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THE DEVELOPMENT OF AN IMPROVED STEEL FOR THE PRODUCTION OF PROPULSION SHAFTING FOR NAVAL VESSELS

PART I: AN EXAMINATION OF STEEL CURRENTLY IN USE

PART II: MODIFICATIONS OF THIS STEEL

R. D. McDONALD & W. A. MORGAN
PHYSICAL METALLURGY DIVISION

OCTOBER 1960

Mines Branch Research Report R 72

THE DEVELOPMENT OF AN IMPROVED STEEL FOR THE PRODUCTION OF PROPULSION SHAFTING FOR NAVAL VESSELS

by

R. D. McDonald* and W. A. Morgan**

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ABSTRACT

This report covers an investigation of properties obtainable in material currently in use for the production of propulsion shafting for naval vessels, and of the possible improvements attainable by increased manganese/carbon ratios and with low alloy additions.

The initial purpose of the program was the improvement of impact properties without sacrificing other mechanical properties attainable in the currently used material. The results indicate that a very considerable improvement is obtainable, with accompanying improvements in tensile and fatigue strength and without any appreciable increase in fatigue notch sensitivity when subjected to rotational bending fatigue stresses.

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* Senior Scientific Officer and ** Head, Ferrous Metals Section, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

Rapport de recherches R 72

Direction des mines

ÉLABORATION D'UN ACIER AMÉLIORÉ DESTINÉ À LA FABRICATION D'ARBRES DE PROPULSION POUR LES NAVIRES DE GUERRE

par

R. D. McDonald* et W. A. Morgan**

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RÉSUMÉ

Le présent rapport traite d'une investigation des propriétés qu'on peut conférer à l'acier d'usage courant dans la fabrication d'arbres de propulsion pour navires de guerre. Il étudie aussi la possibilité d'améliorer les aciers en augmentant les rapports manganèse/carbone et en y ajoutant d'autres éléments en petites quantités.

Ces expériences visaient tout d'abord à améliorer la résistance au choc sans nuire aux autres propriétés mécaniques qu'il est possible de conférer à l'acier d'usage courant. Les résultats indiquent qu'on peut grandement améliorer l'acier et augmenter son endurance à la traction et à la fatigue, sans accroître, pour autant, sa sensibilité à l'effet d'entaille lorsque le métal est soumis à des efforts de fatigue par flexion rotatoire.

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*Agent scientifique senior et ** chef de la Section des métaux ferreux, Division de la métallurgie physique, Direction des mines, ministère des Mines et des Relevés techniques, Ottawa, Canada.

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GENERAL INTRODUCTION

Under operating conditions in Canada's Northland, the propulsion shafting of ships is subject to increasingly severe conditions of low temperatures. For maximum final efficiency, it is also desirable that the tensile properties of shafting steels be improved so that higher design stresses can be utilized without a corresponding weight increase.

Modifications of the manganese/carbon ratios of these steels, and a study of the effects of low alloy additions, showed that their low temperature impact properties could be improved without sacrificing other mechanical properties. The results also show that improved properties in the new steels can be attained without increase in fatigue notch sensitivity factors.

This research was initiated at the request of the Department of National Defence, Royal Canadian Navy, Ottawa.

PROGRAM OF TESTS

A research program of two parts was undertaken in order to assess the following possibilities:

Part I		obtaining the desired properties in the steel now being supplied;
Part II	a)	improving the present steel by modification in composition as nearly as possible within the limits of the existing specification, and
	b)	determining whether or not modifications of composition completely outside the present specification would be necessary.

Although this program was concerned mainly with material in the normalized-and-tempered condition, some properties were investigated in the quenched-and-tempered condition.

PART I. AN EXAMINATION OF STEEL CURRENTLY IN USE

INTRODUCTION

This part of the program comprises the assessment of the material currently supplied for shafting, to determine the possibility of obtaining the desired properties.

TEST PROCEDURES AND RESULTS

Chemical Analyses

Analyses were carried out on samples obtained from opposite ends of shafts because these represent the top and bottom regions of the usable part of the ingots. The purpose of these analyses was to determine whether segregation, particularly of vanadium, could account for differences in impact values in these regions.

Chemical compositions typical of the material used for shafting are shown in Table 1. The composition range covered in Specification E-in-C 25S5 is included. Heats C I to C IV, and C V and C VI, represent materials from two sources.

