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O T T A W A   May 8th, 1944.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1637.

Examination of Broken Rear Axle Pinion and Damaged Rear Axle Shaft from Four Wheel Drive Truck.

(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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Source of Material and Object of Investigation:

On April 27th, 1944, Mr. R. O. McGee, I.O.(M), for Inspector of Materials, Inspection Board of United Kingdom and Canada, 70 Lyon Street, Ottawa, Ontario, sent in a broken rear axle pinion and a damaged rear axle shaft from an F.W.D. truck. In the accompanying letter (File No. 12/4/16) and requisition (No. O.T. 4182), it was requested that a metallurgical examination of the failed parts be carried out in order to determine, if possible, the cause of the failures, which had occurred "after severe service trial".

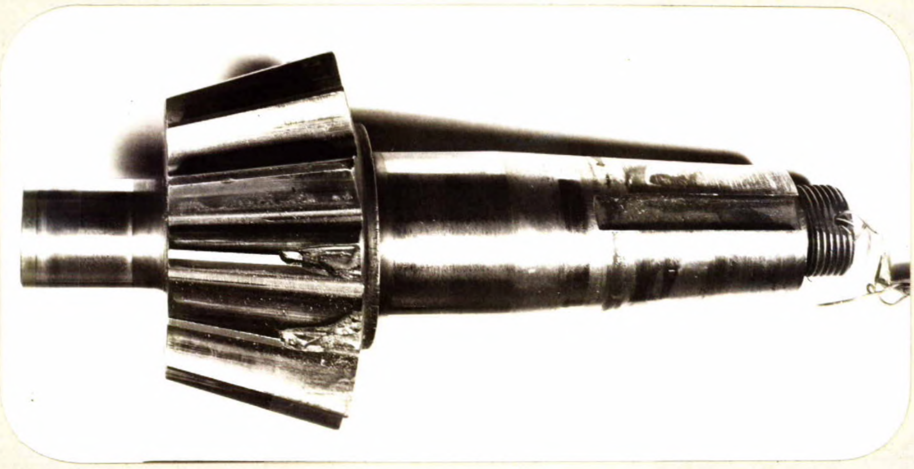
Macroscopic Examination:

Longitudinal cracks were observed on each gear tooth of the pinion "as received". These cracks appeared to have started on one end of the pinion about the middle of the tooth. As the crack progressed, some bits chipped off

(Macroscopic Examination, cont'd) -

from the gear teeth. This condition is illustrated in Figure 1. It was observed that there were fairly heavy machine tool marks on the end of the pinion where the crack originated.

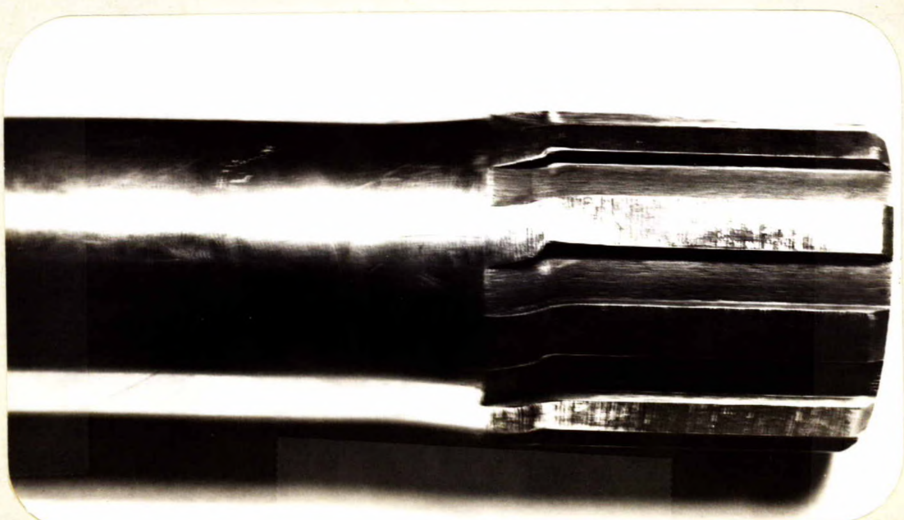
Figure 1.



BROKEN PINION.
(Approximately ½ actual size).

The rear axle shaft was found to have been twisted about 15 degrees on each end at the base of the splined section. (See Figure 2).

Figure 2.



SHOWING TWIST AT END OF SHAFT.
(Approximately to size).

Chemical Analysis:

The results of the chemical analysis of these parts are given in the following table, along with the specified compositions:

		PINION		SHAFT	
		Specified 158 Carpenter	Found	Specified SAE 4340	Found
		- Per		Cent -	
Carbon	-	0.08-0.15	0.12	0.35-0.45	0.39
Manganese	-	0.45-0.65	0.32	0.50-0.80	0.63
Silicon	-	--	0.23	0.15 min.	0.29
Sulphur	-	0.03 max.	0.022	0.05 max.	0.013
Phosphorus	-	0.03 "	0.018	0.04 "	0.014
Chromium	-	1.00-1.50	1.29	0.50-0.80	0.65
Nickel	-	3.25-4.00	3.92	1.50-2.00	2.00
Molybdenum	-	--	N.d.	0.30-0.40	0.28

N.d. = Not determined.

