WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/585

Metallurgical Examination of Nineteen 1/4" Rolled Homogeneous Armor Plates

BY

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WATERTOWN ARSENAL
WATERTOWN, MASS.

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Partial Report on Problem B-4.21

28 January 1944

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ABSTRACT

Metallurgical examination, including Brinell hardness, fracture tests for steel soundness and ductility, macroetch tests, and microscopic examination, were conducted on nineteen (19) plates which had been tested at the Ordnance Research Center as a part of the effect of hardness program. All plates were satisfactorily heat treated and all plates but one (number 146) are considered to have been processed from adequately sound steel.

1. As requested by the Ordnance Research Center, A.P.G. 470.5/3006 - Wtn 470.5/7675(r), metallurgical examination has been completed on sections from nineteen (19) 1/4 inch rolled homogeneous armor test plates fired at the Ordnance Research Center as a part of the program on the effect of hardness on ballistic properties. Thirteen (13) plates were furnished by the Great Lakes Steel Corporation and ballistic results have been reported in AD-505. Six (6) plates were furnished by Standard Steel Spring Company and were processed from steel produced by Jones & Laughlin Steel Corporation. Ballistic results will be reported in AD-504.

2. Metallurgical examination consisted of the following tests:

   a. Brinell hardness.

   b. Chemical analysis.

   c. Fracture test for steel soundness in longitudinal and transverse directions and fracture test for ductility.

   d. Macroscopic tests.

   e. Microscopic examination for structure, grain size, decarburization and nonmetallic inclusions.

3. The detail results of the metallurgical tests are as follows:

a. Brinell hardness. Brinell hardness readings were taken on one face of the plates after careful surface grinding to a depth of approximately 1/16 inch to remove decarburization. Five readings were taken on each sample using a standard Brinell machine fitted with a tungsten carbide ball. The results are shown below:

Brinell Hardness Results

Sample No.	Brinell Hardness Range	Average
GLS 1	388-401	391
4	363-375	373
5	375	375
8	363	363
10	363-375	365
11	341	341
14	352	352
141	429-444	432
142	415-429	426
143	401-415	407
144	341-352	350
145	311-321	317
146	321	321
SCJ 2843	415-429	426
2845	331	331
2846	255	255
2849	375-388	385
2850	269-277	275
2851	302	302

b. Chemical analysis. Chemical analyses were obtained on one plate from each of the three groups involved. The results are shown below:

Sample No.	C	Mn	Si	S	P	Ni	Cr	Mo	B
GLS 1	.36	1.49	.29	.020	.023	tr	.56	.22	.0026
GLS 141	.36	1.52	.30	.014	.022	tr	.58	.22	.0024
SCJ 43	.27	1.60	.23	.014	.015	tr	.01	.30	.0014

The Great Lakes Steel plates are obviously all from the same heat of steel. Both type compositions have more than adequate hardenability for the section size involved.

c. Fracture tests for steel soundness and ductility. Fracture tests for steel soundness were made on specimens from each plate in both the longitudinal and transverse directions on samples tempered at 1050°F. which resulted in a hardness maximum of approximately 310 BHN. Samples for the fracture test for ductility (fibre test) were broken in the as-received heat treated condition. The results are shown below:

	Fracture Test for Steel Soundness		Fibre Fracture Test	
Sample No.	Longitudinal	Transverse	Direction	Result
GLS 1	*B	*B	Longitudinal	Fibrous (Hard)
4	B	C	"	Fibrous
5	B	B	"	"
6	B	B	"	"
10	B	B	"	"
11	B	B	"	"
14	B	B	Transverse	"
141	B	B	Longitudinal	Fibrous (Hard)
142	B	C	"	"
143	B	B	"	"
144	B	B	Transverse	Fibrous
145	B	B	Longitudinal	"
146	B	D	"	"
SCJ 2843	B	B	Transverse	Fibrous (Hard)
2845	B	B	Longitudinal	Fibrous
2846	B	B	Transverse	"
2849	B	B	Longitudinal	"
2850	B	B	Transverse	"
2851	B	C	"	"

*Longitudinal direction means fracture parallel to direction of major reduction as revealed by longitudinal fibers in fractured surface.

