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OTTAWA November 17th, 1943.

# REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1534.

Examination of a Broken Rear Drive
Worm Gear from an F.W.D. Truck.

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(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
-
Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

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Abstract.

A rear drive pinion submitted by the Department of Munitions and Supply was examined and was found to have failed by fatigue. The lack of drawing, the free carbides, and the abnormality of the steel were contributory factors in the lowering of the fatigue strength.


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### Origin of Request and Object of Investigation:

On November 1st, 1943, one broken worm gear from an F.W.D. truck was submitted to these Laboratories for metallurgical examination. An accompanying letter (File No. 73-T-77688), from Mr. R. D. Aselstyne, for Assistant Director-General, Army Engineering Design Branch, Department of Munitions and Supply, Ottawa, Ontario, stated that failures of this type of gear had been recorded several times although no abuse or lack of lubrication was involved and there appeared to be no abnormality in the crown gears and pinions. The alloy used for fabricating these gears was supposed to be "158 Carpenter's".

Macro-Examination:

The following characteristics were observed in the gear "as received". On each tooth of the gear, cracks starting at the root and spreading along only one side of the tooth could be seen. This condition is shown in Figure 1. In some instances, as Figure 2 shows, these cracks resulted in the tearing off of the cased surface at the top of the gear.

Chemical Analysis:

The following table lists the results of chemical analysis on the gear, along with the compositions of 158 Carpenter's steel and SAE 4615 steel:

| | | Worm Gear | 158 Carpenter | SAE 4615 |
|---|---|---|---|---|
| | | | - Per cent - | |
| Carbon | - | 0.15 | 0.15 | 0.13-0.18 |
| Manganese | - | 0.50 | - | 0.45-0.65 |
| Chromium | - | 0.08 | 1.50 | - |
| Nickel | - | 1.65 | 3.50 | 1.65-2.00 |
| Molybdenum | - | 0.23 | - | 0.20-0.30 |

Hardness Measurements:

The surface hardness of the gear was found to 62 Rockwell 'C'.

A hardness survey was also made on the cross-section of a gear tooth. Using the Vickers machine, hardness readings ranging from 736 V.H.N. (62 Rockwell 'C') to 275 V.H.N. (core hardness) were recorded. The results of this survey are shown graphically in the chart, Page 10. As a criterion of case thickness, a hardness level of 500 V.H.N. is taken. In the present example the case thickness is 0.062 inch.

Macro-Etching:

A section of the gear was etched in a hot 50 per cent solution of hydrochloric acid to show the direction of flow lines. Figure 3 shows the result.

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Micro-Examination:

Cross-sections of the gear teeth were examined under the microscope.

In the unetched condition the steel looked clean.

The microstructure of the core consists of ferrite and a low-carbon martensite, as can be seen in Figure 4, taken at X500 magnification.

The microstructure of the case is an undrawn martensite with a few imbedded free carbides. This constituent (i.e., martensite) etches slowly, yielding a brown colour, as seen under the microscope. The microstructure, at 500 diameters, is shown in Figure 5. The acicular nature of the structure is shown in Figure 6, at X1500 magnification. The McQuaid-Ehn grain size was also determined, and this is shown in Figures 7 and 8. The grain size is 7. Note the evidence of abnormality.

Discussion of Results:

Macro-Examination -

The cracks on one side only of the gear teeth are characteristically of a fatigue nature. This result is due to the fact that a piece subjected to alternating stresses apparently never fails by compression. A gear tooth really acts as a cantilever beam, with a tension and a compression side. The stress oscillates from zero to a maximum on each side as the gear tooth is loaded and unloaded. The alternation of stress finally produces failure on the tension side.

The possibility that failure was produced by impact should be ruled out, as such a type of failure would have occurred locally.

Chemical Analysis -

The chemical analysis shows that the steel used in making the gear is SAE 4615 rather than 158 Carpenter. Both of

(Discussion of Results, cont'd) -

these steels are of the case-hardening type, but the 158 Carpenter has a higher hardenability and consequently is more difficult to quench without distortion.

