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EXAMINATION OF A FAILED UNDERGROUND FAN FROM DENISON MINES LIMITED, ELLIOT LAKE, ONTARIO

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

The examination of some aluminum alloy fan blades, which had failed in service at Denison Mines Limited, Elliot Lake, Ontario, indicated that operating conditions had been extremely corrosive, and that the failures had been due to corrosion-fatigue. Diesel fumes appeared to have contributed to the corrosivity of the operating environment.

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INTRODUCTION

Several pieces of failed 72 in. fan blades, and the hub of one of these blades, were received for examination by the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, from Mr. F. C. Lendrum, Mill Superintendent, Denison Mines Limited, Elliot Lake, Ontario.

In the covering letter, dated December 28, 1964, Mr. Lendrum stated that ".....these blades have failed after six years' service. The first three years the fan was in fresh air and the last three years in the exhaust airway". He also stated that "....mining is trackless and the exhaust air would carry the combustion products from the diesels". He further stated that he was interested in knowing if corrosion caused the failure, and whether a different alloy should be employed in this application.

In a letter dated February 17, 1965[1] Mr. Lendrum was informed that investigations by the Physical Metallurgy Division had indicated that the aluminum alloy fans had been operating in an extremely corrosive environment, and that the failures appeared to have resulted from corrosion-fatigue. It was further suggested that such measures as anodizing and/or suitable plastic coating, coupled with improved maintenance, should extend the operating life of the fans.

The present report describes the detailed examination of the pieces of fan sent by Denison Mines, which enabled the above conclusions to be reached.

EXAMINATION OF AS-RECEIVED MATERIAL

The pieces of the fan blades and the hub were photographed in the as-received condition (Figure 1). There appeared to be a total of six fracture faces (the notched end of sample 3 being the tip of a fan blade). The samples were apparently selected at random, as none of the fracture faces could be fitted together. Three of the as-received pieces were covered with a dark, thick adherent deposit, which suggested that they might have been stored in some dirty, perhaps highly corrosive, location after failure. The hub (Sample 1, Figure 1) exhibited patches of an adherent, white chalky substance, but showed less of the dark adherent deposit noted on the other three pieces.

Examination of the Adherent Deposit

The deposit on the surfaces of the pieces of fan blades was, for the most part, black with some white areas. When scraped, it came off mainly in the form of flakes.

Examination by stereomicroscope revealed small hard particles embedded in this deposit. These particles were mostly less than 1/16 in. in diameter, and of varying shapes, sizes and colours. It was assumed that they were fragments of rock from the mining operation.

Samples of the adherent deposit were submitted for wet analysis of sulphate, chloride and carbon. The results, which appear in Table 1, showed that sulphate and carbon were present in considerable quantities, but chloride was detected only to an insignificant extent.

TABLE 1

Wet Analysis of Deposit on Fan Surfaces (Per Cent)

Sample Description	Sulphate	Chloride	Carbon
From fracture surface at hub of sample No. 2	11.9	-	-
From both sides of blade - sample No. 2	3.8	0.01	3.4
From both sides of blade - sample No. 3	13.6	0.02	5.1
From both sides of blade - sample No. 4	7.2	0.02	3.8

Laboratory Tests on the Deposit

A sample of the deposit, obtained from Sample 2 (Figure 1), was mixed with distilled water (pH 5.8) at 78°F (26°C). The pH of the resulting slurry was then measured and found to be 4.3, thus indicating that the deposit was slightly acidic.

To determine the corrosivity of the deposit on aluminum in the presence of moisture, a portion of the deposit was placed on the surface of a piece of clean, bright, 65S-T6 aluminum and kept in a moist atmosphere. Conditions were such that, for the duration of this test, the entire surface of the test piece of aluminum, as well as the deposit, was kept moist. After two weeks of exposure to this environment the entire surface of the test piece was heavily stained and a number of relatively deep pits had developed in the area that had been in direct contact with the deposit.

Chemical Analyses

Chemical analyses of drillings from Sample 4 (Figure 1) yielded the results of Table 2. The composition is seen to correspond reasonably well with that of "Alcan" casting alloy 135.

TABLE 2

Chemical Analyses of Fan Blade

	Composition (Per Cent)							
	Si	Cu	Fe	Mg	Mn	Ni	Cr	Ti
Sample 4	7.11	0.13	0.40	0.20	0.15	0.20	0.06	0.10
"Alcan" Alloy 135	6.5-7.5	0.20	0.50	0.20-0.40	0.10	-	-	0.20

VISUAL EXAMINATION OF FAN BLADES AFTER CLEANING

The adherent deposit was removed from the surfaces of the pieces of fan blades by sand blasting. Care was taken to minimize abrasion of the aluminum during this operation.

