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OTTAWA November 9th, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1520.

Investigation of a Heat of 17-Pdr. A.P. Shot Which Showed a High Percentage of Cracks after Heat Treatment.

(Copy No. 10.)

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

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

OTTAWA November 9th, 1943.

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ORE DRESSING AND METALLURGICAL LABORATORIES.

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Origin of Request and Purpose of Investigation:

An investigation into the cause of cracking of a certain heat of A.P.C. 17-pdr. shot has been requested by the St. Catharines Steel Products Limited, St. Catharines, Ontario, per J. M. Mathewman, Plant Manager. Mr. Mathewman's request letter and another, from Mr. O. A. Vale, Chief Inspector, which gave considerable information about the heat treatment, are copied below:

"St. Catharines, Ontario
October 14, 1943.

Department of Mines and Resources,
Mines and Geology Branch,
552 Booth Street,
OTTAWA, Canada.

Subject: Shot, A.P.C. 17 Pdr.

Attention: Mr. H. L. Lexier

Gentlemen:

We have to-day encountered a particularly erratic heat of Steel Company of Canada material for A.P.C. 17 Pdr. Shot. Although our preliminary sampling did not indicate any unusual characteristics in this material, our production experience has been 955 scrap shot in one day's heat treating, due to quench cracking.

In view of your recent findings, I am most anxious to have your opinion after your examination of these shot. I am instructing Mr. O. Vale to forward you twenty random

(Origin of Request and Purpose of Investigation, cont'd) -

samples from this heat No. 10272 and would be very grateful if you could perform a thorough examination and let us have your comments. This sudden epidemic of scrap loss has occurred with this one heat only, and I feel this is a great opportunity to locate and identify the cause of this trouble.

Yours very truly,

ST. CATHARINES STEEL PRODUCTS LIMITED,

J. M. Matthewman Plant Manager.

JMM/RB
cc: Mr. G. J. Manson,
Dept. of Munitions & Supply,
OTTAWA, Canada."

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"St. Catharines, Ontario
October 16, 1943.

Department of Mines & Resources,
552 Booth Street,
OTTAWA, Canada.

Attention - Mr. H. L. Lexier

Dear Sir:

In answer to your teletype requesting information about heat 10272, we have forwarded 20 shot to you as follows:-

12 heat treated and base drawn with no apparent cracks at time of leaving Plant.
2 showing typical cracks obtained.
6 not heat treated.

These shot were treated in our muffle tube furnace at 1500° F., total time in the furnace 3 hours. Part of them were quenched directly into oil; part were quenched in water and oil, as we were doing when you were here.

All shot were base drawn in the Tocco on the following cycle:-

Heat 5 minutes, Delay 12 minutes, Quench 1 minute, Power 77 Kw. Max.

The partial quench in water before going into the oil was 15 seconds. The total time in the oil was 13 minutes. The percentage of cracks for each type of treatment is given below:

Lot No.	Quench	No. Cracks	No. shot in Lot
C-47	Oil	601	810
C-48	Water & Oil	178	810
C-49	Oil	347	810
C-50	Water & Oil	504	810
C-51	Oil	130	517

The greater portion of these shot cracked after

(Origin of Request and Purpose of Investigation, cont'd) -

base draw, many of them showing up in the Bullard Dunn and grinder though they were not evident at magnaflux.

Yours very truly,

ST. CATHARINES STEEL PRODUCTS LIMITED,

O. A. Vale, Chief Inspector.

OAV/JL."

The cause of cracking of 17-pdr. shot has been under investigation in these Laboratories for some months. The results of this investigation, together with the findings from this particular heat, are incorporated in the present report.

Material Used:

Twelve (12) shot heat-treated and base-drawn, two (2) shot showing typical cracks (longitudinal), and six (6) shot not heat-treated, were supplied by the St. Catharines Steel Products Limited. All shot came from Heat No. 10272, Symbol A.

Subsequently, four shot from Lot No. C-49 were requested and obtained from this company.

