Specification

Metal component with a high-temperature protection coating system and a method of coating the component

The invention relates to metal components with high-temperature protective coating systems and to a method of coating such metal components.

U.S. Patent No. 3,873,347 to Walker et al. and U.S. Patent No. 3,874,901 to Rairden disclose methods of improving the high temperature oxidation and corrosion resistance of a nickel or cobalt-base superalloy body, in particular a gas turbine component, by providing a coating system for the body comprising the steps of placing an alloy layer on the body, the alloy layer being made from an alloy now known as MCrAlY alloy, and placing an aluminide layer on the alloy layer, according to U.S. Patent No. 3,874,901 followed by heat treating the coated body to obtain interdiffusion of aluminum into the alloy layer. The improvement in corrosion and oxidation resistance is ascribed mainly to the aluminide layer, because it increases the amount of aluminum present in the coating system.

U.S. Patent Nos. 4,055,705 to Stecura et al.; 4,321,310 to Ulion et al.; and 4,321,311 to Strangman disclose coating systems for gas turbine components made from nickel or cobalt-based superalloys. A coating system described comprises a thermal barrier layer made from ceramic, which in particular has a columnar grained structure, placed on a bonding layer which in its turn is placed on the substrate and bonds the thermal barrier layer to the substrate. The bonding layer is made from an MCrAlY alloy, namely an alloy containing chromium, aluminum and a rare earth metal such as

yttrium in a basis comprising at least one of iron, cobalt and nickel. Further elements can also be present in an MCrAlY alloy; examples are given below. An important feature of the bonding layer is a thin alumina layer developed on the MCrAlY alloy and used for anchoring the thermal barrier layer.

U.S. Patent No. 5,238,752 to Duderstadt et al. discloses a coating system for a gas turbine component which also incorporates a ceramic thermal barrier layer and a bonding layer bonding the thermal barrier layer to the substrate. The bonding layer is made from an intermetallic aluminide compound, in particular nickel aluminide or platinum aluminide. The bonding layer also has a thin alumina layer which serves to anchor the thermal barrier layer.

U.S. Patent No. 5,262,245 to Ulion et al. describes a result of an effort to simplify coating systems incorporating thermal barrier layers for gas turbine components by avoiding bonding layers. To this end, a composition for a superalloy is disclosed which may be used to form a substrate of a gas turbine component and which develops an alumina layer on its outer surfaces under a suitable treatment. This alumina layer is used to anchor a ceramic thermal barrier layer placed thereon, eliminating the need for a special bonding layer to be interposed between the substrate and the thermal barrier layer.

U.S. Patent No. 5,087,477 to Giggins et al. teaches a method for placing a ceramic thermal barrier layer on a gas turbine component by a physical vapor deposition technique comprising evaporating compounds forming the thermal barrier layer with an electron beam and establishing an atmosphere having a controlled content of oxygen at the component to receive the thermal barrier layer.

U.S. Patent Nos. 5,154,885; 5,268,238; 5,273,712; and 5,401,307 to Czech et al. disclose advanced coating systems for gas turbine components comprising protective coatings of MCrAlY alloys. The MCrAlY alloys disclosed have carefully balanced compositions to give exceptionally good resistance to corrosion as well as to oxidation as well as an exceptionally good compatibility to the superalloys used for the substrates. The basis of the MCrAlY alloys is formed by nickel and/or cobalt. Additions of further elements, in particular silicon and rhenium, are also discussed. Rhenium in particular is shown to be a very advantageous additive. All MCrAlY alloys shown are also very suitable as bonding layers for anchoring thermal barrier layers, particularly in the context of the invention disclosed hereinbelow.

Gas turbine components like blades, vanes and heat shield elements comprising bodies made of metals like nickel or cobalt-based superalloys are commonly protected against corrosive attacks including oxidation and sulfidation at elevated temperatures by coating systems comprising protective coatings covering exposed parts of the bodies. As explained in the documents of the state of the art mentioned above, a coating system placed on an outer surface of a body may include an alloy layer made from an MCrAlY alloy and a ceramic layer, which acts as a thermal barrier layer, placed on the alloy layer.