The convex surfaces of the pieces of blades were found to be generally rough, with numerous deep pits (Figure 2). The concave surfaces were found to be rough for the most part with numerous deep pits, but there were also some smooth areas (Figure 3). Most of the pits observed contained a black residue.

From the more severe corrosion of the convex surfaces of the pieces of fan blades, it was assumed that they had been so positioned that they had been subjected to impingement of abrasive particles carried in the exhausted air.

The thick, or leading edges, of the blades were severely roughened (Figure 4) while the thin, or trailing edges, were relatively smooth. This, again, was attributed to the impingement of abrasive particles upon the leading edges. Some cracks, such as the one illustrated in Figure 5, were observed at the leading edges of the blades.

Examination of the fracture surface of Sample 1 (Figure 1) revealed that failure had occurred in two stages. From Figure 6 it may be seen that there were two relatively smooth semi-circular areas on the fracture surface. These smooth areas were covered with corrosion product. The remainder of the fracture was bright and quite rough, and seemed to represent an area of rapid fracture.

The overall corrosive action of the thick deposit, subsequent to the fractures, prevented as clear-cut a demonstration of a two-stage cracking process for the other fracture faces. However, it could be seen (Figure 1) that the fractures usually exhibited two intersecting planes, inclined at different angles to the edge of the blade. Presumably, one of the planes represented a relatively slow corrosion-assisted cracking, and the other rapid cracking, which occurred when the amount of remaining metal became insufficient to support the operating load.

METALLOGRAPHIC EXAMINATION

A transverse section of a fan blade was obtained from Sample 3 (Figure 1) and a macro-photograph was taken (Figure 7). This figure provides additional evidence that both surfaces of the blade were extensively pitted. It also demonstrates that the casting was very porous.

A micro-specimen was obtained from Sample 2 (Figure 1) transverse to the fracture, at the hub of the blade, as indicated in Figure 8. The structure of the unattacked alloy was seen to consist of aluminum dendrites surrounded by fine eutectic (Figure 9).

It was observed that the corrosion attack was concentrated on the aluminum phase of the eutectic (Figure 10).

Examination of several additional micro-specimens, obtained from other representative areas of the pieces of fan blades, confirmed the findings described above.

DISCUSSION

It was evident from the extreme surface roughening and pitting that the fans had been operating in an extremely corrosive environment. Failure appeared to have resulted from corrosion-fatigue, and some of the fractures showed evidence that the cracking had occurred in two stages. In the initial stage, cracking could be assumed to initiate at some particularly deep pit, in an area of high stress. A good example of this process is illustrated in Figure 5. This initial cracking then propagated, accelerated by corrosion, until the uncracked metal remaining in the fan cross-section was insufficient to withstand operating stresses. The second stage, a rapid cracking, then occurred.

The deposit scraped from the fan blades was assumed to be characteristic of the operating environment. It contained carbon and slightly acid sulphates and was found by laboratory experiment to induce pitting in an aluminum alloy. Both the carbon and the sulphates could be assumed to arise from the diesel fuel, the carbon from incomplete combustion and the sulphates from the combustion of sulphur to sulphur oxides, then combination with atmospheric moisture to sulphuric acid, followed by corrosive attack on the aluminum alloy to yield sulphates. It is known that graphite causes appreciable galvanic corrosion of aluminum, in the presence of a suitable liquid corrodent[2]. In the present case, it appears that carbon, which has an appreciable electrical conductivity, acted in the same way in the presence of dilute sulphuric acid condensate.

Though it appeared that the primary cause of the fan failure was the extremely corrosive operating conditions, the significant porosity of the casting, once the corrosion-fatigue cracking started, would be expected to shorten the service life of the fans.

There does not appear to be an obvious practical material which would withstand these highly corrosive conditions, especially in view of the fact that cost, weight, and availability must be taken into consideration. It appears, rather, that some thought should be given to increasing the service life by protecting the aluminum fans from corrosion. Since the leading edges appear to be weak points, perhaps a substantial plastic protective stripping in this area could be installed, with a thinnner coating of the same plastic, or some other compatible coating, over the remainder of the fan. Periodic removal of encrusted corroded deposits, and "touch-up" on areas where the coating had been removed by abrasion, etc. , would also help to extend the life of the fan, and might also reveal that some fans were on the point of failure. Anodization of the aluminum, prior to the coating, could also be considered as a means of reducing corrosion.