TABLE 1

Chemical Composition (%)

Heat		C I		C II		C III		C IV		C V		C VI	
Specification Requirements (E-in-C 25S5)		Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Carbon*	0.50 max	0.49	0.42	0.53	0.58	0.48	0,45	0.48	0.46	0.38	0.43	0.45	0.43
Manganese	1.00 "	0.78	0.75	0.84	0.84	0.68	0.67	0.74	0.75	0.84	0.75	0.76	0.79
Silicon	not stated	0.25	0.21	0.27		0.24	0.26	0.208	0.207	0.33		0.33	
Sulphur	0.04 max			0.018		0.022	0.020	0.028	0.026	0.008			
Phosphorus	0.04 "			0.029		0.022	0.022	0.025	0.025	0.003		0.021	
Vanadium	0.06 "	0.009	0.009	0.014	0.014	0.12	0.10	0.046	0.043	0.06	0.035	0.035	0.031

* Permission has recently been given to accept carbon contents up to 0.55%, because of a higher yield requirement.

The carbon is slightly higher in heat C II, and the vanadium is higher in heat C III, than the maximum shown in Specification E-in-C 25S5.

Impact Tests

Izod impact tests were conducted at 20°C (70°F), 0°C (32°F), -6.6°C (20°F), and -17.7°C (0°F). The results of these tests are shown in Table 2, along with the requirements of Specification E-in-C 25S5 and the tensile properties of those commercial melts which were tested. The room temperature impact values from top material are low and erratic for melt C IV, but easily exceed 20 ft-lb at the bottom.

TABLE 2

Izod Impact Results With Tensile Strengths

Heat	C I		C II		C III		C IV		C V		C VI	
Specification Requirements (E-in-C 25S5)	Top	Bottom							Top	Bottom	Top	Bottom
UTS, psi (77,000 min)	84,600	80,000			*87,500		*88,320		98,400	92,800	96,600	100,200
Yield Point, psi (46,000 min)	51,000	49,000			49,900		52,200		57,200	49,900	54,200	56,800
Elong, % (23 min)	29.0	28.5			28.0		28.5		25.0	28.0	25.0	24.0
Red. in Area, % (40 min)	49.6	47.2			53.3		47.6		47.0	52.0	50.0	46.0
Izod impact (for information) **	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
70°F, 20 ft-lb	30	22	20		19	25	(10-23)	30	16	(15-33) 25 (8-22)	15	(12-17) 14 (9-20)
32°F, not specified	16	14	13		11	18			14	15	10	15
20°F, " "	12	10	11		9	16			12	14	8	15
0°F, " "	13	8	8		8	9			8.5	6	5	12

* Top.

** Single impact values are averages of three values; wide ranges of scatter are shown in brackets.

Melt C III shows Izod impact values consistently lower at the top than at the bottom, although room temperature Charpy tests (Table 5) do not reveal this. For melt C II, sufficient material was not available for testing the "bottom" material.

The Izod impact results for C I appear to contradict the tendency toward higher impact values at the bottom, although the Charpy values (Table 5) do not. However, a macro-etch of some of the Izod specimens revealed that the forging flow lines, when viewed on the notched face of bottom specimens, were at an angle to the longitudinal axis of the specimen. On top specimens these lines were parallel to the longitudinal axis. Similarly, this observation was made on the Izod impact specimens of heats C V and C VI bottoms, and it appears to have contributed to the scatter of impact values. The high values were obtained on specimens in which the flow lines are parallel to the longitudinal axis on the notched face. Therefore, the Charpy values of C I are considered to show a more correct relationship between the top and bottom impact values.

It is possible that the change in flow line direction occurred at a reduced section in the forging, and that by coincidence some bars were machined from these regions.

Microscopical Examination

Examinations were carried out to compare microstructures and to determine ferritic and austenitic grain sizes. The examination showed that the microstructure consisted of ferrite and pearlite. This microstructure would be anticipated from the double normalizing and tempering treatment that had been used. Examples of the material from melts C IV and C III are shown, in the unetched and etched condition, in Figures 1 to 4.

The austenitic grain size shown by the McQuaid-Ehn method varies in melt C IV from 3 to 5 in the top material and 4 to 7 in the bottom material. A few grains were as large as size 1 (ASTM grain size). This very mixed grain size indicates a grain coarsening tendency throughout, which is most extreme in the top material. The coarser grain in this melt coincides with the region where low and erratic impact values were obtained.

The ferritic grain size was less varied, being estimated to be size 6 to 8. However, in melt C IV the pearlitic and ferritic areas differed in regularity of the grain boundaries in the top and bottom regions. The pearlitic areas appeared to be larger and less uniform in size in the material taken from the top.

The microstructures and the grain sizes will be compared with test heats described in Part II of this investigation.

