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OTTAWA March 5th, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1365.

Examination of Two 22-mm. Armour Plates
Used to Prove A/P Shot.

(Copy No. 10.)

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 October 13th, 1943, at the request of Capt. M. J. Ward, for the Director of Small Arms and Ammunition, Inspection Board of United Kingdom and Canada, Ottawa, Ontario, two samples of 22-mm. armour plate were submitted to these Laboratories, for examination, by F/Lt. D. Reynolds, Acting Superintendent, S.A.E. and P.E., I. B. U. K. and C., P. O. Box 280, Quebec, Quebec. These plates, which had been used at the Valcartier proving ground to prove 0.55 A/P ammunition, were identified as follows:

Plate No. 274 - produced by Dominion Foundries and Steel Limited, Hamilton, Ontario, and
Plate No. 258 - produced by Beardmore, England.

F/Lt. Reynolds' letter accompanying the samples, dated

October 10th, File No. SAV/P-1:SAV/P-52, stated that the Plate No. 274 had shown superior resistance to penetration. It was requested that these plates be examined to find any significant difference that would explain this behaviour.

This report has been delayed by the necessity of attending to work of more pressing nature.

Chemical Analysis:

The chemical analyses of these plates are given in Table I. It should be noted that the steels of these plates are of entirely different composition.

Table I.

		Plate No. 258	Plate No. 274
		-(Per cent)-	
Carbon	-	0.26	0.30
Manganese	-	0.43	0.65
Silicon	-	0.09	0.14
Phosphorus	-	0.017	0.011
Sulphur	-	0.014	0.011
Molybdenum	-	0.57	0.53
Chromium	-	1.72	2.07
Nickel	-	3.45	0.61
Vanadium	-	0.17	Not detected.
Aluminium	-	Not detected.	" "
Tin	-	0.010	0.009

Mechanical Testing:

The mechanical properties of the steel in these plates were determined.

Owing to the hardness of the steel, it was not practical to machine out standard round tensile bars. Bars having a square section were cut out and ground. Owing to the condition of the plate it was not possible to obtain a bar with a gauge length longer than 2 inches. Two bars were cut from each plate, one bar parallel to the direction of rolling (longitudinal) and the other bar across the direction of rolling (transverse). The results of these tests are

(Mechanical Testing, cont'd) -

given in Table II.

Table II. - Mechanical Properties.

	Plate No. 258		Plate No. 274	
	Longitudinal	Transverse	Longitudinal	Transverse
Ultimate tensile strength, p.s.i. -	227,800	229,600	265,000	241,500
0.1 per cent proof stress, p.s.i. -	171,300	154,800	182,100	185,300
Elongation in 2 inches, per cent -	16.5	11	13	10.5
Reduction in area, per cent -	30.5	18.1	23.9	19.5
Cross-sectional area, sq. in. -	0.6545	0.6638	0.5486	0.561
Vickers hardness number -	475		570	
Brinell " " -	444		495	

Microscopic Examination:

Specimens were prepared for microscopic examination. Figure 1 is a photomicrograph, at 100 diameters, from Plate No. 258 in the "as polished" condition. Compare this with Figure 2 which is a photomicrograph, also at 100 diameters, from Plate No. 274 in the "as polished" condition. Note the elongated inclusions in Plate No. 258.

Figures 3 and 4 are photomicrographs at 2,000 diameters showing the structure of the steel in Plates Nos. 258 and 274, respectively, as revealed by a picral etch. It would appear from Figure 7 that there were some carbides at the grain boundaries of the steel in Plate No. 258.

Hardenability:

The McQuaid-Ehn grain size of both of these steels at 1700° F. was found to be 7. The hardenability, calculated from the chemical analysis according to data published by Marcus A. Grossman in Technical Publication No. 1437, A.I.M.E., is given in Table III. This value is expressed as the diameter

(Hardenability, cont'd) -

of a round bar that will just harden at the centre when quenched under ideal conditions.

Table III. - Hardenability Calculated from Chemical Analysis.

	Plate No. 258	Plate No. 274
Ideal bar diameter, inches -	8.41	6.61

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Decarburization:

Decarburization was measured by means of a hardness survey. Results are given in Table IV.

Table IV. - Depth of Decarburization.