Hardness Tests:

A Brinell hardness range for the axle shaft of 290 to 330 is specified on the drawing. Hardness tests taken on ground surfaces in the middle and at each end of the shaft gave hardness values of 321 Brinell.

A Shore scleroscope hardness range of 75 to 85 is specified for the pinion. The hardness of the case and core was determined by the Vickers method. A Vickers hardness value of 701 (Shore, 79) was obtained on the case and 334 on the core.

Microscopic Examination:

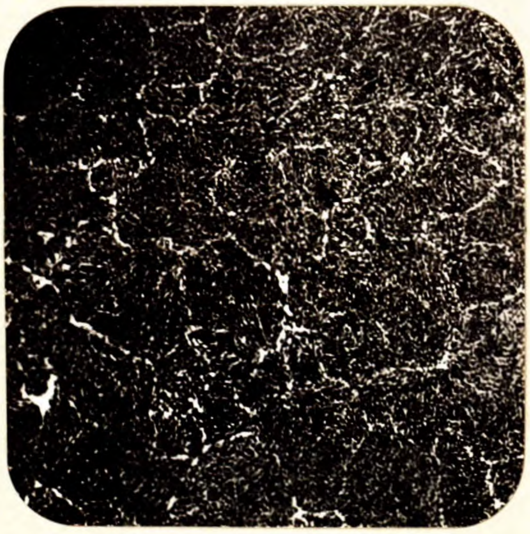
Specimens cut from the pinion and shaft were given a metallographic polish and examined under the microscope in the unetched condition. The two steels appeared to be fairly clean.

The steels were then etched in a solution of 2 per cent nitric acid in alcohol and re-examined. Figures 3 and 4

(Microscopic Examination, cont'd) -

are photomicrographs, at X500 magnification, showing the nital-etched structures of the case and core of the pinion. The microstructure of the case consists of drawn martensite with free carbides enveloping the grains. The structure of the core consists of low-carbon drawn martensite. Figure 5 is a photomicrograph, at X1000 magnification, showing the nital-etched structure of the shaft steel. The structure consists of tempered martensite. The McQuaid-Ehn grain sizes of the pinion and shaft steels were also determined. The grain size of the pinion is 5 and that of the shaft is 7. The case depth was determined with a Brinell microscope and was found to be 0.040 inch.

Figure 3.



X500, etched in
2 per cent nital.

GRAIN BOUNDARY CARBIDES
IN CASE OF PINION.

Figure 4.

X500, etched in
2 per cent nital.

MICROSTRUCTURE OF THE
CORE OF PINION.

(Continued on next page)

(Microscopic Examination, cont'd) -

Figure 5.

X1000, etched in
2 per cent nital.

MICROSTRUCTURE OF SHAFT STEEL.

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Discussion of Results:

The progressive nature of the cracks observed in the pinion gear teeth is characteristic of a fatigue failure. The composition of the steels is within the range specified except the low manganese content of the pinion and the molybdenum in axle shaft steel which is just under the minimum specified. No significance, however, is attached to the low content of these elements. The presence of grain boundary carbides in the cased surface of the pinion would have an embrittling effect and definitely would lower the endurance limit of the part. These free carbides can be eliminated by a diffusion heat treatment or possibly by carburizing under less active conditions. Both pinion and shafting steels had the specified grain size and were heat treated to the specified

(Discussion of Results, cont'd) -

hardness. The absence of ferrite shows that both parts were finally quenched above the upper critical of the interior material. The hardness of the pinion indicates that the quenching most probably was in oil. While the presence of grain boundary carbides is a definite defect, it is possible that other dimensional and mechanical conditions may have contributed to failure. The coarse machining marks would cause severe stress concentration, but poor alignment of parts or a lack of proper contour would cause even more severe concentration of stress.

CONCLUSIONS:

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

2. The presence of free carbides in the grain boundaries is due to faulty heat treatment, and this condition is considered definitely as having contributed to the premature failure of the pinion.

3. No metallurgical reason was observed which would account for the distortion of the axle shaft. Failure apparently was brought about by stresses greater than those which the part was designed to withstand.

4. The distortion of the shafting indicates that test conditions were unusually severe, and it is possible that the metallurgically defective pinion might have withstood less severe service. There is also a possibility that gear alignment and faulty gear contour may have been contributing causes.

Recommendations:

1. Machine tool marks should be reduced to a minimum in order to avoid stress raisers, which definitely accelerate fatigue failure.

2. Shotblasting of the parts will increase the fatigue strength of moving parts subjected to alternating stresses, and it is recommended.

3. A check on the case-hardening heat-treatment cycle used should be made, in order to determine the time-temperature cycle required to eliminate free carbides in the case.

4. The steel specified for the rear axle shaft is considered to be of a suitable composition and should prove satisfactory under normal operating conditions.

5. Pin alignment and dimensions also should be checked.

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