REPORT NO. 314/68

# GUN STEEL - CENTRIFUGAL CASTING

Evaluation of Pressure Bore Quenching for Guns

By

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2 September 1943







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4. This report covers two comparable 76 mm. gun tubes which were rough-turned and bored and were subjected to similar heat treatment with the exception of a pressure bore quench and a routine immersion quench, respectively. While neither gun hardened throughout at the breech, Brinell hardness surveys and transverse tensile and impact tests at several locations from breech to muzzle failed to demonstrate any metallurgical advantages of forcing water through the bore.

For the Commanding Officer:

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(6) ~~GUN STEEL - CENTRIFUGAL CASTINGS~~,

Evaluation of Pressure Bore Quenching for Guns,

OBJECT

To demonstrate the influence of pressure bore quenching upon the structural uniformities and physical properties of gun tubes.

(12) 16

CONCLUSIONS

1. Two comparable 76 MM gun tubes were rough-turned and bored and were subjected to similar heat treatment with the exception of a pressure bore quench and a routine immersion quench, respectively. While neither gun hardened throughout at the breech, Brinell hardness surveys and transverse tensile and impact tests at several locations from breech to muzzle failed to demonstrate any metallurgical advantages of the bore quench.

2. Detailed longitudinal tensile and impact tests and micro examinations at bore, midwall and outside surfaces of each gun confirmed the above conclusion.

3. For the particular gun tubes and quenching set-up employed, it is concluded that good immersion quench practice is equally as effective as pressure bore quenching.

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## INTRODUCTION

In view of the successful spray quenching of cast armor and the resultant use of lower alloy steels, considerable emphasis has been placed on the probable value of a technique for improving the water quench of gun tubes. To this purpose, one of the production quench tanks at the Watertown Arsenal was fitted with an adapter to permit the quenching of individual guns with water forced at high pressure through the bore. Preliminary laboratory experiments with small cylinders* had indicated that a forced bore quench with the cylinder in a tank of water resulted in a more effective quench at the bore than at the outside.

## TEST PROCEDURE

Two gun tubes, Watertown Arsenal castings 3J-851 and 3J-855, were available from pilot production of 76 MM M1E5 guns and were particularly suited to evaluate the merits of pressure bore quenching. Both guns had been selected from routine production of 3" M5 centrifugal castings and had been rough machined after normalize-anneal treatment to the overall dimensions shown in Figure 1. Ladle analyses and complete heat treatment are listed in Figure 1, Items 1 and 2 respectively, while Item 3 lists the midwall physical properties obtained from breech and muzzle discs cut after 2" discard.

From ladle analyses and from practically identical response to simultaneous heat treatment, it was apparent that the two gun tubes were very similar. It was evident also that the muzzle sections (1 3/8") had hardened throughout and that the breech sections (2 1/2") had not. This was confirmed by the appearance of the Charpy fractures (fibrous at the muzzle, crystalline at the breech) and by micro examination of several discs from Gun 3J-851, shown in Figure 2. Theoretically, however, either gun could be hardened throughout the breech section if the rate of quench were sufficiently increased, and it was this possibility

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* Watertown Arsenal Report No. 632/6, Heat Treatment, "Quenching of Hollow Cylinders," 5 February 1943.

which suggested the choice of these two tubes as a practical measure of the probable advantages of pressure bore quenching. One of the guns (3J-851) was cut for test without further treatment as representative of regular quench practice,* while the other (3J-865) was reheat-treated using the bore quench fixture and then cut at comparable sections (Figure 1, Item 4).

Figure 3 shows the general layout of the bore quench arrangement. A cone-based fixture was installed in the tank and the single gun (3J-865) lowered to rest breech in the cone with the muzzle several feet under water. Water was flowing through the bore at approximately 100 gallons per minute within fifteen seconds after the breech started to immerse in the tank. In contrast, during the regular immersion quench, three guns (including 3J-851 and 3J-865) suspended from a heat treat fixture had been lowered simultaneously into the quench and had been maintained in motion by hoisting and lowering with the crane.

## DATA AND DISCUSSION

Earlier in this report data have been submitted to establish that gun tubes 3J-851 and 3J-865 were directly comparable on the basis of ladle chemistry, overall machined dimensions and response to initial heat treatment with regular quench practice. A comparison of physical properties after reheat-treatment using pressure bore quench for gun 3J-865 is shown in Table 1. Transverse tensile and impact tests were machined from the midwall section as detailed in the upper sketch of Appendix "A".

