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O T T A W A July 18th, 1944.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1681.

Examination of Tubing for the Tail Unit of M.L. 2-Inch Mortar Bomb.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
—
Physical Metallurgy
Research Laboratories

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

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Origin of Material and Object of Investigation:

On June 22nd, 1944, under Analysis Requisition No. O.T. 4239, eighteen (18) lengths of tubing for the tail unit of the 2-inch Trench Mortar Bomb were received from the Inspection Board of United Kingdom and Canada, 70 Lyon Street, Ottawa, Ontario. The covering letter, dated June 21st, 1944, File No. 12/4/1, Investigation No. 87, supplied the following information:

"Tubes Supplied -

6 lengths of tubing approximately 8 inches in length.
6 lengths of tubing approximately 4-5/16 inches in length.
(These are cut off to final length).
6 lengths of tubing cut off to a length of 3-5/16 inches and necked at one end.

"The history of splits which occur at the point of necking has been recorded on tail units from material represented by these samples."

The following tests were requested, to be carried

(Origin of Material and Object of Investigation, cont'd) -

out in two stages, (I) upon the tubing as received and (II) upon tubing normalized in these Laboratories, as follows:

"

I.

1. Chemical analysis with determination of carbon, manganese, silicon, sulphur and phosphorus.

2. Sections of the tube bodies microphotographed and an opinion given as to the condition of the steel. Has the tubing been fully normalized? May the necked portions of some of the worked tubes be examined in the "as submitted" state to determine the effect of the necking operation upon the structure.

3. Tensile test on the "as submitted" tubing to show yield, ultimate tensile strength, and elongation.

4. Crushing, flattening and expanding tests on the "as submitted" tubing in accordance with Specification I.G. 397 D.

II.

1. All above tests with the exception of chemical analysis, and emphasis made upon the comparison of structure in the necked portion of the tubing and in the unworked portion of the tubing.

2. Would you also record the normalizing treatment with regard to temperature and time. "

.....

On June 27th, 1944, five tail units (see Figures 1 and 2) were received. The accompanying letter, dated June 26th, stated that the tail units had been subjected to firing proof, and were representative of the tubing covered by samples forwarded under letter dated June 21st. It was suggested that a comparison of the condition of the metal in these units with that of the tubing already received might throw further light upon the situation.

(Continued on next page)

(Origin of Material and Object of Investigation, cont'd) -

Figure 1.

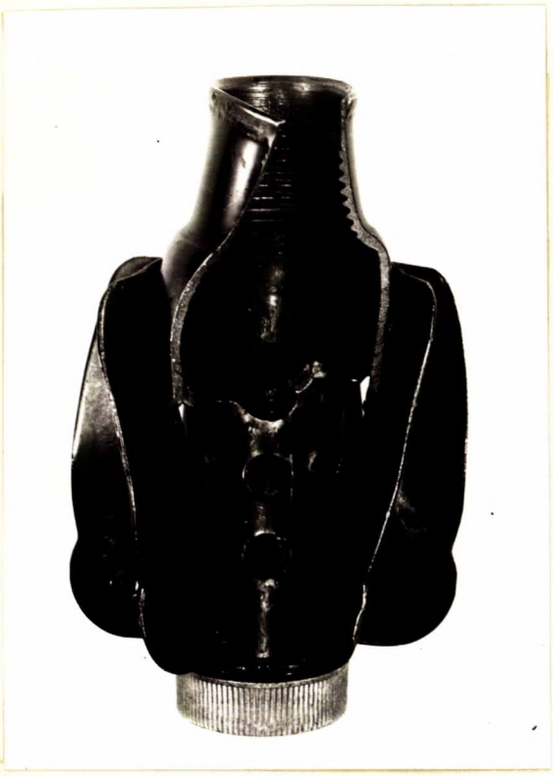
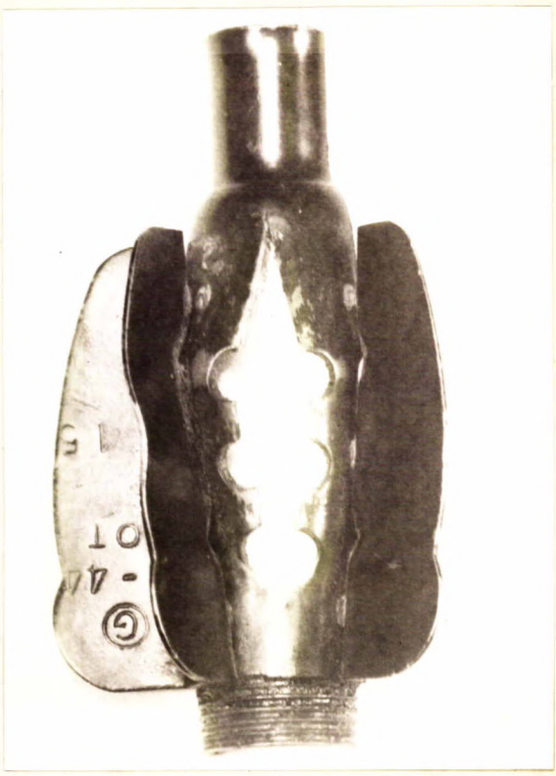


