OTTAWA January 4th, 1944.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1563.

A Metallurgical Examination of Sections
from Two C.D.P. Track Sprocket Steels.

(Copy No. 10.)

Abstract.

Three sections from each of two C.D.P. track sprocket steels (WD 1345 and WD 4140) were examined microscopically, tested for physical properties, notch sensitivity at cold temperature, and end quench hardenability. In addition, non-metallic inclusions and McQuaid-Ehn grain size were rated according to A.S.T.M. standards.

A chemical analysis showed that the WD 1345 steel did not conform to the compositions specified, but the divergence was not regarded as too serious. The WD 4140 passed the chemical specification.

In view of the fact that poor physicals, as well as extreme brittleness at cold temperatures, were exhibited by both steels in the "as received" condition, they were heat treated in order to determine whether improvement could be effected. Mechanical tests made on the sections showed that a marked increase in properties was conferred by a quench-and-draw heat treatment. However, the WD 4140 steel had a greater drop in notched-bar toughness when the testing temperature was reduced to -50° F. An improvement could be effected by giving this WD 4140 steel a normalizing at 1700° F. before the quench-and-draw treatment.

O T T A W A   January 4th, 1944.

R E P O R T

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ORE DRESSING AND METALLURGICAL LABORATORIES.

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A Metallurgical Examination of Sections from Two C.D.P. Track Sprocket Steels.

Origin of Request and Object of Investigation:

On November 16th, 1943, six sections from C.D.P. track sprockets were received from the Division of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Ottawa, Ontario, together with Requisition No. 609 (AEDB Lot No. 396, Report No. 23, 5C, Div. 2, Test No. 27) which requested that the samples be given a metallurgical examination.

The material was obtained from the Montreal Locomotive Works, Montreal, Quebec, through Mr. A. M. Bain, three pieces being listed as WD 1345 steel and three as WD 4140 steel.

Mr. Bain teletyped (Nov. 20th, 1943) that the heat treatment given the steel had been as follows: "Tank sprockets, drawn at 1050° to 1150° F. after flame cutting and before flame hardening, and drawn in oil at 350° F. after flame hardened."

RESULTS OF TEST WORK:

Chemical Analysis:

WD 1345 Steel -

		Steel Received	Specification
Carbon	-	0.46	0.40-0.50
Manganese	-	1.09	1.60-1.90
Phorphorus	-	0.021	0.040
Sulphur	-	0.024	0.050
Silicon	-	0.33	0.15-0.30

WD 4140 Steel -

Carbon	-	0.37	0.38-0.43
Phosphorus	-	0.036	0.040
Sulphur	-	0.019	0.040
Manganese	-	0.80	0.75-1.00
Chromium	-	0.87	0.80-1.10
Molybdenum	-	0.18	0.15-0.25

Inclusions:

Samples were taken from each steel, hardened by water quench, polished, and examined at 100 diameters for inclusions.

Steel WD 1345 showed both globular oxide and stringy sulphide inclusions. The steel was comparatively clean and when applying A.S.T.M. Standard Inclusion Rating Chart it would be classed with a No. 2 rating.

Steel WD 4140 was a clean steel (A.S.T.M. Rating No. 1) and again both types of inclusions were found.

Grain Size:

Specimens of both steels were given a standard McQuaid-Ehn heat treatment.

When etched with boiling potassium ferricyanide, both steels showed a homogeneous No. 6 grain size (A.S.T.M. rating).

Microscopic Examination:

Specimens from each steel were prepared for examination, and examined at 500 diameters after receiving a picral etch.

Figure 1 shows the "as received" structure of the WD 1345 sample. It is to be noted that in the greater part of the sample the carbides are rather coarsely distributed in a ferrite matrix with small fine pearlitic areas present throughout. Figure 2 indicates that the WD 4140 steel was given a spheroidizing heat treatment.

Hardenability:

Standard Jominy bars were prepared from each section and after a normalize at 1650° F. were water end-quenched by standard methods from heat-treat temperatures of 1525° and 1560° F.

Figures 3 and 4 show the results of these tests under the usual hardness survey. It may be noted that WD 1345 gave a better result after the lower heating temperature, while Steel WD 4140 improved under the higher heating temperature.

A high hardenability, however, was obtained in both cases.