Gas turbine components which have to sustain heavy thermal loads when in operation also frequently have internal channels through which a cooling fluid is guided. Normally, a channel has a first opening in a mounting portion of the component at which the component is fixedly held in operation and a plurality of second openings disposed in an active portion of the component which is exposed to a gas stream

streaming along the component during operation. The cooling fluid is generally admixed to the gas stream through the second openings, eventually after having formed a cooling film covering and protecting a surface of the active portion against an immediate contact with the gas stream.

A body of a gas turbine component might well be subject to a corrosive or oxidative attack within a channel formed therein, since the temperature prevailing at an inner surface defined by a channel in a body may still be fairly high, and thus a chemical reaction between a constituent of the fluid flowing through the channel and the material of the body is encouraged. Even if the fluid is air or a mixture of air and steam according to usual practice, contaminants of the air like salt from a marine environment or ammonia and/or sulphur compounds from a rural environment might give rise to corrosion. As a measure against such attacks, inner surfaces of channels in gas turbine components usually have aluminide coatings placed thereon.

When manufacturing a gas turbine component by placing a an alloy layer and a ceramic layer on an outer surface and an aluminide coating on an inner surface, care must be exercised to avoid disadvantageous interactions between the constituents of the coating system on the outer surface and the coating on the inner surface. Particularly critical is the aluminide compound which is placed on the inner surface by gas phase aluminizing and cannot be prevented sufficiently from precipitating also on the outer surface of the component. Usually, the alloy layer is placed on the outer surface but left with its original roughness prior to aluminizing the inner surface. Then, the inner surface is aluminized and the alloy layer inevitably aluminized as well, and subsequently the alloy layer with the aluminizing layer

thereon is smoothened, eventually by grinding and/or polishing, to the desired residual roughness.This treatment removes a considerable part of the aluminide layer on the alloy layer, but never assuredly all. The ceramic layer must thus be placed on a surface with an ill-defined chemical composition, and the robustness of the ceramic layer obtained may be questionable. A complete removal of the aluminide from the alloy layer, however, would require more elaborated measures and render the manufacturing process uneconomically expensive.

As an alternative to the coating process just described, it has been contemplated to place an aluminide layer both on the inner surface and the outer surface of a gas turbine component prior to placing the alloy layer on the outer surface. In that case however, an aluminium rich an thus brittle phase is formed in the body of the component due to diffusion of the aluminum richly present, which might embrittle the body itself and thus render its usefulness questionable.

It is accordingly an object of the invention to provide a metal component with a high-temperature protection coating system and a method of coating the component, which overcomes the above-mentioned disadvantages of the heretofore-known devices and methods of this general type and which fulfills the need to improve known coating systems to make them and their intended function less sensitive to aluminide layers and more adapted to be employed together with aluminide layers independent of the use and location of these aluminide layers, if only an interaction between an aluminide layer and a coating system at any time exists.

With the foregoing and other objects in view there is provided, in accordance with the invention, a method of coating an outer surface of a body of an article of manufacture formed of a metal, the method which comprises the following steps:

placing an alloy layer on an outer surface of the body

polishing the alloy layer;

placing an aluminide layer having a substantially uniform thickness on the alloy layer; and

placing a ceramic layer on the aluminide layer.

In accordance with an added mode of the invention, the step of placing the alloy layer comprises placing the alloy layer onto the outer surface only; and the step of placing the aluminide layer comprises also placing an aluminide layer on the inner surface defined by a channel formed in the body.

In accordance with an additional mode of the invention, the step of placing the aluminide layers comprises providing the aluminide layer on the inner surface having a thickness of up to 50 micrometers; and providing the aluminide layer on the alloy layer having a thickness of up to 10 micrometers.

In accordance with another mode of the invention, the aluminide layers are polished in the placing step. The aluminide layers may be placed by gas phase aluminizing.

