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R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1347.

Examination of Broken Crankshaft from
a Ranger Aircraft Engine.

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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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Origin of Samples:

On January 7th, 1943, Air Commodore A. L. Johnson, Department of National Defence for Air, Ottawa, Canada, submitted for examination a broken crankshaft from a Ranger aircraft engine.® It was reported that other crankshafts of this type had also failed in service.

Object of Study:

Request was made for an investigation of the crankshaft in order to determine, if possible, the cause of failure.

® Engine No. 2905.

Chemical Analysis:

Drillings from the crankshaft were chemically analysed. Our results, compared with Specifications AMS 6382A and AMS 6415A which respectively controlled past and present crankshaft production, are as follows:

		Our Analysis	AMS 6382A	AMS 6415A
			- Per cent -	
Carbon	-	0.45	0.38 - 0.43	0.38 - 0.43
Manganese	-	0.78	0.75 - 1.00	0.60 - 0.80
Phosphorus	-	0.020	0.040 max.	0.040 max.
Sulphur	-	0.021	0.040 max.	0.040 max.
Silicon	-	0.32	0.20 - 0.35	0.20 - 0.35
Nickel	-	0.23		1.65 - 2.00
Chromium	-	0.99	0.80 - 1.10	0.70 - 0.90
Molybdenum	-	0.18	0.15 - 0.25	0.20 - 0.30
Vanadium	-	Not detected.		
Tungsten	-	" "		

Macro-Examination:

A general view of the crankshaft and a close-up of the fractured surface are given respectively in Figures 1 and 2. It was noted that the fracture had the appearance of a fatigue failure, the nucleus of which seemed to be in the fillet in the under side of the crank pin (Point A in Figure 2).

Two of the crank pins, similar to the one in which failure occurred, were removed, halved, and immersed for one hour in a 50 per cent solution of hydrochloric acid in water at 170° F. After this treatment, a crack (Point B, Figure 3) was revealed which seemed to be developing in one of the unbroken crank pins in the same way as the fracture which caused failure. The flow lines of the material do not conform to the outline of the crank pin at this point. These points are illustrated in Figure 3. A further 3/8-inch cut was taken from one of the etched surfaces and the piece was re-etched. The flow lines still left the forging near and at the fillet.

The chamfer on the oil hole in the broken crank pin

(Macro-Examination, cont'd) -

was not well rounded (Figure 4). Some tool marks were found in the oil clearance slot or keyway through which the fracture which caused failure went.

Physical Examination:

A 0.282-inch tensile bar (2-inch gauge length) and an izod bar were machined from the spline shaft. A 0.282-inch tensile bar of 1-inch gauge length and an izod bar were machined from the crank pin perpendicular to the main axis of the crankshaft.

	Shaft	Crank Pin
Ultimate stress, p.s.i. -	153,200	157,600
Yield stress, p.s.i. -	138,800	141,800
Elongation in 1 inch, per cent -	20.5	19.5
Reduction in area, per cent -	58	57.2
Average izod value, foot pounds -	48.5	49
Vickers hardness number -	335	335

A hardness survey through a crank pin showed that the shaft was homogeneously hardened.

Microstructure:

Microscopic examination of the crankshaft steel revealed that it contained a more than usual amount of elongated inclusions near the point where failure is believed to have started. Figure 5 is a photomicrograph of this area at 100 diameters. Figure 6 depicts, at a magnification of 1000, the microstructure of the piece after it had been etched in 2 per cent nital.

The grain size of the steel, determined by a McQuaid-Ehn test, is approximately 7.

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Discussion of Results:

Chemical analysis showed that the carbon was slightly high and that some nickel was present (probably as a tramp element). Any adverse effect upon the fatigue properties of the shaft from this cause is not, however, readily discernible or very likely.

It is significant that a nickel-chromium-molybdenum steel has now replaced the chromium-molybdenum steel originally used in this crankshaft. It is unlikely that the change would have been made had all crankshafts been giving satisfactory service. The nickel-chromium-molybdenum steel would have a better hardenability than the steel that it replaced. More important, it would probably have a higher ductility and fatigue strength for the same ultimate strength or hardness. It would be expected, then, to give better service.