	Plate No. 258	Plate No. 274
Depth of decarburization, inches -	0.02	0.03

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Discussion of Results:

There have been many points of difference found between these two plates.

Plate No. 274 is much harder than Plate No. 258. This in itself could be accepted as the reason why Plate No. 274 resisted penetration better under conditions of test. However, it is a fact that when armour plate becomes too hard it has a tendency to spall and crack when attacked with heavier ammunition; that is, its shock resistance may be lower. Neither of these plates was submitted to a shock test so their behaviour under these conditions is not known.

It will be noted from Table II that there is a

(Discussion of Results, cont'd) -

greater spread between the 0.1 per cent proof stress and the ultimate tensile stress for Plate No. 274 than for Plate No. 258 when taken in the longitudinal direction. There is evidence that when two plates have the same hardness the plate having the wider spread betwen the proportional limit and the ultimate tensile strength may be expected to possess the better ballistic properties.

The other main point of difference is in the type and amount of inclusions. The steel in Plate No. 258 has a fairly large number of very long stringers, composed mainly of sulphides. The steel in Plate No. 274 is much cleaner and there are no long stringers present. These long stringers in Plate No. 258 would have the tendency to cause the plate to spall more readily. This difference in inclusion type and frequency may also explain the low reduction in area obtained on the longitudinal tensile test of Plate No. 258.

From Figure 3 it would appear that there is a slight suspicion of carbides at the grain boundaries of the steel in Plate No. 258. It is interesting to note, in this connection, that the steel in Plate No. 258 contains 0.17 per cent vanadium. Vanadium carbides are very difficult to put into solution unless special precautions are taken in heat treatment. The presence of segregated carbides will be injurious to the ballistic properties.

It has been shown in our Report of Investigation No. 1319 (October, 1942) that there is a certain optimum range for Grossman hardenability values and that as this value increases beyond that range the ballistic properties suffer. The optimum range has not been determined for this thickness of plate but the possibility exists that the

(Discussion of Results, cont'd) -

hardenability of Plate No. 258 exceeds the optimum value.

Before too much significance is attached to the above-mentioned factors, the following points should be brought to mind:

1. The ballistic limits of these plates are not known. It is merely known that Plate No. 274 defeats 0.5 calibre A/P shot at 2,820 feet per second and Plate No. 258 does not. It is not known whether or not Plate No. 274 would have satisfactory shock-resisting properties.

2. When two plates vary widely in ballistic properties it is often quite possible to find some explanation for this variation in the presence of ferrite, massive carbide, inclusion segregation, etc., or some other self-evident indication of faulty manufacturing practice. But when the variations in quality of products of processes reasonably well under control are being studied and correlated it is necessary to have available a large number of samples and the narrower the range of variation the larger is the number of samples required.

Bearing these two facts in mind, the results of this investigation may be analysed as follows:

The higher hardness of Plate No. 274, combined with the wider spread between the proportional limit and ultimate tensile strength, lack of grossly elongated inclusions, cleanliness of steel, and lack of evidence of segregated carbides, all indicate that this plate should be expected to possess higher resistance to penetration by light-calibre ammunition (0.5 calibre) than does Plate No. 258.

It is interesting to note that the steel in this plate, first of all, contains no vanadium, and secondly, is

(Discussion of Results, cont'd) -

a chromium-molybdenum steel. Is this combination of high hardness, low proportional limit, and high ultimate tensile strength a characteristic of this steel or is it merely a characteristic of this heat-treatment process? This question should be answered. If it is possible to produce a duplicate of Plate No. 274 for complete ballistic and shock testing, this should be considered. It would certainly be a worthwhile development if an armour plate of the hardness of this Plate No. 274 and possessing good shock-resisting properties could be produced.

CONCLUSIONS:

1. The steel in Plate No. 274 is harder and possesses mechanical properties superior to those of the steel in Plate No. 258.

2. The steel in Plate No. 258 contains many elongated inclusions. This will lower the resistance of this plate to spalling.

3. The steel in Plate No. 258 contains vanadium. Vanadium forms a very stable carbide that is very difficult to put into solution on heat treatment. Carbide segregations were noted in this steel.

Recommendation:

It is considered that the results of this investigation warrant a more complete investigation into the ballistic properties of plates similar to Plate No. 274.

