File

OTTAWA December 30th, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1564.

Preliminary Investigation of Influence of Longitudinal Stresses on the Ballistic Performance of Armour-Piercing Shot.

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(Copy No. 10.)

Abstract

This report describes results of a preliminary investigation into the effect of longitudinal stresses on the ballistic performance of A/P shot. A method is described for stressing shot in a direction parallel to the axis. Results of proof tests made on shot so stressed are given. The small number of tests performed and the fact that the shot steel did not receive its optimum heat treatment make it difficult to draw any definite conclusions. A suggested further plan of research is outlined.

Bureau of Mines
Division of Metallic Minerals
-
Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

O T T A W A December 30th, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1564.

Preliminary Investigation of Influence of Longitudinal Stresses on the Ballistic Performance of Armour-Piercing Shot.

Origin and Purpose of Investigation:

During a discussion initiated early in 1943 by Capt. D. Weston, of the S.A. and S.A.A. Inspection Directorate, Inspection Board of United Kingdom and Canada, Ottawa, Ontario, consideration was given to the possibility of improving the performance of armour-piercing shot by application of a pre-stressing operation similar to the autofrettage commonly used in the construction of gun barrels.

The subject of this report is a preliminary effort to investigate the influence of the longitudinal stresses (i.e., those occurring parallel to the axis of the shot) on the performance of armour-piercing shot.

Description of Test Shot:

To obtain, so far as possible, equally distributed tensional stresses in the longitudinal direction, a specially constructed shot was used. This is shown in Drawings Nos. 1 and 2, on Page 3.

The projectile is composed of an outer part "A" and an inner part "B" (see Drawings Nos. 1 and 2). Part B is screwed into part A and force-pressed against the inside front surface P of the nose N. The side surface between A and B is held loosely; this free space should allow for contraction of the outer part and expansion of the inner part.

Chemical Composition:

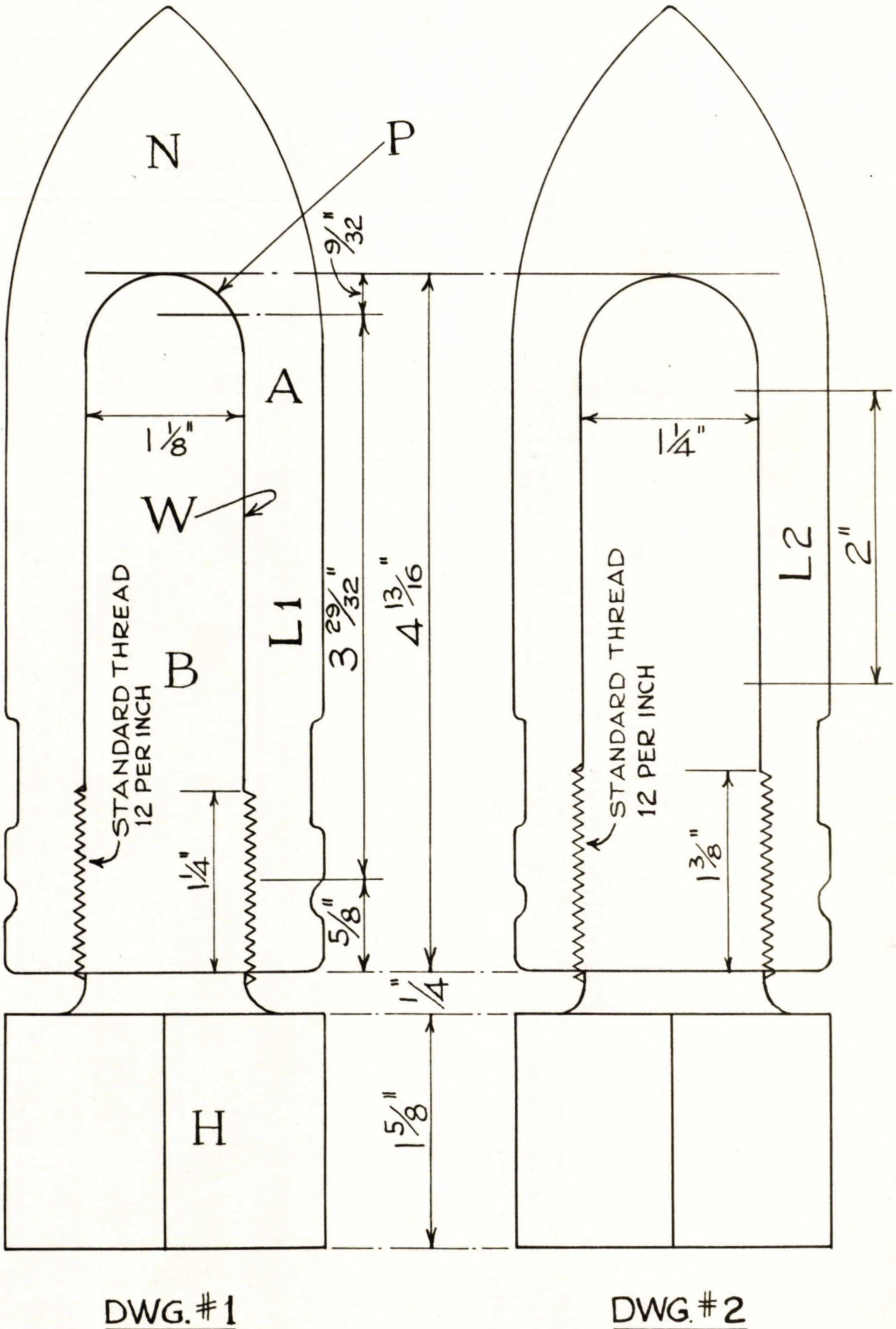
The chemical composition of typical steel* used to manufacture 6-pdr. armour-piercing shot is as follows:

		Per cent
Carbon	-	0.69
Manganese	-	0.79
Silicon	-	0.30
Phosphorus	-	0.014
Sulphur	-	0.018
Chromium	-	0.77
Nickel	-	0.90
Molybdenum	-	0.25

(Figure 1, containing Drawings)
(Nos. 1 and 2, constitutes Page 3.)
(Text continues on Page 4.)

* NOTE: Material taken from Heat No. 12720, from the Steel Company of Canada, used for manufacturing A/P 6-pdr. shot at Thompson Products Limited, St. Catharines, Ontario. (Chem. Lab. Test No. 1039)

FIGURE 1



DWG. #1 DWG. #2

W.A.E.

Heat Treatment:

The heat treatment processes upon part A were performed in such a way as to give practically the lowest value of residual stresses caused by quenching and the maximum hardness of the nose consistent with sufficient ductility of the treated base.

Part A was given the following heat-treatment:

a. Heat slowly for 2 hours, to a temperature of 1450° F., and hold at temperature for 30 minutes.

b. Quench into molten salt (potassium nitrate, 53 per cent; sodium nitrite, 47 per cent) at 305° F. at the beginning of quench and 340° F. at the end. Hold the shot one hour in the salt bath (in order to equalize the stresses and to transform the austenite to martensite).

c. Draw at 250° F. for 2 hours to relieve the stresses, and then cool slowly in furnace.

d. The drawing of the base was done in a fixture in which the shot's nose was immersed to a depth of 2½ inches in circulating water. The remaining part of the shot was covered with sand and the base was exposed to direct furnace heat. The thermocouple was fixed to the base of the shot. The shot was kept two hours at 1000° and cooled slowly in the fixture.