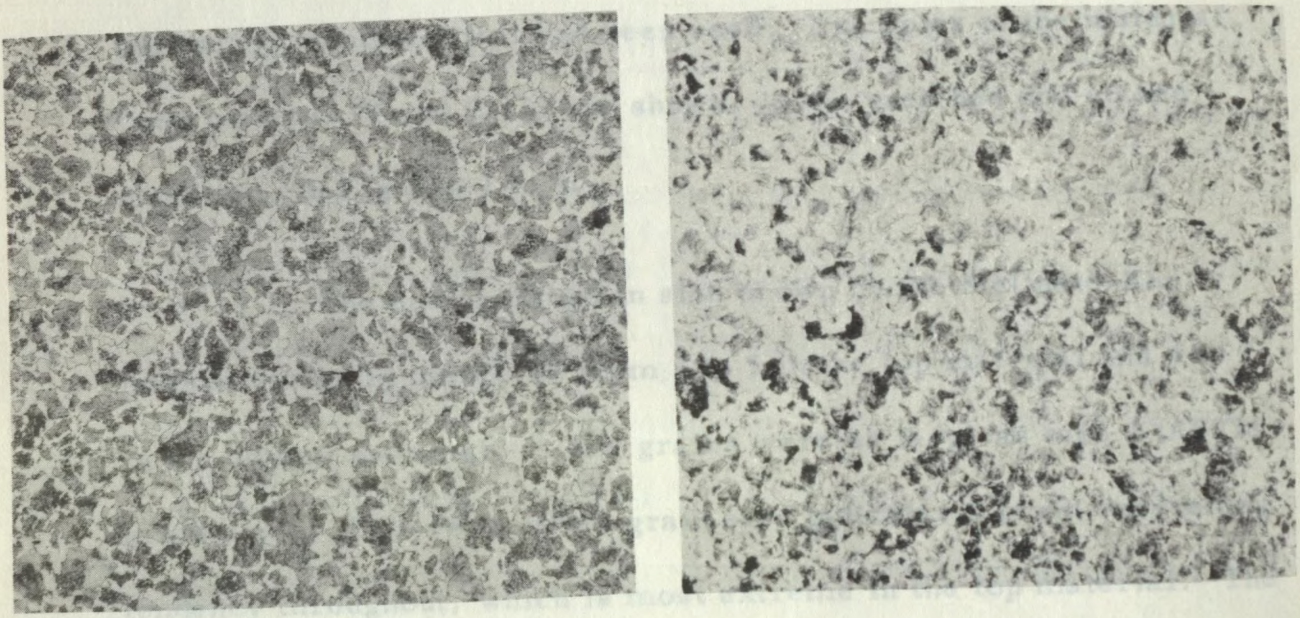
McQuaid-Ehn tests on other commercial melts of shafting material, C I, C II, C III and C V, all show this grain coarsening tendency, this being least evident in melt C III. It was shown by the chemical analyses that this melt contained a higher percentage of vanadium than was in the other melts.

Top

Bottom

Unetched; X100

Figure 1. - Material from shaft from melt C IV. Typical fields showing non-metallic inclusions.

