Karl-Winnacker-Institut High Temperature Materials

Oxidation Resistant Al and PtAl Diffusion Coatings with Improved Oxidation Resistance and Thermomechanical Fatigue Life

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Background

The use of nickel-base superalloys as turbine blade materials requires their protection against environmental attack. It has been shown that diffusion coatings can significantly improve the high-temperature hot corrosion and oxidation resistance of gas turbine components. Of all the diffusion coatings known from the literature, aluminide coatings are the most widely used. During oxidation they may form a protective α-Al_2O_3 scale acting as a barrier against oxidising species present in the atmosphere. Unfortunately, under service conditions, the oxide scale can rapidly spall as a consequence of stresses due to thermal cycling and oxide growth. Then, the continuous re-oxidation of the coating surface associated with interdiffusion between coating and substrate progressively leads to aluminium depletion of the coating. Finally, the Al-concentration near the oxide-metal interface is too low to ensure the selective formation of alumina and non-protective mixed oxides form. Platinum additions are well known to improve the high temperature cyclic oxidation behaviour of the coatings. However, mechanisms by which platinum improves the oxidation resistance of the diffusion coatings are still not well understood. In this work, the influence of the Pt-concentration and of the microstructure on the thermal cycling oxidation resistance of several Pt-modified Ni-aluminide coatings at 1150°C has been investigated. Coatings have been deposited by project partners under the frame of the ORDICO European Growth contract.

Experimental

Materials

Coatings were deposited on the PWA 1484 Ni-base superalloy (see chemical composition in table 1). Button samples (18 mm diameter and 5 mm thickness) were coated with one two-phase ß-(Ni,Pt)Al/$PtAl_2$ coating and four single-phase ß-(Ni,Pt)Al coatings, produced by MTU Aero Engines and SIFCO Turbine Components. Coatings were deposited using standard industrial routes: platinum electrolytic deposition, aluminising and heat treatment at high temperature. In order to obtain the desired coating composition and microstructure, the thickness of the Pt-layer and the parameters of the aluminising process (pack activity, temperature, time) as well as of the heat treatment have been adjusted.

	Ni	Al	Cr	Co	Ta	Mo	W	Re	Hf
PWA 1484	59.2	5.3	5.1	9.9	7.3	6.5	1.9	4.7	0.1

Tab. 1: Chemical composition (wt.%) of the PWA 1484 Ni-base superalloy

Experimental procedure

Specimens were submitted to thermal cycling oxidation tests at 1150°C. Each cycle consisted of 1h at 1150°C, 44 min at ambient temperature and 16 min reheating. Mass changes of the specimens were periodically measured.

Results

Coatings in their as-coated conditions

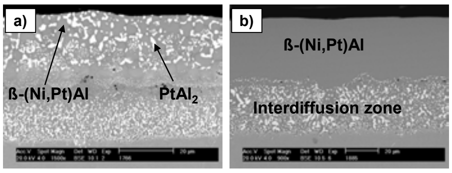

Fig. 1: SEM micrographs of a) coating 1 and b) coating 2

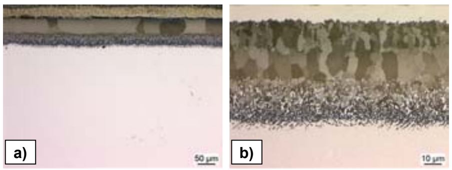

Fig. 2: Optical micrographs of a) coating 2 and b) coating 3

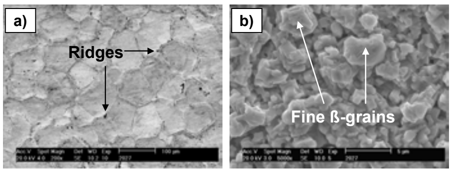

Fig. 3: SEM micrographs of the surfaces of a) coating 2 and b) coating 3

Coating 1 was a two-phase $PtAl_2$ / ß-(Ni,Pt)Al coating with a fine grained (<5 µm) structure. Coatings 2, 3 and 4 were exclusively composed of the ß-(Ni,Pt)Al phase (see Fig. 1). These coatings could however be differentiated through their microstructures. Indeed, coating 2 was composed of a single row of large grains whereas coatings 3 and 4 were fine grained (see Fig. 2). Coating 5 was a fine-grained ß-(Ni,Pt)Al coating containing fine alloying element precipitates. The surface roughness of the coatings was also very different as function of the coating quality. For example, coatings 2 and 4 showed surfaces composed of smooth grains outlined by ridges, typical of an outwardly growing coating. On the contrary, coatings 3 and 5 had rough surfaces composed of fine ß-(Ni,Pt)Al grains more or less detached from the surface. The thicknesses of coatings 1, 2, 3, 4 and 5 were 62, 80, 62, 76 and 80 µm, respectively.

