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The influence of Si on oxidation resistance of aluminide coatings on TiAl alloy

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ABSTRACT

Purpose: Increasing oxidation resistance of TiAl intermetallic alloy by depositing aluminide coating by slurry method and investigation of the influence of Si addition on isothermal oxidation of TiAlNb intermetallic alloy.
Design/methodology/approach: : The isothermal oxidation resistance tests were done in the chamber furnace at 900ºC for 500h time in the air atmosphere. The structure of coatings was investigated by light and scanning microscopy. The chemical composition of coatings and scales was investigated by EDS method and XRD phase analysis was used as well.
Findings: In case of all the samples, the increase of the mass has been observed, as a result of the scale growth. The smallest mass changes have been detected in samples containing the coatings formed from 12,5% Si slurries. The largest weight loss took place in samples with the coatings created in 20, 40 and 60% wt silicon slurries. The oxidation test showed increasing of oxidation resistance of TiAl alloy with aluminide coatings and presence of products of oxidation - Al_2O_3 on surface.
Practical implications: The slurry method can be applied in aerospace and automotive industry as low-cost technology of producing of aluminide coatings on intermetallics.
Originality/value: New method of depositing of aluminide coatings on TiAl alloys
Keywords: Surface treatment; Oxidation resistance

1. Introduction

The research done so far has confirmed that TiAl alloys are the materials which, on the grounds of their strength properties in a wide range of temperatures, can be applied in aircraft and automobile engines. The biggest restraint in the application of these materials is, apart from their high manufacturing costs, their relatively low oxidation resistance in temperatures above 800°C [1,2]. It's associated with their inclination to the formation of mixed titanium and aluminium oxide scale. The improvement of the resistance can be achieved by means of increasing the Al content, and thus forming Al_2O_3 scale, which creates a barrier preventing the corrosion from progressing. The resistance enhancement may also be accomplished by the modification of the chemical composition of the alloy.

The research in Japan has shown the high erosion and corrosion resistance of the TiAl alloys of TNB type, characterised by high niobium content (up to 14% wt).

This type of alloys belongs to the minority of alloys used on a massive scale [3]. Although phases $TiAl_3$ and $TiAl_2$ of the Ti-Al system exhibit high aluminium content, they may not be used as a construction material due to their high embrittlement. However, the possibility remains to create aluminide coating on the surface of TiAl-based intermetallic alloy.

The usage of protective coatings is another prospect of oxidation resistance improvement. MeCrAlY, TBC, enamel coatings and the coatings generated by plasma spraying or magneton sputtering and Arc-PVD methods [4-14] are used for this purpose. Nevertheless, the most popular method, is pack cementation. This method is, among other uses, employed to make aluminide coatings based on high-aluminium Ti-Al system phases [15].

This enables high oxidation resistance without interference in the chemical content of the alloy base. In addition, there is a possibility of modifying the coating with such oxidation-resistance-improving elements as Nb, Ni, Si, Cr.

Silicon is an element which greatly increases the TiAl alloys oxidation resistance. This property of silicon is related to its ability of forming titanium silicides of the types $TiSi_2$, Ti_5Si_3, Ti_5Si_4 and TiSi, that exhibit high oxidation resistance. As well as this, it forming of silicides slows down the process of forming rutile during oxidation (as a result of binding titanium), and thus increasing the activity of aluminium.

2. Experiment

The high-niobium TNB type alloy delivered by Mitsubishi Heavy Industries has been used as the base material. The coating was formed by immersing the samples in slurries with variable Al and Si content: 100% wt Al, 5, 12.5, 20, 40, 60, 80, 100 % wt Si. When the samples had been dried, they were diffusion treated at 950°C in the Ar atmosphere for 4h.

The isothermal oxidation test has been done at 900°C in 500h time in the air atmosphere. The mass change measurement after the completion of the oxidation process has been made.

3. Isothermal oxidation test

Dark-yellow scale has formed on all the samples, whose forming caused the mass increase in all of them. The smallest mass increase has been confirmed in the coatings generated from the slurries containing 5, 80 and 100% wt Si. The largest weight loss has been observed in case of the coatings of 20, 40 and60% wt Si content (Fig. 1).

