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# R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1665.

(Continuation of Investigation
No. 1608, March 9th, 1944.)

Further Investigation of 21-Inch-Torpedo
Connecting Rods.

(Copy No. 10.)

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

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch
O T T A W A June 16th, 1944.

# R E P O R T

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Investigation No. 1665.

## Further Investigation of 21-Inch-Torpedo Connecting Rods.

### Description of Material and Object of Investigation:

On May 5th, 1944, Mr. G. E. S. Hornby, Chief Chemist, British Admiralty Technical Mission, Ottawa, Ontario, requested verbally that further investigation be carried out on 21-inch torpedo engine connecting rods. This report may therefore be considered a continuation of Report of Investigation No. 1608, issued on March 9th, 1944.

The connecting rod consists essentially of a steel forging (SAE 1045). Phosphor-bronze bearing metal is "burnt-on" to either end at a pouring temperature of approximately 2300° F.

Five samples were submitted, four of which were manufactured by the Canadian Westinghouse Company Limited and one by United States production methods. Figure 1 is a photograph of a sample of the American production, showing the bronze on one end.

The Canadian Westinghouse method of "burning-on" the bronze employs a closed, dried-sand mould with a stationary central gate and with two risers from either end to receive the excess metal (see Figure 2). A modification of this method, employing a "pencil" gate (see Figure 3) was tried, the object being to permit a more uniform flow of the molten metal onto the surface of the steel, thus minimizing the shock effect.

The United States method of "burning" the bronze onto

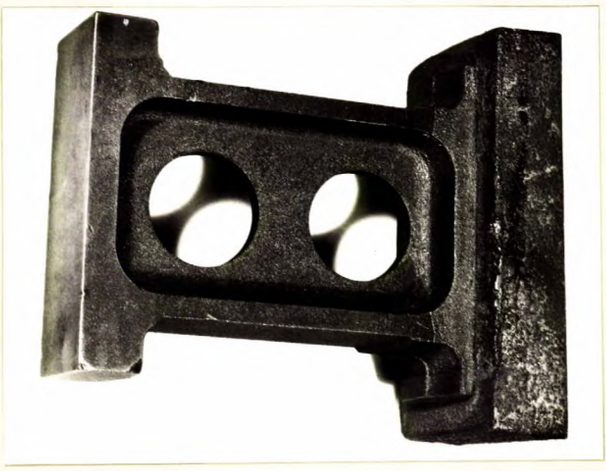
(Description of Material and Object of Investigation, cont'd) -

the steel, which is similar to the "Peter Brotherhood's Overflow Method" of England, consists of casting in an open "green sand" mould, with a trough placed at one end of the rod to receive the excess metal used in the burning-on operation (Figure 4). The stream of molten bronze is played from side to side over the surface of the steel.

In the Canadian Westinghouse production it was found that rather deep-seated cracks occurred in many connecting rods during the pouring operation. These cracks appeared to start at the steel-bronze interface and extended for a considerable distance down into the metal. Figure 5 shows the general disposition of the cracks.

Since no cracking was reported in the United States production, an attempt was made to compare the Canadian and American connecting rods, with a view to ascertaining any difference in materials or mode of manufacture which might explain the reason for the development of the cracks. One sample of Canadian Westinghouse production which was reported sound was compared with several cracked rods.

Figure 1.

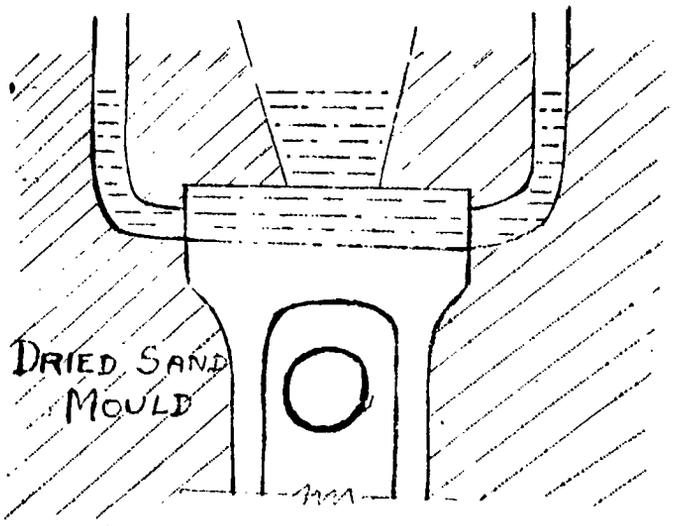


GENERAL VIEW OF 21-INCH-TORPEDO CONNECTING ROD,
U.S. PRODUCTION, SHOWING BRONZE ON ONE END.