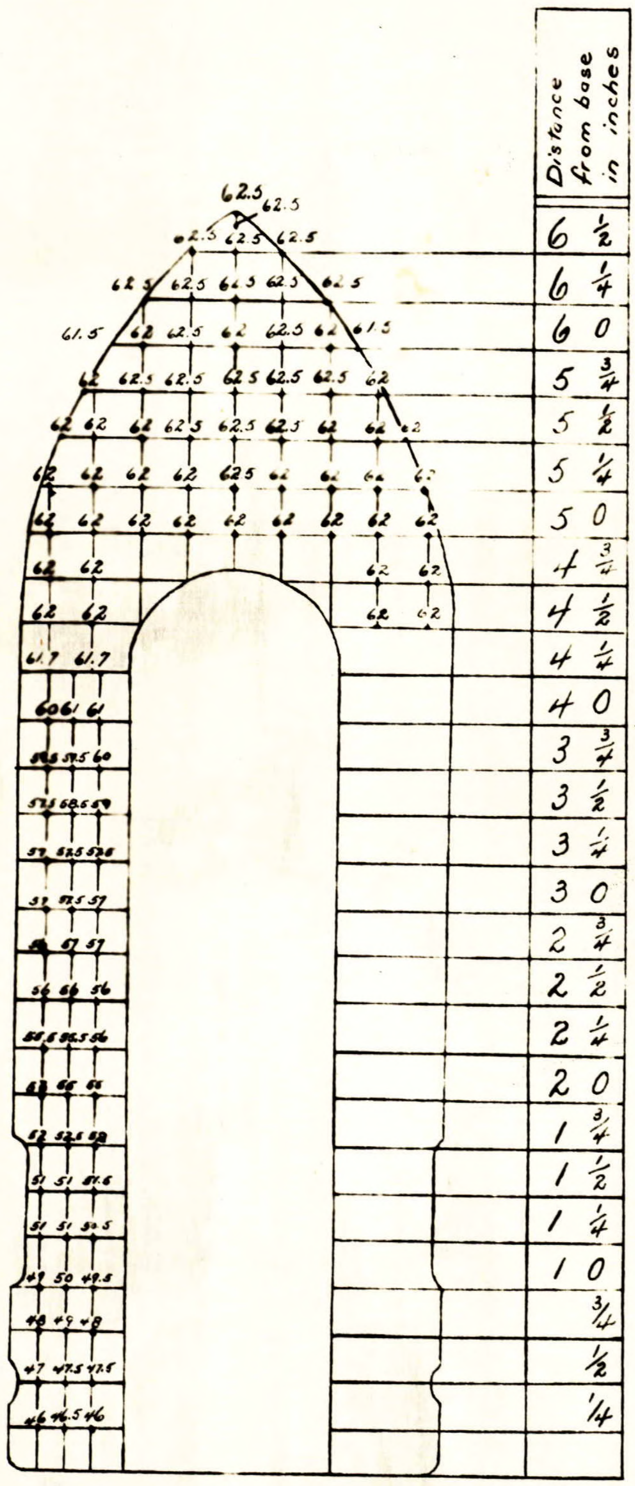
e. A second stress relief was performed at 275° F. for 6 hours.

The hardness pattern of an axial section of the experimental shot is shown in Figure 2 on Page 5.

The heat treatment of part B (plug) was performed under conditions giving the maximum hardness of front part and sufficient ductility of the treated part to enable its being screwed on under heavy load. The operations given in (a) and (b) for Part A were also applied to Part B. This was followed by stress relief at 275° C. for 6 hours. **The mean hardness of part B was 62.5 Rockwell 'C'.**

(Figure 2 constitutes Page 5.)
(Text continues on Page 6.)

FIGURE 2


Distance from base in inches
6 1/2
6 1/4
6 0
5 3/4
5 1/2
5 1/4
5 0
4 3/4
4 1/2
4 1/4
4 0
3 3/4
3 1/2
3 1/4
3 0
2 3/4
2 1/2
2 1/4
2 0
1 3/4
1 1/2
1 1/4
1 0
3/4
1/2
1/4

Residual Stresses:

The tangential residual stresses of "ST" locked in the experimental lot were checked on three cross-sectional rings, ½ inch wide, cut from one shot after heat treatment and before stressing. The measurement results and the calculations are given in Table I.

