High Temperature Oxidation Protection of Ti-Alloys with different Al-content via Pack-Aluminizing and Subsequent Fluorination

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Introduction

Ti-alloys are widely used as structural materials in different industrial fields, but their use at temperatures above about 500°C is limited due to accelerated oxidation/corrosion and environmental embrittlement by oxygen-, nitrogen- and/or hydrogen-uptake. This embrittlement can lead to failure of Ti-components (fig.1).

Orthorhombic Ti_2AlNb-alloys which are also light weight materials suffer from the same problems. Especially environmental embrittlement has hindered any high temperature application so far.

To suppress the high oxidation rate and the embrittlement of the materials a combined treatment by Al-enrichment of a narrow surface zone plus subsequent fluorination is applied in the project.

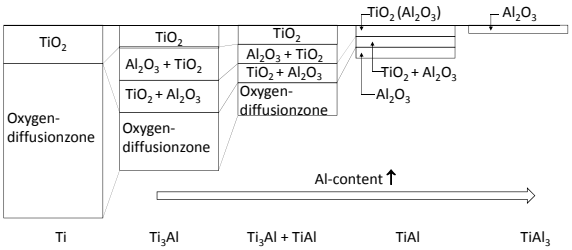

Figure 1: Schematic of the oxide layers and the oxygen diffusion zone of Ti and titanium aluminides (Smialek et al. 1985).

Experimental

Several technical Ti-, Ti_3Al- and o-Ti_2AlNb-alloys were investigated with and without further treatment. The compositions of the alloys (wt.%) were as follows:

Ti6246: Ti-6Al-2Sn-4Zr-6Mo
Ti6242: Ti-6Al-2Sn-4Zr-2Mo-0.1Si
Alloy 1: Ti-22Al-25Nb
Alloy 2: Ti-25Al-21Nb
Alloy 3: Ti-24Al-11Nb
Alloy 4: Ti-24Al-5Nb

The alloys were enriched with aluminium by the powder pack process (fig. 2) and the fluorine was applied afterwards by plasma immersion ion implantation (PI³) at the HZDR so that the fluorine effect could operate (fig. 3).

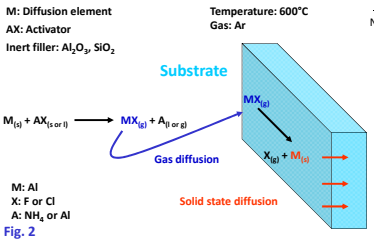

Fig. 2

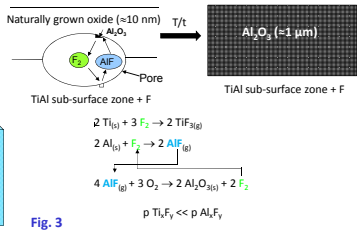

Fig. 3

Figures 2 and 3: Schemes of the powder pack process (left) and the mechanism of fluorine effect (right)

Results

The high temperature oxidation kinetics of an orthorhombic o-Ti_2AlNb alloy (Ti-24Al-21Nb) was measured isothermally via thermogravimetric analysis at 800°C in dry synthetic air (fig. 4a). The oxidation rate is quite high reaching more than 3 mg/cm² after 120h. Fluorination enhances the oxidation in the first hours of exposure and the rate is still too high. Sole Al-enrichment improves the behavior a bit further over the whole test period of 360h but again the oxidation rate is still too high. Slow alumina kinetics are reached by a combined treatment (Al-enrichment + fluorination). This positive effect is still active after 480h. Light optical microscopy investigation of the metallographic cross sections reveal a thick mixed oxide scale (ca. 20µm) with an influenced sub surface zone down to about 50µm on the untreated sample (fig. 4b). The aluminized specimen is also covered by a mixed oxide scale which has almost the same thickness as the untreated sample but without an influence on the sub surface zone (fig. 4c). The combined Al+F treated sample is protected by a thin alumina layer on top of the intact aluminide diffusion layer (fig. 4d). The thickness of the aluminide diffusion layer is less than 10µm (fig. 5a). EPMA analysis indicates the formation of a $TiAl_3$-layer after pack aluminization (fig. 5c). The clearly visible influenced sub surface zone of the untreated sample after oxidation (fig. 4b) can be correlated to an oxygen diffusion profile underneath the oxide scale (fig. 5b). No oxygen is found underneath the aluminide layer after oxidation (fig. 5d), just some Al was consumed due to the formation of the protective alumina layer.