Chemical Analysis:

The analysis of Heat No. 10272, as reported by St. Catharines Steel Products Limited, is as follows:

		Per cent
Carbon	-	0.70
Phosphorus	-	0.022
Sulphur	-	0.024
Manganese	-	0.92
Silicon	-	0.350
Chromium	-	0.915
Nickel	-	0.876
Molybdenum	-	0.280

Thermal History:

The shot were heated in a muffle tube furnace. Total time in the furnace was 3 hours. The shot were quenched from 1500° F. Part of the heat was quenched, nose down, into water to a depth of about 1½" from the driving band for 15 secs., then into oil (130° F.) and held 13 minutes.

The remainder of the heat was quenched directly into oil (130° F.) and held for 13 minutes. Although it was not so stated in Mr. Vale's letter, it is believed that the shot were stress-relieved at 250° F. for 3 hours. All shot were base-drawn by induction as follows:

Heat for 5 minutes,
Delay for 12 minutes,
Water quench for 1 minute, and
Power, 77 kw., max.

Percentage of Cracked Shot:

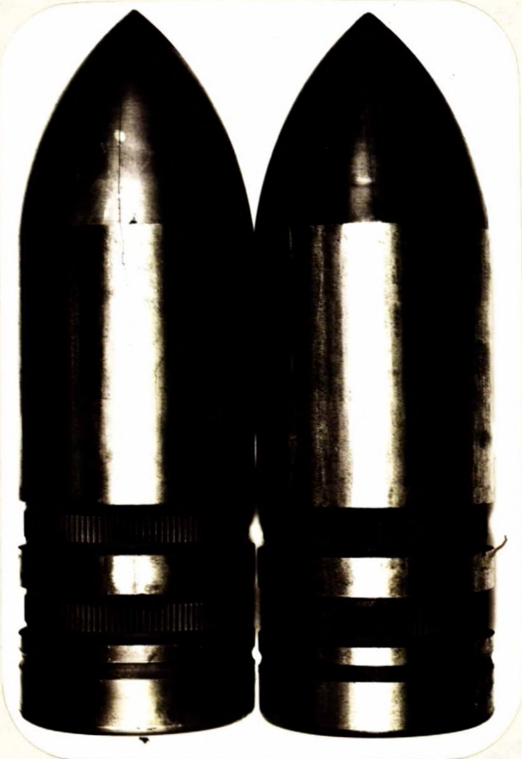
Lot No.	Quench	Number of cracks	Number of shot in lot	Percentage cracked
C-47	Oil	601	810	
C-48	Water and oil	178	810	
C-49	Oil	347	810	
C-50	Water and oil	504	810	
C-51	Oil	130	517	
	Total -	1,760	3,757	47 per cent

Unfortunately it was not stated whether the 12 shot sent for examination were taken from an "oil-quenched" lot or from a "water- and oil-quenched" lot. It is believed that the two shot which showed "typical cracks" were taken from an oil-quenched lot, since this type of crack is supposedly common to this type of heat treatment. The cracks may be seen in the photograph, Figure 1.

(Continued on next page)

(Percentage of Cracked Shot, cont'd) -

Figure 1.



PHOTOGRAPH OF SHOT, DEPICTING "TYPICAL" CRACKS.

EXPERIMENTAL WORK:

Etching -

The twelve heat-treated shot were etched in boiling 50 per cent hydrochloric acid. They were examined every 15 minutes and if a crack was observed the etch was discontinued.

Figure 2 shows the kind of circumferential cracks which developed in four of the twelve shot after etching 15 minutes.

(Continued on next page)

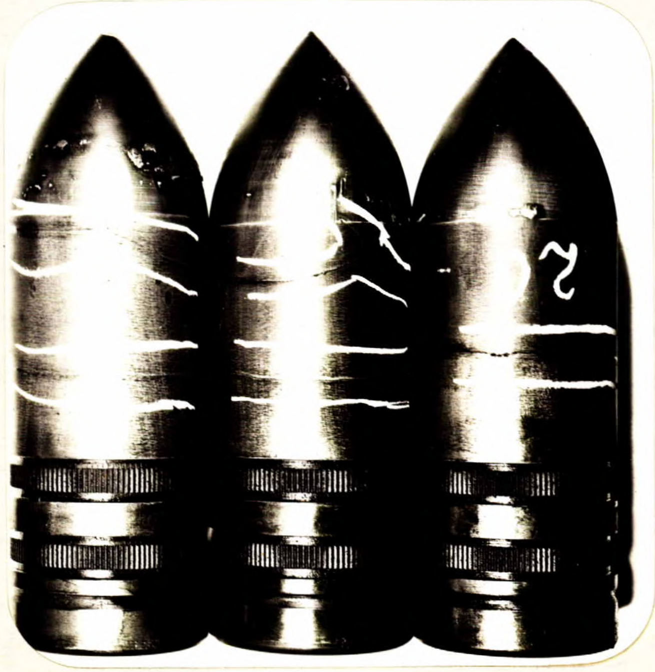
(Experimental Work, cont'd) -

Figure 2.

