File.

FILE COPY

O T T A W A May 21, 1945.

# REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1874.

## Metallurgical Examination of Broken Bolt from Type C-4 Liberator Gas Filter.

==========

(Copy No. 10.)

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

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

OTTAWA May 21, 1945.

# REPORT

of the

# ORE DRESSING AND METALLURGICAL LABORATORIES.

## Investigation No. 1874.

## Metallurgical Examination of Broken Bolt from Type C-4 Liberator Gas Filter.

---

### Origin of Material and Object of Investigation:

On April 16, 1945, two bolts (see Figure 1), taken from a Type C-4 Liberator gas filter and of which one had failed in service, were submitted by the Director of Aeronautical Inspection, for Chief of the Air Staff, Department of National Defence for Air, Ottawa, Ontario. A complete filter unit (see Figure 2), to serve for purposes of comparison, was also submitted.

The covering letter, dated April 21, 1945, File No. 938 HL-1-14 (AMSO DAI), contained the following information:

(Continued on next page)

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

1. The bolt was taken from a crashed aircraft and had been exposed to considerable heat produced by fire.
2. The cause of the crash is obscure, but it has been suggested that the bolt failure may have been the origin of a gasoline leak which resulted in an engine fire in flight, followed by ultimate crashing.
3. It is to be noted that the failed bolt (designated No. 1, Figure 1) does not correspond with its counterpart (No. 3, Figure 2) in that there is no shoulder on the shank. This suggests that a substitution was made, either in the field or by the manufacturer.
4. It was requested that a metallurgical examination be made to determine the cause of failure.

• •

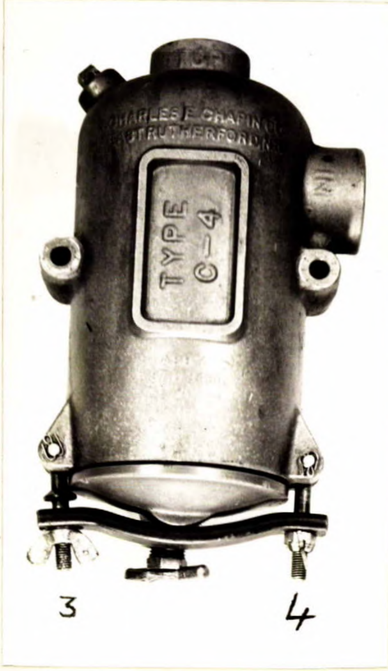
For purposes of identification, the two bolts removed from the crashed plane are designated as Nos. 1 and 2, and the bolts on the unit supplied, said to have withstood 400 hours of service, are designated as Nos. 3 and 4.

Figure 1.

BOLTS REMOVED FROM FILTER UNIT OF CRASHED LIBERATOR AIRCRAFT.

(Approximately 3/4 actual size).

Figure 2.



TYPE C-4 LIBERATOR GAS FILTER UNIT.

(Approximately 1/3 actual size).

Chemical Analysis:

The results of the chemical analysis made on the broken bolt (No. 1) and the good bolt (No. 3) are compared with the chemical limits of an SAE 4130 steel in Table I.

TABLE I. - Chemical Analysis.

| | | Broken Bolt, No. 1. | Good Bolt, No. 3. | Specification SAE 4130 |
|---|---|---|---|---|
| | | - Per Cent - | | |
| Carbon | - | 0.31 | 0.36 | 0.25-0.35 |
| Manganese | - | 0.84 | 0.63 | 0.50-0.80 |
| Silicon | - | 0.32 | 0.28 | |
| Chromium | - | 0.92 | 0.83 | 0.50-0.80 |
| Molybdenum | - | 0.18 | ** | 0.15-0.25 |
| Vanadium | - | Nil. | Nil. | |
| Nickel | - | Trace. | Trace. | |

---

** Insufficient sample.

Hardness Examination:

Hardness tests made with a Vickers hardness tester gave the following readings:

| | | Hardness | |
|---|---|---|---|
| | | Vickers (20-kg. load) | Rockwell "C" |
| Broken bolt (No. 1) | - | 313-321 | 31-32 |
| Good bolt (No. 3) | - | 337-341 | 34-35 |

Microscopic Examination:

Figures 3 and 4, both at X50 magnification, show the contour of the threads of the broken and good bolts respectively.