The discontinuity of the grain at the point where fracture is believed to have started is considered the most serious defect in the crankshaft.

R. A. MacGregor, W. S. Burn and F. Bacon, Relation of Fatigue to Modern Engine Design, Trans. North East Coast Inst. Engineers and Shipbuilders, v. 51, 1935, state:

"There is practical evidence of the necessity of obtaining improved forgings, compared with present standards, to ensure the avoidance of the combined effect of indifferent quality steel at stress concentrations and also to ensure the correct flow of the metal so that the maximum stressing is always across the grain."

"So far experiments have established that there is a difference in fatigue strength using plain specimens having the grain running 'with' or across the bar. Across the grain appears to give about 15 to 20 per cent lower value than with the grain."

If one of the elongated inclusions discovered near the fillet at the point of failure occurred at the surface it would act as a stress raiser and hasten failure.

The heat treatment received by this crankshaft seems

(Discussion of Results, cont'd) -

to be satisfactory. The physical property results are the normal expectancy. The roughness at the oil hole and oil clearance slot are not thought to be starting points for this fracture but might have led to fracture if other defects had not been present.

CONCLUSIONS:

1. With the exception of the carbon content, the steel met Specification AMS 6382A requirements.

2. Physical properties of the crankshaft steel are in accordance with expectations.

3. Fracture indicates the failure to have been caused by alternating stresses, with the fatigue crack starting at a crank pin fillet.

4. Forging practice which failed to hold flow lines to the crank pin constituted the major cause of failure. Elongated inclusions present in the zone of failure may have been a contributing cause.

5. To improve the factor of safety of the crankshaft, the oil hole chamfer should be more rounded.

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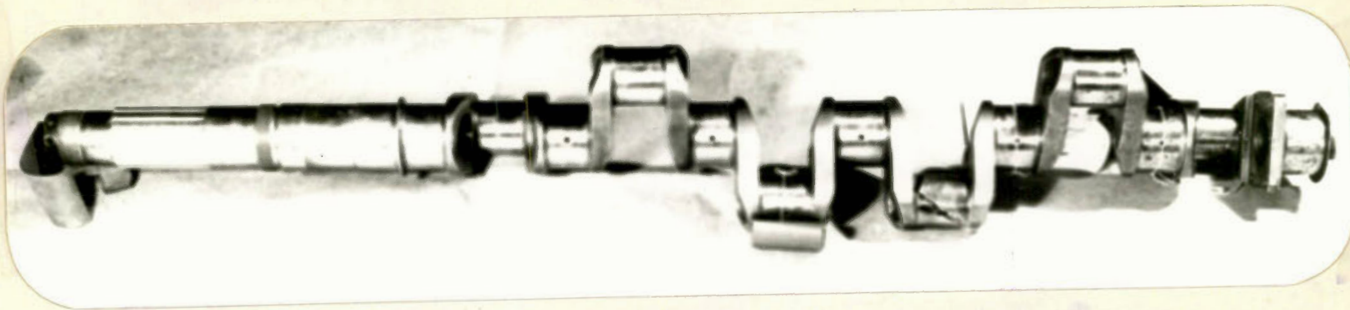
Figure 1.



CRANKSHAFT AS RECEIVED.

(Approximately 1/6 size).

