(1) Copy #2a

War 710/591

WATERTOWN ARSENAL
WATERTOWN, MASS.

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/591

Metallurgical Examination of Twelve 1 Inch Cast Armor Plates

Furnished by McConway-Torley Corporation

BY

N. A. MATTHEWS
Major, Ord. Dept.

DATE 12 February 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

REPRODUCED AT GOVERNMENT EXPENSE

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT WAL 710/591

Final Report on Problem B-4.21

12 February 1944

Metallurgical Examination of Twelve 1 Inch Cast Armor Plates Furnished by McConway-Torley Corporation

ABSTRACT

The plates showed a lack of ductility as evidenced by non-fibrous fractures and poor V-notch Charpy impact values. The characteristic dendritic and, in some cases; conchoidal fractures are believed to reflect poor steel making practice. Heat treatment of the plates appeared to be satisfactory.

1. As requested by the Ordnance Research Center, APG 470.5/3006 - Wtn 470.5/7675(r), metallurgical examination has been completed on sections from twelve (12) 1 inch cast plates furnished by the McConway-Torley Corporation and tested at Aberdeen as a part of the effect of hardness program. Ballistic results have been reported in Armor Test Report AD-564 of The Proving Center.

2. Metallurgical examination included the following tests:

   a. Brinell hardness.

   b. Fracture test for ductility (fibre test).

   c. Macroetch tests.

   d. Chemical analysis and hardenability.

   e. Charpy impact tests.

   f. Microscopic examination.

3. The details of the metallurgical examinations are as follows:

a. Brinell hardness. Brinell hardness determinations across the section and on the surface to check the values reported by the manufacturer were made on a sample from each plate. Cross sectional hardnesses are based upon five impressions at equal intervals across the section. Surface Brinells are the average of three determinations made after careful grinding to remove decarburization.

Plate No.	Cross Sectional Hardness Range	Cross Sectional Hardness Average	Surface Brinells Average	Reported Values of Manufacturer
1	321-341	337	341	352
2	248-255	251	257	269
3	341-352	343	352	352
4	234-248	240	248	248
6	248-255	254	262	269
7	311-321	317	318	331
8	293-302	295	302	311
10	277	277	277	285
12	241-248	245	248	248
13	311-321	319	324	331
14	277-285	279	285	285
15	293-302	298	299	311

Surface and cross sectional hardnesses check closely, and those reported by the manufacturer are in rather close agreement with the determinations made at this arsenal.

b. Fracture test for ductility (fibre test). Sections approximately 5" in length, and 3" wide were notched transversely to a depth of 1 inch from each side and broken by the impact of a steam hammer. The results are tabulated below:

Plate No.	Porosity	Type Fracture	Dendritic	Conchoidal Nature
1	Yes	Mixed, fibrous and crystalline	Yes	No
2	Yes	Mixed, fibrous and crystalline	Yes	No
3	Not evident	Crystalline	-	No
4	Slight	Fibrous	Slight	Yes
6	Slight	Mixed, fibrous and crystalline	Yes	No
7	Slight	Mixed, mainly fibrous	Slight	No
8	Slight	Mixed, mainly fibrous	Slight.	Appreciable
10	Considerable	Mixed, mainly fibrous	Slight	No
12	Considerable	Fibrous	Slight	Appreciable
13	Considerable	Mixed, fibrous and crystalline	Slight	Appreciable
14	Slight	Mainly fibrous	Slight	Appreciable
15	Considerable	Mixed, fibrous and crystalline	Yes	No

Fractures were difficult to interpret because of the presence of porosity, conchoidal areas, and/or a pronounced dendritic condition on all samples. The dendritic and conchoidal aspects undoubtedly have a detrimental effect upon ballistic shock resistance and prevent the obtainment of a completely ductile fracture. It is probable that all plates were satisfactorily heat treated as indicated by the microscopic examination. The inferior fractures, therefore, reflect poor steel making and deoxidation practices.

c. Macroetch tests. Macroetch tests were made on sections from each plate. The results are shown in Figure 1. The pronounced dendritic structure is apparent on all plates. Considerable unsoundness is also indicated on the majority of plates, particularly 1, 6, 7, 12, and 14.

d. Chemical analysis and Jominy hardenability. A chemical analysis was obtained on plate 7 and a Jominy end-quench hardenability test was conducted on a bar from plate 14. The chemical analysis is shown below:

C	Mn	Si	S	P	Ni	Cr	Mo	Al	B
.30	1.65	.47	.031	.037	Tr	.02	.44	.10	.0011

The analysis shows a boron content which correlates with the exceptional hardenability for the analysis. The high residual aluminum content is perhaps one of the factors responsible for the tendency toward a conchoidal fracture condition. Work at Battelle Memorial Institute has shown that the conchoidal fracture may be produced by an aluminum nitride precipitate. High residual aluminum and high nitrogen contents, therefore, tend to promote the conchoidal fracture. It has been shown[1] that the conchoidal condition has an adverse effect upon impact properties.

