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OTTAWA June 2nd, 1943.

# R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1413.

(Project No. ZBS-3 )
(of the Ballistic Sub-Committee)
(of the Associate Committee of )
(Ballistics and Fire Control. )

Examination of Two Bofors 40-mm. Gun Barrels to Attempt to Determine Cause of Wide Variation in Service Life.

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(Copy No. 23.)

Abstract.

A complete metallurgical comparison of the steel in Barrels Nos. L21668 and L21812 failed to reveal any significant difference.

Metallurgical control and supervision over the steel-making and fabrication of the two barrels were found to be very good. Erosion vent plug tests carried out by the National Geophysical Laboratories, Washington, D.C., showed that the resistance to erosion by hot gases formed by explosive charges was identical for the steel from both barrels. Microscopic examination of the surface of the bore of both barrels indicated that Barrel No. L21668 was probably subjected to more intense heating than Barrel No. L21812. A study of the firing record of these two barrels indicates that a real and significant difference existed in the conditions of firing of these two barrels.

It is therefore concluded that the only cause for the wide difference in life of the two barrels is that the conditions of firing of these two barrels were not the same.

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

CANADA
DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

OTTAWA June 2nd, 1943.

# REPORT

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(Project No. ZSS-3
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## Examination of Two Bofors 40-mm. Gun Barrels to Attempt to Determine Cause of Wide Variation in Service Life.

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### Origin of Material and Request:

Wide variation in life of Bofors 40-mm. gun barrels used on the proving ranges has been noted. Consequently, Major General A. E. Macrae, Military Technical Adviser to Department of Munitions and Supply, Ottawa, Ontario, in a letter dated October 9th, 1942, (552/D4/9/6; L.O. 2967, File No. S12-M.2-52) requested that these Laboratories, working in co-operation with the National Research Council, conduct an investigation to determine the cause of this difference.

Two used Bofors barrels were supplied by Major General Macrae. One barrel, No. L21812, had fired 12,962 equivalent full rounds. The other barrel, No. L21668, had

(Origin of Material and Request, cont'd) -

given a useful life of only 2,564 equivalent full rounds.

During the life of such barrels both "proof" rounds and "full" rounds may be fired. In calculating the number of "Equivalent Full Rounds," a "proof" round is considered to be equivalent to two "full" rounds.

A comparison of the life of these two barrels in equivalent full rounds is given in Figure 1. Figure 2 is a photograph, at ½ actual size, showing the eroded surface of the bore of both barrels at the commencement of rifling.

## EXPERIMENTAL PROCEDURE.

### Chemical Analysis:

A very thorough chemical analysis was conducted on the steel of both of these barrels. These results are reported in Table I. Table I also includes the chemical analyses obtained from the records of the Inspection Board of United Kingdom and Canada.

Table I. - Chemical Analysis.

| | | Barrel No. L21668 | | Barrel No. L21812 | |
|---|---|---|---|---|---|
| | | I.B.U.K.&C. | O.D.M.L. | I.B.U.K.&C. | O.D.M.L. |
| | | - P e r | c e n t - | | |
| Carbon | - | 0.29 | 0.29 | 0.28 | 0.29 |
| Manganese | - | 0.56 | 0.56 | 0.52 | 0.55 |
| Silicon | - | 0.21 | 0.22 | 0.27 | 0.12 |
| Phosphorus | - | 0.019 | 0.020 | 0.017 | 0.014 |
| Sulphur | - | 0.017 | 0.016 | 0.021 | 0.020 |
| Nickel | - | 2.75 | 2.75 | 2.66 | 2.68 |
| Chromium | - | 0.76 | 0.77 | 0.78 | 0.75 |
| Molybdenum | - | 0.44 | 0.45 | 0.44 | 0.43 |
| Vanadium | - | 0.22 | 0.23 | 0.16 | 0.19 |
| Oxygen* | - | | 0.0055 | | 0.0093 |
| Hydrogen* | - | | 0.00009 | | 0.00005 |
| Nitrogen* | - | | 0.008 | | 0.008 |

* These values obtained by the vacuum-fusion process, at the laboratories of the Union Carbide Co. of America, Niagara Falls, New York.

