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O T T A W A September 2nd, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1489.

O.K.

The Simultaneous Quench-and-Draw Heat Treatment of 17-Pdr. A.P.C. Shot.

(Copy No. 4.)

Abstract

This report is an account of a method of heat treating 17-pdr. armour-piercing shot in such a manner as to be able to develop the desired hardness pattern and ballistic properties in one operation. This operation consists of quenching a shot into water to a depth of 1½ in. from the forward edge of the driving band and holding for 15 minutes.

The advantages foreseen for this heat treatment are:

1. The operation of tempering the base of the shot is entirely eliminated, by quenching the ogive and part of the body, permitting the base to cool in air.

2. Valuable induction machines are released for other purposes.

3. Less labour is required for this process.

4. There will be no backlog of hardened shot waiting to be base-drawn, thus minimizing another danger of cracking.

5. The possibilities of cracking are minimized by permitting at least 4 inches of the shot, which includes the sensitive driving band area, to cool relatively slowly.

Satisfactory hardness pattern and ballistic properties were developed by this method of heat treatment.

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

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

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ORE DRESSING AND METALLURGICAL LABORATORIES.

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Origin of Request:

In a letter dated May 28th, 1943, Mr. G. J. Manson, of the Ammunition and Gun Production Branch (Shell Division), Department of Munitions and Supply, Ottawa, Ontario, requested that these Laboratories investigate thoroughly all phases of the heat treatment of 17-pdr. A.P.C. shot.

Material Used:

All shot used in this investigation were taken from a shipment of 150 17-pdr. A.P. shot (from Lot D) supplied by the St. Catharines Steel Products Limited, St. Catharines, Ontario.

Chemical Analysis:

These shot, the heat number for which is unknown, had the following composition:

		Per cent
Carbon	-	0.68
Silicon	-	0.33
Manganese	-	0.81
Phosphorus	-	0.026
Sulphur	-	0.018
Chromium	-	0.73
Nickel	-	0.80
Molybdenum	-	0.21
Vanadium	-	0.033

This is within the specification limits and is a fairly representative heat.

General Discussion:

The present-day method of heat treating 17-pdr. A.P. shot, in Canada, is to bring the shot to a temperature of approximately 1500° F. (this temperature varies with every heat) in a gas-fired tubular furnace. The shot are quenched into agitated oil of a temperature of 130° F. and held in the bath for 13 minutes. The whole shot is then drawn at a temperature of 250° F. for 3 hours and the base only is then tempered by induction to give the hardness pattern shown in Figure 3. This hardness pattern was obtained by a survey conducted on heat-treated shot sent to these Laboratories by the St. Catharines Steel Products Limited (covered in P.M. Lab. Report No. 6418, July 22nd, 1943).

Proof papers up to July 21st, 1943, have indicated that shot heat-treated as described above perform satisfactorily at plate proof. It is understood that the one objection to this type of heat treatment is that the shot have a tendency to crack during all stages of production. In some heats 50 per cent were found to have longitudinal cracks.

For this investigation, it was decided to experimentally employ water as a quenching medium because (1) water

(General Discussion, cont'd) -

quenching can give a broad range of cooling rates; (2) water will harden this steel right through to the centre; and (3) this section of steel when hardened by water appears to have tangential stresses in compression at the surface and cracks apparently rarely occur when the surface is under compression.

Oil-quenching this section of steel has a tendency to leave tensional stresses at the surface which are the prime cause of cracking. In fact, so many of these shot are cracking that it may be directly attributed to the method of quenching which is setting up tangential stresses in tension at the surface.

Experimental Work:

It was decided to quench the shot in such a manner as to eliminate entirely the base draw treatment; therefore, the shot was quenched in water to a predetermined distance from the base, thereby permitting the nose and shoulder to harden to the centre and the base to cool slowly to form a softer constituent at the base with the hardness increasing toward the shoulder.

A fixture was designed such that the depth of immersion of the shot could be adjusted and the velocity of the water could be altered to give various cooling rates. A photograph of this fixture appears as Figure 1 herein.

