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INVESTIGATION INTO THE FAILURE OF A PTO DRIVE SHAFT OF A RCAF ALVIS CRASH TRUCK

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

A failed drive shaft from a RCAF Alvis crash truck was examined. The chemical composition and hardness were within specification limits. Metallurgical quality with respect to inclusions, homogeneity, and microstructure was less than ideal but the deficiencies were judged not sufficiently deleterious to account for failure at such a low nominal stress. Visual assessment of the fracture surface characteristics suggested bending stresses, presumably derived from misalignment of some sort, to be the principal cause of the fatigue failure. Mechanical tests, microexamination, and microhardness tests confirm that the tensile strength was too high for the driving load to have caused failure, therefore, additional stresses must have been present. It has been reported that subsequent examination has shown axial misalignment, lack of concentricity, etc., in the production units.

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INTRODUCTION

A failed drive shaft from the power take-off unit of a RCAF Alvis crash truck was submitted with a covering letter dated 8 December, 1965, file HQ4210-2(CTS/DGEL/DVFE 3-4) requesting that the shaft be analyzed to determine the cause of failure. It was suspected that either the material used in the shaft was not that called for in the drawing, or that the heat treatment process was wrong or not carried out at all.

In conversation with F/L G. Hovey, it was established that a prototype power take-off unit had been tested on the proving ground for about a year and that no trouble had been experienced with this drive shaft. The shaft was required to transmit the drive from an engine rated at 365 ft-lb torque, maximum. The actual output of the engine on test rarely, if ever, exceeded 70% of the rated output. The design calculations, based on 365 ft-lb torque, and taking into account the stress concentration at the fracture origin area, showed the maximum stress due to the driving load would be somewhat under 9,000 psi.

Subsequent to completion of the work on the first shaft, a second was submitted along with two ball bearings.

VISUAL EXAMINATION

Figure 1 illustrates No. 1 shaft, as-received. There were no visible signs of damage other than the fracture at the right hand end. Fluorescent magnetic particle inspection showed no evidence of incipient cracks. Figure 3 shows the fracture face. Post-fracture damage obscured the fracture markings to some extent but sufficient evidence remained to show clearly that there was but a single origin at the base of a circumferential groove. From this origin a fatigue crack traversed about 90% of the section. The final shear failure area was located almost diametrically from the origin and touched the surface of the section.

Subsequent examination of No. 2 shaft showed that fracture originated in a radial oil hole, the point of calculated maximum stress. A fatigue crack propagated on a plane at 45° to the shaft axis. Approximately half the section was penetrated by the fatigue crack before final shear failure.

The two ball bearings submitted with No. 2 shaft were the same size and must, therefore, have been in service with two different shafts. The inner race of one bearing had spalled severely on one side of the groove, Figure 5. The balls and outer race of this bearing showed only minor damage. The inner race of the other bearing showed much less spalling. The balls and outer race showed no evidence of significant damage.

CHEMICAL COMPOSITION

Drillings were obtained from No. 1 shaft for chemical analysis. The results are shown in Table 1 along with the limits for the specified grade, SAE 4140.

TABLE 1

Chemical Composition

	Per Cent of Element						
	C	Mn	Si	S	P	Cr	Mo
Sample	0.40	0.87	0.26	0.021	0.012	0.92	0.18
SAE 4140	0.38/ .43	0.75/ 1.00	0.20/ 0.35	0.04 max	.04 max	0.80/ 1.10	0.15/ 0.25

The composition of the sample conforms to the requirements of the standard.

MECHANICAL PROPERTIES

Two longitudinal miniature tensile specimens, 1/8 in. gauge diameter by 1/2 in. gauge length, were tested. The average ultimate tensile strength was 116.5 kpsi, yield point 94.5 kpsi, and reduction of area 40%.

Standard Rockwell hardness tests on a transverse section through the splined portion showed the hardness to range from Rc 20 to 22, average 21. The hardness on the shaft surface adjacent to the collar ranged from Rc 22.5 to 25, average 23.5. Microhardness tests with a 1 kg load using the Knoop diamond indenter were carried out on transverse sections of the bearings. The average hardness of each section was Knoop 758, approximately Rc 61.