It is apparent from relative hardness, tensile and impact test results that the tubes in the final condition were quite similar despite the differences in quench practice. Both tubes have a uniform breech to muzzle bore hardness slightly above 400 BHN. In each case the muzzle sections (1 3/8") have hardened throughout, but at midlength (2 1/8" wall thickness) and further toward the breech, the sections have not hardened uniformly throughout the wall thickness. The trend in hardness

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* While regular quench practice does not force water through the bore, there is evidence of considerable flow under the action of a "steam lift" and crane agitation of the load. It is not practical to attempt an evaluation of the quantity of water involved, but the conditions are definitely not stagnant.

is confirmed in midwall yield and tensile properties and is further evidenced in both tubes by the crystalline fracture of impact tests at all sections other than the muzzle. Muzzle Charpy tests at 18 - 20 foot-pounds show the fibrous fracture associated with through hardening and have normal impact resistance for the relatively high tensile properties. That the tube quenched in regular practice shows comparable hardnesses at the bore and outside surfaces, while the bore quenched gun is definitely softer at the outside breech locations may be ascribed to lack of agitation during quench or to chemical variables.

To demonstrate further the relative cross-sectional properties of regular and bore quenched gun tubes, each casting was sampled for longitudinal tests adjacent to the "C" location. (See Figure 1 and lower sketch of Appendix "A" for details of sampling). Figures 4 and 5 show longitudinal tensile and impact tests at bore, midwall section and outside with microphotographs of representative structure at each location. Chemical analyses of the tensile test bars failed to show any significant segregation across the section.

Longitudinal midwall tests from each gun (Figures 4 and 5) compare favorably with the transverse midwall tests at "C" location (Table 1) and confirm the absence of directional tendencies. As anticipated from hardness data, both bore and outside are appreciably stronger than the midwall and have been quenched essentially to martensite as evidenced by the fibrous fracture of the impact tests. Midwall-sections show traces of ferrite rejected during the quench and have a crystalline or partially crystalline fracture.

In an attempt to locate exactly the maximum section which had hardened throughout, the muzzle half of each gun (from "D" location forward) was notched and fractured lengthwise. Examination of these fractured surfaces showed the first traces of crystalline structure in each gun at the midwall approximately 24" from the muzzle. It is indicated that the wall thickness at this point (1 3/4") is probably the maximum gun section which had hardened uniformly in the quench.

## GENERAL CONSIDERATIONS

The general considerations which influence through hardening in the quench are chemical composition, section thickness and quenching rate. Of these, it is generally conceded that changes in the latter will be the least effective in correcting failure to harden to the midwall section during a water quench. Midwall softness is associated generally with the rejection of ferrite during the quench and with crystalline fracture of a V-notch impact test, and the condition is commonly spoken of as the result of "slack quenching." Assuming good water quench practice, however, "slack quenching" can be corrected most readily by first, reducing the wall section if possible and/or second, by increasing the hardenability of the composition by alloy additions. This recommendation presupposes necessarily that the chemistry is based on sufficient carbon content (.25% minimum) for satisfactory hardening.

In view of the above generalities, it is not surprising that the pressure bore quenched tube failed to show markedly improved midwall hardness; the investigation has served primarily to demonstrate that there must have been adequate water circulation in the bore during the regular immersion quench. Undoubtedly, the quantity was substantially less than the 100 gallons per minute used in the pressure bore quench, but comparative physical properties and micro studies indicate the immersion quench to have been equally effective.

