OVERVIEW ON FAILURE INVESTIGATION: FATIGUE AND STRESS-CORROSION CRACKING ON IAF FLEET

Lt. F. Bagnoli, Lt. L. Allegrucci
Chemistry Department – Flight Test Center
“M. De Bernardi Airport”
00040 Pratica di Mare (RM) Italy
rc.gms@tiscali.it

ABSTRACT

Mechanical and structural components of the military aircrafts and helicopters are subjected to severe conditions during the normal operations. Usually vehicles experience serious damages and the fatigue and stress-corrosion cracking are the main causes of progressive failures occurred on Italian Air Force fleet.

The Chemistry Department of Flight Test Center studies the nature of these phenomena to determine the whys and wherefores of the damage, by both a fractographyc and metallographyc analyses as well as by FEA.

The considerations derived from evaluation of morphological, structural and chemical aspects allow the introduction of new changes in terms of prevention and control procedures and sometimes maintenance operations, in order to preserve the requested airworthiness.

Some examples will be presented to explain this aspect.

1. INTRODUCTION

Stress corrosion cracking and fatigue failures occurred on aeronautic structures and components investigated at Chemistry Department of Flight Test Center represent more than 50 % of the defect reports.

Due to Both severe conditions in service both mechanical (connecting rods, sleeves, gear boxes, blades, bearings, etc.) and structural (main landing gear parts, lower side struts, etc.) components of aircrafts and helicopters are prone to this kind of ruptures *[1]*. The high loads developed in flight and during ground manoeuvres as well as particularly environmentally conditions play a primary role. Therefore, these stuffs and the wide spread of selected materials make difficult the determination of the defect’s first cause. Another matter concerns the need to identify the primary failure when a catastrophic event produces a lot of failures including the creation of small pieces.

The use of both complementary investigation techniques such as fractographyc *[2]* and metallographyc *[3]* analyses (morphology of the crack onset, hardness test, microstructure and chemical composition) analyses as well as FEA *[4]* (to estimate the state of stress of the components) represent the IAF procedure. Furthermore, the information about materials *[5]*, and about maintenance and operating environment are absolutely necessary to point out the first cause and consequently to identify the reason of damage.

The ultimate aim of this investigation consists in avoiding that damages happen again on the same or on analogous parts, by means of suggesting changes in the production (manufacture, assembly, materials selections), and maintenance (visual and ND inspections, work procedure).

The purpose of this article is to provide an overview on some recent case histories, in which especially stress corrosion cracking (SCC) and fatigue failures played the primary role: failures due to SCC occurred on wheel assembly and on lower side strut and while failures due to fatigue were investigated on connecting rod and nose landing gear.

2. CASE HISTORIES

2.1. FAILURES ON WHEEL ASSY

2.1.a Introduction

Cracks on wheel assembly have been often observed during regular eddy-current NDE. These damages are localized in the area of the housing holes of the lock bolts, arise on the inner side of the magnesium alloy hub and proceed in radial direction. Furthermore, they never exceed 7 mm in length and 5 mm in depth.

The evaluation of the damages was carried out by both a fractographic and metallographic analyses as well as by FEA to estimate the state of stress of the hub deriving from the static and centrifugal loads.

2.1.b Fractographic and metallographic analyses

The fracture surface, examined by SEM, appears completely intergranular, Figure 1. The intergranular fracture results clearness since the crack onset, where there are neither corrosion pitting nor different type of initiation defects, Figure 2. The morphology observed was assumed to have resulted only from stress-corrosion cracking.

The results of chemical and metallographic analyses indicated that the part is an AZ81A-T4 magnesium alloy, made of equiaxed grains, UTS 275 MPa. This material offers a low resistance against the stress-corrosion cracking, with a threshold value about 70 MPa.