The approximate magnitude of "ST" in the outside fibre is minus 1,405 pounds per inch (tension), which may be regarded as very low, and we can assume that the applied heat treatment has caused practically no stress. For purposes of record the locations are designated A, B, and C.

TABLE I.

Before Splitting:

Ring No.	Inside diameter, inches	Outside diameter, inches At A	At B	At C	Average
1	1.0264	2.2406	2.2406	2.2406	2.24060
2	1.0181	2.2388	2.2388	2.2388	2.23880
3	1.0235	2.2378	2.2378	2.2378	2.23780
Average	1.02266			Total average -	2.23907

After Splitting:

Ring No.	Inside diameter, inches	Outside diameter, inches At A	At B	At C	Average
1	1.0265	2.2421	2.2408	2.2408	2.24123
2	1.0182	2.2390	2.2392	2.2392	2.23912
3	1.0235	2.2381	2.2379	2.2377	2.23790
Average	1.02273			Total average -	2.23942

"ST" max., outside fibre

$$\text{"ST" max., outside fibre} = \text{Minus } \frac{E}{1 - v^2} \cdot \frac{d}{2} \cdot \frac{R_1 - R_0}{R_0 R_1} = \text{Minus } 1{,}405 \text{ p.s.i.}$$

Key:

E = 30,000,000 p.s.i. : d = Thickness of the ring.
v = Poisson's ratio, 0.3 in. : R_0 = Mean radius before splitting.
: R_1 = " " after "

The changes of dimensions taking place during heat treatment are shown in Table II.

(Table II appears on Page 7.)

TABLE II.

THE CHANGE OF DIMENSIONS DURING HEAT TREATMENT.

No. of shot	NOSE: Outside diameter, in inches		NOSE: Difference in inches x 10^{-4},	BASE: Outside diameter, in inches		BASE: Difference in inches x 10^{-4},	BASE: Inside diameter, in inches		BASE: Difference in inches x 10^{-4},
	Before	After	Average	Before	After	Average	Before	After	Average
1	2.2314	2.2331-4	+18.5	2.2314	2.2340-6	+29	1.2500	1.2513	+13
2	2.2313	2.2326-36	+18	2.2311	2.2339-44	+30.5	1.1250	1.1265	+15
3	2.2313	2.2330-2	+18	2.23125	2.2335-8	+24	1.1250	1.2505	+5
4	2.2313	2.2332-5	+20.5	2.2311	2.2340-4	+31	1.1250	1.1262	+12
5	2.2316	2.2333-6	+18.5	2.2315	2.2337-40	+23.5	1.2500	1.2510	+10
6	2.2314	2.2331-2	+17.5	2.2313	2.2336-7	+23.5	1.1250	1.1255	+5

DESCRIPTION OF THE STRESSING FIXTURE:

Experimental shot described above were stressed in a special fixture, shown in Figures 3 and 4. This fixture consists of four legs supporting an 18-inch-square, ½-inch-thick steel plate on which are fixed two permanently divided bearings, B1 and B2, each lined with two axle box bearings made of copper, C. In order to raise the friction coefficient between the copper inlay and the shot, the former is notched on the inside surface and is sprinkled with sand before use.

Four screws (marked S in Figure 3), two on each bearing, press the stressed shot and the copper bearing very strongly together, not allowing them to move against each other.

The rectangular head of part A (marked H in Figure 1, Drawing No. 1) is used as a screw head and is screwed on by a 6-foot-long spanner (Sp in Figure 4). This length makes it possible, by using the force of three men, to stress the part A to about 100,000 pounds per square inch and part B correspondingly higher.