The above results indicate satisfactory heat treatment for all plates. In this thickness of plate and with the compositions and heat treatments employed, the ductile type of fracture can be maintained and easily recognized at hardnesses up to approximately 400 BHN. Above this hardness

the fracture becomes flat in appearance and difficult to interpret. No crystallinity was evident, however, in any of the samples tested. Only plate GLS 146 showed a rejectable laminated condition and this was developed only in the transverse fracture. Recent experience at this arsenal has demonstrated that the transverse fracture is the more severe criterion of steel soundness. However, fractures in this direction are also more difficult to interpret.

d. Macroetch tests. Macroetch tests were made on each plate and the results are shown as Figure 1. Confirming the fracture test results, only plate GLS 146 appears to have an inferior soundness condition.

e. Microscopic examination. Specimens from each plate were examined for nonmetallic inclusions, grain size, extent of decarburization and microstructure. Grain size was found to be a uniform ASTM #5 in all plates. Decarburization was negligible on all plates. Typical nonmetallic inclusion distributions and microstructures are illustrated in Figures 2 and 3. A description of the results follows:

(1) Nonmetallic inclusions. Photomicrograph of plate SCJ2850 shown unetched at X100 is typical also of plates 2843 and 2846. Micro-specimens are in transverse direction. Well distributed fine oxide-silicate complex inclusions are evident. Photomicrograph of plate 2849 is typical also of plates 2845 and 2851; direction is longitudinal. The same type of inclusions are shown. Total nonmetallic content is rather high but the uniform distribution probably would not have a detrimental ballistic effect.

Nonmetallic distributions in the Great Lakes Steel Corporation plates were uniform and of the type shown by photomicrographs of plates GLS 14 and 145. Direction photographed is longitudinal. Fine complex oxide-silicate inclusions are shown which are fairly well distributed.

(2) Microstructure. All plates exhibited a uniform tempered martensite structure with perhaps a negligible amount of high temperature transformation products visible in some specimens. Typical microstructures are shown in Figure 3.

NOTE: Metallographic work conducted by M. Yoffa.

4. Summarizing the metallurgical examinations, it appears that all plates were satisfactorily heat treated. Only one plate (GLS 146) is of questionable steel quality. Nonmetallic inclusion contents were rather high in all plates but sufficiently well distributed to be considered not detrimental.

