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REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1748.

Metallurgical Examination of Welded Inconel Exhaust Stub for 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

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Exhaust Stub for Mosquito Aircraft.

Origin of Material and Object of Investigation:

On September 8th, 1944, one Inconel exhaust stub (see Figure 1) was received from The De Havilland Aircraft of Canada, Limited, Toronto. The shipping order, No. 23083, stated that "the above is being shipped for test purposes as per memo. from Mr. H. R. Johns, September 5th, 1944."

Visual examination revealed two defective welds in the areas marked A and B in Figure 1. At A, a crack extended along the weld for a distance of 4 or 5 inches. At B, a small crack was observed extending inward for a distance of approximately one inch from the end of the stub.

From the defective welds immediately visible in the stub received, it was apparent--and this was confirmed by the microscopic examination--that the investigation regarding the

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

causes of the defects resolved itself about the welding technique, which was thoroughly covered in O.D.M.L. Report of Investigation No. 1462, dated August 2nd, 1943. It is recommended that that report be consulted.

Figure 1.

GENERAL VIEW OF INCONEL EXHAUST STUB, SHOWING CRACKS ALONG WELDS AT A AND B.

Chemical Analysis:

Chemical analysis of the Inconel material used in this stub gave the following results:

		Per Cent
Nickel	-	80.98
Chromium	-	12.82
Iron	-	6.88
Carbon	-	0.03

Microscopic Examination:

Figure 2 is a photomicrograph, at X100 magnification, showing the normal structure obtained when there is proper fusion between the weld metal and the original metal. Note large grains adjoining the weld metal, caused by the high temperature.

Figure 3, taken at X 50 magnification, shows the crack through the weld in area A. This crack was formed, due

(Microscopic Examination, cont'd) -

to the "bridge effect" created by the welding of the two sheets not in contact with each other, as a result of improper jigging. Note the absence of enlarged grains at the adjoining edge of the Inconel sheet, because of the space between the sheets which acts as an insulator, resulting in lack of fusion.

Figures 4 and 5, taken at X50 magnification, show cracks occurring at either end of the same weld. It should be noted that the cracks occur at the toe of the weld in both cases, resulting from excessive stresses set up because of porosity and lack of fusion between the weld metal and the sheet material (see Figure 5). This sample was cut from area B.

Figure 6, taken at X100 magnification, is an enlarged photograph of the crack shown in Figure 4, illustrating the intergranular path followed by the crack. Figure 7 further illustrates intercrystalline cracking found in a sample taken adjacent to that shown in Figures 4 and 6. Figure 8 shows large gaps caused by the lack of fusion between ends of sheet. Figure 9 is a photograph showing inconsistent penetration of the weld metal.

Discussion:

Examination of the photomicrograph (Figure 3) clearly indicates the reason for the crack in the weld at area A (Figure 1). Since there is a gap between the two sheets that were welded, the resultant "bridge effect" set up would lead to excessive stresses in the weld material. It should be realized that in the primary stages of solidification the molten weld metal has very little mechanical strength, and the gap results in complete lack of mechanical support of the molten metal forming the weld. This condition can be eliminated by

(Discussion, cont'd) -

closer contact between the sheets to be welded, by means of proper jigging.

The cracks at the toe of the weld, shown in Figures 4 and 5, are caused by lack of fusion between the weld metal and the sheet metal, producing areas which are too weak to withstand the contraction stresses of the cooling weld metal. Lack of fusion may result from the incomplete removal of tightly adhering oxide film from the surfaces to be welded. The porosity shown in Figure 5, which is caused by excessive welding heat, would also result in a serious weakening of the weld metal.

Severe intercrystalline attack, as shown in Figure 6, will result when the atmosphere is permitted to become excessively oxidizing during the welding operation. These cracks may possibly have originated at the welding surface as a result of severe oxidation along grain boundaries. A crack thus initiated follows an intercrystalline path. This type of embrittlement can be prevented by maintaining a constant slight excess of a reducing gaseous atmosphere (acetylene) during welding.

Lack of fusion between ends of sheets, as shown in Figure 8, is probably caused by improper alignment between the edges to be welded, as indicated by the width of the gap. Another possible cause is improper torch manipulation, which has resulted in the metal not being brought to the fusion temperature along the joint.

