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DEPARTMENT OF MINES AND RESOURCES

BUREAU OF MINES

CANADA

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Ottawa, February 26, 1947.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 2170.

Investigation of the Premature Failure
of an SAE 4340 Fan Shaft.

(Copy No. 5.)

Bureau of Mines
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Mineral Dressing and
Metallurgy Division

Physical Metallurgy
Research Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

O T T A W A   February 26, 1947.

REPORT

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ORE DRESSING AND METALLURGICAL LABORATORIES.

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Background:

In a letter (File No. H.Q. 114-216-1), dated January 8, 1947, Mr. W. J. Washburn, for Director of Vehicle Development, M.G.O. Branch, Department of National Defence (Army), Ottawa, Ontario, requested the assistance of these Laboratories in the investigation of a Penguin Mk II fan shaft which failed in service. Chemical analyses of two shafts submitted were specifically requested.

Mr. Washburn, in his letter and during a subsequent telephone conversation of January 13, 1947, supplied the following information. The shaft material should conform

(Background, cont'd) -

to that of an SAE 4340 steel, quenched and drawn to a hardness of Rockwell "C" 35 ±3. The shaft is machined before heat-treating. After heat treatment 0.012 inch is removed by grinding to the finish size. The vehicle had travelled 225 miles before this failure. At 12,000 to 13,000 revolutions per vehicle mile, the fan shaft must have made approximately 2,813,000 revolutions before failure.

Accompanying the request letter were:

(a) one mismachined shaft, Part No. B-307516, which had not been in service;

(b) one fan hub insert and shaft assembly, Parts Nos. B-307517 and B-307516, in which the shaft had failed in service; and

(c) blueprint drawings, E-307510 and B-307519, of the fan drive arrangement and bracket assembly.

Purpose:

To determine the cause of failure of the fan shaft submitted.

PROCEDURE:

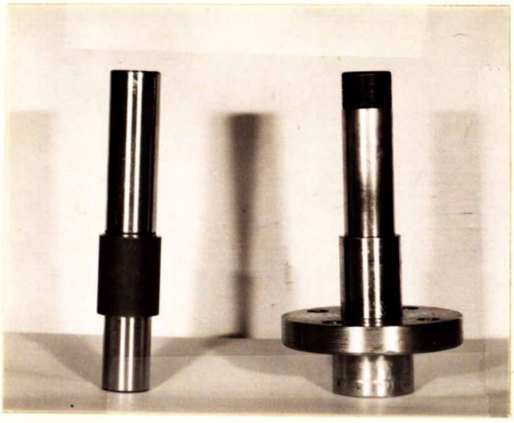
(1) Visual Examination -

The mismachined shaft and the fan hub insert and shaft assembly were photographed as received, and appear as Figure 1. Figure 2 is a photograph of the fractured shaft. It was noted that the failure had taken place at the 90° shaft collar adjacent to the hub insert. The fractured surface has an "oyster shell" or conchoidal appearance. Figures 3 and 4 are photographs of the blueprints showing the fan drive arrangement and bracket assembly.

(Figures 1 to 4 follow)
(on Page 3.)

(Procedure, cont'd) -

Figure 1.



½ actual size.

FAN SHAFT AND ASSEMBLY.

(Showing mismachined shaft at the left and the fan hub insert and shaft assembly at the right.)

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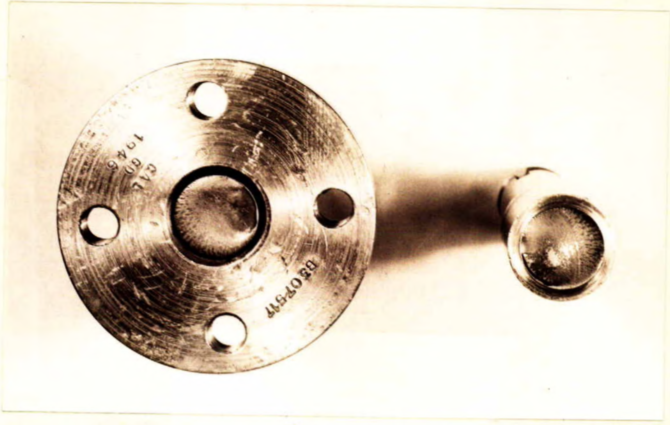
Figure 2.



2/3 actual size.

FRACTURED SHAFT.

(Note the conchoidal fracture and its location at the 90° collar adjacent to the insert.)

