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OTTAWA August 2nd, 1944.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1693.

Examination of Stainless Steel Exhaust Stub from Canadian-built Mosquito 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 August 2nd, 1944.

REPORT

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ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1693.

Examination of Stainless Steel Exhaust Stub from Canadian-built Mosquito Aircraft.

Origin of Material and Object of Investigation:

On July 5th, 1944, a section of a stainless steel exhaust stub was submitted by A/C A. L. Johnson, for Chief of Air Staff, Department of National Defence for Air, Ottawa, Ontario.

The covering letter, dated July 4th, 1944, File No. 938BY-2-5(AMAE DAI), stated that this exhaust stub had been taken from a Canadian-built Mosquito aircraft after arrival in England. The material was said to be stamped "DTD 171", which identified it as 12% Cr/6% Ni stainless steel not stabilized with columbium or other addition.

This letter also pointed out that these parts were originally made of Inconel. Inconel was completely satisfactory.

It was requested that a metallurgical examination be made to determine the nature of the failure of the stainless steel exhaust stub and that, if possible, a more suitable metal be recommended for this application.

Chemical Analysis:

The results of the chemical analysis are as follows:

		Per Cent
Carbon	-	0.08
Silicon	-	0.67
Sulphur	-	0.003
Phosphorus	-	0.017
Manganese	-	0.68
Nickel	-	9.49
Chromium	-	16.57
Molybdenum	-	0.08
Titanium	-	Trace.
Aluminium	-	"
Columbium	-	None detected.

Hardness Test:

The hardness readings obtained on the Vickers hardness tester, using the 20-kg. load, varied from 143 to 166.

Microscopic Examination:

Microscopic examinations were made on sections cut from unwelded (see Figures 1, 2 and 3) and welded portions (see Figure 4) of the exhaust stub. All sections were etched in a solution of hydrochloric acid, nitric acid, and glycerine.

Figure 1 shows typical transcrystalline cracks running parallel to the failure.

Figure 2 shows the microstructure at the failure. Note complete lack of evidence of "burning" or corrosion.

Figure 3 is a photomicrograph, taken at a magnification of 50 diameters, showing the structure of the cross-section of the stainless steel sheet used to make the manifold. Note the coarse grains at either surface. These large grains may be due to either of two causes: (1) decarburization incurred during the rolling operation, or (2) lower-temperature recrystallization of the outer skin because of greater work-hardening in this area during the rolling operation.

Figure 4 shows the junction of the weld and parent

(Microscopic Examination, cont'd) -

metal. Note the precipitation of carbides, marked by dark etching areas.

Figure 1.

X100, etched.*

SHOWING TRANSCRYSTALLINE CRACKS PARALLEL TO FAILURE.

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Figure 2.

X100, etched.*

MICROSTRUCTURE AT FAILURE. (AUSTENITE).

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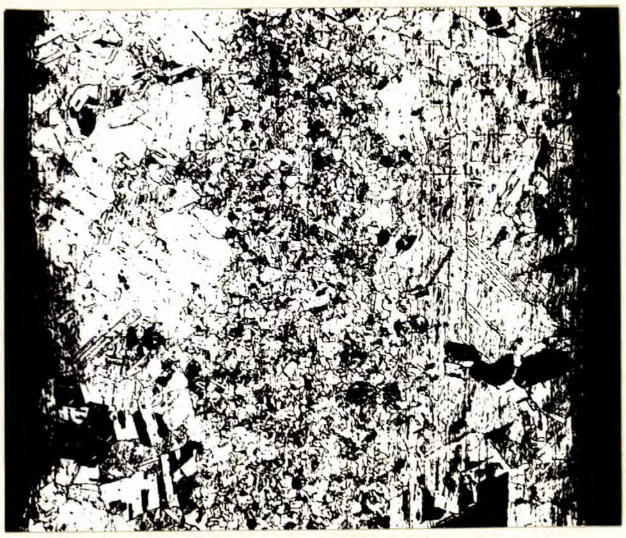
Figure 3.



X50, etched.*

CROSS-SECTION SHOWING LARGE GRAINS AT SURFACE.

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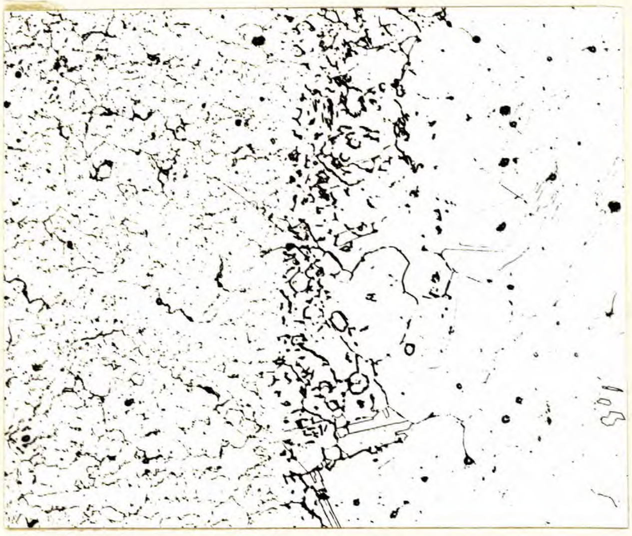
Figure 4.



X100, etched.*

SHOWING JUNCTION OF WELD (LEFT) AND PARENT METAL.

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* Etching Reagent: Nitric acid, 10 cc.
Hydrochloric acid, 25 cc.
Glycerine, 25 cc.

