"OPERATING BEHAVIOUR OF AERONAUTIC TITANIUM COMPONENTS"

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Titanium and titanium alloys are nearing the end of their fourth decade of commercial and industrial service. Application of these material's in many different fields is becoming broader and broader year after year. In spite of such a growth, the sphere of applications in which titanium and its alloys have found the maximum employment is still that of aerospace engineering. This is mainly due to the peculiar characteristics of titanium, summarized in figs.1-2, which perfectly match with the need of aerospace technology. In this regard, fig. 3 shows the percentage of titanium, as compared with other elements, in the overall composition of some modern aircraft.

PECULIAR CHARACTERISTICS OF TITANIUM

- Density: 60% of that of steel
- Cost: 130% of that of stainless steel
- Modulus: 55 % of that of steel
- Corrosion resistance higher than that of a stainless steel in most environments
- Forgeable by standard techniques
- Easily castable (although investment casting is preferred)
- Suitable to powder metal technology processing
- Highly joinable (fusion welding, brazing, adhesives, diffusion bonding, fasteners)
- Formable and readily machinable
- Available in a wide variety of types and forms

Fig. 1

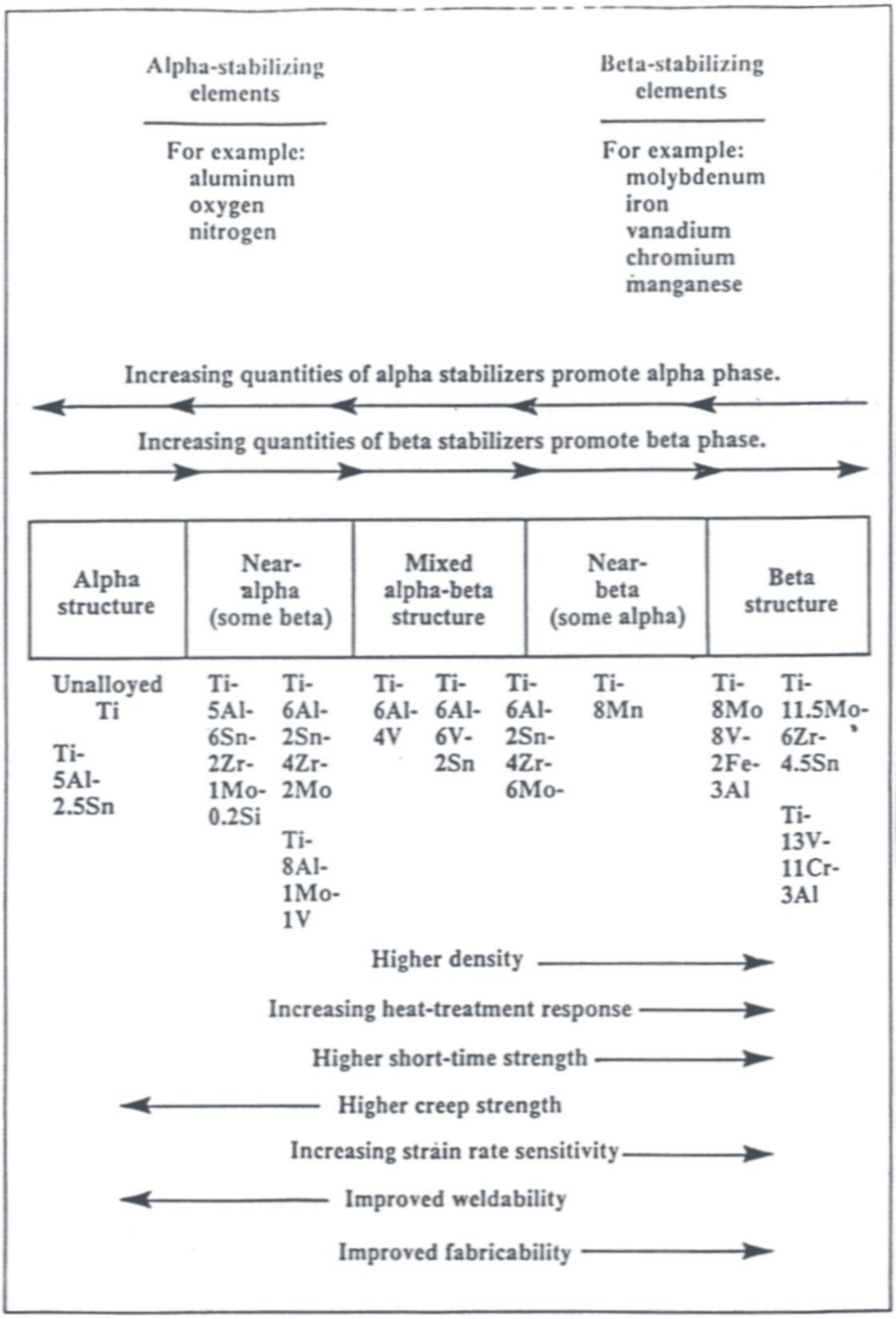


Fig.2: Schematic representation of relationship between structure and technological properties for titanium and titanium alloys.