Mechanical Properties:

The mechanical properties of the steel in the two barrels were obtained in both the longitudinal and the transverse direction. These are reported in Table II, along with the values obtained from the records of the Inspection Board of United Kingdom and Canada:

Table II. - Mechanical Properties.

| | Barrel No. L21668 | | | Barrel No. L21812 | | |
|---|---|---|---|---|---|---|
| | IBUK&C. | O. D. M. L. | | IBUK&C. | O. D. M. L. | |
| | | Transverse | Longitudinal | | Transverse | Longitudinal |
| Maximum stress, p.s.i. | 124,992 | 118,100 | 122,000 | 123,200 | 124,200 | 122,250 |
| Yield stress, p.s.i. | 110,208 | | | 107,520 | | |
| 0.1 per cent proof stress, p.s.i. | | 104,500 | 105,000 | | 109,500 | 108,000 |
| Elongation, per cent | 19 | 23 | 23.5 | 18 | 24 | 23.5 |
| Reduction in area, per cent | 48.2 | 51 | 64.2 | 36.2 | 51 | 63.5 |
| Izod impact, foot pounds | 66 | 61 | 88 | 48 | 42 | 75 |
| Brinell hardness number | 269 | | | 262 | | |
| Diameter of tensile bar, inches | 0.564 | 0.282 | 0.505 | 0.564 | 0.282 | 0.505 |

The reduction in area is reported on a length equal to four times the square root of the cross-sectional area of the tensile bar. The impact values were obtained using the standard round Izod impact test bar.

Comparison of Hardenability and Homogeneity:

Jominy hardenability tests were made on steel from both barrels. The standard 1-inch-diameter Jominy bars were used. The hardenability curves obtained are presented in Figure 3. Note that they are practically identical.

When two steels of the same analysis possess identical hardenability properties it may be assumed that the degree of homogeneity of the various constituents and elements in them is also identical. This was demonstrated by Robert M. Parke and Alvin J. Herzig, metallurgical engineers of the

(Comparison of Hardenability and Homogeneity, cont'd) -

Climax Molybdenum Company, in their article, entitled "Hardenability of Steel, Dendritic Segregation a Factor," published in METALS AND ALLOYS, February, 1942.

Comparison of Types of Carbides:

It was thought possible that a difference in the type of carbide in two steels might exist which could account for the difference in behaviour. Accordingly, samples of the carbides from each steel were prepared by electrolysis and their compositions compared by means of X-ray diffraction and qualitative spectrographic analysis. The X-ray diffraction showed that the same type of carbides existed in both steels and the spectrographic analysis failed to reveal any significant difference in analysis. It was therefore concluded that the carbide constituents of the two steels are identical.

X-Ray Back Reflection Studies:

X-ray back reflection studies on the crystal structure of the steel in the two barrels were conducted by the National Research Council at Ottawa. They have issued a report, No. PX-115, dated April 6th, 1943, showing that there are indications of some preferred orientation in Barrel No. L21668 and that the distribution of strain in this barrel is more irregular than in Barrel No. L21812. These Laboratories could not satisfactorily duplicate the findings of the National Research Council.

Metallographic Examination:

Specimens from the eroded portion of each barrel were prepared for metallographic examination. The surfaces examined were at right angles to the forging direction.

Figure 4 is a photomicrograph showing, at a

(Metallographic Examination, cont'd) -

magnification of 100 diameters, the structure of the steel in Barrel No. L21668 as revealed by an etch in 4 per cent picral. Figure 5 is a similar photomicrograph of the steel in Barrel No. L21812. Note the slightly fibrous appearance in Figure 4. Figures 6 and 7 are similar photomicrographs taken at a magnification of 1000 diameters. Note the marked similarity in structure, suggestive of identical heat treatments. The similarity of heat treatment was also indicated by the similarity of carbides.

A cross-section of the eroded surface of Barrel No. L21668 is shown, at a magnification of 100 diameters, in Figure 8 and that of Barrel No. L21812 in Figure 9. Similar cross-sections, etched in 4 per cent picral, are shown at a magnification of 250 diameters, of Barrel No. L21668 in Figure 10 and of Barrel No. L21812 in Figure 11. Note the larger amount of the white constituent on the surface of Barrel No. L21668.

Comparison of Steel-making Practice:

Through the courtesy and co-operation of the Atlas Steels Limited, Welland, Ontario, we were able to make a comparison of the steel-making practice followed in the heats of steel from which these two barrels were fabricated. Essentially the same practice was followed for both heats of steel. It is not considered pertinent to this investigation to go into the details of this practice. The only points of difference found here were that for Barrel No. L21668 the charge was higher in carbon than the charge for Barrel No. L21812 and the steel was made in a smaller furnace. A program was initiated to attempt to find some correlation between steel-making practice and barrel performance but later

(Comparison of Steel-making Practice, cont'd) -

developments have shown that such an investigation very likely would be of negligible value.

