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Microstructural evolution of an aluminide coating on alloy 625 during wet air exposure at 900 °C and 1000 °C

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ABSTRACT

The microstructural changes of the aluminized alloy 625 during cyclic oxidation in air + 6% H_2O at 900 °C and 1000 °C were analyzed using optical metallography (OM), scanning electron microscopy (SEM) with energy and wave length dispersive X-ray analysis (EDX/WDX) as well as electron backscatter diffraction (EBSD). An in-house developed thermodynamic-kinetic procedure was employed to predict the microstructural evolution of aluminized alloy 625 during high temperature exposure by considering simultaneously occurring surface oxidation and interdiffusion processes. Due to the lack of mobility data for the relevant alloying elements in the σ-phase, assumptions for the mobilities were made based on the value of the mobilities in α-Cr. Despite these assumptions, the calculated results were found to be in good agreement with experimental observations. The complete depletion of β-NiAl in the coating observed during exposure at 1000 °C was correctly predicted by the model. The model was also able to predict dissolution of the precipitate phases α-Cr and σ in the interdiffusion zone during exposures at 900 °C and 1000 °C. The model was however unable to predict the formation of the μ-phase in the alloy after 1000 h of exposure at 1000 °C. The developed modelling approach offers the potential to predict microstructural changes of aluminized nickel base alloys thus reducing cost and time consuming experimental efforts.

1. Introduction

Ni-base superalloys are employed in high-temperature applications due to their high oxidation resistance and excellent elevated-temperature strengths. The oxidation resistance of these superalloys strongly depends on the formation of a dense, well-adherent, slow-growing oxide layer (usually alumina or chromia) on the surface, which protects the alloys from rapid degradation [1]. Their outstanding high-temperature creep strengths combined with oxidation resistance have made many superalloys desirable materials for components like disks, blades and vanes in the aeroengine and industrial gas turbine [2].

A widely used Ni-base alloy for applications, such as turbine engine exhaust systems, turbine shroud rings, sea tubes and bellows, is alloy 625 which is a chromia-forming superalloy [3–6]. The formation of a chromia-rich oxide scale results in continuous consumption of Cr from the alloy, which drives compositional and microstructural changes in the alloy [7–12]. These changes may obviously affect the mechanical properties of the component, like the creep strength, whereby the effects will be more predominant in thin than thick components. The oxidation-induced Cr removal from the alloy and consequent microstructural changes can readily become a life-limited factor in thin-walled components during applications at high temperatures [13], such as heat exchanger components in the applications of solid oxide fuel cell (SOFC) and solid oxide electrolyzer cell (SOEC).

Chromia has higher growth rates than alumina and has the disadvantage of forming volatile CrO_3 (g) at temperatures above 1000 °C in air and the effect is increased with increasing temperature [14]. Also, it is well known that the oxidation induced depletion of Cr may be significantly accelerated by the formation of volatile chromium oxy-hydroxides in gases containing water vapor [15]. On the contrary, alumina scales appear to be less susceptible to the presence of water vapor and are less likely to suffer accelerated attack [16]. Hence, high temperature protective coatings such as overlaying MCrAlY (M = Ni, Co or Fe) [17,18] and aluminide diffusion coatings [19–22], are suitable to extend the operating life of most alloys through forming a protective alumina scale in high-temperature applications.

Some investigations on aluminized alloy 625 have been published to study its oxidation behavior in the aggressive environments at elevated temperatures [23–25]. It was found that aluminized alloy 625 samples revealed a uniform and adherent oxidized layer in comparison with the uncoated specimens after 50 h oxidation in air at 1000 °C and 1100 °C [24]. Uncoated specimens were sulphidized completely during

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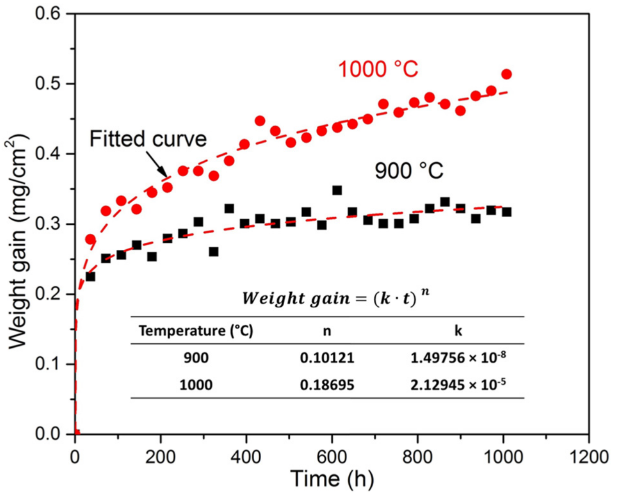
Table 1
Nominal chemical composition of alloy 625 in wt% [60].