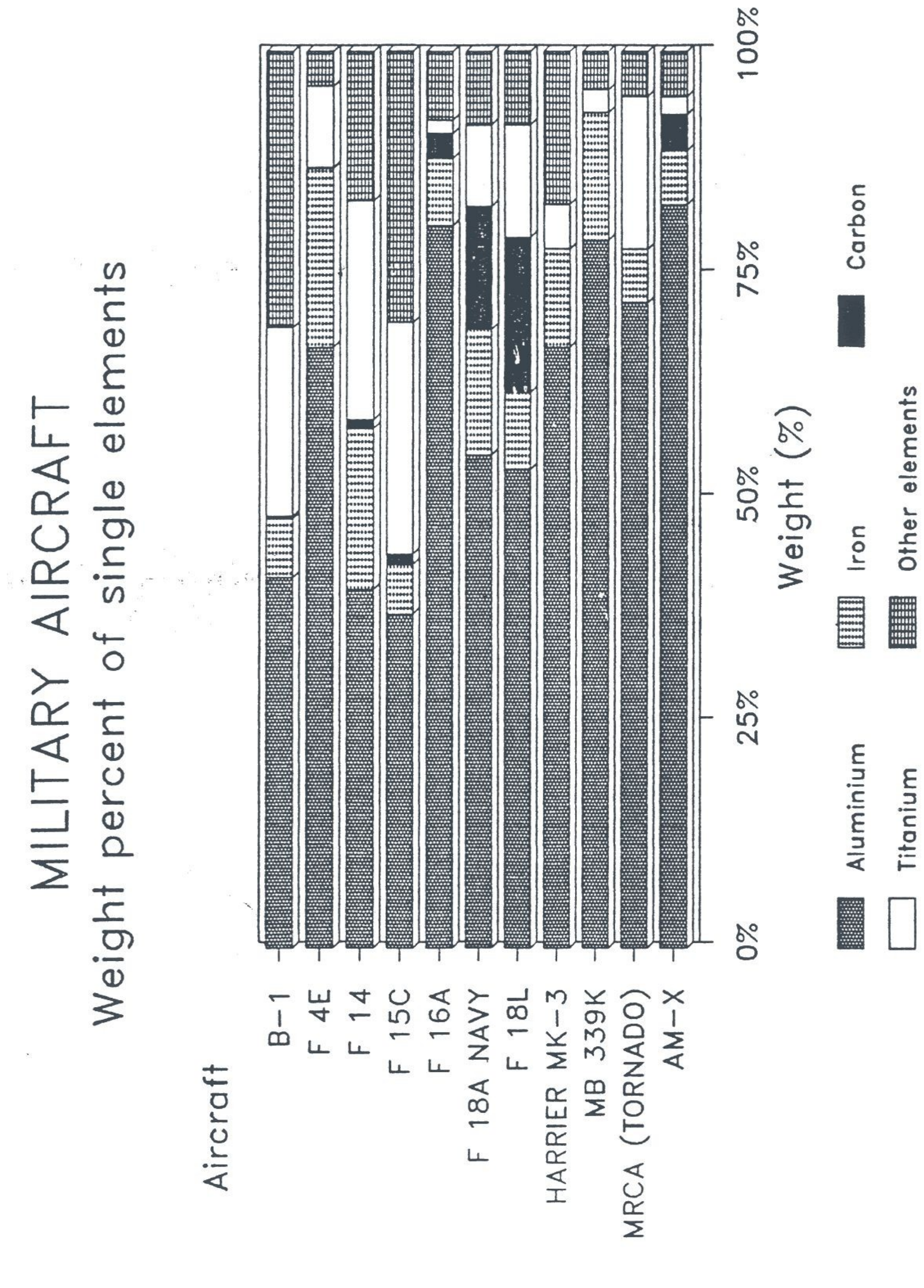

MILITARY AIRCRAFT
Weight percent of single elements
Aircraft
B-1
F 4E
F 14
F 15C
F 16A
F 18A NAVY
F 18L
HARRIER MK-3
MB 339K
MRCA (TORNADO)
AM-X
0%
25%
50%
75%
100%
Weight (%)
Aluminium
Iron
Carbon
Titanium
Other elements

Fig. 3

The purpose of the present investigation is focused on the evaluation of the operating behaviour of titanium components of military aircraft, as detected by the Chemical Research Laboratories of Italian Air Force ("D.A.S.R.S. - Reparto Chimico-Tecnologico", up to 1985 "Direzione Laboratori A.M."), on the basis of all investigations carried out between 1975 and 1990.

The results of the present review are therefore limited to all those failures and inconvenient which were not merely solved at the level of the Peripheral Bodies, but that instead required deeper and more detailed investigations.

Fig. 4 shows the main stages of the general procedure to be followed in failure investigation.

