[redacted] (1)

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/729

Metallurgical Examination of 2" Cast and 2½" Rolled Homogeneous Armor Shock Tested with 105mm. T6 Proof Projectiles

BY
M. YOFFA
Phy. Sci. Aide

DATE 14 March 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

[redacted]

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/729

Final Report on Problem B-4.68

14 March 1945

Metallurgical Examination of 2" Cast and 2½" Rolled Homogeneous Armor Shock Tested with 105mm T8 Proof Projectiles

ABSTRACT

A metallurgical examination has been completed on two 2½" thick rolled homogeneous and four 2" thick cast armor plates which had been tested with 105mm T8 proof projectiles. In general, good correlations were established between ballistic shock properties and metallurgical properties, namely, the fracture test and V-notch Charpy impact energy values. Temper brittleness was detected in three of the castings, two of which had failed the shock test.

1. At the request of the Ordnance Research Center, Aberdeen,[1] metallurgical examination has been completed on two 2½" thick rolled homogeneous and four 2" thick cast armor plates which had been tested with 105mm T8 proof projectiles in order to compare ballistic shock properties with metallurgical properties.

2. Metallurgical examination included the following tests:

   a. Chemical analyses.

   b. Fracture test for steel soundness and fibre characteristics.

   c. Brinell hardness tests.

   d. V-notch Charpy impact tests.

   e. Tensile tests.

   f. Microscopic examination.

---

1. Wtn 470.5/117 - ASF 470.5/983, dated 9 December 1944.

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

a. Chemical analyses.

Chemical analyses of the series of plates tested are given in Table I.

b. Fracture test for steel soundness and fibre characteristics.

Fracture tests were made on notched sections and the steels were rated with respect to steel soundness and fibre for revealing response to heat treatment. The steel soundness of sample No. SSS2070-1M1 was satisfactory. A pronounced lamination of "D" steel soundness rating was present in the transverse section of sample No. SSS2082-1T1. A slight degree of "woodiness" was noted in both of the rolled plates. These plates also fractured in a fibrous manner. As noted in Table III the fracture of the cast plates which were unsatisfactory under the ballistic shock tests displayed a fibrous matrix with scattered crystallinity distributed throughout the section. The satisfactory cast plates had a fibrous fracture although the center of the sections exhibited shrinkage. [redacted]

c. Brinell hardness tests.

Cross-sectional Brinell hardness tests, which were made on surface ground specimens are tabulated in Table II. The Brinell hardness readings across the section were relatively uniform. However, readings made at Watertown Arsenal were somewhat higher than those reported by the manufacturers, especially in the case of sample No. GS1750, where the manufacturer reported a hardness 34 points lower than that obtained at Watertown Arsenal.

d. V-notch Charpy impact tests.

Tests were made on standard V-notch Charpy bars in the "as-received" condition, and after retempering. The "as-received" Charpy bars were cut from positions near the surface and at the center of the sections, the retempered impact bars from halfway between the surface and the center. Specimens from both sets were broken at +70°F and at -40°F. A satisfactory correlation was obtained between the V-notch Charpy impact tests and the ballistic shock tests. Sample No. SSS2082-1T1 which satisfactorily resisted the ballistic shock test had considerably higher V-notch impact energy values than sample No. SSS2070-1M1 which failed the shock test. The relatively low V-notch Charpy values of plate No. SSS2070-1M1 obtained at the surface indicated that the material was improperly heat treated. This was not readily revealed by the impact tests made on the center sections of the plates because of the presence of segregated nonmetallic inclusions which influence the type of fracture. It is believed that the presence of the nonmetallic inclusions in the midsection of this plate increased the V-notch Charpy value. It was also observed that there were no marked directional properties in the two rolled plates Nos. SSS2070-1M1 and SSS2082-1T1. Cast plates Nos. GS1750 and SGL26 which had poor shock resistance

under the impacts of the proof projectiles had low impact energy values at -40°F. Upon retempering these sections at 1175°F for 1 hour and water quenching the values at -40°F increased considerably indicating that the material was temper brittle. However, sample No. GS1753 which passed the shock test was also temper brittle. The results also indicate that when the metal at the surface of armor has good resistance to impact as measured by V-notch impact tests, the ballistic shock properties are satisfactory, even though the center sections of the same plates have relatively poor shock properties. Since ballistic failure is almost always initiated at the plate surfaces, it is reasonable to expect that the surface properties may, to a great extent, determine the ballistic characteristics of the armor. Data on impact energy values obtained from these tests are tabulated in Table III.

e. Tensile tests.

Tensile bars were machined from sections located halfway between the surface and the center of the castings. Longitudinal and transverse tensile test bars in the rolled plates were machined from a similar location to those obtained from the cast plates. The results of the tests are given in Table IV. No correlation was apparent between the tensile tests and ballistic impact properties. Moreover, these tests indicated that the rolled plates were uniformly cross rolled as there was no pronounced difference noted between the ductility of the longitudinal and transverse samples.

f. Microscopic examination.