Figures 5 and 6, taken at X1000 magnification, show the microstructures of the broken bolt and good bolt respectively. The microstructures are similar, consisting of tempered martensite. The structure in Figure 6 is coarser than that in Figure 5, indicating a higher heating temperature before quenching.

Figures 7 and 8, taken at X500 magnification, (Microscopic Examination, cont'd) -

indicate the average extent of decarburization occurring in the broken and good bolts respectively.

Discussion:

The chemical analysis shows that both bolts examined were made from SAE 4130 steel (which is widely used for aircraft bolts).

The hardness tests indicate a slightly lower hardness for the broken bolt. However, this difference is not of very great significance. The hardness value of the broken bolt (31 to 32 Rockwell "C") corresponds to a tensile strength of approximately 155,000 pounds per square inch, which is well above the minimum of 125,000 per square inch required by U.S. Army Specification 57-107-19B.

The microstructure of the broken bolt (see Figure 5) is normal for a quenched and drawn steel.

Figure 7 shows decarburization to a depth of approximately 1/1000 inch at the threads of the broken bolt, incurred during the heat treatment. The decarburization did not result from the fire that consumed the aircraft, since the microstructure and hardness of the bolt indicate that the bolt had not been heated to a temperature high enough to cause decarburization. The presence of decarburization is significant in that it results in a considerable decrease in fatigue strength. However, it should be noted that some decarburization was also evident in the good bolt (see Figure 8) which had withstood 400 hours of service before removal, although the extent of the decarburization is not as great.

Since very little distortion of the metal accompanied the fracture it is concluded that failure had resulted from

(Discussion, cont'd) -

either of:

(1) Sudden impact.

(2) Fatigue.

Sudden Impact -

No noticeable disfigurement which would definitely point to sudden impact was evident in either the nut or the bolt.

Fatigue -

Several factors which suggest fatigue failure were observed. Of these only one, decarburization, may be considered metallurgical, the remainder being mechanical or related to design.

(a) Decarburization -

Decarburization very seriously decreases the fatigue strength of a metal and should be avoided.

(b) Fatigue Resulting from Poor Design -

By far the most important factor involving the fatigue strength of a bolt is the proper tightening of the nut during assembly and the maintaining of that tightness during service. A properly tightened nut is one that applies a tension load to the bolt that is equal to or greater than the external load that is to be supported in service. When this condition is fulfilled, the bolt cannot fail by fatigue because it can experience practically no change in stress, regardless of the fluctuating nature of the load.

Examination of the assembled filter unit (in Figure 2) indicates that vibration of the wing nut and bolt assembly is unavoidable since the nut is tightened against the resistance of the steel bar, which has a certain amount of flexibility. In this connection it should be noted that the bolt with the shoulder (No. 3, shown in Figure 2) would be superior to the bolt which failed, since a rigid member

(Discussion, cont'd) -

could be obtained by tightening the bar up against the shoulder of the bolt. The cross-bar should, of course, be designed so that the lid will be held tightly enough to maintain a proper seal.