It appears clear that every single stage has to be modulated according to the specific failure under examination. It follows that there is not a step that is a *priori* more important than another: a procedure or a testing that can be definitive to clarify the fracture mechanism of a particular failure can be trivial for another and *vice versa.* It is only the experience that can suggest what step can be critical and what step could be passed by.

The following four cases show how all these guidelines. are applied practically.

GENERAL PROCEDURE IN FAILURE ANALYSIS

- Collection of background data and selection of samples
- Preliminary examination of the failed part:
  visual examination and record keeping
- Nondestructive testing
- Selection, identification, preservation and/or cleaning
  of all specimens
- Macroscopic examination and analysis of surface phenomena:
  fracture surface
  secondary cracks
- Microscopic examination and analysis
- Selection, preparation, examination and analysis of
  metallographic sections
- Chemical analyses: bulk
  local
  surface corrosion products
  deposits or coatings
- Mechanical testings
- Determination of failure mechanism
- Analysis of fracture mechanics
- Testing under simulated service conditions
- Analysis of all the evidence, solving of contradictions,
  formulation of conclusions (including recommendations)
- Final report

Fig. 4

1st Case: (commercially pure Ti)

The defects had been revealed by liquid-penetrant inspection, and localized below the thread of all the three forks (see fig. 5). All the defects were ascribed to the rolling process. The validation of the hypothesis came from the examination of the metallographic specimen (fig. 6), which shows the orientation of the grains around the crack. This kind of defect is not particularly dangerous, but nonetheless it was taken out to avoid any misinterpretation in following inspections.

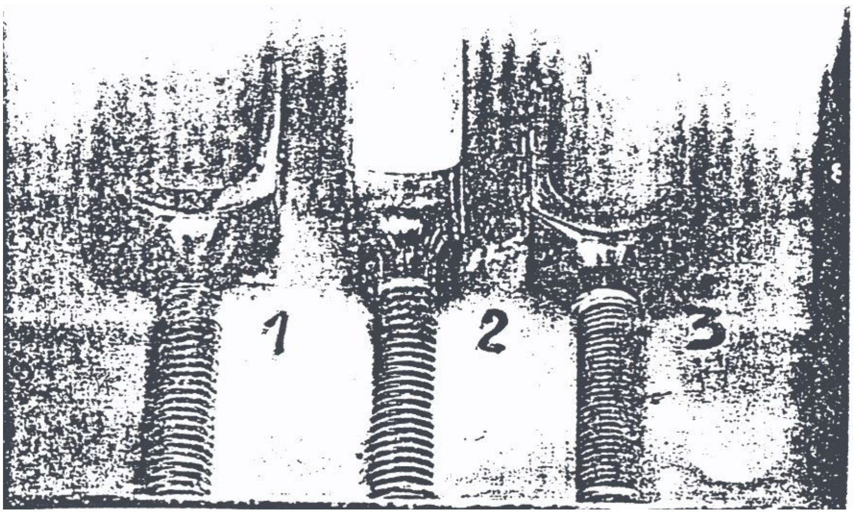
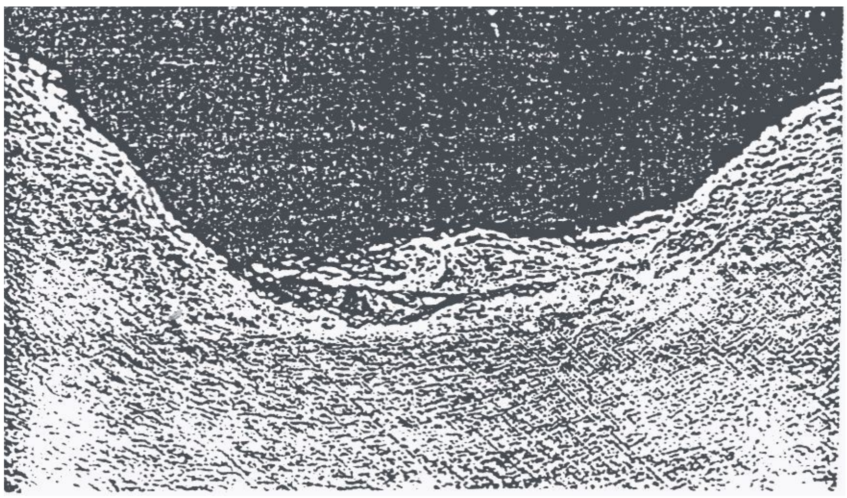


Fig. 5

Fig. 6



2nd Case: (Ti-6Al-4V alloy)

The fracture, localized at the groove of the fourth lowest thread (fig.7), was produced by the growth of a fatigue crack, whose initiation was in the correspondence of sharp tool marks, shown in fig. 8, which caused also the erosion of the other three threads. The SEM examination of the fracture surface was also useful to record the typical fatigue striation (fig.9). Fig.10 shows the microstructure of the material.

