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REPORT NO. 720/62

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WATERTOWN ARSENAL, WATERTOWN, MASS.

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Under Phy. Sec. Aide

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September 26, 1958
WATERTOWN ARSENAL
WATERTOWN, MASS.

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Report No. 710/62
Watertown Arsenal

September 28, 1936

Carburized-Nitrided Armor Plate

Purpose

The purpose of this investigation is to determine the carburizing-nitriding characteristics of cast armor plate and the ballistic properties of this face-hardened plate.

Conclusions

1. The ballistic properties of carburized-nitrided armor plate of the chromium-molybdenum-vanadium type are not superior to those of carburized plate which has been carburized under the same conditions and having approximately the same depth of case.
2. Traces of spalling were evident on the front face of plates face hardened by this method.
3. Plates face hardened by this method lacked ductility as compared to straight case hardened plates.
4. These preliminary tests indicate that the ballistic resistance of carburized-nitrided plates are slightly higher than that of nitrided plates. Both series however lacked ductility.

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5. Nitriding of thin armor plate, .25 inch, is effective in raising the ballistic limit equivalent to that of .437 inch thick homogeneous rolled armor plate or an increase of 450 foot seconds.

6. Carburizing armor plate castings raises the ballistic limit some 200 foot seconds above that of heat treated homogeneous armor plate castings of the same thickness.

Experimental Procedure

Professor Albert Sauveur, Gordon McKay Professor of Metallurgy and Metallography, Harvard University, suggested in October 1935, that a study of ballistic tests on carburized-nitrided armor plate be made. Acting on this suggestion, this investigation was made.

Rolled and Cast Armor plate containing .35/.55 Carbon; 1.10/1.30 Chromium, .60/.80 Molybdenum; .20/.30 Vanadium was normalized and annealed, carburized, heat treated, followed by nitriding and tested ballistically.

Samples of armor plate about six inches square and one-half inch thick were prepared and normalized and annealed as follows:

Rolled Plate - annealed by Henry Disston & Sons Inc.

Cast Plate

Heated 8 hours at 1150°C, 2102°F, air cooled

Heated 5 hours at 950°C, 1742°F, air cooled

Heated 11 hours at 850°C, 1562°F, furnace cooled

The samples were sandblasted, copper plated on the rear face and carburized for 30 hours at 900°C, 1652°F in a standard carburizing mixture and slowly cooled in the box.

The carburized plates were subjected to the following heat treatment:

Heat 2 hours at 871°C, 1600°F, quenched in oil.

Reheated 2 hours at 482°C, 900°F, air cooled.

After sandblasting, the rear face was tin plated by the Boston Nickel Plating Co., Boston, Mass. and nitrided 48 hours at 975°F by the New England Metallurgical Corporation, South Boston, Mass.

Ballistic tests were made with preloaded armor piercing ammunition at a range of 100 yards. All samples were securely bolted to a wooden frame, the back of the samples being unprotected.

Microscopic examination was made on the case hardened-nitrided samples.

One depth hardness curve was constructed illustrating the nitriding characteristics of carburized-nitrided rolled plate No. 4.

Experimental Results

Chemical Analysis

The chemical analysis of the rolled and cast armor plate is given in table 1.

Table 1.

Chemical Analysis

<u>Type of Plate</u>	<u>C</u> %	<u>Mn</u> %	<u>P</u> %	<u>S</u> %	<u>Si</u> %	<u>Cr</u> %	<u>Mo</u> %	<u>Va</u> %
<u>Homogeneous</u>								
Rolled No. 1	.50	.61	.017	.017	.190	1.09	.72	.27
Cast No. 42-1	.40	.68	.007	.02	.318	1.29	.77	.285
<u>Carburized-Nitrided</u>								
Rolled No. 4	.50	.61	.017	.017	.190	1.09	.72	.27
Cast No. 57-4	.34	.38	.005	.02	.17	1.05	.80	.195

Hardness Values of Case and Core are given in table 2.

Table 2.

Hardness Values of Case and Core

<u>Type of Plate</u>	<u>Thickness</u> <u>inches</u>	<u>Hardness</u>		<u>Brinell</u> <u>Hardness</u> <u>Equivalent</u>		<u>Case</u> <u>Depth</u> <u>inches</u>	<u>Rear</u> <u>Face</u> <u>Prot.</u>
		<u>30N</u> <u>Face</u>	<u>Rockwell</u> <u>Core</u>	<u>Face</u>	<u>Core</u>		
<u>Homogeneous</u>							
Rolled No. 1	.500	--	--	387		--	--
Cast No. 42-1	.437	--	--	430		--	--
<u>Carburized-Nitrided</u>							
Rolled No. 4	.469	71	63	477	460		Tin Plate
Cast No. 57-4	.406	70	60	460	364		Tin Plate

ble 3.

