Pergamon

Engineering Failure Analysis, Vol. 5, No. 2, pp. 105–112, 1998

Printed in Great Britain
1350–6307/98 $19.00 + 0.00

PII: S1350–6307(98)00007–7

SOME FAILURE ANALYSES OF SOUTH AFRICAN AIR FORCE AIRCRAFT ENGINE AND AIRFRAME COMPONENTS

J. M. BENSON*

Division of Materials Science and Technology, CSIR, P.O. Box 395, Pretoria, Republic of South Africa

A. REEVES and S. G. LAGRANGE

1 Air Depot, South African Air Force, Private Bag X1001, Voortrekkerhoogte, Pretoria,
Republic of South Africa

(*Received* 3 *February* 1998)

Abstract—Failure analyses of various engine and airframe components from South African Air Force aircraft have been performed by the Division of Materials Science and Technology over several years and these have ranged from crash investigations to minor problems encountered during routine maintenance. The examples discussed in this paper are: foreign object damage to compressor blades, collapse of a landing gear strut, premature degradation of nozzle guide vanes and failure of a first stage reduction gear carrier assembly. © 1998 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Failure analysis, aircraft, engines, compressor blades, nozzle guide vanes, reduction gear, landing gear.

1. INTRODUCTION

Failure analyses of various engine and airframe components from South African Air Force aircraft have been performed by the Division of Materials Science and Technology over several years and these have ranged from crash investigations to minor problems encountered during routine maintenance. The following sections discuss some examples of these.

2. FAILURE INVESTIGATIONS

2.1. *Foreign object damage to PT6-65AR first stage compressor turbine blades*

PT6-65AR engines have been fitted to several C47 Dakota aircraft and in several incidences damage to the leading edges of the airfoils in the first stage integrated-blade compressors were observed. In each case this was found to only have occurred in the port engine. Figure 1 shows a view of the typical damage and initial reaction was that it was caused by some metallic object such as loose locking wire or a tool left in the cowling. However, these appeared to be ruled out as no locking wire was seen to be missing and no other damage was observed elsewhere in the engine.

To determine the possible cause of the damage, surface analyses of the affected regions were done to detect any traces of the impacting article. A scanning X-ray photoelectron spectroscope was used to perform the analyses and comparisons were made of surface compositions at the damaged sites with adjacent areas.

The results of the analyses are shown in Tables 1 and 2.

No indication of any metallic object was detected and the only significant difference between the areas was the higher level of silicon in the damaged region.

It was concluded that the likely cause for the foreign object damage was due to ingestion of a

---

* Author to whom correspondence should be addressed.

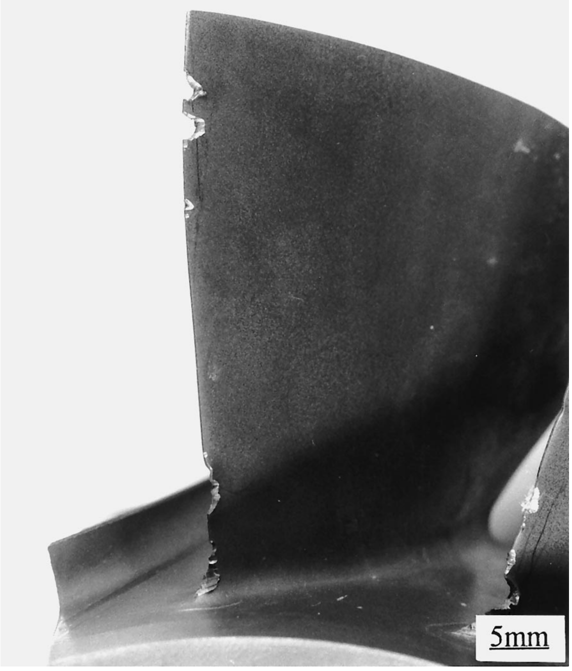


Fig. 1. Foreign object damage to PT6-65AR first stage compressor blades.