Photomicrographs illustrating the typical microstructures of the samples are shown in Figure 1. No marked segregation of nonmetallic inclusions was detected in the sections of the cast plates investigated. The center of the sections of rolled plates, Nos. SSS2070-1M1 and SSS2082-1T1 contained more fine silicate inclusions, (frequently found in steels exhibiting "woody" fractures) than near the surface. The microstructure of rolled plates, Nos. SSS2070-1M1 and SSS2082-1T1 consisted of a coarse acicular structure which was characteristic of both surface and center. The microstructure of cast plates, Nos. GS1750 and GS1753 consisted of a uniform distribution of fine carbides. Fine globular carbides were present in the microstructure of sample No. SG L303 while a fairly uniform distribution of fine carbides was present in sample No. SG L26.

4. In general, correlations were established between ballistic shock properties and metallurgical properties, namely, the fracture test and V-notch Charpy impact values. It was further determined that satisfactory shock properties can be obtained on plates having a fairly high V-notch Charpy impact energy value at the surface although the center section of the same plates may have a relatively low impact value. No correlation was evident between the tensile tests and shock properties. The cast samples were heat treated to an average Brinell hardness range of 243-293. The rolled plates had an average

Brinell hardness of 272-274. The microstructures of the cast plates consisted of a fairly uniform distribution of carbides while the rolled plates had a coarse acicular structure.

M. Yoffa

M. Yoffa
Phy. Sci. Aide

APPROVED:

E. L. Reed

E. L. REED
Research Metallurgist
Acting Chief, Armor Section

TABLE I

Chemical Analyses

Plate No.	Type of Armor	Manufacturer	Thickness	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu	B	Ti	Al
SSS2070-1M1	Rolled Homo.	Standard Steel Spring	2½"	.32	1.61	.21	.014	.020	Nil	.025	.46	Nil	.025	.002	.04	.03
SSS2082-1T1	"	" " "	"	.32	1.62	.18	.014	.021	Tr.	.025	.57	Nil	.03	.001	.04	.03
GS1750	Cast	General Steel (E)	2"	.34	.60	.43	.021	.012	Tr.	2.40	.46	Nil	.12	.001	--	.08
GS1753	"	" "	"	.25	.62	.45	.014	.011	Tr.	2.32	.51	Nil	.12	.0009	Tr	.03
SG L26	"	Symington-Gould (D)	"	.29	1.50	.54	.017	.016	Tr.	.20	.31	Nil	.04	.001	—	.02
SG L303	"	" "	"	.27	1.40	.40	.016	.030	Tr.	.10	.32	Nil	.05	.0008	Tr	.02

TABLE II

Brinell Hardness Survey

Sample No.	Reported by Watertown Arsenal		Reported by Manufacturer
	Range	Average	Average
Rolled Plates			
SS52070-1M1	269-277	274	259
SS52082-1T1	262-285	272	259
Cast Plates			
GS1750	293	293	259
GS1753	255	255	248
SG L26	255-269	267	239
SG L303	235-255	243	229

Plate No.	Manufacturer	Type of Armor	Thickness	Type Chemistry Mn	Mo	Fracture Test
SSS2070-1M1 (Long.)	Standard Steel Spring	Rolled Homo.	2⅛"	1.61	.46	Fibrous Woody in center of section.
SSS2070-1M1 (Trans.)						Fibrous tr woody
SSS2082-1T1 (Long.)	"	"	"	"	"	1.62	.57	Fibrous tr woody
SSS2082-1T1 (Trans.)						Fibrous Woody in center of section.
				Cr.	Mo	
GS1750	General Steel (E)	Cast	2"	2.40	.46	Fibrous, trace of crystallinity throughout section.	Trace cen
GS1753	"	"	"	"	2.32	.51	Fibrous	Trace tra
				Ni	Mo	
33 L26	Symington-Gould (D)	"	"	1.50	.31	Fibrous, trace of crystallinity throughout section.	Prono in re
33 L303	"	"	"	"	1.40	.32	Fibrous, dendritic	Small in ce

Description of V-Notch Charpy Bar Fractures:

F = Fibrous Fc = Fibrous matrix with spots of crystallinity. Cbf = Bright cryst
The fraction following the fracture symbol refers to the estimated surface area which

Critical velocity is defined as velocity at which cracking started.

NOTE: Longitudinal bar = notch perpendicular to major rolling direction.
Transverse bar = notch parallel to major rolling direction.

