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OTTAWA January 3rd, 1941.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 942.

Report on Failure of Heavy Armour Plate.

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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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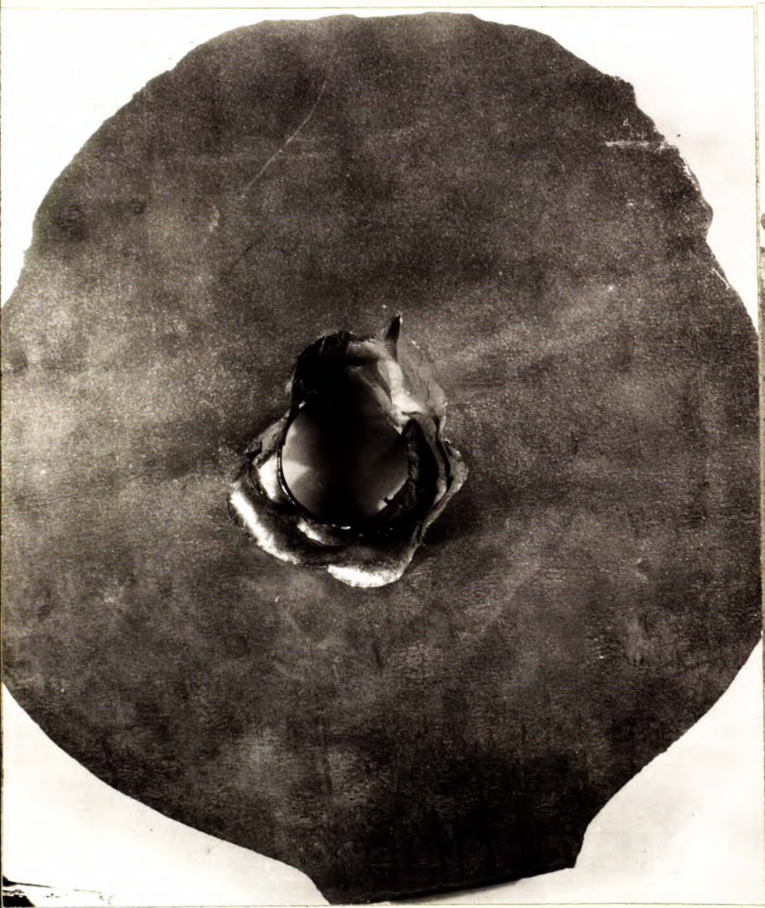
Origin of Problem and Nature of Investigation:

On December 27th, 1940, Mr. H. H. Scotland, Inspector for the United Kingdom Technical Mission, 58 Lyon Street, Ottawa, Ontario, submitted a piece of heavy armour plate which had been broken off a tank by the impact of a 2-inch shell. He requested a report on this material and the probable cause of its failure.

Macro-Examination:

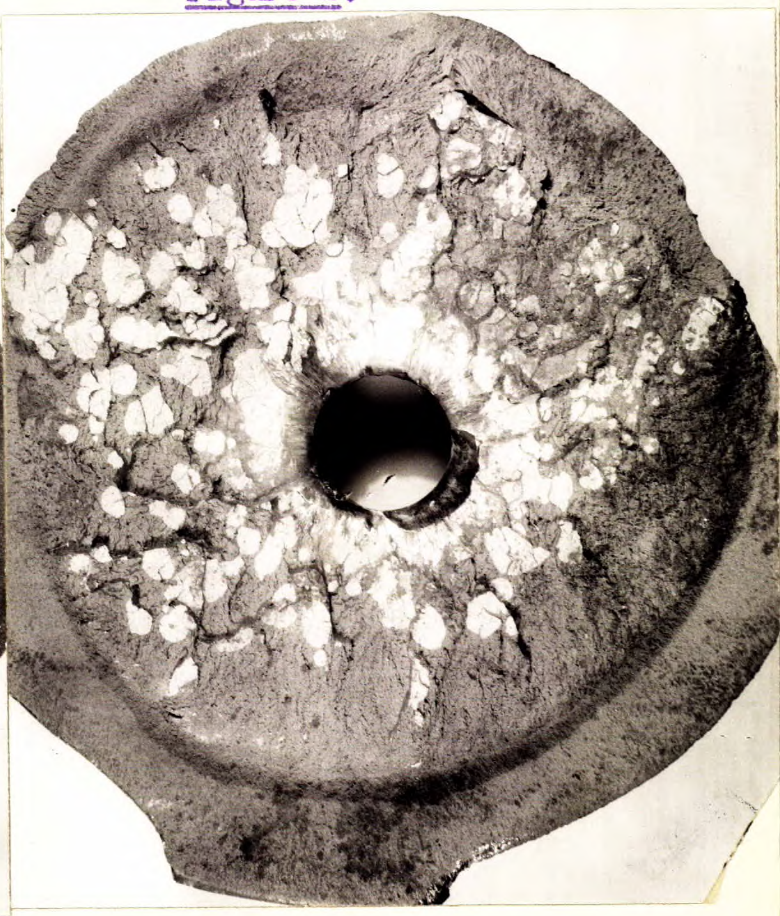
The piece of armour plate is shown as received in Figures 1 and 2.

