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O T T A W A February 3rd, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1352.

Examination of Two Heats of
0.50 Per Cent Carbon Steel.

(Copy No. 14.)

BUREAU OF MINES
DIVISION OF METALLIC MINERALS

ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA

DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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Source of Material and Object of Investigation:

On January 20th, 1943, two 12-inch lengths of steel bar, one being $3\frac{1}{4}$ inches and the other $1\frac{1}{4}$ inches in diameter, were received from Mr. H. H. Scotland, of the Inspection Board of United Kingdom and Canada, 70 Lyon Street, Ottawa, accompanied by the following letter:

(Source of Material and Object of Investigation, cont'd) -

'GM/EC

"In reply quote
File No: Contract 2596
Suborder 3140 G.D.
Index 67.

INSPECTION BOARD
OF
UNITED KINGDOM AND CANADA

70 Lyon Street,
Ottawa, Ontario,
January 18, 1943.

Attention: Dr. Farnham,

Dear Sir:- (Requisition O.T. 3371).

Enclosed is a copy of a letter from Inspector Naval Ordnance referring to 2 samples of steel, one of these 3-1/4" dia. x 12" long, the other 1-1/4" dia. x 12" long, which are now sent to you for investigation. The material is to Admiralty Specification E/21 Class C.

An arrangement was made between D.M.S. and R.A.T.M. whereby basic open hearth steel would be acceptable under certain provision. Unfortunately the steel maker used some aluminium in the ladle in making the steel. The specification prohibits it and I.N.O. considers this addition has caused the steel to be shallow hardening. The 3-1/4" sample is from heat S.E. 15782 in which 190 pounds aluminium was used in 178 tons of steel. The analysis given is C .50, Mn .72, Si .225, P .019, S .034.

I have no information as to whether this 1-1/4" dia. piece is from the same heat or not. In addition to the tests asked for I should welcome an opinion from your department as to the maximum hardness that might be expected in an oil-hardened steel of the above analysis and size in which no aluminium whatever had been used.

Yours faithfully,

(Sgd.) H. H. Scotland

Inspector of Materials,
for Inspector-General.

Dept. of Mines & Resources,
552 Booth Street,
Ottawa, Ontario."

Chemical Analysis:

Although the steel maker's analysis was provided, each bar was analysed. The following analyses were obtained:

(Continued on next page)

(Chemical Analysis, cont'd) -

	C	Mn	S	P	Si	Al
	- Per cent -					
$1\frac{1}{4}$" diam. bar -	0.51	0.81	0.032	0.01	0.26	0.009
$3\frac{1}{4}$" diam. " -	0.52	0.85	0.029	0.014	0.27	0.0156

Hardness Tests:

A section of each bar was normalized at 1600° F., then reheated to 1550° F. and quenched in oil.

Similar heat treatment was given to two more specimens (one from each size of bar) but these were quenched in water.

Hardness was determined on a cross-section of each specimen. The results were plotted and are shown in Figures 7, 8, 9, and 10.

A Jominy hardenability test was conducted on each size of bar. Results are shown in Figures 11 and 12.

Microscopic Examination:

A specimen from each "as received" bar was given a metallographic polish and etched in 2 per cent solution of nitric acid in alcohol. Figures 1 and 2 are photomicrographs of these specimens, at X100 magnification.

Further microscopic examination of each edge of the bars showed that the outer surface was slightly decarburized.

A specimen from each bar was given a McQuaid-Ehn heat treatment to determine the grain size, that is, carburizing at 1700° F. for 8 hours and cooling in the furnace. The specimens were polished and etched in 2 per cent solution of nitric acid in alcohol. The grains are clearly outlined and comparison with the standard A.S.T.M. grain size chart indicates that both bars have a grain size of No. 5. See Figures 3 and 4, photomicrographs at X100 magnification.

(Continued on next page)

(Microscopic Examination, cont'd) -

A sample of each bar was heated to 1550° F., quenched in water, and tempered for 15 minutes at 425° F. to determine the grain size at this temperature. A specimen from each sample was polished and etched in a solution of 5 per cent hydrochloric acid and 1 per cent picric acid in alcohol. The No. 5 grain size at this temperature, as shown by the photomicrographs in Figures 5 and 6, indicates that these steels do not coarsen up to 1700° F.

The coarsening temperatures of these steels were not determined.

Discussion of Results:

1. Both steels are on the dividing line between a coarse- and a fine-grained steel, having a grain size of No. 5.

2. 1.07 pounds of aluminium per ton of steel were added to the heat from which the 3½"-diameter bar was rolled. The 1¼"-diameter bar did not appear to be significantly different.

