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OTTAWA May 29, 1945.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1884.

Metallurgical Examination of Failed
Lever Arm Tubing from Control
System of a Crane Aircraft.

(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

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Origin of Material and Object of Investigation:

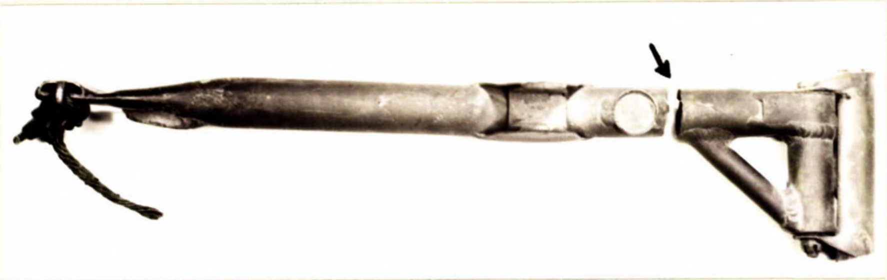
On April 5, 1945, a failed lever arm tubing (see Figure 1) taken from the control system of a Crane aircraft was submitted, for metallurgical examination, by the Director of Aeronautical Inspection for Chief of the Air Staff, Department of National Defence for Air, Ottawa, Ontario.

The covering letter (File No. 938CA-1-5 (AMSO DAI)), dated April 2, 1945, stated that the aircraft had crashed and was subsequently consumed by fire. A metallurgical examination was requested in the hope that information might be secured which would indicate the cause of the failure.

(Continued on next page)

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

Figure 1.



FAILED LEVER ARM TUBING.

(Approximately ¼ actual size).

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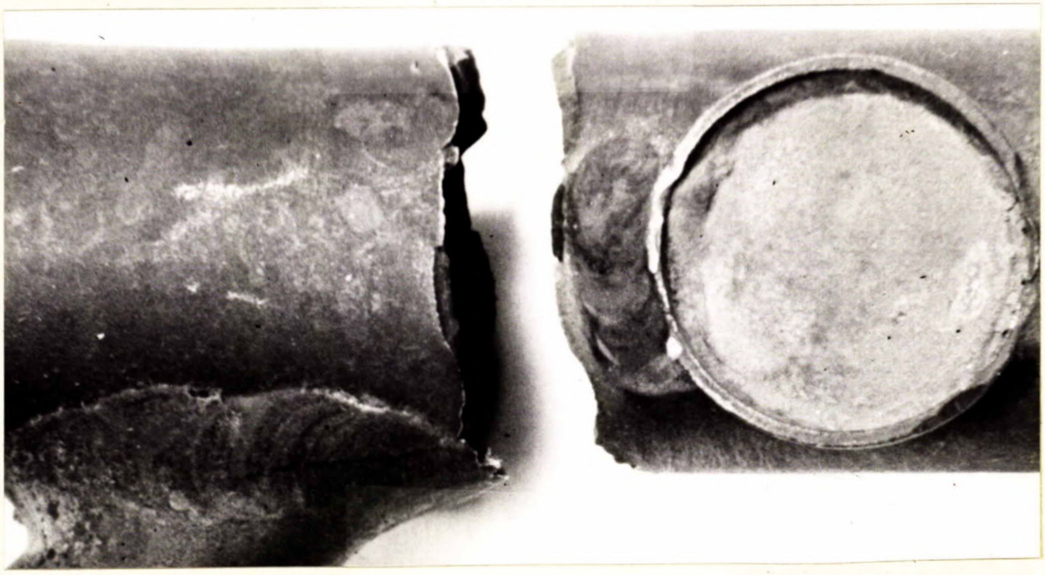
Visual Examination:

Visual examination indicated that the fracture had occurred at the toe of several welds (see Figures 1 and 2). The brittle nature of the fracture is shown in Figure 3.

Figure 2.



SHOWING POSITION OF FRACTURE.

(Approximately 2-1/3 times actual size).

