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Short communication

Diffusion aluminide coatings for TiAl intermetallic turbine blades

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A B S T R A C T

Alloys based on intermetallic phases of a Ti–Al system are materials that, thanks to their resistance characteristics, can be widely used in automotive and aerospace applications. The main restriction for the use of Ti–Al materials is their insufficient oxidation resistance above 850 °C. Oxidation parameters might be improved by aluminide coatings based on $TiAl_2$ and $TiAl_3$ phases, which could induce the creation of an Al_2O_3 scale in the oxidation process. This type of aluminide could be deposited on the surface of TiAl alloys by various methods such as pack cementation, plasma spraying or magnetron sputtering. This article presents a new method of aluminide coating deposition on TiAl intermetallic alloys: out of pack technology. The investigated coating was deposited on turbine blades made of a Ti45Al5Nb intermetallic alloy. The surface morphology, structure, phase and chemical composition have been investigated using XRD phase analysis, SEM and EDS. The phase analysis showed that $TiAl_3$ and $TiAl_2$ were the main components of the deposited coating. An isothermal oxidation test of the TiAl turbine blades was conducted as well. After 1000 h of testing at 950 °C, the scale formed on the surface of the uncoated blades underwent spallation. The scale on the turbine blade with deposited aluminide coatings was very thin and no spallation was observed.

1. Introduction

The intermetallic γ-TiAl-phase-based alloys are characterized by many beneficial features, which have enabled their wide interest for aircraft and automotive industries. The most important features include: low density (3.8 g/cm^3), high specific strength, relatively high oxidation resistance, high specific modulus of rigidity and high creep resistance at high temperatures. Research has been focused on the improvement of mechanical properties, the increase of oxidation resistance and the reduction of manufacturing costs.

The TiAl-phase-based alloys can be used as an alternative material for nickel superalloys, especially on the low pressure turbine blades where the operating temperature was lower (about 900 °C). The main restriction for industrial applications of γ-TiAl alloys has been high manufacturing costs and insufficient oxidation resistance at temperatures above 850 °C. Other barriers include low plasticity and structural instability during prolonged exposure to high temperatures [1,2]. The technical possibility of accomplishing an optimal chemical composition of γ-TiAl alloys has been non-existent, especially if the alloy must provide high-temperature oxidation resistance at low manufacturing costs. Despite the additives, TiAl alloys have been unable to form pure aluminum oxide scale during oxidation. Consequently, protective coatings need to be applied.

The main technology to deposit coatings based on high-aluminum $TiAl_3$ phases on TiAl alloys was the pack cementation method [3,4]. The coating was formed as a result of diffusion from the powder in which the samples were placed with a halogenide activator. The protective coating includes: an outer zone consisting of the $TiAl_3$ phase; and an inner zone composed of the $TiAl_2$ phase. Fractures may have appeared during the cooling from the deposition temperature, due to the brittleness of $TiAl_3$ phase [5]. During the oxidation tests of aluminide coatings at 800–1000 °C, a massive growth of an intermediate $TiAl_2$ zone took place, at the expense of the $TiAl_3$ zone [6]. The coatings deposited on the TiAlNb alloys were characterized by much higher oxidation resistance than those obtained on the TiAl alloy without Nb additives [7].

The studies by Xiang and Rose proved that silicon and aluminum can be deposited simultaneously through pack cementation process [8–11]. The oxidation tests of the coating conducted at 800 °C and 850 °C confirmed that the process occurred according to the parabolic curve [11].

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One of the most widely used methods to investigate the oxidation resistance of γ-TiAl alloys has been ion implantation [12]. Lei et al. [13] proved that Nb, W, Si, Al, Cl, P were the elements that increased the oxidation resistance of TiAl alloys, whereas the implantation of Cr, Zr, Mo, Mn, Pt did not influence the oxidation resistance. Taniguchi et al. [14–17] demonstrated that the ion implantation of silicon caused formation of intermetallic phases such as $Ti_7Al_5Si_{12}$.

Magnetron sputtering of MCrAlY provided an improvement in the corrosion resistance of TiAl alloys at temperatures ranging from 800 to 900 °C [18]. During the oxidation process diffusion reactions between the coating elements and the base material occurred. MeCrAlY coatings may have formed a base material for zirconium-oxide-based thermal barrier coatings (TBC) [19]. Aluminide coatings or preoxidation process might have been used to form an interlayer [20]. Recently, the thermal barrier coatings deposited with electron beam physical vapor deposition (EB-PVD) methods have been researched [21].

In China [22], efforts were made to form protective coatings on TiAl alloys by means of immersion in liquid silumin. The result was a homogenous coating composed mainly of triple phases of $Al_{12}Si_3Ti_5$ and $Ti_7Al_5Si_{12}$. In addition, the formation of titanium silicides was observed.

Excellent properties were achieved in silicon-modified aluminide coatings deposited with the Arc-PVD method (evaporating silumin targets from AK11 alloy) and subsequent vacuum heat treatment. The obtained coating was 40 μm thick [23]. Cyclic oxidation tests, both short and prolonged, were conducted at 950 °C and revealed an exceptionally high oxidation resistance of the deposited coating [24].