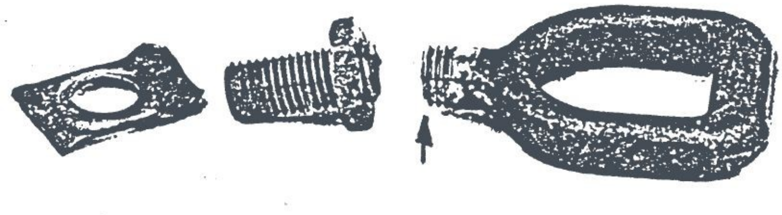


Fig. 7

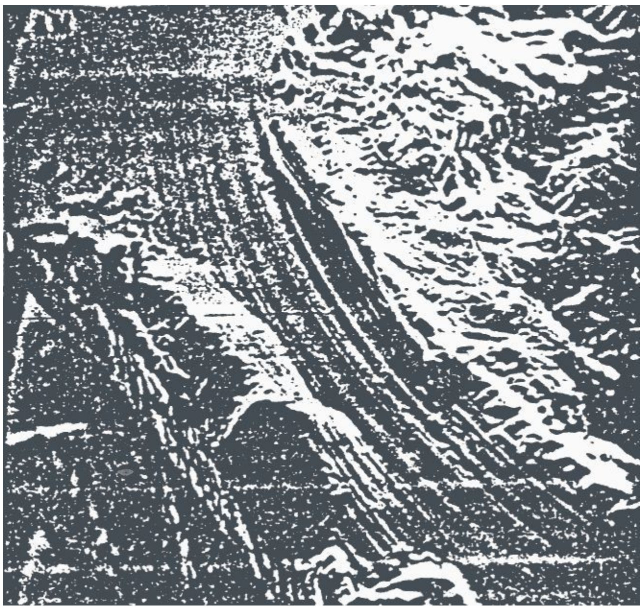


Fig. 8

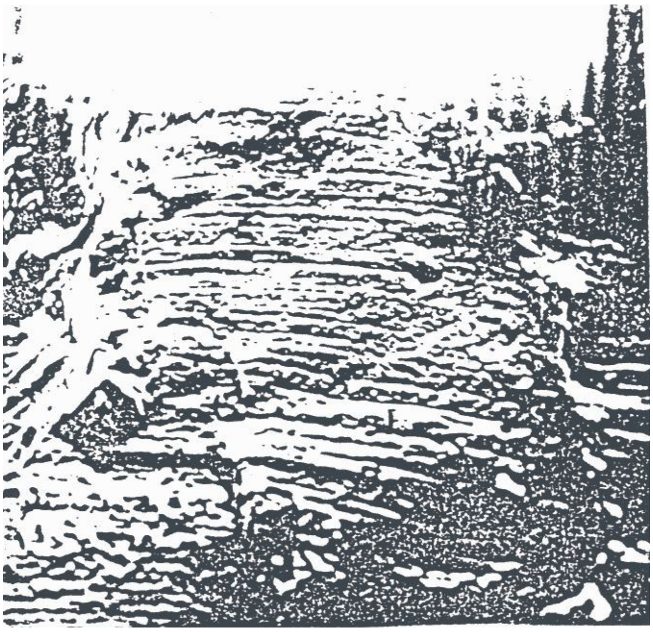


Fig. 9

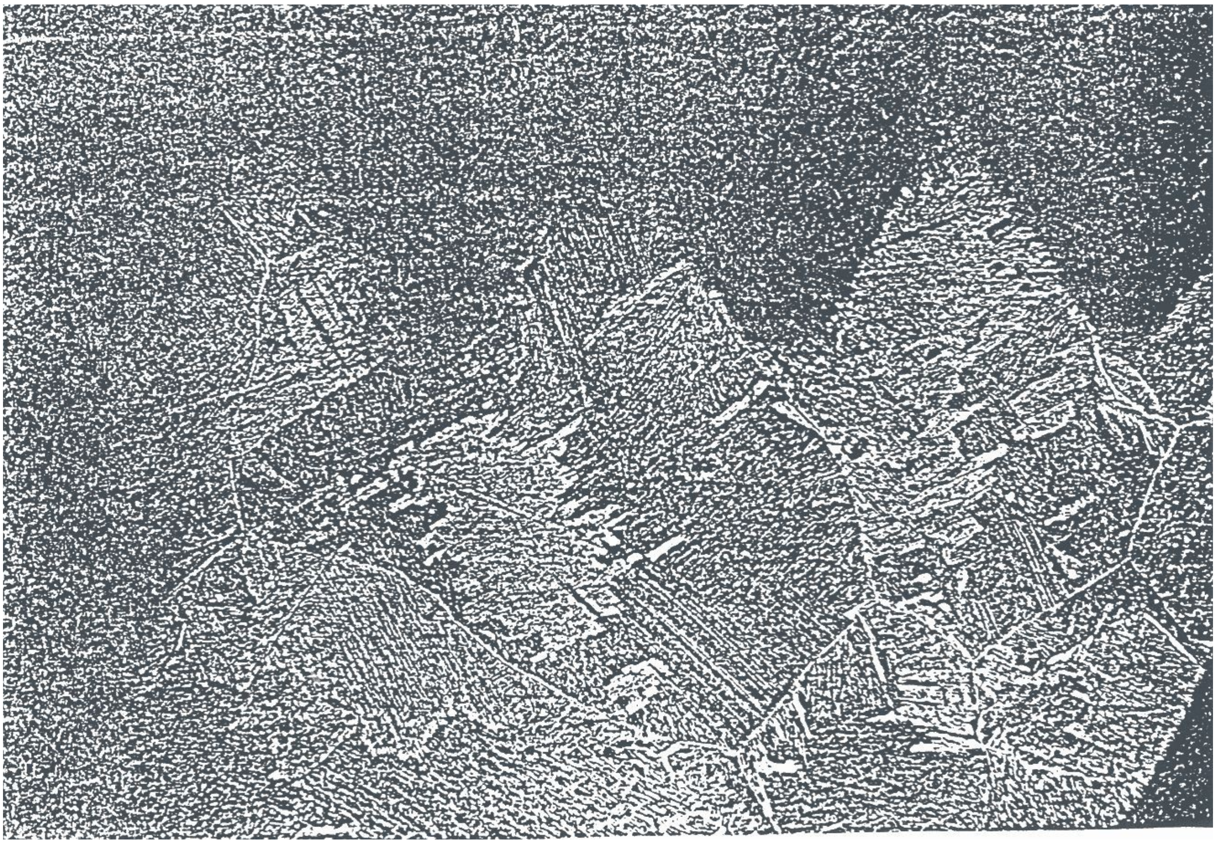


Fig. 10

3rd Case: (Ti-6Al-4V alloy)

This component of a transport aircraft was suspected to be cracked in correspondence of the arrows of figs. 11-12. A careful examination by a stereoscopic microscope, and, more important, the examination of the metallographic section (figs. 13-14) allowed us to exclude the presence of crack, and to ascribe the surface defect to the action of a tool.