Figure 1.



Piece of Armour Plate.
Exit of Projectile.

Figure 2.



Piece of Armour Plate.
Entrance of Projectile.

It is apparent that the shell made a clean hole through the plate. In the fractured surface, two types of surface are seen:

(1) Rough, grey, fine-grained; and

(2) Smooth, silvery, coarse-grained.

Micro-Examination:

The structures of the grey and silvery parts of the fracture are shown in Figures 3 and 4.

(Continued on next page)

(Micro-Examination, cont'd) -

Figure 3.

"Grey"
1000X, Nital etch.

Figure 4.

"Silvery"
1000X, Nital etch.

These metal structures are practically identical. The difference in reflection characteristics is due to the fact that the fracture is grey when passing through grains of metal and silvery when passing through grain boundaries.

Chemical Analysis:

Carbon	-	0.28 per cent
Manganese	-	0.53 "
Silicon	-	0.36 "
Sulphur	-	0.010 "
Phosphorus	-	0.017 "
Nickel	-	4.93 "
Molybdenum	-	0.63 per cent
Chromium	-	0.08 "
Vanadium	-	0.07 "

This analysis corresponds to that of S. A. E. Steel 2525, + 0.60 Mo

Hardness:

Brinell Hardness Number - 367.

Discussion of Results:

The silvery spots shown in the fractured surface are phenomena associated with heavy forged or rolled sections of alloyed steel. They have been called internal fissures, chrome checks, and hairline cracks, but the most generally used term is FLAKES.

Flakes are generally considered to be due to included hydrogen which does not have sufficient time to diffuse out of the metal while it is cooling. High internal stresses developed during the heat treatment of ingot and the forging or rolled section also may be responsible for flaked steel.

Types of steel arranged in order of increasing susceptibility to flakes are as follows:

1. Plain carbon steels (least liable to flakes).
2. Manganese silicon steels.
3. 1.00-2.00 per cent chromium steels (with or without molybdenum).
4. 1.5 per cent nickel steels.
5. Nickel steels.
6. Nickel chromium steels.
7. Nickel chromium molybdenum steels (most likely to have flakes).

The piece of armour plate submitted is a standard nickel steel, S. A. E. 2525, + 0.60% Mo.

Prevention of Flakes:

1. The ingot of steel should be cooled very slowly and carefully.
2. The forging or rolled shape should be cooled at a very slow rate.

(Continued on next page)