Hardness Measurements -

All the hardness numbers found in this present investigation were compared with the figures given by R. B. Schenck, Chief Metallurgist, Buick Motor Company, in his paper, "Metallurgy of Transmission Gears."* This paper states:

> "The case and core characteristics of low-carbon steels usually fall within the following ranges: case depth, 0.030-0.050 inch; case hardness, Rockwell 'C' 55-62; core hardness, Rockwell 'C' 30-40. A rule for depth of case, which has been found quite satisfactory for low-carbon gears in a number of instances, specifies twice as much core as case. Correctly interpreted, this means a case depth equal to one-sixth of the thickness of the tooth at its base."

In the present case, the case hardness is on the high side of the range and the core hardness is on the low side. However, the present core hardness is probably the highest which one could expect from a 0.15 carbon medium alloy steel. In any event, the low core hardness is not considered to have been the cause of failure.

The case depth found does not exceed the value given by Schenck.

Micro-Examination -

The presence of free carbides in the case indicates a high carbon content; also, the slow etching of the case points to a lack of tempering. Both the free carbides in the case (which could have been eliminated by a diffusion heat treatment) and the lack of drawing (which promotes the retention of internal stresses induced by grinding) lower the fatigue

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*"Metallurgy of Transmission Gears," by R. B. Schenck, S.A.E. JOURNAL, Vol. 38, No. 6, June 1936, pp. 13-19.

(Discussion of Results, cont'd) -

strength of the steel.

An opinion relative to this tempering operation is found in the paper, "Heat Treating Aircraft Gears," by John L. Buehler,* Partner, Indiana Gear Works, Indianapolis, Indiana, which reads:

> "Tempering is a very important and often improperly executed operation. The major purpose of tempering is to relieve strain, yet too often it is used to meet blue print hardness specifications. Strain relief is a function of hardness and temperature. Hardness is primarily a function of draw temperature and can usually be achieved in a few minutes. Yet strain relief is not complete in thin sections after 5 hours at 300° F. or after 3 hours at 500° F. Too often, leaving urgently needed parts in a busy furnace for 6 to 8 hours is considered a prodigal waste of time. Yet one unrelieved strain in one small part can easily cause engine failure."

The same reasoning might be applied to a pinion gear which is subjected to fatigue stresses. Residual stresses of an undrawn martensite add to the applied stresses and lower the fatigue strength of the material.

The abnormality of the steel as shown by the McQuaid-Ehn test might also be a contributing factor to failure because of the soft spots developed on quenching this type of steel. However, the hardness tests have not detected these soft areas.

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* "Heat Treating Aircraft Gears," by John L. Buehler, IRON AGE, June 26, 1941, pp. 39-42.

CONCLUSIONS:

1. The gear submitted for examination has failed by fatigue.

2. Fatigue failure might occur in a gear because of incorrect design, poor contact, low tooth strength, excessive overloading, or by notch effects created by undercuts, roughness and scratches. However, none of these defects appeared to have been discovered in this metallurgical investigation.

3. Overstressing of the undrawn martensite is the cause of fatigue failure.

4. Free carbides, and abnormality of the steel, are contributing factors in the lowering of the fatigue strength.

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Recommendations:

1. In view of the fact that the manufacturing and all heat treatment practice prior to the tempering are correct, it appears that good service may be expected from these gears provided that a complete stress relief be given in the drawing operation.

2. If failures of stress-relieved gears are occurring, a change to a homogeneous-type steel, such as SAE 4340, SAE 4640 or SAE 3145, is recommended.

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AD:GHB.

Figure 1.

SHOWING HOW CRACKING OCCURRED ONLY ON ONE SIDE OF THE GEAR TEETH.

