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June 20, 1937

WATERTOWN ARSENAL

WATERTOWN, MASS.

O. A. Form No. 156.

Report No. 710/200 June 20, 1937
Watertown Arsenal

BALLISTIC TESTS OF FACE HARDENED TUNGSTEN STEEL ARMOR PLATE.

Purpose

The purpose of this investigation was to determine the ballistic properties of a face hardened tungsten steel armor plate.

Conclusions

1. Armor plate containing .23% C, 3.36% W, .62% Cr, .20% V, after carburizing and proper heat treatment, resisted penetration with highest practicable velocities, Cal. .30 A.P., M1922, 2700 f.s. at 100 yards.

2. The ballistic limit of this plate, using Cal. .50 A.P., M1 ammunition, was 2057 f.s.

3. No spalling resulted from firing at the plate.

Procedure

1. Casting.

Two experimental compositions were cast in the form of 4 x 4" ingots, the composition of which is given in Table I.

2. Sampling of Ingot

(a) Macro section - A section about 3/4" thick was cut 9" from the bottom of the ingot and reserved for macroscopic study.

(b) Chemical Analysis. Millings were taken from the lower face of the macro section for chemical analysis shown in Table I.

3. Forging

(a) Forging into Rounds. The ingots were placed in a cold furnace, heated to forging heat - 1150-1185°C, (2102-2156°F), in about 3 hours, held within this range for nearly 3-1/2 hours, and forged into bars 2-3/8" in diameter, or to a 3:1 reduction. The forgings were buried in ashes.

(b) Forging into Plate. Sections of forgings about 8" in length were heated to an average temperature of 1190°C (2175°F) for nearly 45 minutes and forged into plate as follows: the preheated sections were placed vertically on the anvil of a forging hammer and upset, after which they were placed horizontally and forged into plate. The average size of the plate was 9 x 9 x 9/16". The plates were forged after one heating and then buried in ashes for the purpose of slow cooling from the forging temperature.

4. Heat Treatment

(a) Normalize and Anneal. The plates were given a normalize and anneal as follows in order to relieve forging strains and also to refine the grain:

Normalizing - Heat 3 hrs at 1750°F, air cool.

Annealing - Heat 3 hrs at 1560°F, furnace cool.

Previous to hardening and tempering, the plates were surface ground to 1/2" in thickness.

(b) Case Hardening. Carburize 52 hours at 938° C. (1700° F) in standard carburizing mixture. cool in box.

(c) Hardening and Tempering

1. Plate 21-B

Heat 2 hrs at 870°C, (1598°F), water quench
Draw 2 hrs at 204°C, (400°F). air cool

2. Plate 22-B

Heat 2 hrs at 800°C, (1472°F) water quench
Draw 2 hrs at 204°C, (400°F). air cool

5. Hardness Tests.

Brinell hardness tests were made on the face and back of the plates. Also, a Vickers-Brinell hardness survey was made on the cross-section of each plate.

6. Ballistic Tests.

Preliminary ballistic tests made at Watertown Arsenal showed that both plates defeated Cal. .30 A. P., M1922 bullets, 2600 f.s. striking velocity at 100 yards.

The plates were sent to Aberdeen Proving Ground for an official test. The results are found in the 120th Partial Report on Test of Thin Armor Plate: Ordnance Program No. 4334, T. S. T. P. No. 1932-107.

Results

1. Chemical Analysis.

The chemical analysis of the two plates is given in Table I.

Table I

Plate No.	C	Mn	Si	S	P	Cr	Mo	V	Al
218	.335	.53	.166	.019	.006	.62	-	.30	3.56
328	.345	.56	.216	.019	.007	.56	.44	.31	2.92

2. Hardness.

(a) Brinell Hardness. The Brinell hardness of Plates 218 and 328 are given in Table II.

TABLE II

Plate	Face	Back
218	600	340
328	600	302

(b) Vickers Brinell hardness surveys are shown in Figure 1.

3. Depth of Case

Plate No.	Thickness of Case Hyper Eutectoid	Eutectoid	Hypo Eutectoid	Total
218	.012"	.08"	.035"	.127"
328	.025	.087	.03	.142

4. Ballistic tests

Plate	Ammunition	Rd. No.	Striking Velocity	Result
218 1/2"	Cal .30 A.P.M1932	1	2607	Partial
	" " " "	2	3702	Partial
	Cal .50 A.P.M-1	3	1951	Partial
	" " " "	4	2089	Complete-broke plate*

Ballistic Limit - Cal. .50 A.P. 2057 f.s.

* Plate was not broken at point of impact. If size of sample had been sufficient to permit support on all sides, it is not believed that breakage would have occurred.

Plate	Ammunition	Rd.No.	Striking Velocity	Result
228	Cal .30 A.P.M1932	1	2704	Complete
1/2"	" " " "	2	2616	Partial
	" " " "	3	2662	Partial

Ballistic Limit - Cal. .30 A.P. 2683 f.s.

Discussion

Plate No. 218 shows an excellent ballistic resistance with no spalling under an impact of high velocity bullet impact. This particular composition passes the Navy requirements SPS-327, April 13, 1933 for 1/2" thick plate using Cal. .50, 750 grain armor piercing bullet.