(This photograph is about 1/3 actual size).

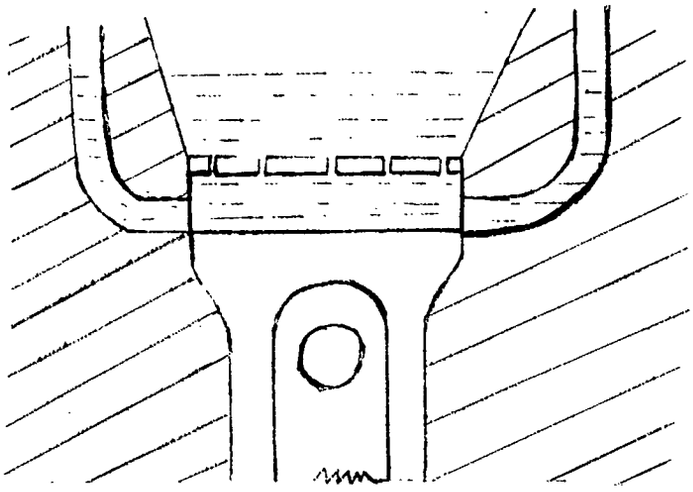
(Figures 2, 3, 4 and 5)
( comprise Page 3. )

Fig. 2



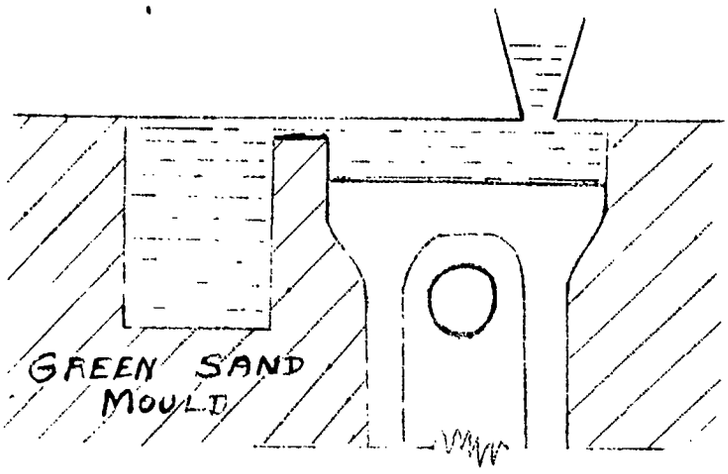

CANADIAN WESTINGHOUSE
OPEN GATE METHOD

Fig. 3



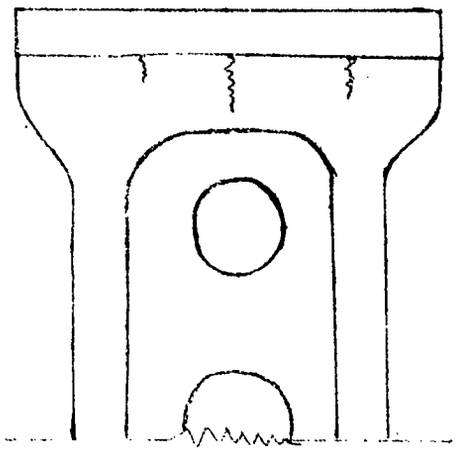
CANADIAN WESTINGHOUSE
PENCIL GATE METHOD

Fig. 4




AMERICAN PRODUCTION
METHOD

Fig. 5



SHOWING POSITION
OF CRACKS

Chemical Analysis:

Chemical analyses of the United States production of both steel and bronze were made and the results were compared with Canadian production. These results were as follows:

STEEL.

| | | Canadian Production | | | United States |
|---|---|---|---|---|---|
| | | Sample 1 | Sample 2 | Sample 3 | Production |
| | | | - Per Cent - | | |
| Carbon | - | 0.47 | 0.50 | 0.50 | 0.44 |
| Silicon | - | 0.24 | 0.21 | 0.23 | 0.25 |
| Manganese | - | 0.62 | 0.67 | 0.67 | 0.58 |
| Sulphur | - | 0.029 | 0.030 | 0.034 | 0.035 |
| Phosphorus | - | 0.008 | 0.014 | 0.014 | 0.017 |
| Nickel | - | 0.44 | 0.04 | 0.03 | Trace. |
| Chromium | - | 0.15 | Nil. | Nil. | Nil. |
| Molybdenum | - | 0.05 | Trace. | Trace. | Trace. |
| Vanadium | - | Nil. | Nil. | Nil. | - |
| Aluminium | - | Trace. | Trace. | Trace. | - |