Series	Ballistic Limit		Coefficient	Specified Ballistic Limit	Brinell Hardness after Carburizing-Nitriding	Depth of Case
	Feet per second	Foot pounds				
by it Vel.						
Imp. Pon. per second						
	2550	2380	1.518	2250	387	
	2050	1538	1.350	1790	430	
	2550	2380	1.592	*1870	460	.02" **.133"
	2050	1538	1.426	*1720	364	.025" **.060"

rienced in measuring depth of heat treated case hardened samples.
e taken from samplos from same compositions after slowly cooling

A list of plates, carburized, ref. Report 710/60, nitrided ref. Report 710/61, and carburized-nitrided as described in the present report have been arranged in order of merit with respect to the DeMarre Coefficient as shown in Table 4.

Table 4

Order of Merit
(Based on DeMarre Coefficient)

<u>Plate No.</u>	<u>Thickness of Plate inches</u>	<u>DeMarre Coefficient</u>	<u>Depth of Case inches</u>	<u>Face Hardening Treatment</u>
Rolled 9R4	.265	2.059	.025	Nitrided 48 hrs. at 975°F
Rolled 9R5	.270	2.032	.014	Nitrided 24 hrs. at 975°F
Rolled 9R2	.254	2.029	.023	Nitrided 60 hrs. at 975°F
Rolled 9R1	.240	2.013	.016	Nitrided 36 hrs. at 975°F
Cast Z	.297	1.803	.028	Nitrided 48 hrs. at 975°F
Rolled 4	.469	1.592	** .13 ₂ .02	Pack carburized 30 hrs. 900°C, 1652°F. Nitrided 48 hrs. at 975°F
Rolled 2*	.500	1.546*	.153	Pack carburized 30 hrs. 900°C, 1652°F
Rolled 1	.500	1.518	---	Homogeneous-heat treated
Rolled 3	.430	1.514	.039	Nitrided 48 hrs. at 975°F
Cast 42-2	.469	1.468	.095	Pack carburized 20 hrs.- 900°C, 1652°F
Cast 71	.344	1.464	.055	Pack carburized 30 hrs.- 900°C, 1652°F
Cast 42-4	.500	1.458	.110	Pack carburized 8 hrs.- 1149°C, 2100°F

Table 4 cont.

Table 4 cont.

<u>Plate No.</u>	<u>Thickness of Plate inches</u>	<u>DeMarre Coefficient</u>	<u>Depth of Case inches</u>	<u>Face Hardening Treatment</u>
Cast 57-2	.500	1.458	.085	Pack carburized 30 hrs.- 900°C, 1652°F
Cast 57-4	.406	1.426	** .06± .025	Pack carburized 30 hrs.- 900°C, 1652°F Nitrided 48 hrs.-975°F.
Cast 45	.454	1.424	.019	Nitrided 48 hrs.-975°F.
Cast 57-1	.437	1.416	.020	Nitrided 48 hrs.-975°F
Cast 36	.313	1.395	.065	Pack carburized 30 hrs.- 900°C, 1652°F.
Cast 42-3	.500	1.370	.035	Carburized 7 hrs.-900°C, 1652°F. Heavy Duty Carbonal Furnace
Cast 57-3	.500	1.353	.049	Carburized 10 hrs.-900°C, 1652°F. Heavy Duty Carbonal Furnace
Cast 42-1	.437	1.350	--	Homogeneous-heat treated.
Cast 73	.406	1.326	.027	Pack carburized 20 hrs.- 900°C, 1652°F.

* DeMarre Coefficient was calculated from highest striking energy not completely penetrating.

** Difficulty was experienced in measuring depth of heat treated carburized samples.

Ballistic Test

Homogeneous Rolled Armor Plate No. 1.

Thickness of Plate .500 inch

Hardness - 387 Brinell

Manufacturer - Henry Disston & Sons Inc.

Range to plate - 100 yards

Bullet Cal. .30 M 1922 AP165gr, core 87.5gr.

<u>Round No.</u>	<u>Str. Vel.ft/sec</u>	<u>A.S54 Rev. 2 Penetration</u>	<u>Depth of Penetration</u>	<u>Ht.of Bulge back</u>	<u>Appearance of Back face</u>
1	2300	Partial	.48"	.05"	
2	2400	Partial		.07"	small crack
3.	2500	Partial		.08"	small crack
4.	2500	Hit previous bullet hole			
5.	2500	Partial C.I.P.		.13"	
6.	2600	Complete C.I.P.			

Chemical Composition

C	Mn	P	S	Si	Cr	Mo	Va
.50	.61	.017	.017	.190	1.09	.72	.27

Heat Treatment

Heated 2 hrs. at 871°C, 1600°F, oil quenched.