Table 1. Analysis of damaged region

Element	Atomic %	Probable compound
Si	1.6	silicate/silicone/silica
S	0.2	sulphate
Cl	0.6	alkali chloride
C	66.1	graphite/adventitious carbon
N	0.8	organic compound
O	30.4	silica
Na	0.4	NaCl

Table 2. Analysis of undamaged area

Element	Atomic %	Probable compound
Si	0.7	silicate/silicone/silica
S	0.1	sulphate
Cl	0.5	alkali chloride
C	69.8	graphite/adventitious carbon
N	0.3	organic compound
O	28.4	silica
Na	0.2	NaCl

stone and this corroborated with the fact that the affected aircraft had been operated from untarred runways.

2.2. *Failed C*47 *rear landing gear strut*

The rear landing gear strut of a C47 aircraft failed unexpectedly and in a brittle manner while being towed out of a hangar. This cast component had been in service for more than 40 years and was made from the aluminium alloy AA520.

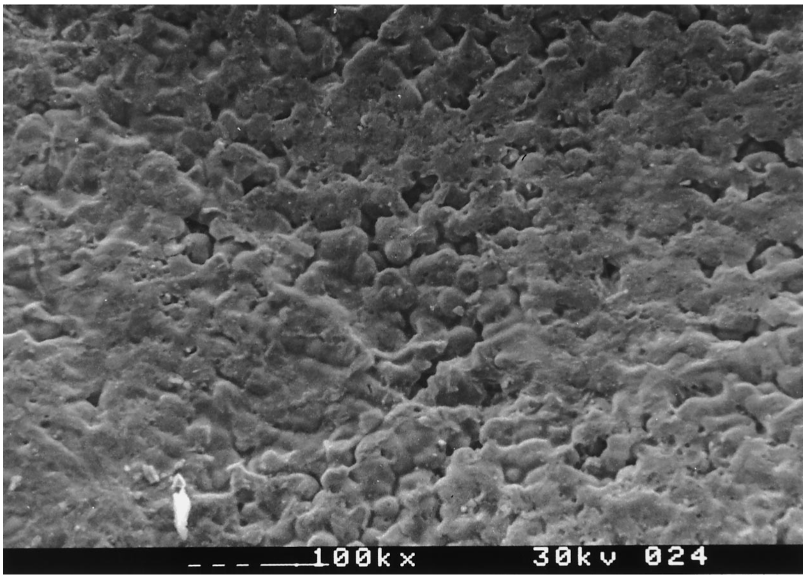


Fig. 2. Fracture surface of failed C47 landing gear strut.

Figure 2 shows a view of the fracture surface and extensive amounts of shrinkage porosity were observed. The cause of the failure however cannot be attributed to the casting porosity as the part had served satisfactorily for several decades and thus some other mechanism was responsible.

Examination of the microstructure showed an extensive amount of precipitation within the grains and along the boundaries (Fig. 3) which, on reference to the Al–Mg phase diagram [1], was concluded to be Al_3Mg_2. The precipitation of additional amounts of this phase would occur gradually during service causing an increase in strength but also a decrease in fracture toughness. It has been reported that the elongation to fracture of this alloy can decrease from 16–0.5% over 13 years [2].

Removal of this phase can be achieved by solution heat-treating above about 390°C followed by fast cooling to prevent re-precipitation and an improvement in the mechanical properties could be expected.