Forging and Heat Treatment Practice:

Little accurate information was available on this subject. The only points of difference were in the original ingot size and the billet size. This information is given in Table III.

Table III. - Ingot and Billet Sizes.

| Barrel number | Size and type of ingot | Size of billet | Reduction in area, per cent |
|---|---|---|---|
| L21668 | 12 in. x 12 in. | $7\frac{1}{2}$ in. x $7\frac{1}{2}$ in. | 60.9 |
| L21812 | $16\frac{1}{2}$ in. diam, corrugated | 10 in. x 10 in. | 53.2 |

Temperature and temperature ranges for forging, annealing, normalizing, quenching, and drawing have been established and these are the temperatures that appear on the Inspection Board of United Kingdom and Canada record sheets. From the mechanical properties and metallographic examination it is evident that, within reasonable limits, the same conditions of forging and heat treating existed during the fabrication of both barrels.

Erosion Vent Plug Tests:

Samples of steel from the two barrels were submitted by Dr. J. W. Greig, of the National Defense Research Committee of the Office of Scientific Research and Development, Washington, D.C. These samples were tested in exactly the manner described in N.D.R.C. Armor and Ordnance Report No. A-148, "Metals Tested as Erosion Vent Plugs," by O. H. Loeffler, G. Phair and H. S. Jerabek. The apparatus used for this test is shown in

(Erosion Vent Plug Tests, cont'd) - .

Figure 12.

Dr. Greig reported the results of these tests in a letter dated March 25th, 1943. This letter is quoted, in part, below:

"The erosion vent tests on these two steels gave results which are the same within experimental error and agree with the erosion results on a sample of steel from a Naval 5-inch 38-calibre gun, which steel is about SAE 4140.

| Rounds | Total Loss, in mm.[3] 5-inch 38-cal. | Barrel No. L21668 | Barrel No. L21812 |
|---|---|---|---|
| 5 | 55.5 | 56.1 | 57.0 |
| 10 | 86.0 | 84.8 | 86.5 |
| 15 | 107.8 | 104.5 | 107.7 |

"The plugs after firing were sectioned axially and examined under the microscope by Dr. H. S. Jerabek, who has the following comments to make:

'Microscopic examination of the two plugs after firing failed to reveal any difference between them and they are very similar to other gun steel plugs such as the 5", 38-calibre mentioned above. The heat-affected zone along the vent in both of the Bofors plugs is irregular in width (60-100 microns) whereas plugs from other gun steels show a sharply defined zone (70-90 microns). This irregularity is due, at least in part, to the presence of some residual dendritic structure in both Bofors barrels which has not been eliminated by the forging operation."

Study of Firing Record:

A study was made of the firing records of both barrels. Two types of rounds were fired. These were "proof" rounds and "full" rounds. The life of the barrel is recorded in "equivalent full rounds". In determining the number of "equivalent full rounds" fired, a proof round is taken as equal to two full rounds.

Two types of propellant charges were used. These

(Study of Firing Record, cont'd) -

are designated as "N.C.T." and "W.M.T.". It is reported that the W.M.T. rounds give a much hotter explosion than the N.C.T. rounds.

In proof firing it is reported that the majority of N.C.T. rounds are fired at approximately 8 rounds per minute except perhaps one burst of 8 rounds at 125 rounds per minute fired on an average of once per day.

The W.M.T. rounds are fired at about one per minute.

Since the proportion of W.M.T. rounds fired might have some effect on the barrel life, this was first determined. Table IV gives these data.

Table IV. - No. of W.M.T. Rounds Fired.

| Age of barrel, in equivalent full rounds | Barrel No. L21668 Proof rounds | Barrel No. L21668 Full rounds | Barrel No. L21812 Proof rounds | Barrel No. L21812 Full rounds |
|---|---|---|---|---|
| 2,564 | 0 | 3 | | |
| 2,572 | | | 1 | 2 |
| 12,926 | | | 1 | 2 |

From these data it is evident that the number of W.M.T. rounds fired could have had little bearing on the performance of the gun barrels being examined.

An analysis was next made of the proportion of proof rounds and full rounds fired from each barrel. The results are given in Table V.