Reheated 2 hrs. at 496°C, 925°F, air cooled.

Ballistic Test

Homogeneous Cast Armor Plate No. 42-1

Thickness of plate .437 inch

Hardness 430 Brinell

Manufacturer - Watertown Arsenal

Range to Plate - 100 yards

Bullet Cal..30 M 1922 AP, 165gr. Core 87.5gr.

Round No.	Str. Vel.ft/sec	AXS54 Rev. 2 Penetration	Depth of Penetration	Ht.of Bulge back	Appearance of Back face
1	2200	Complete	- -	.11"	small cracks
2	2100	Hit in previous hole	- -	- -	- -
3	2100	Complete	- -	.07"	small cracks
4	2000	Complete	.47"	.04"	small cracks

Chemical Composition

C	Mn	P	S	Si	Cr	Mo	Va
.40	.68	.007	.02	.318	1.29	.77	.285

Heat Treatment

Heated 8 hrs. at 1150°C, 2102°F, air cooled

Heated 5 hrs. at 950°C, 1742°F, air cooled

Heated 5 hrs. at 850°C, 1562°F, furnace cooled

Heated 2 hrs. at 871°C, 1600°F, oil quenched

Heated 2 hrs. at 482°C, 900°F, air cooled.

Ballistic Test

Carburized-Nitrided Rolled Armor Plate No. 4

Thickness of Plate .469 inch

Hardness Brinell, Face 477, Back 460

Manufacturer - Henry Disston & Sons Inc.

Range to Plate - 100 yards.

Bullet Cal. .30 M 1922 AP 165gr, Core 87.5gr.

Round No.	Str. Vel. ft/sec	AXS-54 Rev. 2 Penetration	Depth of Penetration	Ht. of Bulge of Appearance of Back face
1	2600	Partial	.51"	.08" Radial cracks
2	2600	Complete	- -	.10" Radial cracks
3	2500	Complete	- -	.11" Radial cracks
4	2400	Partial	.45"	.05" Radial cracks

Chemical Composition

C	Mn	P	S	Si	Cr	Mo	Va
.50	.61	.017	.017	.190	1.09	.72	.27

Heat Treatment

Heated 2 hrs. at 1600°F, quenched in oil

Reheated 2 hrs. at 925°F, air cooled

Carburized 30 hrs. at 900°C, 1652°F, in standard carburizing mixture, cooled in box.

Heated 2 hrs. at 871°C, 1600°F, oil quenched

Reheated 2 hrs. at 496°C, 925°F, air cooled

Nitrided 48 hrs. at 975°F.

Ballistic Test

Carburized-Nitrided Cast Armor Plate No. 57-4

Thickness of Plate .406 inch

Hardness Brinell, Face 460, Back 364

Manufacturer - Watertown Arsenal

Range to Plate - 100 yards

Bullet Cal..30 M 1922, AP 165gr, Core 87.5gr.

Round No.	Str. Vel.ft/sec	AKS-54 Rev. 2 Penetration	Depth of Penetration	Ht.of Bulge back	Appearance of Back face
1	2400	Complete	- -	- -	Radial cracks
2	2100	Complete	- -	.09"	Radial cracks
3	2000	Partial	.38"	.06"	Radial cracks

Chemical Composition

C	Mn	P	S	Si	Cr	Mo	Va
.34	.38	.005	.02	.17	1.05	.80	.195

Heat Treatment

Heated 8 hrs. at 1150°C, 2102°F, air cooled

Heated 5 hrs. at 950°C, 1742°F, air cooled

Heated 5 hrs. at 850°C, 1562°F, furnace cooled

Carburized 30 hrs. at 900°C, 1652°F, in standard carburizing mixture, slowly cooled in box.

Heated 2 hrs. at 871°C, 1600°F, oil quenched

Heated 2 hrs. at 496°C, 925°F, cooled in air

Nitrided 48 hrs. at 975°F.

Discussion

The carburized-nitrided rolled and cast plates showed no evidence of severe spalling after ballistic test. In the case of rolled plate No. 4, however, see Fig. 2, round 2, there was evidence of a slight degree of cracking of the surface layers.

The rear face of the plates, as illustrated in Figs. 3 and 5, showed the presence of radial cracks at areas of impacts while in several cases small fragments were thrown from the areas of impacts.

Microscopic examination of the tin coated rear face failed to show the presence of any nitrided case under the tin coating which might account for this brittleness. This surface was slightly decarburized but there was no evidence of nitride needles present.

