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Influence of the oxide scale features on the electrochemical descaling and stripping of aluminide coatings

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ABSTRACT

Turbine components are subjected to very aggressive environments at high temperatures leading to corrosion and/or oxidation. Because of their high cost, they have to be repaired instead of being replaced. Prior to refurbishment and recoating, the components have to be fully stripped to remove the oxide products and defective coatings.

In this work, an electrochemical stripping method is studied. Cathodic polarization induced the hydrogen evolution reaction (HER) to remove the scales while switching to anodic polarization dissolved the aluminide coating underneath. The influence of oxides on this method is investigated. The effect of grit blasting steps on the dissolution reactions was also evaluated. It will be shown that the most effective stripping can be performed in presence of non-continuous oxides, such as spinel $NiAl_2O_4$, rather than compact oxides such α-alumina. In the latter, a prior grit blasting step allows activation of the sample surface. The dissolution mechanisms of the coatings are finally discussed after the solution was able to go through the oxide scales.

1. Introduction

Nickel-based superalloys of turbine components withstand the very harsh operating conditions [1,2] of the engine through the formation of protective Al_2O_3 or Cr_2O_3 oxide scales [3–5] grown from the bare nickel-based superalloys exposed at relatively low temperatures or from the Al-diffusion coated superalloys for higher temperatures. However, with time and temperature the oxide scales evolve in composition and morphology as do the underlying (un)coated superalloys [6–10], in particular under cyclic oxidation regimes. As a result, non- (or less-) protective scales form (e.g. NiO, $NiAl_2O_4$…) and the (un)coated superalloy is not protected any longer. Therefore, the subsequent mechanical degradation results in scraping such high added value components.

A more economical alternative is to strip the unprotective oxide scales and the underlying worn coating. Grit blasting techniques are often used [11,12], but they lack of reproducibility, as they often depend on the operator and can also lead to excessive removal and/or deformation of the components. Thereafter, the stripping step is carried out using chemical baths. For oxides and/or thermal barriers, alkaline baths based on potassium or sodium hydroxides are commonly employed [13–16], but they can cause local damage of the parts and require an appropriate cleaning afterwards. Metallic coatings are stripped using strongly acidic baths [17–21] which are also hazardous for substrates. Besides, a complimentary FIC (Fluoride Ion Cleaning) step may be required to clean the oxide products from the cracks [22,23], but it can lead to alloy depletion and to intergranular attack (IGA) [24].

An alternative method consists in stripping electrochemically. This approach was previously investigated in the literature. A method for the removal of aluminide coatings from iron substrates was claimed already in 1973 [25] while many years later the removal of aluminide layer was focused on titanium substrates [26]. In both cases, stripping was carried out at temperatures between 50 and 80 °C. A few other existing methods [27–31] were developed for nickel substrates but were not designed for the removal of both aluminide coatings and corrosion products. Furthermore, the 2 electrode set-ups did not allow live monitoring of the process. Recently, a three-electrode cell was demonstrated to allow in-situ control of the stripping process while at room temperature [32]. Bouchaud et al. also demonstrated the feasibility of employing electrochemical means to control the removal of both the Al_2O_3 oxide scales and the aluminide coatings using environmentally friendly electrolytic solutions [33]. The combination of cathodic polarization to promote cracking and spallation of the oxide scales through hydrogen bubbling and anodic polarization to dissolve the underlying aluminide coating in a controlled manner is retained in this work. Besides, Bouchaud et al. focused mainly on galvanostatic stripping,