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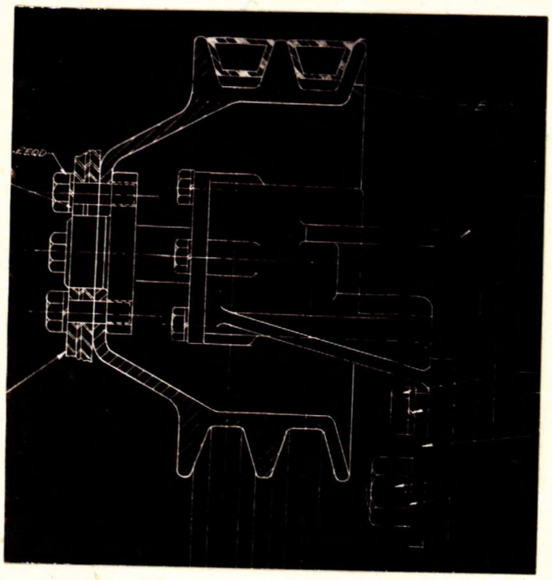
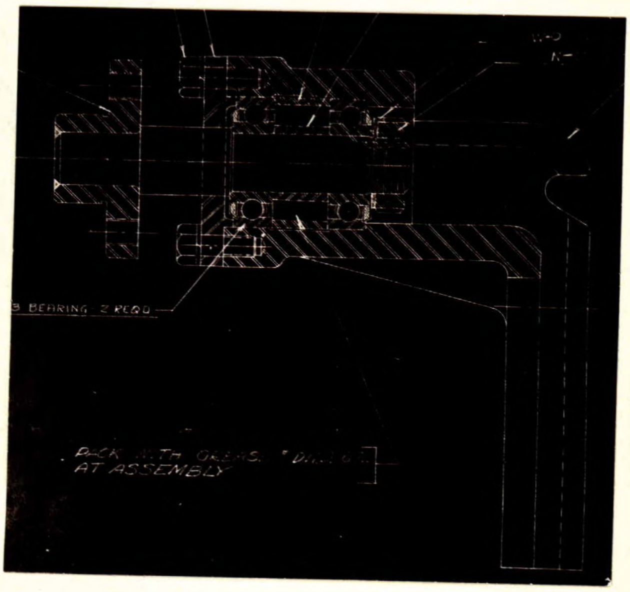
Figure 3.



FAN DRIVE ARRANGEMENT.

Figure 4.



BRACKET ASEEMBLY.

(Showing location of fan hub insert and shaft.)

- -

(Procedure, cont'd) -

(2) Chemical Analysis -

Samples for chemical analysis were prepared by machining the cross-section of the two shafts. The results are listed in Table I. For comparative purposes, the specification* for SAE 4340 steel is also shown.

TABLE I.

	Mismachined Shaft	Fractured Shaft	SAE 4340 Specification
	-	Per Cent	-
Carbon -	0.40	0.39	0.38/0.43
Manganese -	0.72	0.72	0.60/0.80
Phosphorus -			0.04 max.
Sulphur -			0.04 max.
Silicon -	0.26	0.26	0.20/0.35
Nickel -	1.72	1.74	1.65/2.00
Chromium -	0.71	0.72	0.70/0.90
Molybdenum -	0.21	0.22	0.20/0.30

*SAE Hdbk., 1943 edition.

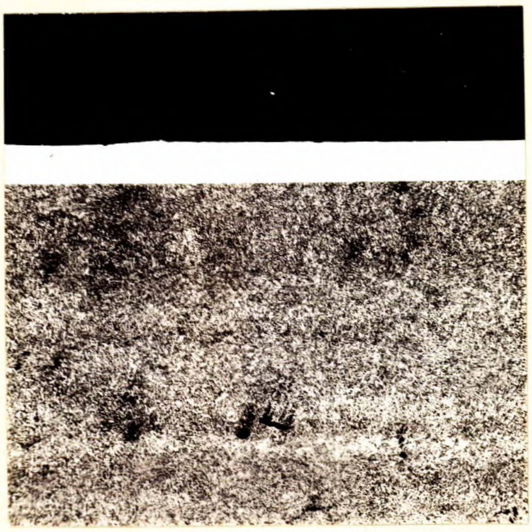
(3) Microscopic Examination -

Samples from the two sections of the fractured shaft were prepared for metallographic examination. On that part of the shaft which fitted into the hub, a distinct surface layer to a depth of 0.002 inch was evident (see Figure 5). Subsequent spectrographic analysis identified this layer as a nickel deposit. The remainder of the areas examined revealed a uniform tempered martensitic structure (see Figure 6).