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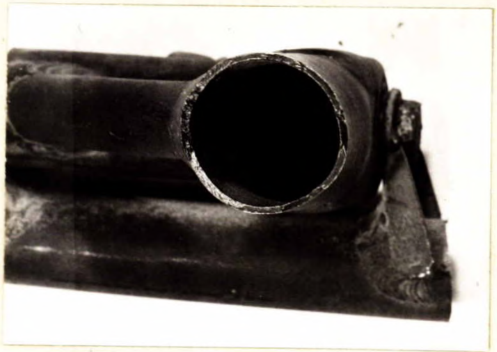
(Visual Examination, cont'd) -

Figure 3.



Note fracture suggesting brittle failure.

(Approximately 4/5 actual size).

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Chemical Analysis:

The results obtained from a chemical analysis made on the tubing is compared with the chemical limits for SAE X4130 steel in the following table:

		Found	Specification, SAE X4130
		- P e r	c e n t -
Carbon	-	0.35	0.25-0.35
Manganese	-	0.47	0.40-0.60
Silicon	-	0.30	
Sulphur	-	0.009	
Phosphorus	-	0.024	
Nickel	-	0.07	
Chromium	-	1.13	0.80-1.10
Molybdenum	-	0.27	0.15-0.25
Vanadium	-	Nil.	

Tensile Test:

The tensile properties of the tubing as received by the welder were determined by pulling, on a Hounsfield tensometer, a micro-tensile test piece cut from the tubing. In the table below, the results obtained are compared with the U.S. Army-Navy Specification AN-T-3[1] for X4130 aircraft tubing:

(Continued on next page)

(Tensile Test, cont'd) -

	As Found, p.s.i.	U.S. Army-Navy Specification, p.s.i.
Yield strength	- 83,300	75,000 min.
Tensile strength	- 104,200	95,000 "

Normalizing Experiment:

A piece of the tubing was normalized by heating at 1650° F. followed by cooling in air.

Hardness Testing:

Hardness readings, using the Vickers machine (20-kg. load), were taken on the tubing as follows:

(a) Portion of tubing remote from heat of welding.

(b) Portion of tubing adjacent to fracture.

(c) Normalized tubing.

The results are as follows:

	HARDNESS READINGS	
	Vickers (20-kg. load)	Rockwell "C" (converted)
(a) Tubing remote from heat of welds	- 254-264	24-25
(b) At fracture	- 248-310	22-31
(c) Normalized	- 329-347	33-36

Microscopic Examination:

Figure 4, taken at X1000 magnification, shows the microstructure of the tubing as supplied to the welder. The structure consists of partially spheroidized carbides in a ferrite groundmass.

Figures 5 and 6, at magnifications of X1000 and X500 respectively, are photomicrographs of sections immediately adjacent to the fracture. The structure shown in Figure 5 is spheroidized and has not been affected by the welding heat, while that in Figure 6 is martensitic in appearance and is caused by a high welding heat followed by fairly rapid cooling.

Figure 7, taken at X200 magnification, indicates the structure of the weld metal.

(Continued on next page)

(Microscopic Examination, cont'd) -

Figure 8 shows the deep notch effect produced at the toe of the weld by improper fusion. This would lead to high stress concentration.

Figure 9, taken at X500 magnification, shows the degree of decarburization evident in the tubing under examination.

Figure 10, taken at X1000 magnification, indicates the microstructure obtained by normalizing, that is, heating at 1650° F. and cooling in air. The structure is martensitic.

Discussion:

The results of the chemical analysis show that the tubing was manufactured from SAE X4130 steel and is satisfactory from the point of view of chemical content. The tensile properties satisfactorily meet the requirements of U.S. Army-Navy Specification AN-T-3.

The brittle nature of the fracture suggests that failure could have resulted from either of two causes:

(1) Sudden impact, as in a crash.

(2) Fatigue while in service.

Sudden Impact -

Failure by sudden impact, such as in a crash, would most likely occur at a section which is quite brittle or which is defective. Hardness readings taken on a cross-section of the tubing cut immediately adjacent to the fracture show a variation in hardness from 22 to 31 Rockwell "C", caused by the welding heat. It is thought that tubing having a maximum hardness of 31 Rockwell "C" would not be considered unduly brittle.

Fatigue -

Several factors which may have contributed to failure of the tubing by fatigue were noticed. These are as follows:

(Discussion, cont'd) -

(1) Spheroidized condition of the tubing.

(2) Decarburization.