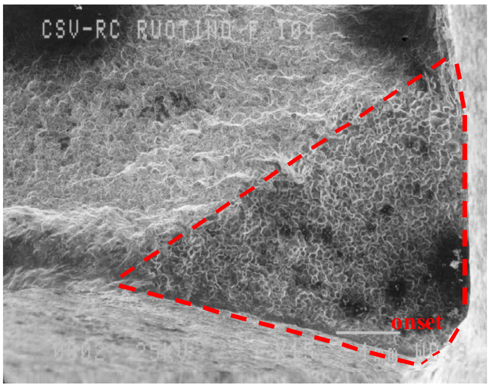

Figure 1

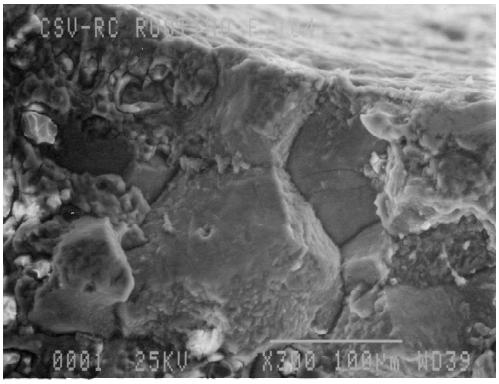

Figure 2

2.1.c FEA

A hub model was loaded considering both static and centrifugal loads, Figure 3.

The results obtained showed that the highest stresses take place only in a restricted area located around the holes of the lock bolts, turned to the rotation axle.

The direction of the principal stress was found perpendicular to that of cracks propagation, Figure 4.

Furthermore, the share of the stress deriving from the centrifugal loads was considerably lower than that from static.

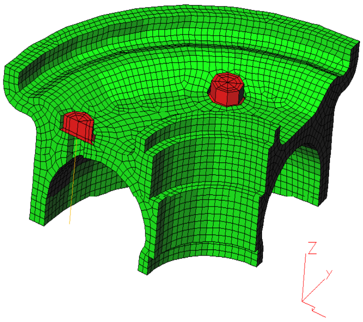

Figure 3

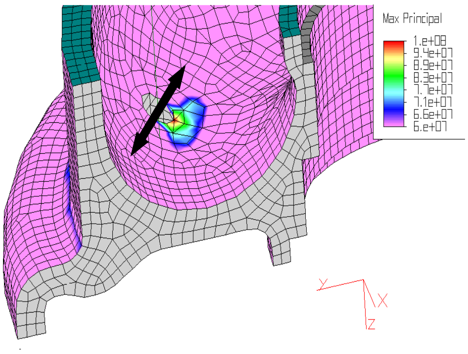

Figure 4

2.1.d Conclusions

The cracks observed are the result of a stress-corrosion cracking mechanism and they can propagate up to about 10 mm from the center of the housing hole. Beyond this length do not exist the proper conditions for the sustenance of the stress-corrosion, Figure 5.
In accordance with this investigation, the wheel assemblies were recommended to be safely employed when this kind of cracks do not exceed 10 mm in length, Figure 6.
Following these results the NDE procedure was properly revised.

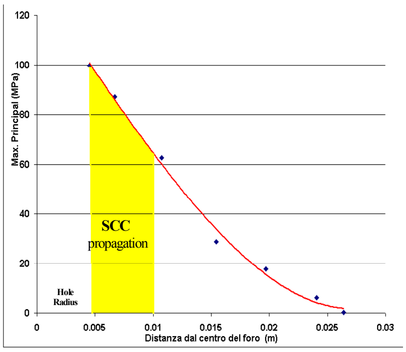

Figure 5

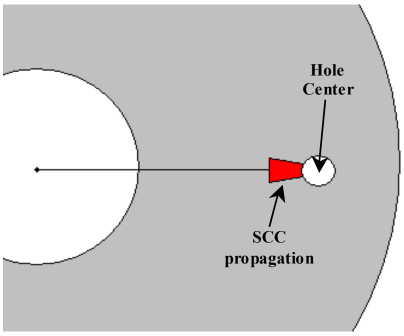

Figure 6

2.2. FAILURES ON LOWER SIDE STRUT

2.2.a Introduction

After many *touch and go* manoeuvres, suddenly a the main landing gear of an aircraft had not been retracted. The visual inspection pointed out the failure of *Lower Side Strut*. In particular, both upper and lower holes, linked to the main landing gear by the lower universal, as indicated in Figures 1 and 2, were found broken in three pieces, each hole showing six fracture surface, Figure 3. During maintenance operations, steel bushings are located in the holes to make up for the lack of the right thickness of the holes modified to remove corrosion products.

