1 hr.
(4) Air cool

Treatment C (1) 1550° F for ½ hr.
(2) Water quench
(3) 1000° F for 1 hr.
(4) Air cool

Treatment D (1) 1600° F 1 hr.
(2) Cool to 400° F at 200° F per hr.
(3) 930° F for 4 hrs.
(4) Cool at 200° F per hr.

Treatment E (1) 1600° F for 1 hr.
(2) Cool to 400° F at 200° F per hr.
(3) 700° F for 1 hr.
(4) Cool at 200° F per hr.

Treatments A and D given to the copper-bearing steels included aging at 930°F, a temperature for maximum age-hardening effect. The tempering temperature of 1000°F in treatment C was selected to give a good combination of strength and ductility. The tempering temperature of 700°F in treatments B and E was selected to give a sufficiently high yield strength to meet the specified properties. The cooling rate of 200°F per hr., used in treatments D and E, was selected to correspond with the cooling rate of the center of a 15-inch section. The retarded cooling cycles were conducted in a small furnace with a control device for adjusting the cooling rate.

Standard tensile test specimens 0.505 inch in diameter, and V-notch Charpy specimens were made and tested. Duplicate tests were made in all cases except for double-normalizing heat treatments.

On the basis of test results of the 13 preliminary steels, two large heats of composition shown in Table 5 were made in a 2000-pound high-frequency induction furnace and cast into 12x12x24 inch ingots, hereinafter referred to as ingots No. 1 and No. 2. Raw materials used were Armco iron and commercial alloy additions. The final deoxidation was made with aluminum in the proportion of 2 lb. per ton of steel in order to minimize the presence of grain boundary inclusions as shown by Sims and Dahle.[5] The steel was top-poured into green sand molds with large refractory hot tops to insure adequate feeding.

The bottom 5 inches was saw-cut from ingot No. 1, and 1x1x5 inch coupons were saw-cut from the surface and center of the resulting 12x12x5 inch block, with the 5-inch dimension of the coupons parallel with the 5-inch dimension of the block. These coupons were used to determine the relative merits of single and double normalizing; consequently, half of the coupons were treated in accordance with the first group of cycles listed below, and

[5] Sims, C. E., and Dahle, F. B., Trans. AFA, 46, 65-104, 1938.

half with the second.

Single Normalize:
- 1700° F for 1 hr.
- Cool to 400° F at 300° F per hr.
- 1000° F for 1 hr.
- Cool to 400° F at 300° F per hr.

Double Normalize:
- 1800° F for 1 hr.
- Cool to 400° F at 300° F per hr.
- 1650° F for 1 hr.
- Cool to 400° F at 300° F per hr.
- 1000° F for 1 hr.
- Cool to 400° F at 300° F per hr.

Standard tensile and V-notch Charpy specimens were made from these coupons and tested. On the basis of these tests, it was decided to single-normalize and draw the remainder of ingot No. 1 and ingot No. 2.

Normalizing was accomplished by slowly heating the ingots in a gas-fired car-bottom furnace to 1700° F, holding at temperature for 4 hours and then pulling the car to allow the ingots to cool in still air. The ingots were elevated above the furnace car floor by placing them on refractory bricks, thus allowing free circulation of air around the bottom of the ingots and preventing contact between the ingots and the hot slow-cooling refractories of the car floor. After normalizing, coupons were saw-cut from surface and center of the ingots and were drawn at 1000° F for 1 hr. Cooling from 1000° F was controlled at 300° F per hr. which is approximately the cooling rate at the center of a 12-inch section.

Standard tensile, V-notch Charpy, slow bend, and density tests were made representing surface and center of the ingots.

RESULTS

The chemical compositions of the 13 preliminary heats are shown in Table 1. Mechanical properties of these steels, after treatment in accordance with the cycles outlined above, are shown in Tables 2, 3, and 4. (Notice both A and B treatments are listed in Table 2 as are both D and E treatments in Table 4. This was done because Steels 1 and 2 are the copper age-hardening steels which require the special A and D heat treatments.)

Ladle analyses and ingot analyses of ingots No. 1 and No. 2 are shown in Tables 5 and 6. The latter indicates the amount of segregation in the ingots since it includes compositions of the surfaces and centers of the ingots. Mechanical properties of ingots No. 1 and No. 2 are shown in Tables 7, 8, 9, and 11.

