OTTAWA September 11th, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1493.

Examination of Two Cheetah Engine Cylinder Heads, Cracked in Service.

(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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Origin of Samples and Object of Investigation:

Two aluminium alloy Cheetah Engine cylinder head castings were submitted (with letter, File No. 935U1-1-5, AMAE DAI) on August 4th, 1943, by Air Commodore A.L. Johnson for Chief of Air Staff, Department of National Defence, Air Service, Ottawa, Ontario. These were said to be typical of many cylinder heads of this type which developed cracks after several hundred hours' service. One cylinder head (designated No. 1 herein) had developed cracks at a spark plug hole, while the other (No. 2) was severely cracked in the exhaust port. The covering letter reported that the parts were believed to have been made of DTD 133, R.R.50 alloy.

Request was made for an examination to determine, if possible, the reason for the cracking.

Chemical Analysis:

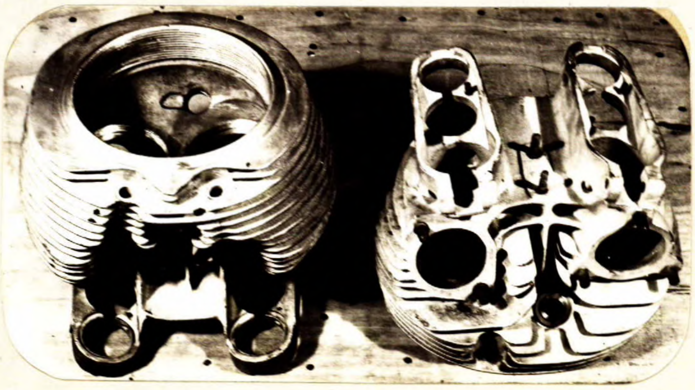
Drillings from the cylinder heads were chemically analysed. The results, and some specification requirements, follow:

	Head No. 1.	Head No. 2.	SPECIFICATIONS DTD 131A (R.R.53)	DTD 238 (R.R.53)	DTD 133B (R.R.50)
	-	P e r	C e n t	-	
Copper	2.32	2.36	1.5-2.5	1.5-2.5	0.8-2.0
Manganese	0.035	0.051	--	--	--
Silicon	1.06	1.41	2.0 max.	2.0 max.	1.5-2.8
Magnesium	1.78	1.22	1.3-1.7	1.4-1.8	0.05-0.30
Nickel	1.38	1.16	0.5-2.0	0.5-2.0	0.8-1.75
Iron	1.07	1.12	0.8-1.3	1.2-1.5	0.8-1.4
Titanium	0.06	0.10	0.02-0.12	0.02-0.12	0.05-0.25
Chromium	Not detected.	Not detected.			
Zinc	"	"			

Macro-Examination:

Figure 1 is a general view of the castings as received. Close-ups of defective areas are given in Figures 2 and 3.

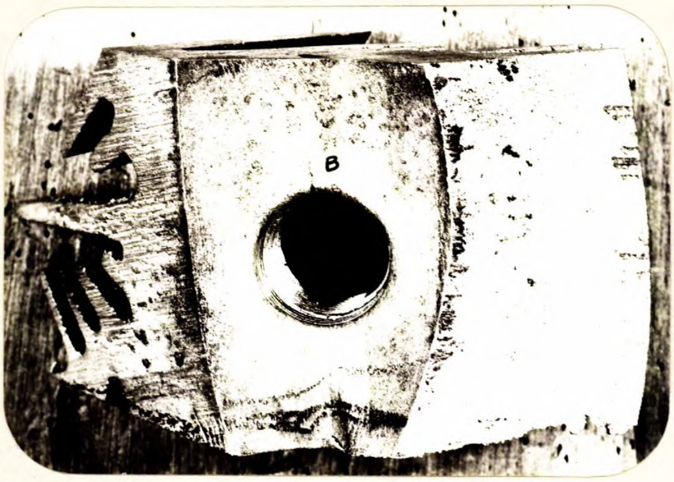
Figure 1.



CASTINGS AS RECEIVED.
(Approximately 1/5 size).