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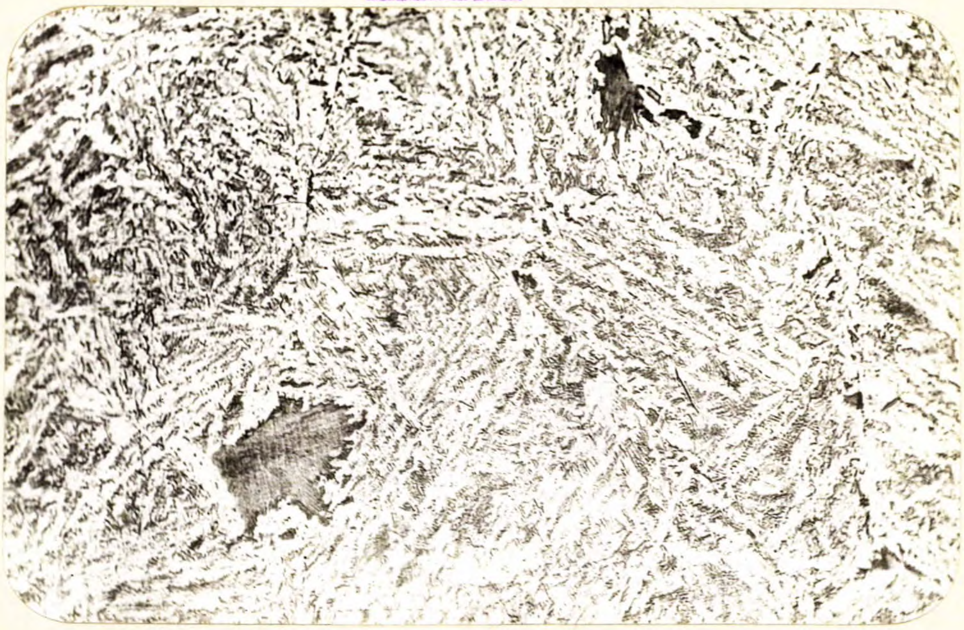
(Figures 1 to 4 follow,
on Pages 4 and 5.
Text continues on Page 6.)

Figure 1.

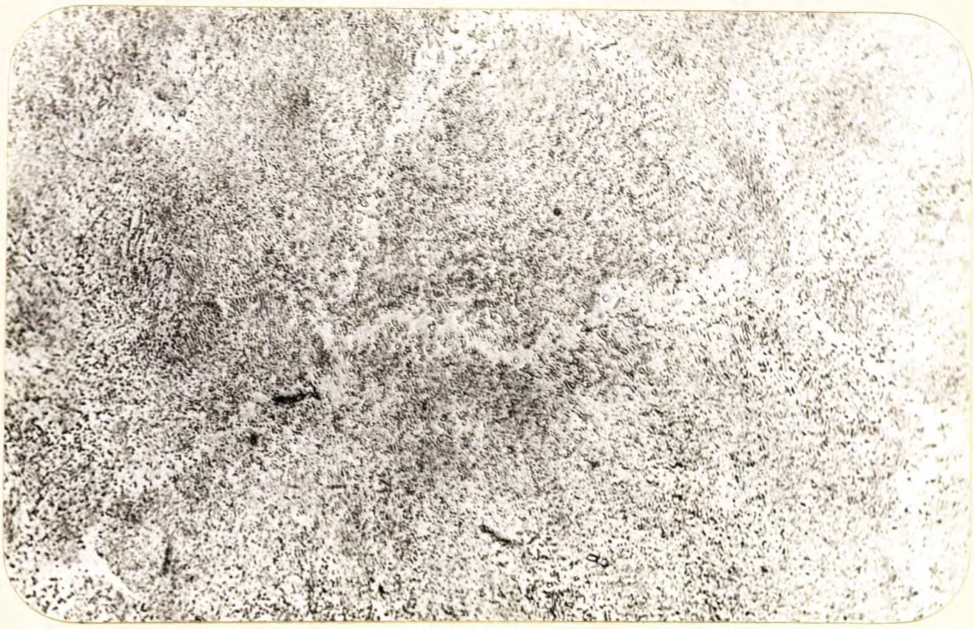


X500, picral etch.

WD 1345 STEEL.

Note small fine pearlitic areas present in coarse distribution of carbides.

Figure 2.



X500, picral etch.

WD 4140 STEEL.
FINELY SPHEROIDIZED STRUCTURE.

Figure 3.

