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O T T A W A   October 7th, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1507.

Examination of Two Cracked Hoover Propeller Hub Forgings.

(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 Request and Object of Investigation:

On September 13th, 1943, two cracked Hoover propeller hub forgings were received at these Laboratories from the Chief of the Air Staff, Department of National Defence for Air, Ottawa, Ontario, and it was requested by F/O N. S. Spence, who delivered the material, that a metallurgical examination be made in order to determine, if possible, the cause of the crack.

Written confirmation of the above verbal request was later supplied by A/C A. L. Johnson, for the Chief of the Air Staff, in a letter dated October 7th, 1943, File No. 902-69-10(AMAE-DAI).

Macro-Examination:

Figure 1 shows, at approximately ¼ size, a top view of one of the propellers "as received". The cracks had been previously marked by the R.C.A.F. inspector and their presence was confirmed by the Magnaflux magnetic test. All cracks, except one, were located in the circular ring shown at "A" in Figure 1. This exceptional crack ran obliquely along the sides of the bored hole, about half-way from the top of the hub.

It was not possible to determine the point of commencement of cracking. The machining operation had taken away a good part of the crack.

Chemical Analysis:

A chemical analysis of the two hubs was made. It gave the following results:

		Heat No. 4696	Heat No. 4691
		- Per cent -	
Carbon	-	0.44	0.44
Manganese	-	0.80	0.77
Silicon	-	0.22	0.23
Sulphur	-	0.011	0.011
Phosphorus	-	0.023	0.023
Chromium	-	0.66	0.66
Nickel	-	1.81	1.81
Molybdenum	-	0.22	0.19

Flake Detection:

As it was suspected that flakes (which may occur if the billet is cooled too rapidly from the forging temperature and which show up as bright circular or elliptical spots on a fracture) might be the starting point of the cracks, every effort was made to reveal their presence. However, fracture tests, tensile tests, and deep etching gave negative results.

Micro-Examination:

All the cracks were sectioned and examined under the microscope in the unetched condition. Figures 2 and 3 show the appearance of one of the cracks, under the microscope. All the cracks found in the two hubs were analogous, each being filled completely with a similar one-phase, non-metallic inclusion. The shape of the crack-filling material definitely indicated it was not a silicate-type inclusion. Its blue colour suggested the possibility of its being a sulphide- or an oxide-type inclusion. Figure 4 shows the sample after being treated in a hydrogen atmosphere at 1100° F. The point to be noted is that the non-metallic inclusion has disappeared; this fact proves that the crack was previously filled with iron oxide (FeO).

Figure 5 shows the condition of the steel along the crack. Note the very slight amount of decarburization and the particle of steel entirely surrounded by the iron oxide.

The fact that the steel grain surrounded by the iron oxide eliminated the possibility of the oxide originating in the formation of the ingot. This argument was reinforced by the fact that no such heavy inclusion could be found in the steel, the cracks being confined to the surface of the machined hub. Figure 6 shows the general microstructure of the steel.

It was then suggested that these cracks had formed on quenching and were oxidized during the tempering operation. However, doubt was expressed as to whether such a complete oxidation was possible. In order to check upon this statement, part of the hub was intentionally cracked by delaying the drawing after quenching in oil from 1525° F. The newly cracked specimen was drawn at 1100° F. for 5 hours. Figure 7 shows a part of the crack after the treatment. Note the complete

(Micro-Examination, cont'd) -

filling of the crack with the same type of inclusion as was found in the "as received" material. Figure 8 shows the same sample after etching. Note again the slight decarburization.

Discussion of Results:

The starting point of the cracks found in these specimens is unknown, as the machining operation done on the propellers took away part of the cracks.

All cracks were of the same type and were completely filled with iron oxide.

The way that this crack was analysed was to examine the following possibilities:

(1) The inclusions found were part of the original ingot.

(2) The cracks were formed and oxidized during the forging operation.

(3) The cracks were due to flaking and oxidized during subsequent heat-treatment operations.

(4) The cracks were formed and oxidized during the heat-treating operation of the forged billet (i.e., before machining).

(5) The cracks were formed and oxidized during the heat treatment of the partially machined hub.

To the first possibility, the answer is negative. The occurrence of these inclusions only at the surface of the "as received" hub, their uniphase appearance, and the fact that they surround entirely some grains of the steel, definitely show that the ingot was not defective.

To the second possibility, the answer is also negative. It is well known that cracks opened by forging are characterized by heavy decarburization.

To the third possibility, the answer is also negative. The absence of flaking in this steel sufficiently removes this possibility. Moreover, if these cracks were formed during the

(Discussion of Results, cont'd) -

cooling from forging, a great decarburization would have occurred in the subsequent treatment at 850° C.