Figure 2.



TYPICAL FAILURES OF TAIL UNITS
OF 2-INCH TRENCH MORTAR BOMB.

(Approximately full size).

Chemical Analysis:

The results of the chemical analyses on samples taken from the tubing and from the tail unit of a 2-inch mortar bomb which had failed in proof firing are given in Table I. These may be compared with the chemical requirements under Specification I.G. 397D, as shown in Table II.

(Continued on next page)

(Chemical Analysis, cont'd) -

TABLE I.

	Tubing for Tail Unit of M.L. 2-inch Mortar Bomb.	Tail Unit of M.L. 2-inch Mortar Bomb Failed in Proof Firing.
	- Per Cent -	
Carbon -	0.20	0.21
Manganese -	0.50	0.55
Silicon -	0.07	0.07
Sulphur -	0.032	0.036
Phosphorus -	0.007	0.013

TABLE II. - Chemical Limits Required Under Specification I.G. 397 D.

	Per Cent
Carbon -	0.15-0.25
Manganese -	0.4-0.8
Silicon -	0.35 max.
Sulphur -	0.06 "
Phosphorus -	0.06 "

-

Normalizing Treatment:

Samples of the tubing submitted were given a normalizing treatment by holding in a salt bath at 1700° F. for 10 minutes, followed by air cooling.

Tensile Tests:

Tensile tests were performed on four samples of the 8-inch-length tubing, two of which were in the "as submitted condition and two normalized as above.

The results of these tests are given in Tables III and IV. These may be compared with the requirements as given under Specification I.G. 397 D (see Table V).

(Continued on next page)

(Tensile Tests, cont'd) -

TABLE III. - Tensile Test on Tubing "As Submitted".

	No. 1	No. 2
Yield strength, p.s.i. -	47,500	47,500
Ultimate tensile strength, p.s.i. -	68,400	68,200
Elongation on 2 inches, per cent -	35	35

TABLE IV. - Tensile Test on Tubing in the "Normalized" Condition.

Yield strength, p.s.i. -	44,800	44,750
Ultimate strength, p.s.i. -	67,000	66,600
Elongation on 2 inches, per cent -	37	39

TABLE V. - Mechanical Properties As Required under Specification I.G. 397 D.

Ultimate stress -	26 long tons (58,240 p.s.i.)
Elongation on 2 inches, per cent -	28

Crushing, Flattening and Expanding Tests:

Samples of the tubing, both in the "as submitted" and in the normalized condition, were subjected to crushing, flattening and expanding tests (Figure 3), as required under Specification I.G. 397 D. These tests are:

Expanding Test -

"The tubes will be subjected to expanding tests at tube manufacturer's works and shall, when cold, withstand expanding by a drift tapered not less than 1 in 3 on the diameter, to an increase of 15 per cent in external diameter, without showing crack or flaw."

Crushing Test -

" . . . two test specimens of 1 inch in length will be cut from each and every length of tubing, one

(Crushing, Flattening and Expanding Tests, cont'd) -

from each end, and crushed endwise until the outside diameter is increased in one zone by 25 per cent or until one complete fold is formed, without showing signs of cracking."

Flattening Test -

(This could not be found in the specification).

—

Figure 3.

RESULTS OF FLATTENING, EXPANDING AND CRUSHING TESTS (left to right).

(Approximately full size).

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Hardness Tests:

Hardness tests, using the Vickers hardness tester, were made on the following:

(1) "As submitted" tubing.
(2) "Normalized" tubing.
(3) A tail unit failed in proof firing.

Readings were taken on areas unaffected by the "necking" operation, and on "necked" portions. The results are given

(Hardness Tests, cont'd) -

in Table VI.