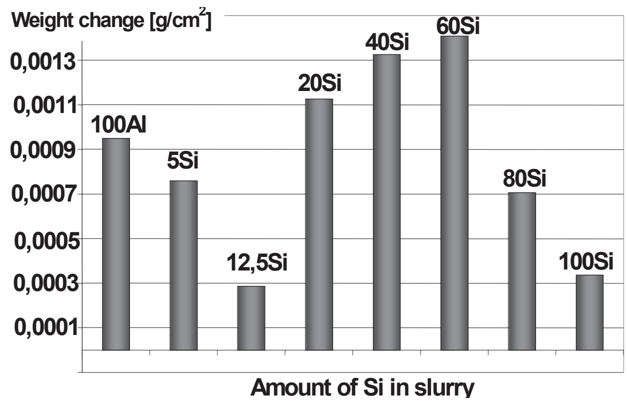

Fig. 1. The mass change in the samples with the coatings after the isothermal oxidation test 900°C/500h

3.1. Surface morphology

The examination of the morphology and the chemical content of the samples' surface after the isothermal oxidation test has shown the double-layered structure of the scale in all cases. The inner layer displayed high aluminium content (Fig. 2, Table 1, point 1) while the outer layer the titanium content prevailed remarkably (Fig. 2, Table 1, point 2). The appearance of the surface of the sample with 20% Si content has been presented in Fig. 2, samples' surface after the isothermal oxidation tests has confirmed the while the results of EDS analysis have been presented in Table 1.

The phase content analysis of the presence of the oxidation products, specifically aluminium and titanium oxides, on all of them. In addition, the phases of Ti-Al system, being the phase content of both the coating and the alloy base, have been observed. On the surface of the coatings containing Si, the phases $TiAl_2$ and TiAl, as well as Ti_5Si_3 were present.

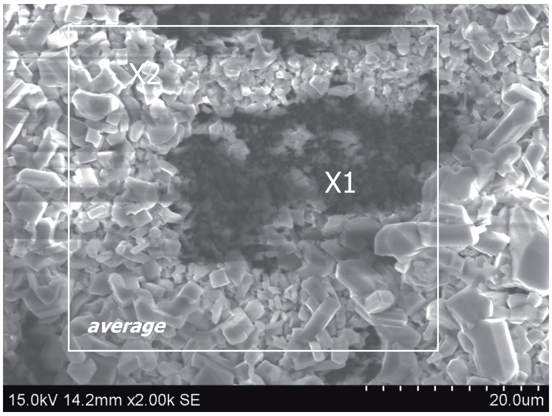

Fig. 2. The surface morphology of aluminide coating from slurry containing 20% Si after isothermal oxidation test

Table 1.
The results of the EDS analysis of the areas marked in Fig. 2

Point	Al		Ti	
	% wt	% at	% wt	% at
average	19.66	30.28	80.34	69.72
1	67.88	78.95	32.12	21.05
2	11.87	19.30	88.13	80.70

3.2. The structure of the aluminide coating after oxidation test

The chemical content analysis performed on the scale has presented its double-layered structure presented on Fig. 3 and the results of EDS analysis was presented in Table 2. The outer zone was formed by TiO rutile, which has been confirmed by EDS analysis showing the presence of titanium (Fig. 3, Table 2, point 1 and 2).

Beneath this area, the presence of aluminium oxide has been detected, being proved by almost 100% content in the chemical analysis (Fig. 3, Table 2, point 3).

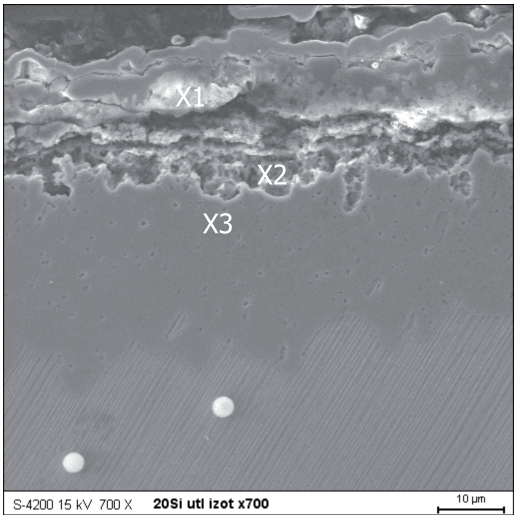

Fig. 3. The structure of aluminide coating from slurry containing 20% Si after isothermal oxidation test

Table 2.
The results of the EDS analysis from the points marked on Fig. 3

point	Al		Nb		Ti	
	%wag	% at.	%wag	% at.	%wag	% at.
1	---	---	---	---	100	100
2	26,60	16,95	---	---	73.40	83,05
3	93,98	96,98	1,72	0,52	4,30	2,50

3.3. The structure of the coatings obtained from the slurries containing silicon

The chemical content analysis of the cross-section of the coatings after the isothermal oxidation test has been performed both linearly and in points. The linear EDS analysis of the coating obtained from 20% Si slurry has been shown in Fig. 4.