The dial marked D on Figure 4 is 17 inches in diameter and is attached to part A by a small screw. The pointer I is fixed to part B on the rectangular head H. Fixed in this way, dial and pointer permit reading of the angle of a turn between parts A and B with ½° accuracy. The fixture used had 12 threads to the inch. A 1° turn of the twisting mechanism, then, is equivalent to a movement along the longitudinal axis of a length, X, equal to:

$$\frac{1}{12 \times 360} = \frac{1}{4320} = 2.315 \times 10^{-4} \text{ inches.}$$

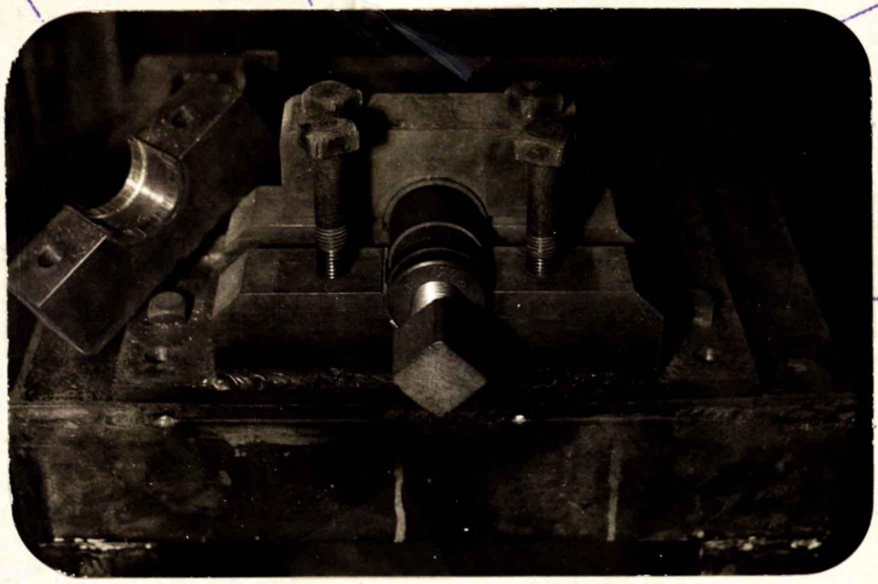
EXPERIMENTAL STRESSING PROCEDURE:

The shot, constructed as shown in Figure 1, were stressed in the fixture described above.

The stressing operation took place after completion

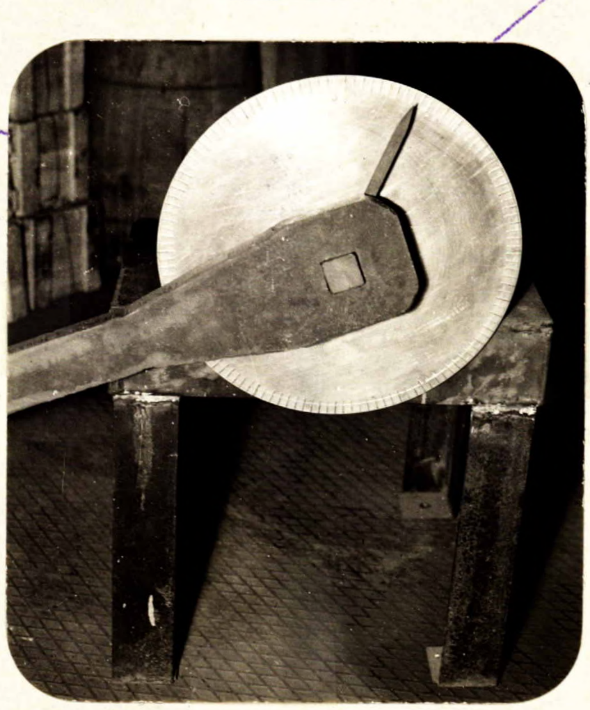
(Figures 3 and 4 are on Page 9.)
(Text continues on Page 10.)

Figure 3.



View of Bearings and Shot.

Figure 4.



View of Dial and Spanner.

STRESSING FIXTURE.