(Continued on next page)

(Study of Firing Record, cont'd) -

Table V. - Distribution of Full and Proof Rounds in Firing of Barrels.

| Barrel number | Life, in equivalent full rounds | Diameter, 1 inch from commencement of rifling | Proof rounds | Full rounds | Total rounds | Percentage of proof rounds to total rounds fired |
|---|---|---|---|---|---|---|
| L21668 | 0 | 1.575 | | | | |
| | 2,564 | 1.665 | 1,146 | 272 | 1,418 | 81 |
| L21812 | 0 | 1.576 | | | | |
| | 1,762 | | 380 | 1,002 | 1,382 | 27.4 |
| | 2,572 | 1.592 | 550 | 1,472 | 2,022 | 27.2 |
| | 12,962 | 1.6445 | 2,926 | 7,110 | 10,036 | 29.2 |

There is evidence here that there exists a significant difference in the firing of these two barrels.

Discussion of Results:

Evidence has been presented to show that the steels in both Barrel No. L21668 and Barrel No. L21812 are similar in chemical analysis, mechanical properties, hardenability, degree of homogeneity, constitution of carbides, and condition of heat treatment. Metallurgically, these two steels are as nearly identical as could be expected. This indicates that the conditions of steel-making and of manufacture of these barrels are under excellent metallurgical supervision and control.

In view of the identical metallurgical nature of the steels in these two barrels, their great difference in life would lead one to suspect that there was some difference in life. This suspicion is strengthened by Dr. J. W. Greig's report on the erosion vent plug tests performed by him at the National Geophysical Laboratories, Washington, D.C.

Dr. Greig comments on these vent plug tests as follows:

"Dr. Merwin . . . . thought there had been considerable melting of the surface of the bore, especially of the gun that had the shorter life. Examinations of the pieces that you sent us on March 2 have given additional evidence for this conclusion. This, in conjunction with the apparent identity of the steel, would seem to indicate a real difference in the firing of the two guns."

Figures 9 and 10 would tend to confirm the views of Doctors Greig and Merwin concerning the greater degree of melting on the bore of Barrel No. L21668. The data presented in Table IV show that there actually was a very real difference in the conditions of firing of the two guns, namely, in the proportion of full rounds and proof rounds fired.

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CONCLUSIONS:

1. The steels in both barrels are as nearly identical metallurgically as it is possible to expect.

2. The conditions of heat treatment and forging are likewise identical for both barrels.

3. The behaviour of steel from both barrels in erosion vent plug tests is identical.

4. There are indications that the bore of Barrel No. L21668 was subject to more intense heat than the bore of Barrel No. L21812.

5. There is a very real difference in the conditions of firing of the two barrels.

Our final conclusion, therefore, is that the only cause of the wide difference in life of the two barrels is that the conditions of firing of these barrels were not the same.

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oooooo
oo

HVK:GHB.

Figure 1.