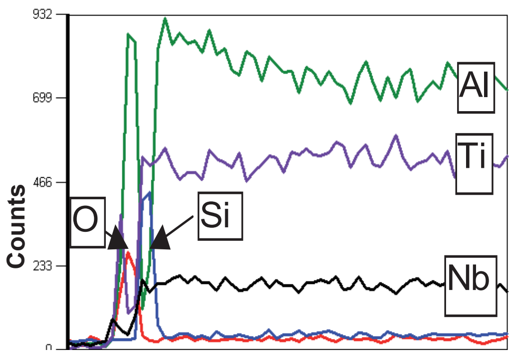

Fig. 4. The linear analysis of the element concentration in the cross-section of the coating obtained from the slurry containing 20% Si after the isothermal oxidation test 900°C/500h

It has confirmed the minor increase of titanium component in the inner layer. Beneath it, a remarkable growth of the aluminium and oxygen contents have been observed, which proves that the scale Al_2O_3 has formed. Beneath the scale, in the coating, the immense growth of the Si and Ti contents followed, which indicates the forming of silicides. In the inner layer of the coating, the amount of aluminium was increased again, whereas the silicon and titanium numbers fell considerably.

The structure of coating obtained from pure-silucon slurry after isothermal oxidation test was presented on Fig. 5. The results of EDS analysis from marked area were presented in Table 3.

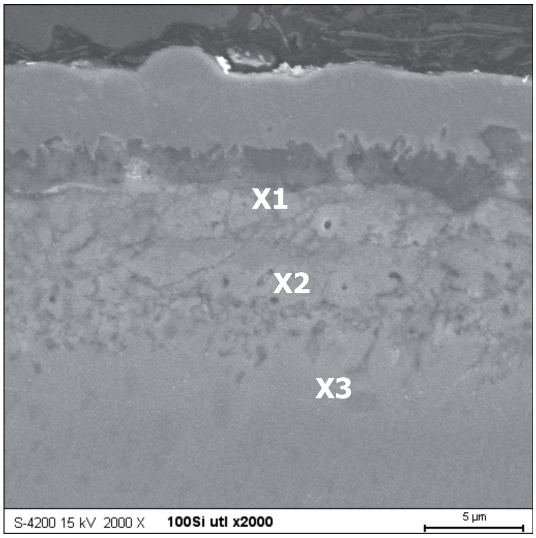

Fig. 5. The structure of the coating obtained from the slurry containing 100% Si after the isothermal oxidation test 900^{o}C/500h

Table 3.
The results of the EDS analysis of the points marked in Fig. 5

Pt	Al		Si		Nb		Ti		Cr	
	% wt	% at.	% wt	% at.	% wt	% at.	% wt	% at.	% wt	% at.
1	75,03	84,21	-	-	-	-	24,97	15,79	-	-
2	5,30	9,17	13,55	22,53	22,61	11,37	56,40	55,00	2,14	1,93
3	62,87	79,84	-	-	18,44	6,80	18,68	13,36	-	-

4. Discussion

The isothermal oxidation test has shown that the smallest mass increase took place in case of the samples with the coatings obtained from the 12,5% Si slurry. The chemical content and phase analysis performed on the samples have confirmed the presence of a thin layer of rutile oxides on the surface and a much thicker layer of the aluminium oxide scale. In addition, a high silicon and titanium content has been observed under the Al_2O_3 layer, which proves that the titanium silicide zone has formed. An area rich in aluminium has been found beneath.

Such scale and coating layer structure affirm the beneficial influence of the coatings obtained from slurries containing silicon. Besides a small amount of rutile on the surface, aluminium oxide is the major component of the scale, forming a thin layer which prevents the progress of oxidation. The high silicon and titanium content indicates the forming of titanium silicides which create a continuous zone protecting the base from oxidation, as confirmed by Taniguchi's [15]. The high aluminium content below this zone has a positive effect on the aluminide oxide scale forming as well.

One of the advantages of the production of aluminide coatings from the slurries containing metallic powders, followed by diffusion treatment, is the low cost of such procedure, as well as the convenience of chemical content modification (it's done by adding other elements in the form of powders).

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