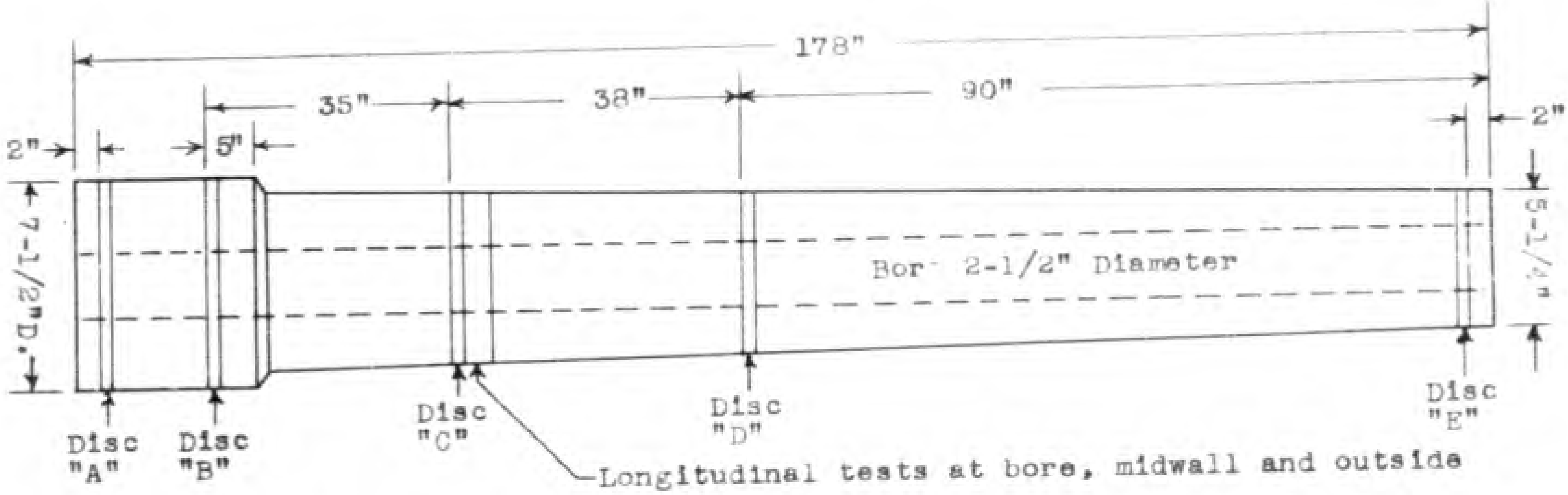



FIG. 1 HEAT TREATMENT AND TEST DETAIL FOR 76MM GUNS 3J-851 AND 3J-865

**1. Ladle Analyses:**

| | C | Mn | Si | Cr | Mo | V |
|---|---|---|---|---|---|---|
| 3J-851 | .30 | .88 | .28 | 1.06 | .51 | .10 |
| 3J-865 | .31 | .84 | .28 | .97 | .53 | .10 |

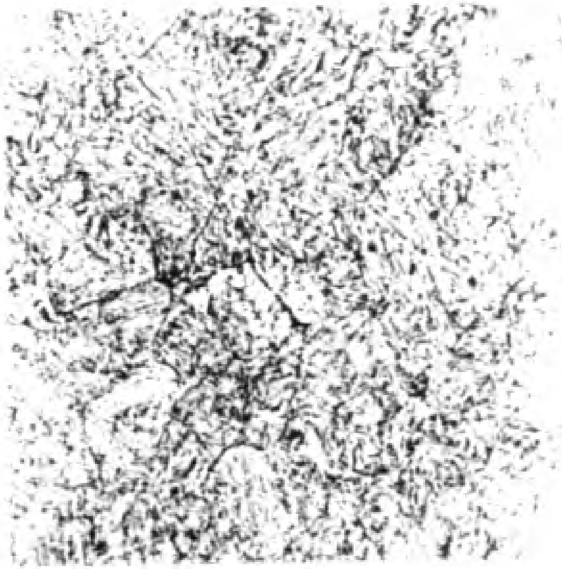
**2. Heat Treatment:** 2200°F - 16 hrs - Air Cool 6 hrs, 1600 - 7 hrs - Furnace Cool to 1000 - Air Cool, then 1600 - 6 hrs - Regular Water Quench to 50°F, Draw at 1000 - 6 hrs - Water Cool. Both guns quenched and drawn at same time.

**3. Physical Tests:** These are regular breech and muzzle control discs for gun treatment.

| | | Y.S.(.01%) | T.S. | R.A. | Fracture | CHARPY | Fracture |
|---|---|---|---|---|---|---|---|
| 3J-851 | Disc A | 123,000 | 178,400 | 46. | C.P. | 16.5 | Crystalline |
| | " | 124,000 | 178,800 | 41. | " | 17.7 | " |
| | Disc E | 172,000 | 204,000 | 39. | C.P. LC | 18.7 | Fibrous |
| | " | 171,000 | 201,400 | 30. | I.P. LC | 20.9 | " |
| 3J-865 | Disc A | 118,000 | 171,400 | 46. | C.P. | 15.5 | Crystalline |
| | " | 120,000 | 169,800 | 47. | " | 19.4 | " |
| | Disc E | 170,000 | 202,400 | 36. | " | 20.6 | Fibrous |
| | " | 174,000 | 203,400 | 38. | " | 18.4 | " |

**FIGURE 1**

**4. Disposition:** Gun 3J-851 was sectioned further at B,C and D. Gun 3J-865 was reheated at 1600°F - 6 hrs - Pressure Bore Quenched to 65°F, 1000 - 6 hrs - Water Cool then sectioned for new A and E discs, and at B,C and D locations.