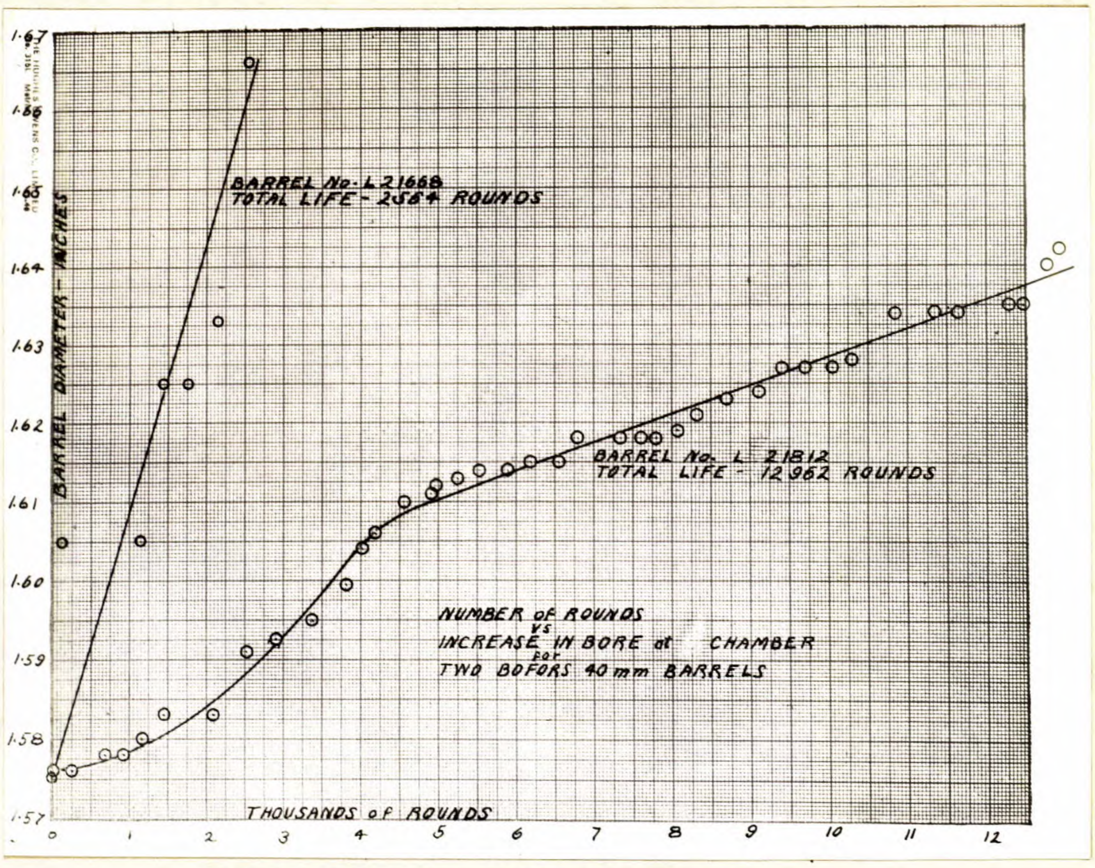
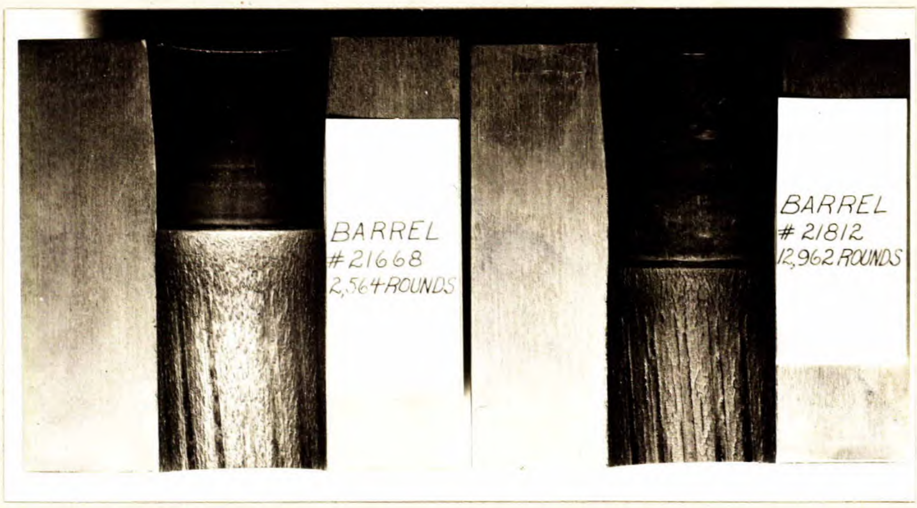



CHART OF LIFE HISTORY OF TWO BOFORS BARRELS BEING EXAMINED.

Figure 2.




PHOTOGRAPH, ½ ACTUAL SIZE, SHOWING CONDITION OF ERODED SURFACE OF BORE IN BARRELS NOS. L21668 AND L21812 AT COMMENCEMENT OF RIFLING.

