File

OTTAWA April 18, 1945.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1842.

Preliminary Report on Metallurgical Examination of 60-mm. British Armour Plate.

(Copy No. 18.)

ABSTRACT

Through-plate mechanical properties correlate very well with ballistic properties of rolled plate. Those plates with the higher through-plate mechanical properties gave the better ballistic results.

Ballistic limits of the cast plates were too uniform and the mechanical properties too varied to obtain good statistical correlation.

Ballistically the rolled plates could be divided into four groups in order of merit as follows:

1.	Firth Brown	1½ Cr-Mo	Basic Electric.
2.	E. S. C.	1½ Cr-Mo	Acid Open Hearth.
3.	(Colvilles	1½ Cr-Mo	Basic Open Hearth.
	(E. S. C.	Low Alloy	Basic Electric.
4.	(Firth Brown	Low Alloy	Acid Open Hearth.
	(Colvilles	Low Alloy	Basic Open Hearth.

There was little drop in hardness from surface to centre in any of the plates.

Variations in melting practice (time at heat, etc.) may be responsible for differences between the various groups of rolled plates, but the significance of the difference is such that further investigation is in order.

Bureau of Mines
Division of Metallic
Minerals

Physical Metallurgy
Research Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

O T T A W A   April 18, 1945.

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Origin of Material and Object of Investigation:

On May 31, 1944, Mr. E. W. Shaw, Inspecting Officer, Directorate of Tanks and Motor Transport, Inspection Board of the United Kingdom and Canada, Ottawa, Ontario, requested (by letter, File No. 4/10/102/11) that a quantity of 60-mm. British armour plate which was then being proof-tested at the Proof and Development Establishment, Valcartier, Quebec, be given a thorough metallurgical examination. The object of this examination was to correlate the mechanical and metallographic properties with the ballistic properties.

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

The firings at Valcartier were carried out at cold (-40° to -30° F.), medium (0° to 20° F.), and warm temperatures (60° to 80° F.). Armour-piercing shot used consisted of 2-pounder, 6-pounder and 75-mm. on the rolled plate and of 2-pounder, 6-pounder and 37-mm. on the cast plate. Further information on the ballistic testing may be found in the report of the Artillery Proof Establishment, Valcartier, Que., entitled "Trial of British Armour at Low Temperatures" (V412: Dec. 1944), and also in the British Ministry of Supply's Armour Branch Report M6088A/4 No. 12, "Low Temperature Ballistic Tests on Armour" (Dec. 30, 1944).

Data on Plates:

Pertinent data on the plates received are listed in Table I.

TABLE I.

Plate Nos.	Manufacturer	Nominal Composition	Melting Practice
		ROLLED PLATES	
1-6	English Steel Co.	1½ Cr-Mo	Acid Open Hearth
7-12	Colvilles	1½Cr-Mo	Basic Open Hearth
13-18	Firth Brown	1½ Cr-Mo	Basic Electric
19-24	Firth Brown	Low Alloy	Acid Open Hearth
25-30	Colvilles	Low Alloy	Basic Open Hearth
31-36	English Steel Co.	Low Alloy	Basic Electric
		CAST PLATES	
43-48	Hadfields	Vibrac 45	Basic Electric
55-60	Hadfields	1½ Cr-Mo	Basic Electric
67-72	Hadfields	Low Alloy	Basic Electric

No mention was made of deoxidizing practice in the information received.

Program of Test Work -

It was felt that the rather large expenditure made in firing the plates warranted a thorough metallurgical examination, and an extensive program was drawn up. This included the following:

1. Tensile (through thickness) Tests: Elongation, reduction in area, yield, and maximum strength.

2. Izod notched-bar impact, on through-plate specimens, at -40° F., 0° F. and room temperature.

3. Hardness surveys through the thickness.

4. Inclusion counts.

5. As-quenched grain size determinations, to be used in Grossman's method of calculating hardenability from chemical composition. (There was insufficient material available for end-quench tests).

6. Chemical analyses.

7. Metallographic examination.

With the large amount of data available the problem resolved itself into one of interpreting the results of the mechanical and ballistic tests and subjecting them to statistical analysis. It is with this that the present preliminary report deals. Included herein are the mechanical properties at room temperature, the hardness surveys, and the inclusion counts.

Mechanical Tests:

Tensile specimens had been cut from the top and bottom of the original ingots in both the transverse and longitudinal direction. To eliminate plate-to-plate variations, however, two through-plate specimens were cut from each sample. It was felt that the through-plate properties would give better correlation with the ballistic properties, since both are affected by laminations, rolled inclusions and change in hardness through the thickness of the plate. Two through-plate Izod specimens were also made from each plate. The results are shown in Tables II and III.

(Continued on next page)

(Mechanical Tests, cont'd) -

TABLE II. - ROLLED PLATES.