CIRCUMFERENTIAL CRACKS DEVELOPED BY 1:1 HCl ETCHING FOR 15 MINUTES.

Figure 3 shows the kind of circumferential cracks which developed in three of the twelve shot after etching for 20 minutes.

Figure 3.



CIRCUMFERENTIAL CRACKS DEVELOPED BY 1:1 HCl ETCHING FOR 20 MINUTES.

(Experimental Work, cont'd) -

Figure 4 shows the kind of circumferential cracks which developed in two of the twelve shot after etching for 45 minutes. None of the shot cracked longitudinally, which indicates that all twelve shot came from a lot which had been partially water-quenched and then oil-quenched, since this type of crack is common to that heat treatment.

Figure 4.

CIRCUMFERENTIAL CRACKS DEVELOPED BY 1:1 HCl ETCHING FOR 45 MINUTES.

The four shot from Lot C-49 were etched and two of these developed circumferential cracks after 45 minutes. All showed many grinding cracks, indicating that grinding was too rapid.

Heat Treatment -

Six unheat-treated shot from this heat were included in the shipment to these Laboratories. Five of the six were now heat-treated as follows:

Shot No. 1 was quenched, nose down, into flowing

(Experimental Work, cont'd) -

water to a depth of 1½" from the driving band for 15 minutes, after which it was removed and stress-relieved for 3 hours at 250° F. Shot Nos. 2 and 3 were quenched from 1500° F., nose down, into flowing water to a depth of 2 inches from the driving band. The shot remained in the water for 17 minutes, after which they were removed and stress-relieved for 3 hours at 250° F. Shot Nos. 4 and 5 were quenched from 1500° F., nose down, into flowing water to a depth of 2¾" from the driving band. The shot remained in the water for 20 minutes, after which they were removed and stress-relieved for 3 hours at 250° F.

The above heat treatment has been developed in these Laboratories (refer to Investigation No. 1489, dated September 2nd, 1943, and Information Memo. No. 68, dated October 4th, 1943) and fairly extensive tests have shown that ballistic properties are satisfactory and the shot generally are free from cracking, after heat treatment. The only deviation from the established heat treatment was in the temperature of the quenching water, which was at 57° F. rather than at 70° F. as used previously. However, the cold water did not appear to affect the rate of cooling of the shot.

All five shot were etched in the same manner as the twelve shot which cracked after etching. None of these five shot cracked after etching for 45 minutes.

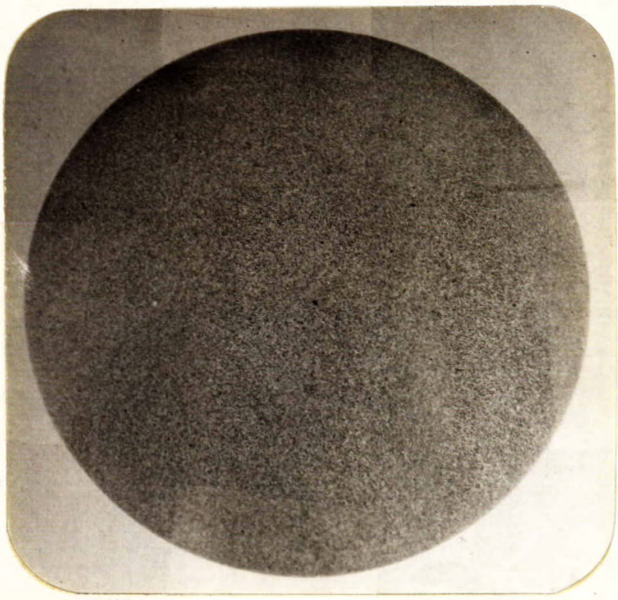
Macro Etching -

One of the six unheat-treated shot was ground and etched on the cross-section in a 10 per cent solution of ammonium persulphate. The etched surface is shown in Figure 5.