The out of pack process operates at temperatures between 900 and 1050 °C into Ar atmosphere. The out of pack method has a number of advantages over pack cementation method (a) faster cycle time because the parts are not surrounded by pack, (b) better coating uniformity on each part, (c) less variation in coating thickness from one place in the retort to another, (d) no coating defects caused by pack inclusions, (e) lower cost of operation because less pack material is used [25].

2. Experimental

The turbine blades used in the study were made of a Ti45Al5Nb alloy, whose chemical composition has been presented in Table 1.

The shell casting of the turbine was performed in a centrifugal casting device. Oxygen pick-up between 300 and 400 wt. ppm was expected during melting and super-heating. The key parameters were: super-heating of the alloy, shell mold temperature, rotation speed for fast mold filling, high casting pressure, proper shell mold positioning in order to ensure use of centrifugal and Coriolis forces and cooling curves. Further processing included knock-off of the ceramic shell, cutting and polishing of the castings. The knock-off and polishing were completed with sand blasting; and cutting was completed with a high pressure water jet. High-temperature isostatic pressing (HIP) was used to close rest porosities. HIP parameters were strictly controlled to prevent corrosion, deformation or microstructure modifications.

The cast blades underwent surface preparation processes, including cleaning and degreasing. The aluminizing process was done with the out of pack method. The blades were placed in a container between suitably pre-prepared granules containing aluminum and fluoride activator (AlF_3) The container was placed in the retort furnace. The process was carried out at 1050 °C/4 h in a protective argon atmosphere.

Table 1
The chemical composition of the alloy used for turbine blades producing (at.%).

Alloy	Al	Nb	Cr	B
Ti45Al5Nb	45	5	0.2	0.2

The structural analysis was performed by a high-resolution scanning electron microscope FEI Inspect F, equipped with a Schottky Field Emission source and connected to Edax EDS detector. X-Ray Diffraction Analysis (XRD) was performed with a JDX-7S Jeol diffractometer.

The oxidation tests were carried out at 950 °C in static laboratory air. An aluminide-coated blade and an uncoated blade were used in the investigation. After each 100 h of exposure at high temperatures, the blades were removed in order to assess the degree of destruction caused by oxidation and to take photographs. The testing of all samples ended after 1000 h of exposure. The individual mass changes of blades were not measured. After the testing had been completed, the blades underwent surface morphology and structural examinations, as well as chemical and phase composition analyses.

3. Results

The TiAlNb turbine blade, presented on Fig. 1a was aluminized with the out of pack method. The obtained coating completely covered the turbine blade.

The XRD phase analysis of the sample surface detected the presence of high-aluminum phases in the TiAl system: $TiAl_2$ and $TiAl_3$. The cross section of the coated blade is given in Fig. 2a showed two characteristic layers (Fig. 2a, results of EDS analysis – Table 2). The outer layer was made up of equiaxed grains containing approximately 50 at.% Ti and 44 at.% Al (Fig. 2a, point 1). Between the grains, a high-aluminum area was present (about 69 at.%, point 2, Fig. 2a). The inner zone contained columnar grains with high-aluminum content (approximately 74 at.%) and niobium (about 10 at.%) (Fig. 2a, point 3). The aluminum content between the grains amounted to about 67% at.%, whereas the niobium content was approximately 5 at.% (point 4, Fig. 2a). In the transitional area, the aluminum content amounted to 50 at.%, and the niobium content was about 9.5 at.%. (point 5, Fig. 2a).

After the oxidation test, the uncoated blade, presented on Fig. 1b, was covered with yellow scale that spalled. The largest damage was revealed in the edge of attack and flow areas of turbine blade. The XRD phase analysis of the sample surface revealed the presence of aluminum, titanium and niobium oxides, titanium nitrides and the TiAl phase. The scale formed on the uncoated

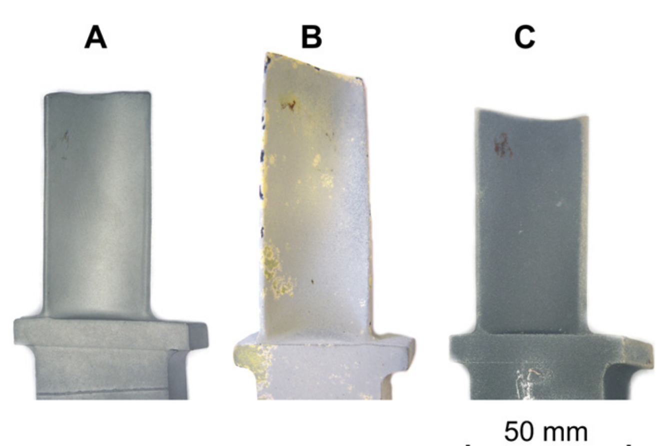

Fig. 1. The overview of TiAl turbine blades: (A) after aluminizing, (B) after 1000 h oxidation test (without aluminizing) (C) after aluminizing and 1000 h oxidation test.