(Experimental Stressing Procedure, cont'd) -

of the machining, heat treatment, grinding, and banding. After stressing, the rectangular heads H were removed with a rubber-bonded abrasive cut-off wheel. The angle of turn was measured as being from the point at which the front part of plug B was felt to touch the nose, i.e., starts to press the inside surface P).

The measurement of stresses produced was accomplished by:

(a) Direct measurement of strain on a measuring length (see mark L_2 on Drawing No. 2), i.e., two circles two inches apart, marked before stressing, around the outside of the shot.

(b) Indirect measurement by measuring the twist shown on the stressing fixture by pointer and dial arrangement.

Tension-induced strain in part A and compression-induced strain in part B are together equal to the movement of the rectangular head H. This movement is determined by twist angle, using the ratio of 1° angle = 2.315×10^{-4} inch, the angle being measured from the point where the plug B has touched the nose of the shot. Table III (Page 11) shows stressed conditions achieved.

The ratio of cross-section in A and B, of course, determines the ratio of tensile stress in A and compressive stress in B. For a 1-1/8 inch diameter plug the surface ratio is 2.926; for a 1¼-inch-diameter plug, 2.180.

The stress measurements of the first experimental lot were made by both of methods (a) and (b) described above. These shot were set aside to be used in investigating the influence

(Page 11 contains Table III.)
(Text resumes on Page 12.)

TABLE III. - THE LONGITUDINAL EXTENSION "E" OF PART A AND LONGITUDINAL COMPRESSION "C" OF PART B.

A/P SHOT WITH 1-1/8 IN. PLUG.

E L A S T I C

Tensile Stress in Part A, p.s.i.	(σ 1) Compression Stress in Part B, p.s.i.	Extension (E) of Part A, x 10^{-4}, inches	(σ 2) Compression (C) of Part B, x 10^{-4}, inches	Total (E) + (C), x 10^{-4}, inches	Required Angle of Turning to obtain σ 1 and σ 2
25,000	73,150	32.733	95.777	128.510	55.5°
50,000	146,300	65.466	191.554	257.020	111.0°
75,000	219,450	98.199	287.331	385.530	166.5°

Remarks: 1° turn corresponded to σ1 = 450.4 p.s.i.

A/P SHOT WITH 1¼ IN. PLUG.

25,000	54,510	29.166	63.595	92.761	40.1°
50,000	109,020	58.332	127.190	185.522	80.2°
75,000	163,530	87.498	190.785	278.283	120.3°

Remarks: 1° turn corresponded to σ1 = 623.44 p.s.i.

(Experimental Stressing Procedure, cont'd) -

of the grinding operation and deep etching on stressed shot. The results of this work will be discussed in a separate report.

The stress measurements of the second experimental lot were performed by method (b), i.e., by measuring the twist angle of the rectangular head <u>H</u>.

The stresses were calculated, for A/P shot with 1-1/8 inch plug, on an approximate length equal to the total length of the plug B (4-13/16 inches) minus half the length of the thread (5/8 inch) and half the height of the front hemispheric part of the plug (9/32 inch), giving a total measuring length of 3-29/32 inches (3.928 inches). This length is marked as L_1 in Figure 1, Drawing 1. Similarly, for a 6-pdr. shot with a $1\frac{1}{4}$-inch plug, the length used was $3\frac{1}{2}$ inches.

The results of longitudinal stress calculations made on the second lot of shot stressed are given below, in Table IV:

TABLE IV.

THE VALUE OF LONGITUDINAL STRESSES IN A/P SHOT STRESSED MECHANICALLY.