BRONZE.

| | | Canadian Production | | | United States |
|---|---|---|---|---|---|
| | | 18-Inch 37 WF 7 | 21-Inch WL 449 | 21-Inch WL 580 | Production |
| | | | - Per Cent - | | |
| Copper | - | 87.95 | 87.66 | 87.40 | 87.51 |
| Tin | - | 11.61 | 11.52 | 11.87 | 12.08 |
| Zinc | - | Nil. | 0.15 | 0.20 | N.D. |
| Lead | - | 0.02 | 0.19 | 0.19 | 0.06 |
| Phosphorus | - | 0.14 | 0.016 | 0.11 | 0.10 |
| Iron | - | 0.06 | 0.04 | 0.05 | 0.08 |
| Antimony | - | Nil. | 0.03 | 0.05 | 0.08 |
| Nickel | - | Nil. | 0.09 | 0.16 | 0.16 |
| Manganese | - | Nil. | Nil. | Nil. | N.D. |
| Silicon | - | " | " | " | 0.006 |
| Aluminium | - | " | " | " | - |

N.D. - None detected.

Fracture Tests:

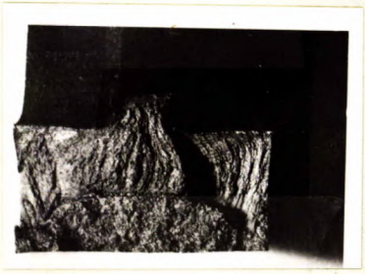
Fracture tests were made on the tensile machine.

Figure 6 shows the appearance of the fracture on the U.S. production. Note the fibrous structure and complete absence of penetration of the bronze. Figure 7 is the structure obtained on an open gate Westinghouse production, revealing a fibrous structure and slight penetration of the bronze. Figure 8 is

(Fracture Tests, cont'd) -

also that of an open gate Westinghouse production, showing finer grain and less fibrous structure, with deep penetration of the bronze. Figure 9 shows the fracture obtained by breaking a sample poured by the pencil gate method. Note the fine grain, and the depth of penetration of the bronze.

Figure 6.



U.S. PRODUCTION, SHOWING FIBROUS FRACTURE.

No penetration of bronze.

-

Figure 7.

WESTINGHOUSE OPEN GATE PRODUCTION, SHOWING FIBROUS STRUCTURE AND SLIGHT PENETRATION OF BRONZE.

-

Figure 8.

WESTINGHOUSE OPEN GATE PRODUCTION, SHOWING LESS FIBROUS STRUCTURE AND DEEP PENETRATION OF BRONZE.

-

Figure 9.

WESTINGHOUSE PENCIL GATE METHOD.

Note fine grain size and deep penetration of bronze.

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## Experiments Made to Measure the Actual Temperature of the Steel Adjacent to the Bronze during the Burning-on Process:

Experiments were conducted at the Canadian Westinghouse Company Limited, Hamilton, Ontario, on March 23rd, to determine, by means of a Speedomax, the actual steel temperature during the "burning-on" operation, for both the Westinghouse open gate method and the pencil gate method. The results of these experiments are given in Figures 10 and 11.

Figure 10.