Figure 9 illustrates inconsistent penetration of the weld metal. It will be noted that in some areas very complete penetration has been secured whereas in others the unfused edges of the joint are clearly visible. Incomplete fusion of this type is a very probable cause of cracking in parts subjected to rapid vibration at high temperatures.

Conclusions:

The evidence in this investigation discloses that the cracks were formed as a direct result of faulty welding technique. (This type of cracking must not be confused with that encountered in the stainless steel exhaust stub investigated by these Laboratories in August, 1944, (see Report of Investigation No. 1693), in which investigation it was found that the cracks were of a transcrystalline nature and were caused as a result of stress corrosion, bearing no relation to the welding technique.)

The following welding defects were found:

1. Improper jigging, resulting in considerable space between sheets to be welded.

2. Porosity, which usually results from excessive welding heat.

3. Lack of fusion, resulting from improper oxide removal and insufficient welding heat.

4. Intercrystalline cracking, probably resulting from excessive welding heat accompanied by an oxidizing atmosphere. High welding temperatures cause rapid oxidation along grain boundaries, which initiates cracking.

5. Improper alignment, resulting in lack of fusion.

6. Incomplete penetration, caused by irregular welding speed and also possibly by insufficient heat input.

Recommendations:

It is recommended that the welding technique be reviewed in the light of the information disclosed in this investigation.

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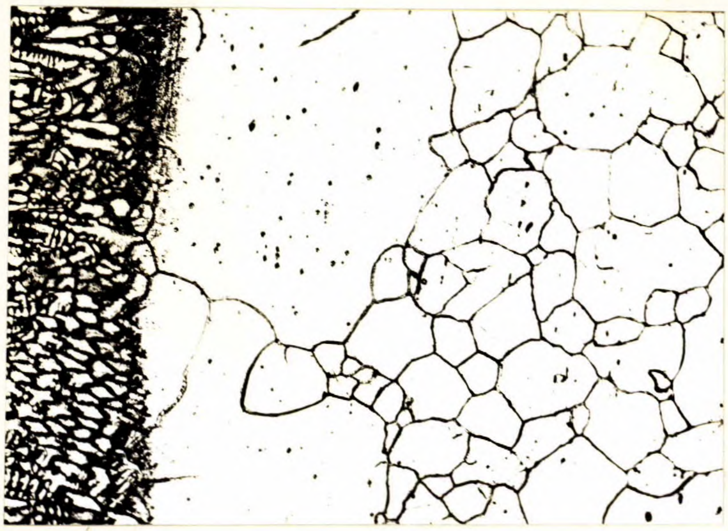
Figure 2.



X100, aqua regia and glycerine etch.

NORMAL STRUCTURE OBTAINED BY PROPER FUSION OF
WELD METAL ONTO ORIGINAL METAL.

Note large grain size adjoining weld metal.