This was confirmed experimentally using material taken from the fractured strut as well as another retired strut. Charpy impact test specimens and compact tension specimens were prepared from

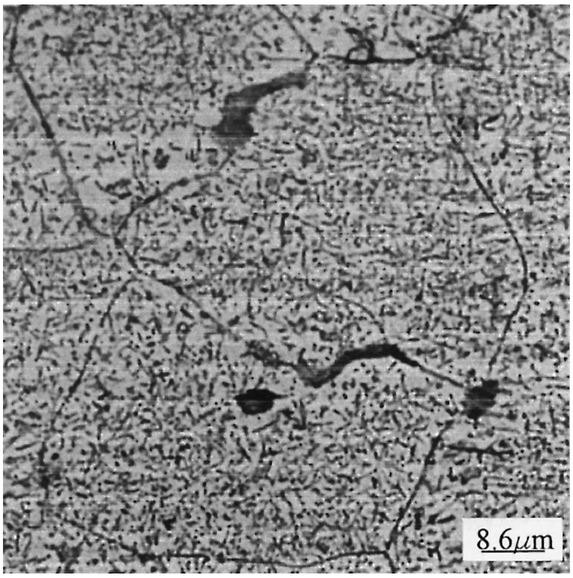


Fig. 3. Microstructure of failed C47 landing gear strut.

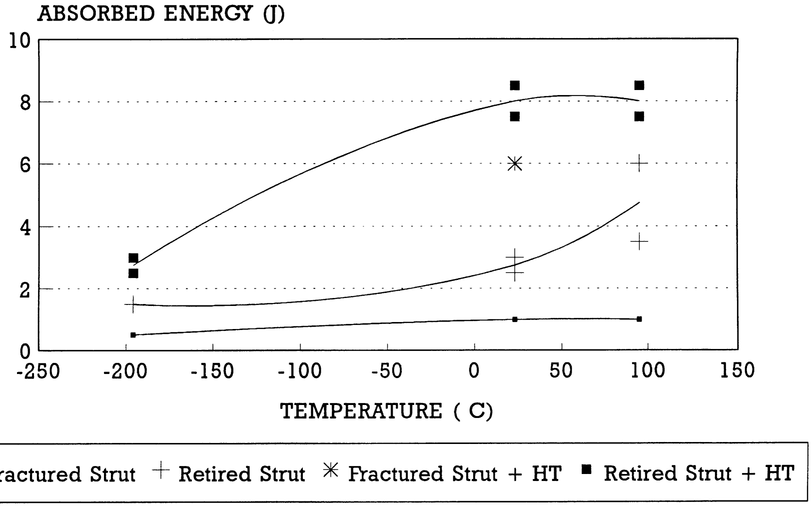


Fig. 4. Charpy impact test results for as-received and heat-treated AA520 material.

these materials in as-received and heat-treated conditions. The heat-treatment used was 425°C for 8 h followed by quenching in hot water (70°C). Figure 4 shows the improvement in impact toughness after removal of the Al_3Mg_2 precipitates. The fracture toughness tests, conducted at room temperature under tension–tension cycling ($R = 0$) at a constant load amplitude and at a frequency of 5 Hz, also showed improvement as indicated in Table 3.

The cause of the failure was thus concluded to be due to progressive embrittlement during service as a result of the precipitation of Al_3Mg_2.

2.3. *Premature degradation of Allison T56 nozzle guide vanes*

In earlier versions of the Allison T56 engine the first stage nozzle guide vanes were made from the nickel-based alloy IN713: however, later upgrades changed this to a cobalt alloy X-40, presumably to improve thermal fatigue resistance. A mixture of these types was allowed to be used in the same engine during the up-grade transition period.

Selective and severe degradation was observed to have occurred to the cobalt vanes (Fig. 5) in a particular engine resulting in premature removal of these from service. The nickel-alloy vanes did not show any obvious external damage.

Examination of the microstructures of the X-40 vanes showed a significant increase in carbide precipitation as well as subsurface oxidation and cracking (Fig. 6). In the case of the IN713 vanes the microstructure at the leading edges was seen to have become considerably coarser than elsewhere as shown in Fig. 7.

The reason for these changes was concluded to be over-heating and the cause for this was eventually traced to faulty thermocouples in the engines.

