File

FILE COPY

O T T A W A   November 13th, 1944.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1742.

Metallurgical Examination of Fractured
Steel Aircraft Bolt.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
-
Physical Metallurgy
Research Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

O T T A W A   November 13th, 1944.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1742.

Metallurgical Examination of Fractured
Steel Aircraft Bolt.

Origin of Material and Object of Investigation:

On August 28th, 1944, a fractured steel bolt (see Figure 1) was submitted, for metallurgical examination, by H. M. Kemp, for Chief Inspector, British Air Commission, 1785 Massachusetts Avenue, Washington, D. C. This bolt had been intended for use in the engine mount of a Douglas "Dakota" aircraft.

Mr. Kemp's covering letter, dated August 25th, 1944, File No. PA/58784, stated that a relatively large number of these bolts had failed in a similar manner, both before and after assembly into the structure. The bolt under examination had failed during the initial tightening. No detailed information concerning the method of manufacture or the alloy used was available. The opinion was expressed that the failure developed

(Origin of Material and Object of Investigation, cont'd) -

from strain cracks introduced possibly during the formation of the heat. The letter requested:

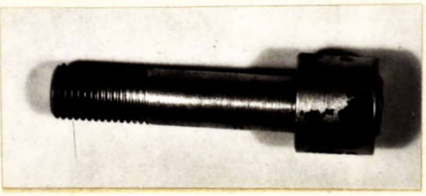
(1) A macro photograph of a section through the head of the bolt, to confirm the contention that the heat was produced by an up-ending (i.e. "upsetting") operation.

(2) An opinion as to the possible cause of the failure.

ooo

A request was subsequently made by these Laboratories for additional sample bolts, which would be necessary for a complete investigation, but no additional bolts were available at the time of writing. Consequently, this report will be necessarily of a general nature.

Figure 1.



STEEL AIRCRAFT BOLT, FRACTURED AT JUNCTION OF STEM AND HEAD.

-

Chemical Analysis:

A sample of the bolt was submitted for chemical analysis. In Table I the results are given and a comparison made with the chemical limits specified for an SAE 4135 steel.

(Continued on next page)

(Chemical Analysis, cont'd) -

TABLE I.

		As Found	Specification SAE 4135
		- Per Cent -	
Carbon	-	0.37	0.30-0.40
Manganese	-	0.85	0.60-0.90
Silicon	-	0.58	
Sulphur	-	0.007	
Phosphorus	-	0.019	
Chromium	-	0.98	0.80-1.10
Molybdenum	-	0.16	0.15-0.25

Hardness Test:

The hardness was obtained on a Vickers hardness tester, using a 20-kilogram load. This was found to be:

406 Vickers (average of 4 readings),
or 41 Rockwell 'C'.

Microscopic Examination:

Samples were cut and examined in the etched as well as in the unetched condition. Figure 2 shows, at X750 magnification, the microstructure obtained by etching in 2 per cent nital. The structure is typical tempered martensite.

Figure 3 is a macro photograph of a section through the fractured head of the bolt which had been etched in 50 per cent HCl. The flow lines indicate that the head was made by the "upsetting" method.

(Continued on next page)

(Microscopic Examination, cont'd) -

Figure 2.

X750, nital etch.

MICROSTRUCTURE, CONSISTING OF TEMPERED MARTENSITE.

-

Figure 3.

FLOW LINES PRODUCED BY "UPSETTING" METHOD OF FORGING.

(Approximately 2½ times normal size).

-

Examination of the steel in the unetched condition indicates that it is fairly clean and free from inclusions.

Discussion of Results:

SAE 4135 steel, from which this bolt is made, is widely used for highly stressed bolts in aircraft structures. The specifications call for a heating range of from 1575° F. to 1650° F., followed by oil quenching and a draw at 950° F. This heat treatment would result in a hardness of 40 Rockwell 'C'.

Since the hardness of the bolt was found to be 406 Vickers, or 41 Rockwell 'C', it would appear that the drawing operation must have been in the neighbourhood of 950° F.

Because many of the bolts had failed previous to assembly into the structure, it is obvious that these failures

(Discussion of Results, cont'd) -

are not due to fatigue. However, it is also possible that failures occurring after assembly may have resulted from fatigue.

It has been suggested in the literature that failures similar in character to that encountered in these bolts are due to inclusions in the steel. However, this suggestion may be discounted for the bolt under examination, because of the relative cleanliness of the steel.

Failure of the bolt could have occurred as a result of any one of the following:

(1) Faulty forging practice.

(2) Improper heat treatment after forging.

(3) Faulty design of the fillet.

(4) Overstressing of the bolt during installation.

(5) Insufficient tightening of the nut, resulting in failure due to fatigue.

(6) Careless machining or grinding.

...

(1) Faulty Forging Practice.

If the forging operation is carried on at too low a temperature, excessive stresses are set up in the bolt and would result in failure. Examination of cracks formed during the forging operation will usually reveal heavy decarburization. Practically no decarburization along the fractured edge was evident, thus confirming that, for this particular bolt, failure had occurred subsequent to the forging operation.

(2) Improper Heat Treatment after Forging.

SAE 4135 chrome-molybdenum steel is deep hardening and must be quenched in oil. If too severe a quench is employed, such as water quenching, very severe internal stresses would be set up resulting in failure. Delay in drawing after the

(Discussion of Results, cont'd) -

quenching operation would greatly increase the danger of cracking. Hence, it is important that the time interval between the quench and the draw be kept to a minimum.

(3) Faulty Design of the Fillet.

High strength bolts (200,000 p.s.i. tensile and over) are very susceptible to brittle failure underneath the head, due to insufficient radius of the fillet. It is claimed* that the embrittlement of the head is dependent primarily, not upon the fibre as determined by the heading process, but upon the notch effect of the head contour (fillet). It has also been proven that this embrittlement is greatly increased by eccentric loading, that is, the application of bending superimposed on tension, often resulting in a reduction of the strength down to 20 per cent of the ultimate. The deleterious effect of eccentric loading may be minimized by the employment of a generous fillet (1/16-inch radius).

(4) Overstressing of the Bolt during Installation.

A very frequent cause of bolt failure may be attributed to the overstressing of the bolt by the man with the wrench, and this feature should not be overlooked.

(5) Insufficient Tightening of the Nut, Resulting in Fatigue Failure.

For those bolts which may have failed in fatigue, the most likely reason for such failure is insufficient tightening of the nut. A properly tightened nut is one that applies a tension load to the bolt that is equal to or greater than the external load to be supported in service. A bolt so tightened is placed under a minimum of stress change and will not fail

---

* G. Sachs: "Strength of Heat Treated Alloy Steel Bolts." Trans. A.S.M., 1944, Vol. 33, p. 396.

(Discussion of Results, cont'd) -

in fatigue.

(6) Careless Machining or Grinding.

If the machining or grinding operations leave imperfections in the fillet, areas of high stress concentration will be produced which greatly increase the danger of failure under the head.

CONCLUSIONS:

1. The head of the bolt was produced by the "upset" method of forging.

2. The steel from which the bolt was made is satisfactory. Hence, the failure did not occur as a result of faulty material.

3. Generally speaking, failures could have occurred from any one of the following reasons:

(a) Faulty forging practice.

(b) Improper heat treatment after forging.

(c) Faulty design of the fillet.

(d) Overstressing of the bolt during installation.

(e) Insufficient tightening of the nut, resulting in fatigue failure.

(f) Careless machining or grinding.

However, in this particular case, it is most likely that failure occurred because of reasons (c) or (d).

ooooooooooo
ooooo
o

AF:GHB.