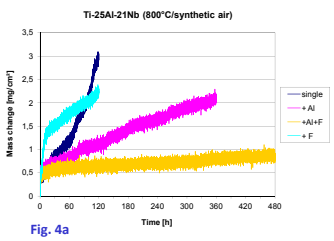

Fig. 4a

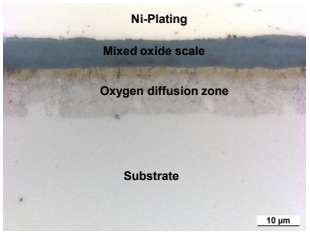

Fig. 4b

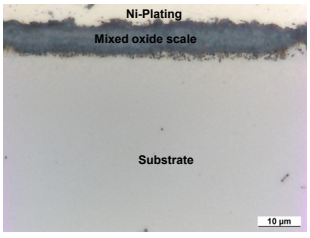

Fig. 4c

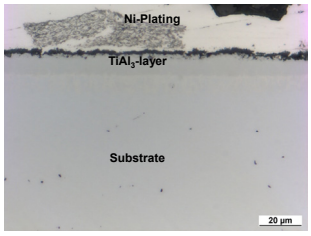

Fig. 4d

Figures 4a - d: Thermogravimetric mass change curves of untreated, single F-implanted (PI³), single Al-enriched and combined Al+F treated Ti-24Al-21Nb during isothermal oxidation at 800°C in dry synthetic air (a) and corresponding light optical images of the untreated (b), Al-enriched (b) and combined Al+F treated specimens after 120h oxidation at 800°C in dry synthetic air

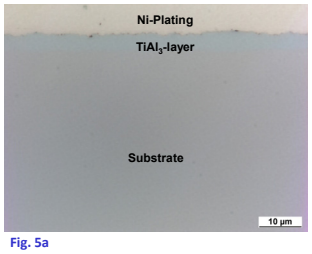

Fig. 5a

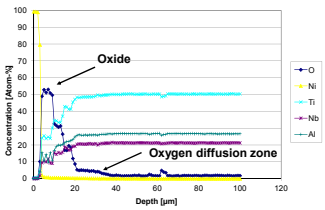

Fig. 5b

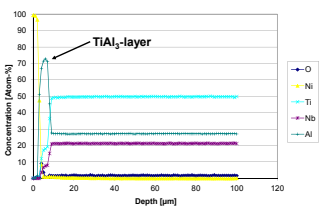

Fig. 5c

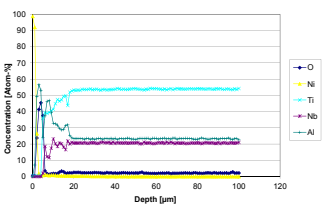

Fig. 5d

Figures 5a - d: Light optical image of a Ti-24Al-21Nb sample after Al-enrichment without oxidation (a) and EPMA depth profiles of the untreated sample after oxidation (b), aluminized sample after pack (c) and combined Al+F treated sample after oxidation (d)

Conclusions

Oxidation and oxygen ingress into Ti-based materials during high temperature exposure in oxidizing environments can be suppressed by a combination of Al-enrichment plus F-treatment. Hence, no severe material loss due to oxidation or environmental embrittlement occurs so that they are suitable for applications at higher temperatures than today.

Acknowledgement

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