METALLOGRAPHIC EXAMINATION

A longitudinal section through the fracture origin and an adjacent transverse section of No. 1 shaft were examined. No structural abnormalities were noted in the vicinity of the origin. The incidence of non-metallic inclusions, Figure 6, was rather high for an alloy steel but is probably within commercial limits for a non-premium grade. Etching showed a banded microstructure, Figure 7. At high magnification it can be seen that the dark bands consist of highly tempered martensite in which the carbides are well developed with a little ferrite, the light etching bands have much more ferrite. This banded structure reflects heterogeneity in chemical composition. Probably the dark bands are high in chromium and carbon. In general, the structure indicates a rather slack quench in final heat treatment followed by a high tempering temperature.

Microhardness tests using the Knoop diamond indenter with a 500 g load showed the hardness of the dark bands to be about Knoop 300 (approximately Rc 29), that of the light bands to be Knoop 254, (approximately Rc 21).

Transverse sections of both races of both bearings were examined. As expected, a multiplicity of cracks were observed underlying the severely damaged areas. These cracks appeared typical of overloaded bearings. No cracks were noted in any other part of the sections. The microstructure appeared typical of quenched and tempered AISI 52100, the standard ball and roller bearing grade of steel. No significant metallurgical deficiencies were found.

COMMENTS

The chemical composition of No. 1 shaft is within the limits of the specified standard, SAE 4140. The hardness conforms to the limits specified by Department of National Defence. The non-metallic inclusion content is higher than expected for good alloy steelmaking practice but probably is within commercial limits for a non-premium grade. The heterogeneity of chemical composition, evidenced by the banded microstructure, is also considered excessive for good steelmaking practice. However, standards for this quality are nebulous and it may well be within commercial latitude. In any event, the minimum hardness at the origin of failure is within the limits imposed by DND. There was no apparent metallurgical deficiency to which the fracture could reasonably be ascribed.

The hardness of Rc 21 at the fracture origin indicates a local tensile strength of about 110,000 psi. The normal ratio of notched fatigue limit to ultimate tensile strength would indicate a fatigue limit of about 27,000 psi. This is three times the calculated maximum stress derived from the engine load. Since fatigue failure did occur, additional stresses must have been imposed. This confirms the visual assessment of fracture surface characteristics, i.e., that bending stresses were the principal stresses leading to the fatigue failure.

It has since been reported by F/L Hovey that examination of power take-off units showed misalignment and lack of concentricity to be present in production units. Stresses derived from such sources would be variable in magnitude and direction but each would impose additional stresses. Since the cause of the failures was located in these mechanical features, no detailed examination was carried out on either the bearings or No. 2 drive shaft.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of Mr. R.C.A. Thurston, Head, Engineering Physics Section, in assessing the nominal maximum stress imposed by the driving load and confirming the reported value, and of Mr. W.H. Bott, Nondestructive Testing Section, for carrying out the fluorescent magnetic particle inspection.

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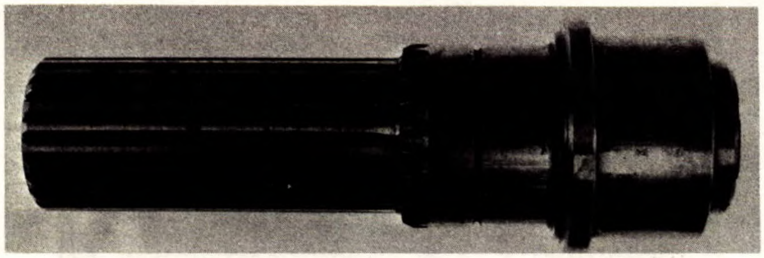

Approximately 1/2 full size

Figure 1. Drive shaft No. 1 as-received. Break is at right hand edge.