Microscopic examination of the nitrided layer at the surface of the carburized plate reveals a very fine structure as illustrated in Fig. 1. The nitrided layer diffuses gradually into the carburized case, see Figs. 1a,b,c, and d. Difficulty was experienced in measuring the depth of the carburized layer since the plates necessarily had to be heat treated previously to the nitriding operation. On other occasions, however, after the same steels were carburized for the same length of time and slowly cooled in the

carburizing box. The depth of case was found to be .153 inch in the rolled plate and .085 inch in the cast plate. A depth hardness curve was constructed illustrating the nitriding characteristics of carburized-nitrided rolled plate No. 4, see Fig. 6.

Since it is difficult to compare the ballistic resistance of plates of different thicknesses, plates which have been carburized, Report No. 710/60, nitrided, Report No. 710/61, and those which have been carburized and nitrided discussed, the present report has been classified, see Table 4, in the order of merit, based solely on the value of "K", the DeMarre Coefficient. This expression is large or small in accordance with the magnitude of the striking velocity and therefore "K" can be used to compare plates of the same general type but having different thicknesses. This method of comparison of plates has its shortcomings, however, since it does not include factors covering ductility and toughness values.

The preliminary tests made on carburized-nitrided plate indicate that the ballistic properties of this plate are not superior to those of straight carburized plate carburized under the same conditions and having about the same depth of case. The ductility of the carburized plate under bullet impact was found to be superior to that of the carburized-nitrided plate.

The face hardness of the carburized-nitrided plate was 55 to 72 points Brinell lower than that of the straight carburized plate. This may have been due to the tempering of the heat treated carburized case by the nitriding operation at 975°F, this temperature being 50°F above the drawing temperature of the case hardened plate.

Preliminary tests indicate that carburized-nitrided plate has a slightly higher ballistic resistance than straight nitrided plate. Both methods show, however, traces of brittleness on the rear face of the plate.

Nitriding alone, however, is effective in raising the ballistic limit of thin rolled plate, about .25 inch thick to the extent where the ballistic limit of a nitrided .25 inch thick plate is equivalent to the specified limit of a .437 inch thick homogeneous plate or an increase of 450 foot-seconds.

This nitrided cast plate, .297 inch thick, resists a striking velocity of 2000 foot-seconds which is 50 foot-seconds in excess of ballistic limit of 1/2 inch thick cast plate. This plate did not possess satisfactory ductility.

On the other hand, nitriding does not appear to be effective in raising the ballistic resistance of thicker plates, that is in the neighborhood of .500 inch.

The ballistic resistance of nitrided plates is not superior to that of carburized plates.

Carburizing of armor plate castings is effective in raising the ballistic limit 200 foot-seconds above that of heat treated homogeneous castings of the same thickness.

Recommendations

It is recommended that further work be conducted on the following:

1. Carburize-nitride thin armor plate of the chrome-moly-vanadium type.
2. Carburize-nitride heavy plate of the chrome-moly-vanadium type.
3. Carburize-nitride various thickness compositions containing aluminum.

Respectfully submitted,

E. L. Reed
S. L. Kruegel
E. L. Reed,
Research Metallurgist
S. L. Kruegel,
Under Phy. Sc. Aide.

PLATE No. 4.
ROLLED CARBURIZED-NITRIDED ARMOR
PLATE.

CARBURIZED - 30 HRS. - 900°C.
NITRIDED - 48 HRS. - 975°F.