Results of the preliminary tests of ingot No. 1, which were intended to compare single and double normalizing, are shown in Table 10.

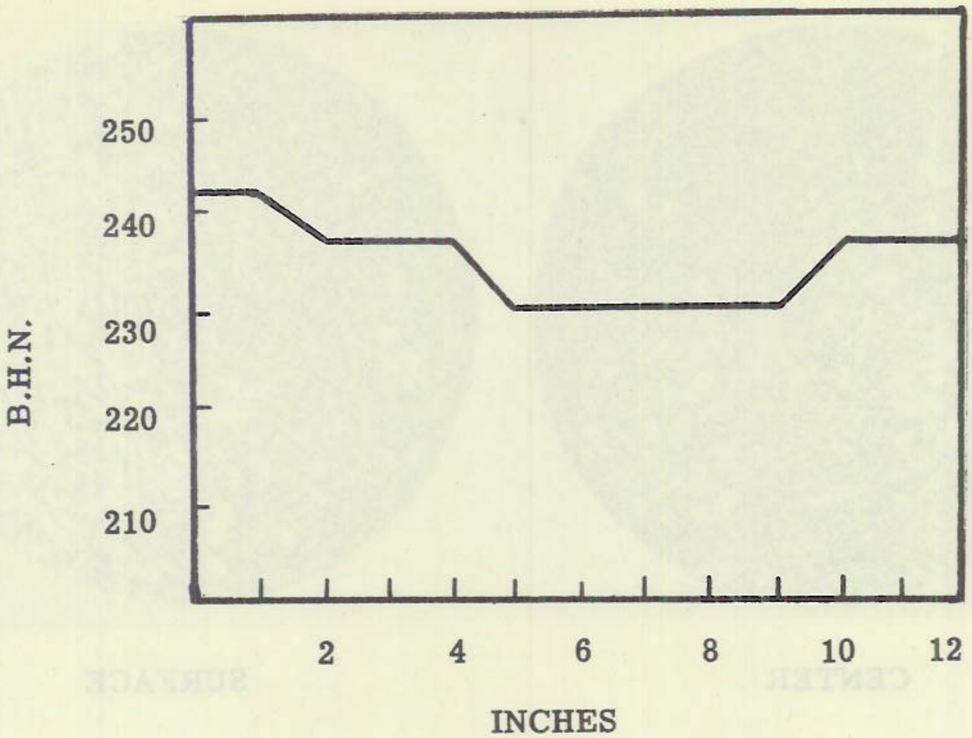


Figure 1-Brinell hardness across section of ingot No. 1

A Brinell hardness survey across a transverse section four inches from the midpoint of ingot No. 1 is shown in Figure 1.

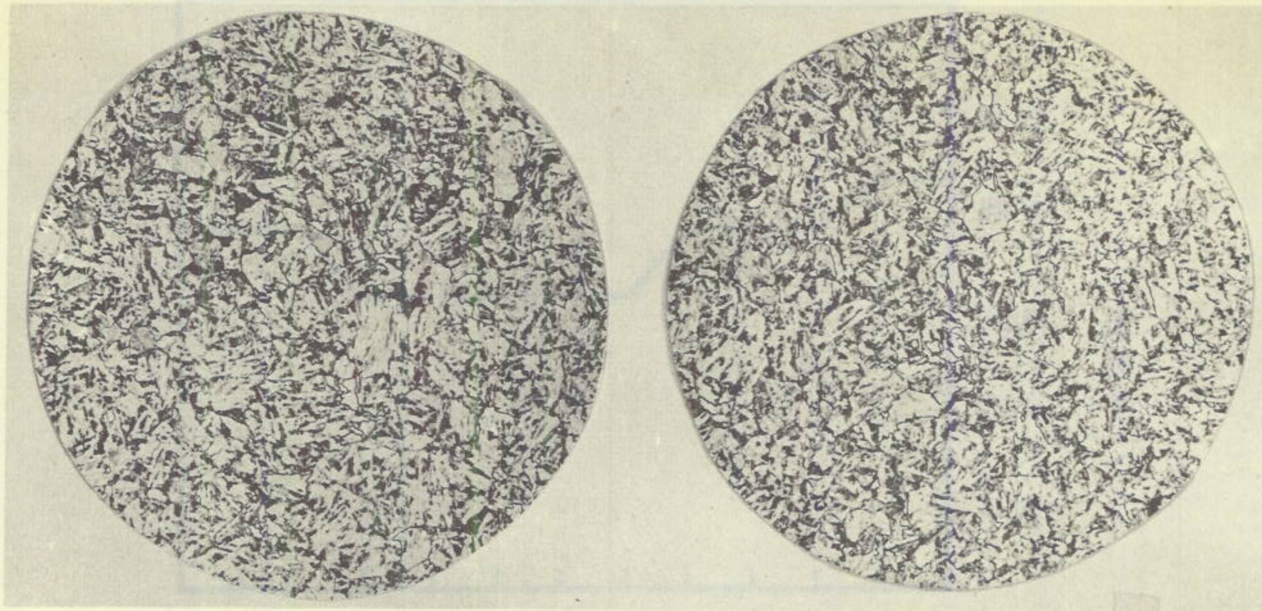
Microstructures of specimens at the surface and center of ingots No. 1 and No. 2 after normalizing and drawing are shown in Figure 2.