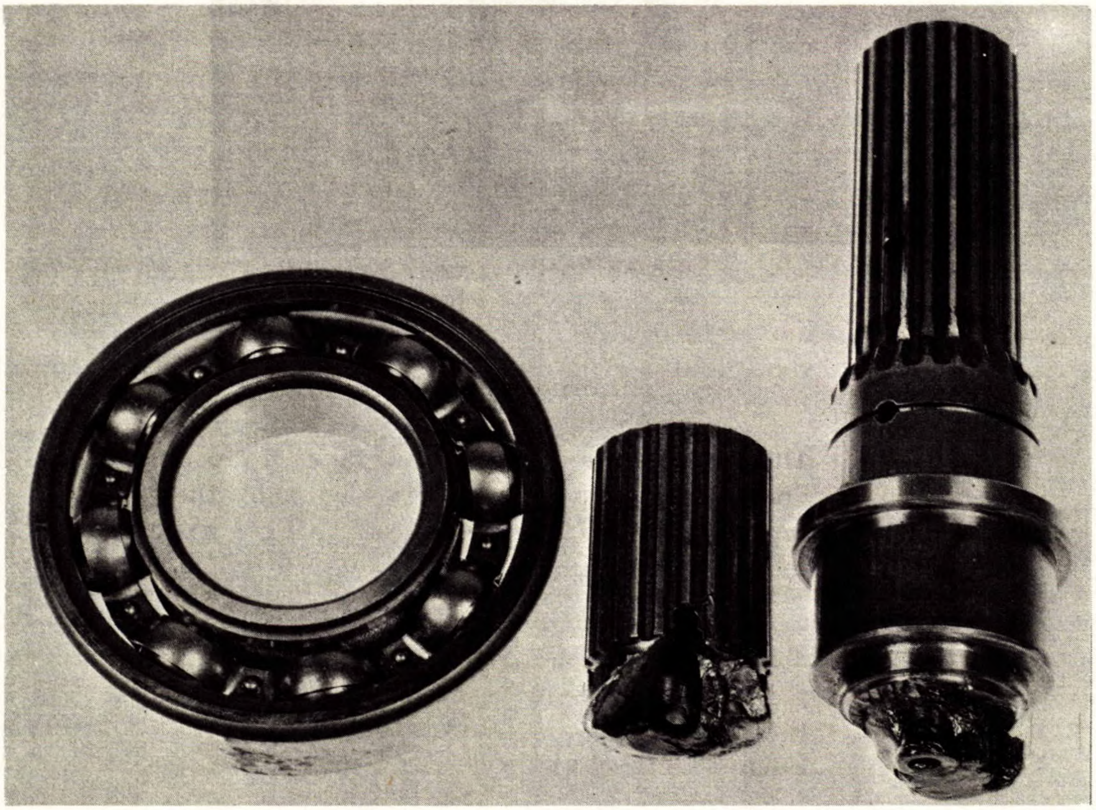

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Figure 2. Drive shaft No. 2 and associated ball bearing.

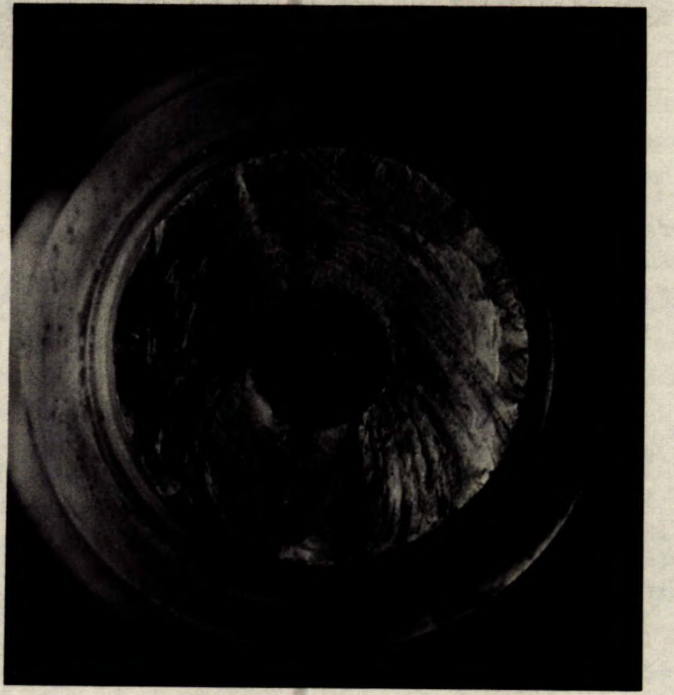

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Figure 3. Illustrating the fracture surface of No. 1 shaft. The fatigue crack origin is shown by the arrow, upper right. The final shear failure area is shown by the inked lines, lower left.