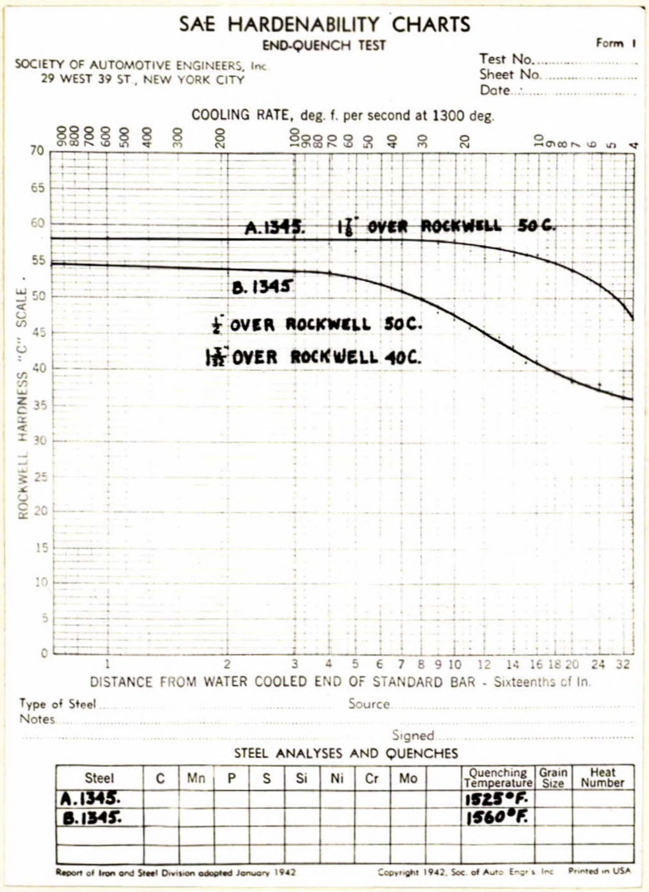
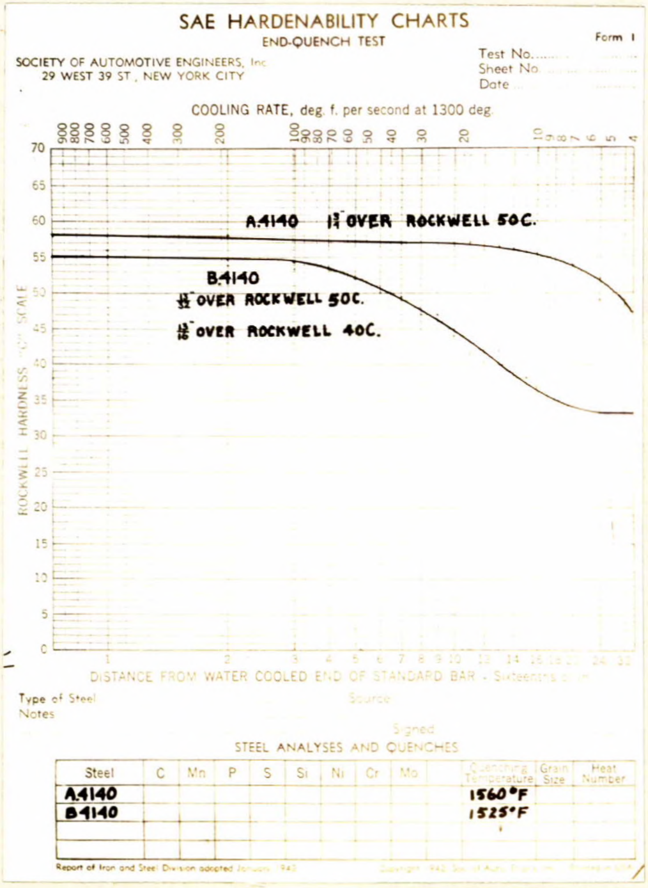


Figure 4.



Heat Treatment:

A standard commercial heat treatment was given samples of both steels, to determine to what extent the physical properties could be improved.

As it is difficult to maintain heating temperatures within ± 25° F. in industrial practice, both steels were heated to 1550° F. before oil quenching, this temperature being within limits of the optimum quenching temperature of either steel.

Three sections from each of the two steels were then drawn at 1000° F., 1100° F., and 1200° F., respectively.