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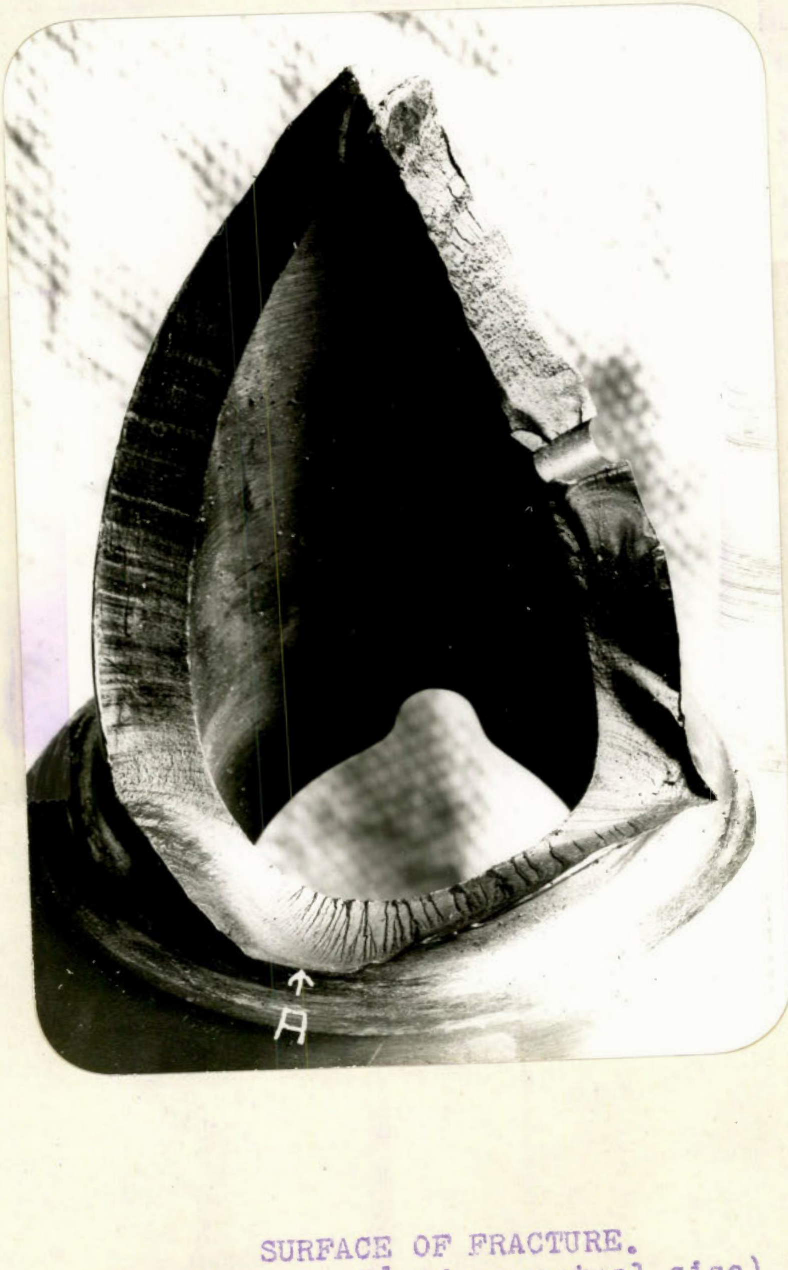
Figure 2.



SURFACE OF FRACTURE.
(Approximately $1\frac{1}{2}$ times actual size).

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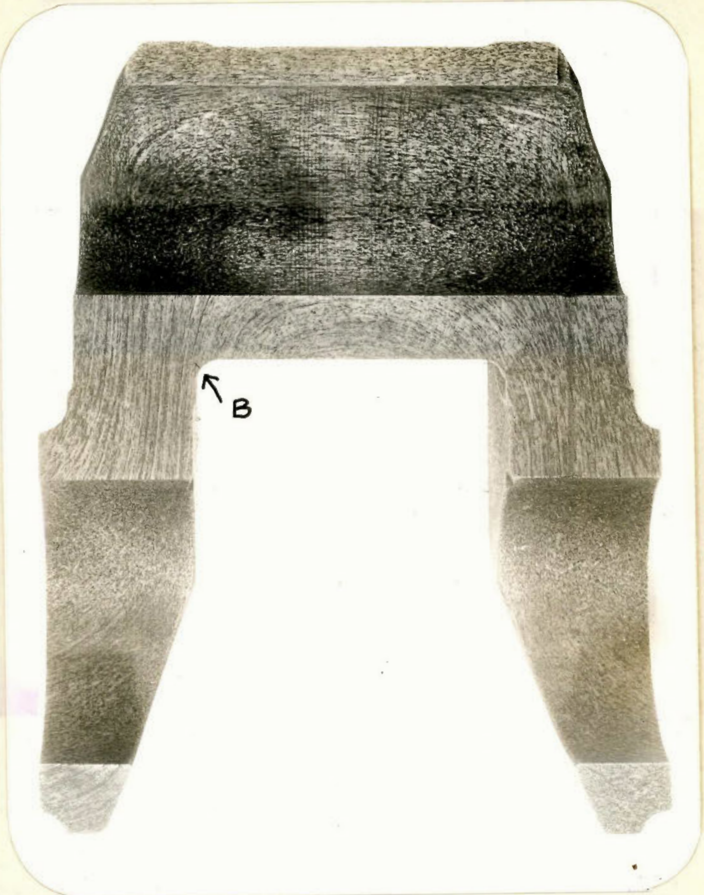
Figure 3.