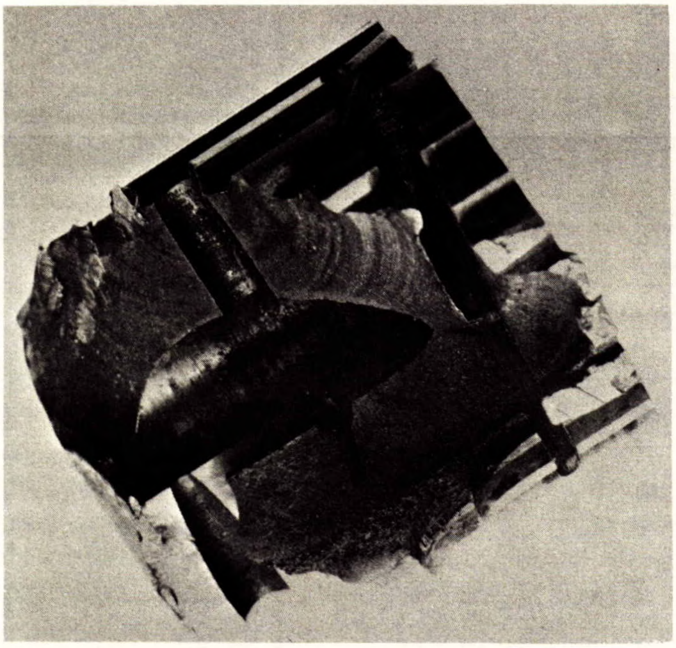

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Figure 4. Fracture surface of No. 2 shaft, illustrating origin of fatigue crack at the oil hole.