Discussion of Results; Conclusions:

The chemical analysis indicates that the steel is a standard 18-8 variety, and not the 12 Cr/6 Ni indicated in the covering letter.

The hardness tests and the micro-examination show that the steel is austenitic throughout and is typical of hot-rolled 18-8 stainless.

Visual and microscopic examinations of the exhaust stub at the point of failure did not reveal any evidence of "burning". Microscopic examination also failed to show any intergranular corrosion.

Micro-examination of the weld shows the presence of precipitated carbides, which may be considered normal for 18-8 steel which has not been stabilized with columbium, titanium, or other stabilizing elements. Since the failure occurred at right angles to the welds, it is reasonable to assume that the welding was not responsible for the failure.

The transcrystalline failure definitely indicates that the failure was due to either of two causes: (1) stress-corrosion cracking, or (2) simple fatigue. The fact that the steel failed a very short time after being installed would also lend support to the claim that failure had occurred due to fatigue or stress-corrosion, rather than "burning", as the failure can occur in fatigue or stress-corrosion after only a very few cycles, provided the stress is high enough.

(1) Stress-Corrosion Cracking -

This type of failure is commonly encountered in the austenitic nickel-chrome steels, and is caused by the action of a corrosive medium on a highly stressed material. This stressed condition is produced by rapid quenching, and also by welding. The corrosive medium in this case would be

(Discussion of Results; Conclusions, cont'd) -

provided by the tetraethyl-lead fumes. However, for this type of corrosion, highly corrosive atmospheres are not necessary to produce cracking.

The tendency for stress-corrosion cracking in this part may be overcome by the following stress-relieving anneal after welding: Heat for 1 hour at 1350° F. and furnace cool. In order to prevent the precipitation of carbides, which might result in intergranular corrosion, the steel should contain stabalizing elements, such as columbium or titanium.

(a) Simple Fatigue -

This implies failure due to the inferior mechanical properties of 18-8 stainless at elevated temperatures. Since failure was not encountered when Inconel was used, it is possible that the absence of failure in that material can be attributed to its better mechanical properties at elevated temperatures.

Table I, taken from the A.S.M. Handbook (1939), shows the mechanical properties of 18-8 stainless at elevated temperatures. These may be compared with the mechanical properties of Inconel at similar temperatures, as shown in Table II, which was derived from "Nickel and Nickel Alloys", published by the International Nickel Company.

TABLE I.* - Short-Time Tensile Tests on Wrought Alloys 18-8 (Type 304).

Temperature, degrees Fahrenheit	Ultimate strength, p.s.i.	Elongation in 2 inches, per cent	Reduction of area, per cent
Room	91,500	68.0	75.5
200	78,600	59.0	79.5
400	70,250	47.0	73.1
600	71,430	46.5	70.6
800	67,025	45.2	68.8
1000	61,625	44.5	69.0
1200	44,375	46.7	64.1
1400	23,650	53.2	51.0
1600	14,500	50.0	45.0

* From A.S.M. Handbook, 1939.

(Continued on next page)

(Discussion of Results; Conclusions, cont'd) -

TABLE II.* - Short-Time High-Temperature Tensile Properties of Hot-Rolled Inconel.

Temperature, degrees Fahrenheit	Ultimate strength, p.s.i.	Yield strength, p.s.i.	Elongation in 2 inches, per cent
Room	85,000	36,000	49.5
200	81,000	32,000	48.5
400	78,000	28,000	47.5
600	79,000	27,000	51.0
800	83,000	28,000	50.0
1000	79,000	22,000	21.0
1200	71,000	22,000	5.5
1400	47,000	19,000	12.0
1600	23,000	-	32.0

* From "Nickel and Nickel Alloys" (International Nickel Co.).

A study of the tables clearly shows the greater strength of the Inconel over the 18-8 stainless, at elevated temperatures. As an estimate, the fatigue strength can be taken as approximately half of the ultimate.

A variety of stainless steel which is commonly used in place of the standard 18-8, because of its increased resistance to corrosion and superior strength at elevated temperatures, is given in Table III. This is the 25-20 (Type 310).

TABLE III.** - Short-Time Tensile Tests on Wrought 25-20 (Type 310).

(C, 0.07%; Cr, 25%; Ni, 20%).

Temperature, degrees Fahrenheit	Ultimate strength, p.s.i.	Elongation, in 2 inches, per cent	Reduction of area, per cent
Room	82,380	55.0	79.0
300	73,350	51.5	78.0
500	69,870	45.0	75.0
700	70,620	48.0	73.0
900	69,120	50.5	71.0
1000	66,760	50.0	67.0
1200	47,500	24.0	29.0
1400	31,950	26.5	27.0
1600	17,900	33.0	46.5

** From A.S.M. Handbook, 1939.

A comparison of Tables I, II and III indicates that

(Discussion of Results: Conclusions, cont'd) -

the 25-20 variety of stainless steel has superior mechanical properties at elevated temperatures to the 18-8, but inferior to Inconel.

Recommendations:

1. It is suggested that 18-8 stainless steel, preferably stabilized with columbium or titanium, be tried. After welding, the manifold should be given a stress-relieving anneal of 1350° F. for 1 hour, followed by a furnace cool.

2. If the above be unsatisfactory, the stainless 18-8 should be replaced by Inconel.

3. Other stainless steels, such as the 25 Cr/20 Ni (Type 310), which has superior mechanical properties at elevated temperatures to the 18-8 but is inferior to Inconel, might be tried where the latter is not available.

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AF:HVK:GHB:PES.