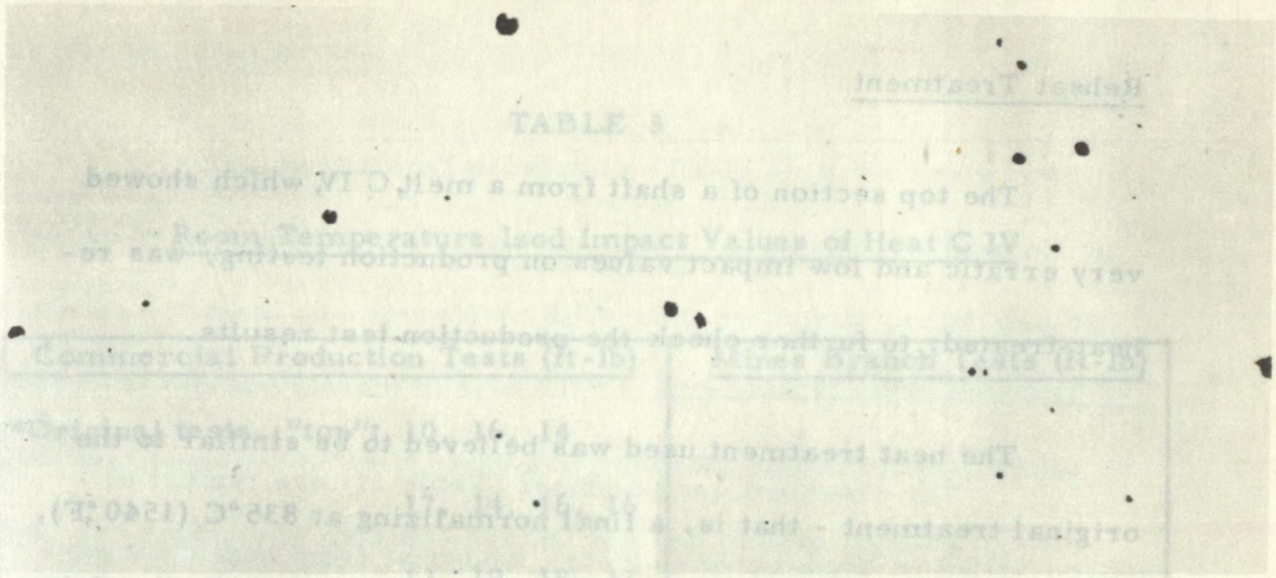


Top

Bottom

Etched in 2 per cent nital; X100

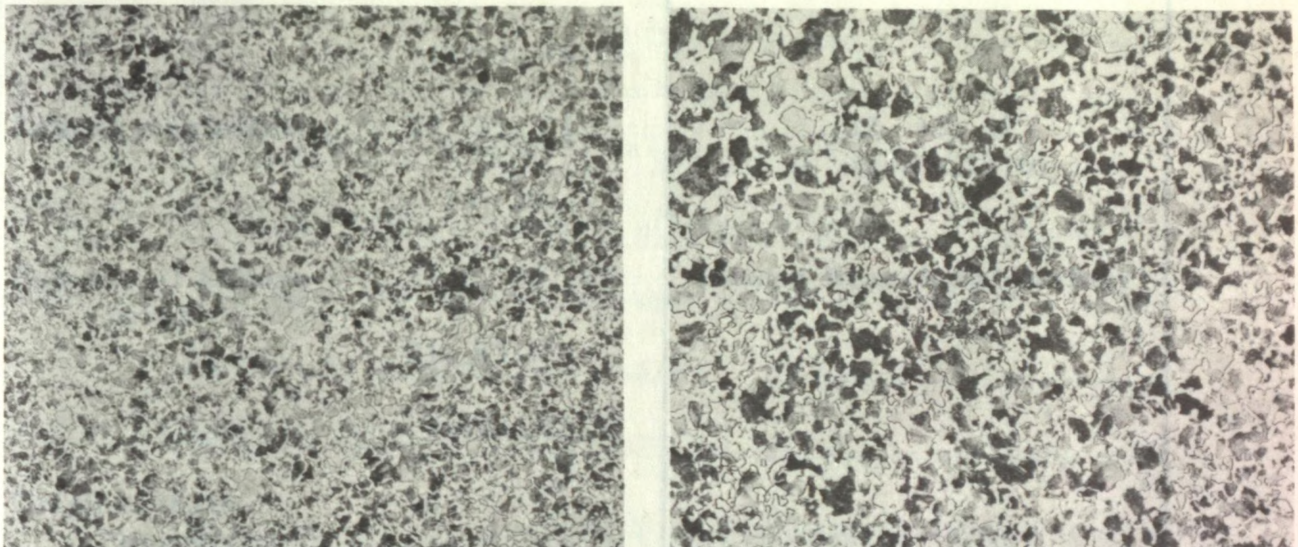
Figure 2. - The same regions as in Figure 1, showing microstructures consisting of ferrite and pearlite.



Top　　　　Bottom

Unetched; X100

Figure 3. - Tail shaft. Heat C III; dirtiest fields. Impact values are lower at the top, but not as erratic as in Heat C IV.



Top　　　　Bottom

Etched in 1:1 solution of 2% nital and 4% picral. X 100

Figure 4. - The same material as in Figure 3.

Reheat Treatment

The top section of a shaft from a melt, C IV, which showed very erratic and low impact values on production testing, was reheat-treated, to further check the production test results.

The heat treatment used was believed to be similar to the original treatment - that is, a final normalizing at 835°C (1540°F), tempering at 620°C (1150°F), and cooling in the furnace to simulate a large mass effect.

The impact values obtained for this material are shown in Table 3.

TABLE 3

Room Temperature Izod Impact Values of Heat C IV

Commercial Production Tests (ft-lb)		Mines Branch Tests (ft-lb)
*Original tests, "top":	10, 16, 14	
	17, 14, 16, 16	
	11, 19, 18, 17	
	(aver., 15.2)	
Retests from prolong:	18.5, 20.5,	
	17.5, 17.5	
	22, 16.5	
	20, 18	
	(aver., 18.8)	
Reheat treatment:	23, 23, 21	12, 18, 17 (aver., 15.6)
	19, 20	
(Industrial Laboratory)	21.5, 22, 27	(Mines Branch Laboratory)
	21, 23.5	
	(aver., 22.1)	
Original tests "bottom":	30	

* The original tests had not been obtained at the location generally used for these tests, and the retest from the prolong was believed by the manufacturer to approximate more closely the desired location.

DISCUSSION

Chemical Compositions

The chemical compositions (Table 1) are typical of silicon-killed medium carbon steels. Material from heat C IV contains slightly less vanadium, and material from C III contains more than that shown by the current specification. Heats C I and C II appear to contain only residual amounts of vanadium, which indicates that no additions were made. There is no appreciable segregation of this element from top to bottom to account for differences in grain size or impact values in heat C IV.

Except for the excess of vanadium in heat C III, and of carbon in C II, these materials conform to Specification E-in-C 25S5. Heats C V and C VI, which represent a different supplier, meet the specification chemically. These show evidence of additions of vanadium and no appreciable differences in the quantity of this element at the top and bottom of each.