CONCLUSIONS

1. The operating environment of the fans appeared to be highly corrosive, with diesel fumes a contributing factor.
2. Failures of the fans were probably due to corrosion-fatigue.
3. The use of coated aluminum blades, i.e., by anodizing and/or the use of a suitable paint or plastic system, incorporating additional protection to the fan leading edges, and a program of preventative maintenance would probably yield a longer service life.
4. There does not appear to be an obvious low-cost alternative fan blade material that could be expected to give better performance than the aluminum alloys now being used.

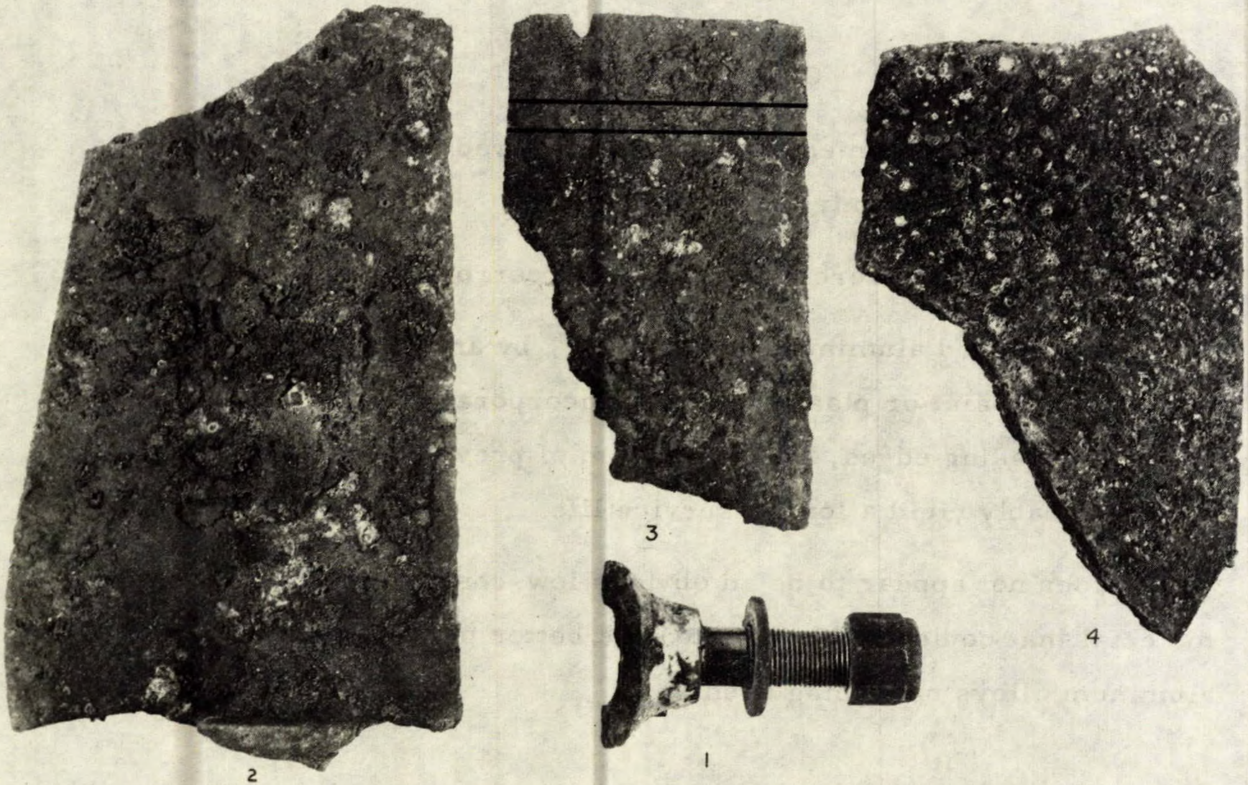
ACKNOWLEDGEMENTS

The macro-photographs were taken by the Photographic Services, Physical Metallurgy Division. The chemical analyses were carried out by the Mineral Sciences Division.

REFERENCES

1. G. J. Biefer, Physical Metallurgy Division, Department of Mines and Technical Surveys, Ottawa, Letter dated February 17, 1965 to F. C. Lendrum, Mill Superintendent, Denison Mines Ltd., Elliot Lake, Ontario.