The exceptional hardenability considering the analysis can only be explained by the observed boron content. No boron additions are reported by the manufacturer. The hardenability (See Figure 2.) is more than adequate for a 1 inch section and is satisfactory for a 2 inch section as regards the transformation to high temperature products such as ferrite and pearlite.

e. Charpy impact tests. In order to confirm the fracture test indications, V-notch Charpy impact tests were conducted on specimens from the four plates, numbers 1, 7, 8, and 10. Tests were conducted on these four plates to cover a range of hardness and because the fractures of these plates were among the best of those examined. Duplicate specimens were broken at 70°F and -40°F.

Plate No.	Hardness	V-Notch Charpy Impact Values 70°F	-40°F
1	337	14.2	5.6
		9.2	8.6
		Ave. 11.7	Ave. 7.1
7	317	22.2	10.8
		20.1	11.8
		Ave. 21.1	Ave. 11.3
8	295	25.3	18.7
		24.3	20.5
		Ave. 24.8	Ave. 19.6
10	277	24.6	19.7
		29.5	23.3
		Ave. 27.1	Ave. 21.5

The change in impact absorption with temperature is not excessive, which confirms the satisfactoriness of the heat treatment. However, the level of energy absorption is low at any particular hardness or temperature.

1. Watertown Arsenal Laboratory Report No. WAL 710/413, "A Preliminary Study of the Effects of the Conchoidal Fracture upon the Physical and Metallurgical Characteristics of Cast Armor", October 1943.

This condition is probably a function of the steel quality and reflects the inferior properties resulting from the dendritic and conchoidal aspects. From the impact energy standpoint, this material is at best approximately 80% efficient as compared to 1 inch cast armor at comparable hardnesses produced by another manufacturer.[2]

f. Microscopic examination. Specimens from each plate were examined for non-metallic inclusions, grain size, extent of decarburization and metallographic structure. Decarburization was not excessive on any plates, amounting to approximately .015" on each face. It was impossible to accurately determine the grain size on the quench and tempered samples. However, a small specimen of the material quenched after heating for two hours at 1600°F developed an A.S.T.M. grain size of #7.

Typical non-metallic inclusion distributions are illustrated in Figure 3. Total non-metallic inclusion content is high. The inclusions are of two general types, (1) the larger type silicate inclusions and (2) the extremely small spheroidal inclusions of an unknown type which are lined up in a direction parallel to the larger dendrites below the plate surfaces and which may be associated with the dendritic aspects of this material. This type inclusion is illustrated in the photomicrograph of plate #15.

Typical microstructures are illustrated in Figure 3. The microstructures are essentially tempered martensite, with no evidence of high temperature transformation products but with the possibility of partial transformation to bainites as evidenced by the acicular structures shown of plates, numbers 7 and 15. However, the plates tempered to lower hardnesses, as indicated by the photomicrograph of plate 12, display a normal tempered martensitic structure. It is, therefore, believed that the plates have been well heat treated. This evidence is substantiated by that obtained on the impact test values as influenced by temperature.

NOTE: Metallographic work conducted by M. Yoffa.

4. Summarizing the metallurgical tests conducted on plates, it was found that the material lacked the proper ductility expected of good quality cast armor in this thickness. Fractures were not fibrous even at comparatively low hardnesses and the impact values were poor. These deficiencies are not attributable to inferior heat treatment but rather to faulty steel making practices which are probably responsible for the conchoidal and dendritic aspects of the material.