ALL PHOTOMICROGRAPHS AT 1000 MAGNIFICATION; PICRAL ETCH

DISC "A" (BREECH)

TEMPERED MARTENSITE WITH FERRITE REJECTED DURING QUENCH. CRYSTALLINE FRACTURE.

DISC "B"

TEMPERED MARTENSITE WITH CONSIDERABLE FERRITE. CRYSTALLINE FRACTURE.

DISC "E" (MUZZLE)

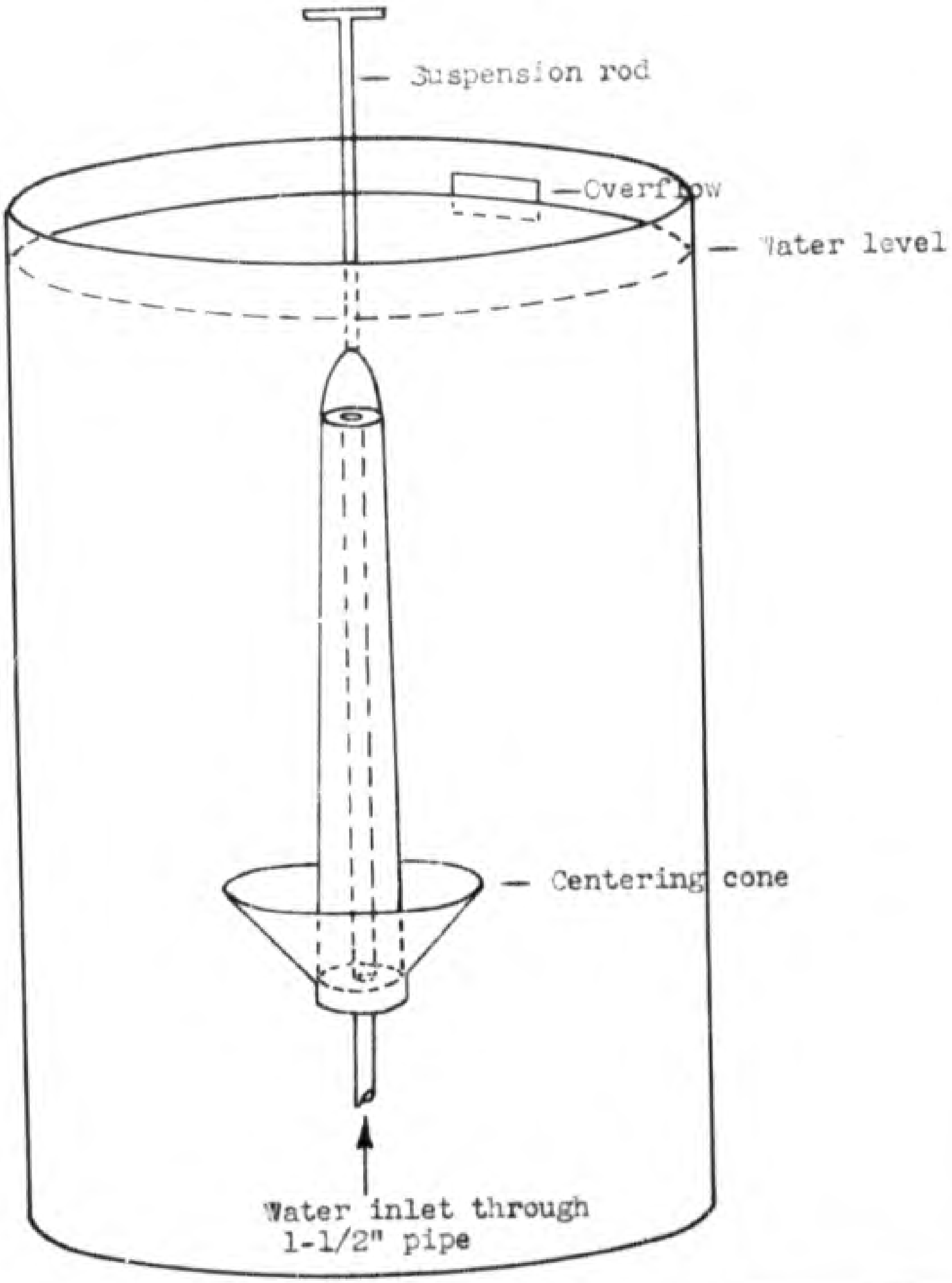
TEMPERED MARTENSITE WITH OCCASIONAL TRACES OF FERRITE. FIBROUS FRACTURE.