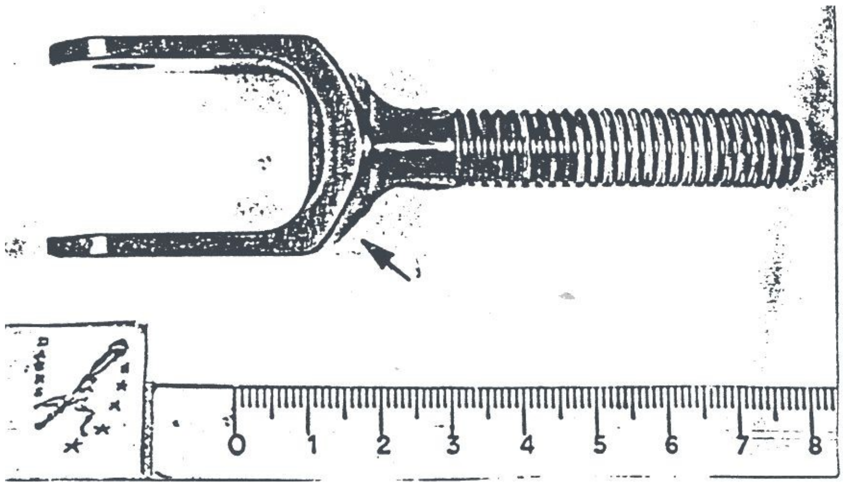


Fig. 11

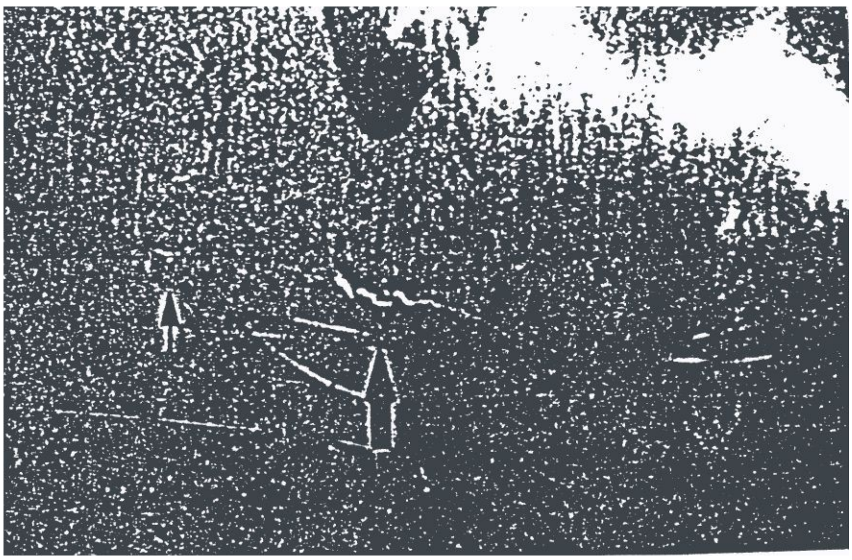


Fig. 12

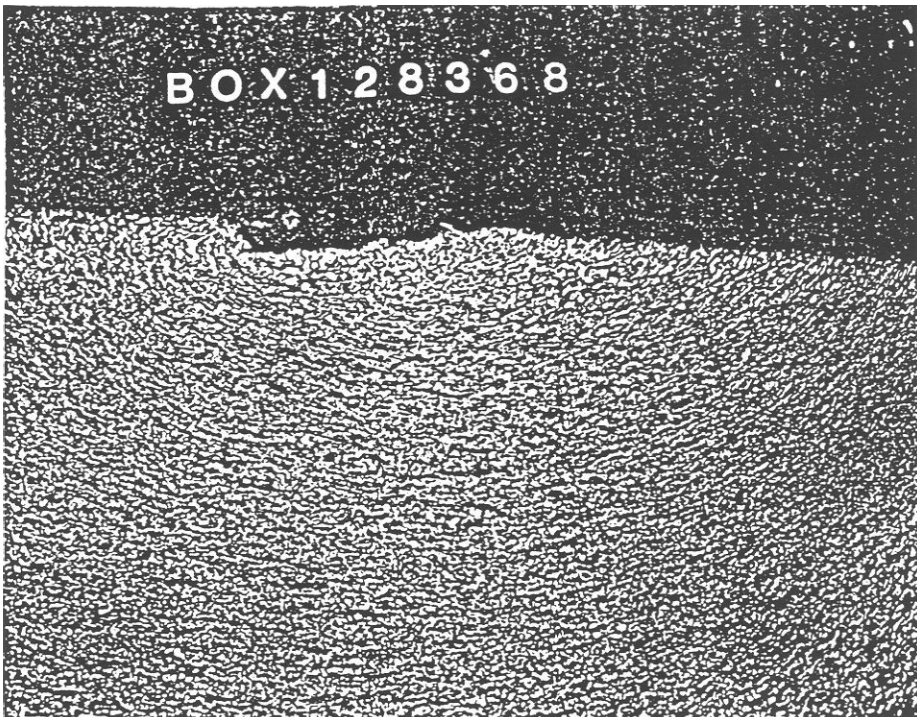


Fig. 13

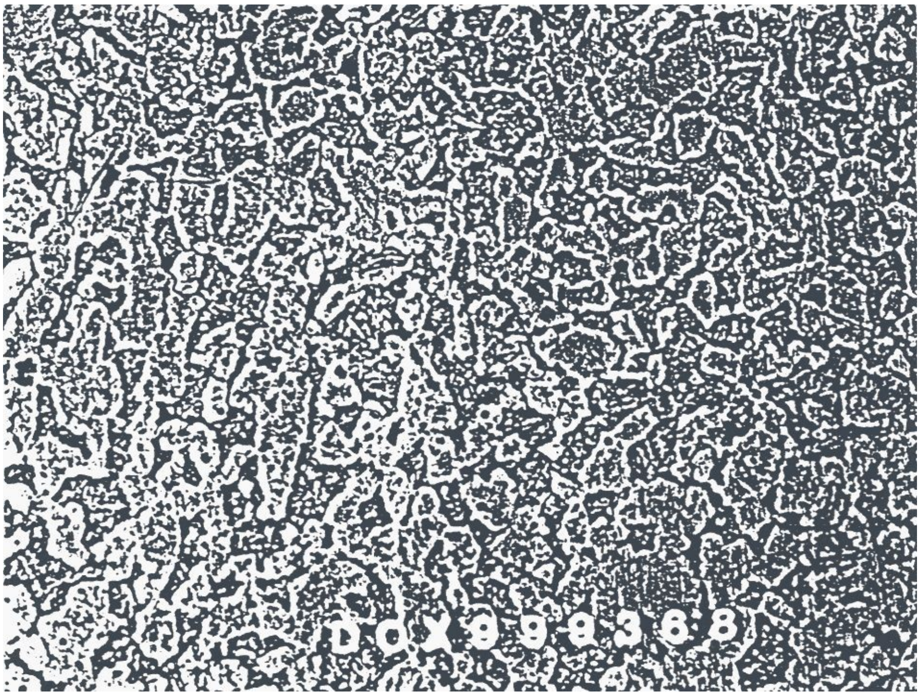


Fig. 14

4th Case: (Ti-6Al-4V alloy)

The failure of the structure shown in fig.15 began with the fracture of the posterior hinge (fig.16), being the fracture of the anterior hinge due to tension, with a component of torsion, overload (fig.17). Therefore the anterior hinge has been thoroughly examined with different techniques. On the fracture surface (fig.18) have been identified the typical striations due to the growth of a fatigue crack (figs.19-20): the cyclic loading is in this case to be ascribed to vibration, deriving from the imperfect closing of the panel. This inconvenient is a direct consequence of the too strict tolerance limits taken into account in the designing of this particular: it follows that even a lightly defective assembly can be responsible of the previously described vibrations.