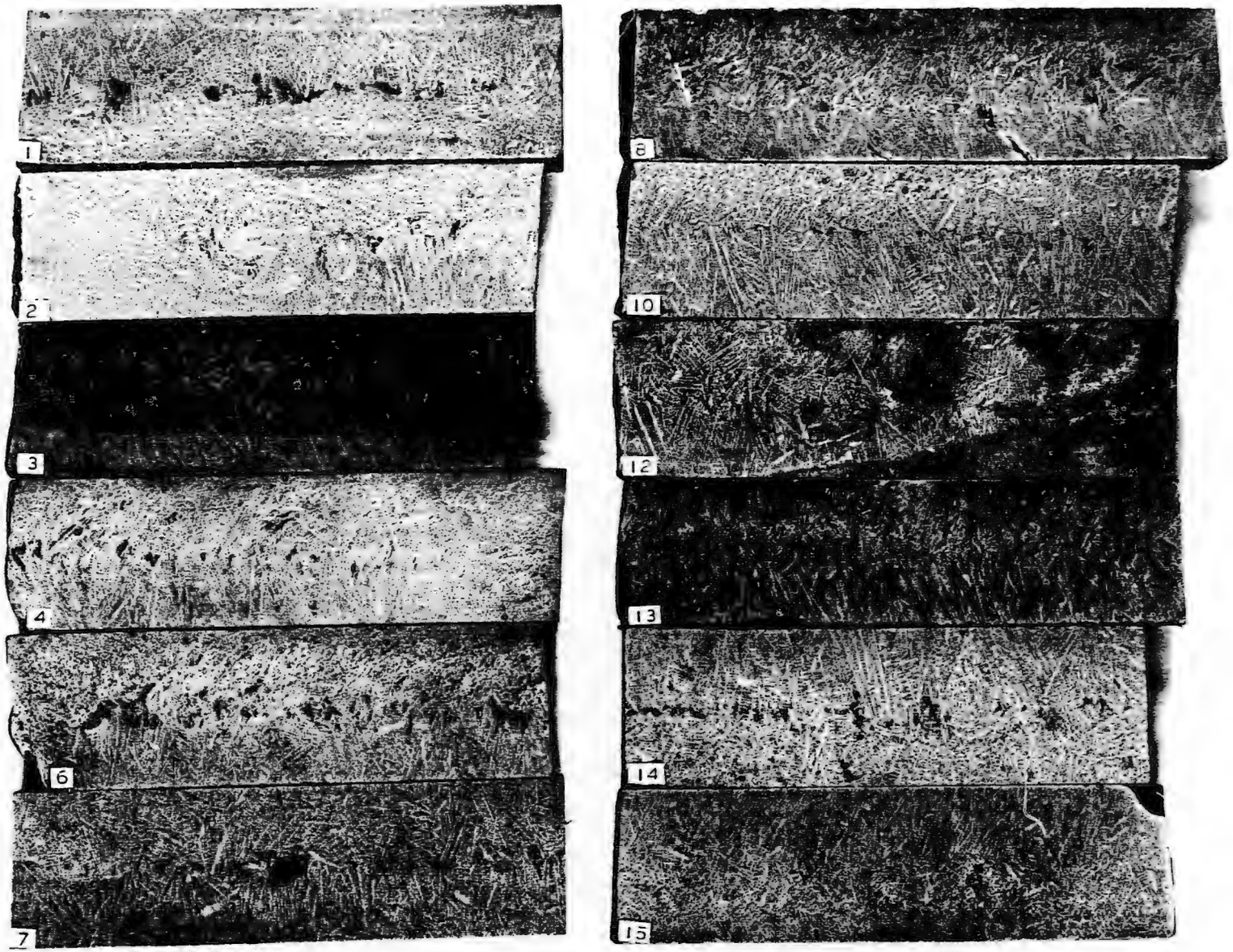
---

2. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/567, "Metallurgical Examination of Twelve 1 Inch Cast Homogeneous Armor Plates of Varying Hardnesses Manufactured by Lebanon Steel Foundry", 10 December 1943.