The concentration profiles shown in Fig. 4 indicate low Al-gradients within the outer part of the five coatings. The Al-contents were however very different as function of the nature of the coating. Coating 1, due to the presence of the $PtAl_2$ phase, revealed the highest Al-contents up to ~ 56 at.% close to the coating surface. The Pt-concentration curves typically showed two different kinds of behaviour. Coatings 1 and 5 exhibited significant Pt-gradients characterised by high concentrations close to the coating surface decreasing quickly to the zero value in the vicinity of the interdiffusion zone. On the contrary, Pt-concentration profiles of coatings 2, 3 and 4 evidenced plateaus throughout the coating.

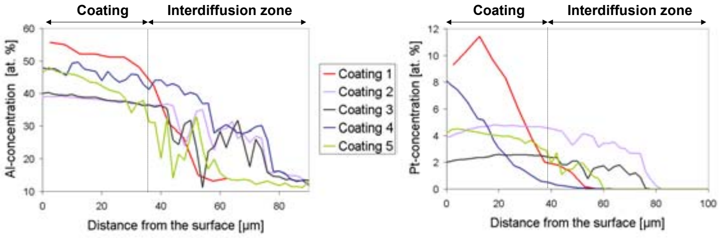

Fig. 4: Al- and Pt-concentration profiles of the coatings tested.

Thermogravimetric investigations

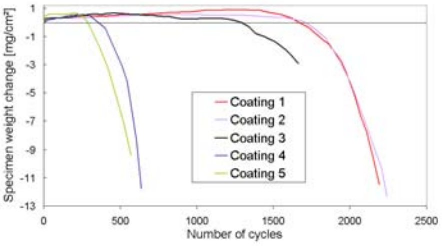

Fig. 5: Specimen weight change curves as function of the number of cycles.

Based on the weight change curves, the coatings could be merged into two groups:

- Coatings 1, 2 and 3 having a good resistance to cyclic oxidation and exhibiting positive weight gains up to 1665, 1701 and 1288 cycles, respectively.

- Coatings 4 and 5 having a low resistance to cyclic oxidation and exhibiting positive weight gains up to 350 and 289 cycles, respectively.

Degradation mechanisms

Periodical inspection of the specimens during testing revealed that coatings 4 and 5 developed less protective Al_2O_3 scales rich in spinel $NiAl_2O_4$. Consequently, early spallation occurred leading to Al-depletion of the coating. On the contrary, the alumina scales formed on coatings 1, 2 and 3 were adherent and could efficiently protect the coatings. However, Al-depletion mainly due to interdiffusion between coating and substrate led to the transformation of the ß-NiAl phase to the γ'-Ni_3Al phase. This induced a volume contraction of the coating (theoretical value of 35 %) resulting in the following degradation steps: rumpling of the coating surface, formation of cracks, Al-depletion and oxide scale spallation (Fig. 6).

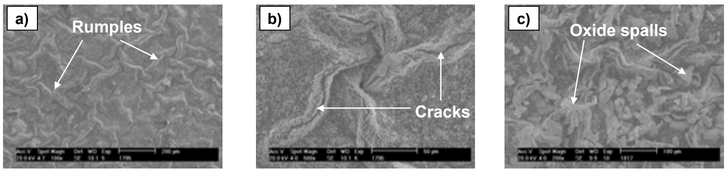

Fig. 6: SEM micrographs of the surface of coating 1 after a), b) 1100 cycles and c) 1600 cycles.

Correlation between Al / Pt contents and thermal cycling performance

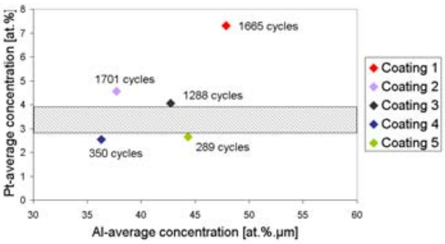

Fig. 7: Correlation between Al / Pt contents and thermal cycling performance.

In order to investigate the effects of the chemical composition on the cyclic oxidation resistance, Pt- and Al-average contents have been correlated to coating performance. It has been shown that there seems to be a critical Pt-content value lying between ~ 2.9 and ~ 3.9 at.% (Fig. 7). Moreover, results showed also that the coating microstructure had a relevant effect. Indeed, the comparison of the behaviour between coatings 2 and 3 revealed that fine grained coatings with rough surfaces should promote the formation of rapid growing oxide scales (due to the presence of numerous nucleation sites). Such scales show lower resistance against spallation.

Conclusion

Investigations showed that the Pt-average content of the coating had a determinant effect on the cyclic oxidation resistance. It has even been shown that there exists a critical Pt-average content to ensure the positive effect of Pt. The concentration of Al, contrary to Pt, did not show any significant influence. Results also revealed that coatings with smooth surfaces and large grains were more favourable for the formation of a protective alumina scale during thermal cycling.