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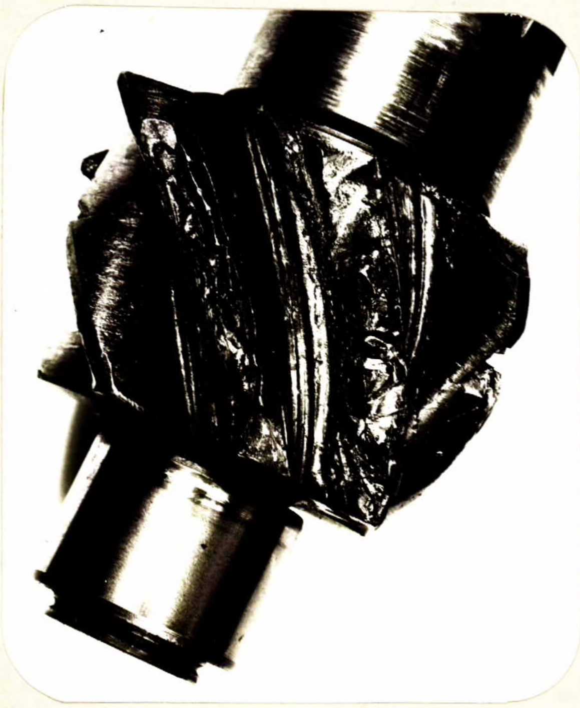
Figure 2.



SHOWING THE GEAR "AS RECEIVED".

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Figure 3.

Etched in 50 per cent HCl.

SHOWING THE DIRECTIONS OF THE FLOW LINES.

Figure 4.

X500, picral etch.

SHOWING THE STRUCTURE OF THE CORE, i.e., MARTENSITE AND FERRITE.

Figure 5.

X500, picral etch.

SHOWING THE STRUCTURE OF THE CASE, i.e., MARTENSITE AND FREE CARBIDES.

Figure 6.

X1500, picral etch.

SHOWING THE ACICULAR STRUCTURE OF THE CASE.

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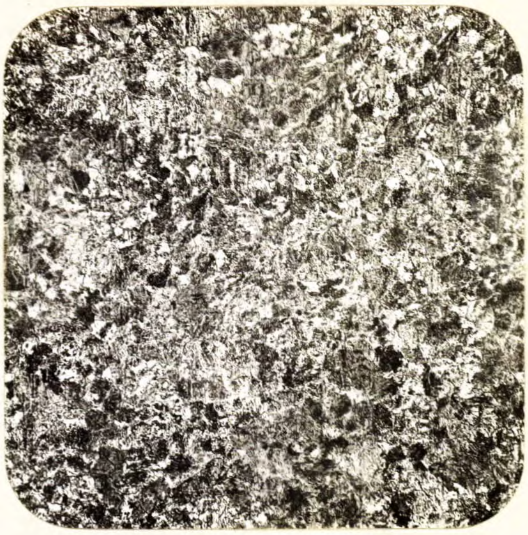
Figure 7.



X100, nital etch.

MCQUAID-EHN TEST SHOWING GRAIN SIZE NO. 7.

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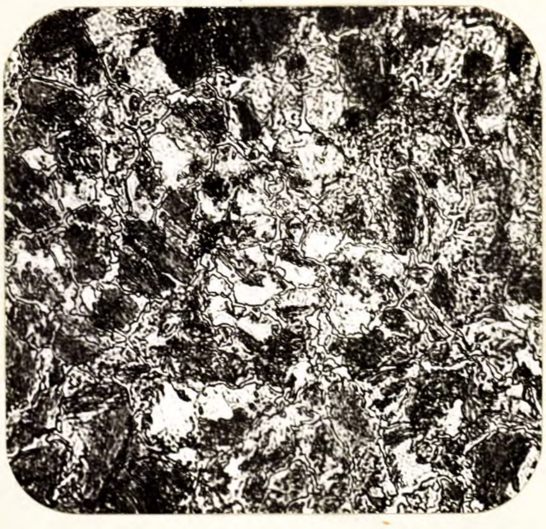
Figure 8.



X500, nital etch.

SHOWING THE ABNORMALITY OF THE STEEL.

Note the ferrite segregated along the carbide grain boundaries.