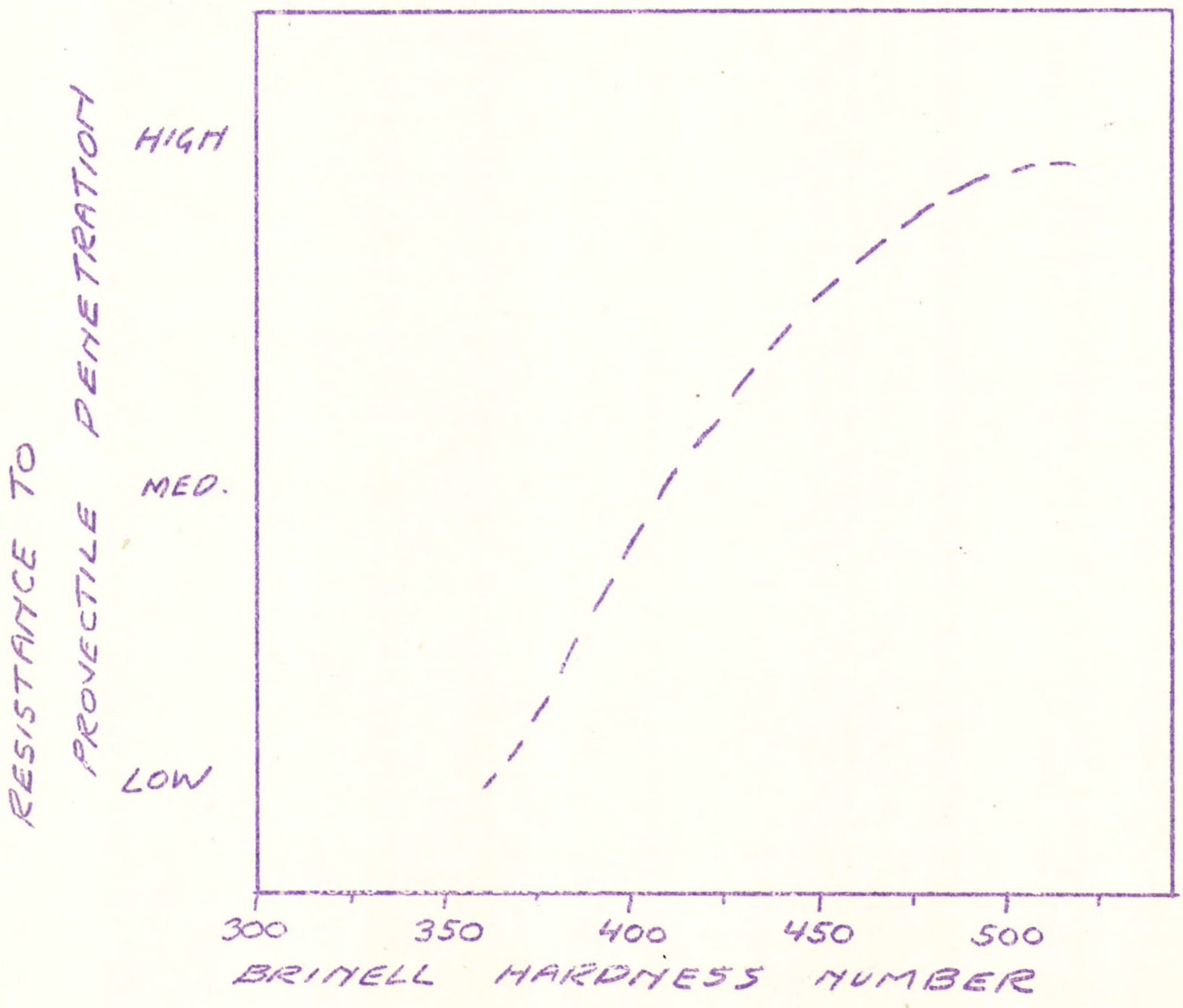
(Prevention of Flakes, cont'd) -

If sufficient care is taken in ingot and after-hot-work heat treatment, a sound product which can be quenched to a high hardness should result.

Detecting Flakes:

Flakes can be shown up by machining a cross-section and etching with 1:1 HCl (one part water to one part hydrochloric acid) or by using a Magnaflux instrument. Impact or bending tests to destruction will also show up the presence of flakes.

Hardness and Resistance to Projectile Penetration:



Some experiments on one type of armour plate

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(Hardness and Resistance to Projectile Penetration, cont'd) -

conducted by our laboratory have indicated that resistance to projectile penetration increases with Brinell hardness up to about 500 Brinell. A piece of metal with a hardness of 367 Brinell, therefore, could be made much more resistant to penetration by heat treating to a higher hardness. The selection of a hardness range for armour plate is guided by several considerations.

Soundness of Steel -

If steel containing cracks, flakes, seams, or large dirt inclusions is permitted, the resistance to projectile penetration will not increase with increased hardness. The internal defects will act as notches and the harder the steel is made, the greater will be the notch embrittlement effect. Therefore, inferior grades of steel, such as the sample examined herein, are better when used in the soft state.

If a sound, high quality steel is to be used, the maximum projectile penetration resistance will be obtained at a considerably higher hardness than that of the sample examined in this investigation.

Machining -

400 Brinell hardness appears to be near the limit of machinability. Therefore, in order to get the best properties, heat treatment must be performed after machining.

Warping -

In order to prevent warping, quenching fixtures

(Continued on next page)

(Hardness and Resistance to Projectile Penetration, cont'd) -

(Warping, cont'd) -

can be used or the part can be flame-hardened. (Austempering results in a minimum of distortion on thin pieces, i.e., pieces under ½ inch in thickness).

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Conclusions:

(1). This armour plate has not been treated to its optimum hardness. This is probably due to two reasons:

(a) Heat treating methods which will prevent warping are not used; consequently, the metal must be left soft for machining.

(b) Low quality steel containing flakes usually fractures due to notch embrittlement at higher hardness.

(2). This armour plate failed due to flakes or internal fissures, which indicates that sufficient care was not exercised in the ingot and rolling phases of its production.

(3). A sound steel would be much more resistant to projectile penetration if heat treated to a hardness greater than that of the piece of armour plate examined.

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