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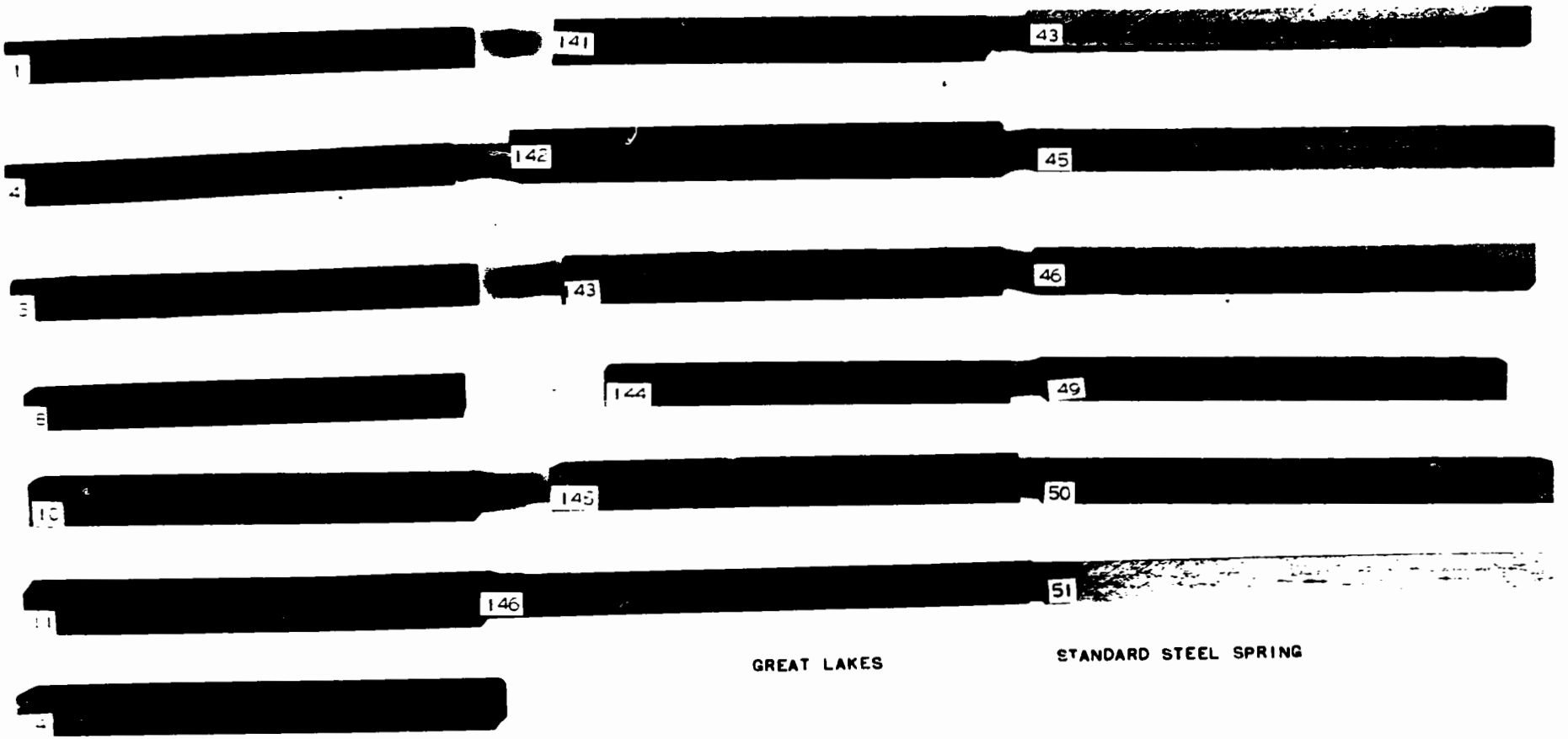
MACROETCH TESTS OF 1/4" ARMOR PLATE



GREAT LAKES STEEL AND STANDARD STEEL SPRING 1/4" ARMOR PLATE
8 JANUARY 1944
WTN. 710-2241

FIGURE 1

Nonmetallic Inclusion Distributions

1/4 Inch Rolled Homogeneous Armor

(Photomicrographs X100, Unetched)