In basic open hearth practice, one pound of aluminium per ton of steel is considered the minimum amount necessary to produce a fine-grained steel.

3. Figures 7, 8, 9, and 10 indicate that these two heats of steel are shallow-hardening whether quenched in oil or in water. The surface of each bar showed some decarburization, which would tend to decrease the surface hardness.

4. The Jominy hardenability curves of Figures 11 and 12 show the cooling rates which will give any desired hardness.

CONCLUSIONS:

1. These two steels are shallow-hardening steels and, in these sizes, will have an unhardened core.

2. Both bars showed core hardnesses of Rockwell 'C' 22-25 after quenching in either oil or water. Although physical tests were not conducted on either of the bars, a hardness of Rockwell 'C' 20-25 indicates that a tensile strength of about 110,000 pounds per square inch may be expected on a specimen machined from the centre of the bar. This should satisfy the requirements of the specification if the bar is properly heat treated.

3. Water quenching will give a greater depth of hardness than oil quenching. This is shown in Figures 7, 8, 9, and 10. In these two bars, water quenching will leave an unhardened core although the core hardness is somewhat higher than the oil-quenched sections. It is not likely that water quenching will cause cracking of a round section such as this.

4. Calculations were made in order to determine the critical diameters of bars, for various grain sizes, which would harden right through for various quenches. The results of this calculation are shown in Table I (on Page 6) and are based on the analysis of the 3½" diameter bar, which is as follows:

C	Mn	S	P	Si	Al
- P e r			C e n t -		
0.52	0.85	0.029	0.014	0.27	0.0156

(Continued on next page)

(Conclusions, cont'd) -

5. The specification permits the addition of vanadium, 0.25 per cent (max.); molybdenum, 0.10 per cent (max.); and chromium, 0.25 per cent (max.). If these elements were added to this steel it would increase the depth of hardness to a considerable extent.

Table I.

Grain Size	Critical Dia. of bar Which Will Harden Right Through at Various Grain Sizes				
	4	5	6	7	8
Mildly Agitated Water Quench	.78	.66	.60	[illegible]	.43
Mildly Agitated Oil Quench	.38	[illegible]	.27	.22	.20
Violently Agitated Water Quench	1.10	1.08	.97	.88	.78
Violently Agitated Oil Quench	[illegible]	[illegible]	.58	.50	[illegible]

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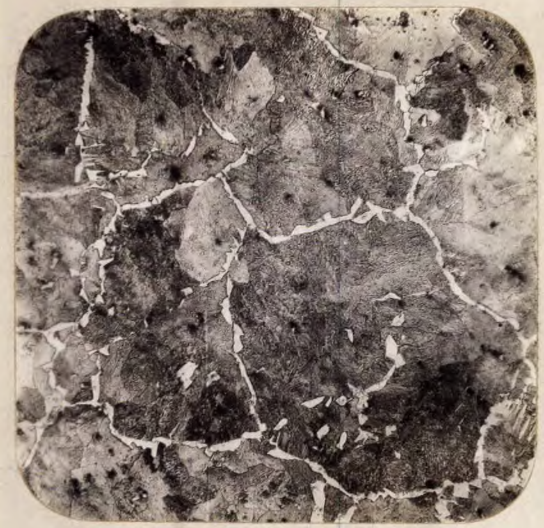
HLL:GHB.

Figure 1.



X100, nital etch.
3¼"-DIAMETER BAR AS RECEIVED.

Figure 2.

X100, nital etch.
1¼"-DIAMETER BAR AS REC'D.

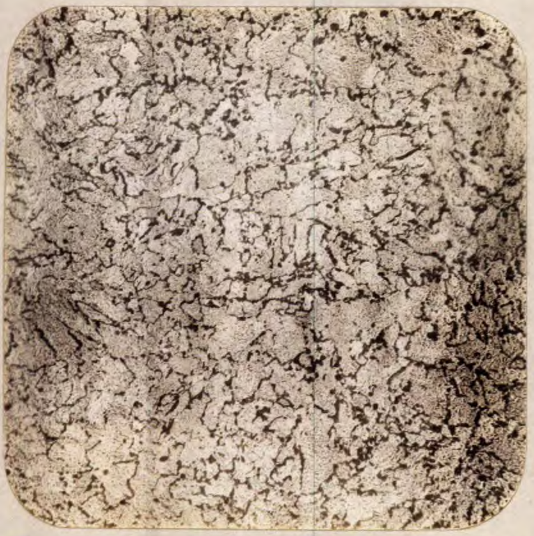
Figure 3.

X100, nital etch.
Grain size of 3¼"-diameter bar at 1700° F.

Figure 4.