Results of Experimental Work:

A great many shot had to be quenched in the fixture described above, because of the 4 variables involved, namely,

(1) Velocity of water,
(2) Distance of water from base,
(3) Time of immersion, and
(4) Quenching temperature.

It was found, finally, that a desirable hardness

(Results of Experimental Work, cont'd) -

pattern could be obtained by quenching from 1500° F. and immersing the shot to a depth of 1½ in. below the forward edge of the driving band. The shot is held in water, flowing at the rate of 3.7 cu. ft. per minute, for 15 minutes and is then immediately placed in a low-temperature draw furnace and held at 275° F. for 3 hours.

Eight shot were prepared in this manner and permitted to "age" for 3 weeks. Three of these were sent to the St. Catharines Steel Products Limited plant where they were ground to size, banded, and capped. They were then sent to the Port Dalhousie proving ground for proving. The results of proof, which were satisfactory, are shown in Figure 2.

Of the remaining five shot, two were slit in half, wet-ground to remove any tempered material, and polished for Vickers hardness readings. The two shot had a hardness pattern as shown in Figure 4.

The other three shot were placed in hot concentrated HCl for 15 minutes. No cracks were found after this treatment, an indication that any stresses which were at the surface of the shot were compressional.

CONCLUSIONS:

1. The following heat treatment results in a desirable hardness pattern and, if the few tests conducted are to be accepted as a criterion, gives ballistic performance equal to shot produced by the present method of heat treatment:

Heat to 1500° F. for one hour. Quench in flowing water to a depth of 1½ inches from the forward edge of the driving band (water flowing 3.7 cu.ft./min.) Hold for 15 minutes, and transfer at once to a low-temperature furnace at 275° F. for 3 hours. Air cool.

2. In no instance was a crack found in a shot quenched

(Conclusions, cont'd) -

by this method nor were cracks produced after etching in hot HCl, indicating that there are compressional stresses at the surface -- a desirable condition.

3. Experimental work conducted has shown that when this steel is hardened and tempered in the range of 1200° F. to 900° F. and subsequently slowly cooled, it is brittle. This condition is known as "temper brittleness". Since the base of the shot is cooled at a moderate rate and is never hardened, it is unlikely that the steel will be brittle, nor is the hardened portion tempered in the brittle range.

4. This method of heat treatment, which produces shot of the same hardness pattern and of apparently equal, if not superior, ballistic properties to present production shot, is a very simple method, requiring less time than the method now in use.

This statement is based on the information received that, in present production, drawing the base and quenching after drawing takes approximately the following time:

Quench in oil, 13 minutes.
Base draw, 12 at a time, 5 minutes.
Quench after draw, 1 minute.

The "Simultaneous Quench-and-Draw" method takes 15 minutes total time.

It may be seen that although the quenching operation takes longer in the proposed method, one whole operation is eliminated and labour and costly induction equipment are released for other work. Moreover, in view of the fact that the present base-draw machines are unable to take care of the number of hardened shot, it seems to be advantageous to eliminate them if possible.

5. The new heat treatment described herein apparently

(Conclusions, cont'd) -

constitutes a cheaply installed and highly satisfactory method of heat-treating 17-pdr. A.P. shot. It seems probable that much time could be saved and valuable equipment released for other purposes (perhaps to increase the production of 6-pdr. A.P. shot).

However, the main consideration is that this kind of heat treatment offers the possibilities of producing shot which are free from cracks, either longitudinal (a result of tangential tensional stress) or circumferential (due to longitudinal tensional stress). The driving band grooves are places which are quite sensitive to sudden changes in temperature and it is decidedly advantageous to permit this area to cool slowly rather than to be quenched and then tempered to the required hardness. Sudden quenching of sections which have an abrupt change in section size causes unequal cooling and a crack is a likely result.

6. The experimental work was conducted on a single heat only, but it is unlikely that slight changes in analysis will have an ill effect on the final result.