Physical Tests:

Standard 0.505-inch bars cut from each steel in the "as received" and heat-treated conditions gave the following results:

WD 1345 Steel	AS RECEIVED	HEAT TREATMENT Drawn at 1000° F.	Drawn at 1100° F.	Drawn at 1200° F.
Tensile stress, p.s.i.	140,215	166,250	165,100	125,700
0.2 per cent proof stress, p.s.i.	104,830	151,600	149,200	106,500
Per cent elongation on 2 inches	14.8	16	15.5	17.5
Reduction of area, per cent	38.3	47	49	42
Brinell Hardness Number	285	345	305	250

WD 4140 Steel	AS RECEIVED	HEAT TREATMENT Drawn at 1000° F.	Drawn at 1100° F.	Drawn at 1200° F.
Tensile stress, p.s.i.	90,000	146,500	125,500	120,600
0.2 per cent proof stress, p.s.i.	47,470	126,800	102,400	99,800
Per cent elongation on 2 inches	26.6	16	23	29
Reduction of area, per cent	54.7	51	56	63.3
Brinell Hardness Number	179	311	255	229

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Impact Tests:

In order to confirm the inclusion rating of the steels, impact test bars were cut, both along and across the direction of rolling, from the "as received" sprockets, while bars from the heat-treated sections were cut only from the rolling direction.

To determine the rolling direction, a portion of the top face of each plate was given a macro-etch in hot 1:1 HCl for ½ hour. This was sufficient to reveal the rolling line of the section.

The impact bars were cut as V-notched Charpy's in order that cold-temperature tests could be performed rapidly.

WD 1345 Steel.

Temperature, degrees F.	AS RECEIVED: Rolling direction, ft-lb.	Across roll. direction, ft-lb.	HEAT TREATED (Rolling Direction): Drawn at 1000° F. (ft-lb.)	Drawn at 1100° F. (ft-lb.)	Drawn at 1200° F.* (ft-lb.)	Drawn at 1200° F. (ft-lb.)
Room	5.8	4.7	43	48.5	21	59
-40	3.0	2.0				
-50	3.5	2.0	23.5	36.0	21	52
-60	3.0	2.0				

*Since there was an unusual drop of impact strength in the heat-treated sample which was drawn to 1200° F., a second section from the same steel was similarly treated and its results are shown in the right-hand column of the above table.

WD 4140 Steel.

Temperature, degrees F.	AS RECEIVED: Rolling direction, ft-lb.	Across roll. direction, ft-lb.	HEAT TREATED (Roll. Dir'n.): Drawn at 1000° F. (ft-lb.)	Drawn at 1100° F. (ft-lb.)	Drawn at 1200° F. (ft-lb.)
Room	13.3	13.0	33.5	57.5	76.0
-40	3.5	3.0			
-50	2.0	1.5	13.5	20.0	35.5
-60	3.0	2.0			

Figure 5 shows the broken section of four of the Charpy test bars.

(Figure 5 follows, on Page 8.)

Figure 5.

1 2

4 3

SECTIONS FROM BROKEN CHARPY BARS.

(1) WD 1345. Quenched from 1550° F., drawn at 1200° F. Section from bar which had remarkably low impact. Note banded fracture due to slag stringers.

(2) WD 1345. Quenched from 1550° F., drawn at 1200° F. Second test piece which gave improved impact properties; no slag stringers present. Note fine structure present.

(3) WD 4140. "As Received." Note very coarse crystalline fracture, indicating a heterogeneous structure, probably due to free ferrite at the grain boundary.

(4) WD 1345. "As Received." Note fairly coarse fracture, also indicating lack of homogeneity. Again, this may be attributed to the free ferrite areas.

Microscopic Examination of Heat-Treated Section:

Figure 6 shows WD 1345, after being drawn to 1100° F., as a typical tempered martensitic structure.