TABLE VI. - Vickers Hardness Values (20-kilogram load).

	Unaffected Zone	"Necked" Zone
Normalized tubing -	135-138	150-156
"As submitted" tubing -	196-200	179-219
Failed tail unit -	202-212	216-228

Quench-Ageing and Strain-Ageing Tests:

Experiments were conducted to determine whether the tubing is susceptible to quench ageing, or strain ageing.

In the former, samples of the tubing were quenched from 1250° F. into water. Hardness readings were taken immediately after quenching and then after several days, in order to ascertain whether an increase in hardness had occurred on ageing. The results are given in Table VII.

In the latter, samples of tubing were subjected to straining by squeezing in a vise. Hardness readings were taken immediately after straining and after a period of several days. The results are given in Table VIII.

TABLE VII. - Quenching-Ageing Test on Tubing.

Hardness immediately after quenching	-	162-172 Vickers
Hardness after two days	-	174-180 "
Hardness after four days	-	183-186 "

TABLE VIII. - Strain-Ageing Test on Tubing.

Hardness immediately after straining	-	200-213 Vickers
Hardness after two days	-	194-217 "
Hardness after four days	-	194-228 "

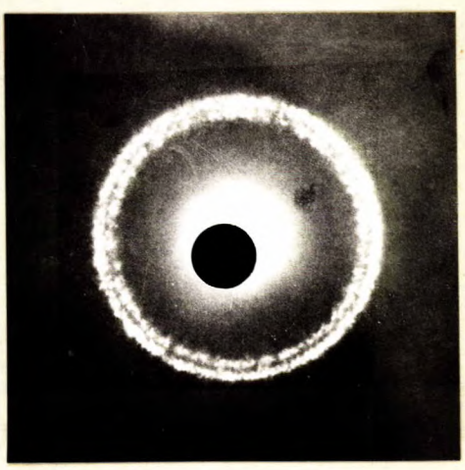
Work Hardness Test by X-Ray Diffraction:

Samples of the tubing in the "as submitted" and normalized conditions were subjected to x-ray diffraction, and the resultant patterns were compared in order to determine whether the "as submitted" tubing had been as completely normalized as the "normalized" tubing. Figures 4 and 5 are photographs of the x-ray diffraction patterns as obtained from the "as submitted" and "normalized" tubings respectively:

Figure 4.

TUBING IN "AS SUBMITTED" CONDITION, SHOWING MINOR STRAINING.

Figure 5.



TUBING AS "NORMALIZED", SHOWING UNSTRAINED CONDITION.

X-RAY DIFFRACTION PHOTOGRAPHS.

Microscopic Examination:

Photomicrographs were taken on the following samples:

(1) Tubing in the "as submitted condition,
(2) Tubing in the "normalized" condition, and
(3) Tail unit of 2-inch mortar bomb failed in proof firing.

Figures 6 and 7 are photomicrographs of a sample taken from tubing in the "as submitted" condition. Figure 6 shows the structure of the steel unaffected by the "necking" operation, whereas Figure 7 shows the structure of the "necked" portion of the tubing.

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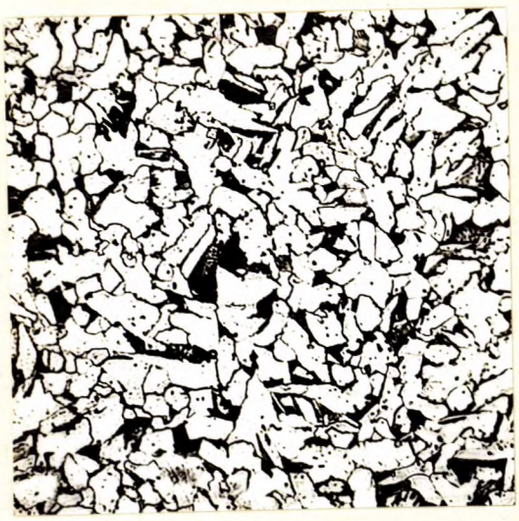
(Microscopic Examination, cont'd) -

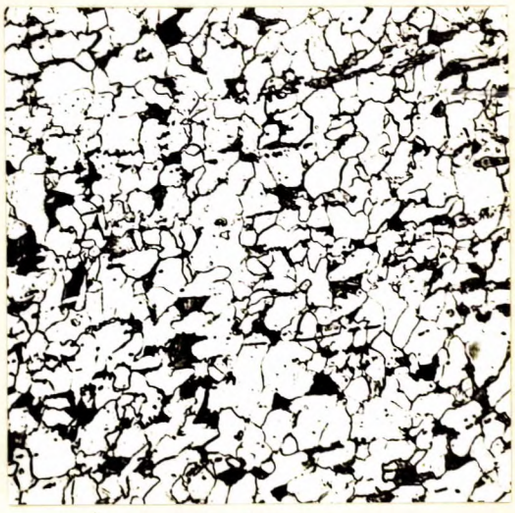
Figure 6.



