

FILE COPY

0 14. 1392

July 15th, 1943.

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1449.

Examination of Sample of Flame-Hardened Armour Plate.

(Copy No. 10.)

Bureau of Mines
Division of Metallurgical
Minerals

Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT

OF

MINES AND RESOURCES

Mines and Geology Branch

O T T A W A July 15th, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1449.

Examination of Sample of Flame-Hardened Armour Plate.

=====

Origin of Material:

On June 16th, 1943, Mr. J. W. Fairlie, for Director General of Ammunition Production, Department of Munitions and Supply, Ottawa, Ontario, submitted a piece of flame-hardened armour plate, dimensions 12" x 12" x 2½", for examination.

In his covering letter Mr. Fairlie asked for a complete physical and chemical investigation and stated that no history of the sample is available. The sample was received from the Aberdeen Proving Grounds, Aberdeen, Maryland, U.S.A.

The purpose in requesting this investigation was to obtain information that might aid in the production of this flame-hardened armour plate in Canada, in thicknesses from 70 mm. and up, this being required for shot proof of the 17-pdr. A.P.C., B.C. shot.

Object of Investigation:

To determine physical properties, chemical analysis and microstructure of the hardened case, the transition zone, and the unaffected plate metal.

Procedure:

(1) The sample was magnafluxed[®] in an attempt to determine the direction of travel of the flame-hardening machine. No evidence of direction of travel was obtained.

(2) Two $\frac{3}{4}$ -in.-thick sections at right angles to one another were machined from the sample and macro-etched. Neither section showed an overlap of two passes of the flame-hardening head. Figure 1 is a macro-etched section showing the depth of the hardened zone.

(3) Brinell hardness tests were made on both the flame-hardened and the untreated surface of the sample. The following table shows the averages of the results obtained:

Brinell Hardness Numbers		
Flame-hardened surface	=	461
Untreated surface	=	235

(4) The following table lists the results of the chemical analysis:

Per cent			Per cent		
Carbon	=	0.20	Chromium	=	None
Phosphorus	=	0.019	Nickel	=	3.50
Sulphur	=	0.016	Molybdenum	=	0.25
Manganese	=	0.48	Vanadium	=	None
Silicon	=	0.24	Boron	=	None

(5) Hardness readings, using a Vickers hardness tester and a 10-kg. load, were taken from surface to surface. Figure 2 shows a graph of hardness versus distance from surface.

(Continued on next page)

(Procedure, cont'd) -

(6) Five micro-tensile test specimens were machined with their axes perpendicular to the plate surface and were then pulled in the tensometer machine. In addition, two round Izod test bars were machined from the centre of the plate. Three "V" notches 0.130 inch in depth were machined on each bar. The following table gives the averages of the test results:

Yield, P.S.I.	Ultimate, P.S.I.	Elongation, per cent	Red. of Area, per cent	Izod, ft.lb.
117,500	132,400	12.4	25.6	50

(7) Sections at right angles to the flame-hardened surface were examined under the microscope. Figure 3 shows the structure of the flame-hardened zone. Figure 4 shows the structure of the transition zone. Figure 5 shows the structure of the core of the plate.

Discussion:

Both the magnaflux test and the macro-etched sections fail to indicate the direction of travel of the flame-hardening machine. This would indicate that the entire section was flame-hardened in one pass, since no overlap was detected. This would require a flame-hardening head at least 12 inches in width or a multiple mounting of heads. To the best of our knowledge, flame-hardening heads this wide have not been reported in the literature. It is, however, possible that wide heads may be a recent development in this field.

An examination of Figures 1 and 2 shows a hardened zone approximately 0.50 inch in depth and a wide transition zone. A case depth of this magnitude on a plate of this thickness would require very slow hardening rates.

The chemical analysis is unusual for armour plate

(Discussion, cont'd) -

for flame hardening, in that the low carbon and manganese and high nickel and the absence of chromium and vanadium would result in a steel of low hardenability (Grossman hardenability factor, 2.4 inches), for the high percentage of nickel present does not greatly contribute to steel hardenability. The low hardenability is confirmed by the presence of precipitated ferrite in the hardened case. The low carbon content would result in a wide critical range, which would account for the wide transition zone and the gradual reduction of hardness in the hardness traverse.