The severe surface damage to the cobalt vanes compared with the IN713 vanes can be explained by the fact that the former rely on Cr_2O_3 to give oxidation protection whereas the nickel vanes form Al_2O_3. At elevated temperatures above 1000°C the Cr_2O_3 starts to degrade to form the volatile CrO_3 by the following reaction:

Table 3. Effect of heat-treatment on the fracture toughness of alloy AA520

Material	As-received	Heat-treated
Fracture toughness (K_c)	26.7 $\mathrm{MPa}\sqrt{\mathrm{m}}$	28.8 $\mathrm{MPa}\sqrt{\mathrm{m}}$
Fatigue crack propagation rate (at $\Delta K = 20\ \mathrm{MPa}\sqrt{\mathrm{m}}$)	1.2×10^{-3} mm/cycle	7.6×10^{-4} mm/cycle
Threshold stress intensity (ΔK_{th})	7.5 $\mathrm{MPa}\sqrt{\mathrm{m}}$	10 $\mathrm{MPa}\sqrt{\mathrm{m}}$

Fig. 5. Degraded cobalt alloy (X-40) Allison T56 first stage nozzle guide vane.

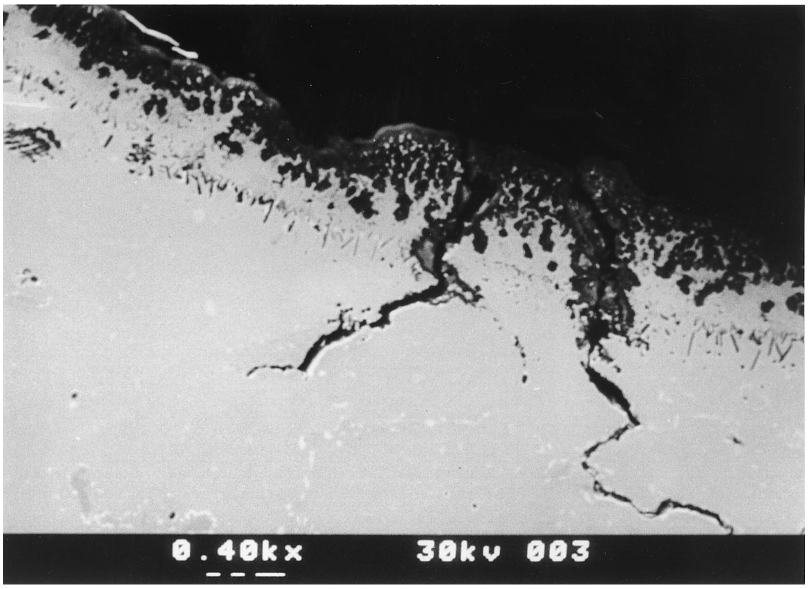


Fig. 6. Sub-surface oxidation and cracking in X-40 nozzle guide vane.

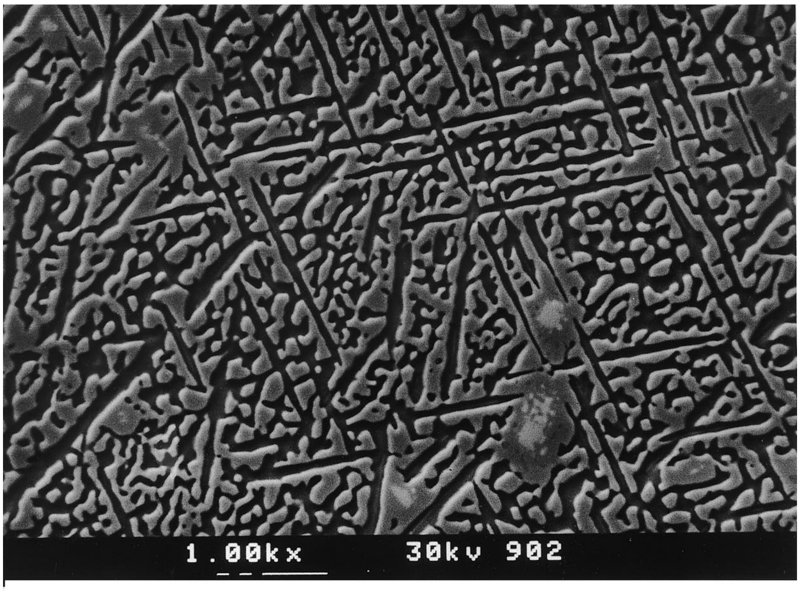
$$2Cr_2O_3(s) + 3O_2(g) \rightarrow CrO_3(g)$$

which results in the rapid degradation of the vane surfaces as seen.