To the fourth possibility, the answer remains negative. The presence of the crack in a part which was the centre of the billet (in the absence of any evidence of flaking) indicates that cracking could occur only in the partially machined hub.

The last possibility is the only one which completely explains the problem. All the facts observed in the present investigation indicate that these cracks were formed during the quenching operation and oxidized during the drawing operation, for if the cracks had been formed prior to quenching or in the heating to quenching temperature they would reveal a heavier decarburization. The simultaneous absence of heavy decarburization and presence of scale (FeO) definitely show that the steel was not heated above its lower critical temperature during its oxidation. (Heating to above the critical temperature is a condition which would have produced heavy decarburizing, together with scaling). Thus, cracking must have occurred just after the final quench, and oxidation or scaling took place during the tempering operation. The slight decarburization adjacent to the iron oxide is consistent with the one expected to take place at the drawing temperature. In fact, Figure 8 shows the same amount of decarburization in the artificially cracked-and-oxidized specimen as Figure 5 shows for the "as received" condition. The chemical analysis shows that the molybdenum content is on the low side of the permissible range; in one case, Heat No. 4691, it is 0.19 per cent whereas it should be at least 0.20 per cent. In view of this fact, it is recommended that the hubs be water-quenched from the drawing temperatures in order to minimize the tendency of this steel to temper brittleness.

CONCLUSION:

The cracks found in these hubs were formed during the final quenching operation and oxidized during the tempering operation. Improper heat treatment procedures (such as letting the steel get too cold before drawing) or machining procedure (undercutting, etc.) are responsible for the defect.

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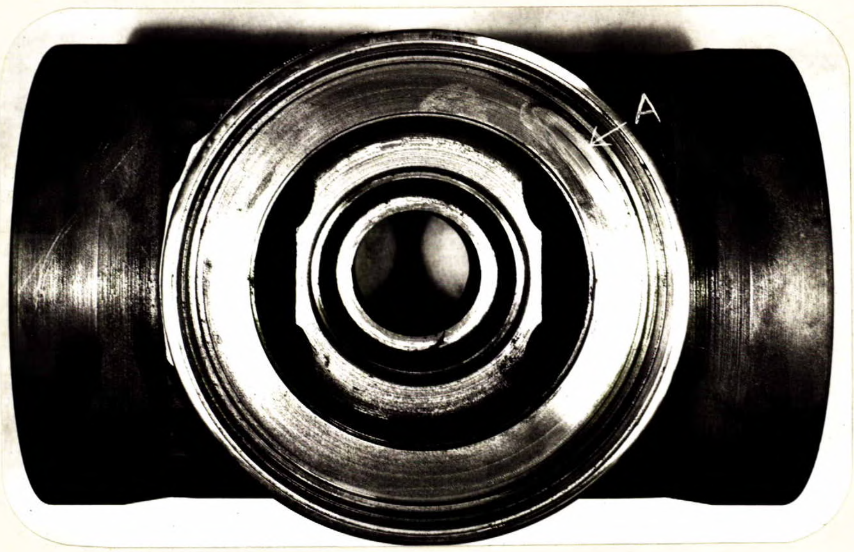
Figure 1.



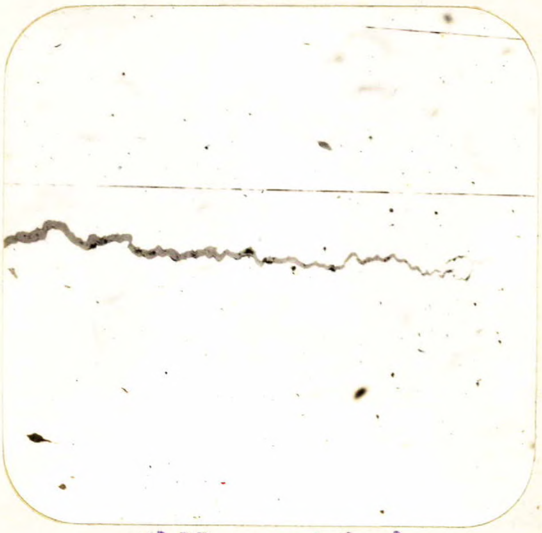
SHOWING A PROPELLER HUB AS RECEIVED.

Figure 2.

X100, unetched.

SHOWING THE APPEARANCE OF THE CRACK AND INCLUSION IN THE "AS RECEIVED" MATERIAL.