C	Mn	Si	S	P	Cr	Mo	Va
.50	.61	.190	.017	.017	.109	.72	.27

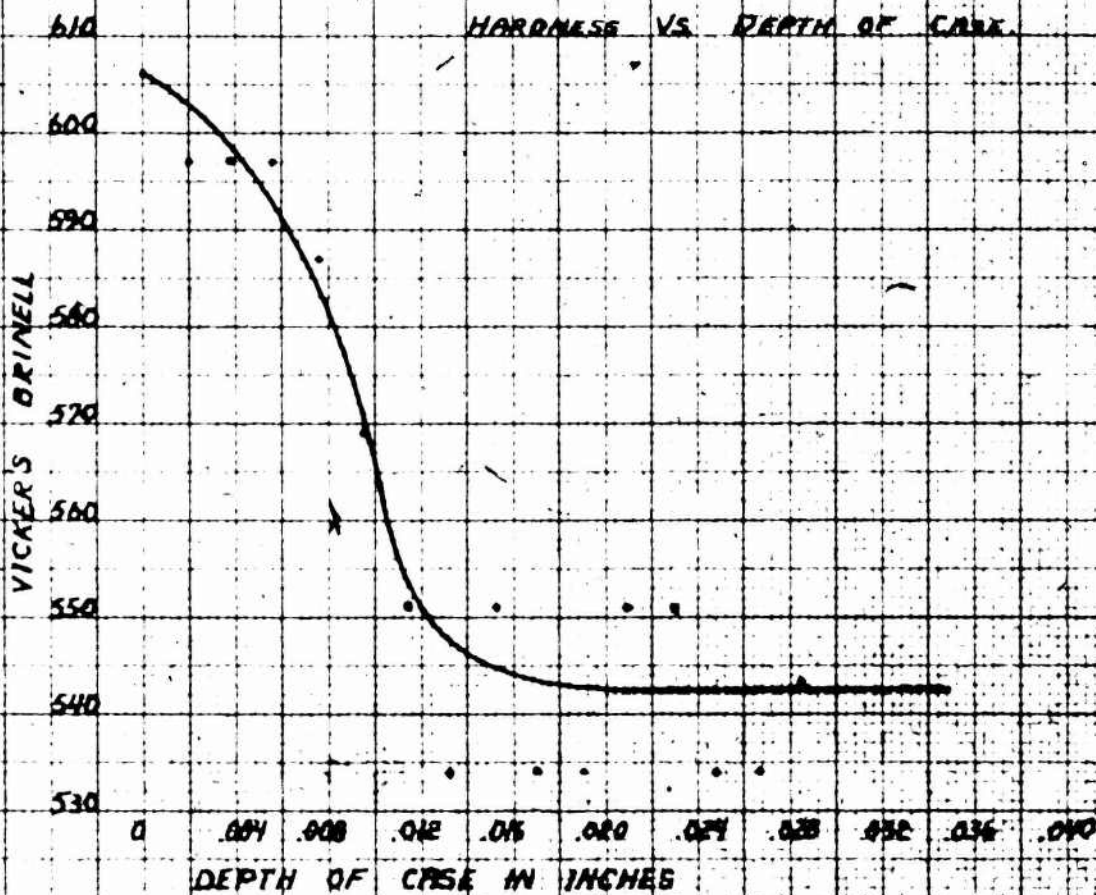


FIG. 6.

Figure #1.

- a. X5 Rolled Plate No. 4 - Carburized 30 hrs. at 900°C, 1652°F in standard carburizing mixture, cooled slowly, heated 2 hrs. at 871°C, 1600°F, quenched in oil, reheated 2 hrs. at 496°C, 925°F, air cooled.
Nitrided 48 hrs. at 975°F.

.02" depth of nitrided case
.130"± " of carburized case
.132"± total depth of case

MA 577

- b. X5 Cast Plate No. 57-4 - Carburized 30 hrs. at 900°C, 1652°F, in standard carburizing mixture, cooled slowly, heated 2 hrs. at 871°C, 1600°F, quenched in oil, reheated 2 hrs. at 496°C, 925°F, air cooled.
Nitrided 48 hrs. at 975°F.

.025" depth of nitrided case
.060" depth of carburized case
.085" total depth of case

MA 575

- c. X100 Showing microstructure of case shown in (a)
Etched in picric acid
Light colored portion of case is nitrided layer
Evidence of some free carbide near surface resulting from carburizing.

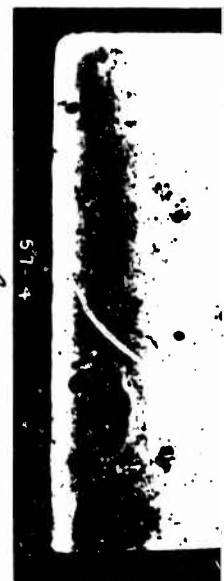
MA 567 (a,b,c)

- d. X100 Showing microstructure of case shown in (b)
Etched in picric acid
Light colored portion of case is nitrided layer
Evidence of some free carbide near surface resulting from carburizing.

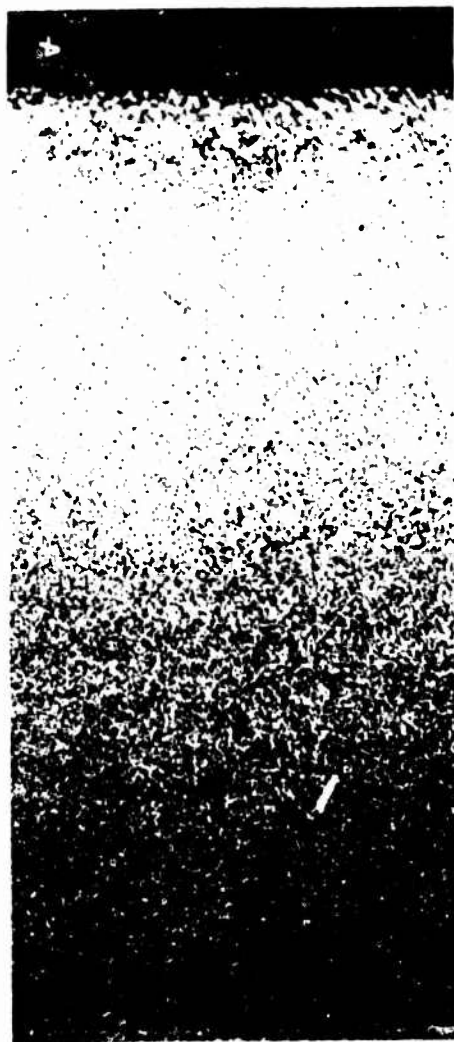
MA 566 (a,b)