No.	Diam. of shot, inches	Measuring length, in inches	Turns, in degrees	Longitudinal tensional stress in A, p.s.i.	Longitudinal compressional stress in B, p.s.i.	Firing Trial Round No.
1	$1\frac{1}{4}$	3.5	75.3	46,950	102,359	4
3	$1\frac{1}{4}$	3.5	64.2	40,025	87,270	5
5	$1\frac{1}{4}$	3.5	67.0	41,705	90,933	6
2	1-1/8	3.906	92.1	41,480	121,370	7
4	1-1/8	3.906	72.5	32,650	95,530	8
6	1-1/8	3.906	58.5	26,350	77,100	9
7	1-1/8	3.906	41.9	18,870	55,213	- Broke (see Figure 5)

NOTE: 1° twist on stress fixture equals, for $1\frac{1}{4}$ in. diam. shot, 623.44 p.s.i.; for 1-1/8 in. diam. shot, 450.40 p.s.i.

Longitudinal stretching of the outside part A produces contraction of the transverse section of this part, and simultaneously the contraction of compressed part B (plug) results in extension of the transverse section of that part. The approximate value of these contractions and extensions are given in Table V.

(Table V follows on Page 13.)

TABLE V. - THE TRANSVERSE CONTRACTION "C" OF PART A ON INSIDE DIAMETER AND TRANSVERSE EXTENSION "E" ON DIAMETER OF PART B.

A/P SHOT WITH 1-1/8 IN. PLUG.

(σ1) Tensile Stress in Part A, p.s.i.	(σ2) Compression Stress in Part B, p.s.i.	Contraction (C) of Part A, x 10^{-4}, inches	Extension (E) of Part B, x 10^{-4}, inches	Total, (C) + (E), x 10^{-4}, inches	Remarks
25,000	73,150	2.81	8.23	11.04	Equal space left between
50,000	146,300	5.62	16.46	22.08	A and B in all shot,
75,000	219,450	8.43	24.69	33.12	40 x 10^{-4} inches.

A/P SHOT WITH 1¼ IN. PLUG.

25,000	54,510	3.125	6.814	9.939	Equal space left between
50,000	109,020	6.250	13.628	19.878	A and B in all shot,
75,000	163,530	9.375	20.442	29.817	40 x 10^{-4} inches.

NOTE: Calculated using E = 30,000,000 p.s.i.
V = Poisson's ratio, 0.3.

(Experimental Stressing Procedure, cont'd) -

No great difficulty was encountered in stressing the shot. However, a smooth shot surface was found to be essential, as surface markings caused stress concentration which produced cracking.

Figure 5 is a photograph of broken shot No. 7 which broke at a 1/10-in. machining mark after stressing to $\sigma_1 = 18,870$, $\sigma_2 = 55,213$ p.s.i. (See N on Figure 5).

Figure 5.

N

BROKEN SHOT NO. 7.

-

Firing Trials:

The following experimental shot were proof tested:

Shot Nos. 2, 4, 6 with 1-1/8 in. plug.

Shot Nos. 1, 3, 5 with $1\frac{1}{4}$-in. plug.

The longitudinal stresses in these shot have been given in Table IV, on Page 12.

These firing trials were performed at the Proof and Development Establishment of the Inspection Board of the United

(Firing Trials, cont'd) -

Kingdom and Canada, at Valcartier, Quebec, under the supervision of Lieut. H. A. Allan. A copy of his report is appended to this report (see Page 17).

CONCLUSIONS:

The small number of shot tested makes it impossible to check on the effect of numerous metallurgical and mechanical variables. As a consequence, this investigation must be considered as being only preliminary.

Proof test results obtained were not conclusive, although there is some indication that the stressed shot make a bigger hole than standard shot, the difference being from 1/8 to ¼ inch. This may be because the stressed shot remain whole at the first instant of contact, only shattering in penetration.

Proof tests made on standard shot heat-treated similarly to the experimentally stressed shot showed that this heat treatment used did not confer good ballistic properties. This is unfortunate as the effect of the heat treatment may have masked stressing effects. The salt quenching procedure was used, however, because it was thought it would hold internal stresses to a minimum while still maintaining a high hardness.

To truly equate the effect of stressing shot, the performance of longitudinally stressed shot should be compared not with the standard shot performance but rather with results obtained from shot of the same construction with the plug twisted to give practically no stress and also various stress increments.

