Cold spraying method for MCrAIX coating

Gas-dynamic spraying of MCrAIX alloy particles, wherein M is selected from one or more of Ni, Co, and Fe and wherein X is an element other than M, Cr, and Al, including the steps of providing a supersonic gas stream having solid-phase MCrAIX alloy particles entrained therein and having a gas stream temperature to maintain the particles below their melting temperature and impinging the solid-phase particles in the supersonic gas stream against an unheated nickel or cobalt base superalloy substrate to deposit an MCrAIX overlay coating thereon.

FIG. 1

Diagram of the cold spraying method.
Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method for cold spraying MCrAlX alloy particles to form an overlay coating on a substrate.

BACKGROUND OF THE INVENTION

[0002] MCrAlY overlay coatings, where M is selected from one or more of Ni, Co and Fe, are applied to hardware, such as turbine components including turbine airfoils (e.g., blades and vanes) and shroud bodies of gas turbine engines, as a hot corrosion resistant and oxidation resistant coating. Shroud bodies collectively form an annular sealing surface against which the turbine blade tips seal as they rotate as is well known. In the past, such MCrAlY overlay coatings have been applied by various techniques. For example, initially MCrAlY overlay coatings were applied using electron beam physical vapor deposition (EB-PVD). Thermal spraying techniques were developed to overcome certain disadvantages associated with the EB-PVD deposition process. Such thermal spraying techniques have included low pressure plasma spraying (LPPS), high velocity oxygen fuel spraying (HVOF), and air plasma spray which are widely used today.

[0003] In low pressure plasma spraying, MCrAlY alloy powder particles are heated in a high temperature plasma jet to above their melting point and propelled towards a substrate inside a vacuum chamber which maintains the spray environment at some low pressure below 1 atmosphere, and typically below 50 torr. Powder particle heat and velocity are achieved using a plasma torch designed or modified for operation under reduced ambient pressure.

[0004] The high velocity oxygen fuel coating method is a supersonic flame spray process that transfers thermal and kinetic energy to powder particles of the MCrAlY alloy powder particles using a combustion torch, rather than a plasma. The particles are heated by the torch to above their melting point before they impact the substrate. The method typically is performed in a spray environment at local atmospheric pressure, and the torch may be manipulated manually or using automated systems. The component being coated is typically fixtureed and attached to a table or drive system.

[0005] Thermal spraying processes such as the LSSP, HVOF and air plasma spray processes for applying MCrAlY overlay coatings suffer from certain disadvantages. For example, the thermal sprayed coating applied on hollow airfoil substrates typically covers surface-film cooling holes on the exterior surface of the airfoil substrate. If airfoils with advanced cooling schemes are coated by thermal spraying, the cooling holes must be opened after coating such as by, for example, pumping hot acid through the hollow airfoil substrate so that the acid exits through the covered cooling holes in a manner to corrode away the coating overlying the cooling holes. Alternately, the MCrAlY coating can be drilled through to expose the underlying cooling holes. The acid pumping and drilling operations are expensive and time consuming.

[0006] Such thermal spraying processes are disadvantageous in that the as-sprayed MCrAlY overlay coating exhibits a rough surface (e.g. greater than 300 micro-inch) such that it is necessary to perform expensive and time consuming shot peening and polishing operations on the as-sprayed coating to achieve an airfoil surface finish required by engine manufacturers (e.g. less than 75 micro-inch surface finish).

[0007] Such thermal spraying processes can be inefficient from the standpoint that deposit efficiency (percentage of the initial powder sprayed and deposited on the substrate) is low. For example, the deposition efficiency of HVOF process typically is only 30% to 35%. Since thermal spray powders can cost form $40.00 to $60.00 per pound, the low deposition efficiency represents a significant waste of expensive raw material.

[0008] In applying MCrAlY overlay coatings by HVOF or plasma spray process, the surface of the airfoil substrate must be rough (e.g. greater than 200 micro-inch surface roughness) to create a good mechanical bond between the coating and the substrate. The necessary surface roughness of the substrate is achieved by an aggressive grit blasting operation (e.g. 55-65 psi with 16 grit alumina particles). The grit particles can become embedded in the substrate surface and require a subsequent grit particle removal operation as described, for example, in US Patent 6 194 026.

[0009] Finally, thermal spray processes require significant heating of the substrate prior to coating deposition. For example, in applying MCrAlY overlay coatings using the LPPS process, the process can require heating the substrate to 1400 to 1800 degrees F over a four minute time period followed by reverse arc cleaning over a four minute time period before coating deposition. The pre-coating steps of heating and reverse arc cleaning can consume over 50% of the total time to coat the substrate.