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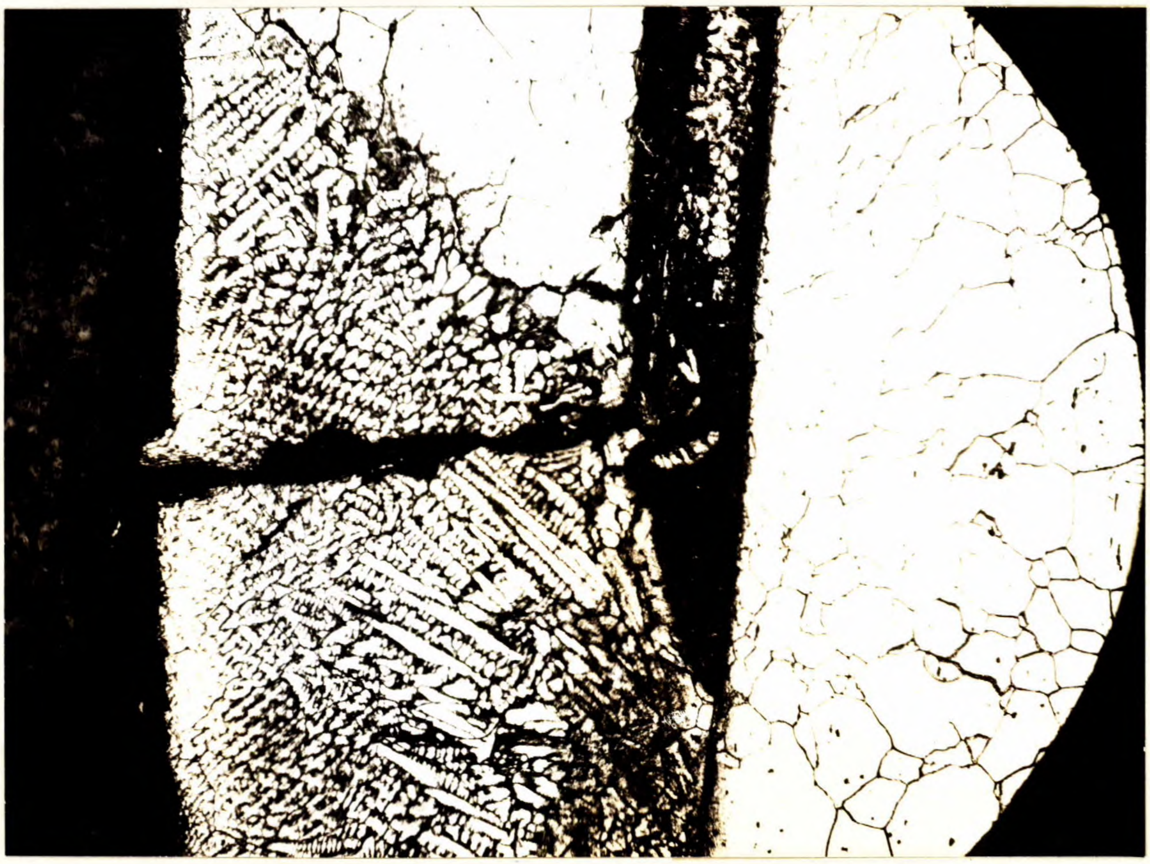
Figure 3.



X50, aqua regia and glycerine etch.

CRACK IN WELD AT SECTION A.

Due to space between sheets, resulting
in weak "bridge" effect. Caused by
improper jigging.

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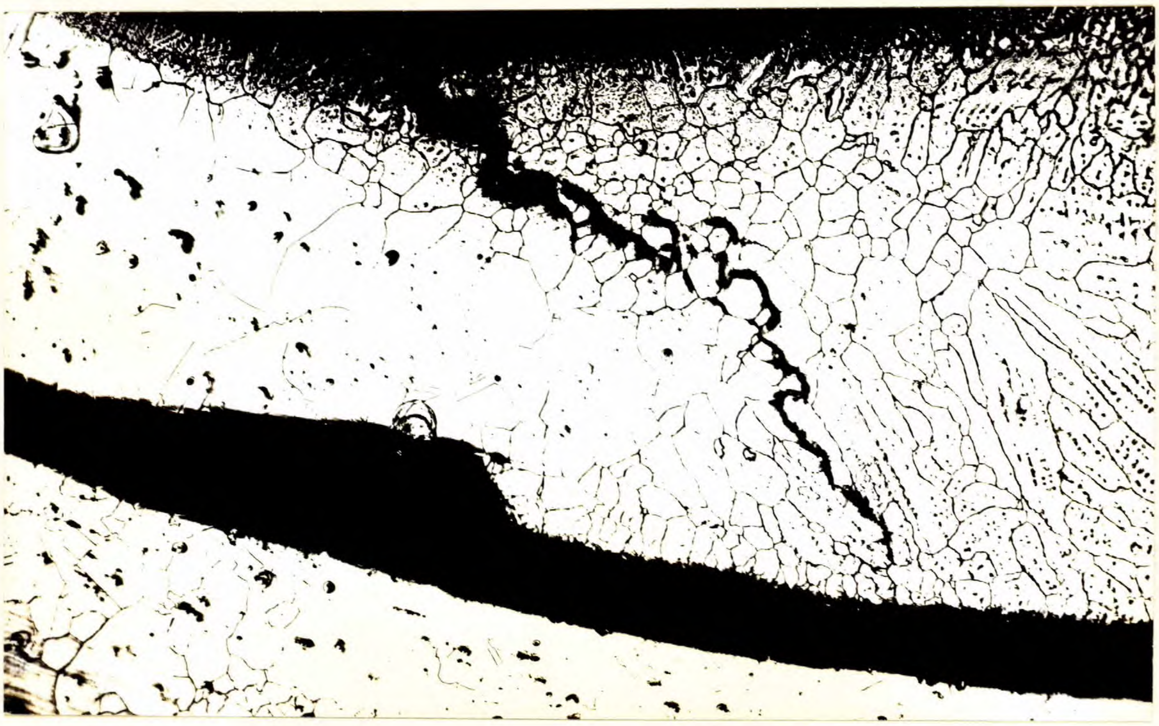
Figure 4.