N. A. Matthews

N. A. MATTHEWS
Major, Ord. Dept.

MACROETCH TESTS



MC CONWAY AND TORLEY CORPORATION 1 INCH CAST ARMOR TEST PLATES
11 JANUARY 1944 MAG. XI WTN.710-2244

FIGURE 1

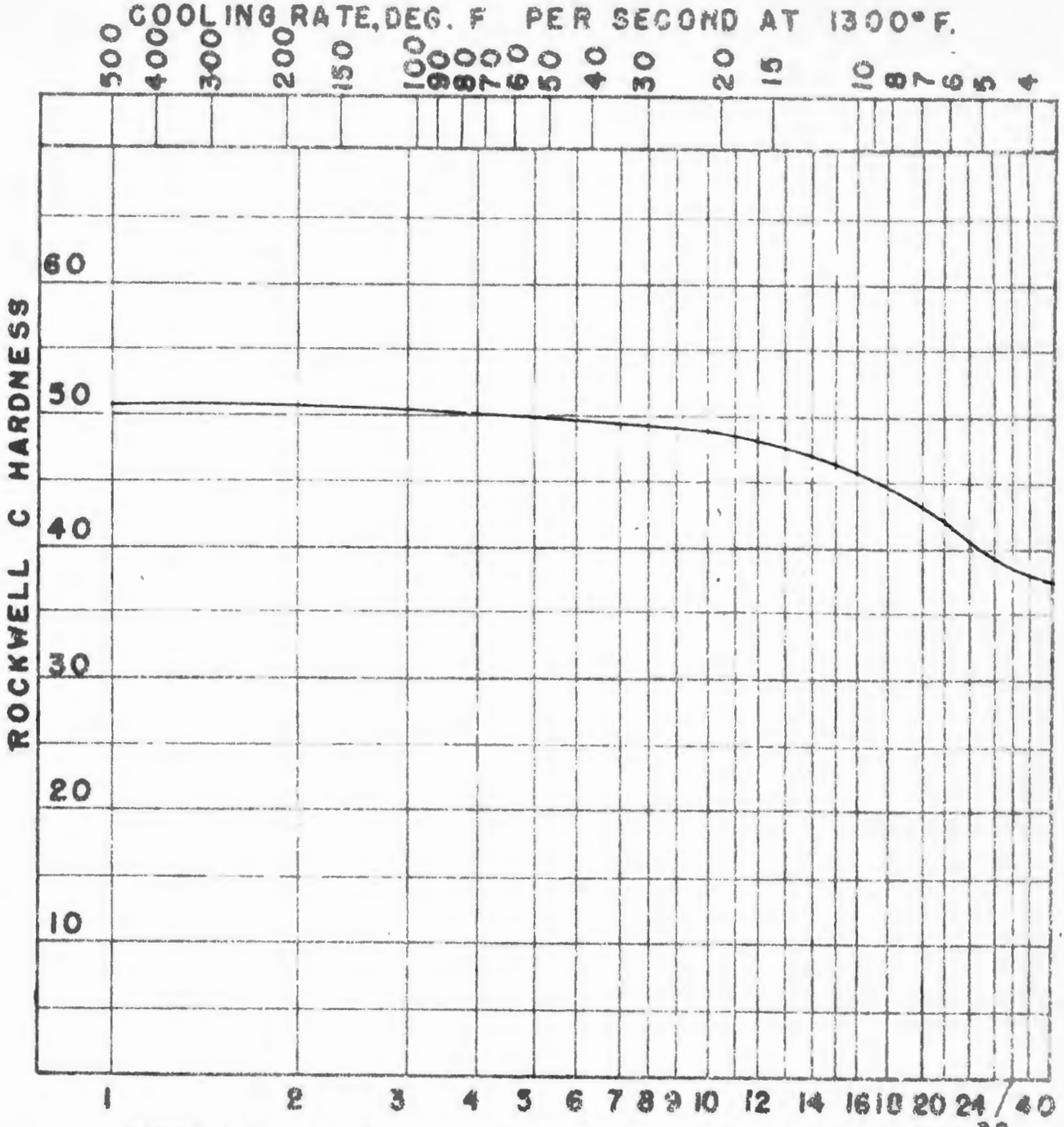
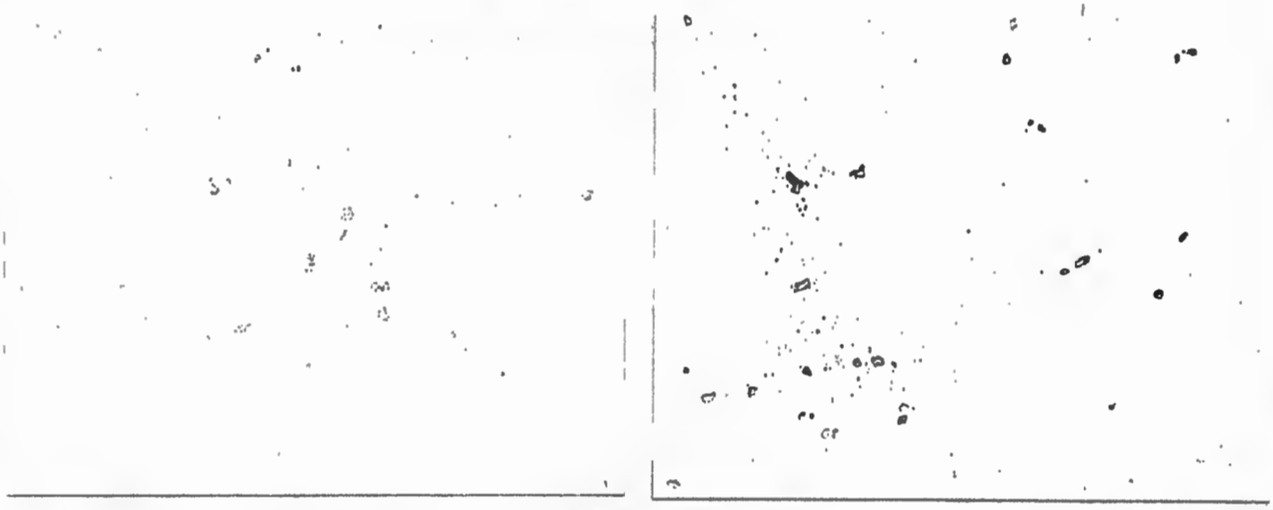