The structure of the case consists of a fine distribution of complex tungsten-chromium carbide. A very fine grain was found in the core.

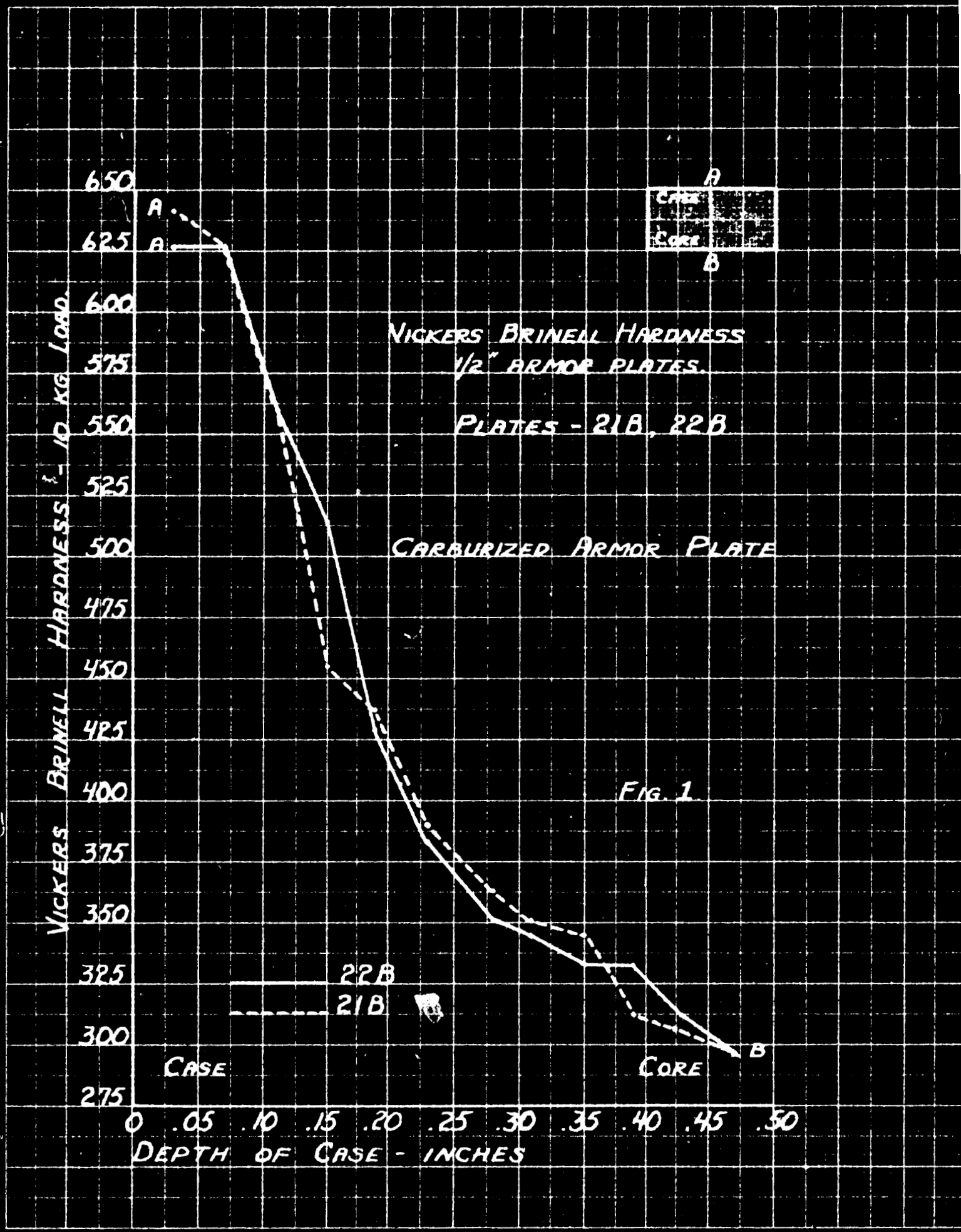
The high hardness of 600 Brinell on the face is effective in shattering the bullet core, for example, this plate defeated a Cal. .30 A.P. M1932 with a striking velocity of 2700 f.s. A relatively soft core, on the other hand, is effective in absorbing the energy of impact.

The ballistic properties of Plate No. 228 is 433 foot-seconds in excess of that specified for 1/2" thick plate. No spalling was evident unter bullet fire. Large chunks of complex carbides were present in the case of this plate, possibly due to the presence of a higher carbon content in the basic composition. It is possible that if this plate

had been so heat treated as to cause a solution of the excess carbides in the case, the ballistic properties would have been higher. The hardness of the face and back of Plate 12B approximated those of Plate 11A.

Respectfully submitted,

E. L. Reed,
Research Metallurgist.


650
625
600
575
550
525
500
475
450
425
400
375
350
325
300
275
A
A
B
Case
Core
VICKERS BRINELL HARDNESS
1/2" ARMOR PLATES.
PLATES - 21B, 22B
CARBURIZED ARMOR PLATE
FIG. 1
22B
21B
CASE
CORE
B
0 .05 .10 .15 .20 .25 .30 .35 .40 .45 .50
DEPTH OF CASE - INCHES
VICKERS BRINELL HARDNESS - 10 KG LOAD