X100, nital etch.
Grain size of 1¼"-diameter bar at 1700° F.

Figure 5.

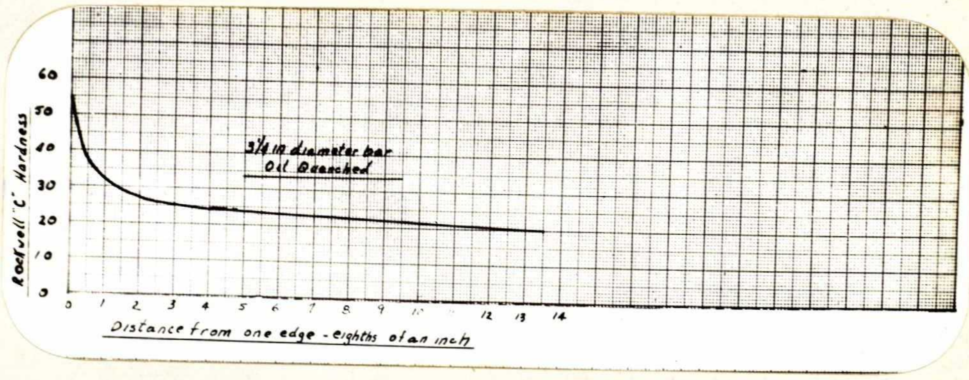


X100, HCl-picric acid etch.
Grain size of 3¼"-diameter bar at 1550° F.

Figure 6.

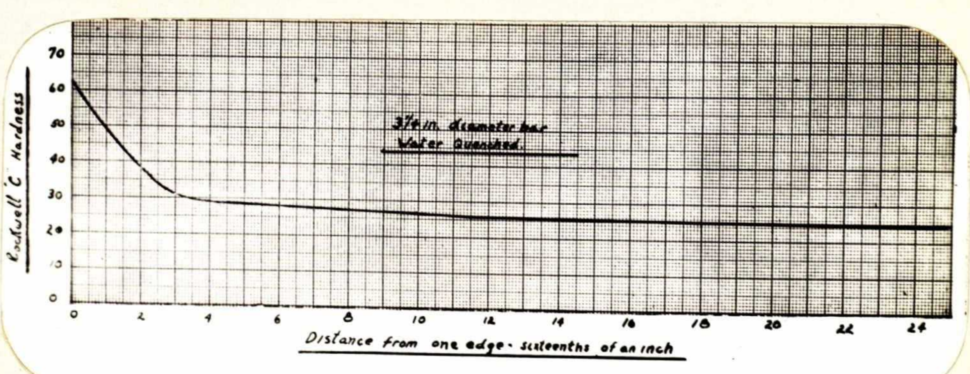
X100, HCl-picric acid etch.
Grain size of 1¼"-diameter bar at 1550° F.

Figure 7.



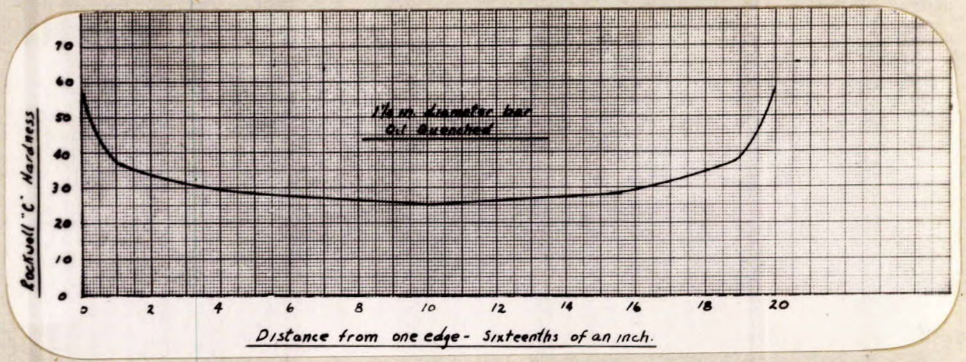
Hardness Traverse of Cross-Section of 3¼"-Diameter Round Bar Normalized and Oil-Quenched.

Figure 8.