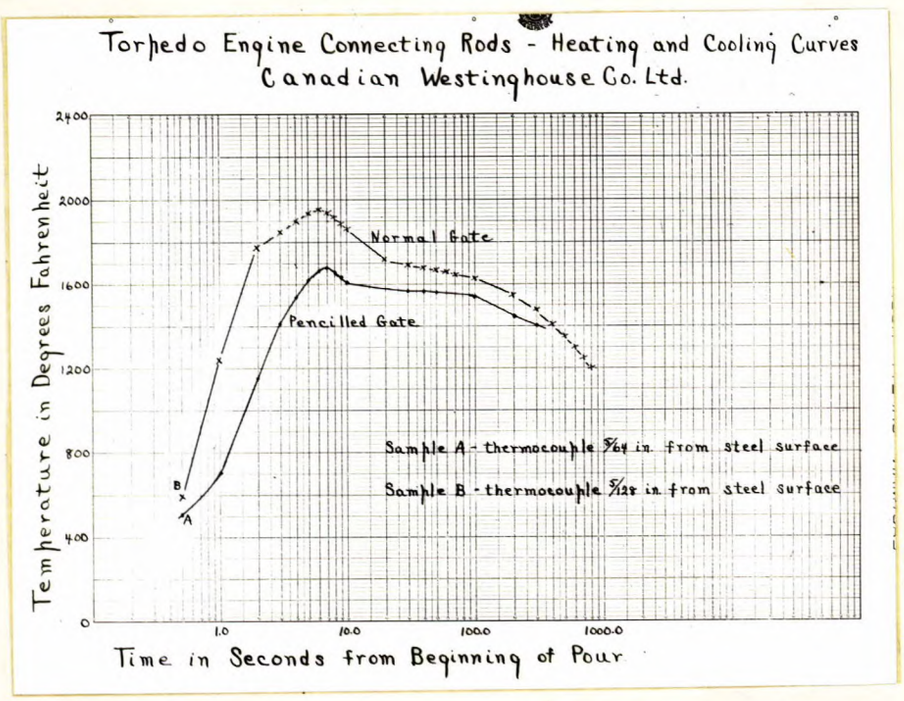
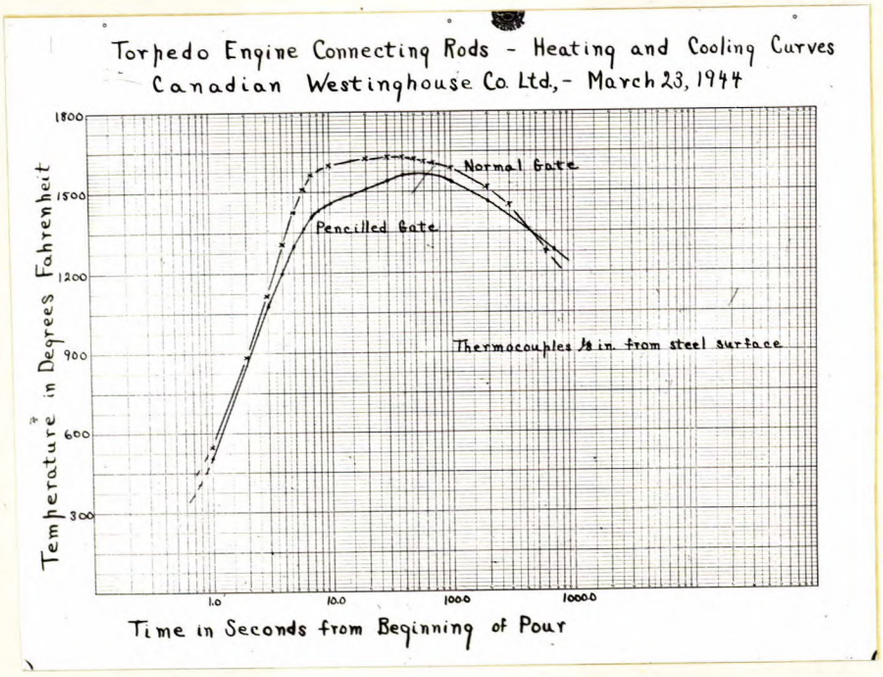



Figure 11.



Microscopic Examination:

Sections were obtained from all five samples, for microscopic examination.

Figures 12 and 13 show the penetration of the bronze into the steel. The bronze had been poured through a pencil gate. Note the intercrystalline penetration of the bronze (Figure 13).

Some of the specimens revealed a reaction product between the bronze and the steel. Figures 14 and 15, photomicrographs taken at magnifications of X100 and X1000 respectively, show this reaction product on a cracked open gate Westinghouse production. No evidence of this product was found on the U.S. production.

Figures 16 and 17 show the microstructure of the U.S. production in the original unaffected and altered zones, respectively.

Figures 18 and 19 show the altered and unaltered structures, respectively, of Canadian Westinghouse production which had not developed cracks.

Figures 20 and 21 show the altered and unaltered structures, respectively, of a Canadian Westinghouse pencil gate production rod which had cracked very badly during the pouring operation.

Figure 22 is a photomicrograph of Sample No. WL 552, Canadian Westinghouse open gate production, showing large grains formed in the forging operation and not completely eliminated during the subsequent normalizing operation. This rod cracked during the pouring operation.