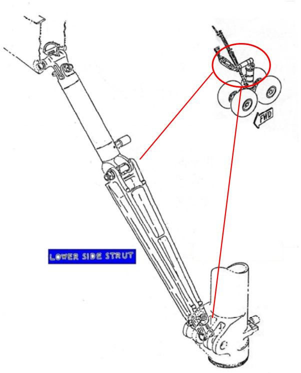

Figure 1

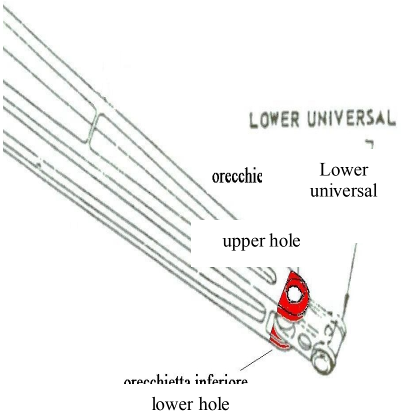

Figure 2

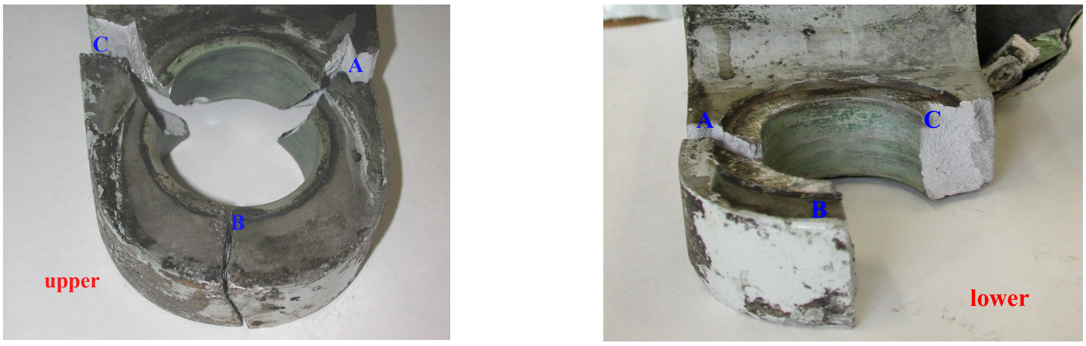

Figure 3

2.2.b Fractographic and metallographic analyses

Fracture surface A on upper and lower holes

The fracture surface showed two areas with different morphology: one appears dark and corroded and the other is characterized by dimples, which are typical in overload cases. Parallel cracks to fracture surface are localized in proximity to the steel bushings.

Fracture surface B on upper hole

The fracture surface revealed two areas with different morphology: one appears flat with intergranular aspect, while the other is characterized by radial marks and dimples due to overload.

Fracture surface B on lower hole

The fracture surface showed two different morphology, zones α and β in Figure 4.

zone α: about 40% of total surface, it appears severely corroded and shows a completely intergranular mechanism due to stress corrosion cracking, Figure 5, on parallel planes, Figures 6 and 7. The intergranular cracks are originated in proximity to the steel bushing.

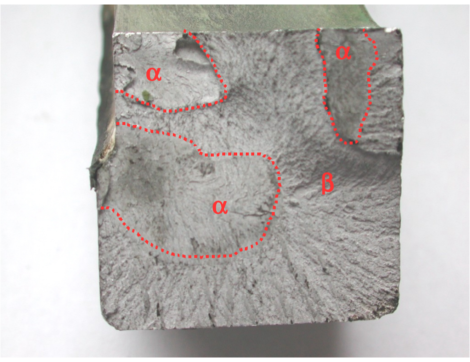

Figure4

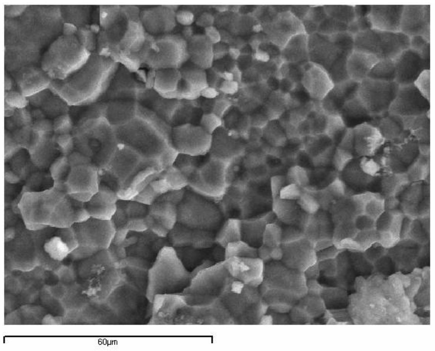

Figure 5

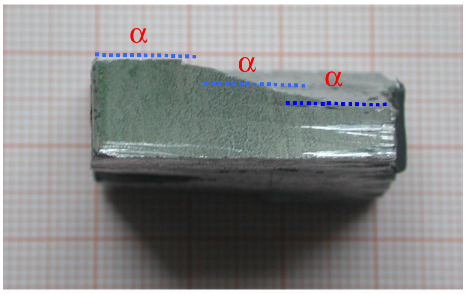

Figure 6

Figure 7

Zone β: about 60% of total surface, it shows a dimples morphology due to overload, Figure 8.