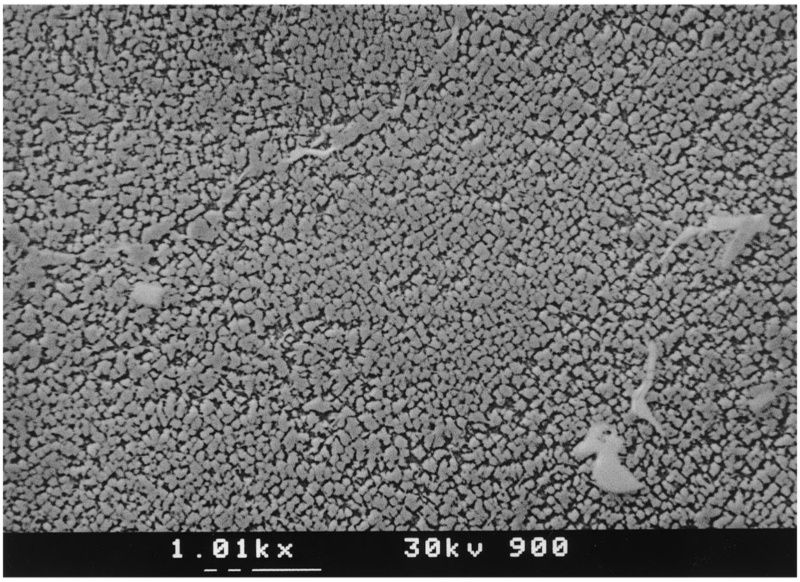
Furthermore at temperatures of 1100°C and higher it has been reported that $CoWO_4$ forms in the oxide layer and, as this melts in this temperature range, causes catastrophic destruction of any remaining protective oxide [3].

2.4. *PT6A*-114 *carrier first stage reduction gear failure*

A Casa aircraft crash-landed while attempting an emergency manoeuvre and the subsequent investigation revealed that the first stage reduction carrier assembly had failed. The fracture took place near the junction of the spline and planetary gear assembly (Fig. 8). The engine was apparently



a)



b)

Fig. 7. Microstructure of IN713 vane at (a) leading edge and (b) mid-section.

operating at full thrust at the time and the question was whether or not the failed gear was the cause of the crash.

Examination of the fracture surface showed that extensive damage to this had obliterated any evidence of the fracture mechanism due to rubbing of the mating surfaces (Fig. 9). No other indications were observed that would have suggested any material defects or fatigue cracking. Furthermore the position of the fracture did not correspond with a region of high stress concentration. In fact the fracture appearance suggested a torsional overload failure.

Discussion with the maintenance staff revealed that this component was in fact designed to shear if the load on the gear box became abnormally high so as to minimise damage to the rest of the gear box and engine.

Putting all these facts together, the conclusion was that the fracture of the reduction carrier