(Macro-Examination, cont'd) -

Figure 2.



CRACK AT SPARK PLUG HOLE (Point B).
(Approximately 7/8 size).

Figure 3.

CRACKS IN EXHAUST PORT.
(Approximately 2/3 size).

Sections from cracked portions of the cylinder heads were broken open and the failures were examined.

The cracks around the spark plug hole in Cylinder Head No. 1 had just begun to develop and their nature was not visually ascertainable.

On breaking open the No. 2 casting at the extensive cracking in the exhaust port, the cracked area was seen to be

(Macro-Examination, cont'd) -

definitely duplex in nature, one portion, which appeared to be of more recent origin, exhibiting conchoidal markings. The nucleus of the failure could not be located because that part of the fracture was covered with a black residue (apparently carbon). It was noticed, however, that the fracture extended farther on the outside of the part between the fins than it did on the inside.

Hardness tests were taken (using a Vickers machine with a 10-kilogram load) on samples removed from the cracked portions of the cylinder heads. The following results were obtained:

		V. H. N. (10-kg. load)
Cylinder Head No. 1	-	59.6-60.4
" " No. 2	-	57.1-64.3

Results of Vickers hardness tests on samples taken from a similar location (remote from the cracking) in each cylinder where the metal was approximately ¼-inch thick were:

		V. H. N. (10-kg. load)
Cylinder Head No. 1	-	54.4-69.4
" " No. 2	-	61.3-69.6

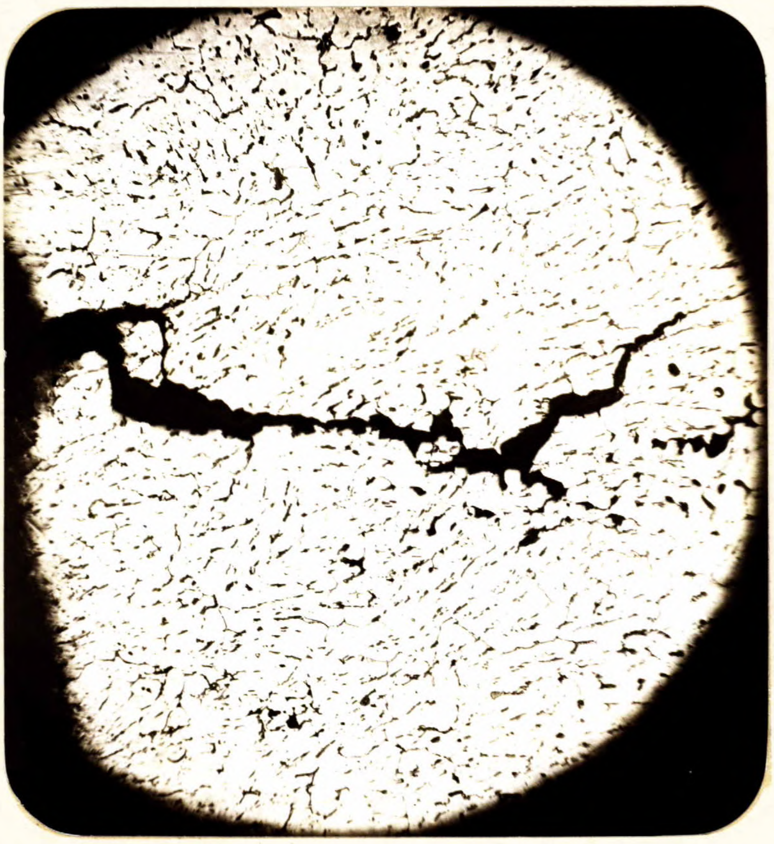
Micro-Examination:

Sections were cut from the cracked portions of the cylinder heads and then polished. Shrinkage cavities were found in the region of the failures and in other locations in both cylinder heads (see Figures 4, 5 and 6). After an etch with 0.5 per cent hydrofluoric acid in water, thin stringers (such as those shown, at 250 diameters, in Figure 7) were found in both cylinder heads, mostly in fields containing shrinkage cavities. These stringers have the

(Micro-Examination, cont'd) -

appearance of oxides but may be part of the shrinkage defects. Beyond these findings, nothing unusual was noticed in the microstructure of the castings.