X250, nital etch.

Portion unaffected by necking.

Figure 7.



X250, nital etch.

"Necked" portion.

TUBING "AS SUBMITTED".

-

Figure 8 is a photomicrograph showing the tubing in the normalized condition.

Figure 8.

X250, nital etch.

TUBING IN "NORMALIZED" CONDITION.

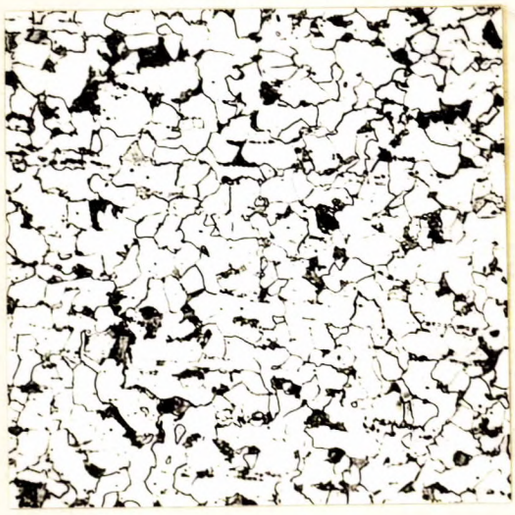
-

(Continued on next page)

(Microscopic Examination, cont'd) -

Figures 9, 10 and 11 are photomicrographs of sections taken from one of the tail units which had failed in proof firing. Figure 9 shows the microstructure obtained after etching in nital. Figures 10 and 11 (unetched) show the typical inclusions found in the bomb tails, and also in the tubing. The inclusions in Figure 10 are probably Al_2O_3, whereas the larger ones in Figure 11 are probably duplex sulphides and silicates.

Figure 9.



X250, nital etch.
SHOWING MICROSTRUCTURE OF A TAIL UNIT FAILED IN PROOF FIRING.

Figure 10.

X250, unetched.
Probably Al_2O_3.

Figure 11.

X500, unetched.
Probably duplex sulphides and silicates.

INCLUSIONS IN TAIL UNIT OF 2-INCH MORTAR BOMB FAILED IN PROOF FIRING.

DISCUSSION OF RESULTS; CONCLUSIONS:

The chemical analyses show that both the tubing and the bomb tails fall within the specification requirements.

The results of the tensile, crushing, expanding and flattening tests indicate that the tubing material completely satisfies the specification requirements. The results of the hardness tests indicate that the tubing "as submitted" and the bomb tail are considerably harder than the tubing which had been normalized in these Laboratories. This may be due to either of two reasons:

1. The tubing may be incompletely normalized.
2. The material may be subject to strain ageing.

Since the strain-ageing tests do not show any appreciable increase in hardness on ageing, it is to be concluded that the material has not been completely normalized, that is, the cold work induced by the rolling operation has not been completely eliminated.

The physical properties of an SAE 1020 steel in the normalized condition are as follows:

Tensile strength, p.s.i.	-	65,000
Yield point, p.s.i.	-	43,000
Elongation on 2 inches	-	34 per cent
Hardness	-	131 Brinell (131 Vickers).

This hardness value is approximately identical with that of the tubing normalized in these Laboratories (135 to 138) and in considerably below that of the bomb which had failed in proof firing (202 to 212 Vickers).

The x-ray diffraction test clearly shows that the tubing "as submitted" still retains some work hardness.

The microscopic examination of the etched materials does not show any abnormality in the microstructure. However,

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

the unetched specimens show a very considerable quantity of inclusions present in the steel, typical examples of which are shown in Figures 10 and 11.

It is not possible to ascribe the failure of the bomb tails to either the dirtiness of the steel or the incomplete normalizing, but it is thought that these may both be contributing factors.

Recommendations:

1. It is recommended that the tubing be given a more complete normalizing treatment, resulting in a hardness of approximately 130 to 140 Vickers.

2. It is recommended that the tubing used should be as free from inclusions as possible.

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