X50, aqua regia and glycerine etch.

CRACK OCCURRING AT TOE OF WELD, DUE TO IMPROPER FUSION.

(Section taken from area B).

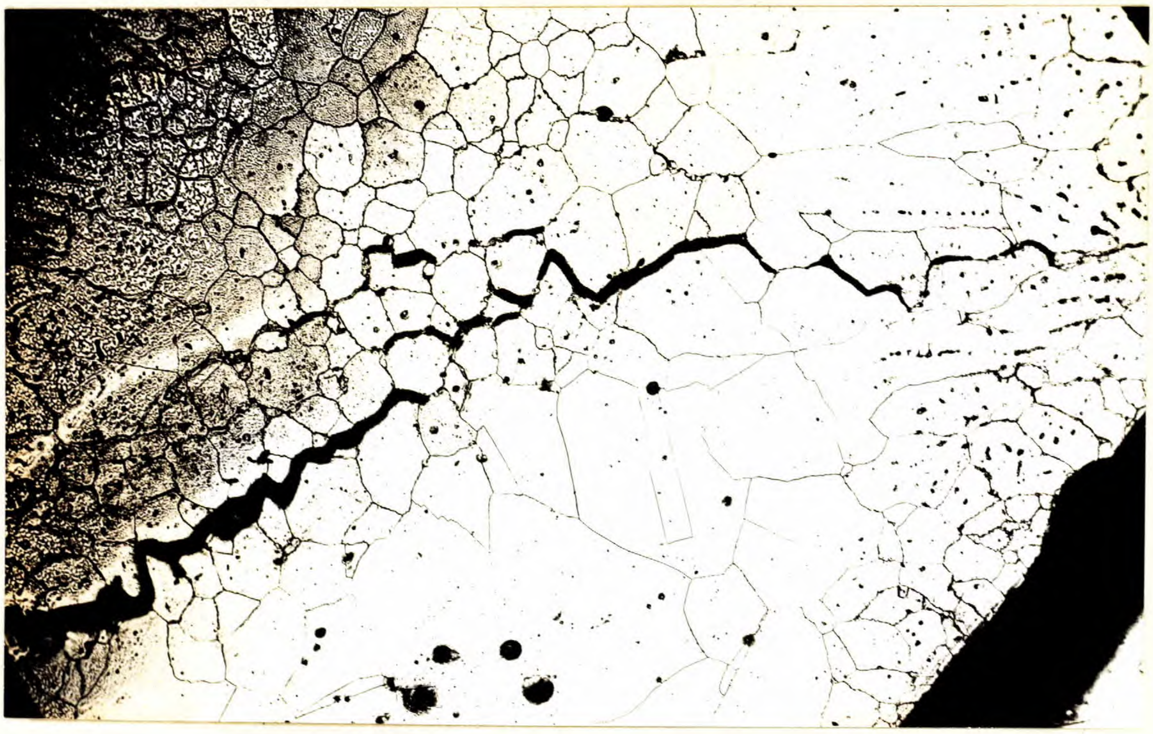
Figure 5.

X50, aqua regia and glycerine etch.

CRACK OCCURRING AT OTHER EDGE OF WELD, CAUSED BY LACK OF FUSION AND POROSITY.

(Section taken from area B).

Figure 6.