In accordance with a further mode of the invention, the method includes a step of polishing the aluminide layer placed on the alloy layer prior to the step of placing the ceramic layer.

In accordance with a concomitant mode of the invention, the step of polishing the alloy layer comprises providing the alloy layer having a surface roughness Ra being less than 2

micrometers. The term Ra indicates a surface roughness which has been determined by a standardized method for measurement. In particular, Ra is determined as follows: On a surface whose roughness is to be measured, a reference line of suitable length is defined. A smooth profile of the surface along the reference line is determined by a least-sgares fit. Ra is determined as the aithmetic mean value of the absolute values of deviations of the actual surface from the smooth profile along the reference line. The reference line must be long enough to eliminate influences of statistical fluctuations on the value of Ra, and it must be short enough to retain ist significane as a representative of the whole surface.

With the foregoing and other objects in view there is also provided, in accordance with the invention, an article of manufacture, comprising a metal substrate defining a body with an outer surface; and a coating system disposed on the outer surface, the coating system including

an alloy layer placed on the outer surface and having a polished surface facing away from the outer surface;

an aluminide layer placed on the alloy layer and having a substantially uniform thickness; and

a ceramic layer placed on the aluminide layer.

The aluminide layer has a preferred thickness of less than 10 micrometers (mm).

The alloy layer has a preferred surface roughness of less than 2 micrometers at a surface adjacent the aluminide layer.

In accordance with yet another feature of the invention, the alloy layer is formed of an MCrAlY alloy, and the metal substrate is a nickel or cobalt-based superalloy substrate.

In accordance with yet an additional feature of the invention, the aluminide layer consists essentially of a compound selected from the group consisting of aluminum, nickel aluminide and platinum aluminide.

In accordance with an added feature of the invention, the body has a channel formed therein defining an inner surface of the body, the inner surface having an aluminide layer placed thereon. The aluminide layer on the inner surface has a preferred thickness of less than 50 micrometers and it may also be formed of aluminum, nickel aluminide or platinum aluminide.

In accordance with again a further feature of the invention, the body and the coating system together form a gas turbine component. The gas turbine component may be an airfoil component comprising an airfoil portion for exposure to a gas stream streaming along the article in operation, the airfoil portion being covered by the coating system.

In accordance with a concomitant feature of the invention, the body has a channel formed therein extending through the airfoil portion and defining an inner surface of the body, the inner surface having an aluminide coating placed thereon.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a metal component with a high-temperature protection coating system and a method of coating the component, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit

of the invention and within the scope and range of equivalents of the claims.

The construction of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of the specific embodiment when read in connection with the accompanying drawings.

Fig. 1 is a fragmentary cross-sectional view through a coating system applied in accordance with the invention; and

Fig. 2 is a perspective view of a gas turbine airfoil component comprising the substrate and protective coating system shown in Fig. 1.

Referring now to the figures of the drawing in detail and first, particularly, to Fig. 1 thereof, there is seen a substrate having a protective coating system incorporating an alloy layer, an aluminide layer and a ceramic layer placed thereon as well as an aluminide layer placed on an inner surface formed in a channel.

The substrate 1 forms the base of an article of manufacture, in particular a gas turbine component, which in operation is subject to a heavy thermal load and concurrently to corrosive and erosive attack. The substrate 1 is formed of a material which is suitable to provide strength and structural stability when subjected to a heavy thermal load and possibly an additional mechanical load by severe forces like centrifugal forces. A material which is widely recognized and employed for such a purpose in a gas turbine engine is a nickel or cobalt-based superalloy.

In order to limit the thermal load imposed on the substrate 1, it has a coating system placed thereon. This coating system also protects the substrate 1 against corrosive attack including oxidative attack. The coating system comprises an alloy layer 2, an aluminide layer 3 placed thereon and a ceramic layer 4 placed on the aluminide layer 3.made in form of a ceramic layer 2 disposed thereon. The alloy layer 2 consists of an MCrAlY alloy and preferably of an MCrAlY alloy as patented in one of the above-mentioned Czech et al. U.S. Patent Nos. 5,154,885; 5,268,238; 5,273,712 and 5,401,307 and incorporated herein by reference. The ceramic layer 4 is made from a columnar grained ceramic, in particular consisting essentially of a stabilized or partly stabilized zirconia.