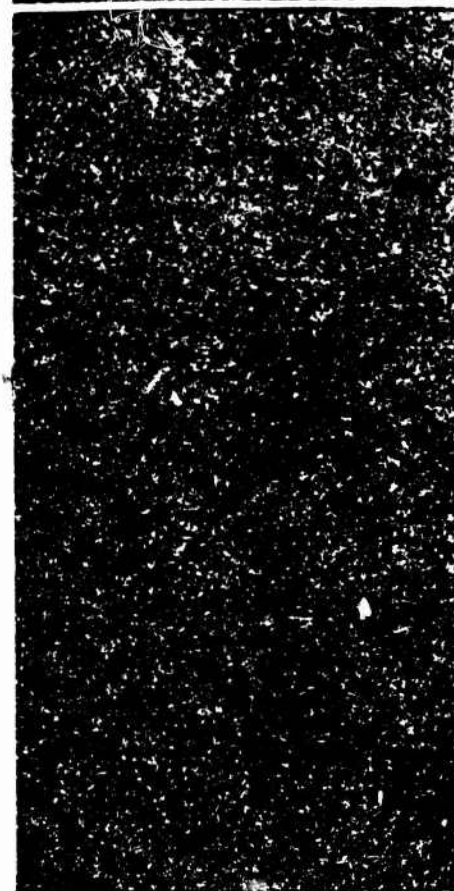
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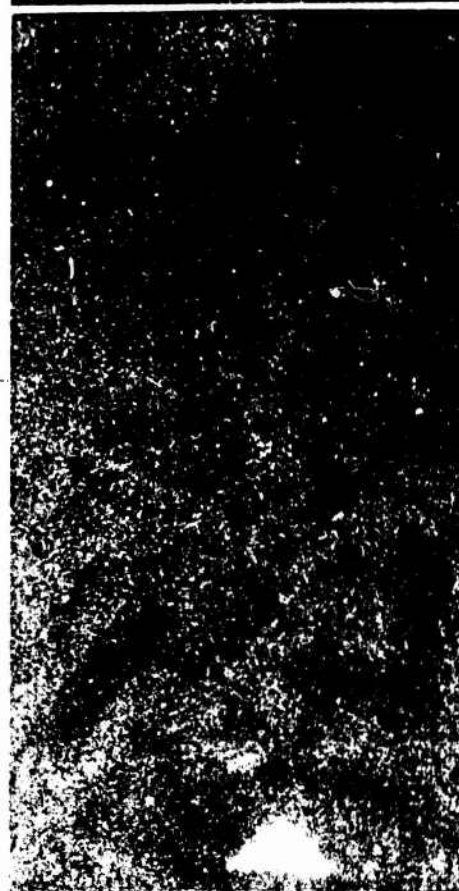
57-4