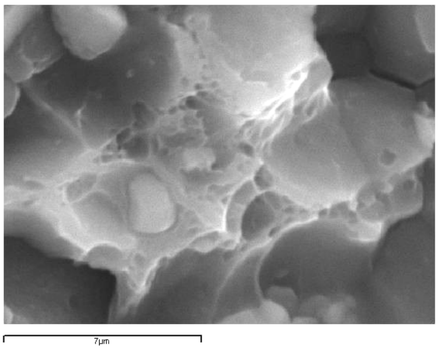

Figure 8

Fracture surface C on upper and lower holes

The fracture surfaces are characterized by dimples, as such overload failure morphology.

In agreement with the project requirements, chemical and metallographic analyses indicate that the part is an 7075 – T6 (HRB = 90) aluminum alloy whith elongated grains in the direction of the working marks, Figure 9.

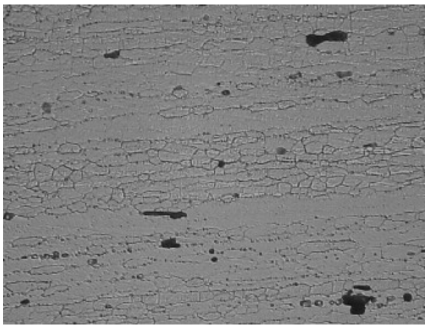

Figure 9

2.2.c Conclusions

By means of the investigations on all failure surface, it has been assumed that the primary damage was the fracture B on lower hole; a pre-existent corrosion in the near of the steel bushing has been the first step, while a stress-corrosion cracking mechanism has been the driving force in propagation. The last overload rupture was originated by cohesion of different parallel planes which showed intergranular morphology due to the applied stresses.

Due to this investigation and following these results it has been proposed to check by visual and ND methods the internal surface of the hole properly just at 6 o'clock zone.

2.3. FAILURE OF A NOSE LANDING GEAR UPPER LOCK LINK

2.3.a Introduction

During a final landing approach the crew was warmed that the nose landing gear of an aircraft had not been extracted. After landing a visual inspection showed that the upper lock link failed separating into two pieces after 31175 cycles since original manufacture and 886 cycles from the last installation, Figure 1.

Visual and optical examination of this part, a forged aluminum alloy, showed clearness a coarse superficial finish flash line besides considerable rough repainting on all surface, Figure 2.

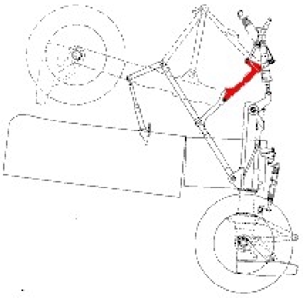

Figure 1

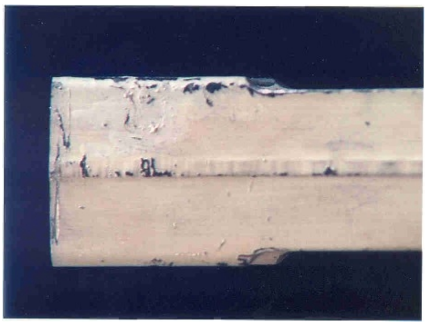

Figure 2

2.3.b Fractographic and metallographic analyses

SEM analysis of surface fracture revealed the presence of three distinct regions, as indicated in Figure 3.In particular:

region A: about 20% of total surface, fine grained, semicircular shape to a maximum depth of 5 mm from the flash line acting as crack initiation site, Figure 4. In according to this shape it's was found acceptable that the failure was initiated by fatigue process, whose details were obliterated by corrosion products;

region B: about 40% of total surface, fine grained, semicircular shape, was found to contain fine fatigue striations as crack propagation mechanism, Figure 5;
region C: about 40% of total surface, coarse grained, showed a dimples morphology due to overload.