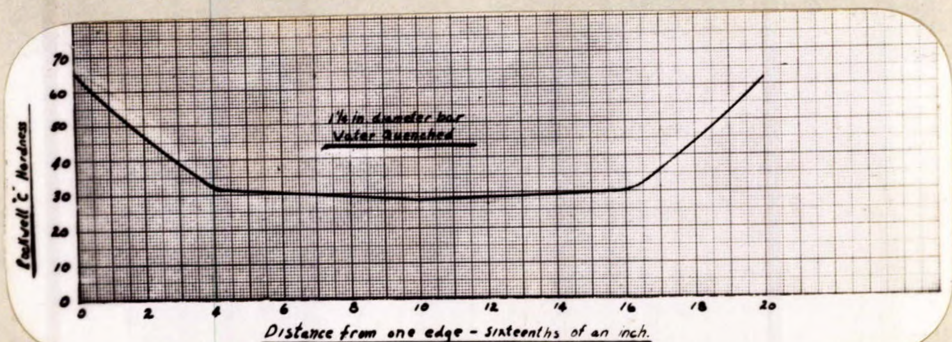
Hardness Traverse of Cross-Section of 3¼"-Diameter Round Bar Normalized and Water-Quenched.

Figure 9.



Hardness Traverse of Cross-section of $1\frac{1}{4}$"-Diameter Round Bar Normalized and Oil-Quenched.

Figure 10.



Hardness Traverse of Cross-section of $1\frac{1}{4}$"-Diameter Round Bar Normalized and Water-Quenched.

Figure 11.

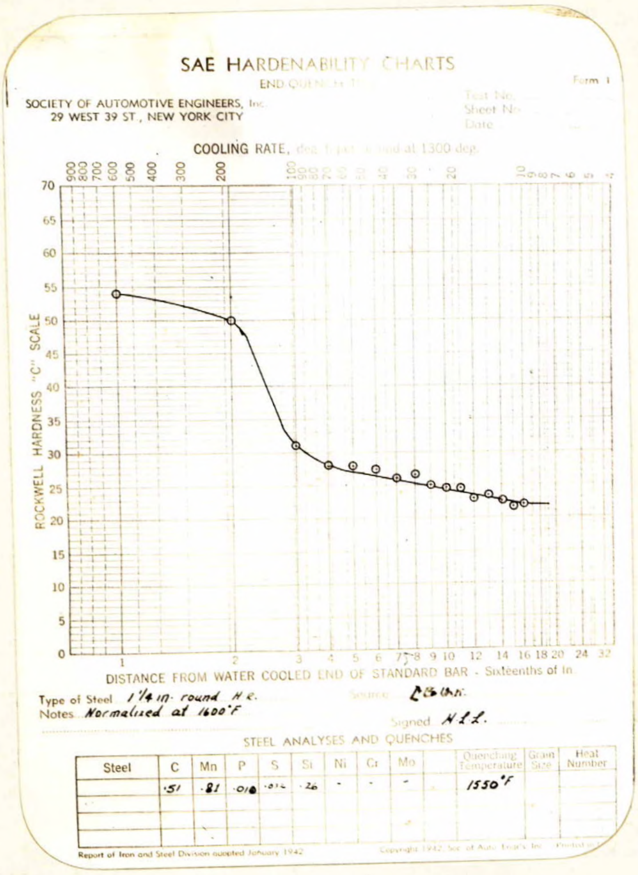
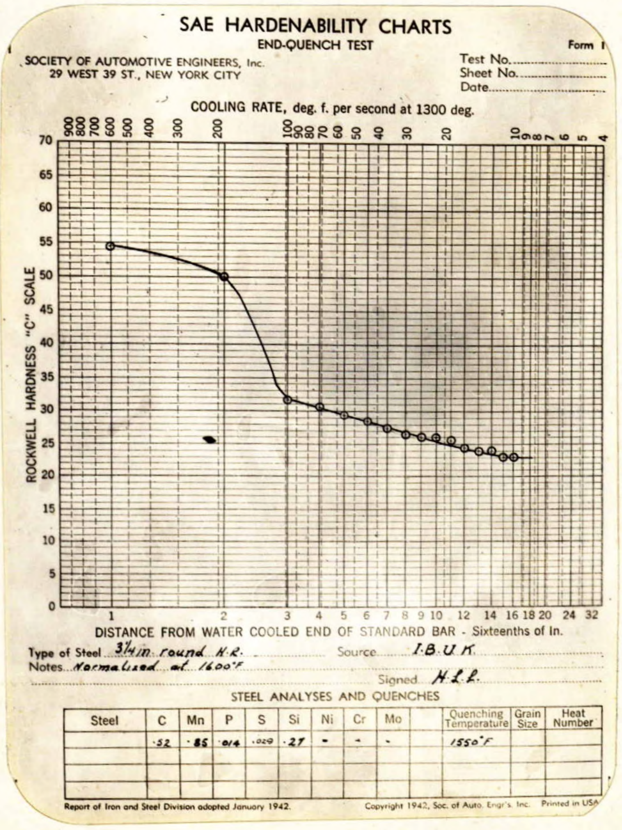


Figure 12.



HLL:LB.