SUMMARY OF THE INVENTION

[0010] The present invention provides a method of gas-dynamic spraying of particles comprising MCrAlX alloy, wherein M is selected from one or more of Ni, Co, and Fe and wherein X is an element other than M, Cr, and Al and preferably is selected from one or more of Y, a rare earth element, and a reactive element, including the steps of providing a supersonic gas jet stream having solid-phase MCrAlX alloy particles entrained therein and having a gas stream temperature to maintain the particles below their melting temperature and impinging the solid-phase particles in the supersonic gas stream against a nickel or cobalt base superalloy substrate to
deposit an MCrAlX overlay coating thereon.

In an illustrative embodiment of the invention, the particles comprising MCrAlX alloy preferably have a mean particle size (diameter) of about 20 microns and below, and more preferably of 10 microns and below, to provide substantially increased deposition efficiency and substantially reduced as-sprayed coating surface roughness.

In another illustrative embodiment of the invention, the as-sprayed MCrAlX overlay coating is deposited on an unheated superalloy substrate residing in ambient air.

In another illustrative embodiment of the invention, the as-sprayed MCrAlX overlay coating deposited on the superalloy substrate subsequently is heat treated to form a diffusion bond between the coating and the substrate.

The above advantages of the present invention will become more readily apparent when taken with the following detailed description and drawings.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of spray apparatus for practicing an embodiment of the invention.

Figure 1A is an end view of the supersonic section of the nozzle.

Figure 2 is a graph depicting deposition efficiency versus mean particle size for CoNiCrAlY alloy powder sprayed pursuant to an embodiment of the invention.

Figure 3 is a graph depicting as-deposited surface finish versus mean particle size for a CoNiCrAlY alloy coating sprayed pursuant to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

An embodiment of the present invention relates to gas-dynamic spraying of particles comprising an MCrAlX alloy on a nickel or cobalt base superalloy substrate to deposit an MCrAlX alloy overlay coating thereon. The MCrAlX alloys are hot corrosion resistant and oxidation resistant protective alloys applied as an overlay coating or layer onto turbine components such as airfoils, which include turbine blades and vanes, and shroud blocks as well other turbine components, and non-turbine engine components. By overlay coating is meant that the as-sprayed coating is not bonded to the substrate by a metallurgical diffusion bond or zone between the coating and substrate, but is adherent to the substrate by virtue of a mechanical bond to the substrate. In these alloys, the M alloying element is selected from the group consisting of Ni, Co, and Fe and combinations thereof. The X alloying element comprises an element other than M, Cr, and Al. X preferably is selected from the group consisting of Y, a rare earth element such as Ce and/or La, and a reactive element such as Si, Hf, Zr, an alkali element such as K, and/or alkaline earth element such as Ca and/or Mg and other reactive elements (where reactive element refers to an element that forms stable sulfides, borides, phosphides, and other compounds with species such as S, B, P, etc. detrimental to oxidation resistance of the coating), and combinations of two or more of Y a rare earth element, and reactive element.

The MCrAlX coating typically consists essentially of, in weight %, about 14% to about 35% Cr, about 4% to about 30% Al, about 0.1% to about 3% X where X is selected from one or more of the above-described elements, and balance essentially M where M is iron and/or nickel and/or cobalt.

The present invention involves providing a supersonic gas stream having solid-phase MCrAlX particles entrained therein and having a gas stream temperature low enough to maintain the MCrAlX particles below their melting temperature and impinging the solid-phase particles in the supersonic gas jet stream against a nickel or cobalt base superalloy substrate to deposit the overlay MCrAlX coating thereon. Apparatus for practicing the invention is shown in Figure 1 as including a source 10 of compressed carrier gas, which preferably comprises helium, although the invention can be practiced using other carrier gases such as air, nitrogen, and mixtures thereof. The compressed carrier gas is typically at a pressure in the range of 100 to 600 psig. For purposes of illustration and not limitation, a high pressure cylinder of helium at 400 psi can be used to practice the method of the invention. The compressed carrier gas is supplied to a gas preheater 12 and to a powder particle feeder 14 via respective conduits 13 and 15. Respective valves 16 and 18 are provided in conduits 13 and 15 for the purpose of gas shut-off.

The gas pre-heater 12 functions to preheat the carrier gas (e.g. He) to a temperature above ambient but well below the melting temperature of the MCrAlX particles being sprayed so that the MCrAlX particles are not melted and remain in the solid phase in the supersonic stream. The gas pre-heater can comprise a conventional electrical resistance gas heater or any other type of heater capable of heating the compressed gas such as a gas pre-heater like that described in US Patent 5 302 414, whose teachings are incorporated herein by reference.