(3) Notch effect at the toe of welds, caused by improper welding.

The spheroidized or partly spheroidized condition of the tubing as supplied to the welder is evident from the photomicrographs (Figure 4 and 5), and also by the hardness (24 to 25 Rockwell "C"). It is thought that tubing in this condition would be considerably weaker in fatigue strength (because of the ferrite matrix) than tubing that had been normalized, or normalized and then drawn to a temperature below that resulting in spheroidization.

SAE X4130 tubing employed in aircraft is most commonly supplied to the welder in the normalized condition. However, it is thought that because of the high hardness (33 to 36 Rockwell "C") attained on normalizing the tubing under examination, the manufacturers found it necessary to resort to a high draw in order to restore the required ductility. The drawing temperature employed was evidently high enough to cause spheroidization, which, it is felt, would result in a steel of lower fatigue strength. Assuming that this contention is true, then the obvious procedure in preventing a similar occurrence is to draw the tubing at a temperature below that resulting in spheroidization.

It should be noted that failures encountered in an aircraft previously examined (see Report of Investigation No. 1805, March 5, 1945) occurred in tubing which was very similar in microstructure, that is, partly or wholly spheroidized. This fact may lend additional support to the opinion that tubing in the spheroidized condition has lower fatigue strength.

The decarburization observed (see Figure 9) occurring both on the inside and outside surfaces of the tubing, and which must have resulted during the heat treatment (the presence of the spheroidized structure proves this), contributes very considerably to a decrease in the fatigue strength of the metal.

(Discussion, cont'd) -

The deep notch effect noted in Figure 8, resulting from improper welding technique, acts as an area of high stress concentration, thus seriously decreasing the tensile strength of the tubing. This type of defect must be avoided in aircraft components.

Conclusions:

The following is a summary of the conclusions:

1. The failed tubing was manufactured from SAE X4130 steel and satisfactorily complies with the U.S. Army-Navy specifications as regards both chemical content and mechanical properties.

2. Hardness tests made on the tubing adjacent to the failure failed to disclose undue brittleness which would result in failure by impact.

3. It is thought that failure resulted because of low fatigue strength. The factors noted which might have contributed to this condition are as follows:

(a) Partially spheroidized condition of the tubing.
(b) Decarburization.
(c) Notch effect at the toe of welds, resulting from improper welding.

Recommendations:

The following recommendations are suggested:

1. The tubing should be supplied to the heat treater in a condition so heat-treated as to avoid spheroidization.

2. Special care during heat treatment should be taken to avoid decarburization.

3. The welding technique must be of the highest quality in order to prevent the occurrence of deep notch effects and the resultant highly stressed areas.

References

1. "Bright Gas Quenching of SAE X4130 and NE 8630 Welded Aircraft Tubes." - Wm. Lehrer.

Trans. A. S. M., Vol. 33, 1944, p. 290.

2. "Flash Welding SAE 4130 Steel Tubing." - W. Pestrak and W. W. Ackerman.

The Iron Age, Jan. 25, 1945, p. 46.

3. "Weldability of NE 8630 Steel for Aircraft Structures." - A. R. Lytle and K. H. Koopman.

The Welding Journal, Feb. 1943.

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Figure 4.

X1000, nital etch.

MICROSTRUCTURE OF TUBING AS
SUPPLIED TO WELDER.

Note partially spheroidized condition.

Figure 5.

X1000, nital etch.

MICROSTRUCTURE OF TUBING IMMEDIATELY
ADJACENT TO FRACTURE.

Note spheroidized condition similar to Figure 4.

Figure 6.

X500, nital etch.

MICROSTRUCTURE OF TUBING IMMEDIATELY
ADJACENT TO THE FRACTURE.

Note martensitic appearance of structure.

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Figure 7.

X200, nital etch.

MICROSTRUCTURE OF WELD METAL.

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Figure 8.

X50, nital etch.

NOTCH EFFECT AT TOE OF WELL,
PRODUCED BY IMPROPER FUSION.

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Figure 9.

X500, nital etch.

SHOWING DECARBURIZATION.

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Figure 10.

X1000, nital etch.

MARTENSITIC STRUCTURE
OBTAINED BY NORMALIZING.

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