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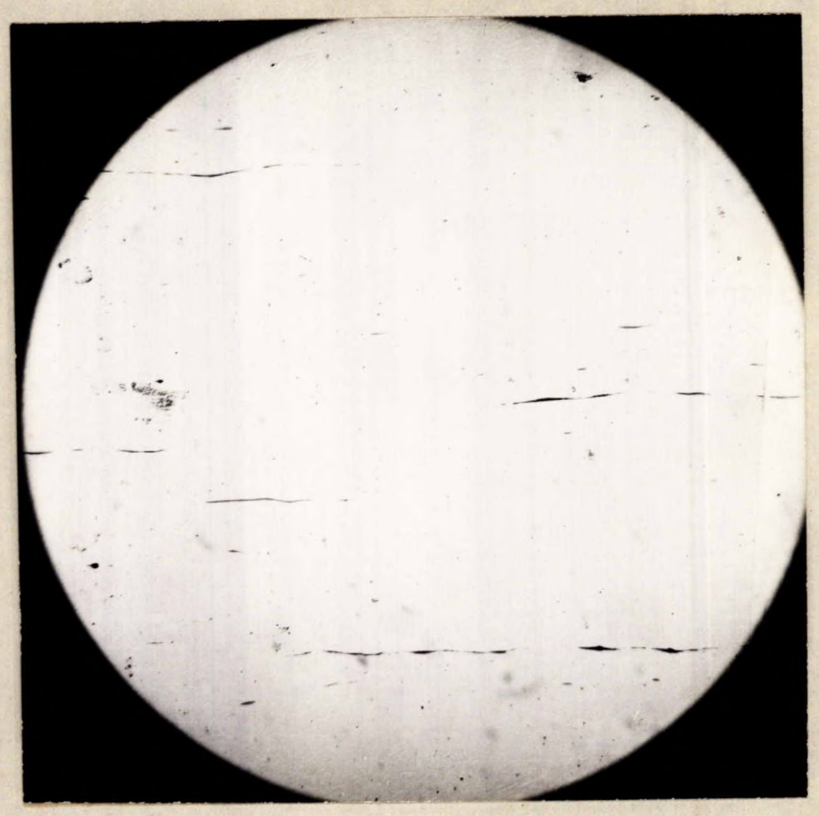
HVK:FES:GHB.

Figure 1.

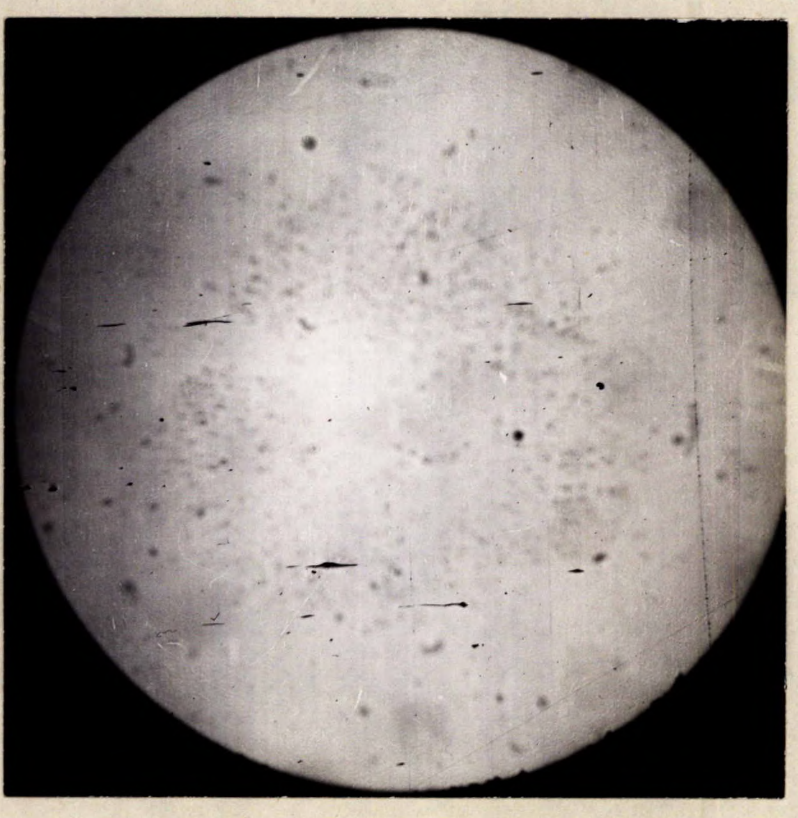


X100, as polished.