(c) Thread Design -

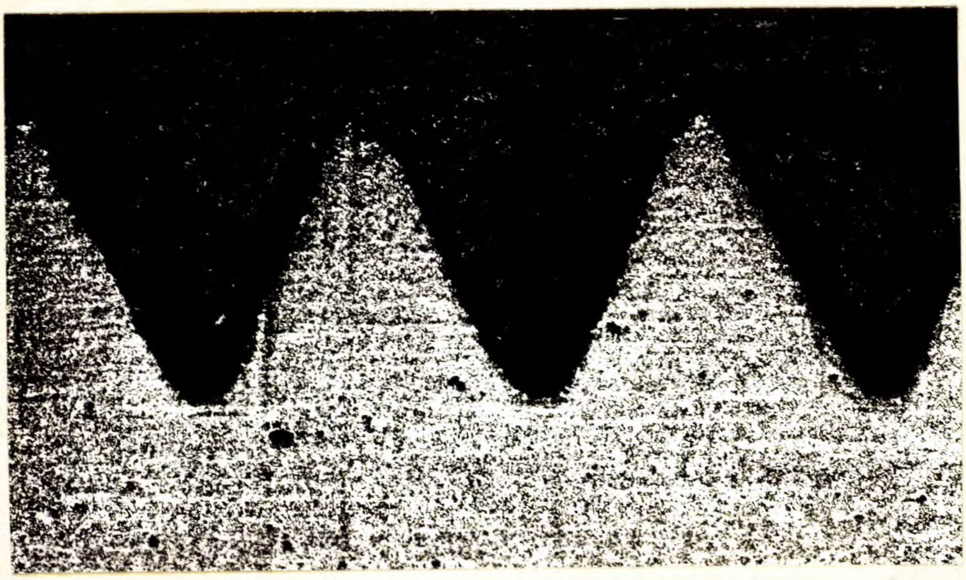
The deep and often sharp notches formed by the threads act as very severe stress raisers. Figures 3 and 4 show (because of lack of distortion at the roots) that the threads in both broken and good bolts were cut and had been heat-treated after cutting. It should be noted, however, that the root radius of the broken bolt is less than that of the good one, thus resulting in increased stress concentration at the thread roots. Hence, the thread design of the broken bolt is definitely inferior to that of the good bolt.

It is generally acknowledged that the fatigue strength of rolled threads is greater than that of cut or ground threads, and that it is possible to increase the fatigue strength of cut threads by compressively stressing the material at the thread roots by a superficial rolling operation, after heat treating.

(Figures 3 to 8 follow )
( on Pages 7 to 9. )
(Text follows on Page 10.)

(Discussion, cont'd) -

Figure 3.

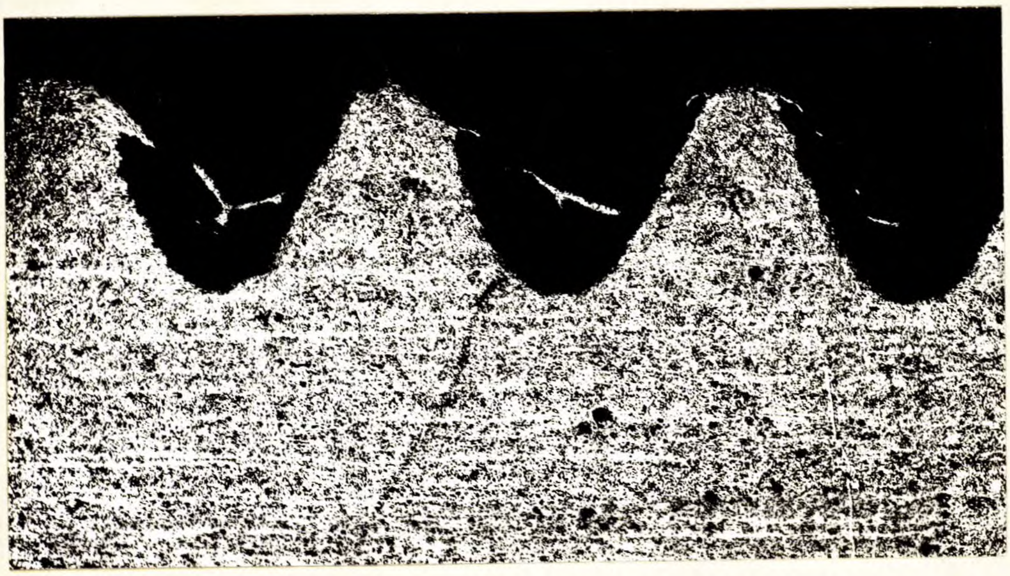


X50, nital etch.

BROKEN BOLT (NO. 1).

Threads cut from blank.
Note rather small root radius.

Figure 4.



X50, nital etch.

GOOD BOLT (NO. 3).

Threads cut from blank.
Note greater radius of root as compared with Figure 3, resulting in decreased notch sensitivity.

(Discussion, cont'd) -

Figure 5.

X1000, nital etch.