It was noticed that the heat-affected zone on the U.S. production was slightly deeper than that of the Canadian Westinghouse open gate production which had developed cracking (see Figure 23). It is rather difficult to assign any importance to this, however.

( Figures 12 to 23 follow, )
( on Pages 8 to 10. )
(Text continues on Page 11.)

Figure 12.

X200, picral etch.

BRONZE-STEEL INTERFACE, SHOWING PENETRATION OF BRONZE INTO STEEL.

Figure 13.

X500, nital etch.

SHOWING INTERCRYSTALLINE PENETRATION OF THE BRONZE.

PENCIL GATE PRODUCTION.

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Figure 14.

X200, nital etch.

Figure 15.

X1000, nital etch.

CANADIAN WESTINGHOUSE OPEN GATE PRODUCTION.

SHOWING REACTION PRODUCT BETWEEN BRONZE AND STEEL.

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Figure 16.

X200, nital etch.

SHOWING ORIGINAL STRUCTURE UNALTERED BY BURNING-ON OF BRONZE.

Figure 17.

X200, nital etch.

SHOWING STRUCTURE ALTERED BY BURNING-ON OF BRONZE.

U.S. PRODUCTION.

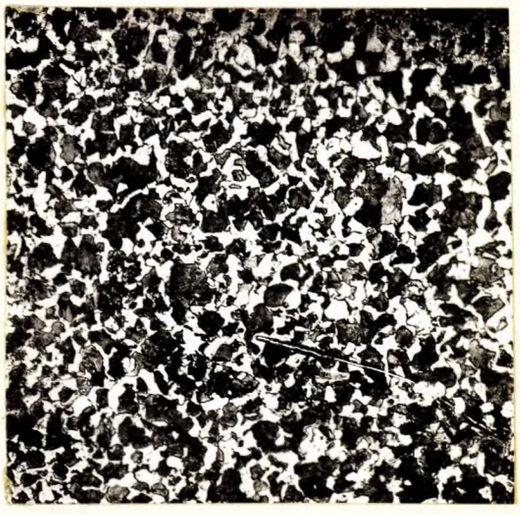
—

Figure 18.

X200, nital etch.

SHOWING ORIGINAL UNALTERED STRUCTURE.

Figure 19.



X200, nital etch.

SHOWING STRUCTURE ALTERED BY BURNING-ON OF BRONZE.

CANADIAN WESTINGHOUSE OPEN GATE PRODUCTION
(Not Cracked).

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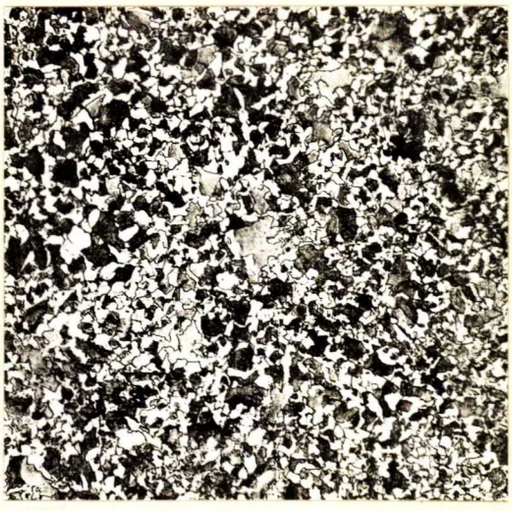
Figure 20.

X200, nital etch.

SHOWING ORIGINAL
UNALTERED STRUCTURE.

Figure 21.



X200, nital etch.

SHOWING STRUCTURE ALTERED
BY BURNING-ON OF BRONZE.

CANADIAN WESTINGHOUSE PENCIL GATE PRODUCTION.

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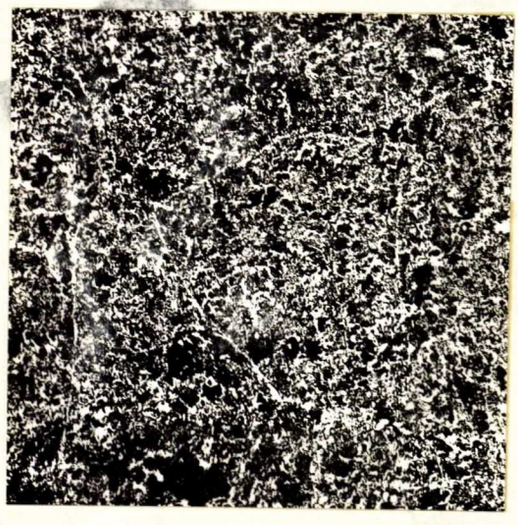
Figure 22.



