Early detection and in situ monitoring of the oxidation of a MCrAlY coating by thermoreflectometry

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Abstract

The continuous improvement of the performance of aeronautical turbines imposes on structural materials ever higher levels of temperature and stress. These extreme service conditions give rise to early damage, which is unexpected and accentuated by the oxidation/deformation localization synergy (mechanical-chemical phenomenon). The early detection and monitoring of such surface damage is then essential to ensure the safe use of these high-performance components. The study presents the feasibility of detecting and monitoring high temperature oxidation of an aluminum forming coating (MCrAlY)

MCrAlY coatings play a double role in the mechanical and thermal resistance of aeronautical turbine blades. On the one hand, they provide a bonding layer ensuring the adhesion of the thermal barrier to the metal substrate and, on the other hand, they protect the metal component against oxidation and corrosion at high temperatures by forming a stable, compact, adhesive and slow-growing oxide layer (α-Al_2O_3 commonly called Thermal Growth Oxide (TGO). The extreme conditions of use associated with a possible synergy oxidation/localization of the deformation (mechanical-chemical phenomenon) can give rise to early damage of the oxide layer which results in a spalling of all or part of the thermal barrier. Its origin is generally the initiation, propagation and coalescence of microcrack networks within the oxide.

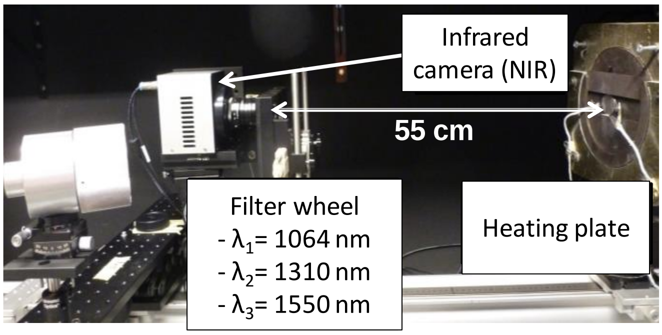

Figure 1: Trichromatic thermoreflectometer

The challenge of the work carried out in this study is the early detection of this damage by an analysis of the surface state of the oxide by a method of local investigation, “in situ”, in line and at high temperature of the thermal mechanisms and oxidation of the surface. Indeed, these mechanochemical phenomena imply local changes in the reactivity of the surface which are manifested in particular by changes in its thermo-optical properties. The local, “in situ” and on-line monitoring method proposed to analyze both these optical properties variations (reflectance) and the temperature of the oxidation phenomenon is thermoreflectometry [1]. As illustrated in Figure 1, this optical method measures both the bidirectional reflectivity fields (active phase) and the radiance temperature fields (passive phase). These measurements introduced in a multi-wavelength system which enable to deduce the true temperature and reflectance fields values. More precisely, the reflectance is the product of two terms:

- the bidirectional reflectivity ρ [sr^{-1}] which is measured directly from the bench of thermoreflectometry with a given configuration in angle of incidence and reflection,
- the scattering function fη [sr] whose parameters are estimated when solving the multi-wavelength system.

The monitoring of the reflectivity measurement and the estimated parameters of the scattering function will be a signature of the evolution of the reflectance and therefore of the optical properties of the oxidation phenomenon. A change of the reflectance slope corresponds to a change in the oxidation regime and therefore to a change in the chemical nature of the surface. Likewise, monitoring the radiance temperature measurements and the true temperature estimate will be a second signature of the oxidation regime of the material and the chemical nature of the oxides formed on its surface.

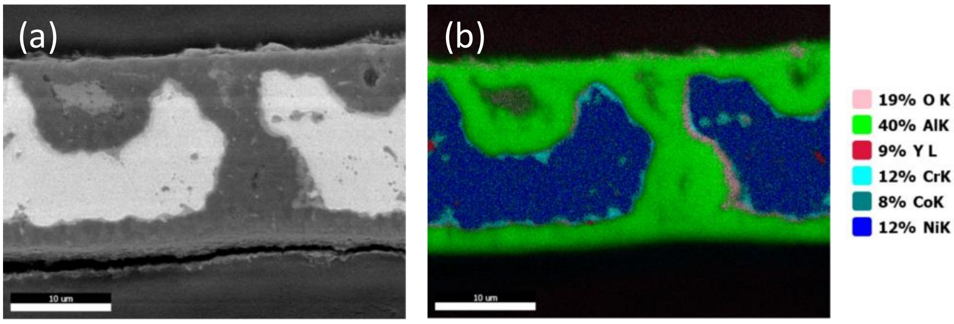

Figure 2: Cross section of coating 20 µm oxidized 225h at 1150 °C in (a) BSE and (b) EDS

A possible approach to evaluate the suitability of the method is to perform interrupted oxidation tests with different surface states and to compare them with a conventional method and the proposed thermoreflectometry method.

The interrupted oxidation tests are based on the formation of oxides due to "breakaway" phenomena of thin samples [2], leading to a limited content of reactive elements to form the TGO.

Conventional methods (Figure 2) are based on ex-situ and multi-scale analysis of the microstructure and chemical compositions of the oxides formed [3].

These measurements are correlated with the measurement of the local optical properties of the oxides, which are the bidirectional reflectivity and reflectance provided by spectrometry and thermoreflectometry methods.

The pre-oxidized sample of 15 µm thickness is placed on the heating plate and the radiance temperature is captured. The thermoreflectometry equation system is then solved to calculate the true temperature field and the reflectance field, as showed in Figure 3. From these early results, the reflectance map depicted in Figure 3.c exhibits a clear heterogeneity that originated from the different nature of oxide covering the surface.

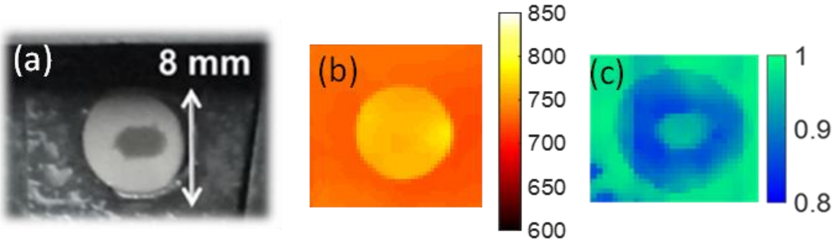

Figure 3: (a) 15 µm sample preoxidized 20h at 1100 °C before heating, (b) true temperature field and (b) in reflectance field at 1.550 µm

The application of the thermoreflectometry technique to the partially oxidized MCrAlY material has demonstrated the feasibility of detecting oxidized areas during oxidation. Conventional non-contact temperature measurement techniques (thermography) lack the ability to capture the onset of oxidation mainly because its feature may be hidden within a strong thermal gradient. Alternatively, thermoreflectometry allows to isolate the signature of the reflectance alone and is therefore promising for *in-situ* diagnosis on this type of material.

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