Specimen No.	Type of Plate	Maximum stress, p.s.i.	Yield stress, p.s.i.	Elongation, per cent in 1 inch	Reduction of area, per cent	Izod impact at room temperature, ft-lb.
1	ENGLISH STEEL CO. 1½ Cr - Mo A.O.H.	137,100	118,100	13.0	25.5	19.5
			126,000	7.5	12.0	20.5
2		138,800	122,500	10.0	16.9	15.0
		138,000	123,400	10.0	9.0	20.5
3		138,100	124,400	11.5	24.6	21.0
		136,100	--	8.0	14.7	22.0
4		135,500	125,800	7.0	17.7	17.0
		133,900	125,800	7.0	21.0	25.0
5		134,000	117,700	10.0	11.3	17.5
		124,500	--	12.0	8.1	20.0
6		135,000	121,700	14.5	29.2	20.0
		135,200	123,000	13.0	31.1	19.0
7	COLVILLES 1½ Cr - Mo B.O.H.	114,100	102,000	5.0	6.3	16.0
		114,100	102,100	5.0	6.6	17.5
8		110,000	94,700	6.5	7.5	16.0
		110,400	94,000	7.0	9.0	17.0
9		118,300	100,300	7.5	9.6	18.0
		118,500	97,400	10.0	12.5	14.5
10		109,300	93,000	6.5	7.5	15.0
		104,300	91,300	4.0	4.8	42.0
11		112,200	94,100	8.0	11.3	16.0
		112,200	93,600	8.0	11.3	18.5
12		112,350	110,600	5.0	8.0	15.0
		112,200	110,100	6.0	8.0	15.5
13	FIRTH BROWN 1½ Cr - Mo Basic Electric	134,000	123,000	16.0	30.3	43.0
		134,000	118,000	16.0	35.0	44.0
14		133,400	119,000	17.0	35.0	36.0
		132,600	115,400	12.0	19.0	42.0
15		130,400	121,700*	16.0	36.5	43.0
		131,100	113,700	16.0	37.5	46.0
16		132.400	116,100	14.0	32.8	40.0
		131,100	114,100	14.5	28.7	35.5
17		130,700	112,100	18.0	49.0	47.0
		129,400	110,600	19.0	46.7	51.0
18		130,000	115,000	19.0	49.1	21.5
		129,400	117,400	14.0	32.3	20.0

* Probably high.

(Continued on next page)

(Mechanical Tests, cont'd) -

Table II, Rolled Plates (continued)

Specimen No.	Type of Plate	Maximum stress, p.s.i.	Yield stress, p.s.i.	Elongation, per cent in 1 inch	Reduction of area, per cent	Izod impact at room temperature, ft-lb.
19	FIRTH BROWN Low Alloy A.O.H.	138,700	127,400	6.0	9.3	11.0
		134,800	122,600	5.0	9.5	11.0
20		135,200	127,000	4.0	3.0	15.0
		141,300	128,500	10.0	19.0	17.0
21		128,000	115,600	6.0	6.0	7.0
		125,000	112,500	3.0	8.0**	9.0
22		138,700	121,000	6.0	14.5	16.0
		127,900	116,100	6.0	11.3	12.0
23		136,400	120,000	5.0	9.5	15.0
		126,400	116,000	5.0	9.5	11.0
24		142,700	120,000	12.0	22.6	35.0
		142,000	122,600	12.0	19.0	12.0
25	COLVILLES Low Alloy B.O.H.	117,700	98,200	9.0	11.3	22.5
		104,700	--	Nil	Nil	22.0
26		122,600	106,500	10.0	17.7	21.0
		123,200	106,500	9.0	14.5	21.0
27		107,000	90,200	6.0	6.3	15.0
		104,600	100,000	6.0	7.8	15.5
28		106,000	95,200	6.0	8.1	18.0
		104,900	96,800	5.0	9.7	14.5
29		115,100	111,300	5.0	6.4	15.0
		114,900	107,500	5.0	6.4	14.0
30		110,400	109,700	3.0	1.6	12.0
		111,300	111,300	1.0	3.2	11.0
31	ENGLISH STEEL CO. Low Alloy B.E.	122,200	111,100	12.0	25.4≠	30.0
		121,300	115,800	11.0	20.6≠	30.0
32		117,100	108,100	15.0	33.9≠	20.0
		117,500	109,700	11.0	24.2≠	22.0
33		113,900	108,100	13.0	24.2	40.0
		114,500	106,500	12.0	25.8	42.0
34		118,600	109,600	12.0	24.2	29.5
		119,000	111,300	12.0	22.6	34.0
35		117,700	104,800	10.0	27.3	42.5
		118,300	103,100	14.0	32.0	42.0
36		121,900	111,300	10.0	21.0≠	21.0
		122,600	114,500	12.0	24.2	18.0

** Broke on gauge line.
≠ Broke outside middle third.

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(Mechanical Tests, cont'd) -

TABLE III. - CAST PLATES.