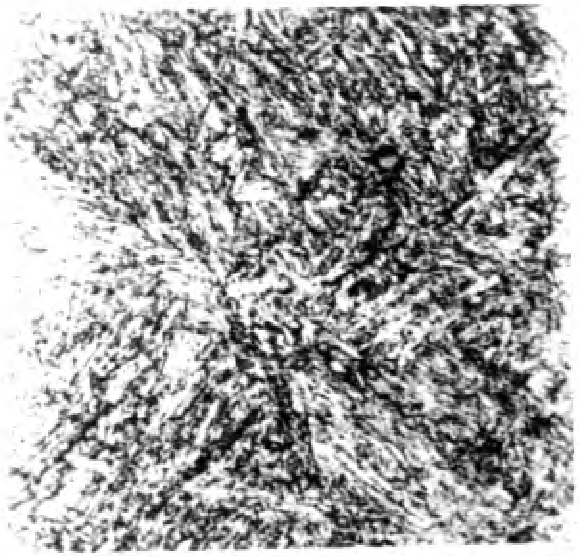
FIG. 2 MIDWALL MICROSTRUCTURES OF 76MM GUN 3J851 AFTER REGULAR QUENCH AND DRAW TREATMENT

WTN.639-55.4

FIG. 3

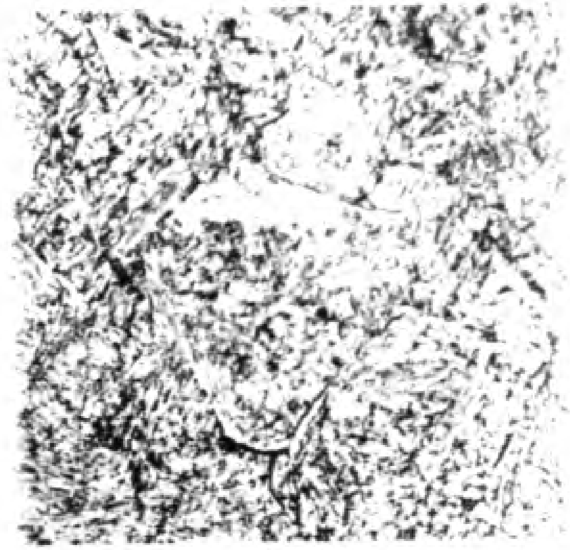
SCHEMATIC DIAGRAM OF QUENCH BATH AND
FIXTURE FOR BORE QUENCH.





"VERY LITTLE FERRITE"

"CONSIDERABLE FERRITE THROUGHOUT"



"SLIGHT AMOUNT OF FERRITE"

ALL PHOTOMICROGRAPHS AT 1000 MAGNIFICATION; PICRAL ETCH

FIG. 4 PRESSURE BORE QUENCH —— LONGITUDINAL TESTS OF 76MM GUN 3J-865

**TANGENT TO BORE**

| ANALYSIS | |
|---|---|
| C | .36 |
| MN | .79 |
| SI | .30 |
| CR | .96 |
| MO | .48 |
| V | .09 |

| PHYSICAL TESTS | |
|---|---|
| Y.S. (.01%) | 164,000 |
| | 163,500 |
| T.S. | 195,400 |
| | 192,700 |
| EL. | 8.5 |
| | 8.5 |
| R.A. | 22.2 I.P.LC |
| | 27.1 I.P.LC |
| CHARPY | 17.8 FIBROUS |
| | 17.2 FIBROUS |

**AT MIDWALL**

| ANALYSIS | |
|---|---|
| C | .36 |
| MN | .80 |
| SI | .30 |
| CR | .94 |
| MO | .46 |
| V | .09 |

| PHYSICAL TESTS | |
|---|---|
| Y.S. (.01%) | 139,000 |
| | 135,000 |
| T.S. | 177,700 |
| | 176,700 |
| EL. | 13.5 |
| | 12.0 |
| R.A. | 45.4 C.P. |
| | 46.0 C.P. |
| CHARPY | 14.3 CRYSTALLINE |
| | 16.1 CRYSTALLINE |

