FRACTURED SURFACE OF AN INCONEL 713 SUPERALLOY TURBINE BLADE

Naïma BOUTAREK\textsuperscript{a}, Mohames Amine ACHEHE\textsuperscript{b}

\textsuperscript{a}Laboratoire de Technologie des Matériaux, USTHB, Alger, Algeria, nboutarek@usthb.dz
\textsuperscript{b}Laboratoire de Science et Génie de Métallurgie LSG2M, Ecole des Mines de Nancy, Parc Saurupt, Nancy Cedex, France

Abstract:
The turbine blades are parts submissive, in addition to the aggressive environment, to very strong thermal and mechanical constraints but also variable through time, from which the combined phenomena of thermo-mechanic fatigue, of creep and corrosion under constraint. The break of these parts (turbine failure) is not a simple phenomenon; it depends on the material, on temperature, stress mode and the speed application of the constraints. The objective of our work is to formulate a diagnostic on the causes and mechanisms involved in the damaging of a turbine blade. One type of break drags into a characteristic facies and by reference to a facies-type, we can analyse the fracture. However, the observation of the break facies allowed us to display the competition between tow modes of breaks. Finally, we propose some hypothesis showing the causes of the premature break in service of turbine blade.

Keywords: Turbine blade, rupture modes, fissures propagation, superalloys

1. INTRODUCTION
Rupture of metal parts is a complex phenomenon that depends on the nature of material (composition, structure and morphology), its temperature, excitation mode (traction, flexion, fatigue…), and the pace at which strain is applied [1]. An examination of the fractures leads to various indications on the surface, the origin and the cause of the fracture: heterogeneity, ductility and sometimes grain size.

Compressors, engines and turbines are normally exposed to erosive environments. The ceramic coatings are considered as powerful barriers against performance deterioration of machine parts exposed to particulate flow at high temperatures w1x. The erosion resistance of these coatings is strongly dependent on the coating process and on the substrate materials. Additionally, turbine blades are in an aggressive environment, with strong thermal and mechanical stress (high temperature, high pressure, and high rotation speed), favouring the damaging phenomena. In this case, the rupture phenomena will be in priority purely mechanical fatigue and the one associated to gradient and thermal evolution [2-3].

Super-alloys, particularly those based on nickel, owing to their remarkable mechanical properties and their resistance to corrosion at elevated temperature are choice materials for manufacturing turbine blades. These alloys include additional elements such as Cr, Mo, W, Al, Ta, Ti, V and C. The complexity of those alloys is made necessary by user's requirement who try to increase the turbines yield by increasing the chamber combustion temperature.

Those materials are hardened by supersaturating the phase, the formation of the ordered \( \gamma' \) precipitate, having stoichiometry \( \text{Ni}_3(\text{Al,Ti}) \) coherent with the austenitic \( \gamma \) matrix and the stabilizing carbides. Hardening is due to interaction of the matrix dislocations with the precipitates and carbides [4]. Composition and combination of these alloys is finely optimized and important, as any minute variation to nominal composition can change the ratio of the \( \gamma \) and \( \gamma' \) phases, and can therefore have a direct effect on the properties of these materials [5-7].
2. MATERIALS AND METHODS

Samples were sectioned and observed by scanning electron microscopy (SEM). The microstructures of the alloys were studied using a Jeol JSM 6360LV scanning electron microscope equipped with EDX (Energy Dispersive X-ray) analysis used to determine accurately the composition (semi-quantitative) of the phases. The EDX analysis of different phases is performed under controlled conditions (counts.s⁻¹ and size of phases) in order to be able to compare the results from different specimens. In Regards to scanning electron microscopy, practically speaking, no sample preparation is needed, apart from taking a few cubic centimeters sample. However, optical microscopy observations require mechanical polishing with up to 0.1 µm grade alumina followed by chemical etching with a reactant. The exact composition was determined using the conventional wavelength-dispersive (Philips, X’Unique) X-Ray Fluorescence Spectrometry (XRF). Carbon has been measured by dosing CO and CO₂ gases produced during combustion of the alloy.