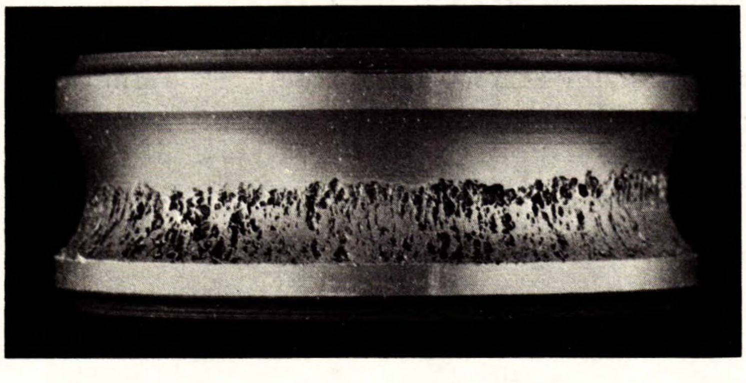

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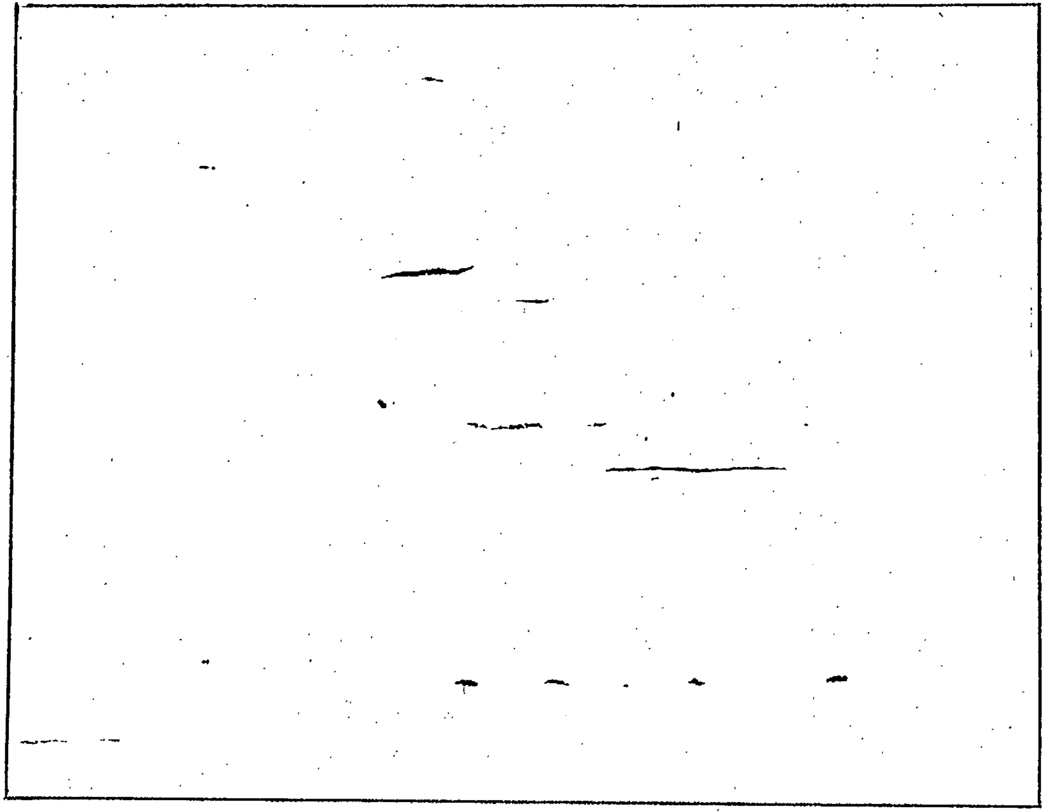
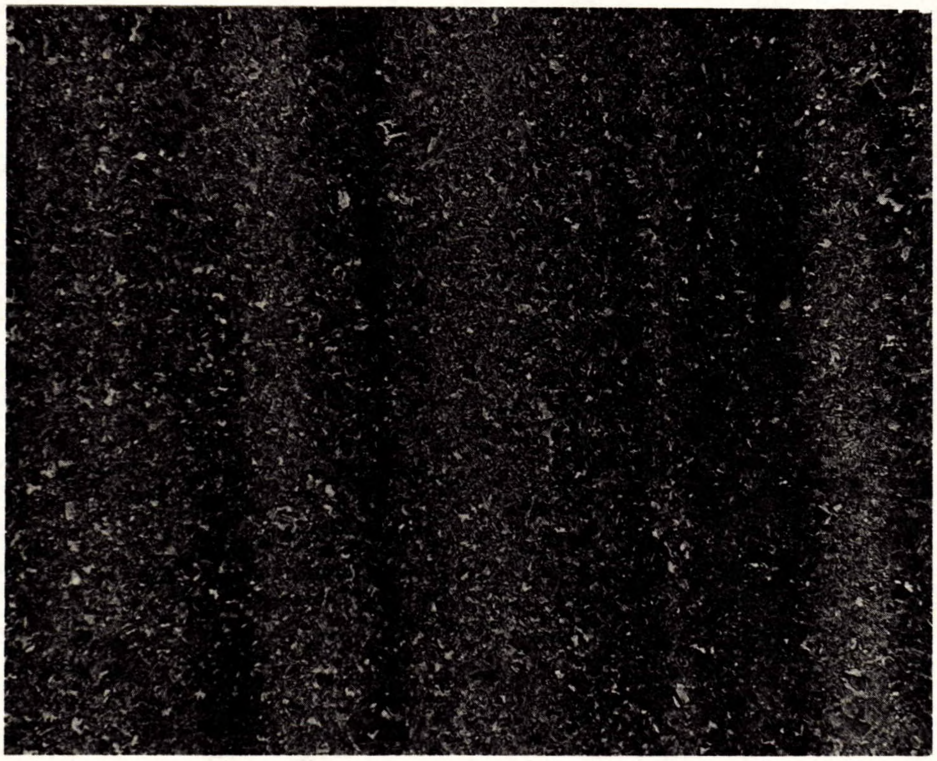
Figure 5. View of inner race of ball bearing.



X500, unetched

Figure 6. Longitudinal section, near fracture origin, illustrating non-metallic inclusions.



X100, etched in 2% nital

Figure 7. Longitudinal section, near fracture origin, illustrating banded appearance due to differential etching which is a consequence of compositional heterogeneity.