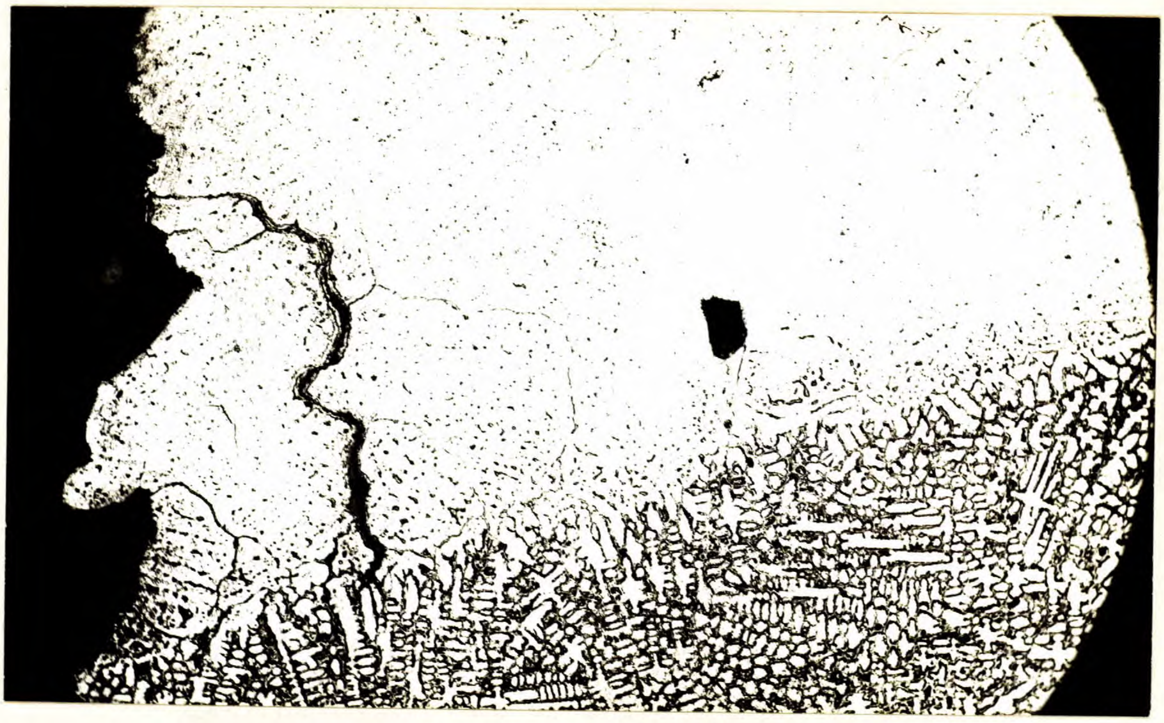


X100, aqua regia and glycerine etch.

SHOWING INTERGRANULAR PATH OF CRACK AT TOE OF OF WELD, CAUSED BY LACK OF FUSION.

(Area B).

Figure 7.



X50, aqua regia and glycerine etch.

INTERGRANULAR CRACKS ADJACENT TO FRACTURE.

Note also large blow hole.

(Area B).

Figure 8.

X50, aqua regia and glycerine etch.

LACK OF FUSION BETWEEN ENDS OF SHEET.

(Area B).

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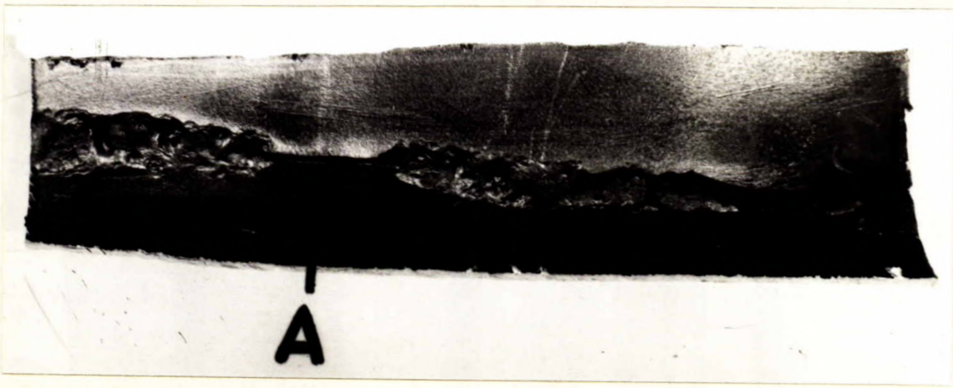
Figure 9.



INSIDE OF WELD.

Note incomplete penetration of weld metal at A.

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