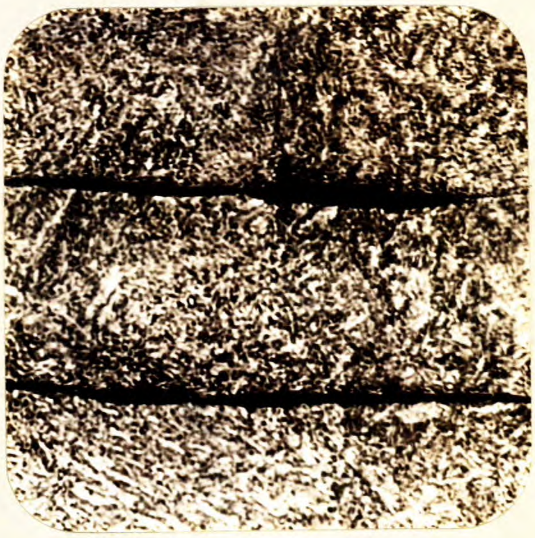
A section, from the third impact test specimen drawn at 1200° F., which gave what appeared to be unusually low results (21 ft-lb.) was examined after a picral etch at 500 diameters (Figure 7). The etching produced dark parallel banded areas within which long slag stringers were found.

Figure 8 is WD 4140 steel after a picral etch, oil-quenched, and drawn to 1100° F. Note that some of the spheroidal carbides are still present in a tempered martensitic structure.

Figure 6.

X500, picral etch.
OIL-QUENCHED AND DRAWN TO 1100° F.

Figure 7.



X500, picral etch.
OIL-QUENCHED AND DRAWN TO 1200° F.
Note large slag stringers and dark banding in structure.

Figure 8.

X500, picral etch.
OIL-QUENCHED AND DRAWN TO 1100° F.
Note carbides still present.

DISCUSSION OF RESULTS:

Chemical Analysis -

The WD 1345 sample, although lower in manganese than required, still has a good hardenability. However, as manganese is a very effective alloying element its deficiency would probably prevent this steel from obtaining the required properties of a WD 1345 steel.

The WD 4140 sample, apart from being slightly low in carbon, conforms with specification.

Inclusions -

One might question the observed results for inclusions when a section is recorded as having poor impact properties due to the presence of long slag stringers. It is thought that this apparent discrepancy can be accounted for by the assumption that the samples that show slag stringers were taken from the end portion of the bloom which was unrepresentatively high in inclusions.

Grain Size and Hardenability -

The grain size and hardenability are considered satisfactory for the service.

Microscopic Examination -

The cooling received in the heat treatment of the WD 1345 steel could possibly cause the formation of the fine pearlite areas, due to a cutting into the nose of the "S" curve. The coalescence of the carbides may be attributed to the high-temperature draw given after flame cutting. There is also a possibility that the so-called 'pearlitic' areas may have been of a martensitic nature after cooling, due to segregated portions of the alloying element, and after drawing have become a sorbitic structure.

The grain boundaries of the WD 4140 steel are made visible because of the rarity of carbides in this area. One could hardly expect good properties to be found in such a structure.

(Continued on next page)

(Discussion of Results, cont'd) -

Heat Treatment -

The WD 1345 steel is apparently sufficiently improved in strength, toughness and low-temperature impact to cause the given heat treatment to be considered suitable. However, in the case of the WD 4140 steel the sample's heat treatment does not afford sufficient time for the solution of all the carbides, and their presence would probably account for the high drop in impact on cold-temperature tests. A normalizing before heat treatment would undoubtedly improve the quality of this steel still further.

Physical Tests -

The results shown are not a fair comparison for these two steels as under a straight quench and draw heat treatment. Due to the nature of WD 4140 steel in the "as received" condition, it would require a normalizing before its optimum properties could be developed.

Impact Tests -

These tests on the "as received" samples prove the cleanliness of the steel. However, their extreme brittleness at low temperature indicates how poorly this steel would serve in such a condition.

The cold-temperature impacts (after heat treatment) drop off considerably more in the WD 4140 steel. This is probably due to the presence of undissolved carbides, and the suggested further heat treatment should improve cold notch toughness considerably.

The poor physicals and impact of the third test from WD 1345 (drawn at 1200° F.) are due to the presence of slag stringers. As mentioned, this is not characteristic of the WD 1345 steel received.

CONCLUSIONS:

1. The properties of both "WD 1345" and "WD 4140" steels "as received" are not considered to be sufficiently good (in the absence of subsequent heat treatment other than tooth flame-hardening) to warrant their use in track sprockets.

2. Oil quenching from 1525° F. and drawing to 1150° F., with a fairly rapid cool from the draw, put the "WD 3145" material into satisfactory condition for track sprocket service.

3. Normalizing at 1700° F., oil quenching from 1560° F., and drawing at 1150° F. with a fairly fast cool from draw put the "WD 4140" into satisfactory condition for track sprocket service.

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