Recommendations:

Since the results of this type of heat treatment are favourable, it is recommended that production on a small scale be commenced in order to positively establish the following facts:

1. That the shot will consistently pass ballistic tests;
2. That the hardness pattern can be consistently duplicated;
3. That the shot will not crack;
4. That the effect of varying analysis has little or no effect on the final result.

A suggested procedure is to construct a fixture

(Recommendations, cont'd) -

similar to the one shown in Figure 1 (a modification would be to employ a spray rather than flowing water, so that the intensity of quench could be controlled more accurately) and to install the fixture alongside the present oil-quenching bath. About 30 shot could then be quenched from every heat, following which they could be placed immediately in the low-temperature draw furnace at 250 to 275° F. for 3 hours, and then they could be magnafluxed to show up any cracks formed by quenching.

The following test procedure could be used:

Slit 10 per cent for hardness survey;

Prove 20 per cent;

Etch 35 per cent in hot concentrated HCl for 30 minutes, then magnaflux to show up cracks (it is assumed that if the shot do not crack after this treatment, they will never crack); and

Store 35 per cent for two to three weeks to see whether any cracks develop during ageing. Magnaflux the shot to show up cracks.

The above procedure should prove beyond a doubt the efficiency of this heat treatment. Hardness surveys will determine whether the depth of immersion is correct. (Since changes in analysis changes hardenability, it may be necessary to change depth of immersion but this is doubted).

Etching in HCl will determine whether the velocity of cooling is such as to leave the surface of the shot in compression.

Proving, which is, of course, the final criterion of acceptance, will judge the quality of the shot.

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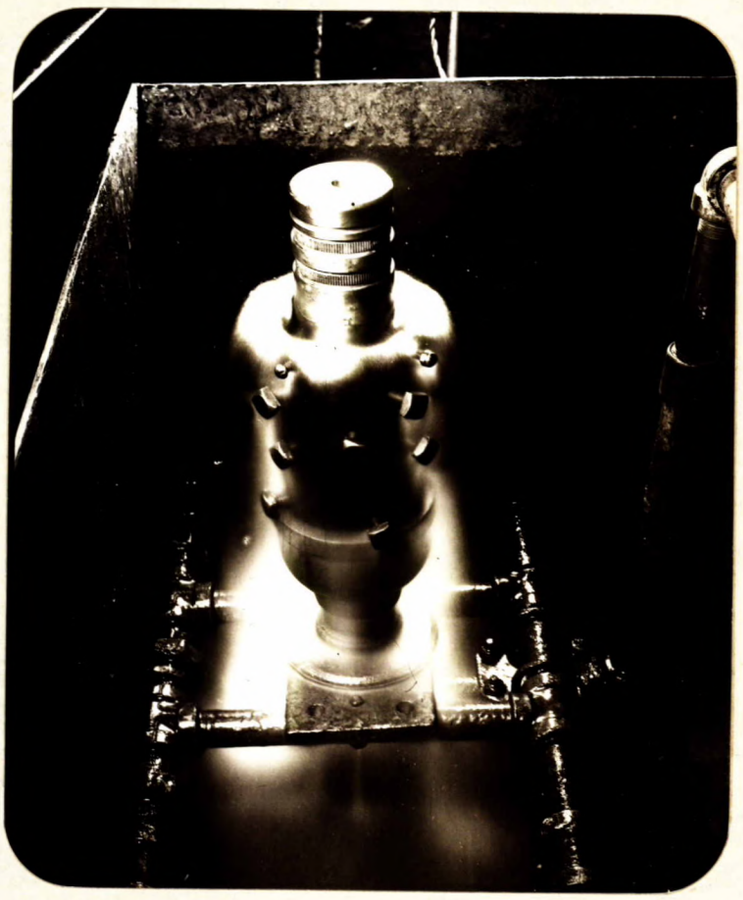
Figure 1.