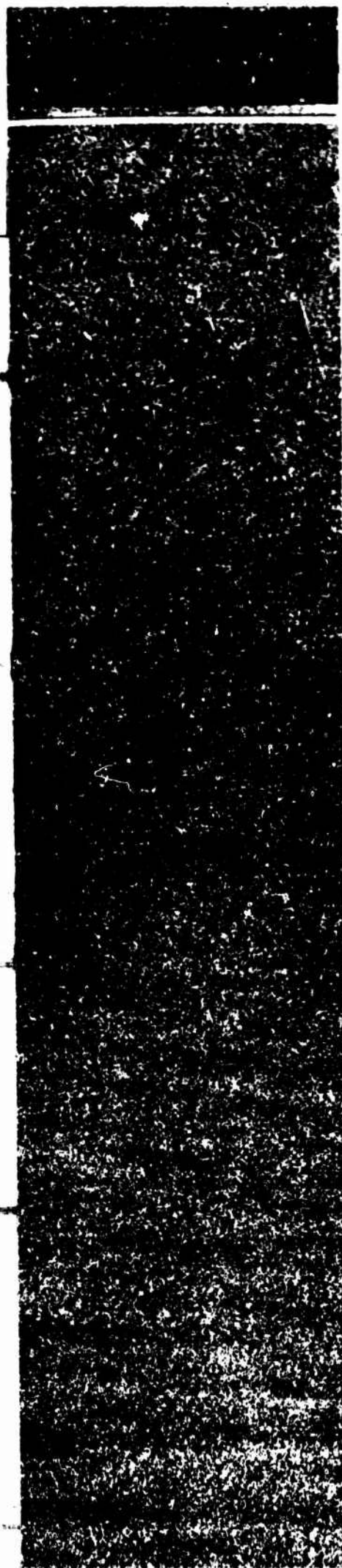


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Figure #2

Carburized-Nitrided Rolled Armor Plate No. 4

After Ballistic Test

Front

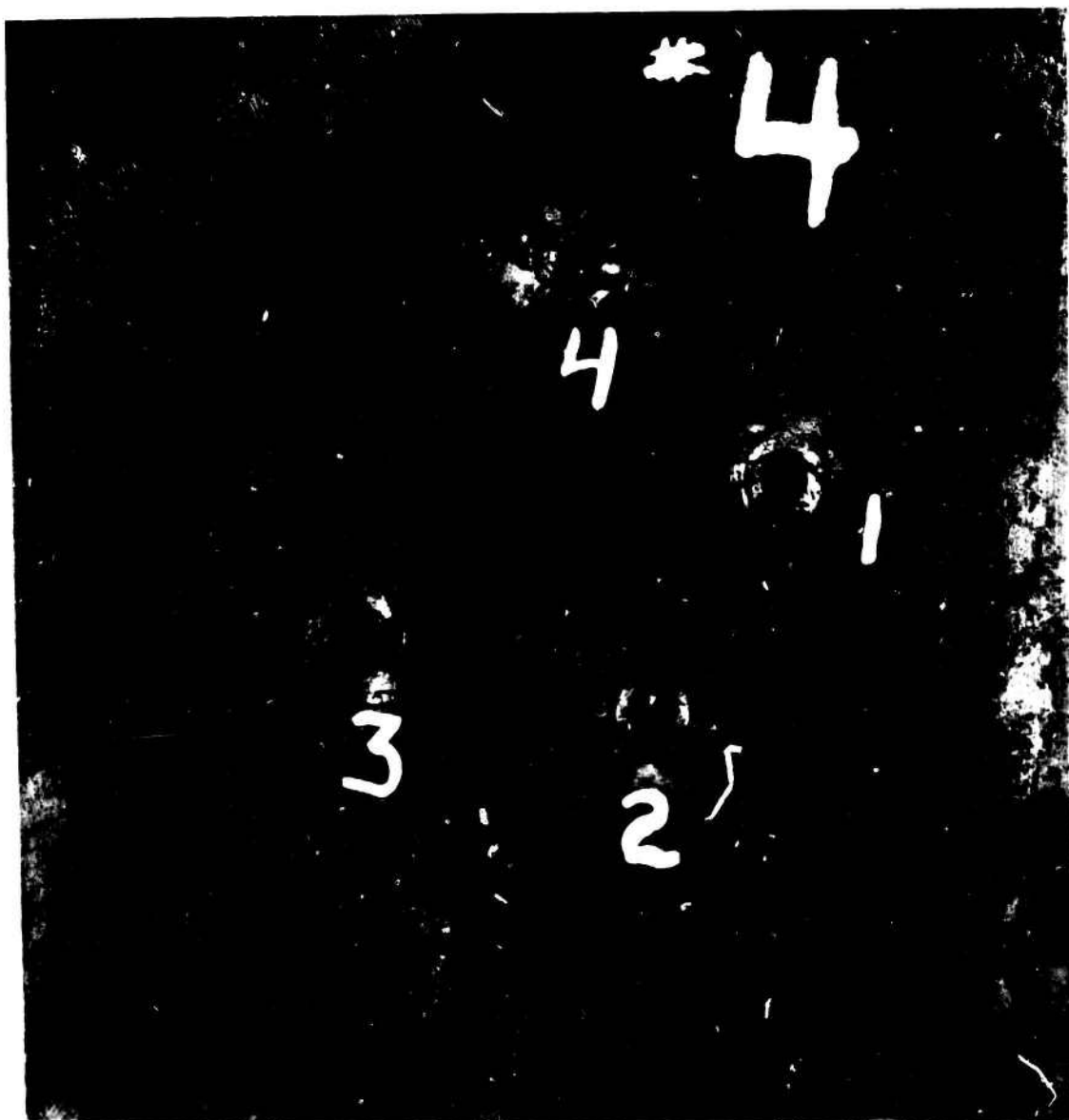
Cal..30 M 1922 AP

Distance - muzzle to plate - 100 yards

Angle of indent - normal

Carburized 30 hrs. at 900°C, 1652°F, in
standard carburizing mixture, cooled slowly
in box.