Speci-men No.	Type of Plate	Maximum stress, p.s.i.	Yield stress, p.s.i.	Elongation, per cent in 1 inch	Reduction of area, per cent	Izod impact at room temperature, ft-lb.
43A		140,600 137,700	127,500 116,200	14.0 11.0	25.8 16.1	44.0 46.0
43B	HADFIELDS Basic Electric	117,700 135,500	Nil 122,500	2.0 7.0	3.2 14.5	30.0* 33.0
44A		131,200 133,300	117,700 125,800	16.0 9.0	35.5 19.4	59.0 58.0
44B		138,400 137,700	122,600 125,800	12.0 11.0	24.2 21.0	40.0 40.0
45A		132,900 116,100	116,100 Nil	10.0 3.0	12.9 6.4	33.0 42.0
45B		122,600 129,000	116,100 114,500	7.0 9.0	14.5 14.5	53.0 48.0
46A	HADFIELDS Vibrac 45	139,400 141,900	121,000 127,400	9.0 15.0	17.7 29.0	18.0 40.0
46B		138,700 141,300	122,200 127,400	12.0 14.0	17.5 32.5	64.0 38.0
47A		136,100 139,000	121,000 127,400	16.0 15.0	37.1 32.5	30.0 32.0
47B		135,500 136,100	125,800 121,000	8.0 8.0	11.3 12.9	28.0 30.0
48A		135,800 136,100	125,800 121,000	11.0 15.0	16.1 30.0	49.0 47.0
48B		134,300 134,800	121,000 119,400	11.0 11.0	21.0 21.0	29.0 34.0
55A		130,700 130,000	109,300 116,100	7.0 5.0	16.9 9.2	23.0 28.0
55B	HADFIELDS 1½ Cr Mo B.E.	138,700 139,000	124,200 124,200	15.0 15.0	29.0 29.0	30.0 28.0
56A		137,000 137,900	122,500 127,500	7.0 7.0	13.0 11.3	30.0 30.0
56B		Poor Quality Sample			- - - -	26.0 32.0
57A		-- 141,000	-- 117,700	15.0 10.0	29.0 14.5	42.0 44.0
57B		142,900 139,600	127,400 121,000	16.0 11.0	29.0 17.7	45.0 43.0

* Broke outside middle third.

(Continued on next page)

(Mechanical Tests, cont'd) -

Table III, Cast Plates (continued)

Speci-men No.	Type of Plate	Maximum stress, p.s.i.	Yield stress, p.s.i.	Elongation, per cent in 1 inch	Reduction of area, per cent	Izod impact at room temperature, ft-lb.
58A	HADFIELDS 1½ Cr - Mo B. E.	128,200	106,500	8.0	16.1	43.0
		128,200	104,800	8.0	16.1	42.0
58B		127,500	108,000	12.0	25.8	43.0
		128,200	106,500	8.0	25.8	47.0
59A		121,000	100,000	6.0	8.9	55.0
		121,500	100,000	11.0	22.6	56.0
59B		121,300	100,000	10.0	29.0	51.0
		120,600	100,000	10.0	20.0	48.0
60A		139,000	119,400	7.5	11.3	32.0
		137,100	119,400	8.0	14.5	35.0
60B		141,300	121,000	16.0	30.0	37.5
		142,500	127,400	16.0	33.9	35.0
67A	HADFIELDS Low Alloy B. E.	117,700	108,100	10.0	21.0	55.0
		118,100	104,800	15.5	38.7	60.0
67B		110,700	96,400	14.0	24.2	62.0
		104,200	95,200	7.0	14.5	52.0
68A		116,800	104,800	20.0	43.6	58.0
		116,100	104,800	19.0	43.6	56.0
68B		109,000	90,300	16.0	41.9	64.0
		110,000	98,400	13.0	38.2	59.0
69A		118,700	101,600	18.0	45.3	58.0
		117,200	101,600	18.0	46.8	50.0
69B		115,100	101,600	19.0	48.4	66.0
		116,100	103,200	16.0	22.6	69.0
70A		102,000	83,000	15.0	32.5	68.0
		102,500	96,800	7.0	16.1	70.0
70B		110,500	93,000	14.0	26.9	64.0
		113,700	97,800	18.0	40.9	65.0
71A		114,900	103,100	14.0	32.2	68.0
		117,700	108,000	18.0	41.9	70.0
71B		119,400	108,100	15.0	33.9	
		118,000	108,100	19.0	48.4	
72A		110,600	104,800	4.0	4.8	
		116,500	101,600	7.0	8.0	
72B		113,800	96,200	10.0	22.1	57.5
		112,100	94,600	9.0	12.8	51.0

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(Mechanical Tests, cont'd) -

Hardness readings were taken on through-plate specimens 5 mm. and 15 mm. from each edge and also in the centre. The Rockwell "C" scale was used. In some cases on the cast plates, where porosity was suspected, these readings were checked, using a 30-kilogram load, on the Vickers hardness machine. The readings at the two 15-mm. points were later discarded as superfluous, as there was little change in hardness from the surface to the centre of the plates. The figures in Table IV are the average of at least three readings.