# SAE HARDENABILITY CHARTS (Page 12)

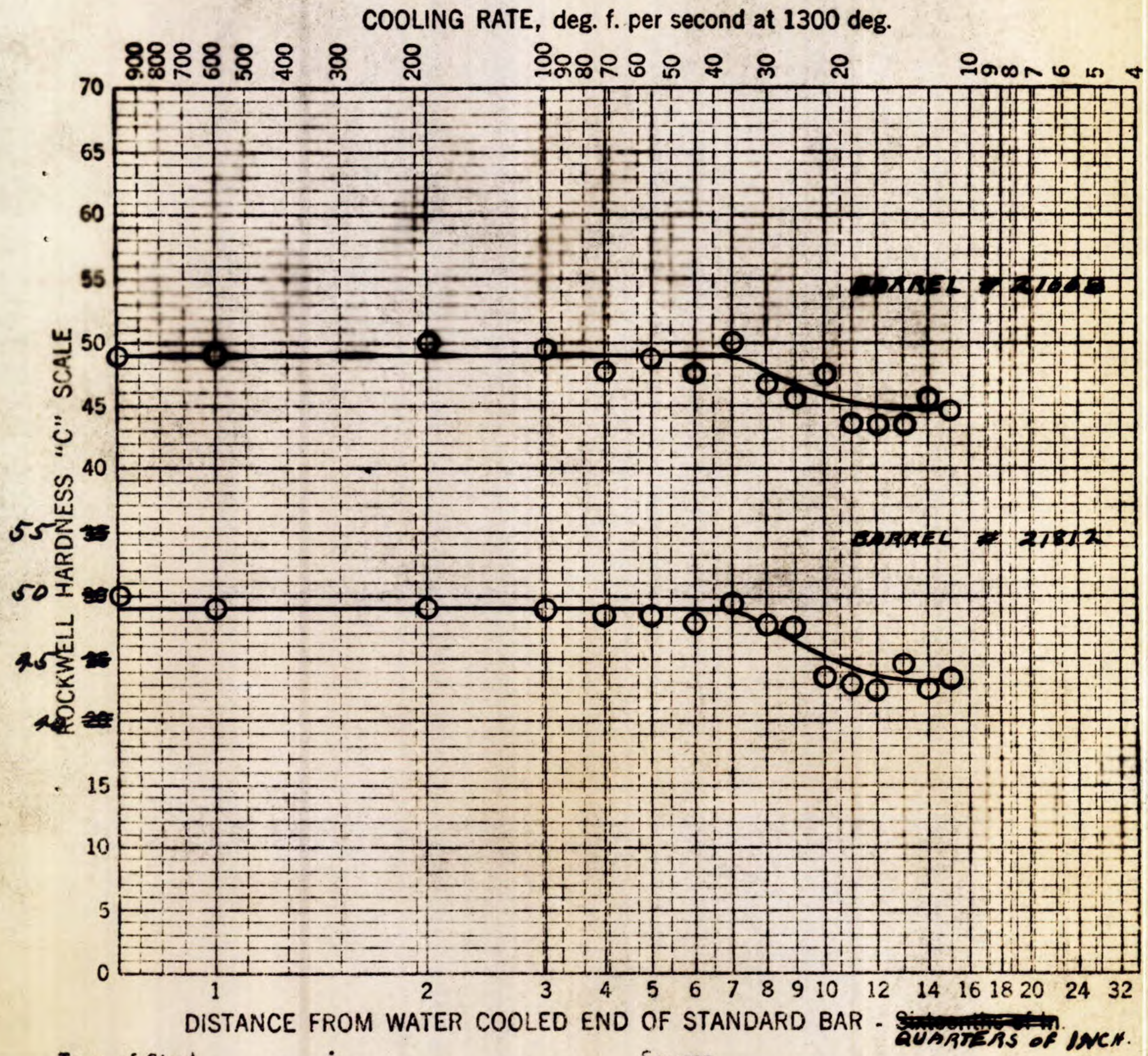
Figure 3.

## END-QUENCH TEST

Form 1

SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.
29 WEST 39 ST., NEW YORK CITY

Test No. ..........
Sheet No. ..........
Date ..........




Type of Steel .......... Source ..........

Notes Bofors 40 mm Anti-aircraft gun barrels

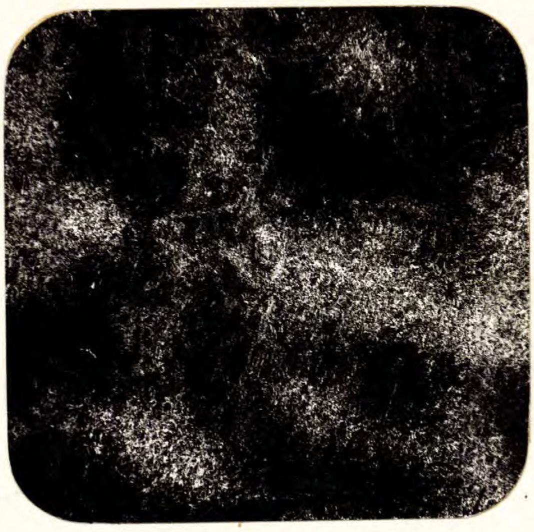
Signed ..........