QUENCHING FIXTURE USED TO SIMULTANEOUSLY QUENCH AND DRAW 17-PDR. A.P. SHOT.

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Figure 2.

Plate No.	-	D26.
Brinell Hardness	-	262 - 277.
Plate Thickness	-	123 m.m.
Proof Velocity	-	2547 ft./sec.
Critical Velocity	-	2447 "

TRIAL			CALIBRATION	
Lot No.	Velocity, ft./sec.	Hole in plate	Velocity, ft./sec.	Hole in plate
3D	2559	Hole.	2319	Dent.
4D	2590	Hole (base lodge).	2417	Dent.
			2517	Hole.
5D	2576	Hole.	2477	Hole.

RESULTS OF FIRING TRIAL OF SHOT HEAT-TREATED BY SIMULTANEOUS QUENCH-AND-DRAW.

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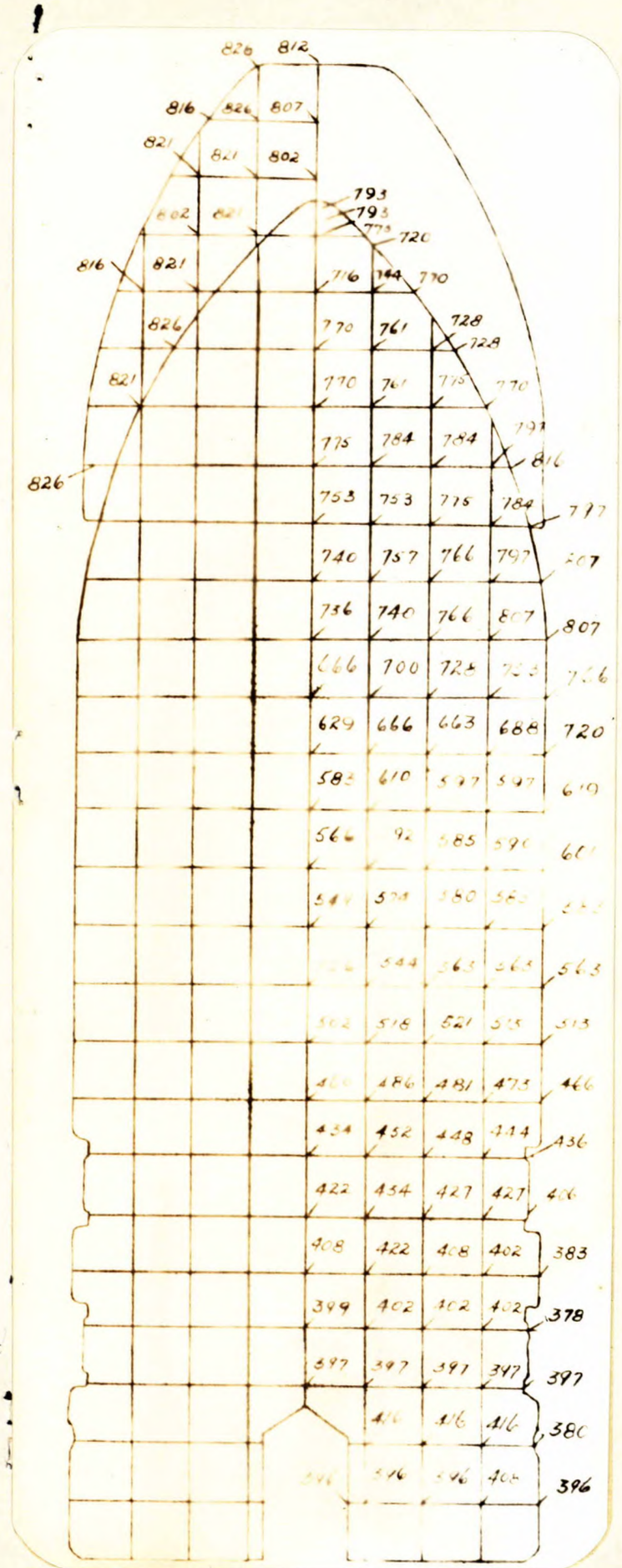
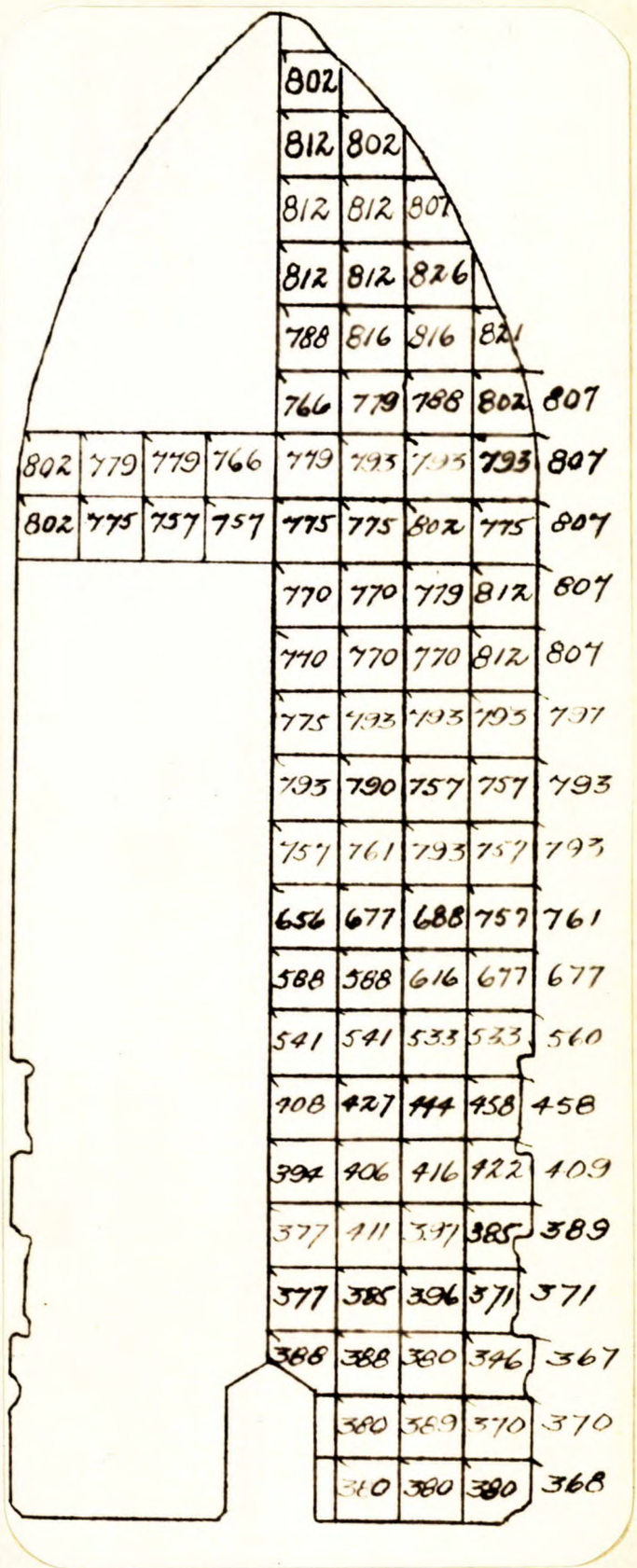
Figure 3.



VICKERS HARDNESS PATTERN (50-KG. LOAD) OF A.P.C. SHOT MANUFACTURED BY ST. CATHARINES STEEL PRODUCTS.

Figure 4.



VICKERS HARDNESS PATTERN (50-KG. LOAD) OF 17-PDR. A.P. SHOT SIMULTANEOUSLY QUENCHED AND DRAWN.

CONVERSION GUIDE

Rock. 'C'	Vickers (50-kg.)	Rock. 'C'	Vickers (50-kg.)
65	825	60	705
64	795	50	522
63	770	40	391
62	748	30	300
61	725		

HLL:GHB.