Mechanical Properties

The mechanical properties (Table 2) of the heats considered here meet all requirements of the specification. Production tests do not show an appreciable difference in tensile properties between the top and bottom of heat C IV. However, it is known that different tensile and yield strengths, usually slightly higher at the top, are frequently obtained for the top and bottom regions of the ingots used for these shafts. Slight differences in tensile ductility are consistent with these strength differences.

Impact tests at temperatures lower than 20°C (70°F) have not previously been required.

From the results shown in Table 2, it is apparent that the impact strength of this material decreases rapidly as the testing temperature falls below 20°C (70°F). In Table 5 of Part II, on page 22, these values are compared with values obtained in test melts of different compositions.

Microscopical Examination

The metallographic examinations showed only slight differences in microstructure between the top and bottom of heat C IV and a recognizable, although not extreme, difference in the ferritic grain size. However, McQuaid-Ehn grain size tests show size ranges of 3 to 5 (ASTM) at the top and 4 to 7 at the bottom. It was concluded from these tests that both the top and the bottom showed grain coarsening tendencies, this being more definite at the top.

In the unetched condition the bottom material appeared to contain less non-metallic material than the top.

The differences observed in microstructures, grain sizes and non-metallic contents probably would have a cumulative effect on impact strength. However, the greater grain coarsening tendency at the top would be likely to have a dominating effect.

Reheat Treatment

The reheat treatment of material from the top of heat C IV, along with other test results presented, confirmed that it would be extremely difficult, if not impossible, to consistently develop in this material the desired impact strength at room temperature.

CONCLUSIONS

1. The steels which are now being supplied for destroyer escort shafting do not consistently develop impact strengths of 20 ft-lb Izod at room temperatures, as suggested in E-in-C 2585 "for information", and cannot be expected to develop 15 ft-lb Charpy at 0°C (32°F), which is the impact strength now desired.

2. This material shows a strong tendency to vary in impact strength when tested at 20°C (70°F). This tendency does not appear to be the result of segregation of the grain refining material, but is believed to reflect the particular impact transition and grain coarsening temperatures inherent in this material.

PART II. MODIFICATIONS OF THIS STEEL

INTRODUCTION

It was evident, from the results of tests on the existing tailshaft steel, that it was not possible to obtain impact values of 20 ft-lb Izod at temperatures lower than 20°C (70°F). The steel was also prone to show irregular grain size, indicating that the grain coarsening temperature may be below, or near, the final normalizing temperature. It has been shown in many investigations that the impact strength of steels is proportional to the grain size; therefore, a uniformly fine grain size would be desirable.

Two means are available for increasing the yield and impact strengths of the tailshaft steel. These are as follows:

(a) Strengthening of the ferritic matrix and the production of fine lamellar pearlite by increasing the manganese/carbon ratio, in addition to adding vanadium as a grain refiner.

(b) Raising the grain coarsening temperature by the addition of strong grain refining additions, for example, vanadium and/or niobium.

This part of the program covers Part II (a) and (b) of the program described under "Program of Tests".

EXPERIMENTAL PROCEDURES

Split heats of 500 lb weight were made by the double slag basic electric melting process having various Mn/C ratios and with the additions of small quantities of vanadium and niobium. The compositions of these heats are shown in Table 4. Only a difference in vanadium was intended in the splits of each heat,with the exception of those containing molybdenum and niobium. In the latter heat the halves contain equal additions of molybdenum with a niobium addition in the second half only. Differences in elements other than those intended did occur in different halves of heats. However, comparisons were made ultimately on the basis of composition.

TABLE 4

Chemical Analyses of Laboratory Heats

Heat	(%)								
No.	C	Mn	Si	S	P	Cr	Mo	V	Nb
A 1233-1	0.48	0.92	0.22	0.019	0.011	0.08		0.11	
A 1200-1	0.42	1.04	0.39	0.015	0.013	0.08		0.14	
A 1200-2	0.40	1.04	0.37	0.013	0.017	0.13		0.18	
A 1233-2	0.35	0.89	0.14	0.017	0.012	0.08		0.21	
A 1108-1	0.33	0.95	0.22	0.015	0.012	0.00		0.07	
A 1171-1	0.30	1.01	0.27					0.11	
A 1210	0.53	1.33	0.20	0.020	0.020	0.13		0.16	
A 1241-1	0.48	1.30	0.38	0.018	0.017	0.32		0.09	
A 1178-1	0.44	1.34	0.20	0.021	0.014	0.37		0.09	
A 1178-2	0.41	1.32	0.19	0.021	0.017	0.44		0.17	
A 1241-2	0.43	1.27	0.34	0.018	0.008	0.34		0.18	
A 1213-1	0.47	1.11	0.16	0.019	0.022	0.08		0.08	
A 1213-2	0.38	1.10	0.14	0.029	0.017	0.00		0.16	
A 1108-2	0.32	1.15	0.19	0.015	0.011	0.00		0.12	
A 1106-1	0.33	1.34	0.28	0.017	0.027	0.00	0.24		0.00
A 1106-2	0.32	1.15	0.19	0.015	0.011	0.00	0.24		0.19

