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OTTAWA June 12th, 1944.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1662.

Metallurgical Examination of Steel Plate from German Scout Car.

(Copy No. 13.)

Bureau of Mines
Division of Metallic
Minerals
-
Physical Metallurgy
Research Laboratories

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

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Metallurgical Examination of Steel Plate from German Scout Car.

Origin of Request and Object of Investigation:

On May 20th, 1944, three pieces of German steel plate were received from the Division of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Ottawa, Ontario, under Requisition No. 648 (Lot No. 540, Report No. 13, Test No. 62). These sections had been taken from an enemy scout car and were of two sizes (two 0.35-inch bulletproof plates and one 0.085-inch steel sheet).

It was requested that a complete metallurgical investigation be made on the material, including an examination of all weldments. The present report covers only the first part of the request; the study of the welds will be given in another investigation.

For the purposes of this report, the thinner plate is referred to as Plate No. 1, and the thicker, bulletproof plate as Plate No. 2.

Chemical Analysis:

		Plate No. 1	Plate No. 2
		- Per Cent -	
Carbon	-	0.13	0.43
Manganese	-	0.33	1.11
Phosphorus	-	0.075	0.013
Sulphur	-	0.057	0.019
Silicon	-	0.01	1.50
Nickel	-	N.D.	N.D.
Chromium	-	N.D.	1.13
Molybdenum	-	Trace.	

N.D. = None detected.

Grain Size:

Specimens from each plate were given a standard carburizing treatment for McQuaid-Ehn test, polished, etched in 4 per cent picral, and examined for grain size. Figure 1 shows a McQuaid-Ehn grain size of 1-2 (ASTM Standard) for Plate No. 1, while Plate No. 2 had a fine McQuaid-Ehn grain size, 5 (see Figure 2).

Fracture tests made on bars in the "as received" condition gave the following grain size numbers:

Plate No. 1: 4 (ASTM Standard).
Plate No. 2: 5 (" ").

Inclusions:

Samples were taken from each plate and polished for inclusion examination. The thinner plate appeared to be quite dirty, yet, as the plate was so soft, a satisfactory polish could not be made except by electrolytic means. As such electrolytic apparatus was not available at the time of examination, inclusions were observed carefully at high magnification in order to distinguish them from pits. Sulphide inclusions were numerous, while smaller amounts of basic silicate and oxide types were also present. The bulletproof Plate No. 2 was cleaner (Figure 3) although it still could not be considered a "clean steel." A complex SiO_2 Al_2O_3 type of inclusion was quite prevalent

(Inclusions, cont'd) -

which was very similar to the pink titanium nitride type but lacked the angular contour. Figure 4 is a photomicrograph of globular acid silicate inclusions, with the grey elongated sulphide type adjoining. This type of inclusion appeared most frequently, which would be expected because of the large amount of silicon present in the steel.

Metallographic Structure:

Figure 5 is a photomicrograph of Plate No. 1, showing the structure to be made up entirely of ferrite grains. It is of interest to note the overlapping effect of the grains within a grain, indicated by a double-line boundary.

Figure 6 (photomicrograph of sample cut across the rolling direction) shows the structure of the No. 2, bullet-proof plate to be mainly tempered martensite. However, it will be noticed that there are also present some areas with the acicular structure of a bainite product.

A sample cut in the rolling direction shows decided banding, which is a very common occurrence with high-silicon steels. (See Figure 7).

Decarburization and Hardness:

Etching disclosed a slight amount of decarburization on the rolled surfaces of Plate No. 2. However, as it was not possible to make an estimate of the amount by microscopic observation, due to an indistinct line of demarcation, the decarburization was determined by hardness tests.

The readings were made by a Tukon hardness tester under a 500-gram load. They showed a decarburization of 0.0095 inch on one side and 0.0075 inch on the other.

The hardness of the plate was 440 Brinell (46½ Rockwell 'C' scale) with the outer surface 332 Brinell (36 Rockwell 'C'

(Decarburization and Hardness, cont'd) - scale).

Plate No. 1 showed an average hardness of 120 Brinell. This hardness reading was taken on a Rockwell 'F' scale and converted to the Brinell scale.

Hardenability:

This property would not be under consideration in the case of Plate No. 1, as the carbon content would be too low for any hardening from quenching.

Plate No. 2 had a calculated Grossman hardenability of 5.14 inch, which is very high considering the thickness of plate. A Jominy hardenability test was not made, as it was assumed that with the high alloy content the plate would naturally harden throughout on quenching.