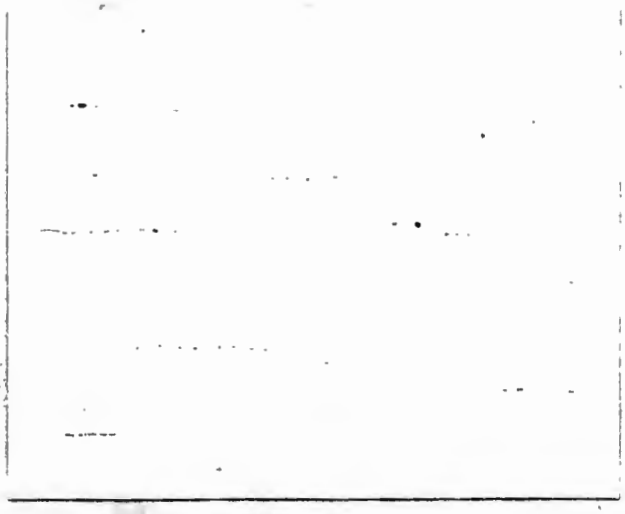


Plate GLS 14

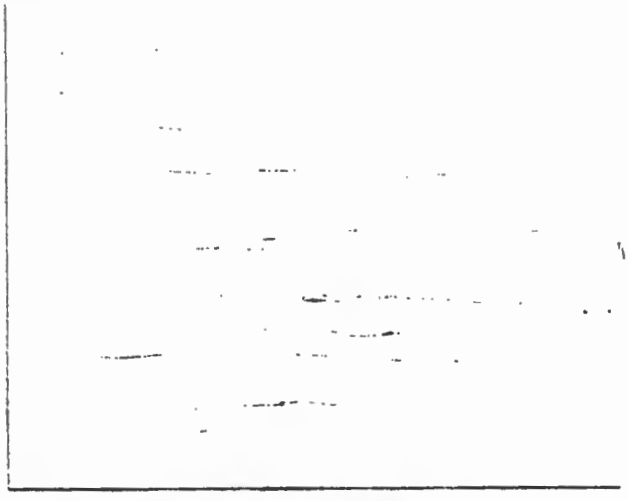


Plate GLS 145

Inclusion distributions typical of all Great Lakes Steel Corporation plates.
Longitudinal direction, fine complex silicate-oxide inclusions, well distributed.

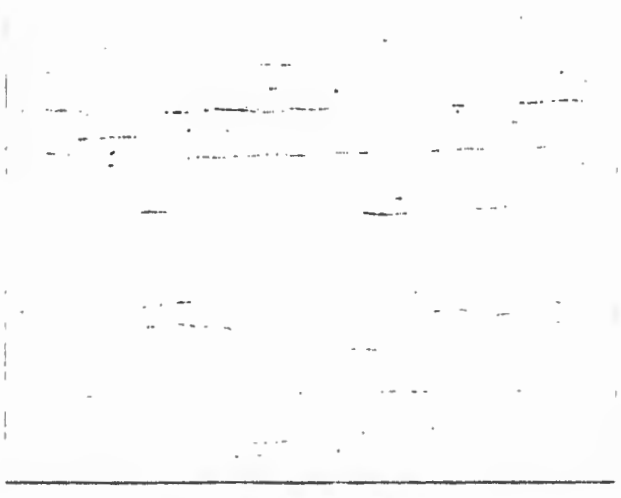


Plate SCJ 2849
Longitudinal

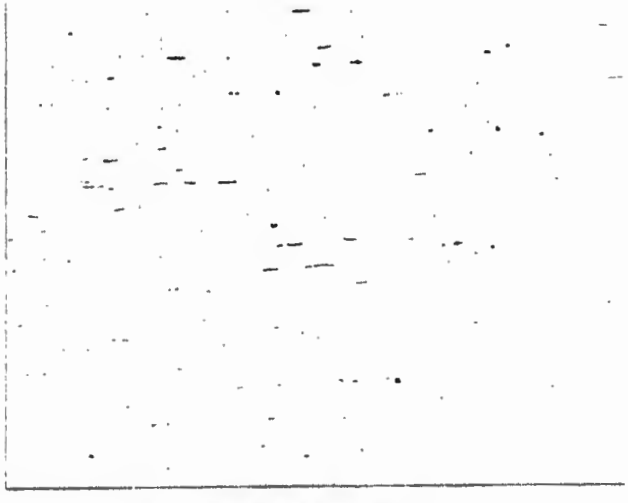


Plate SCJ 2850
Transverse

Inclusion distributions typical of all Standard Steel Spring Company plates.
Fine, complex, silicate-oxide inclusions well distributed.

FIGURE 2

Microstructures

1/4 Inch Rolled Homogeneous Armor

(Photomicrographs X1000, Picral Etch)