The melts were poured into 120-lb ingots, cropped and forged to a 6:1 reduction (2 in. square billets from an ingot approximately 5-1/2 in. in diameter). The billets were heat treated by double normalizing 895°C (1640°F) and 840°C (1540°F), and tempered at 620°C (1150°F) for 1-1/2 hr. To simulate cooling conditions of a larger mass, the billets were cooled in the furnace after normalizing and tempering.

The cooling rate of the furnace used was approximately 72 Centigrade degrees (130 Fahrenheit deg) per hour through the range 705°C (1300°F) to 315°C (600°F). An estimate of the cooling rate of a forging 15 inches in diameter, cooled in air, is approximately

72 C deg (130 F deg) per hour. The cooling rate through the critical range would be somewhat slower, and was approximately 61 C deg (110 F deg) per hour for the laboratory tests.

After heat treating the billets, tensile and impact tests were carried out on each of the materials in order to determine which would meet the required yield strength and the desired Charpy impact value at 0°C (32°F). In all cases except melts A 1106-1 and A 1106-2, Izod *impact tests were carried out at -18°C (0°F), -6.6°C (20°F) and 0°C (32°F) and at room temperature. The tests at -18°C (0°F) were omitted for melt A 1106.

Subsequently, this information was supplemented by fatigue tests (notched and unnotched) for material from melts A 1106-1 and A 1106-2, A 1200-1, A 1108-1 and A 1108-2.

Bend tests were then conducted on specimens of the A 1200-1 and A 1200-2 material for shafting. The longitudinal axis of these specimens was taken parallel with the forging direction. The dimensions of the specimen used were 1 inch x 1/2 inch, with the corners slightly rounded. The radius of the bend was 3/8 inch.

Estimates of the austenitic grain size were made by the McQuaid-Ehn method, for comparison with the currently used material.

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* Izods were used for comparison with accumulated information on shafting material now available.

RESULTS

Tensile, Impact and Bend Tests

The mechanical test results and the chemical compositions of the material tested are given in Table 5. Included are Izod impact and some Charpy impact results, and the bend test results for A 1200-1.

TABLE 5

Mechanical Properties of Forged Steels

Identification	Ult. tensile Strength, psi	Yield Strength, psi (0.01% offset)	Elongation, %	Reduction of Area, %	Impact (ft-lb Izod)**				Impact (ft-lb Charpy)				Comments
					0°F	20°F	32°F	70°F (RT)	0°F	20°F	32°F	70°F (RT)	
Normalized													
C I Top	84,600	51,000	29.0	49.6	13	12	16	30			11	17.5	"C" indicates commercial melts.
Bottom	80,000	49,000	28.5	47.2	8	10	14	22			11	22.5	
C II Top	Not sufficient material								8	11	13	20	
C III Top	87,500	49,900	28.0	53.3	8	9	11	19			14	21	
Bottom	93,400	52,300	28.0	48.7	9	16	15	25			10	19.3	
C IV Top	88,320	52,200	28.5	47.6				10-23					
Bottom								30					
C V Top	98,400	57,200	25.0	47.0	9	12	14	16					
Bottom	92,800	49,900	28.0	52.0	6	14	8-22	15-33					
							Av 15	Av 25					
C VI Top	96,600	54,200	25.0	50.0	5	8	10	15					
Bottom	100,200	56,800	24.0	46.0	12	15	9-20	12-17					
							Av 15	Av 14					
A 1233-1	89,700	55,800	28.5	54.4	16	15	21	25			14		Experimental melts tempered at 1150°F and furnace cooled except where noted.
A 1200-1	94,500	65,900	28.0	58.2	30	41	38	61			38	43	Satisfactory bend (180°).
A 1200-1	92,000	59,800	31.0	58.8	25		34	49			37	49	Tempered at 1200°F.
A 1200-2	95,800	63,300	29.0	57.8	35	37	40	59			27	40	Satisfactory bend (180°).
A 1233-2	81,800	51,000	33.0	59.0	30	34	36	54			25	54	
A 1108-1	80,400	51,400	35.0	62.0	22	30	32	59			32	74	
A 1171-1	77,800	50,600	37.0	63.7	30	55	55	78			44	71	
A 1210	105,000	94,700	22.0	46.2	6	9	11	20					
A 1241-1	103,000	64,400	27.0	54.4	19	17	23	35					
A 1178-1	98,200	58,200	25.0	55.9	18	17	21	37			24		
A 1178-2	93,600	64,400	32.0	64.1	36	44	45	68			37		
A 1241-2	107,000	67,000	25.5	56.2	19	23	22	37					
A 1213-1	93,200	51,900	29.0	49.9	6	6	9	23					Slight over-oxidation believed cause of low impact.
A 1213-2	92,600	51,800	28.0	50.5	9	12	19	25					
A 1108-2	82,200	52,300	32.0	64.6	42	40	53	62					Tempered at 1150°F, A.C.
A 1108-2	-	-	-	-	52	-	59	79	56		71	86	* Retempered at 1150°F, F.C.
A 1106-1	107,700	72,000	24.5	57.0		34	32	40					
A 1106-1	92,000	67,000	28.0	60.3	33			56	30	39	49	58	Tempered at 1150 and 1200°F.
A 1106-2	94,700	65,000	27.5	58.3		45	50	62					
A 1106-2	95,600	62,400	26.0	59.8	34			62	43	45	73	80	Tempered at 1150 and 1200°F.
Water Quenched													
A 1108-2	110,700	92,200	23.0	68.0	91	88	91	90	80	95	91	95	Tempered at 1150°F.
A 1200-1	116,000	108,000	25.0	65.2					57	54	89	87	Tempered at 1200°F.
A 1200-2	117,700	103,300	23.0	64.1	37	45	79	93	31	38	48	64	Tempered at 1200°F.
A 1106-1	116,500	92,500	25.0	66.5	87	80	88	86	85	91	94	94	Tempered at 1200°F.
A 1106-2	111,200	98,500	24.0	63.3	78	84	83	88	100	103	85	88	Tempered at 1200°F. Charpy 64 at -51°C(-60°F).