**TANGENT TO OUTSIDE**

| ANALYSIS | |
|---|---|
| C | .37 |
| MN | .77 |
| SI | .28 |
| CR | .95 |
| MO | .48 |
| V | .10 |

| PHYSICAL TESTS | |
|---|---|
| Y.S. (.01%) | 166,000 |
| | 166,000 |
| T.S. | 192,600 |
| | 195,000 |
| EL. | 12.0 |
| | 6.5 |
| R.A. | 39.1 C.P. |
| | 16.7 I.P.LC |
| CHARPY | 19.6 FIBROUS |
| | 18.2 FIBROUS |

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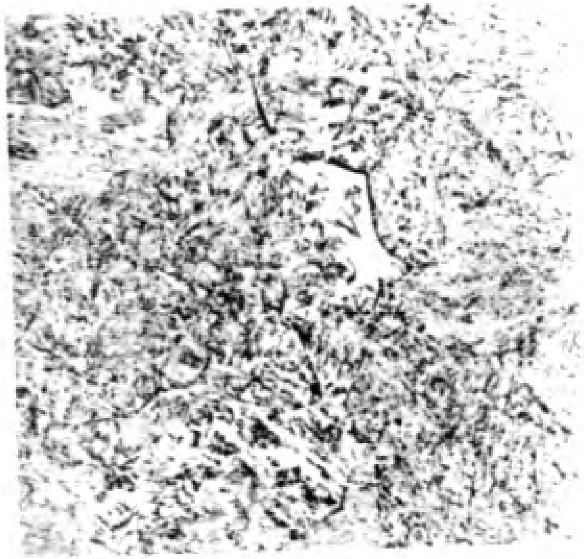
FIG. 4

"VERY FEW SMALL FERRITE PATCHES"



"SCATTERED PATCHES OF FERRITE"

"TEMPERED MARTENSITE, NO FERRITE"

ALL PHOTOMICROGRAPHS AT 1000 MAGNIFICATION; PICRAL ETCH

FIG. 5 REGULAR QUENCH — LONGITUDINAL TESTS OF 76MM GUN 3J-851

**TANGENT TO BORE**

| ANALYSIS | |
|---|---|
| C | .34 |
| MN | .82 |
| SI | .34 |
| CR | 1.20 |
| MO | .49 |
| V | .10 |

| PHYSICAL TESTS | | |
|---|---|---|
| Y.S. (.01%) | 164,000 | |
| | 166,000 | |
| T.S. | 200,000 | |
| | 199,800 | |
| EL. | 13.0 | |
| | 9.0 | |
| R.A. | 35.4 | C.P.SLC |
| | 19.2 | I.P.LLC |
| CHARPY | 18.0 | FIBROUS |
| | 20.1 | FIBROUS |

**AT MIDWALL**

| ANALYSIS | |
|---|---|
| C | .33 |
| MN | .82 |
| SI | .35 |
| CR | 1.19 |
| MO | .49 |
| V | .10 |

| PHYSICAL TESTS | | |
|---|---|---|
| Y.S. (.01%) | 148,000 | |
| | 144,000 | |
| T.S. | 190,000 | |
| | 188,000 | |
| EL. | 14.0 | |
| | 14.0 | |
| R.A. | [illegible].8 | C.P.SLC |
| | 43.[illegible] | C.P. |
| CHARPY | 17.2 | [illegible]OUS WITH |
| | 15.2 | C[illegible]LLINE A[illegible] |

**TANGENT TO OUTSIDE**

| ANALYSIS | |
|---|---|
| C | .34 |
| MN | .82 |
| SI | .35 |
| CR | 1.16 |
| MO | .50 |
| V | .10 |

| PHYSICAL TESTS | | |
|---|---|---|
| Y.S. (.01%) | 174,000 | |
| | 170,000 | |
| T.S. | 203,200 | |
| | 203,200 | |
| EL. | 12.0 | |
| | 13.0 | |
| R.A. | 30.8 | I.P.LC |
| | 34.8 | C.P.SLC |
| CHARPY | 20.5 | FIBROUS |
| | 19.5 | FIBROUS |