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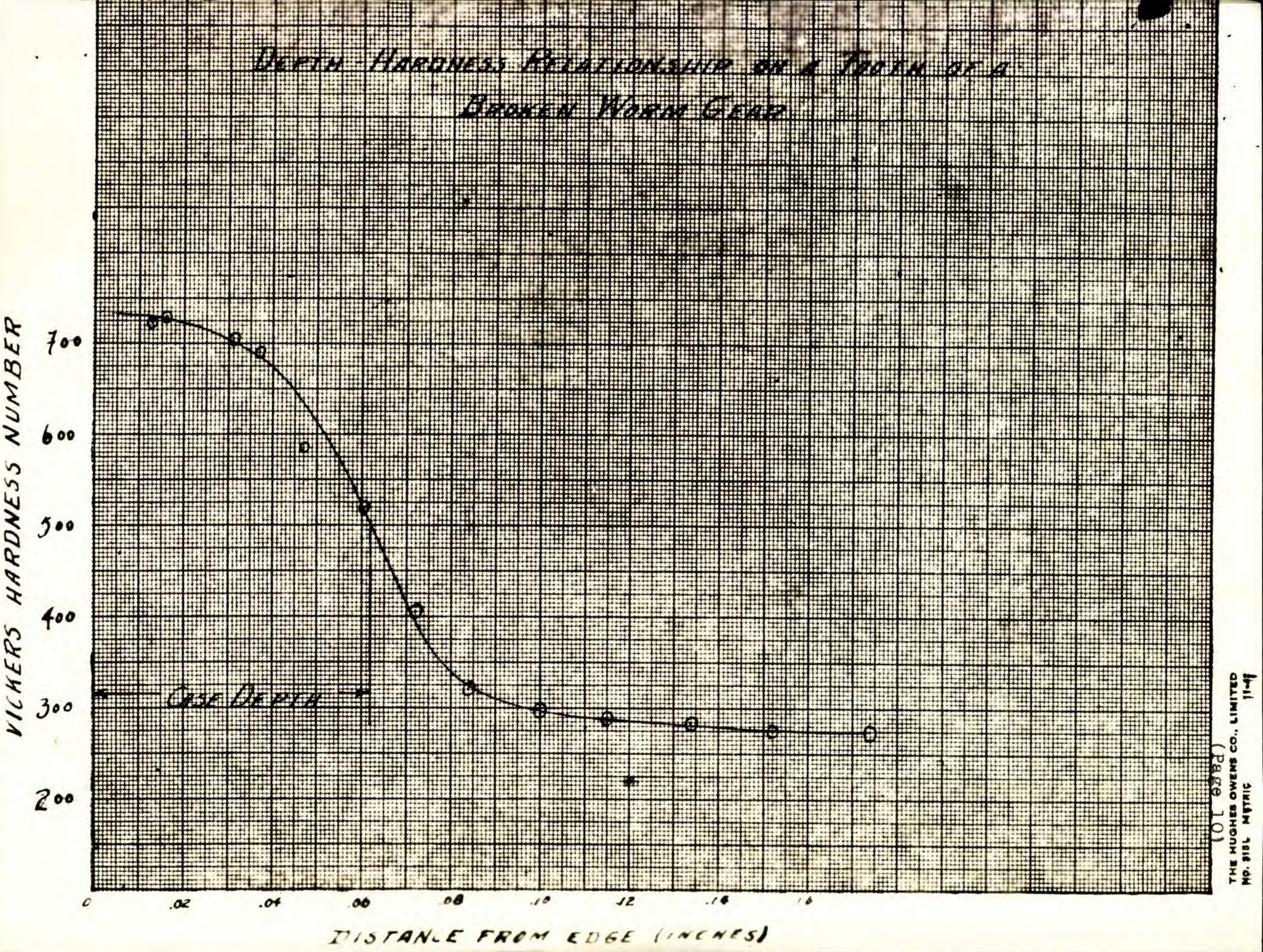
AD:GHB.


DEPTH-HARDNESS RELATIONSHIP ON A TOOTH OF A BROKEN WORM GEAR
VICKERS HARDNESS NUMBER
700
600
500
400
300
200
CASE DEPTH
0
.02
.04
.06
.08
.10
.12
.14
.16
DISTANCE FROM EDGE (INCHES)
THE HUGHES OWENS CO., LIMITED
NO. 315L METRIC