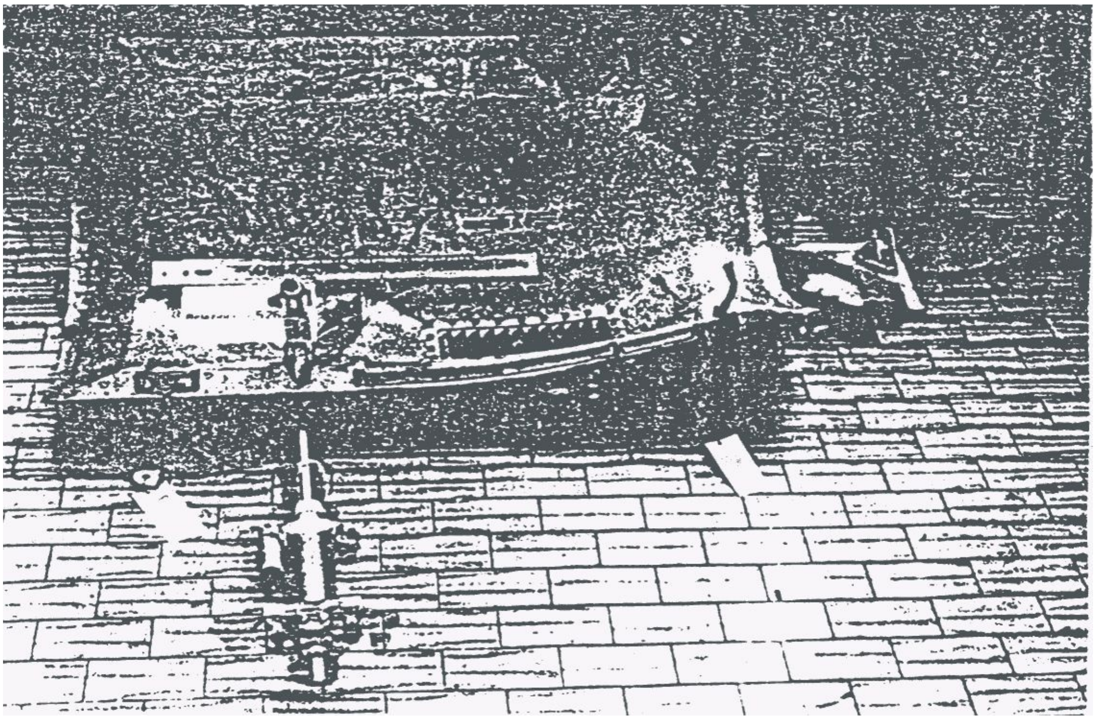


Fig. 15

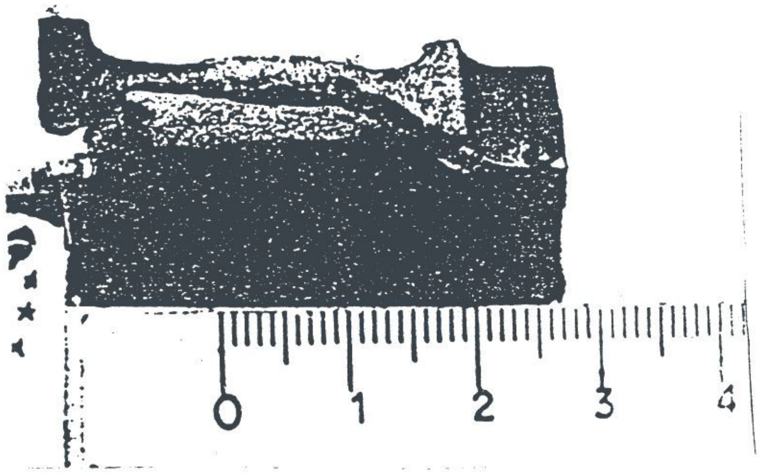


Fig. 16

Fig. 17a

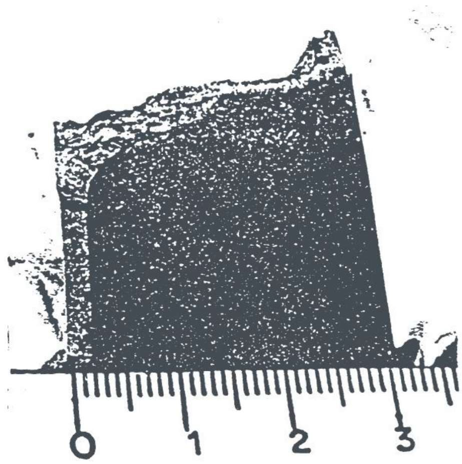


Fig. 17b

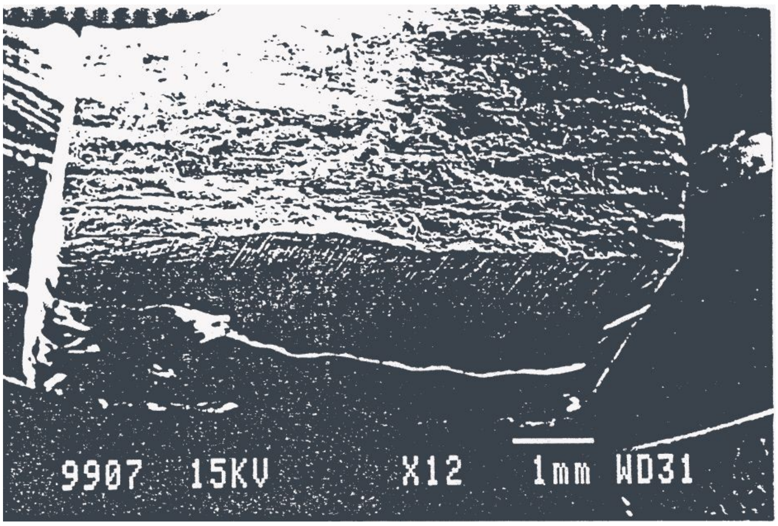


Fig. 18

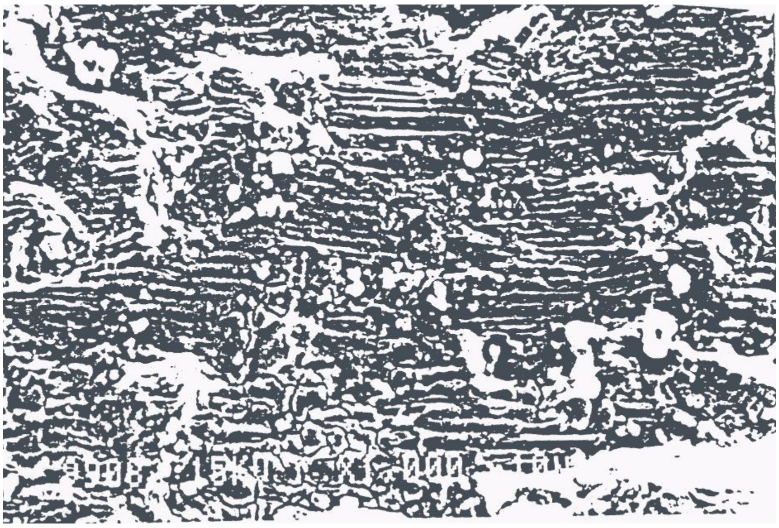


Fig. 19

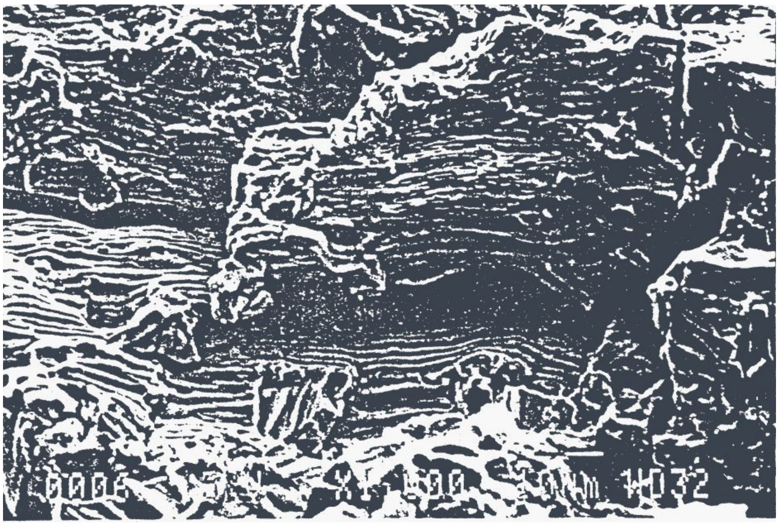


Fig. 20

Conclusions

Some relevant indications can be evinced tram the data here presented.

First of all, it is evident that the number of failures involving titanium components is extremely small; moreover it appears even smaller if compared to the number of failures of other metallic components.

In addition to this, it has to be taken in the due account that the present study is limited to military aircraft, whose operating conditions are generally extremely severe, and cause stress concentrations definitely higher than those acting on civilian aircraft.

Finally, it is worthwhile to highlight that all failures here presented and discussed are induced by factors that are not directly concerned with a reduction of the technological properties of the material; indeed, causes of failure have to be inquired into design errors, detective production and incautious and/or improper use of the component under investigation.

In conclusion, the present results once more confirm the extreme suitability of titanium and titanium alloys for aerospace applications.

Acknowledgement:
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References

1. "Titanium and Titanium Alloys -Source Book" M.J.Donachie Jr. (Ed.), ASM, 1982 (4th printing, 1987)
2. "Titanium: a Technical Guide" M.J.Donachie Jr. (Ed.), ASM, 1988
3. "Metals Handbook, 9th Edition, vol.11: Failure Analysis and Prevention" ASM, 1986
4. G.Oddone "Guida all' interpretazione delle caratteristiche morfologiche delle superfici di frattura al microscopio elettronico a scansione" Ragno Editore, Roma, 1981.