Figure 4.



X42. Etch, 0.5 per cent HF in water.

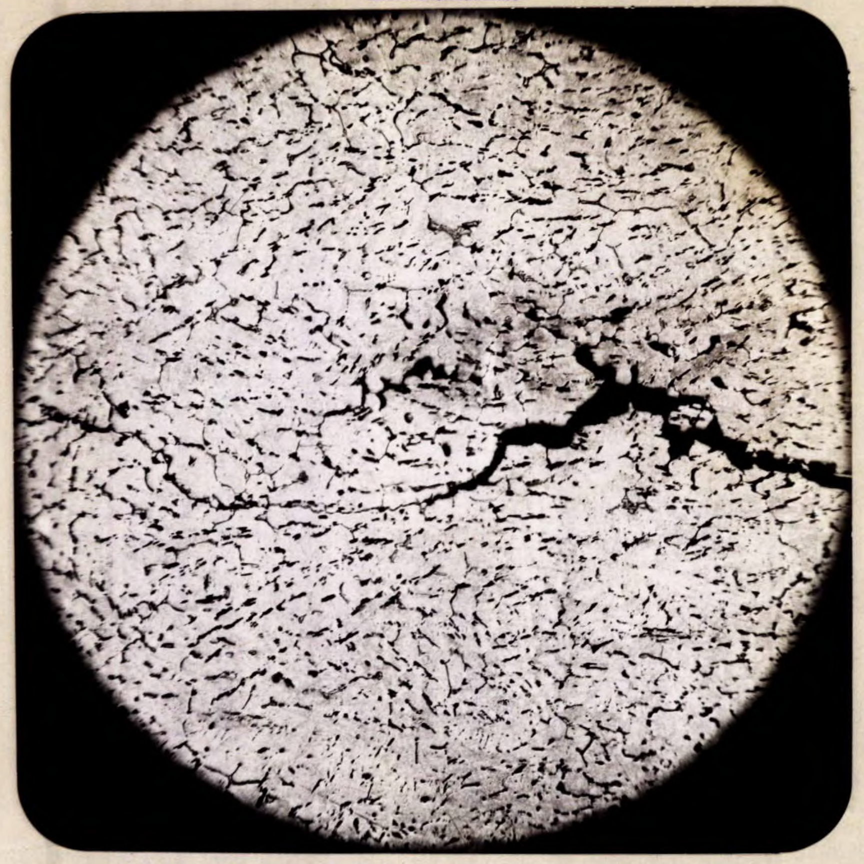
CRACK AT SPARK PLUG HOLE.

Note shrinkage cavities.

(Continued on next page)

(Micro-Examination, cont'd) -

Figure 5.



X42. Etch, 0.5 per cent HF in water.

CONTINUATION OF CRACK SHOWN IN FIGURE 4.

Note shrinkage cavities.

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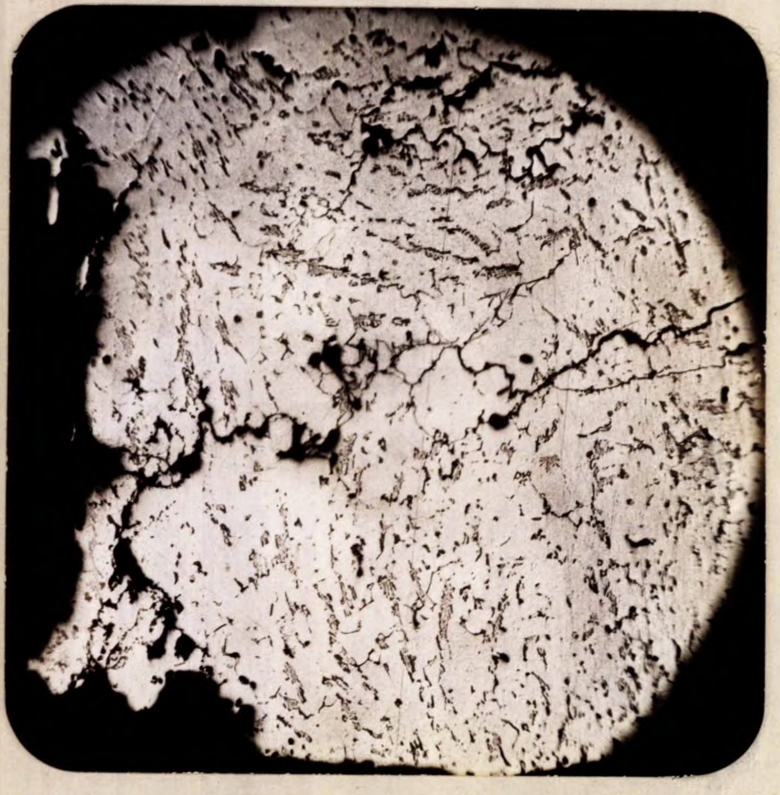
Figure 6.