DISCUSSION

Inspection of Table 1 will show that the thirteen preliminary steels can be divided into three broad classifications. (1) Heats 1 and 2 are copper-bearing age-hardening steels which have shown promise for high-strength heavy-section steel castings.[6,7] For anchor castings, this type of steel would have an advantage in its relative insensitivity to cooling rates, the excess copper being retained in solution at slow rates and precipitated in the subsequent isothermal aging. (2) Heats 3 to 8 inclusive are manganese-molybdenum steels with some variations made by additions of boron, copper, and vanadium. The manganese-molybdenum combination is attractive because it provides economical strengthening; the alloying elements are in adequate domestic supply as compared with most other alloying elements; and

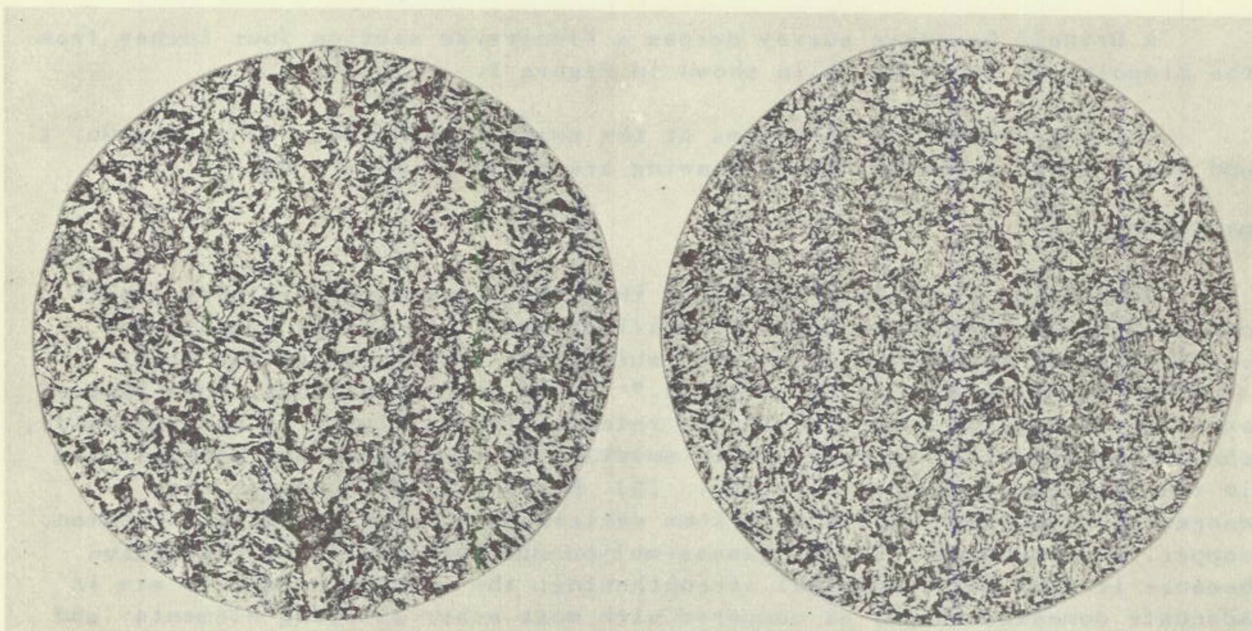
[6] Taylor, H.F., Bishop, H.F. and Wayne, R.C., Trans AFA, 54, 213-224, 1946.