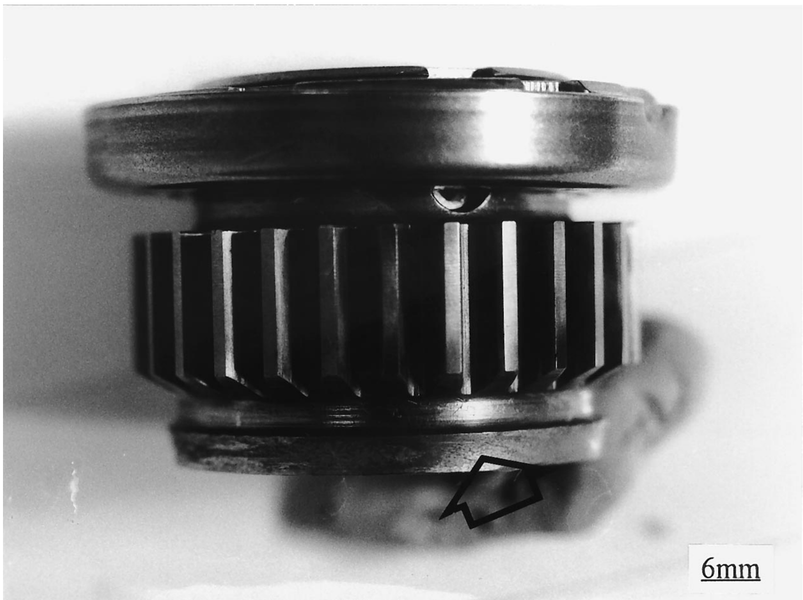


Fig. 8. Fractured PT6A-114 first stage reduction carrier (arrow indicates fracture surface).

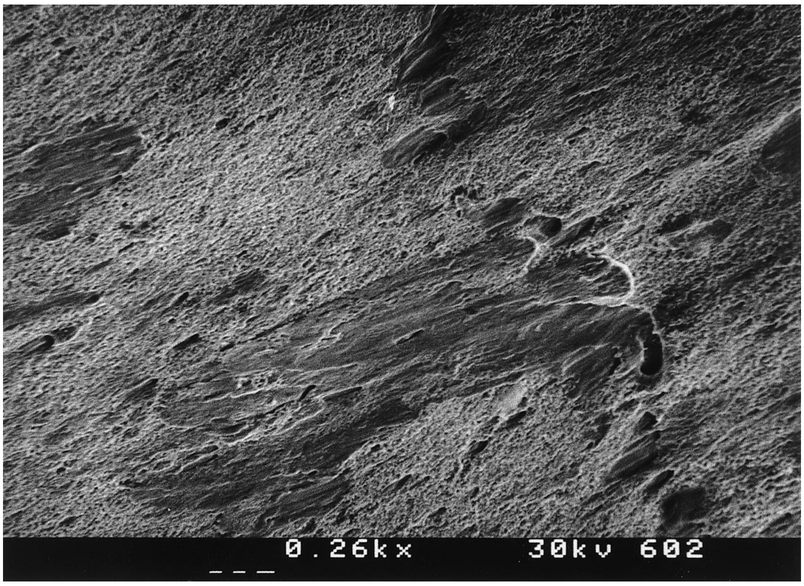


Fig. 9. Fracture surface of reduction carrier.

occurred during the crash itself, when the propeller hit the ground. The resultant sudden stop in rotation would have created very high loads on the planetary gear and torsional overloading of this would have ensued with fracture occurring at the designed “weak point”.

The failed component was therefore not the cause of the crash.

3. CONCLUSIONS

A discussion has been made of some failure investigations that were carried out for the South African Air Force. Quite often the necessary information to “solve” the enquiry is incomplete due to damage to the fractured components, part manufacturing details unavailable or individual item service histories uncertain (as in the case of transferable parts such as vanes and blades etc). This makes it difficult to arrive at a definite conclusion and consequently it is vital to collect all possible information together and to try and eliminate as many possibilities as can be safely done. Where possible the perceptions of the maintenance and operational personnel should be obtained as these can be invaluable and can prevent the investigation from following a wrong course.

REFERENCES

1. Massalski, T. B. (ed.), *Binary Alloy Phase Diagrams*, 2nd Ed, ASM International, 1990.
2. Kaigorodova, L. I., *The Physics of Metals and Metallography*, 1994, **78**, 490.
3. Sims, C. T. and Hagel, W. C., *The Superalloys*, John Wiley and Sons, 1972.