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**WATERTOWN ARSENAL
LABORATORY**

MEMORANDUM REPORT

NO. WAL 710/722

Metallurgical Examination of 4" Thick Cast Armor

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BY

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DATE 13 February 1945

**WATERTOWN ARSENAL
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WATERTOWN ARSENAL LABORATORY

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MEMORANDUM REPORT NO. WAL 710/722

Final Report on Problem B-4,65

13 February 1945

Metallurgical Examination of 4" Thick Cast Armor

ABSTRACT

Metallurgical examination was conducted on a 4" thick cast plate No. C977B-1, heat 2934 submitted by American Steel Foundries, East Chicago Plant. This plate failed to meet 155mm. shock and 90mm. ballistic limit requirements of specification AMS 1C13. The results of this investigation indicated that the material was incompletely quench hardened due to inadequate hardenability and that it showed some evidence of embrittlement by temper brittleness (not pronounced).

1. As requested by the Ordnance Research Center, Aberdeen¹, metallurgical examination has been completed on a 4" thick cast plate No. C977B-1, heat 2934, submitted by the American Steel Foundries, East Chicago Plant.

2. Metallurgical examination included the following tests:

- a. Brinell hardness survey.
- b. Fibre fracture test for revealing response to heat treatment.
- c. Reheat treatment of sample resulting in a fibrous fracture.
- d. V-notch Charpy impact tests.
- e. Chemical analysis.
- f. Microscopic examination.

3. The results of the metallurgical examination are as follows:

- a. Brinell hardness survey.

On a properly ground cross section, five equidistantly spaced Brinell hardness readings were made through the section. The results are as

1. AFG 470.5/875 - #tn 470.5/8520(r) - 8 November 1944

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follows:

<u>Range</u>	<u>Average</u>
255-269	262

b. Fibre fracture test.

A properly notched section was fractured and rated with respect to the fibre fracture test for revealing response to heat treatment. The section exhibited a crystalline fracture. However, as described below in paragraph 3C when reheat treated an essentially fibrous fracture was obtained.

c. Samples, 6"x4"x3/4", reheat treated at Watertown Arsenal.

A section cut from the casting was given the following reheat treatments:

<u>W.A. Heat Treatments</u>		
<u>Temperature</u>	<u>Time</u>	<u>Coolant</u>
	(Retempered)	
1125°F.	3½ hrs.	Water
	(Quenched and Tempered)	
1650°F.	4 hrs.	Water
1125°F.	6 hrs.	Water

The section fractured after retempering remained crystalline. However, when quenched and tempered an essentially fibrous fracture was obtained.

d. V-notch Charpy impact tests.

V-notch Charpy tests were made on samples "as-received" and after reheat treatment. The low impact value obtained at -40°F. was probably due to a combination of factors, namely incomplete quench hardening as the result of inadequate hardenability and embrittlement by brittleness. The impact value at -40°F. was raised to some degree by retempering at the temperature used by the manufacturer and subsequently quenching in water.

V-Notch Charpy Impact Tests

"As-Received"

<u>Location</u>	<u>Temp.</u>	<u>Ft. Lbs.</u>	<u>*Description of Fracture</u>	<u>BHN</u>
Midwall	+70°F.	40.7	Fc 1/3	241
	-40°F.	17.1	Cbf	

After Watertown Arsenal Reheat Treatments

Retempered

1125°F. - 3½ hrs. - water quench

Midwall	+70°F.	43.2	F (tr. shrinkage)	235
	-40°F.	24.7	Cbf	

Quenched and Tempered

1650°F. - 4 hrs. - water quench

1125°F. - 6 hrs. - water quench

Midwall	+70°F.	35.8	Fc tr (1/3 shrinkage)	255
	-40°F.	39.1	F (small am't shrinkage)	

e. Chemical analysis.

The result of the chemical analysis obtained was as follows:

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>	<u>Cu</u>	<u>B</u>
.20	.73	.45	.014	.012	1.63	1.55	.62	Nil	.08	Tr

Undoubtedly this low carbon composition had insufficient hardenability to properly quench harden throughout a section 4" thick.

*F - Fibrous

Fc - Fibrous matrix with spots of crystallinity.

Cbf - Bright crystalline patch surrounded by fibrous border.

f. Microscopic examination.

Microscopic examination was made on samples "as-received" and after the Watertown Arsenal quench and tempering treatment. In regard to nonmetallic inclusion content, the casting was fairly clean with occasional segregated areas of sulphide inclusions in the primary grain boundaries. The microstructure in the "as-received" condition consisted of fine carbides in a ferrite matrix with carbides at the grain boundaries. A tempered martensite microstructure containing some ferrite was evident in the microstructure after the Watertown Arsenal reheat treatment. Typical microstructures of the casting "as-received" and after reheat treatment are shown in Figure 1.

4. In conclusion these tests indicate:

- a. The material had inadequate hardenability (0.20% C) to properly quench harden throughout.
- b. The material was slightly susceptible to embrittlement by temper brittleness.
- c. Correlations were established between fracture, V-notch impact tests and ballistic properties.

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APPROVED:

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Typical Microstructures of 4" Thick Cast Armor
Manufactured by American Steel Foundries

"As-Received" Condition

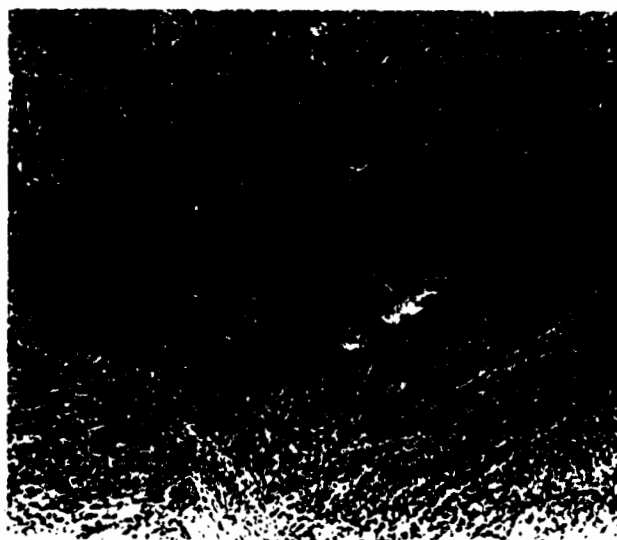


X1000 Picral
Fine carbides in a matrix of ferrite
with carbides at great boundaries.



X100 Unetched
Occasional segregated area of sul-
phide inclusions in the primary grain
boundaries.

after W. A. Reheat Treatment



X1000 Picral
Tempered martensite containing some
ferrite at grain boundaries.