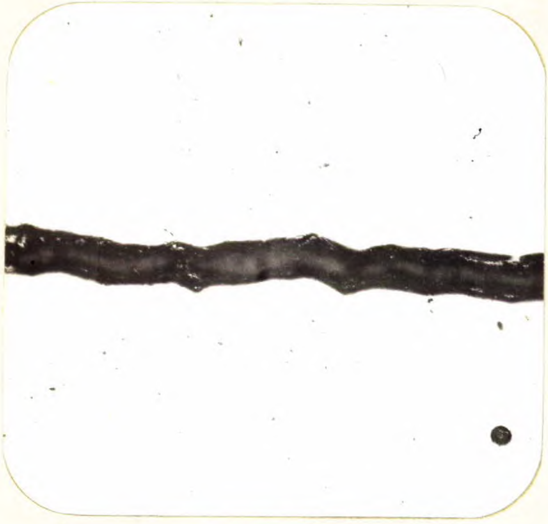
Figure 3.



X100, unetched.

SHOWING THE COMPLETE FILLING OF THE CRACK, WITH THE FeO INCLUSION IN THE "AS RECEIVED" MATERIAL.

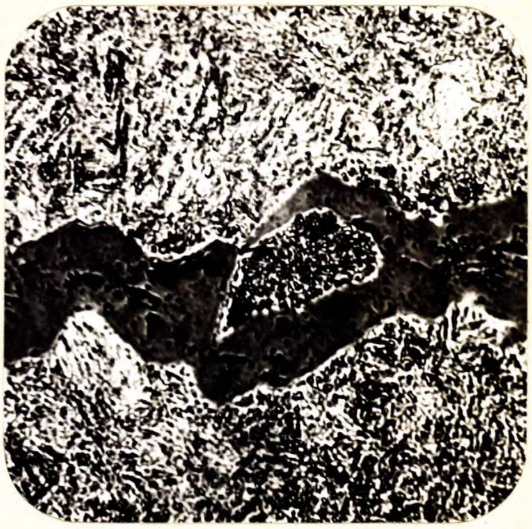
Figure 4.



X100, unetched.

SHOWING THE DISAPPEARANCE OF THE INCLUSION AFTER TREATING IN A HYDROGEN ATMOSPHERE AT 1100° F.

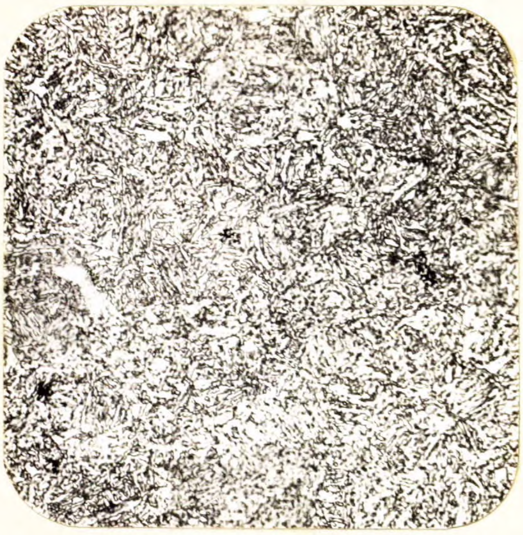
Figure 5.



X1000, picral etch.

SHOWING THE CONDITION OF THE STEEL ALONG THE INCLUSION AND SLIGHT DECARBURIZATION IN THE "AS RECEIVED" MATERIAL.

Figure 6.



X500, picral etch.

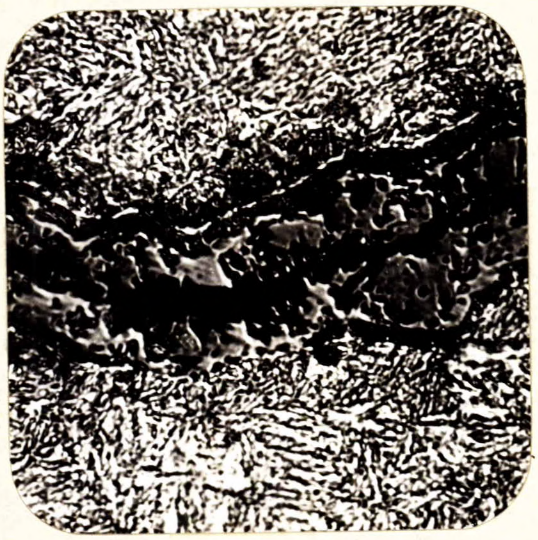
SHOWING THE MICROSTRUCTURE OF THE "AS RECEIVED" MATERIAL.

Figure 7.

X100, unetched.

SHOWING AN ARTIFICIALLY MADE AND OXIDIZED CRACK.

Figure 8.



X1000, picral etch.

SHOWING THE MICROSTRUCTURE AND EXTENT OF DECARBURIZED ZONE ALONG THE ARTIFICIALLY MADE AND OXIDIZED CRACK.

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