Within the substrate 1, there is located a channel 5 where cooling fluid may flow through to cool the substrate 1 during operation. This channel 5 is bounded by an inner wall 6, on which an aluminide layer 7 is placed.

The placing of the different layers 2, 3, 4 and 7 is performed according to a special program in order to avoid disadvantageous interactions between the layers 2, 3, 4 and 7 and their constituents. Particularly critical are the aluminide layers 3 and 7. On the inner wall 6, the aluminide layer 7 is dedicated to a special function, namely to protect the inner wall 6 against corrosive attack. The aluminide layer 3 outside the channel 5 may be unnecessary with respect to the function the coating system is provided for, but it is a hardly avoidable byproduct of the process of placing the aluminide layer 7 on the inner wall 6.

To incorporate the aluminide layer 3 into a well-functioning coating system and to avoid any disadvantage which might result from its presence, this aluminide layer 3 is placed

between the priorly placed and polished alloy layer 2 and the ceramic layer 4 to be placed subsequently. The polishing of the alloy layer 2 defines a smooth boundary to the aluminide layer 3, which in turn can be polished or surface-treated otherwise as may be desired. It is preferred to adjust a thickness of the alumide layer 3 below 10 micrometers, expediently by surface-finishing after placing. To this end, it is also preferred to polish the alloy layer 2 prior to placing the aluminide layer 3 to have a surface roughness below 2 micrometers.

The thickness of the aluminide layer 7 on the inner surface can be matched to the particulars of the function intended for this layer. It is preferred to keep a thickness of that aluminide layer 7 below 50 micrometers.

The selection of the material for the aluminide layers 3 and 7 is not particularly critical. Preferredly, one of aluminum, nickel aluminide and platinum aluminide is used. The aluminide layers 3 and 7 are expediently placed by gas phase aluminizing, which is a process well known and frequently employed in the art but which has the disadvantage of spilling the aluminide onto locations where it might not be desired, necessitating special measures as disclosed herein.

The placing of the alloy layer 2 is generally less critical, aws it is normally done by a plasma spraying process which is more selective as to locations to be coated than the gas phase process used to aluminize and generally poses no special problem. Eventually, the placing of the alloy layer 2 requires a dedicated thermal treatment to homogenize and/or bond the alloy layer 2 to the substrate 1.

The placing of the aluminide layer 3 between the alloy layer 2 and the ceramic layer 4 has the additional benefit of providing a source of aluminum to diffuse into the alloy layer 2, increasing its desired protective properties, and providing an interface to develop under suitable conditions a thin alumina layer which is an excellent means for anchoring the ceramic layer 4. The thickness of the aluminide layer 3 should however be not too high, in order to avoid an embrittling of the alloy layer 2 by ttaining an aluminum content being too high. Generally, a limit of 10 micrometers for the thickness of the aluminide layer is considered to be effective.

Fig. 2 shows the whole gas turbine component, namely a gas turbine blade 8. The component 8 has an airfoil portion 9, which in operation forms an "active part" of the gas turbine engine and subjected to a gas stream streaming along, a mounting portion 10, at which the component 6 is fixedly held in its place during operation, and a sealing portion 11, which prevents the gas stream from leaving a flow path designed.

The sectional view of Fig. 1 may be taken along the line I-I.

In order to cool the turbine blade 8, it has channels 5 to guide a cooling fluid therethrough, as exemplified in Fig. 1. The cooling fluid is usually supplied at the mounting portion 10, as indicated by arrow 12. The cooling fluid leaves the turbine blade 8 through orifices 13 and merges into the gas stream streaming along the airfoil portion 9.