2. Hugh P. Goddard, "Galvanic Behavior of Aluminum in the Atmosphere" Materials Protection 2, p. 38 (June 1963).



X1/3 (approximately)

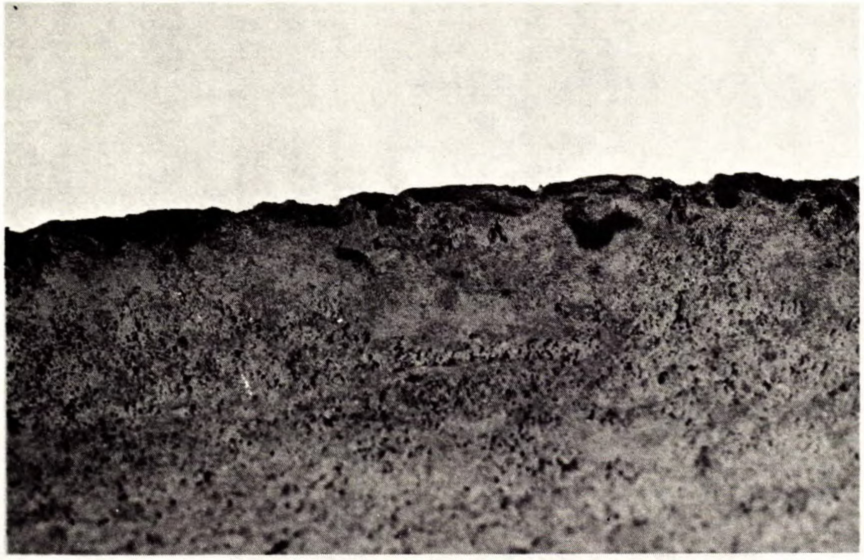
Figure 1 - Pieces of as-received fan blade and hub. The location from which a transverse section of the blade was taken is indicated by black lines on Sample No. 3.

X1.5

Figure 2 - Convex surface of fan blade after removal of adherent deposit.

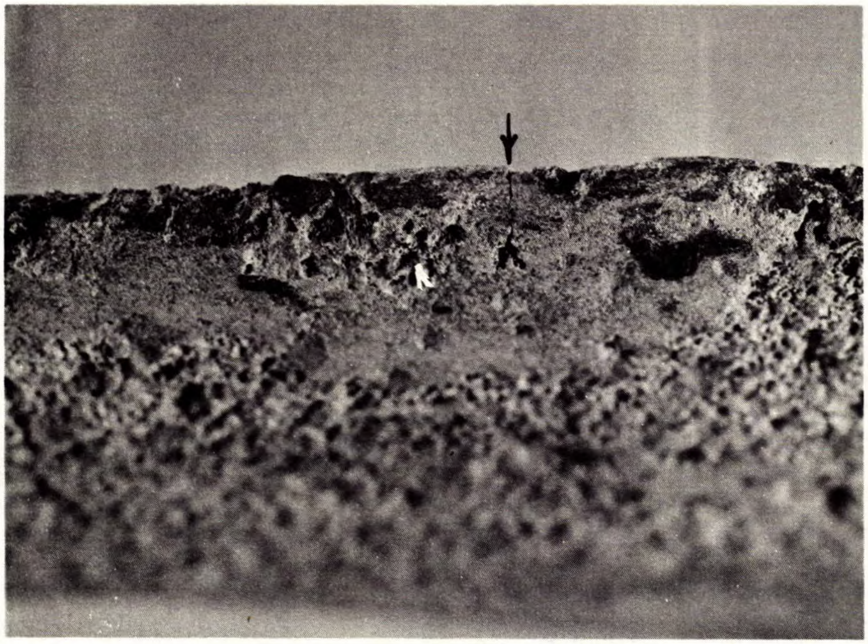
X1.5

Figure 3 - Concave surface of fan blade after removal of adherent deposit.