WTN.639-1516

FIG. 5

TABLE I

COMPARISON OF PHYSICAL PROPERTIES. PRESSURE BORE QUENCH VERSUS REGULAR QUENCH

Refer to Figure 1 (items 2 and 4) for details of heat treatment and test lo

| Test Location ............. | | Disc "A"(1) | Disc "B" | Disc "C" | Disc "D" |
|---|---|---|---|---|---|
| Gun Wall Thickness ........ | | 2-1/2" | 2-1/2" | 2-1/4" | 2-1/8" |
| **GUN 3J-865. PRESSURE BORE QUENCHED.** | | | | | |
| Brinnel Tests(2) | 1/4" from bore | 401 | 401 | 401 | 404 |
| | At midwall | 358 | 346 | 372 | 372 |
| | 1/4" from outside | 385 | 388 | 404 | 394 |
| Yield Strength, psi(3) | | 130,000 | 125,000 | 143,000 | 142,000 |
| | | 125,000 | 122,000 | 135,000 | 146,000 |
| Tensile Strength, psi | | 172,500 | 170,000 | 181,000 | 180,500 |
| | | 171,500 | 169,000 | 177,000 | 181,500 |
| Red. of Area,% Fracture(4) | | 42.8 C.P. | 44.5 C.P. | 46.1 C.P. | 43.6 C. |
| | | 46.5 " | 45.7 " | 46.5 " | 44.1 " |
| Impact, ft-lbs Fracture(5) | | 15.5 Cryst. | 16.8 Cryst. | 16.8 Cryst. | 14.2 Cr |
| | | 14.9 " | 16.1 " | 15.9 " | 15.6 |
| **GUN 3J-851. REGULAR QUENCH PRACTICE.** | | | | | |
| Brinnel Tests(2) | 1/4" from bore | 415 | 404 | 401 | 415 |
| | At midwall | 375 | 363 | 388 | 398 |
| | 1/4" from outside | 415 | 408 | 422 | 415 |
| Yield Strength, psi(3) | | 123,000 | 140,000 | 154,000 | 156,000 |
| | | 124,000 | 140,000 | 150,000 | 157,000 |
| Tensile Strength, psi | | 178,400 | 180,000 | 192,000 | 194,500 |
| | | 178,800 | 182,000 | 190,500 | 194,500 |
| Red. of Area,% Fracture(4) | | 46.5 C.P. | 44.5 C.P. | 41.1 C.P. | 38.5 C. |
| | | 41.9 " | 45.3 " | 40.7 " | 41.9 " |
| Impact, ft-lbs Fracture(5) | | 16.5 Cryst. | 18.1 Cryst. | 16.1 Cryst. | 18.1 Cr |
| | | 17.7 " | 18.1 " | 17.4 " | 19.4 |

NOTES:

(1) Discs "A" and "E" after 2" discard from ends of gun as quenched and

(2) Each value reported is the average of four tests.

(3) At .01% offset.

(4) C= Cupped　　I= Irregular　　SLC= Small lustrous cavit
P= Pitted　　LC= Lustrous cavities　　LLC= Large lustrous cavit

(5) Standard V-notch Charpy Specimen. Cryst.= Crystalline

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TABLE I

SON OF PHYSICAL PROPERTIES. PRESSURE BORE QUENCH VERSUS REGULAR QUENCH PRACTICE.

er to Figure 1 (items 2 and 4) for details of heat treatment and test location.

| tion ............ Thickness ....... | Disc "A"(1) 2-1/2" | Disc "B" 2-1/2" | Disc "C" 2-1/4" | Disc "D" 2-1/8" | Disc "E"(1) 1-3/8" |
|---|---|---|---|---|---|
| **5. PRESSURE BORE QUENCHED.** | | | | | |
| 1/4" from bore | 401 | 401 | 401 | 404 | 412 |
| At midwall | 358 | 346 | 372 | 372 | 401 |
| 1/4" from outside | 385 | 388 | 404 | 394 | 385 |
| rength, psi(3) | 130,000<br>125,000 | 125,000<br>122,000 | 143,000<br>135,000 | 142,000<br>146,000 | 179,000<br>175,000 |
| Strength, psi | 172,500<br>171,500 | 170,000<br>169,000 | 181,000<br>177,000 | 180,500<br>181,500 | 201,000<br>200,000 |
| Area,% Fracture(4) | 42.8 C.P.<br>46.5 " | 44.5 C.P.<br>45.7 " | 46.1 C.P.<br>46.5 " | 43.6 C.P.<br>44.1 " | 27.9 C.P.<br>50.2 " |
| ft-lbs Fracture(5) | 15.5 Cryst.<br>14.9 " | 16.8 Cryst.<br>16.1 " | 16.8 Cryst.<br>15.9 " | 14.2 Cryst.<br>15.6 " | 18.3 Fibrous<br>18.3 " |
| **51. REGULAR QUENCH PRACTICE.** | | | | | |
| 1/4" from bore | 415 | 404 | 401 | 415 | 408 |
| At midwall | 375 | 363 | 388 | 398 | 415 |
| ) 1/4" from outside | 415 | 408 | 422 | 415 | 381 |
| trength, psi(3) | 123,000<br>124,000 | 140,000<br>140,000 | 154,000<br>150,000 | 156,000<br>157,000 | 172,000<br>171,000 |
| Strength, psi | 178,400<br>178,800 | 180,000<br>182,000 | 192,000<br>190,500 | 194,500<br>194,500 | 204,000<br>201,400 |
| Area,% Fracture(4) | 46.5 C.P.<br>41.9 " | 44.5 C.P.<br>45.3 " | 41.1 C.P.<br>40.7 " | 38.5 C.P.<br>41.9 " | 39.8 C.P.LC<br>30.3 I.P.LC |
| ft-lbs Fracture(5) | 16.5 Cryst.<br>17.7 " | 18.1 Cryst.<br>18.1 " | 16.1 Cryst.<br>17.4 " | 18.1 Cryst.<br>19.4 " | 18.7 Fibrous<br>20.9 " |