As the degree of stressing is limited by the compressional stress on the plug, it might be of interest to run tests

(Conclusions, cont'd) -

on shot plugged with tungsten carbide, which has high compression strength. The increased density of the tungsten carbide plug may also improve performance.

Supplementary investigations are being conducted by these Laboratories into further methods of stressing shot during heat treatment, by use of different quenching media (water, oil, salt) at various temperatures and other conditions affecting the magnitude and distribution of stresses.

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TWW:GHB.

APPENDIX.

(COPY)

File No. V-409

Valcartier, P.Q.
October 6th, 1943.

INSPECTION BOARD
of
UNITED KINGDOM AND CANADA
Proof and Development Establishment

T.W. Wlodek,
Bureau of Mines and Resources,
552 Booth Street,
Ottawa, Ont.

Dear Sir,

Attached please find copy of report of recent trial of 6 pr. stressed shot, with photographs of plate.

May I say that we would be pleased to carry on any further trials of this nature at any time.

Yours truly,

(Signed) H. M. Allan, Lieut.
Assistant Proof Officer,
for/Proof Officer,
Valcartier.

HMA/EA
Encls.

V.409

REPORT OF TRIAL OF Q.F. 6 Pr. "STRESSED" A/P SHOT.

Plate Rolled Homo
Manufactured by Dominion Foundries & Steel
D.A.P. 8097
B.H.N. 269-285
Actual thickness 2.81"

Gun Q.F. 6 Pr. No. 2221
E.F.C. 18¼

Shot St. Catherines Steel Products Lot 29A
Sub-standardized at 9 f.s. better than Hadfields.

Object of Trial

To find the manner in which shatter occurred with the stressed shot on oblique impact at a high velocity.

(Continued on next page)

(Appendix, Report of Trial of Q.F. 6 Pdr. "Stressed" A.P. Shot, cont'd)-

Summary of Results

All shots shattered in very small pieces at striking velocities of 2800 f.s. and above. Full details regarding shatter will be published in a separate report by Mr. C. S. Parsons of the Bureau of Mines and Resources.

Round by Round Results

Trial Rd. No.	Shot No.	Weight	S.V.	Damage
1	Sub-standard	6-4-8	2176 f.s.	H.N. P.O.

Clean hole 2½" diameter. Shot recovered complete in rear of plate.

2	Sub-standard	6-4-10	2102 f.s.	S.B.

Impression 2½". Bulge 5/8". Shot complete.

3	Sub-standard	6-4-11	2167 f.s.	S.B.

Bulge ½". Shot recovered broken.

4	1	6-5-15	2340 f.s.	C.B.

Bulge 1 1/8". Several pieces of core and shot recovered.

5	3	6-5-14½	2854 f.s.	N.F.N.

Near Rd. 2. Shattered pieces of core and shot recovered in front and rear of plate.

6	5	6-6-7½	2833 f.s.	H.S. 3¼" P.O.

Large piece of core, shattered longitudinally, recovered rear of plate.

7	2	6-5-13	2857 f.s.	H.S. 3 3/8" P.O.

Small pieces of core and shot recovered in front and rear of plate.

8	4	6-5-12½	2847 f.s.	N.F.H.

Through Trial Rd. 1.

9	6	6-5-13	2848 f.s.	H.S. 3¼" P.O.

Pieces of base recovered front and rear of plate. Approximately 50% of core, (nose and shoulder) broken horizontally, recovered in rear of plate.

10	Sub-standard	6-4-12	2805 f.s.	H.S. 3 1/8" P.O.

Shot broken below shoulder. Base and part of body, weight 3-1-11 recovered in front of plate.

Valcartier, P.Q. 30-9-43.

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(Page 19 contains the two photographs of Lieut. Allan's report.)

(Appendix,
Report of Trial of Q.F. 6 Pdr. "Stressed" A.P. Shot, cont'd)-

PHOTOGRAPHS.

(Copied, Dec. 1943, GHB.)