X42. Etch, 015 per cent HF in water.

CRACK IN EXHAUST PORT.

Vertical edge of photomicrograph is exterior edge of casting. Horizontal edge at bottom is fractured surface. Note other cracks and shrinkage cavities.

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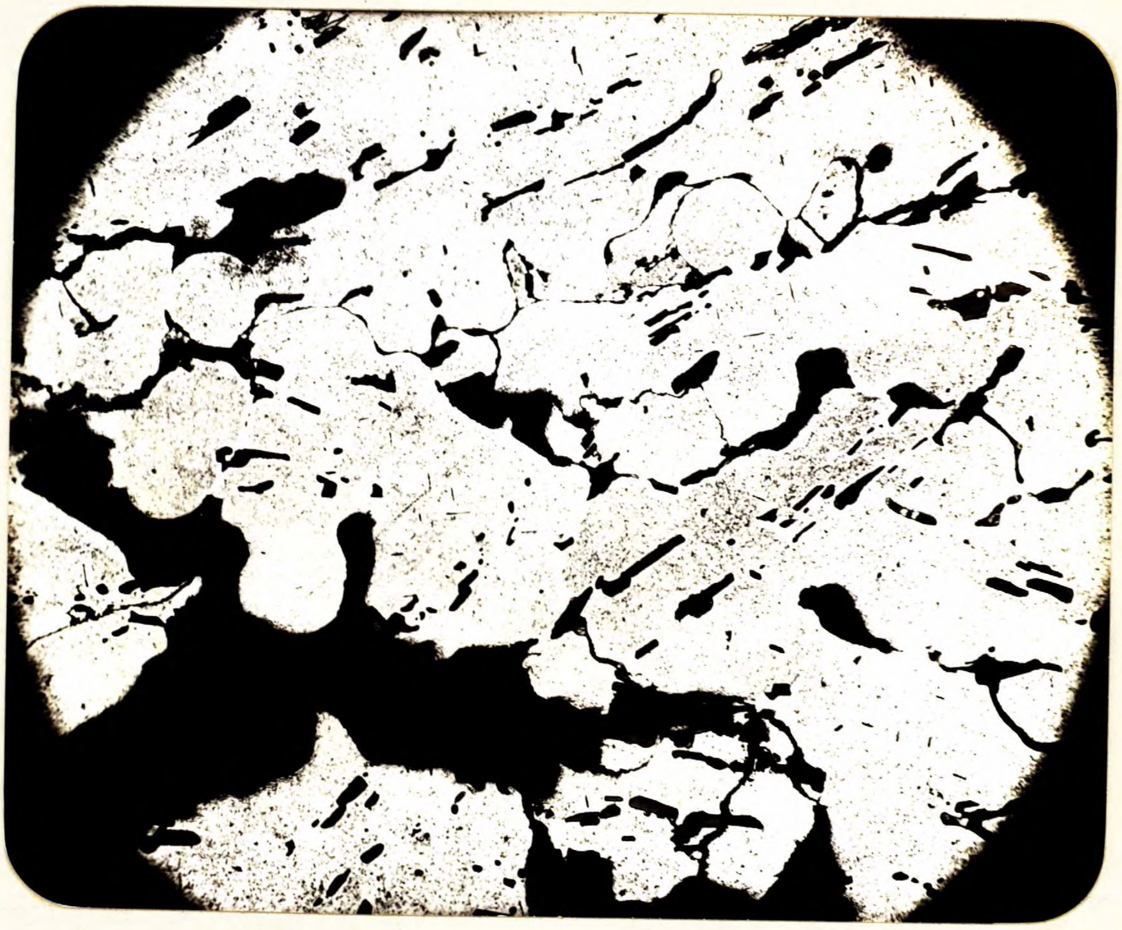
(Continued on next page)