TABLE IV. - ROCKWELL HARDNESS

ROLLED PLATES.					CAST PLATES.				
Plate No.	Type of Plate	Rockwell "C" Hardness			Plate No.	Type of Plate	Rockwell "C" Hardness		
		5 mm.	Centre	5 mm.			5 mm.	Centre	5 mm.
1	English Steel Co., 1½ Cr-Mo Acid open hearth	28.7	29.7	30.5	43A	Hadfields Vibrac 45 B.E.	29.3	28.8	29.0
2		29.0	29.5	28.2	43B		28.3	28.2	28.5
3		29.0	28.7	28.5	44A		25.0	26.0	27.2
4		27.0	25.0	28.0	44B		29.0	27.5	29.0
5		28.7	28.5	28.7	45A		25.5	26.0	27.0
6		27.2	27.2	27.6	45B		27.0	24.7	26.5
7	Colvilles 1½ Cr-Mo Basic open hearth	24.7	23.2	25.0	46A		28.3	28.7	28.5
8		22.8	21.5	22.4	46B		27.3	27.7	27.7
9		24.0	23.0	22.7	47A		27.7	26.7	28.0
10		20.0	21.0	20.7	47B		28.0	28.0	28.0
11		19.2	19.9	19.0	48A		26.7	26.5	27.0
12		23.3	25.2	24.3	48B		28.0	26.8	27.0
13	Firth Brown 1½ Cr-Mo B.E.	27.7	28.0	27.2	55A	Hadfields 1½ Cr-Mo B.E.	26.7	26.4	27.0
14		25.5	27.5	27.8	55B		28.0	26.5	28.3
15		23.8	25.5	26.4	56A		28.2	27.7	28.3
16		26.2	26.2	26.2	56B		27.8	26.2	27.3
17		23.8	26.1	27.6	57A		29.5	28.3	29.5
18		27.0	26.2	26.2	57B		28.3	27.7	28.3
19⊕	Firth Brown Low alloy A.O.H.	30.0	28.5	27.1	58A		25.3	24.7	23.3
20⊕		28.6	28.7	29.2	58B		25.8	25.0	24.6
21⊕		28.7	26.6	29.0	59A		25.2	21.5	20.0
22⊕		29.8	28.0	28.8	59B		24.2	21.5	22.0
23⊕		26.3	26.4	27.6	60A		28.5	27.3	28.7
24⊕		28.8	30.0	29.7	60B		28.0	27.0	28.5
25	Colvilles Low alloy B.O.H.	21.5	20.8	21.4	67A	Hadfields Low Alloy B.E.	22.2	21.0	26.2
26		24.0	22.5	23.8	67B		17.7	18.4	20.0
27		23.3	18.4	22.7	68A		25.0	20.7	23.0
28		23.7	19.2	24.0	68B		19.2	18.8	22.7
29		21.7	22.7	23.0	69A		23.7	20.8	25.2
30⊕		26.5	20.3	26.8	69B		24.3	22.2	20.3
31	English Steel Co. Low alloy B.E.	25.7	23.7	25.5	70A		23.7	21.2	20.3
32		23.5	21.3	20.3	70B		23.3	21.2	20.3
33⊕		21.4	19.8	22.2	71A		21.0	20.2	21.3
34		24.1	22.6	24.0	71B		24.0	21.3	23.8
35⊕		24.5	21.5	23.7	72A		19.9		21.0
36		26.0	23.5	27.2	72B		21.7	21.2	23.0

⊕ (Plates cracked during firing trial.)

(Mechanical Tests, cont'd) -

Three scatter plots were made for both rolled and cast plates. Ultimate strength was used as abscissa while per cent elongation, per cent reduction in area, and Izod impact strength were used as ordinates. These plots were then split horizontally and vertically and the average ballistic limit for each resulting section was calculated. The same procedure was followed using the flaking factor. Results are shown in Figure 1.