The powder particle feeder 14 functions to meter via conduit 20 the MCrAlX particles at a selected powder flow rate to a mixing chamber 22 while the compressed, pre-heated gas enters the chamber 22 via conduit 24 from the gas pre-heater 12. The powder particle feeder 14 can comprise a drum-type feeder like that described in US Patent 5 302 414, whose teachings are
incorporated herein by reference. The invention can be practiced using other powder particle feeders such as including, but not limited to those that are based on a rotating feeder wheel or feeder screw or a fluidized feeder bed.

[0021] The mixture of compressed carrier gas and MCrAIX powder particles is flowed through a supersonic (convergent-divergent) nozzle 30 having a gas distribution baffle 30a, convergent (sonic) section 30b, and divergent (supersonic) section 30c. By flow through the nozzle 30, the carrier gas and powder particles entrained therein are accelerated to a supersonic velocity in the range of 350 to 1800 m/s (meters/second) corresponding approximately to Mach numbers of 1 to 5.2 as described in above-noted US Patent 5 302 414 whose teachings are incorporated herein by reference. The supersonic gas jet stream impinges on the unheated substrate S to deposit the MCrAIX overlay coating thereon. The nozzle 30 and the substrate S are disposed in ambient air with the substrate at ambient air temperature; i.e. no pre-heating of substrate S is required.

[0022] The following example is offered to further illustrate the invention without limiting the invention. Substrate specimens comprising a nickel base superalloy known as Rene'41 were sprayed pursuant to the invention to deposit a CoNiCrAlY overlay coating thereon. The substrate Rene'41 nickel base superalloy has a nominal composition of, in weight %, 19% Cr-11% Co-10% Mo-5% Fe-0.09% C-1.5% Al-3% Ti-balance Ni. The substrate specimens comprised a plate shape having dimensions 2 inches wide by 4 inches long by 1/8 inch thick and were pre-treated prior to spraying by grit blasting using 220 grit aluminum oxide particles at 40 to 60 psi air pressure. CoNiCrAlY powder of different particle sizes were used and are available as CO-210-6 and CO-210-23 from Praxair Surface Technologies. The powder produced a coating analyzed after spraying and heat treatment as having a nominal composition of, in weight %, 31.4% Ni-20.5% Cr-9% Al-0.9% Y-balance Co. Two powder different particle sizes were sprayed in different spray trials; namely, particles having a mean particle diameter of 6.4 microns (CO-210-6) and 14.8 microns (CO-210-23). Mean particle diameter means that half of the particles had a diameter greater than the given size and the other half had a diameter less than the given size.

[0023] For purposes of illustration and not limitation, the spray parameters used in the trials included use of a supersonic nozzle section 30a, Figure 1, having a rectangular cross-section with dimensions a = 2 mm and b = 10 mm. The length, l, of nozzle section 30c was 100 mm. Helium at 400 psi and pre-heated to 400 degrees C by pre-heater 12, Figure 1, was used as the compressed carrier gas. The nozzle section 30a was spaced a standoff distance of 25 mm from the substrate specimen, which was at ambient air temperature. These parameters achieved particle velocities in the supersonic jet of helium of 19 to 25 mm/sec. The drum-type feeder described above similar to that in construction and operation to that described in US Patent 5 302 414 was used to provide a feed rate of powder of 3 to 5 kg/hr. The CoNiCrAlY overlay coatings were deposited to a thickness of 0.004 to 0.008 inch on the unheated substrate specimens. The invention is not limited to the above nozzle rectangular configuration and spray parameters since a circular cross-section or other cross-sectional shape of nozzle 30 as well as other nozzle dimensions and other spray parameters can be used in practice of the invention.

[0024] The deposition efficiency of the spray processes using the two different powder particle sizes set forth above were determined by spraying a known weight of the powder at each plate specimen of known initial plate specimen weight, determining the final weight of the plate specimen after spraying, and calculating the weight increase of each plate specimen due to the powder applied thereon, and determining a percentage by dividing the weight increase of each specimen by the initial weight of powder sprayed for that specimen and multiplying by 100. The deposition efficiencies are shown in Figure 2. As can be seen in Figure 2, the deposition efficiency for CoNiCrAlY powder increased as the powder particle size decreased. A maximum deposition efficiency of 55% was achieved for the mean particle diameter of 6.4 microns. This represents a substantial improvement (e.g. 1.7 to 1.8 times higher) in deposition efficiency as compared to that observed for spraying using LPPS and HVOF processes of similar powders so as yield significant cost savings for coating powder. Since the powder particles are not melted in practice of the spray process pursuant to the invention, it may be possible to recycle the oversprayed MCrAIX powder, thus further improving powder utilization and reducing raw material costs.