* Tempered at 620°C (1150°F) after a temper at 620°C (1150°F) on the same material.
A.C. - Air cooled.
F.C. - Furnace cooled.

* Charpy and Izod values are averages of two or three tests, except where a range is shown.

Fatigue Tests

Tests were carried out on material from selected test melts. Standard R. R. Moore rotating beam specimens were used for the unnotched bar tests; a modified R. R. Moore specimen having a theoretical stress concentration factor of 1.88 was used for notched fatigue tests. The latter specimen is illustrated in Figure 5.

The results of tests carried out to date are shown in Table 6. Included are tests on present shafting material, for comparison.

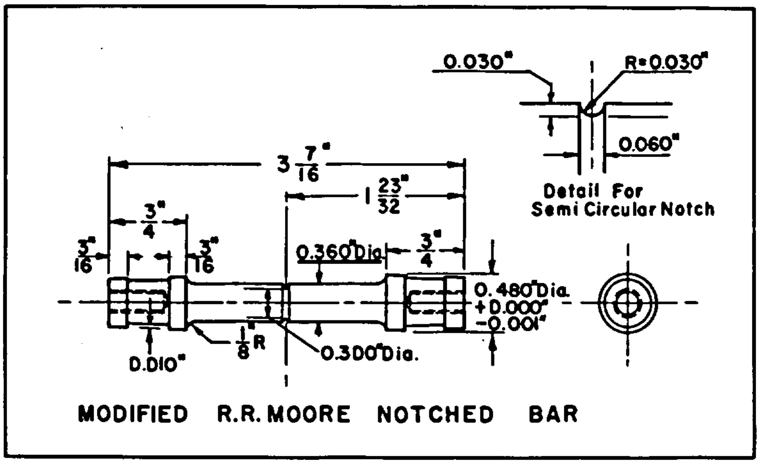


Figure 5. - Modified, notched, R. R. Moore fatigue specimen.