<u>Figure 1.</u>

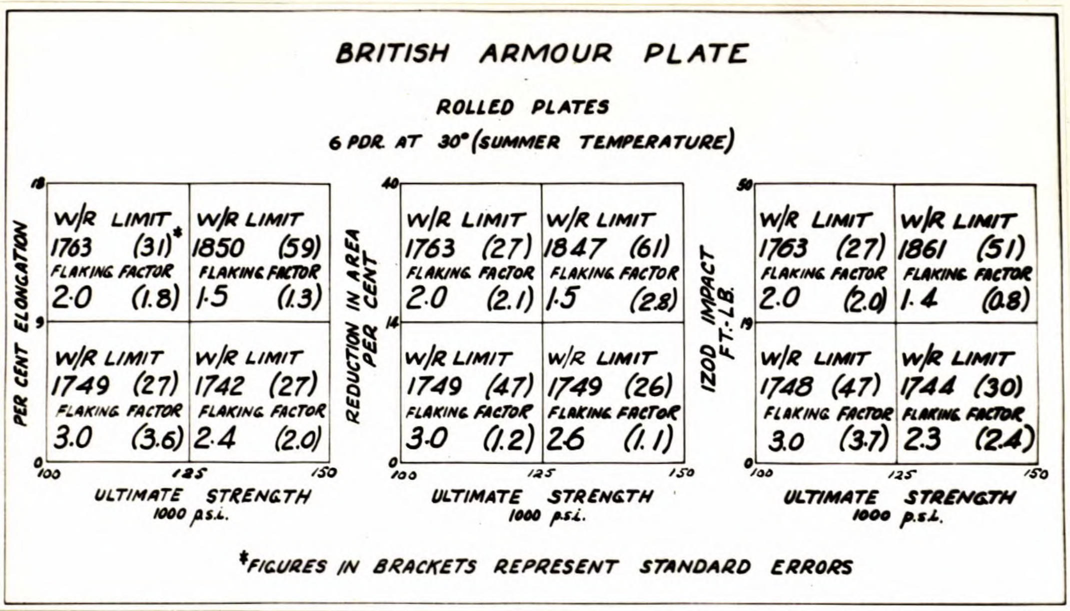


CHART SHOWING CORRELATION OF BALLISTIC LIMITS AND MECHANICAL PROPERTIES.

W/R limits are for 6-pounder at 30° angle.

Note: The velocities shown here are the ballistic limits as corrected to 60-mm. thickness by a straight proportion method. The D.T.D. Standard Curve would give a velocity of approximately 1830 f.s. for a 60-mm. plate.

The figures for the ballistic limits are those for the 6-pounder A.P. shot at 30° angle of attack and are taken from Table VII of "Trial of British Armour at Low Temperature" (Artillery Proof Establishment, Valcartier, Que., December, 1944). The W/R Limits for the 6-pounder attack at 30° were used in the correlation work. This was done for a number of reasons, of which the following are the more important:

(Mechanical Tests, cont'd) -

1. More plates were tested in this shoot.

2. More shots were fired at each plate to get the W/R limit, thus giving more reliable values for the flaking factor.

3. The method of correcting W/R limits to 60-mm. thickness which was used gave the least deviation from results obtained from specified correction methods (in this case, OB Proc. 14981).

Figure 1 indicates quite plainly that higher mechanical properties result in better ballistic properties. No correlation could be obtained from the cast plates as the range of ballistic limits was very small and consequently, with the small number of results available, no significant difference between the cast plates could be found. The Vibrac 45 and 1½ Cr-Mo plates had similar properties. The low-alloy plates had lower values of tensile and yield strength as well as core hardness, with higher Izod values, per cent elongation and per cent reduction in area. The averages for these three groups were not significantly different. They were as follows:

Group		Ft./sec.
Vibrac 45	- -	1644
1½ Cr-Mo	-	1661
Low Alloy	-	1670

Table V lists the average ballistic limits and the standard deviations for each group of Rolled Plates.

(Continued on next page)

(Mechanical Tests, cont'd) -

TABLE V.

Manufacturer	Melting Method	COMPOSITION	NO. OF PLATES	AVERAGE W/R LIMIT	STANDARD DEVIATION
Firth Brown	B.E.	1½ Cr-Mo	4	1883	54.1
E. S. C.	A.O.H.	1½ Cr-Mo	6	1817	39.2
Colvilles	B.O.H.	1½ Cr-Mo	4	1780	28.5
E. S. C.	B.E.	Low Alloy	4	1763	30.6
Firth Brown	A.O.H.	Low Alloy	4	1731	16.7
Colvilles	B.O.H.	Low Alloy	4	1721	36.3
All Low Alloy Plates			12	1738	36.3
All 1½ Cr-Mo Plates			14	1827	47.1

In order to estimate whether sampling variations alone would account for the differences in ballistic limits, the significance of the difference was checked by statistical analysis (see Appendix I for method used).

It was found that the plates could be divided into four distinct groups according to their ballistic limits. These were:

1.	Firth Brown	Basic Electric	1½ Cr-Mo
2.	E.S.C.	Acid Open Hearth	1½ Cr-Mo
3.	(Colvilles (E.S.C.	Basic Open Hearth Basic Electric	1½ Cr-Mo Low Alloy
4.	(Firth Brown (Colvilles	Acid Open Hearth Basic Open Hearth	Low Alloy Low Alloy

The 1½ Cr-Mo plates as a group were definitely superior to low-alloy plates. It is interesting to note that Basic Electric was the best, followed by Acid Open Hearth and Basic Open Hearth in that order, for plates of both alloy compositions.