[7] Greenidge, C.T., Udy, M.C. and Grube, K., "The Effect of Copper in Some NE and Low Alloy Cast Steels," Trans AFA, 52, 501, 1944.



CENTER SURFACE

No. 1



CENTER SURFACE

No. 2

Figure 2- Microstructure of ingots. Nital etch 150x.

many foundries are experienced in the melting of this steel. Boron unquestionably offers the cheapest strengthening effect, and a shortage of boron for steel additions is inconceivable. However, the use of boron is not general because of the lack of consistent effectiveness of boron in increasing strength. Copper and vanadium were considered to be sufficiently promising to warrant inclusion in these preliminary tests. (3) Heats 9 to 13 inclusive are of the multiple-alloy type developed during the last war for economy of alloys. Copper and boron were added to some of these heats for additional hardenability. Although chromium and nickel are obtained chiefly from foreign sources and are therefore potentially scarce, the small amounts used simulate the residuals in scrap and take full advantage of the large increases in hardenability made by small additions of several alloying elements.

Tables 2, 3 and 4 show mechanical properties of the thirteen preliminary heats after the heat treatments A,B,C,D, and E, outlined above. While the quenched and tempered properties represented by Table 3 are at variance with the original premise that liquid quenching is undesirable, these data were obtained to determine the alloy economy and superior mechanical properties, especially notch toughness, which could be realized by quenching and tempering of small anchors with maximum sections of 1 to 2 inches.

Table 4 is the most applicable to the subject problem for it represents properties after cooling rates typical of a large anchor. The effects of the various alloy combinations at these cooling rates are summarized as follows:

(a) The copper age-hardening steels (heats 1 and 2) had too low a yield point to indicate promise.

(b) The use of chromium, nickel, vanadium, or copper did not appear to be necessary or markedly advantageous.

(c) The effect of boron on strength at slow cooling rates was highly dependent upon the hardenability of the steel to which it was added. (Cf. heats 12 vs 13; 3 vs 5; 7 vs 8.)

(d) Manganese-molybdenum steel of about 0.30% carbon met the strength requirements but had reductions of area and elongations inferior to those required by existing anchor specifications (49S1). However, this composition was the most promising and was selected as the basis for making two large ingots, each 12x12x24 inches.

Inspection of Table 7 shows that the yield strength of large ingot No. 1 is somewhat lower, and that of large ingot No. 2 somewhat higher, than the 80,000 psi requested by BuShips. It is considered that this is largely due to the effect of carbon; although the analyses of the two ingots were selected for a 0.30%-carbon level, ingots No. 1 and No. 2 were approximately four points low and high respectively in carbon.

Inspection of Tables 7 and 8 shows that both ingots No. 1 and No. 2 fail to meet one or more of ductility requirements of the current specification. It should be considered, however, that the specification requirements apply to relatively small cast test coupons which do not necessarily reflect properties in large sections. In this connection, reference (1) reports the properties of specimens cut from 10x10x20 inch cast-steel ingots made to the current anchor specifications. The elongations and reductions of area of those lower strength steels do not differ significantly from the test results of Tables 7 and 8.

CONCLUSIONS

A yield strength of 80,000 psi minimum in anchors with sections up to at least 12x12 inches can be realized without the use of potentially scarce materials or liquid quenching. A manganese-molybdenum steel, single-normalized and drawn, is a practicable combination of composition and heat treatment.

RECOMMENDATIONS

It is recommended that several large LWT anchors be made to the following analysis:

C	0.28 - 0.32%
Mn	1.60 - 1.80%
Si	0.30 - 0.50%
Mo	0.40 - 0.50%
P	0.04 max.
S	0.04 max.

It would also be desirable to cast test coupons from each of these anchor heats in sections as large as the largest section of the anchor. After normalizing at 1600-1700° F and drawing at 950-1050° F, the coupons should be used for determination of mechanical properties of surface and center. The anchors should be subjected to conventional proof and service tests.