For phase identification and crystallinity analysis, X-ray experiments were carried out using a Philips PW1730 diffractometer and a scanning rate of 0.004°s⁻¹ over the range 2θ = 20–140°, with unfiltered Cu-Kα radiation (λ = 1.54 Å), and the system operating at 45 kV and 45 mA.

3. RESULTS

The microstructure of the ruptured surface (figure 1) shows two distinct domains: a light and rough area with a large relief and a more or less broken darker area composed of flat areas (smooth look). Those areas are located at the edge of the surface preferably at the leading edge or very near to, and at the trailing edge or near to. Looking away from these edges, the clear area overcomes over the dark areas, with total disappearance at the centre of the fracture.

![Fig. 1: SEM microstructure of the fractured surface topography](image)

At more important enlargements, a detailed examination of the dark areas (figure 2) shows the presence of parallel lines. All of these lines converge in the same direction which starts at the edge towards the core of the surface.
The morphology is typical of cracks obtained by intra granular fatigue [10-12]. Effectively, frequent differential expansion and contraction between various areas of the blade can produce a fatigue of the part. At microscopic scale, ruptures obtained by fatigue are intra granular, and surfaces are often marked out by micro relief named fatigue cracks [10-12]. On ruptured traces of surfaces cyclic deformations are observed as streaks corresponding to the position of the crack after each loading cycle.

In our case, rupture by thermo mechanical fatigue which begins at edges, is coming from the fact that the leading and trailing edges are areas which are periodically thermally and mechanically activated.

The rough light area located at the core of the surface shows two aspects: a flat area and a tormented matt light area (fig. 3).

Observation at high magnification of the first area (figure 4) shows the presence of parallel micro facets in the same crystal. This structure is typical of strain corrosion inter-granular cracks. It shows oriented crystallographic faceted streaks [13]. It is therefore a progression of intra-granular strain corrosion streaks with well defined crystallography. For CFC type materials (our case), micro faceting features are all parallel in the same crystal and are {111} planes with an average <110> orientation [14]. Under stress corrosion
mechanism is a combination of mechanical action and an aggressive medium. Combustion gas in our case. This gas contains pollutants in particularly S which is in significant quantity in the fuel.

In a material damaged by fatigue under stress, a fracture of the passivation film is produced. This provokes by sliding a fracture of the passivated film $\text{Cr}_2\text{O}_3$, creation of clean surfaces in the form of steps in contact with the aggressive medium.

Micrography (fig. 3) shows at the centre, a progression zone by strain corrosion and a tormented matt light zone close to it. Large magnification of the tormented zone (figure 5) shows presence of a surface formed by a visible juxtaposition of micro cavities named microcupules [15]. These micro porosities testify the ductile character of splitting of matter [15]. This is due to deformation incompatibility between matrix and inclusions (here carbides). Therefore grain boundaries which are germination sites for heterogeneous inclusions (precipitates and carbides) form a strain concentration zone. This local enhancement can become sufficient to produce a rupture of the inclusions or their decohesion at the interface inclusion / grain boundary. A quick distribution of micro cavities around the grain boundaries is obtained. These microcupules develop and expand slowly. The cross section of the grain boundary bearing the excitation finally reaches locally the rupture value [16-17]. The rupture surface with strong inter-granular character showing numerous cupules is typical of rupture by creeping.
4. CONCLUSIONS

This study focuses on the characterization and examination of the fracture mechanisms acting simultaneously on the fractured surface of a nickel-based Inconel 713 superalloy gas turbine blade. The main fracture mechanism is intergranular thermo-mechanical fatigue starting at the border of the blade. However, intragranular fracture by stress corrosion under load, and intergranular fracture by creep are also operative simultaneously in the center of the observed surface.

LITERATURE