One fundamental difference between the various

(Mechanical Tests, cont'd) -

groups of rolled plates was that the properties of the Firth Brown $1\frac{1}{2}$ Cr-Mo were the most uniform. This would indicate a greater degree of control in the manufacturing process.

Inclusion Rating:

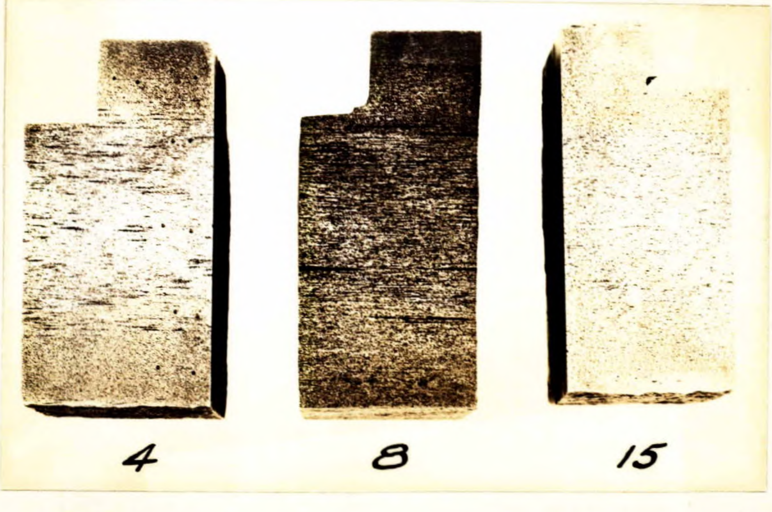
Inclusion rating, using the recommended A.S.T.M. procedure (A.S.T.M. designation: E 45), showed very little difference between the plates, either rolled or cast, as all plates were very clean. Another means of comparing inclusion contents will possibly have to be devised. An almost complete absence of sulphide and silicate inclusions from the rolled plate was noted. Absence of sulphide inclusions and the presence of moderate amounts of alumina would seem to indicate that the steels were deoxidized with aluminium.

The grain size, which will be included with the hardenability in a subsequent report, was practically the same in all samples examined to date, being $4\frac{1}{2}$ to $5\frac{1}{2}$ (according to the A.S.T.M. grain size chart).

Macro-Examination:

Through-plate sections were macro-etched in 50:50 HCl-water solution. Photographs were taken of typical plates from each group and also of exceptional plates. The rolled plates are shown in Figures 2, 3 and 4.

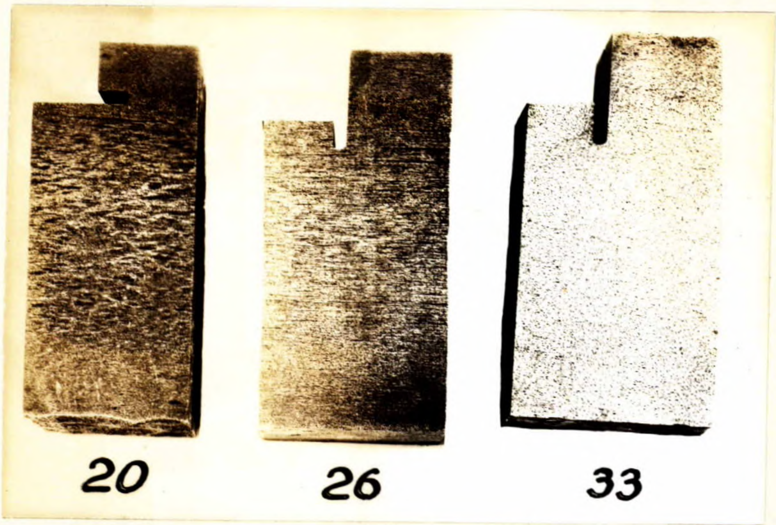
Figure 2.



MACRO-ETCHED SECTIONS OF ROLLED PLATES NOS. 4, 8 AND 15.
(approximately 5/6 full size).

(Macro-Examination, cont'd) -

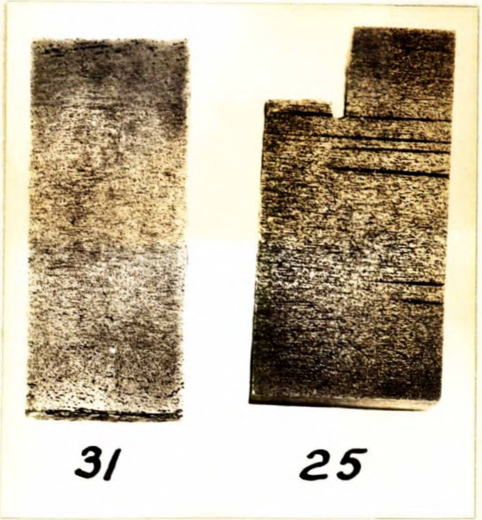
Figure 3.