SURFACE, MACRO-ETCHED.
(Approximately $\frac{3}{4}$ size).
Note crack at B.

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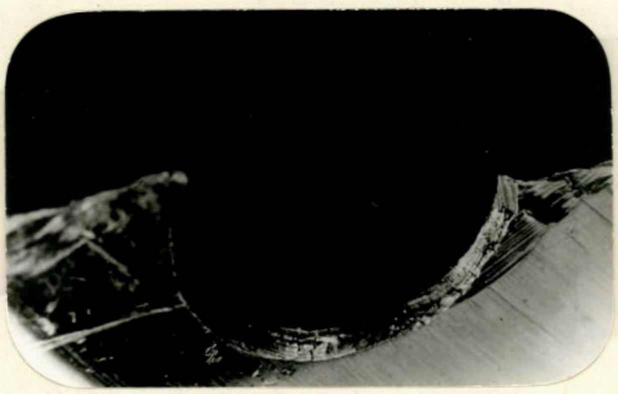
Figure 4.



CHAMFER ON THE OIL HOLE.

(Approximately X6 magnification).

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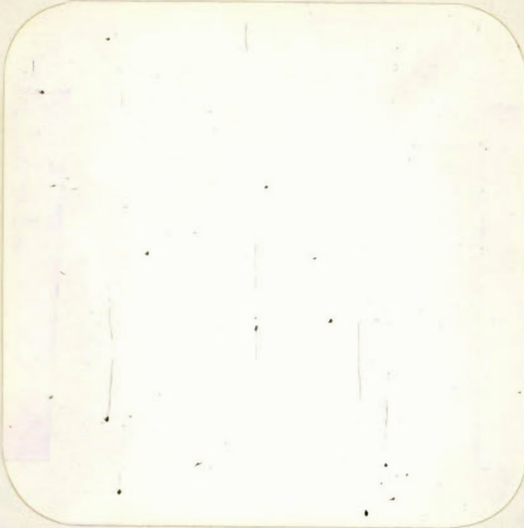
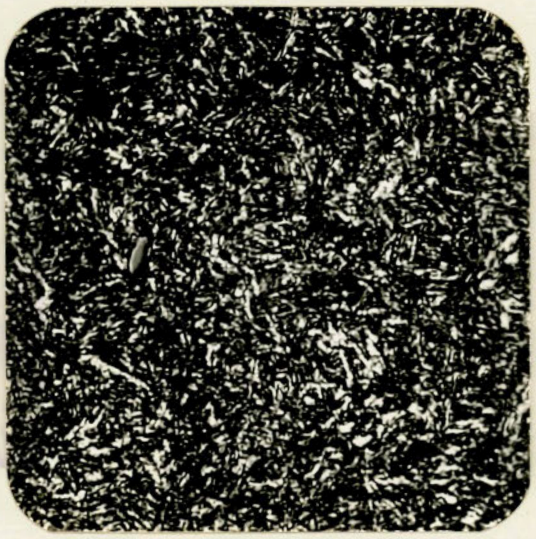
Photomicrographs:

Figure 5.



X100, unetched.
Note elongated inclusions.

Figure 6.



X1000, etched in 2 per cent nital.

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