TABLE 6

Endurance Limits of Notched and Unnotched R. R. Moore Fatigue Specimens

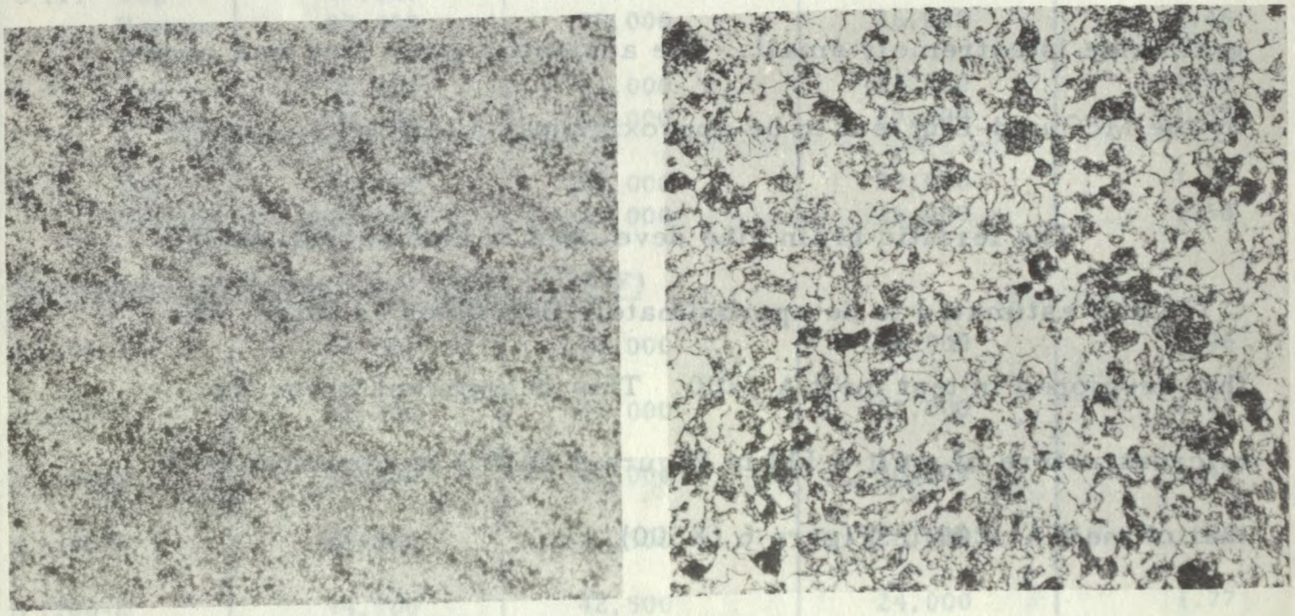
Melt No.	Ult. tensile strength, psi	Unnotched, psi	Notched, psi	Strength Reduction Factor,
Commercial Treatment (Normalized and Tempered) -				
C I Top	84,600	39,000	24,000	1.63
C II Top	(Insufficient material)	42,000	(Insufficient material)	
Bottom		42,000		
C III Top	87,500	37,000	25,000	1.48
Bottom	93,400	38,000	26,000	1.46
C V Top	98,400	41,000	24,000	1.71
Bottom	92,800	43,000	27,000	1.59
C VI Top	96,600	40,000	29,000	1.38
Bottom	100,200	41,000	26,000	1.58
Normalized and Tempered at 620°C (1150°F) -				
A 1200-1	94,500	47,000	24,000	1.96
A 1108-1	80,400	40,000	30,000	1.33
A 1108-2	82,200	43,000	30,000	1.44
A 1106-1	107,700	47,500	25,000	1.90
A 1106-2	94,700	42,500	24,000	1.77
Tempered at 648°C (1200°F) After Tempering Previously at 620°C (1150°F) -				
A 1200-1	92,000	44,000	30,000	1.46
A 1106-1	92,000	47,000	28,000	1.68
A 1106-2	94,600	46,000	28,000	1.64
Normalized and Water Quenched (Tempered as Noted) -				
A 1108-2 (1150°F)	110,700	58,000	38,000	1.53
A 1200-1 (1200°F)	116,000	(Insufficient material)	34,000	
A 1200-2 (1200°F)	117,700	61,000	37,000	1.65
A 1106-1 (1200°F)	116,500	61,000	35,000	1.74
A 1106-2 (1200°F)	111,200	64,000	35,000	1.82

Microscopical Examination

Melt A. 1200 was selected for comparisons of microstructure and grain size, and both parts of the split heat were examined.

The microstructures (A 1200-1 and A 1200-2) were similar and a typical field is shown in Figure 6. The ferritic grain size is extremely small. The austenitic grain size was shown by the McQuaid-Ehn test to be approximately 8 (ASTM).

The ferritic grain size developed in commercial melt C III was estimated to be approximately five times as large as that developed in test melt A 1200. This is apparent where the microstructure of melt C III in Figure 4 (X100) is compared with that of melt A 1200 in Figure 6 (X500).



X 100

X 500

Etched in 2 per cent nital

Figure 6. - Material from heat A 1200-1, showing the microstructure, which consists of ferrite and pearlite.

The very fine-grained microstructure contrasts sharply with that of heat C IV shown in Figure 2.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of these test results it has been concluded that a composition such as that for heats A 1200-1 or A 1200-2 would be suitable for service in shafting. Therefore, the following composition range has been recommended for the pouring of a prototype forging:

		Per Cent
Carbon	-	0.35 to 0.45
Manganese	-	0.80 to 1.20
Silicon	-	0.15 to 0.35
Sulphur	-	0.04 max
Phosphorus	-	0.04 "
Vanadium	-	0.12 to 0.18

The most suitable combination of properties for this material should be developed by a double normalize and temper at 650°C (1200°F).

If a tempering temperature of 620°C (1150°F) is used, the carbon, manganese and vanadium contents should be within the ranges:

		Per Cent
Carbon	-	0.30 to 0.38
Manganese	-	0.90 to 1.20
Vanadium	-	0.10 to 0.15

o o o

RDM:WAM:(PES):vb