Plate No.	Manufacturer	Type of Armor	Thick-ness	Type Chemistry Mn	Mo	Fracture Ty Fibre Fracture Zone	
SSS2070-1M1 (Long.)	Standard Steel Spring	Rolled Homo.	2½"	1.61	.46	Fibrous Woody in center of section.	
SSS2070-1M1 (Trans.)						Fibrous tr woody	
SSS2082-1T1 (Long.)	"	"	"	"	"	1.62 .57 Fibrous tr woody	
SSS2082-1T1 (Trans.)						Fibrous Woody in center of section.	
				Cr	Mo		
GS1750	General Steel (E)	Cast	2"	2.40	.46	Fibrous, trace of crystallinity throughout section.	Trac ce
GS1753	"	"	"	"	"	2.32 .51 Fibrous	Trac ren
				Mn	Mo		
37 L26	Symington-Gould (D)	"	"	1.50	.31	Fibrous, trace of crystallinity throughout section.	Pron in c
39 L303	"	"	"	"	"	1.40 .32 Fibrous, dendritic	Small in c

*Description of V-Notch Charpy Bar Fractures:

F = Fibrous Fc = Fibrous matrix with spots of crystallinity. Cbf = Bright crys
The fraction following the fracture symbol refers to the estimated surface area which

**Critical velocity is defined as velocity at which cracking started.

NOTE: Longitudinal bar = notch perpendicular to major rolling direction.
Transverse bar = notch parallel to major rolling direction.

TABLE III

Summary of Physical and Ballistic Tests Made on 2" Cast and 2½" Rolled Homogeneous Shock Tested with 105mm. T8 Proof Projectiles

Fracture Tests	Steel Quality	Average Cross-Sectional BHN Determined at W.A.	As-Received Surface Ave. Rc	As-Received Surface +70°F	As-Received Surface -40°F	As-Received Center Ave. Rc	As-Received Center
					Foot Pounds		
[illegible]	B			39.1 Cbf	18.1 Cbf		5
		274	25.8			24.9	
	B			34.2 Cbf	18.1 Cbf		4 t
	F			61.7 F	45 Cbf		6 t
		272	27.0			25.5	
[illegible]	F			60.3 F	64.7 F tr woody		7 t
[illegible] of ty tion.	Trace of shrinkage in center of section.	232	29.0	36.2 F tr shrinkage	24.3 Cbf	26.5	39.1 tr sh
	Trace of shrinkage in center of section.	255	23.8	62.8 F tr shrinkage	35.8 Fc-1/3	22.0	4 tr sh
[illegible] ty tion.	Pronounced shrinkage in center of section.	267	27.3	46.6 F dendritic, tr shrinkage	17.4 Cbf	25.5	35.8
ittle	Small amt of shrinkage in center of section.	243	23.5	48.4 F tr shrinkage	37.8 F tr shrinkage	24.0	3 tr sh

Bright crystalline patch surrounded by fibrous border.
area which is crystalline.

Rolled Homogeneous Armor

V-Notch Charpy Results

Specimen	As Received Center Ave. Rc	As Received Center +70°F	As Received Center -40°F	After Retempering (Midsection) Tempering Temp.	Time at Tempering Temp.	Coolant	Ave. Rc	+70°F Foot Pounds	-40°F Foot Pounds
		55.7 F steady	23.6 Cbf	1175°F	1 hour	Water	25.0	46.2 Cbf-1/3	22.9 Cbf-
		49.2 Fc tr steady	23.6 Cbf	--	--	--	--	----	----
		57.1 F tr steady	60.3 F tr steady						
				--	--	--	--	----	----
		72.3 F tr steady	61.9 F						
		39.1 F-1/3 tr shrinkage	23.5 Fc½	1175°F	1 hour	Water	29.5	45.8 F tr shrinkage	39.9 F tr shrink
		42.7 F tr shrinkage	32.6 Cbf tr shrinkage	1175°F	1 hour	Water	22.5	66.6 F	66.6 F tr shrink
	35.3 F-1/3		21.5 Fc½	1175°F	1 hour	Water	25.8	49.2 F tr shrinkage	41.5 Fc dendritic
		34.2 F tr shrinkage	35.8 F tr shrinkage	1175°F	1 hour	Water	22.8	53.2 F tr shrinkage	45.8 Fc-1/ some shrinkage

Reinvering (Midsection)				
Cool-ant	Ave. Rc	+70°F Foot Pounds	-40°F Foot Pounds	Results of Shock Test **Critical Velocity
Water	25.0	46.2 Cbf-1/3	22.9 Cbf-7/8	
				CP at 1560 f/s; plate cracked 27½" to edge.
--	--	----	----	
				PP at 1736 f/s.
Water	23.5	45.8 F tr shrinkage	39.9 F tr shrinkage	940 f/s (approx.)
Water	22.5	66.6 F	66.6 F tr shrinkage	1175 f/s (approx.)
Water	25.8	49.2 F tr shrinkage	41.5 Fc½ dendritic	873 f/s (approx.)
Water	22.8	53.2 F tr shrinkage	45.8 Fc-1/4 some shrinkage	1170 f/s (approx.)