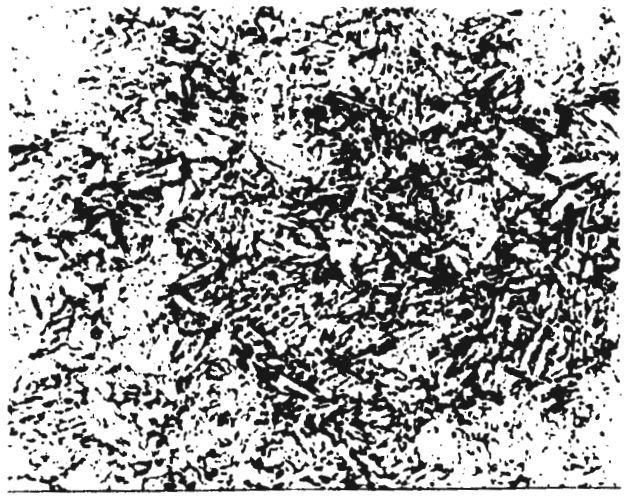


Plate GLS 11, BHN 341

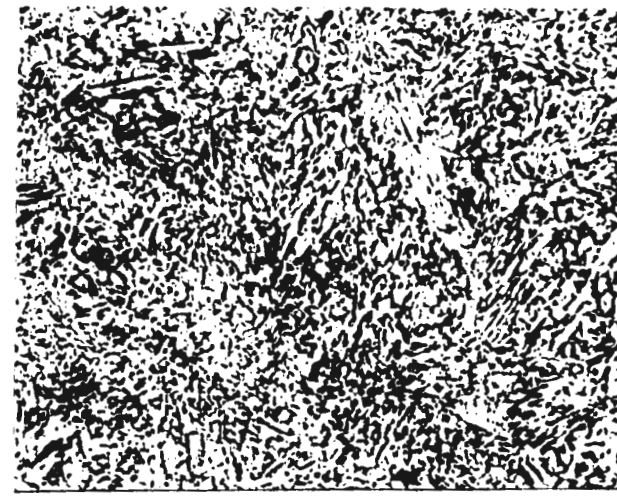


Plate GLS 141, BHN 432

Tempered martensitic structures characteristic of all Great Lakes Steel Corporation plates examined.

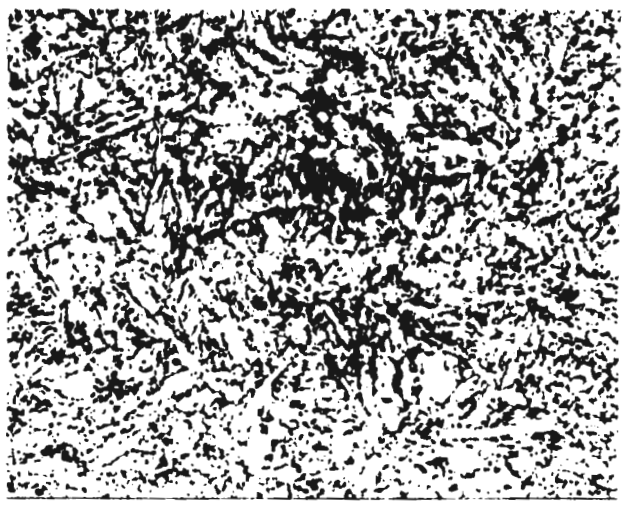


Plate SCJ 2850, 275 BHN

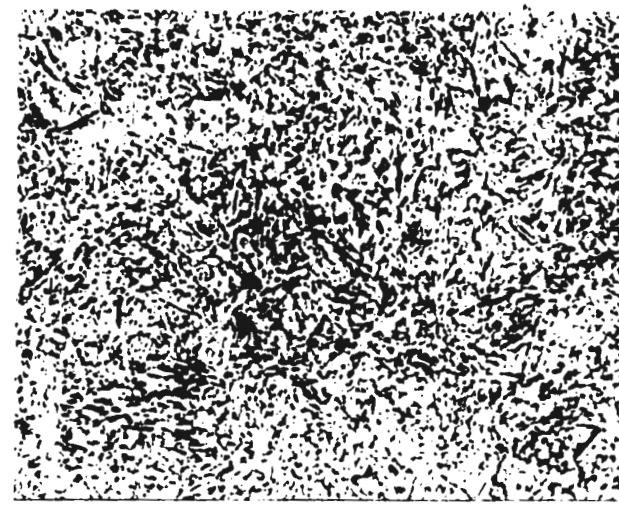


Plate SCJ 2849, 385 BHN

Tempered martensitic structures characteristic of all Standard Steel Spring Company plates examined. Carbide precipitation evident in plates at lower Brinell hardnesses.

FIGURE 3