WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/321

Metallurgical Examination of Two 1/4" Rolled Homogeneous Armor Plates Which Exhibited Differences in Steel Soundness under Ballistic Tests

BY

P. V. RIFFIN
Pvt. Ordnance Department

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WATERTOWN ARSENAL
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Final Report on Problem B-4.55

28 October 1944

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ABSTRACT

In this report two 1/4" plates were examined one of which exhibited back spalls when subjected to impacts with cal. .30 AP M2 projectiles at a velocity such that the jacket went through the plate; the other plats exhibited a clean punching condition under the same circumstances. It was found that a centerline plane of weakness caused by a concentration of silicate type stringers was responsible for the back spalls. This plane of weakness was not revealed by the fracture test for steel soundness yet its presence was disclosed by the macroetch test and a special torsion test.

1. As requested in a letter from the Ordnance Research Center, Aberdeen dated 9 September 1944 (APG 470.5/587 - Wtn 470.5/63), a metallurgical examination has been conducted on two samples of 1/4" rolled homogeneous armor manufactured by Disston, and the results are included in this report. Plate #2-36588 (reported in APG report Ar-14490) exhibited a back spalling condition when the jacket went through during a cal. .30 machine gun burst at 2450 f/s (± 25). Plate #3-36587 (reported in APG report Ar-14489) exhibited clean punchings under similar conditions.

2. The difference in ballistic behavior between the two plates is attributable to the presence of a centerline plane of weakness in plate #2 (the plate exhibiting spalls) which was not observed in the other plate. Consideration should be given to the fact that the ballistic test employed was extremely severe for 1/4" plate, and the difference in exit condition is of minor importance from

a vulnerability standpoint when it is considered that the plate is effectively defeated in either case.

3. A segregation of silicate type nonmetallic stringers was considered to be responsible for the centerline defect in the spalled plate. The defect was revealed by macroetch tests and a special torsion test which is described in paragraph 5e. The fracture test for steel soundness failed to reveal the defect adequately and it appears that the PTP type ballistic test using a jacketed projectile against light plate is much more selective in opening up planes of weakness in steel than is the fracture test, and once opened up the laminations exposed extend for a much greater distance as a result of the ballistic penetration.

Since the torsion test does reveal laminations not exposed by the fracture test, it appears that an investigation on other samples should be undertaken to determine the properties that are revealed by the two tests, and whether the fracture test is completely satisfactory in segregating light armor exhibiting poor ballistic properties under less severe tests.

4. The metallurgical examination consisted of the following tests:

a. Chemical analysis.

b. Hardness tests.

c. Fracture test for fibre and steel soundness.

d. Macroetch tests.

e. Torsion tests.

f. Microscopic examination.

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

a. Chemical Composition. The analysis of plate #2 was obtained in order to determine the type of steel employed, and it was found to be as follows:

	C	Mn	Si	S	P	Ni	Cr	Mo	Ti
Plate #2	.25	.55	.25	.022	.009	3.90	.05	.31	.09

The steel is a nickel-molybdenum type with a titanium bearing deoxidizer.

6. Hardness Surveys. Surface Brinell hardness readings and cross section Rockwell C and Vickers hardness readings were obtained and the results are as follows:

d. Macroetch Tests. Longitudinal and transverse sections were cut from an area 1" from the fractures and others 1" away from one of the ballistic penetrations exhibiting a backspall and etched in hot acid. The results are shown in Figure 1D. A faint centerline segregation is visible in the longitudinal direction and a disconnected segregation is observed in the transverse direction of plate #2. Plate #3 appears to be reasonably free from any extensive segregations of nonmetallic inclusions. The segregations observed in Plate #2 were considerably more prominent before the smudge was removed from the etched surface, indicating that the defect though pronounced was probably discontinuous.

e. Torsion Tests. It was learned that a torsion test has been employed at the Naval Proving Center for revealing laminations in steel, and consequently a few tests were conducted on the subject plates to ascertain whether the subject defect could be revealed. Sections ½" x 3" x T (thickness) were cut adjacent to the macroetch test bar, clamped in a vise, and twisted with a wrench. The deformed bars (Figure 1A) from plate #2 exhibit a continuous lamination in the central plane of the plate extending completely across the bars. Since the first bar tried was twisted over three turns before the lamination was noticed, a second bar was tried, and it was found that 3/4 of a turn revealed the lamination. For comparison a bar from plate #3 was twisted till the end sheared off yet no laminations were observed.

f. Microscopic Examination. An examination of the unetched specimens revealed a preponderance of silicate type stringers at the center of the plate #2, (Figure 2A). The sheared end of a torsion bar from this plate was examined microscopically, and it was observed that silicate type inclusions were present in the crack as well as in the undeformed metal in the same plane as the crack (Figure 2C).

The microstructure in both plates was a homogeneous tempered martensite (Figure 2D and E).

The metallographic work was conducted by B. Phelps.

P. V. Riffin

P. V. RIFFIN
Pvt., Ord. Dept.

APPROVED:

E. L. Reed

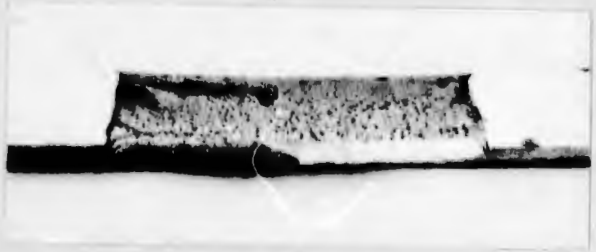
E. L. REED
Research Metallurgist
Acting Chief of Armor Section

A 1X

Comparison of torsion bars from Plates #2 and #3 showing lamination in Plate #2.

B X1½

Fracture of Plate #2.



C X1½

Fracture of Plate #3.

D X1

Macro-etched sections.

Plate #2 - spalled.
Plate #3 - satisfactory.

FIGURE 1

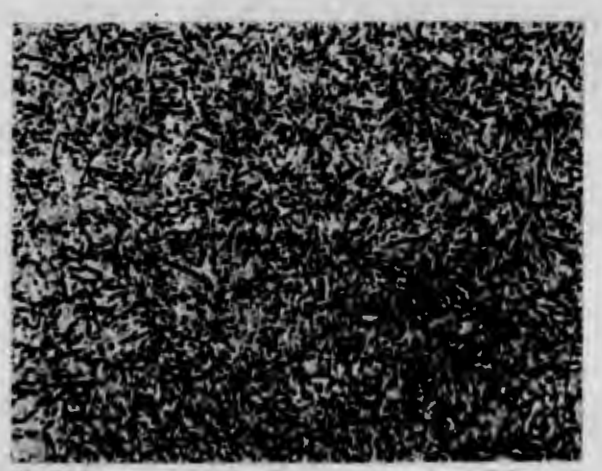
Microstructure of 1/4" Disston Armor

X100 A Unetched
Plate #2 centerline inclusions.

X100 B Unetched
Plate #3 - typical distribution of inclusions.

Lamination opened up by torsion test.

X100 C Nital Etch
Plate #2 - centerline inclusions in same plane as lamination.



X1000 D Picral
Plate #2 - Tempered Martensite.

X1000 E Picral
Plate #3 - Tempered Martensite.

Plate #2 - spalled.
Plate #3 - satisfactory.

FIGURE 2