In placing the coating system onto the turbine blade 8 as explained above, the orifices 13 might eventually need special attention to keep them from being choked with

material during the placing of a layer 2, 3, 4 or 7, where the placing of the alloy layer 2 and the placing of the ceramic layer 4 are usually most critical. It is therefore preferred to check the orifices 13 after a layer 2, 3, 4 or 7 has been placed. Eventually, the orifices 13 are not made until at least some of the layers 2, 3, 4 and 7 are placed. Preferably, the orifices 13 are made, particularly by laser milling or ECM, after the alloy layer 2 has been placed, but before it is polished.

After placing the aluminide layers 3 and 7, throttle sheets can be inserted and fastened into the channel 5, if necessary.

A final heat treatment, particularly dedicated to finish the ceramic layer 4, may expediently finish the manufacturing process.

Claims:

1. A method of coating an outer surface of a body of an article of manufacture formed of a metal, the method which comprises the following steps:

placing an alloy layer on an outer surface of the body polishing the alloy layer;

placing an aluminide layer having a substantially uniform thickness on the alloy layer; and

placing a ceramic layer on the aluminide layer.

2. The method according to claim 1, wherein the body has at least one channel formed therein defining an inner surface of the body;

the step of placing the alloy layer comprises placing the alloy layer onto the outer surface only; and

the step of placing the aluminide layer comprises placing an aluminide layer on the inner surface concurrently.

3. The method according to claim 2, wherein the step of placing the aluminide layers comprises

providing the aluminide layer on the inner surface having a thickness of up to 50 micrometers; and

providing the aluminide layer on the alloy layer having a thickness of up to 10 micrometers.

4. The method according to claim 3, wherein the step of placing the aluminide layers comprises polishing the aluminide layer placed on the alloy layer.

5. The method according to one of claims 1 to 4, wherein the step of placing the aluminide layers comprises placing by gas phase aluminizing.

6. The method according to claim 1, wherein the step of placing the aluminide layer comprises placing by gas phase aluminizing.

7. The method according to one of the preceding claims, which comprises the step of polishing the aluminide layer placed on the alloy layer prior to the step of placing the ceramic layer.

8. The method according to one of the preceding claims, wherein the step of polishing the alloy layer comprises providing the alloy layer having a surface roughness Ra being less than 2 micrometers.

9. An article of manufacture, comprising a metal substrate defining a body with an outer surface; and a coating system disposed on said outer surface, said coating system including

an alloy layer placed on said outer surface and having a polished surface facing away from said outer surface;

an aluminide layer placed on said alloy layer and having a substantially uniform thickness; and

a ceramic layer placed on said aluminide layer.

10. The article according to claim 9, wherein said aluminide layer has a thickness less than 10 micrometers.

11. The article according to claim 9 or 10, wherein said alloy layer has a surface roughness Ra less than 2 micrometers at a surface adjacent said aluminide layer.

12. The article according to one of claims 9 to 11, wherein said alloy layer is formed of an MCrAlY alloy.

13. The article according to one of claims 9 to 12, wherein said metal substrate is a nickel or cobalt-based superalloy substrate.

14. The article according to one of claims 9 to 13, wherein said aluminide layer consists essentially of a compound selected from the group consisting of aluminum, nickel aluminide and platinum aluminide.

15. The article according to one of claims 9 to 14, wherein said body has a channel formed therein defining an inner surface of said body, said inner surface having an aluminide layer placed thereon.

16. The article according to claim 15, wherein said aluminide layer on said inner surface has a thickness less than 50 micrometers.

17. The article according to claim 15 or 16, wherein said aluminide layer on said outer surface and said aluminide layer on said inner surface consist essentially of a compound selected from the group consisting of aluminum, nickel aluminide and platinum aluminide.

18. The article according to one of claims 9 to 17, wherein said body and said coating system form a gas turbine component.

19. The article according to claim 18, wherein the gas turbine component is an airfoil component comprising an airfoil portion for exposure to a gas stream streaming along the article in operation, said airfoil portion being covered by said coating system.

20. The article according to claim 19, wherein said body has a channel formed therein extending through said airfoil portion and defining an inner surface of said body, said inner surface having an aluminide coating placed thereon.

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