Physical Properties:

Tensile test bars were cut from each plate in the rolling direction, to determine the physical properties of the "as received" material.

		Plate No. 1	Plate No. 2
Tensile strength, p.s.i.	-	60,000	202,500
0.2 per cent proof stress, p.s.i.	-	43,000	187,300
Elongation in 2 inches, per cent	-	29*	9
Reduction of area, per cent	-	52.5	19.2
Brinell hardness	-	120	440

* 50 per cent in 1 inch.

Discussion:

Plate No. 1 -

Plate No. 1 has been manufactured by the open hearth process and represents an ordinary low-carbon rimmed steel. The practice in this county in making sheet steel tends toward a

(Discussion, cont'd) -

lower carbon, and whether this represents a German sheet specification is not known. It is not usual to find phosphorus and sulphur remaining so high when a heat has been worked for a long period in order to run down to such low carbon. It is possible that the heat has been hurried too rapidly by continued "oreing", preventing the good slag formation that is necessary for proper phosphorus elimination. There is, also, an indication that poor quality scrap or high impurity pig iron was used in making up the charge. However, the possibilities are numerous and any one cannot be specified as being responsible for the numerous impurities present.

The difference in grain size, as determined by fracture and McQuaid-Ehn tests, is probably the fault of the latter test. The carburizing of such a low-carbon steel would make the grain in the case larger than the grain in the core, due to the lowering of the critical temperature in the outer zone. This would produce a greater grain-coarsening action in the case, due to the increased heating above critical temperature.

The "overlapping" phenomenon of the ferrite grains would indicate that cold rolling was given at some time during the fabrication of the steel sheet. Since the grains are not elongated the cold work would be followed by a stress-relieving anneal, which conforms to normal practice.

Plate No. 2 -

Plate No. 2 is probably an electric-furnace, aluminium-killed product. This is indicated by the low sulphur content, which would not be characteristic of an open hearth alloy steel.

The use of silicon to increase hardenability indicates the growing scarcity of nickel and molybdenum, although the possibility that the Germans prefer silicon steel for this type of bulletproof plate must not be overlooked.

The addition of chromium to this silicon steel could

(Discussion, cont'd) -

possibly have been made to improve the quality of the quenched product. The upper nose of the "S"-curve is moved well to the right by 1 per cent chromium and there is also the formation of a lower nose which would produce bainite on continuous cooling. Thus, quenching may be at such a rate as to produce a combination of bainite and martensite which on tempering would yield a product having toughness combined with strength.

A theory advanced as to the cause of banding in these steels is that proeutectoid ferrite formed during annealing would have a high percentage of silicon dissolved in it. This would make these ferrite areas more resistant to carbon solution than the remainder of the steel, thus developing the segregated portion which shows up as light etching.

The decarburization of this plate is not considered extensive, especially since a high-silicon steel is being treated. This would indicate the use of a controlled-atmosphere furnace during heat treatment.

The hardness might seem high, yet the combined martensite-bainite structure could possibly add sufficient toughness to prevent any serious spalling effect.

The British specification for aircraft bulletproof plate calls for 470 Brinell hardness while the U.S.A. prefer the softer 400 Brinell plate. Such aircraft armour has not been used on tanks, for the reason that although it withstands attack successfully up to the 20-mm. shell, any larger projectile causes serious shattering.

The Germans could possibly have had such success with this high-hardness armour in aircraft that its use was adopted for land vehicles as well. However, the ability of this armour to withstand impact from large-calibre shells would seem to be

(Discussion, cont'd) -

poor and it would probably be subject to cracking and shattering.

CONCLUSIONS:

The thin steel sheet is of a poor grade low-carbon steel. It would offer no protection from shell fragments and would undoubtedly be used only within an armoured vehicle where it would not be subject to attack of any kind.

The bulletproof plate is a good steel of high strength but lacks ductility. The hardness is much higher than that specified by British armour manufacturers for land fighting vehicles and there would seem to be a possibility of its shattering under heavy impact. However, the structure is sound and seems to have been developed to give combined strength and toughness. The ballistic properties could be determined only by firing-range tests.