(Continued on next page)

(Experimental Work, cont'd) -

Figure 5.



MACRO-ETCHED SURFACE.

The cross-section was then reground and etched in 50 per cent boiling hydrochloric acid for half an hour. The etched surface was similar to that in Figure 5, showing that the steel is quite sound.

One of the twelve shot which had cracked after deep etching was cut off transversely just below the crack; the surface was ground and then etched for ½ hour in boiling 50 per cent hydrochloric acid. There was no evidence of the steel's being unsound.

Micro Examination -

A section of steel from the unheat-treated shot was polished for microscopic examination. There appeared to be nothing unusually different about the microstructure, which was a very fine lamellar pearlite. The steel was fine grained. There was nothing unusually different about the microstructure of the heat-treated steel.

DISCUSSION OF RESULTS; CONCLUSIONS:

There is nothing to indicate that the cause of cracking can be attributed to unsound steel. None of the 16 shot that were deep-etched showed any indication of surface segregation or any defects which could contribute to cracking. On the basis of the few shot examined, it may be said that the steel is a fine-grained, deep-hardening steel showing little evidence of segregation, etc.

The evidence points to the fact that the method of heat treatment is responsible for excessive cracking which occurs in 17-pdr. shot.

It is not considered necessary to elaborate upon the theory involved but it has been established by many investigators that cracking is caused by surface tensional stress. It is evident, therefore, that circumferential cracks which were brought out in the twelve shot by acid etching were the result of longitudinal tensional stress at the surface. The two shot pictured in Figure 1 show longitudinal cracks which were caused by tangential tensional stress at the surface. Of the two shot from C-49 which cracked, it may be said that grinding likely caused these cracks. If steel is tempered under the grinding wheel the metal is reduced in volume and thereby put under permanent tensional stress which may cause cracks.

Howard Scott in his paper, The Origin of Quenching Cracks,* has stated: "tensional surface stress of a magnitude sufficient to crack is produced in simple shapes of <u>completely hardened steel</u> only when the cooling rate is slow (oil quenched) and the diameter moderate, or when the diameter is small and the cooling fast (water quenched)." . . . "Fast quenching . . . produces compressional stress at the surface."

Steel will not withstand a very high tensional stress

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* Scientific Paper No. 513, Sept. 25, 1925, U.S. Bureau of Standards.

(Discussion of Results; Conclusions, cont'd) -

at the surface but it will withstand high compressional stress at the surface. A cylinder is one of the simplest shapes to quench. A 17-pdr. shot is very nearly a true cylinder, and it should be possible to quench this shot with very little cracking.

In considering the two types of heat treatment now in use, the following factors are apparent:

1. Partial water-quenching followed by full oil-quenching has apparently induced longitudinal tensional stress at the surface in the vicinity of the water line. This stress may or may not be sufficiently high to crack the shot. However, the tensional stress usually induced by quenching after the base draw (this is purely thermal stress) could cause the stress to become high enough to crack. The fact that a mild etch was sufficient to develop these cracks in shot which previously did not show evidence of cracks indicates that probably all of the shot in this heat are stressed very nearly to the breaking point, and many of them may, in time, develop cracks.

There is no logical advantage to be gained by quenching in this manner; in fact, it is rather a rough treatment for a steel so sensitive as this. Half of the shot is quenched to below the critical temperature by the water-quench while the upper half is still above it. Then after a quenching of the whole shot in oil, the transformation to martensite proceeds at different rates, creating a peculiar condition of stress in the shot. A more logical treatment would be to full-quench this shot in water for a predetermined time and then quench in oil. This would establish a temperature gradient between the surface and the centre, and the shot would also cool slowly through the martensitic transformation range. Upon completion of the quench, compressional stress at the surface

(Discussion of Results; Conclusions, cont'd) -

would very likely have been induced. In fact, were it not for the presence of the driving band grooves and tracer hole, full water-quenching and base-drawing (subsequently slowly cooled) would very likely produce a good shot with a minimum of cracking. Of 30 shot from Lot No. D-16 heat treated this way, only one cracked.