Element	Ni	Cr	Fe	Mo	Nb (+Ta)	C	Mn	Si	Al	Ti
Concentration	58.0 min	20.0–23.0	5.0 max	8.0–10.0	3.15–4.15	0.10 max	0.50 max	0.50 max	0.40 max	0.40 max

Table 2
Chemical composition of substrate alloy for studied material in wt% indicated by EDX spectrum point 22 in Fig. 2 and Table 3.

Element	Ni	Cr	Fe	Mo	Nb	Al
Concentration	62.9	20.9	4.6	8.3	3.2	0.2



$$Weight\ gain = (k \cdot t)^n$$

Temperature (°C)	n	k
900	0.10121	1.49756×10^{-8}
1000	0.18695	2.12945×10^{-5}

Fig. 1. Measured (symbols) weight changes of aluminized alloy 625 during 1000 h oxidation at 900 °C and 1000 °C in wet air. The dotted lines indicate the fit to the experimental data points with a power law function.

exposure in H_2/1.6% H_2O/1.1% H_2S at 1000 °C, but aluminized alloy 625 specimens did not show significant sulphidation up to 1500 h [23]. The aluminized alloy 625 exhibited good oxidation resistance due to the selective formation of an Al_2O_3 scale during 1000 h cyclic oxidation in air at 1100 °C [25].

In the present study the microstructural development of the aluminized alloy 625 occurring during cyclic oxidation in wet air at 900 °C and 1000 °C will be described. Firstly, the microstructure of as-aluminized alloy 625 will be presented. Then the microstructural changes induced by oxidation and interdiffusion processes will be illustrated using analytical techniques such as SEM/EDX/WDX and EBSD. Finally, the diffusion processes and phase equilibria will be discussed by comparing calculated phase distributions of the aluminized alloy using a thermodynamic-kinetic CALPHAD [26] method with the experimental results. The aim of the development of the proposed modelling approach is to provide a generalized procedure to predict microstructural and compositional changes in aluminized Ni-base alloys.

2. Experimental procedure

The nominal chemical composition of the substrate alloy 625 is shown in Table 1. The specimens (20 × 10 mm^2) were delivered in as-aluminized condition with a nominal thickness of 0.3 mm. The chemical composition of the substrate alloy in the studied material was analyzed by the EDX and shown in Table 2. From the comparison of element composition between Tables 1 and 2, and the illustration of estimated average element concentration profiles of the substrate in Fig. 6, the substrate alloy in the studied material corresponded to the concentrations of major alloying elements given in the nominal chemical composition of the alloy 625. The cyclic oxidation tests were

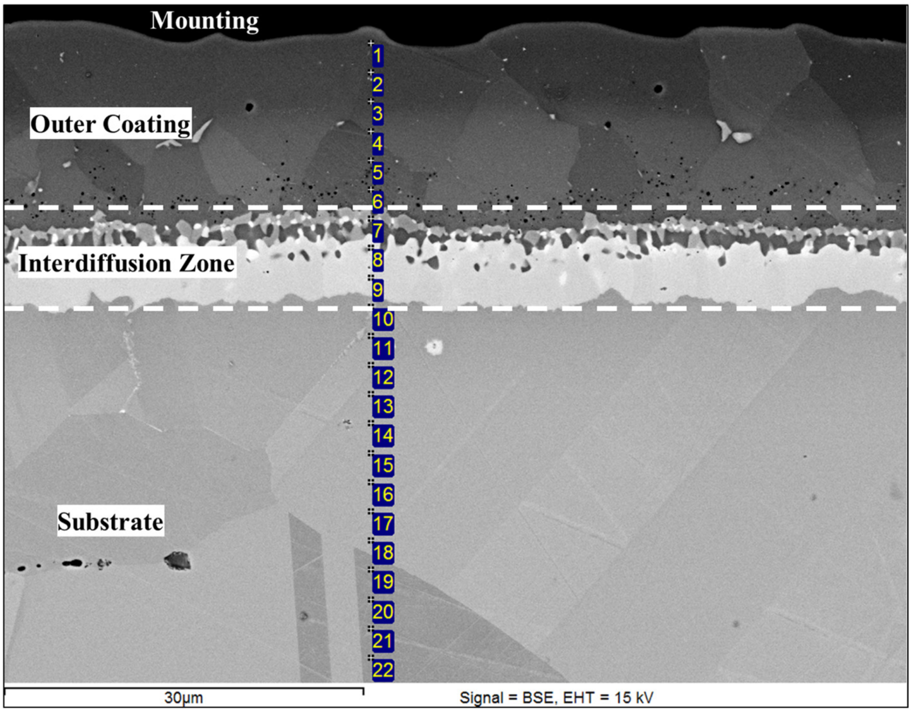


Fig. 2. BSE image showing the cross section of as-aluminized alloy 625. Points 1–6 and 22 refer to EDX point analysis data shown in Table 3. Dashed lines indicate the OC/IDZ and IDZ/substrate interfaces.