TABLE IV

*Tensile Tests

Test Bar .357" Diameter

Plate No.	Type	Y.S. Lbs./Sq.In.	T.S. Lbs./Sq.In.	% El.	% R.A.
SSS2070-1M1 (Long.)	Rolled Homo.	114,300	130,000	18.6	59.2
SSS2070-1M1 (Trans.)	"	114,400	130,000	18.6	57.4
SSS2082-1T1 (Long.)	"	106,250	127,500	19.3	59.6
SSS2082-1T1 (Trans.)	"	99,370	132,500	18.6	57.4
GS1750	Cast	108,750	140,500	3.6	16.1
GS1753	"	90,000	111,800	4.3	13.0
SG L26	"	109,370	119,000	12.9	17.1
SG L303	"	106,000	117,500	3.6	10.3

*Tensile test bars were machined from sections located halfway between the surface and the center of the plates.

Typical Microstructures

2½" Thick Rolled Homogeneous Armor

Plate No. SSS2070-1M1
Coarse acicular structure.

Plate No. SSS2082-1T1
Coarse acicular structure.

2" Thick Cast Armor

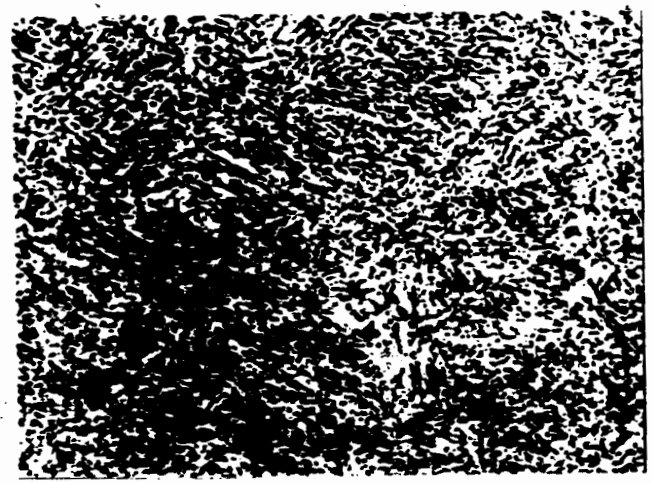

Plate No. GS1750
Uniform distribution of fine carbides.
Same as Plate No. GS1753.

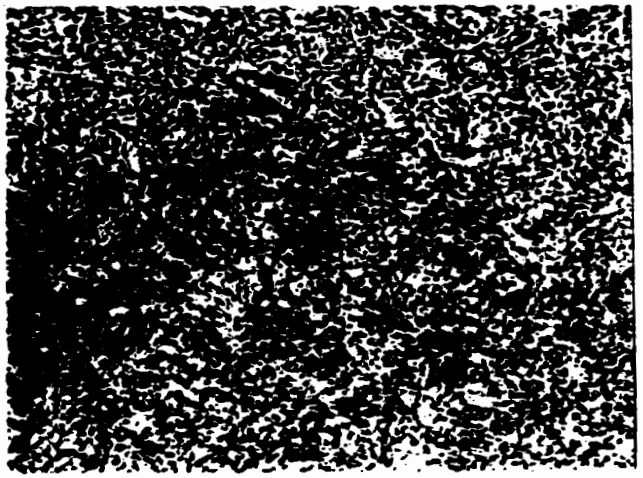

Plate No. SG L303
Fine globular carbides.

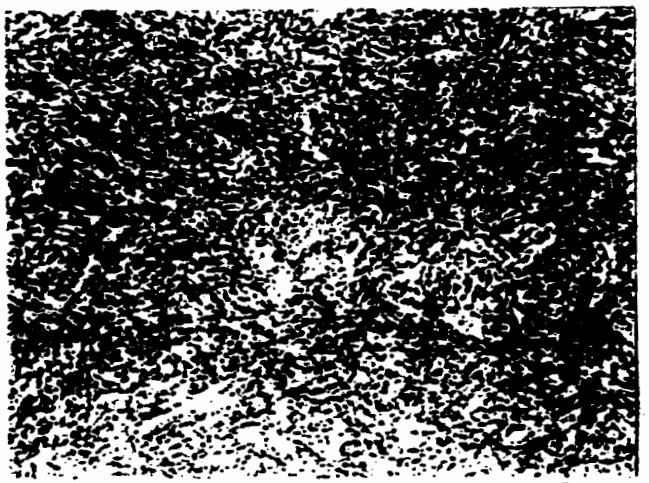

Plate No. SG L26
Fairly uniform distribution of fine carbides.

FIGURE 1

All microstructures X1000, etched in Picral.