MACRO-ETCHED SECTIONS OF PLATES NOS. 20, 26 AND 33.

(Approximately 5/6 full size).

Figure 4.



MACRO-ETCHED SECTION OF ROLLED PLATED NOS. 31 AND 25.

(Approximately 5/6 full size).

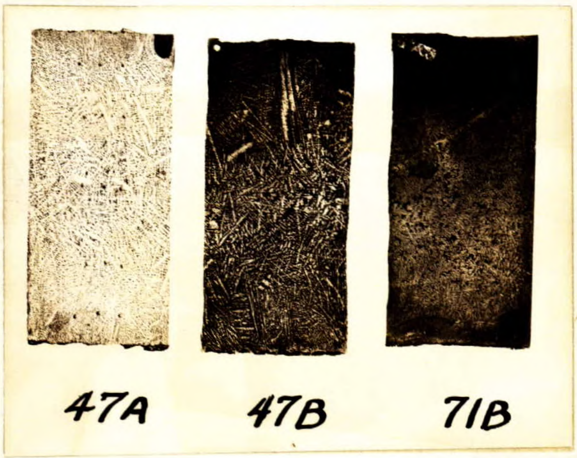
Plate No. 25 showed a number of deep pits. Plate No. 31 showed pits near the surface, which might indicate poor cropping before rolling. The pits in Plate No. 25 were due to segregation of both the inclusions and the alloy content.

(Continued on next page)

(Macro-Examination, cont'd) -

It was rather difficult to pick samples from the cast plates which might be called typical, as the dendritic structure varied between even the two plates cut from the same loop casting. The three plates shown in Figure 5 may be taken as representative, however, with the exception of the surface defects shown which occurred only in these three samples.

Figure 5.



MACRO-ETCHED SECTIONS OF CAST PLATES.

Dendritic structure is representative but surface defects are not.

(Approximately 2/3 full size).

Conclusions:

1. Through-plate mechanical properties correlate very well with ballistic properties of rolled plate.

2. Those rolled plates with the highest through-plate mechanical properties were the best ballistically.

3. The variation in ballistic limits for the cast plates was too small to obtain any statistically significant correlations. Further investigation may uncover a variable more closely related to the ballistic properties.

4. The rolled plates could be divided into four

(Continued on next page)

(Conclusions, cont'd) -

distinct groups according to their ballistic limits:

a)	Firth Brown	1½ Cr-Mo	Basic Electric
b)	E. S. C.	1½ Cr-Mo	Acid Open Hearth
c)	(Colvilles	1½ Cr-Mo	Basic Open Hearth
	(E. S. C.	Low Alloy	Basic Electric
d)	(Firth Brown	Low Alloy	Acid Open Hearth
	(Colvilles	Low Alloy	Basic Open Hearth

5. There was little drop in hardness from surface to centre in any of the plates.

6. Variations in melting practice (time at heat, etc.) may be the cause of differences between various groups of rolled plates but the significance, while not conclusive proof of the superiority of any one group of plates, is such that further investigation is warranted.

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APPENDIX I.

In connection with the statistical analysis, the following methods were used:

Standard Deviation $= \sigma = \sqrt{\frac{\Sigma x^2}{N} - \left(\frac{\Sigma x}{N}\right)^2} = \sqrt{\frac{\Sigma x^2}{N} - \bar{X}^2}$

where X = W/R limit of any individual plate.

$\bar{X}$ = average W/R limit for a group of plates.

N = number of plates in group.

Standard Deviation of an average $= \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{N}}$

Significance $= t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\sigma_{\bar{x}_1}^2 + \sigma_{\bar{x}_2}^2}}$

Figures for significance were taken from standard tables giving areas under the normal curve of error.