It can be shown that the hardness obtained on the flame-hardened surface (461 Brinell) is very close to the maximum possible for this steel. It is customary to aim for a surface hardness of approximately 550 Brinell, this hardness being desired in order to break up the armour-piercing shot. Such a surface hardness, on this particular steel, could not be obtained.

The physical properties of the plate are consistent with the analysis and the usual heat treatment of armour plate.

CONCLUSIONS:

1. The sample submitted has been flame-hardened in one pass or by multiple mounted heads.
2. The flame-hardened case has a depth of approximately 0.50 inch.
3. The surface hardness obtained is the maximum possible for this steel but lower than that usually desired.
4. The chemical analysis is unusual and the

(Conclusions, cont'd) -

hardenability low.

5. The physical properties are consistent with the analysis and usual heat treatment of armour plate.

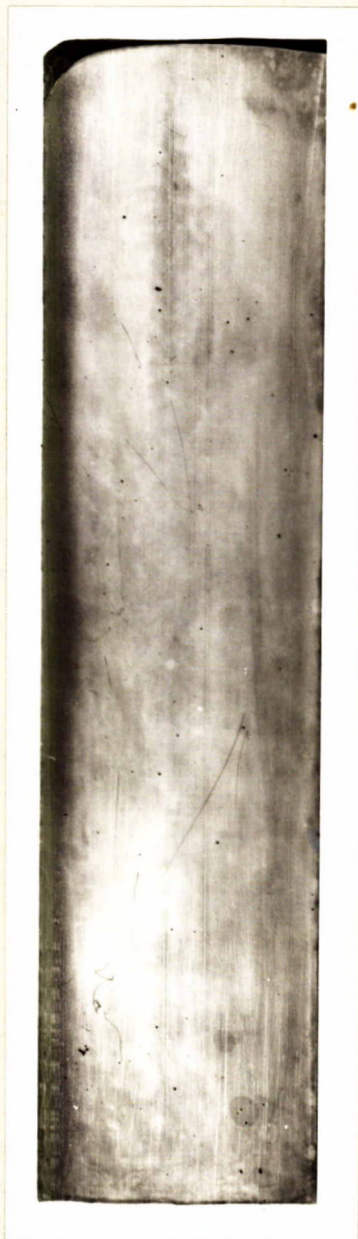
oooooooooooo

ooooo

o

BJN:GHB.

Figure 1.



Macro-etched (ammonium persulphate solution)
section of flame-hardened armour plate,
showing hardened case approximately 0.30
inch in depth and a wide transition zone.

(Figure 2, on next page, is a graph of
hardness vs. distance from surface.)



Figure 3.



X500, etched in
2 per cent nital.

MARTENSITIC STRUCTURE OF
CASE WITH SOME FERRITE
(WHITE AREAS).

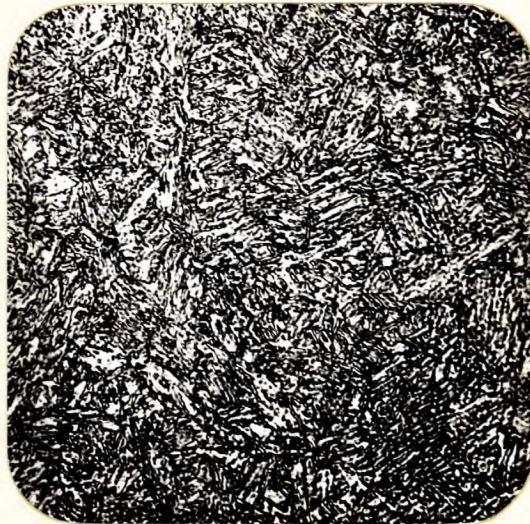
Figure 4.



X500, etched in
2 per cent nital.

TRANSITION ZONE - COARSE
MARTENSITE AND SOME FERRITE
(WHITE AREAS).

Figure 5.



X500, etched in
2 per cent nital.

CORE STRUCTURE - TEMPERED MARTENSITE.