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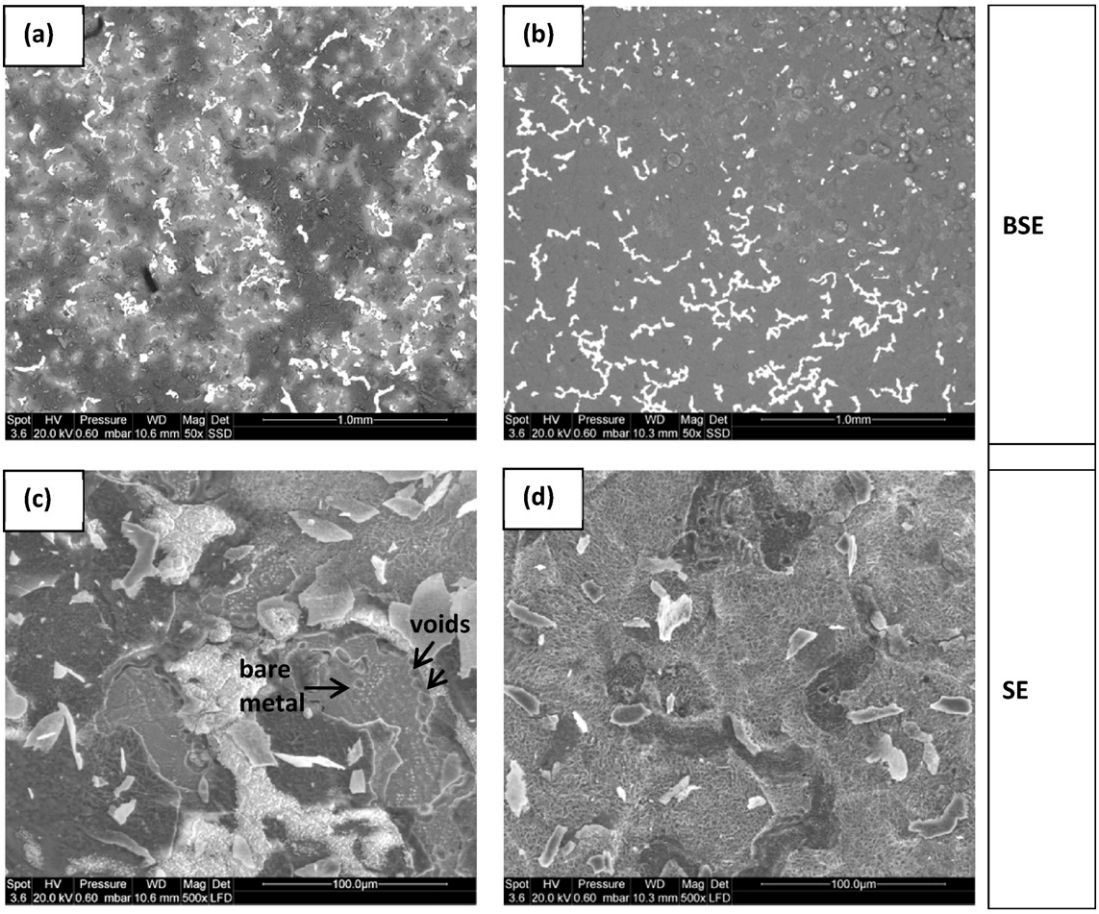

Aluminized and oxidized Ni	Aluminized and oxidized Ni20Cr	at%
35.78 ± 2.22	43.44 ± 2.15	O
16.21 ± 2.30	46.58 ± 2.05	Al
--	0.77 ± 0.09	Cr
47.88 ± 1.87	9.21 ± 0.75	Ni

Fig. 1. SEM observation of oxide layers morphology after 3 oxidation cycles of 24 h at 1100 °C in air. (a) and (c) aluminized Ni and (b) and (d) aluminized Ni20Cr, respectively at different magnifications in the SE (secondary electrons) and BSE (backscattered electron) modes. The table provides average EDS results on the oxide scales (naked metal areas were disregarded).

showing line current uniformity issues [33]. In our work, potentiostatic stripping will be used in order to palliate these drawbacks.

In this work, aluminized pure Ni and Ni20Cr (model materials for Ni-based superalloys) were oxidized at high temperatures and times to form different oxide scales whose electrochemical descalability was investigated to simulate the complex oxide scales grown in turbine blades. Characterization of the oxide scales and stripped surfaces was performed using SEM/EDS and XRD. Cyclic voltammetry was used to investigate the electrochemical activity of the oxidized surfaces; hence to adapt the electrochemical parameters to descale the underlying (un)-coated substrates. The correlations between the oxide scale characteristics and the electrochemical fingerprints were finally established.

2. Experimental methods

2.1. Materials of study

The substrates were cut from Ni and Ni20Cr bars with, respectively, 12.7 and 12 mm diameters, and about 2 mm thick. The samples were aluminized using SR Technics Airfoil Services Ltd. (Cork, Ireland) out-of-pack (SVPA) process, at 1080 °C for 6 h. The aluminized specimens were oxidized cyclically in a muffle furnace in air for a period of 24 h intervals repeated 3 times (up to 72 h) at 1100 °C, and air cooled. This temperature and time allows the formation of a continuous superficial layer of alumina, and this cycle was chosen to promote interdiffusion, Al depletion and oxide scaling phenomena [33].

2.2. Characterization techniques

A Field Emission Gun (FEI) Quanta 200 F apparatus in environmental mode at 0.60 mbar coupled to an EDAX EDS detector was employed to characterize the surfaces and cross sections and to perform elemental chemical analyses. The evolution of the crystallographic phases was also monitored by XRD in a BRUKER AXS D8 Advance device, using CuKα radiation in a θ–2θ configuration, as well as a 5° glancing incidence (in particular for probing of the superficial oxide scale). The evaluation of diffracting species was performed using DIFRAC$_{plus}$ software.

2.3. Electrochemical features

The stripping bath used for electrochemical stripping was patented by our group and consists of a diluted aqueous solution of HNO_3, HCl