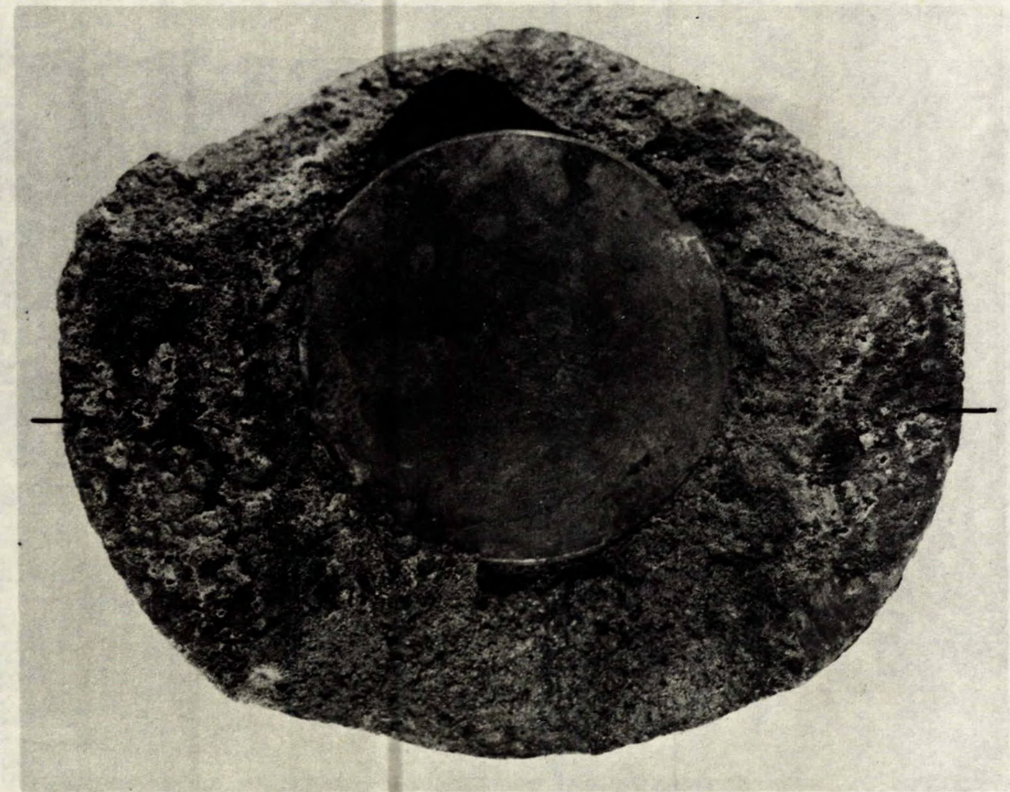
Full scale

Figure 4 - Leading edge of a typical fan blade showing deep indentations.



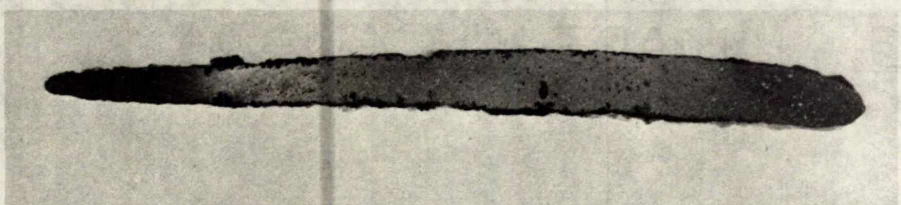
X1.5

Figure 5 - Crack (arrow) on the leading edge of a fan blade.