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	AL	B	QUENCH TEMP	QUENCH TIME	G.S.
14	635	.30	1.06	.47	.031	.037	Tr	.02	.44	.10	.0011	1600F	2	7

FIGURE 2.

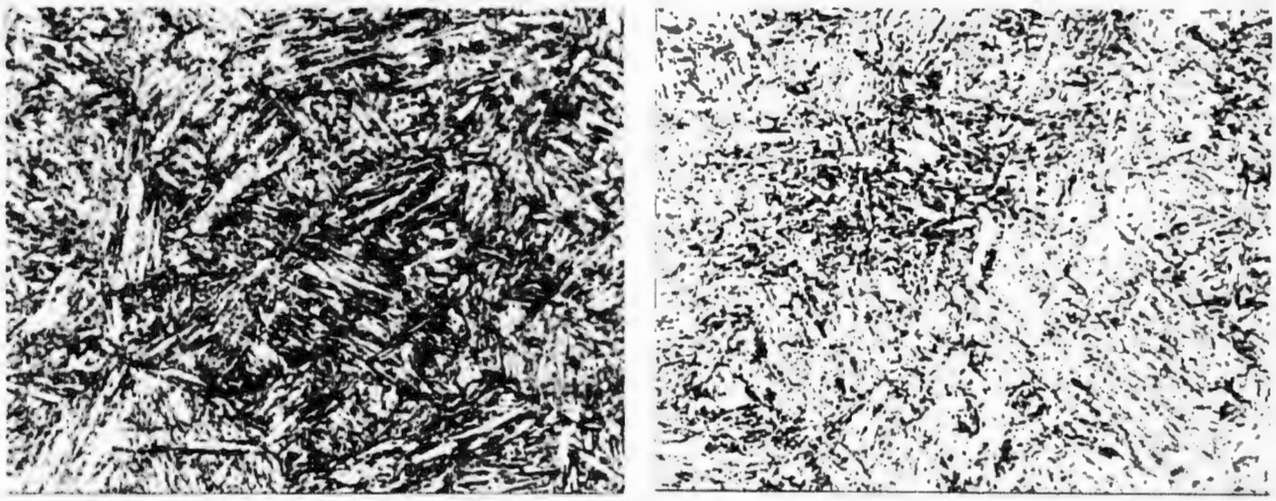
McConway and Torley 1 Inch Cast Plates

Typical Microstructures



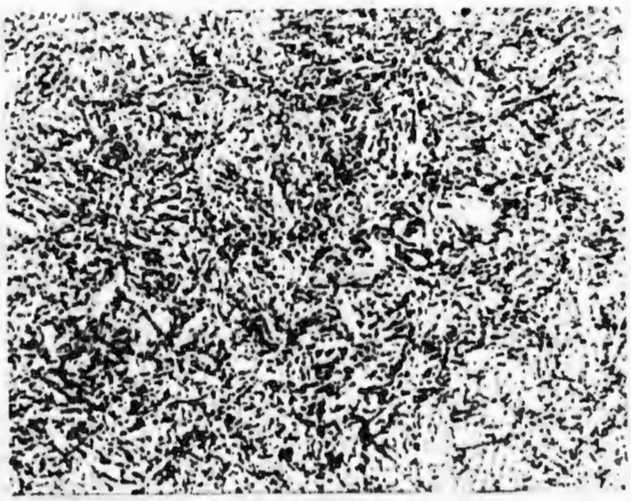
Unetched Plate 2 Plate 15 X100

Silicate inclusions common to all plates. Small spheroidal inclusions in line formation shown in case of plate 15 appear to be associated with dendritic fracture aspect. Condition common to several plate specimens.



Picral Etch Plate 7 Plate 15 X1000

Tempered martensitic structures characteristic of plates 1, 3, 4, 7, 13 14 and 15.



Picral Etch

Tempered martensitic structure characteristic of plates 2, 6, 8, 10, 12 at the lower hardnesses.

X1000

FIGURE 3.