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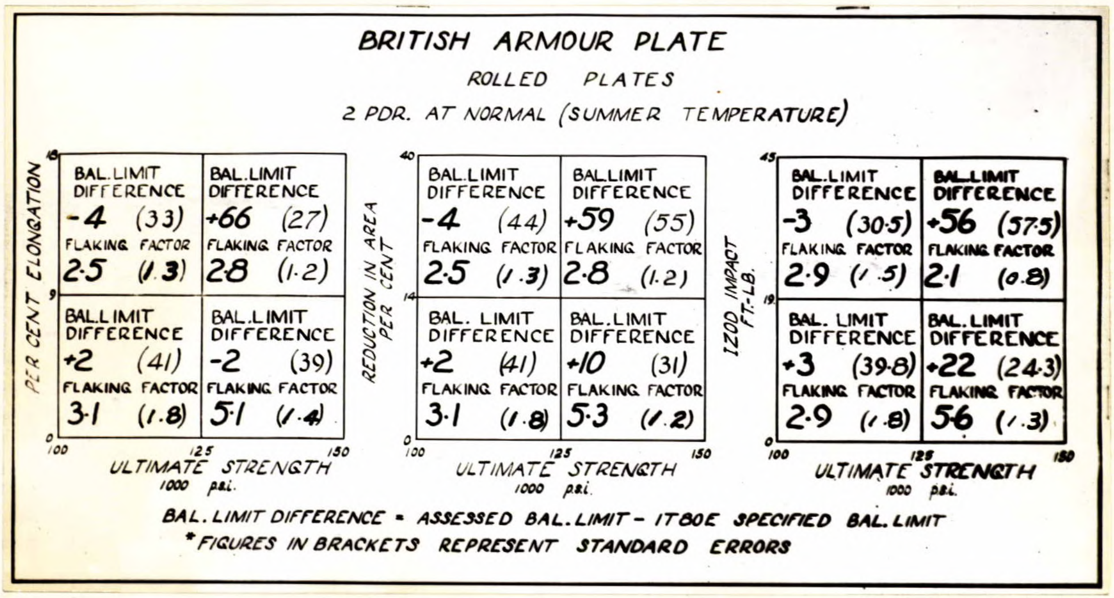
APPENDIX II.

The procedure used in obtaining the chart in Figure 1 was repeated, using the ballistic limits from the 2-pounder and 75-mm. trials at summer temperature. In this case, however, the assessed values of the ballistic limits were used. The differences between these values and the required ballistic limits, as specified by either IT 80E or AXS 488 rev. 2, were then marked on the chart as either positive or negative numbers. These two charts are shown below, in Figures 6 and 7.

Figure 6.

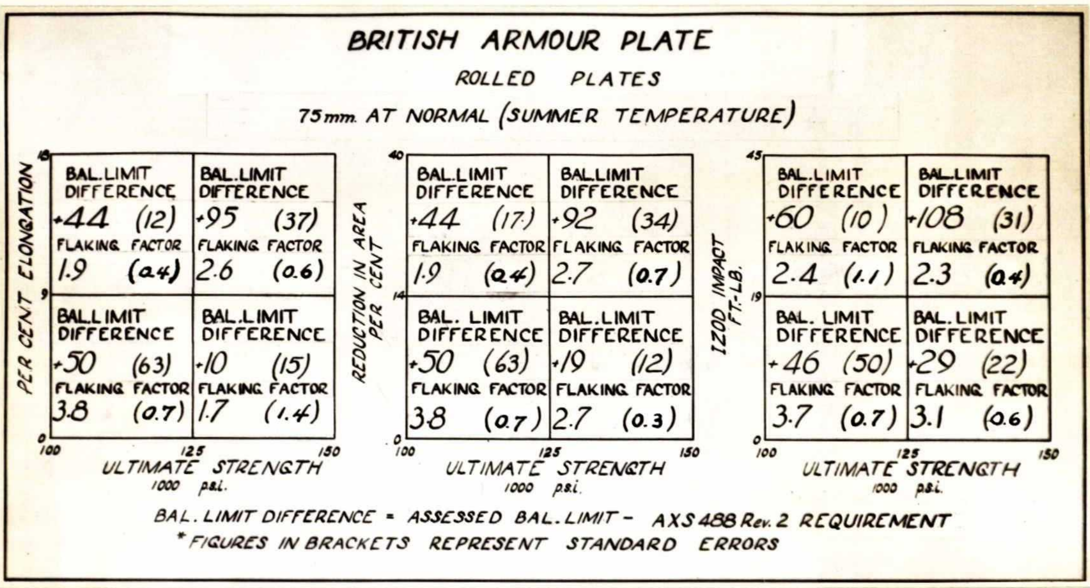


THROUGH-PLATE MECHANICAL PROPERTIES AND BALLISTIC RESULTS FROM 2-POUNDER AT NORMAL TRIAL AT SUMMER TEMPERATURE.

(Continued on next page)

(Appendix II, cont'd) -

Figure 7.



THROUGH-PLATE MECHANICAL PROPERTIES AND BALLISTIC RESULTS FROM SUMMER TEMPERATURE TRIAL OF 75-MM. AT NORMAL TRIAL.

Apparently the 75-mm. trial is not as severe as either the 2-pounder or the 6-pounder trial. It will be noted that the lowest ballistic limits occur in the upper left-hand corner of the chart in the 2-pounder trial and in the lower right-hand corner for the 75-mm. This would seem to bear out the fact that the 2-pounder is predominantly a test of hardness (and thus tensile strength), while the 75-mm. is affected more by ductility.

Ottawa, Ont.
April 18, 1945.
TCH:LB.