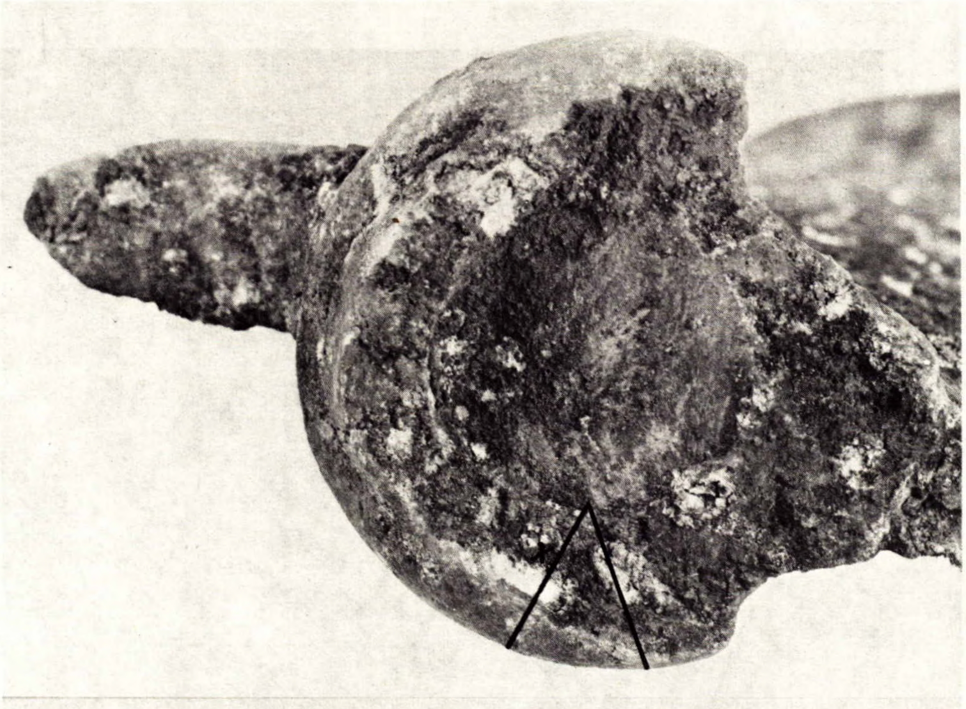
X1$\frac{3}{4}$

Figure 6 - Fracture surface of Sample No. 1 (Figure 1). The corroded areas are indicated by arrows.



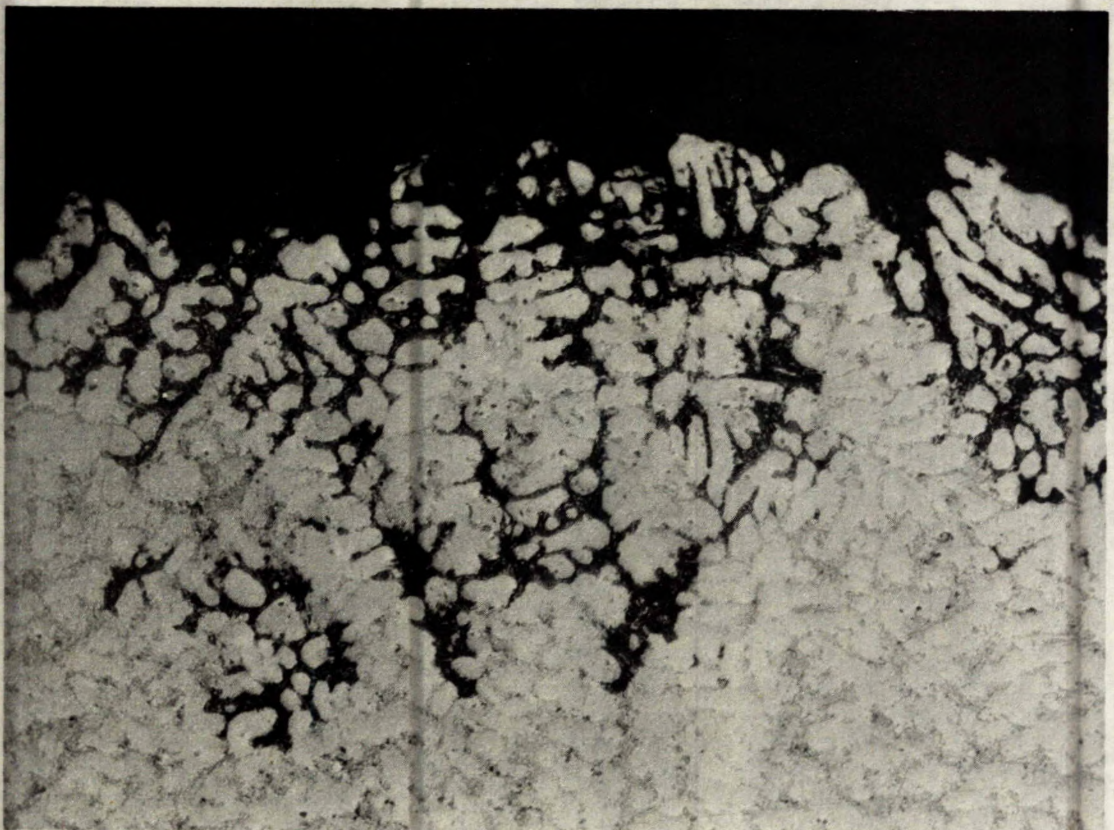
Full Scale

Figure 7 - Transverse polished section of blade showing pitting at surfaces and porosity. (Unetched)



Full Scale

Figure 8 - Fracture surface at hub of Sample No. 2 (Figure 1). Area from which a micro-specimen was obtained is indicated by black lines. The surface examined is indicated by an (X).



X100

Figure 9 - Micro-photograph at failed surface of the fan blade (Sample 2) showing aluminum dendrites surrounded by fine eutectic. Preferential corrosion attack of the eutectic is also illustrated. (Unetched).

X600

Figure 10 - A portion of the area shown in Figure 9 at higher magnification, showing preferential corrosion attack on the aluminum phase of the eutectic. (Unetched)