* * *

TABLE 1

Chemical Analyses of Preliminary Heats+ (%)

Heat No.	C	Mn	Si	Mo	Cu	Cr	Ni	V	B
1	0.15	0.61	0.64	-	1.68	-	-	-	-
2	0.17	1.11	1.43	-	1.83	-	-	-	-
3	0.28	1.48	0.22	0.33	-	-	-	-	-
4	0.28	1.22	0.20	0.36	-	-	-	0.14	-
5	0.29	1.22	0.39	0.33	-	-	-	-	*
6	0.29	1.58	0.37	0.31	1.05	-	-	-	*
7	0.29	2.32	0.46	0.31	-	-	-	-	-
8	0.30	2.30	0.46	0.29	-	-	-	-	*
9	0.32	0.63	0.25	0.25	-	0.43	0.52	-	-
10	0.32	0.58	0.24	0.25	-	0.45	0.52	-	*
11	0.29	0.65	0.23	0.30	1.21	0.43	0.50	-	*
12	0.31	1.23	0.71	0.25	-	0.67	0.50	-	-
13	0.31	1.21	0.71	0.25	1.32	0.58	0.48	-	*

+ Sulphur and phosphorus are approximately 0.02 and 0.01% respectively in all heats.

* 0.003% boron added.

TABLE 2

Mechanical Properties of Preliminary Heats after Heat Treatments A or B
(Normalized in 1-inch Sections, and Drawn)

Heat No.	Treatment	Tensile Strength (psi)	0.2% Yield Strength (psi)	% Elong.	% RA	V-Notch Charpy (ft lb)			
						95°C	30°C	0°C	-45°C
1	A	107000	86250*	23.5	55.6	-	32.0	21.0	10.0
2	A	111500	87500*	24.2	46.8	53.0	17.0	15.5	-
3	B	128500	115000	12.8	45.8	-	22.0	11.0	10.5
4	B	143250	136250	12.8	41.3	-	22.0	-	12.5
5	B	139000	122500	14.0	41.4	-	16.5	5.5	5.0
6	B	152000	135700	9.4	19.7	-	14.5	5.0	4.5
7	B	176500	151500	10.9	30.8	15.0	11.0	8.0	-
8	B	194500	161000	9.8	27.5	18.0	14.0	12.5	-
9	B	106500	84500	20.0	42.5	-	29.5	23.5	11.0
10	B	114500	107000	15.6	42.0	-	25.0	13.0	10.0
11	B	121750	110000	-	-		-	-	-
12	B	150000	111700	13.3	32.2	18.0	8.5	8.0	-
13	B	167000	139750	11.3	23.3	16.0	12.5	8.0	-

*Yield point

TABLE 3

Mechanical Properties of Preliminary Heats after Heat Treatment C
(Water Quenched in 1-inch Sections and Drawn)

Heat	Tensile Strength (psi)	0.2% Yield Strength (psi)	% Elong.	% RA	V-Notch Charpy (ft lb)		
					30°C	0°C	-45°C
1	121500	105000	21.0	50.8	55.0	31.5	16.0
2	118000	97000	18.8	42.4	26.5	15.0	-
3	159500	147000	14.7	41.5	39.0	32.5	29.0
4	169000	160000	14.0	33.8	30.0	26.0	21.0
5	157000	150000	14.0	40.4	46.0	47.0	32.0
6	160000	150000	15.6	36.6	38.0	35.0	22.0
7	--	--	-	-	28.5	26.0	-
8	148500	--	13.3	34.7	31.0	31.0	-
9	144000	131000	15.6	47.2	60.0	51.0	27.0
10	152000	141000	15.6	42.8	55.0	43.5	42.5
11	--	--	-	-	-	-	-
12	160000	144000	12.5	32.4	25.0	22.5	-
13	164500	--	13.3	29.2	20.5	17.0	