X100, nital etch.

CANADIAN WESTINGHOUSE
OPEN GATE PRODUCTION,
SHOWING LARGE FORGING GRAIN.

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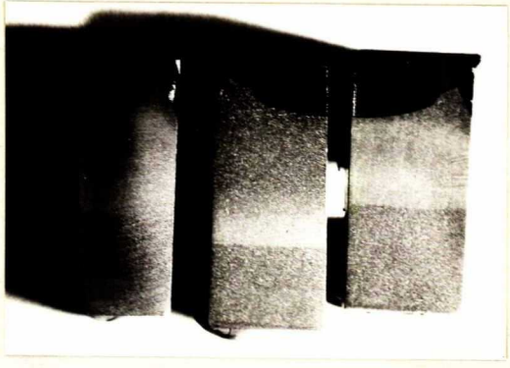
Figure 23.



Actual size, nital etch.

SHOWING HEAT-AFFECTED ZONE.
(U.S. production in centre;)
(Canadian Westinghouse open)
(gate production on either )
sides.)

—

Discussion of Results:

The chemical analysis shows no essential difference between the steel and the bronze used by the Canadian Westinghouse and that of the U.S. production.

The fracture tests do not offer anything which might lead to definite conclusions.

The heating and cooling curves do not offer any evidence in explanation of the cracking.

The slightly greater depth of penetration of the heat caused by the burning-on of the bronze, in the American sample, may or may not be of any significance. More samples would have to be examined before making any definite conclusions.

Examination of the microstructure does not reveal any defects common to all of the cracked rods, and hence nothing definite may be concluded.

However, the answer to the problem may be found in the effect of hydrogen introduced into the steel during the pickling operation. Quotations in support of this will be freely taken from a paper entitled "Penetration of Steel by Brass during Brazing and the Effect of Previous Pickling" in "The Metallurgist", supplement to "The Engineer", December 1934. This paper records the results of experiments on various grades of steel which had been pickled in 2:1 HCl and then dipped into the molten brass at 1100° C. It was found that intercrystalline penetration of the brass into the steel occurred invariably, due to the absorption of hydrogen during the pickling operation. In many cases the intercrystalline penetration opened out into lakes filled with brass.

> "In a series of experiments, steels, after pickling in acid, were immediately heated for a period of twenty minutes to temperatures of 100, 150, 200 and 500° C. in order to drive out the absorbed hydrogen, and were then immersed in the molten brass. Examination showed that marked penetration occurred in all cases, the depth having no relation to the temperature at which degassing had proceeded. Similar results were obtained in samples which

(Discussion of Results, cont'd) -

had been degassed by resting at room temperature for eight weeks."

"In one series of tests the 'gassed' steels were immersed immediately in the molten brass, while in another they were allowed to rest at the ordinary temperature for eight weeks after pickling before entering the brazing metal. In this period of resting all the hydrogen was liberated from the steel. Examination of sections through the steels after immersion showed that in all cases the brazing metal had penetrated into the steel. The depth of penetration was the same in the steels which had been degassed by resting as it was in the corresponding samples brazed immediately after pickling. These experiments revealed a close parallelism between the susceptibility to penetration by molten brass and the embrittlement of steels which had been charged with hydrogen."

"A series of experiments were carried out to determine whether the susceptibility to penetration found in steels which has previously been gassed with hydrogen could be reduced or eliminated by any form of heat treatment. Specimens which had been charged with hydrogen were heated at 750° C. for periods of one, five, and ten hours and were then immersed in the brazing metal. Heating for one hour was found to reduce the depth of penetration considerably. The five-hour treatment produced a greater improvement, and after heating for ten hours the steel was practically immune to the action of the brass, penetration only occurring to a very slight degree in a few places."

"A series of experiments were conducted on cold-worked steel, and it was found that cold-worked material always developed cracks filled with brass, on dipping into the molten metal. On the other hand, a steel which had been annealed, so as to remove the internal stresses caused by the cold work, is only susceptible when it has been pickled after annealing and no further heat treatment has been applied."

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CONCLUSIONS AND RECOMMENDATIONS:

1. The examination of the five specimens did not offer any definite clues as to the cause of the cracking.

2. It is recommended that experiments be conducted in which bronze is cast onto stress-free steel which has not been at any time subjected to a pickling operation.

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AF:GHB.