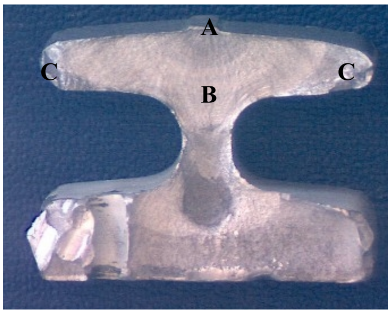

Figure 3

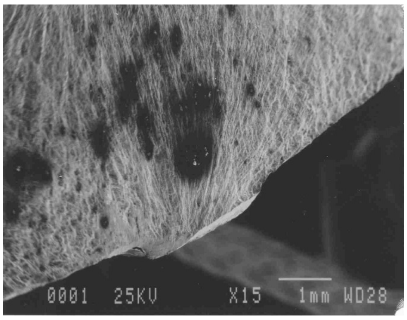

Figure 4

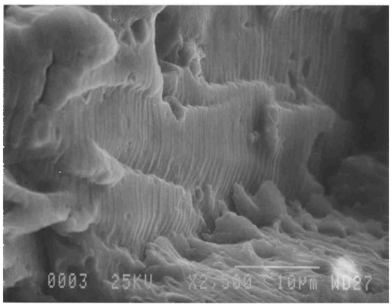

Figure 5

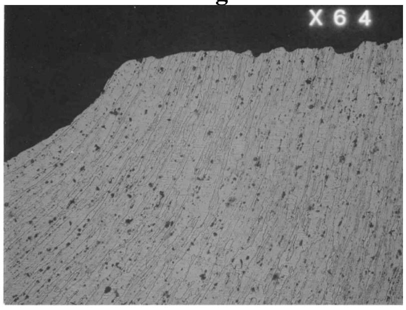

Figure 6

The alloy was found to be a 7075 aluminum alloy having a UTS of 55 kg/mm^2, suggesting the alloy was in a T-73 temper condition. This alloy was in accordance with the specification requirements called for in this kind of alloy.
The examination of the metallographic section obtained near the flash line showed that the forging had an elongated grains structure oriented along the S-T direction, Figure 6.

2.3.c Conclusions

The nose landing gear upper lock link was conformed to the requirements of AA 7075 aluminum alloy, with respect to hardness and chemical composition.
The failure occurred to this component was due to the presence of a rough flash line that had served as stress concentration site to initiate and propagate the fatigue and allowed a adverse grains orientation. Moreover, this orientation made the part more susceptible to a corrosion process.

2.4 FAILURE FATIGUE OF A HELICOPTER ENGINE CONNECTING ROD

2.4.a Introduction

In consequence of a defect's report occurred on helicopter, a connecting rod broke and its shell bearing, as indicated in Figure 1, has been investigated to determine the first cause of the damage.

Figure 1

2.4.b Fractographic and metallographic analyses

The connecting rod showed:

- the failure of the head (red arrow in Figure 1) with clear plastic deformations on both areas indicated (green arrows) in Figure 1;
- the failure of a bolt;
- wearing damage on the head internal wall (blue arrow in Figure 1).

The primary fracture is shown in Figure 2 and the surface, light and fine grained, revealed the presence of typical concentric beach marks. The origin of this fatigue failure (arrow in Figure 2) was on the internal wall, and this coincides with a small region of fretting damage which can be seen in Figure 3.

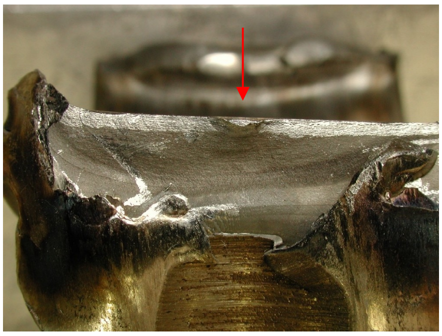

Figure 2

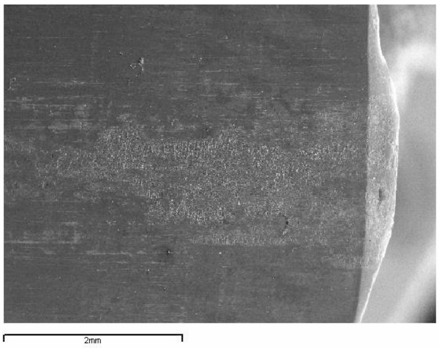

Figure 3

The metallographic analysis indicated that the part is a martensitic structured AISI 8740H with a hardness HRC= 31 free from material‘s defects.

The subordinate fracture of the bolt was characterized by dimples, typical of overload failure morphology; this fracture followed the break of the head of the connecting rod.

2.4.c Conclusions

The small fretted zone on the internal wall of the connecting rod, originated from the rotational oscillatory motion of the shell bearing, has been the fatigue origin, which is the primary fracture. This failure has been related to the inadequate restraint of the bearing shell.

3. CONCLUSIONS

The paper has presented some of the most recent progressive failures investigated by the IAF and associated with a SCC and fatigue mechanisms acting on aircrafts and helicopters. The results of the investigations allowed to propose possible changes in maintenance procedures and inspections.

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