TABLE 4

Mechanical Properties of Preliminary Heats
After Heat Treatments D or E*

Heat	Treat-ment	Tensile Strength (psi)	0.2% Yield Strength (psi)	% Elong.	% RA	V-Notch Charpy (ft lb) 30°C	0°C	-45°C
1	D	85000	63750**	29.7	58.6	65.0	32.0	20.2
2	D	89500	64400**	30.5	47.0	35.0	25.0	-
3	E	104500	87500	17.2	34.7	26.5	17.0	10.0
4	E	113000	98750	12.5	36.0	21.0	13.5	12.0
5	E	127000	107000	15.6	48.0	17.0	9.0	8.5
6	E	138500	121250	10.8	30.7	19.0	9.0	3.5
7	E	148000	124000	16.4	34.2	10.5	10.5	-
8	E	148000	129000	15.6	33.0	11.5	8.5	-
9	E	84000	43700	26.5	39.8	35.0	15.0	8.0
10	E	103000	78750	20.4	41.9	22.5	5.0	5.0
11	E	110000	102000	14.0	33.1	-	-	-
12	E	114000	77200	20.3	26.1	21.0	12.5	-
13	E	145000	119000	19.5	28.1	12.0	5.0	-

* Cooling rates were equivalent to cooling rate of the center of a normalized 15x15-inch section.

** Yield Point.

TABLE 5

Chemical Analyses of Ingots No. 1 and No. 2 in %

	Ladle Analysis				
Ingot No.	C	Mn	Si	Mo	B
1	0.26	1.65	0.19	0.30	*
2	0.35	1.55	0.19	0.47	-

* 0.003 Boron added.

TABLE 6

Ingot Analyses* of Ingots No. 1 and No. 2 in %

Ingot No.	C	Mn	Si	P	S	Mo	Al (Acid Sol.)	Cu
1 - Surface	0.27	1.69	0.18	.007	.021	0.25	.075	.05
1 - Center	0.22	1.61	0.19	.006	.020	0.26	.071	.05
2 - Surface	0.34	1.58	0.17	.006	.022	0.45	.053	.05
2 - Center	0.32	1.55	0.18	.008	.020	0.40	.055	.05

* Trace or less of Cr, Ni, V

TABLE 7

Tensile Properties of Ingots No. 1 and No. 2 Single-Normalized and Drawn at 1000°F

Ingot No.	Location	Tensile Strength (psi)	0.2% Yield Strength (psi)	% Elong.	% RA
1	Surface	101500	77000	17.9	48.4
1	Center	96000	74000	19.3	41.8
2	Surface	113750	88750	17.5	40.6
2	Center	109250	84500	14.6	15.6

TABLE 8

Slow Bend Tests of Ingots No. 1 and No. 2
Single-Normalized and Drawn at 1000°F

Ingot No.	Location	Max. Load Lbs.	Angle at Failure
1	Surface	10900	>160°
1	Surface	11900	>160°
1	Center	10600	99°
1	Center	10600	>160°
2	Surface	11250	62°
2	Surface	11300	58°
2	Center	10100	30°
2	Center	10600	47°

TABLE 9

V-Notch Charpy Tests of Ingots No. 1 and No. 2
Single-Normalized and Drawn at 1000°F (ft lb)

Ingot No.	Location	Temp. of Test 100°C	20°C	0°C	-25°C
1	Surface	52.5	26.0	9.0	8.5
1	Center	56.0	25.0	20.5	7.5
2	Surface	30.5	9.0	-	-
2	Center	30.5	12.5	-	-

TABLE 10

Preliminary Tests of Specimens from Ingot No. 1
Heat Treated in 1x1x5-inch Coupons at Cooling Rates
Corresponding With Those at the Center of a 12-inch Section

Location	Normalize	^oF Draw	Tensile Strength (psi)	0.2% Yield Strength (psi)	% Elong.	% RA
Surface	Double	600	133600	-	15.5	40.0
"	"	800	109500	90000	17.5	43.1
"	"	1000	107000	88000	19.5	41.0
"	"	1200	92500	73000	22.5	49.3
"	Single	600	108500	76500	17.5	42.6
"	"	800	108000	87800	16.0	40.8
"	"	1000	101000	-	20.0	44.0
"	"	1200	92000	70000	22.0	48.4
Center	Double	800	106500	85400	13.0	34.3
"	"	1000	101000	84400	15.5	28.6
"	Single	800	104000	82400	14.5	32.5
"	"	1000	96400	79000	9.5	17.1

TABLE 11

Specific Gravity of Ingots No. 1 and No. 2

Ingot	Position	S.G.
1	Surface	7.850
1	Center	7.860
2	Surface	7.859
2	Center	7.837