(Figures 5 and 6 follow)
(on Page 5.)

(Procedure, cont'd) -

Figure 5.



X100, etched in 2 per cent nital.

LONGITUDINAL SECTION OF THE HUB END OF THE SHAFT.

Note nickel deposit (white area). Thickness of deposit, 0.002 inch; hardness of deposit, Rock"C" 12.

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Figure 6.

X1000, etched in 2 per cent nital.

TEMPERED MARTENSITE - TYPICAL STRUCTURE OF THE SHAFT.

Hardness values average Rock"C" 38 to 41.

-

(Procedure, cont'd) -

(4) Hardness Tests -

Eight readings of Rockwell "C" 38 to 41 were obtained across the diameter of the shaft. The nickel plating noticed in the microscopic examination was found to have a hardness of Rockwell "C" 12 (converted from a Knoop number of 217, taken on a Tukon Hardness Tester).

Discussion:

The chemical analyses of both shafts submitted conform to the specification limits of an SAE 4340 steel.

In the visual examination, it was noticed that the broken shaft had a conchoidal, or "oyster-shell", type of fracture (see Figure 2). This type of fracture is typical of a fatigue failure where the rate of propagation of a crack preceding the final break is not constant. Consideration of the fan assembly and shaft design (see Figures 3 and 4) reveals the following significant facts. The finished shaft has an integral collar with sharp, 90° faces. High stress concentrations may therefore be expected at either end of the collar. A press fit is used to secure the hub to the shaft and a sharp right angle exists between the hub face and the shaft. Hence at the shaft collar, a definitely critical area, there will be a further increase in stress concentration due to the "notch" effect of such design features. It will be noted that failure occurred at this point.

Metallographic examination revealed the presence of a surface deposit, 0.002 inch thick, on a specimen representing that part of the shaft which fitted into the hub. The hardness of this deposit, which was identified as nickel, was Rockwell "C" 12 (converted from a Knoop number 217 taken

(Discussion, cont'd) -

on a Tukon Hardness Tester). Specimens representing the remainder of the shaft exhibited a uniform tempered martensitic structure.

The presence of the nickel layer at such a critical area undoubtedly had an adverse effect on the endurance limit of the part. Since the maximum stress developed is at the surface of the fan shaft, the presence of a soft weak skin would favour the initiation of a fatigue crack. On continued service, such a crack would propagate into the harder core. The fatigue failure is attributed to the stress-raising "notch" effect of the design in conjunction with this soft surface deposit.

Hardness values of Rockwell "C" 38 to 41 were obtained across the diameter of the unplated shaft. These values were above the maximum of the reported specified limits of Rockwell "C" 35±3. The hardness values obtained are not considered to be a contributing factor towards failure in this instance.

While increasing the hardness (tensile strength and hence endurance limit) through cold working or heat treatment, is sometimes used to improve the fatigue limit of a steel, it should be borne in mind that this effect holds true only in the <u>absence</u> of "notch" effects. Since the notch sensitivity of a steel also increases with hardness, there will be a resultant decrease in the endurance limit of a component subject to the "notch" effect.

<u>Conclusions</u>:

<u>1</u>. The chemical analyses of both shafts submitted conform to SAE 4340 specification.

<u>2</u>. Hardness values of Rock"C" 38 to 41 were

(Conclusions, cont'd) -

obtained. These values were above the reported specified limits of Rock. "C" 35 ±3. As a contributing factor towards failure, the Hardness values obtained are not considered significant.

3. The metallographic examination of the fractured shaft revealed a uniform tempered martensitic structure with a soft (Rock. "C" 12) nickel deposit, 0.002 inch in thickness, on the surface of the shaft fitting into the hub.

4. Several features in the design were noticed which would have a stress-raising effect in localized areas. These features, consisting chiefly of a press fit and sharp 90° angles at critical areas, are outlined in the discussion.

5. The fracture of the fan shaft is attributed to fatigue failure arising from the "notch" effect of the design features and the presence of a soft surface deposit at a critical area.

Recommendations:

1. It is recommended that changes be made in the design, to incorporate fillets at areas of high stress concentration. A solid hub and shaft component, with a generous fillet at the junction of the hub face and shaft, should eliminate many of the stress-raising features of the present design.

2. In this assembly the use of nickel plating to rebuild a misfitting fan shaft should be discontinued. Any shafts thus plated should be removed from service.

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