2. Full oil-quenching apparently induces tangential tensional stress at the surface which may easily cause a longitudinal crack. The crack may not become visible until ordinary temperatures are reached; and if the stress is low enough, so that the shot does not crack after quenching, the quench after base draw may raise the stress sufficiently to cause a crack to develop. Tempering, which sometimes results from grinding, may further raise this stress.

It is considered likely that all 17-pdr. shot quenched by the present method of oil quenching are in a state of tangential tension at the surface, the magnitude of which will determine whether or not the shot will crack. The rough treatment which the shot receives upon being quenched from the base draw is sufficient in itself to cause a crack, due to the abrupt change in section at the driving band grooves which usually have unfilleted and sometimes undercut corners. Of course, the temperature to which the base is raised plays a great part in determining the magnitude and nature of stress. Quenching from the draw could induce temporary tensional stress at the surface. This, combined with a similar stress already present, may be sufficiently high to cause a crack. Treatment of shot in the Bullard-Dunn apparatus (used to clean shot) causes many cracks to develop. This very likely is due to the effect of the pickling action and to subsequent quenching from

(Discussion of Results; Conclusions, cont'd) -

hot liquid to cold water.

3. The five shot which were heat-treated by quenching the nose of the shot in water showed no evidence of cracks after short etching times. Heat treating shot in this manner seems to produce shot that are comparatively free from cracks and will also perform satisfactorily at proof (refer to Investigation No. 1489 and Information Memo. No. 68), provided the conditions of heat treatment are satisfactory.

4. The fact that all twelve shot that were heat-treated at St. Catharines subsequently developed cracks after a mild etch, as contrasted with five shot from the same heat heat-treated without cracking, further substantiates the conclusion that the method of heat treatment now used in production is the cause of cracking. Slight changes in analysis should have little or no effect on the quantity of cracked shot in a heat, if the heat treatment is consistent and sound. This heat, however, appears to have much higher hardenability than previous heats, although some statistical study of the effect of this should be made before a definite answer can be given.

It is impossible to say definitely why a higher percentage of cracks should result from this heat than from any other heat, other than that the surface stresses are probably undesirable in all heats. The combination of oil bath temperature, bath agitation, quenching temperature, temperature of shot upon removal from oil (apparently unknown), could result in a shot which is stressed in tension at the surface. A change in any of these factors could cause a change in the magnitude of the tensional stress at the surface. In fact, increasing the quenching temperature or bath agitation could give a cooling

(Discussion of Results; Conclusions, cont'd) -

rate as rapid as water-quenching and the surface of the shot should then be under compressive stress. The whole process is therefore marginal and if continued requires a full investigation in an effort to correct the condition of cracking.

Shot which have low tensional stress at the surface and have not cracked may crack upon being improperly ground. It may be well, therefore, to consider grinding the shot almost to size before heat treatment.

Stress measurements performed on an oil-quenched and base-drawn shot from another heat of steel show that although the shot was not cracked it was in a state of tangential tensional stress at the surface. Any slight change sufficient to raise this tensional stress would have resulted in a cracked shot rather than a sound shot, and that condition could exist in the whole heat.

Unfortunately, the firm were unable to send shot in the "as quenched" condition; otherwise, stress measurements would have been made and actual figures presented showing the amount of tensile stress at the surface. Furthermore, some shot without the driving band groove would have been water-quenched and comparison of the kind of stresses made. This investigation will be conducted immediately but on another heat of steel.

Shot from that heat which have been base-drawn will also be measured for stresses and a comparison again made.

In summing up, it may be said that although only a few shot from this heat were examined, the fact that all of them cracked after a short etch indicates that probably the remainder of the heat is in a condition which may result in

(Discussion of Results; Conclusions, cont'd) -

cracks developing after an ageing period. Very likely, other heats are in the same condition. It is believed that the method of heat treatment now used in production was the cause of the high percentage of cracks. It must be stated, however, that in order to evaluate the acceptability of one heat treatment over another, whole heats must be divided in half and each half heat-treated by a different method and a comparison made. Only in this way can a true picture of the relative merits of a heat treatment be established. A few heats treated in this manner will soon give the answer.

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