PLATE NO. 258.

Note inclusions and
compare with Figure 2.

Figure 2.



X100, as polished.

PLATE NO. 274.

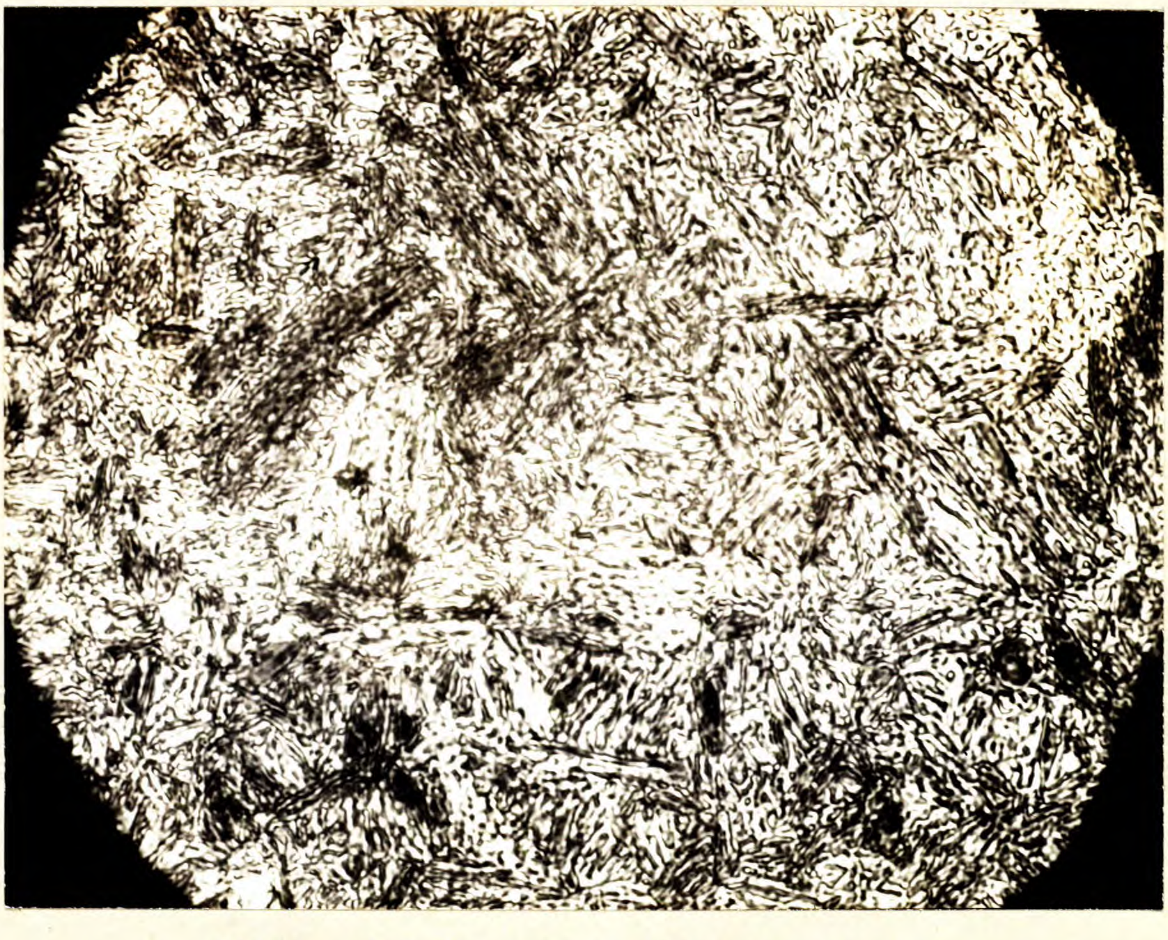
Note inclusions and
compare with Figure 1.

Figure 3.

X2000, electro polish, picral etch.
PLATE NO. 258.

Little particles that might be carbides appear along one of the grain boundaries in this picture.

Figure 4.



X2000, electro polish, picral etch.
PLATE NO. 274.

HVK:GHB.