### STEEL ANALYSES AND QUENCHES

| Steel | C | Mn | P | S | Si | Ni | Cr | Mo | V | Quenching Temperature | Grain Size | Heat Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| #21668 | 0.29 | 0.55 | 0.020 | 0.016 | 0.22 | 2.75 | 0.77 | 0.45 | 0.23 | 1550°F | | |
| #21812 | 0.29 | 0.55 | 0.014 | 0.020 | 0.19 | 2.68 | 0.75 | 0.43 | 0.19 | 1550°F. | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

Report of Iron and Steel Division adopted January 1942.

Figure 4.



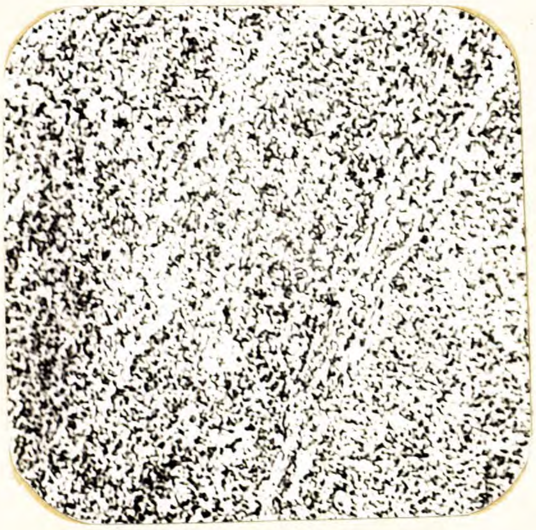
BARREL NO. L21668.
Note fibrous appearance.

Figure 5.

BARREL NO. L21812.

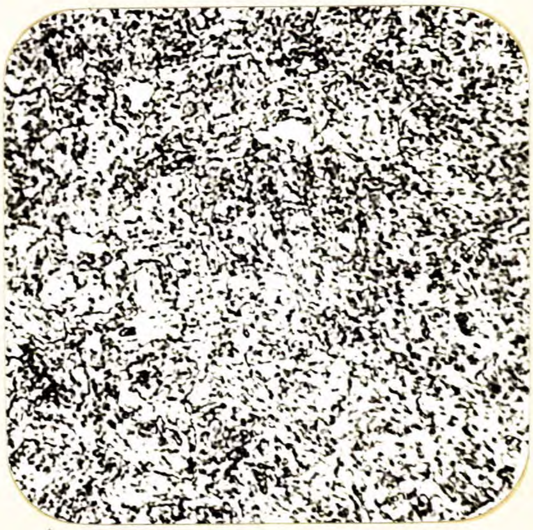
Photomicrographs, X100, picral etch.

Figure 6.



BARREL NO. L21668.

Figure 7.



BARREL NO. L21812.

Photomicrographs, X1000, picral etch.

Figure 8.

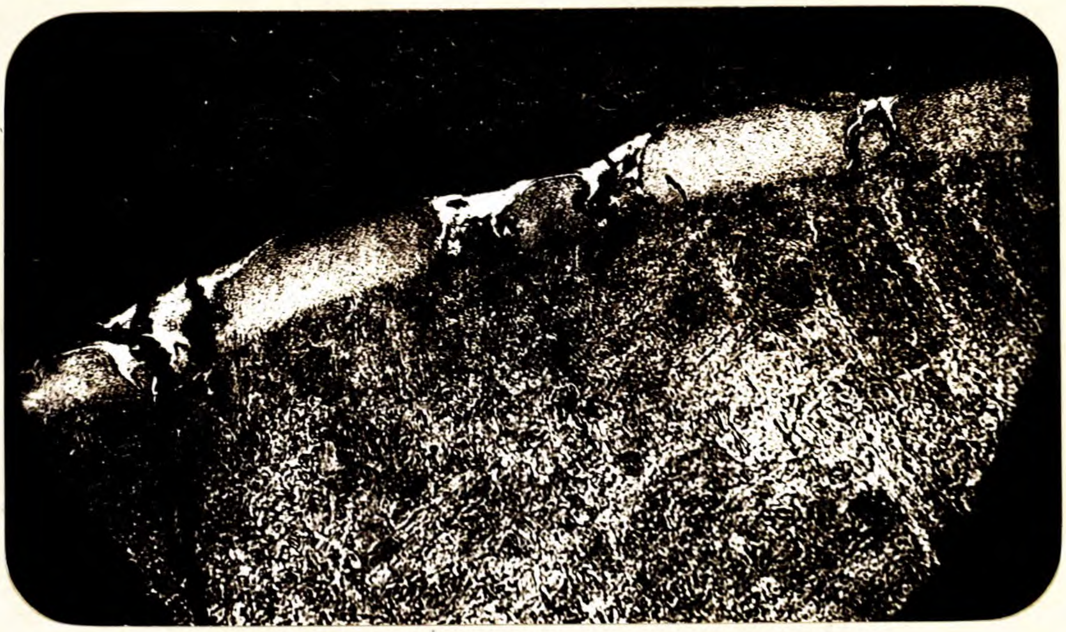
BARREL NO. L21668
CROSS-SECTION OF ERODED SURFACE,
TAKEN ABOUT 2 INCHES FROM
COMMENCEMENT OF RIFLING