(Micro-Examination, cont'd) -

Figure 7.



X250. Etch, 0.5 per cent HF in water.

TAKEN FROM CYLINDER HEAD NO. 1.

Note shrinkage cavities (black voids) with connecting stringers or streaks. Black void near bottom of photomicrograph is part of the crack.

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Discussion of Results:

Chemical analysis results indicate that the composition of these castings conforms to Specification R.R. 53 (DTD 131A or DTD 238) rather than R.R. 50, DTD 133B. R.R. 53 alloy is recommended in the literature, as is R.R. 50, for air-cooled cylinder heads and other parts operating at high temperatures. R.R. 53 has a higher thermal conductivity but its foundry properties are said to be inferior to those

(Discussion of Results, cont'd) -

of R.R. 50.

The hardness of the castings is much less than the maximum possible for fully heat-treated R.R. 53 alloy. This could indicate either that they were used as cast or that the heat encountered in service softened them after heat treatment, but according to published photomicrographs* the visible microstructure of R.R. 53 is practically the same in the "as cast" and in the "quenched-and-aged" condition, so it is not possible to check on this point by microscopic examination. Whether or not these cylinder heads are being supplied in the "as cast" or "heat-treated" condition could probably only be determined by an examination of cylinder heads which have not been in service. Certainly, harder material will be expected to have better fatigue strength, but the determining hardness would be that which the material would have after some time at the operating temperature. If this part eventually is to encounter high temperatures in service (and according to R. R. Kennedy,** cylinder heads in air-cooled engines generally reach a temperature in the neighbourhood of 550° F.), there would appear to be little advantage in heat treatment. Indeed, there may be some disadvantage, due to danger of warping and stressing on quenching.

The duplex and conchoidal nature of the cracked

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* Bulletin D2, NICKEL IN LIGHT ALUMINIUM ALLOYS, The Bureau of Information on Nickel, The Mond Nickel Co. Limited, London. Page 14.

** "The Effect of Elevated Temperatures on the Strength and Dimensional Stability of Certain Aluminium Alloys used in Aircraft," by Richard R. Kennedy, THE METAL INDUSTRY, London. Vol. 46, February 8, 1935, P.169.

(Discussion of Results, cont'd) -

surfaces, particularly noticeable in the case of Cylinder Head No. 2, would fairly definitely indicate that failure was of a fatigue nature. The direction of the conchoidal markings on the fractured surface of Cylinder Head No. 2, as well as the fact that the fracture extended farther on the outside of the part than on the inside, would seem to indicate that failure originated on the exterior surface of this casting between the fins.

Shrinkage cavities, and some accompanying stringers that may possibly be oxide, present in the region of the fracture would materially lower the fatigue resistance of the parts. Because of the extreme complexity of the castings, however, these shrinkage defects may be difficult, if not impossible to eliminate. No other defects were discovered in the microscopic examination.

Cracks may have started as a result of thermal stresses imposed in the heating and cooling of the engine but more probably were caused by overstressing induced by engine vibrations. Indeed, examinations made in these Laboratories of steel cylinders from this type of engine showed that they may fail from fatigue if not perfectly sound, so vibrational stresses must be considerable.

CONCLUSION:

The examination indicates that the cracking was produced by the action of alternating stresses. Casting defects, which are probably unavoidable in so complicated a structure, no doubt contributed to failure, which consequently must be expected after a certain service life.

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