(1) Discs "A" and "E" after 2" discard from ends of gun as quenched and drawn.

(2) Each value reported is the average of four tests.

(3) At .01% offset.

(4) C= Cupped, P= Pitted, I= Irregular, LC= Lustrous cavities, SLC= Small lustrous cavities, LLC= Large lustrous cavities

(5) Standard V-notch Charpy Specimen. Cryst.= Crystalline

W.A. 7-14-43 Lt. Birch

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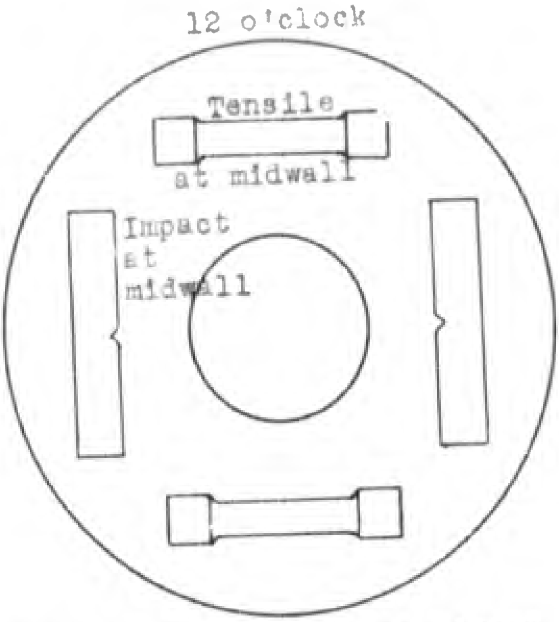
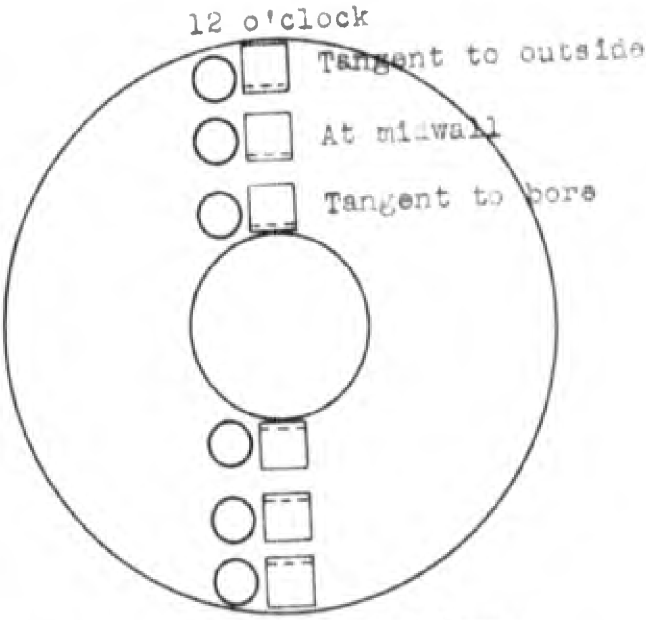
APPENDIX A




.394" V-notch Charpy specimens and .357" dia. tensile tests.

Transverse tests from discs at locations "A", "B","C","D", and "E" of Figure 1.




.394" V-notch Charpy specimens and .252" dia. tensile tests.

Longitudinal tests from disc cut adjacent to "C" location of Figure 1.

APPENDIX A

LAY-OUT OF TESTS FROM 76MM GUNS 3J-851 AND 3J-865