Figure 9.

BARREL NO. L21812.
CROSS-SECTION OF ERODED SURFACE,
TAKEN ABOUT 2 INCHES FROM
COMMENCEMENT OF RIFLING.

Photomicrographs, X100, unetched.

Figure 10.



Photomicrograph, X250, picral etch.

CROSS-SECTION OF ERODED SURFACE
ABOUT 2 INCHES FROM COMMENCEMENT OF RIFLING.
BARREL NO. L21668.

Note white constituent on surface.

Figure 11.

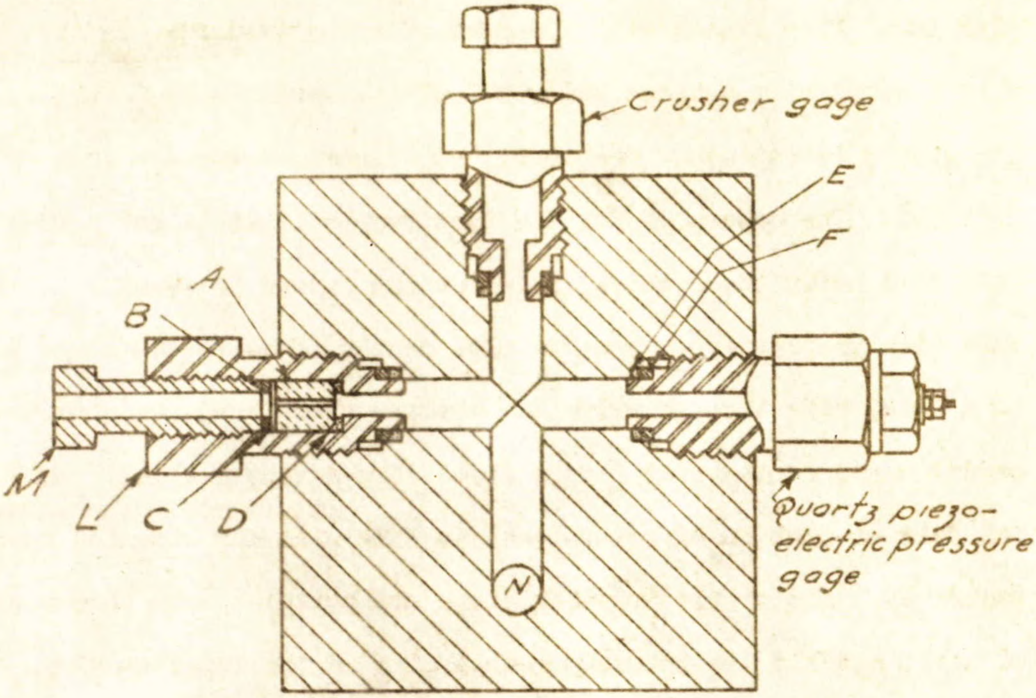
Photomicrograph, X250, picral etch.

CROSS-SECTION OF ERODED SURFACE
ABOUT 2 INCHES FROM COMMENCEMENT OF RIFLING.
BARREL No. L21812.

Note white constituent on surface.

HVK:GHB.

Figure 12.





Ignition plug

~~Fig.~~ Erosion explosion chamber. A, erosion test plug; B, steel rupture ring; C, 1/32-in. copper rupture disk; D and E, copper washers; F, coned steel ring; G, ground terminal; H, platinum-rhodium terminal; J, limestone and talc pressure packing; K, ignition plug; L, case plug for test specimen; M, bolt with 1/4-in. bore; N, loading chamber.