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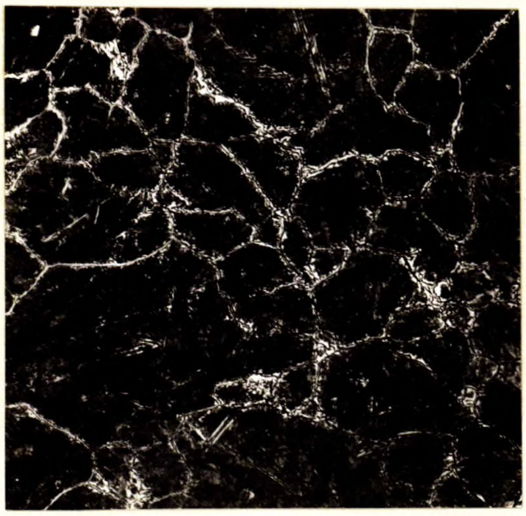
BMH:GHB.

Figure 1.

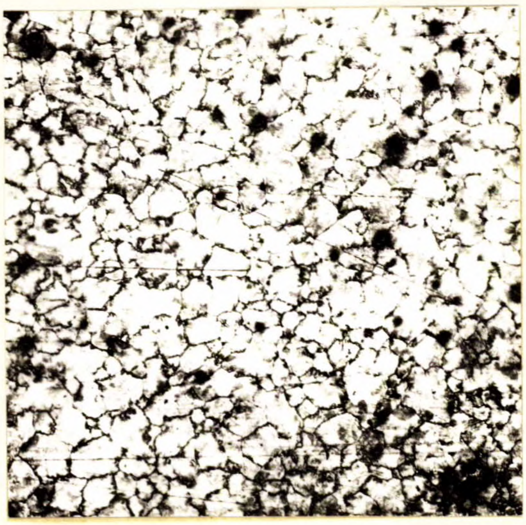


X100, picral etch.

MCQUAID-EHN GRAIN SIZE
FOR PLATE NO. 1.

ASTM rating: 1-2.

Figure 2.



X100, picral etch.

MCQUAID-EHN GRAIN SIZE
FOR PLATE NO. 2.

ASTM rating: 5.

Figure 3.

X100, unetched.

INCLUSIONS IN PLATE NO. 1.

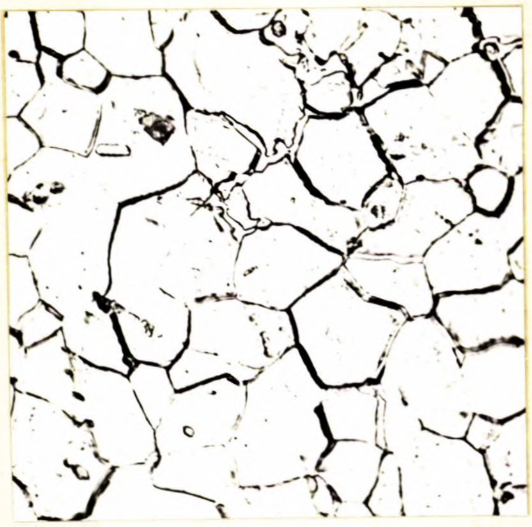
ASTM rating: 2.

Figure 4.

X1000, unetched.

ACID SILICATE INCLUSIONS AND
ADJOINING ELONGATED SULPHIDE-TYPE
INCLUSIONS.

Figure 5.



X500, picral etch.

MICROSTRUCTURE OF PLATE NO. 1.

Note overlapping grains of ferrite, indicated by a double-line boundary.

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Figure 6.

X1000, picral etch.

MICROSTRUCTURE OF PLATE NO. 2, SHOWING TEMPERED MARTENSITE BAINITE STRUCTURE.

(Sample cut across rolling direction).

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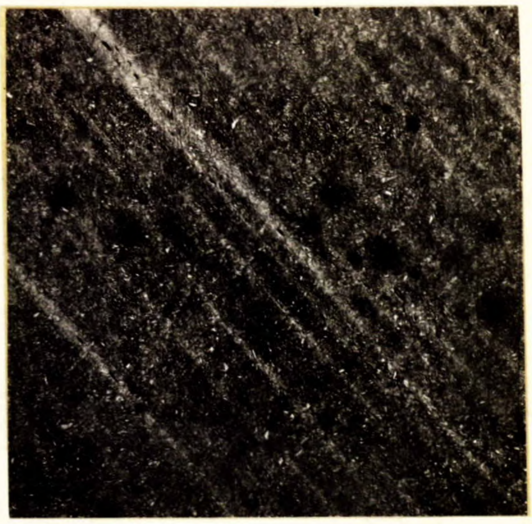
Figure 7.



X100, picral etch.

MICROSTRUCTURE OF PLATE NO. 2.

Note segregated banding.

(Sample cut along rolling direction).

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BMH:GHB.