Nitrided 48 hrs. at 975°F.



ORDNANCE DEPT USA
WATERTOWN ARSENAL

#4 Front 5-6-36 710-220

Figure #3

Carburized-Nitrided Rolled Armor Plate No. 4

After Ballistic Test

Back



ORDNANCE DEPT USA
WATERTOWN ARSENAL

#4 Back 5-6-36 710-221

Figure #4

Carburized-Nitrided Cast Armor Plate No. 57-4

After Ballistic Test

Front

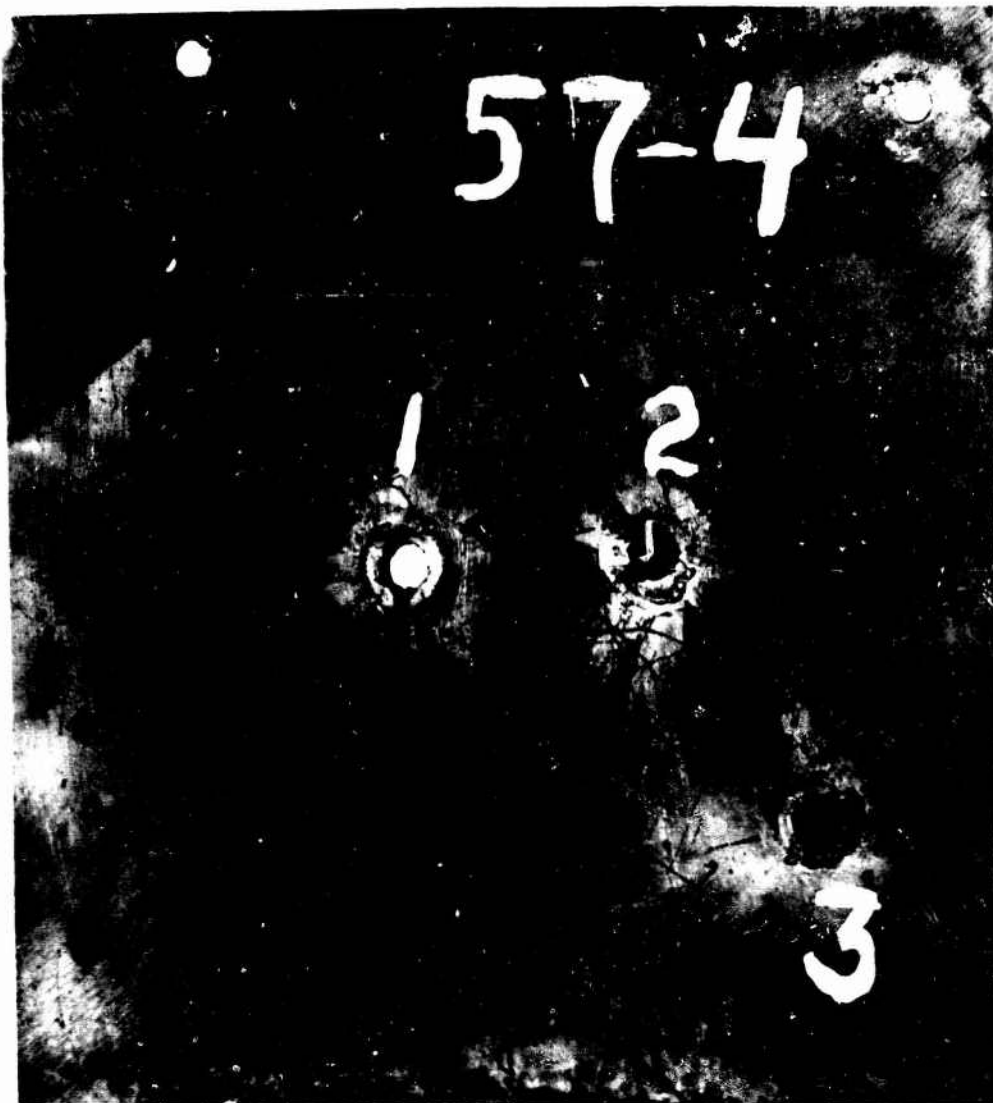
Cal..30 M 1922 AP

Distance - muzzle to plate - 100 yards

Angle of indent - normal

Carburized 30 hrs. at 900°C, 1652°F, in standard
carburizing mixture, cooled slowly in box.

Nitrided 48 hrs. at 975°F.



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#57-4 Front 5-6-36 710-212

Figure #5

Carburized-Nitrided Cast Armor Plate No. 57-4

After Ballistic Test

Back



ORDNANCE DEPT U.S.A.

WATERTOWN ARSENAL

#57-4 Back 5-6-36 710-213