BROKEN BOLT (NO. 1).

Tempered martensite.

-

Figure 6.

X1000, nital etch.

GOOD BOLT (NO. 3).

Tempered martensite.

-

Figure 7.

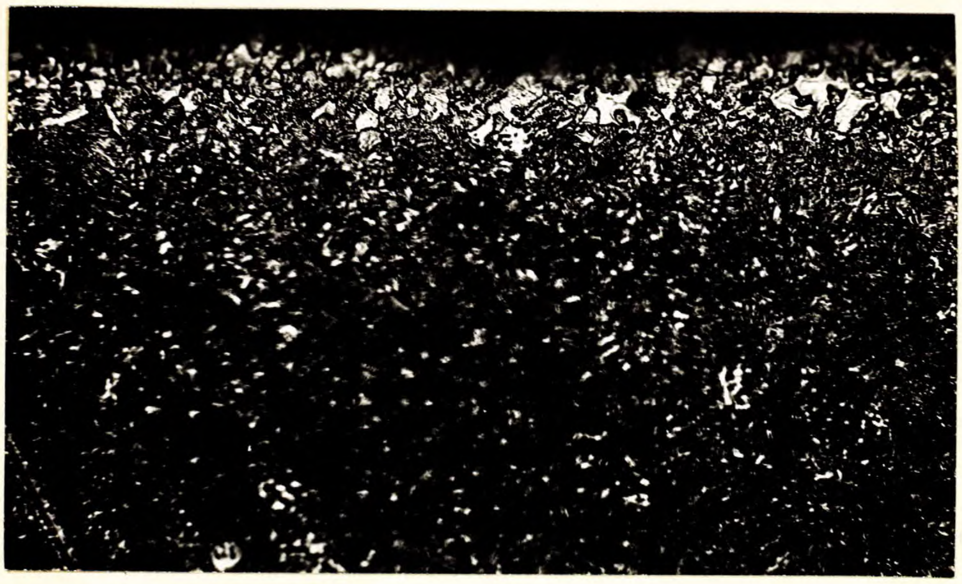
X500, nital etch.

BROKEN BOLT (NO. 1).

Showing decarburization on threads (approximately 0.001 inch).

-

Figure 8.



X500, nital etch.

GOOD BOLT (NO. 3).

Showing very slight decarburization.

Conclusions:

The following is a summary of the conclusions:

1. The steel employed in the manufacture of the failed bolt (SAE 4130) is similar to that of the good bolt examined, and satisfies the requirements of U.S. Army Specification 57-107-19B both as regards heat treatment and chemical content.

2. Failure of the bolt occurred as a result of either sudden impact on crashing, or fatigue in service.

3. Factors pointing to fatigue failure are:

(a) Decarburization along the threads.

(b) Lack of rigidity, due to faulty design of the unit.

(c) Inferior design of the threads.

4. A comparison of the failed bolt with the good one supplied with the unit revealed a superiority in design of the latter because of:

(a) Shoulder on shank permitting greater rigidity of the assembly.

(b) Greater radius of the thread roots.

Recommendations:

The following recommendations are suggested:

1. Stringent measures should be taken to prevent the employment in service of decarburized bolts.

2. The wing nut should be so tightened during installation as to apply a tension load to the bolt that is equal to or greater than the external load to be supported in service.

3. The design of the bolt assembly should be such as to ensure as great a rigidity as possible.

4. The employment of bolts containing rolled rather than cut threads; or the use of cut threads subsequently given a superficial rolling after heat treating.

(Recommendations, cont'd) -

5. The use of bolts incorporating the following design features:

(a) A large root thread radius.

(b) A shoulder on the shank to give greater rigidity.

(c) A reduced diameter of the shank up to the threaded section, in order to increase the elasticity of the bolt.

---

## References

1. "On the Strength of Highly Stressed, Dynamically Loaded Bolts and Studs." J. O. Almen - S.A.E. Journal, April, 1944.

2. "Effect of Screw Threads on Fatigue." S. M. Arnold - American Society of Mechanical Engineers, July 1943, p. 497.

oooooooooooo
oooooooo
oo

AF:LB.