[0025] The surface finish of the as-sprayed CoNiCrAlY coatings was measured with a profilometer both parallel and perpendicular to the spray direction. Multiple measurements (6 in each direction) were averaged, and the average surface finish was plotted as function of powder particle size as shown in Figure 3. Figure 3 reveals that the surface finish improved as the mean particle diameter decreased. A surface finish of 243 micro-inches was achieved for the CoNiCrAlY coating using the mean particle diameter of 6.4 microns. For both particle sizes sprayed, the surface finish of the coatings was better than or equal to that obtained using the LPPS, HVOF and air plasma spray processes, which produce coating surface finishes greater than 300 micro-inches. Since gas turbine engine manufacturers require a surface finish of less than 100 micro-inches, the improved surface finish achieved by the invention will require less post-coat processing than a similar MCrAIX coating sprayed by LPPS, HVOF and air plasma spray processes.

[0026] For example, typical post-coating processing for a typical MCrAIX overlay coating applied by LPPS
involves firstly a diffusion heat treatment (e.g. 2-5 hours at 1080 degrees C) to form a diffusion bond between the coating and the substrate and to form equilibrium phases in the coating alloy. Secondly, the overlay coating is shot peened for 400 seconds to achieve about a 125 micro-inches surface finish. Thirdly, the heat-treated and peened coating must be vibratory polished for 3 hours to reduce the surface finish to less than 75 micro-inches using conventional media bowl polishing procedures.

By comparison, for a CoNiCrAlY overlay coating deposited by in the above-described trials using the mean powder particle size of 6.4 microns having a coating surface finish of 243 micro-inches, the coated substrate also was diffusion heat treated (e.g. 2-5 hours at 1080 degrees C) to form a diffusion bond between the coating and the substrate and to form equilibrium phases in the coating alloy. However, only 210 seconds of shot peening was needed to reduce the surface finish of the coating to 79 micro-inches, representing a 47% reduction in peening time as compared to a typical MCrAIY coating applied by LPPS. A final surface finish of 69 micro-inches was obtained on the CoNiCrAlY coating with just 30 minutes media bowl polishing time as compared to 3 hours for an MCrAIY coating applied by LPPS, representing an 84% reduction in polishing time as compared to a typical MCrAIY coating applied by LPPS.

Moreover, the above-described spraying trials demonstrate that substrate surface preparation using less aggressive grit blasting can be used and still obtain acceptable green bond strength (prior to diffusion heat treatment) of the MCrAlX overlay coatings. Furthermore, the invention can be practiced without any substrate pre-heating prior to spray deposition so as to eliminate the need for a grit-removal operation, pre-heat operation, and reverse arc cleaning as required by the LPPS process.

Test results also demonstrated that an MCrAIX overlay coating deposited on an airfoil substrate having surface film cooling holes on its exterior surface will not bridge over or close off the cooling holes as is characteristic of MCrAlX coatings deposited by the LPPS and HVOF processes.

Although the invention has been shown and described with respect to certain embodiments thereof, it should be understood by those skilled in the art that other various changes, modifications and omissions in the form and detail thereof may be made therein without departing from the spirit and scope of the invention.

Claims

1. A method of coating a nickel or cobalt base superalloy substrate comprising
   a) providing a supersonic gas stream having solid-phase MCrAlX alloy particles therein and having a gas stream temperature to maintain the particles below their melting temperature, wherein M is selected from the group consisting of one or more of Ni, Co, and Fe, and combinations thereof, and wherein X is an element other than M, Cr, and Al, and
   b) impinging said solid-phase particles in said supersonic gas stream against said substrate to deposit an MCrAlX overlay coating thereon.

2. The method of claim 1 wherein said MCrAlX alloy particles include X that is selected from the group consisting of Y, a rare earth element, and a reactive element, and combinations thereof.

3. The method of claim 1 or 2 wherein said particles have a mean particle diameter of about 20 microns and below.

4. The method of claim 3 wherein said particles have a mean particle diameter of about 10 microns and below.

5. The method of one of the preceding claims wherein said gas stream temperature is in the range of 100 to 800 degrees C.

6. The method of one of the preceding claims wherein said substrate is at ambient air temperature when it is impinged.

7. The method of one of the preceding claims wherein said particles consist essentially of, in weight %, 14% to 35% Cr, 4% to 30% Al, 0.1% to 3% X, and balance selected from the group consisting of Ni, Co, and Fe, and combinations thereof.

8. The method of one of the preceding claims including the step of heat treating the as-sprayed MCrAlX overlay coating deposited on the superalloy substrate to form a diffusion bond between the coating and the substrate.

9. The method of one of the preceding claims wherein an airfoil substrate is impinged by said solid phase particles.

10. Coated gas turbine engine component, comprising a nickel or cobalt base superalloy substrate and an MCrAlX overlay coating sprayed thereon in accordance with any one of claims 1 to 7.

11. The component of claim 10 which is a turbine airfoil.

12. The component of claim 10 or 11 which is a shroud block that forms a portion of sealing surface for tips
of turbine blades of a gas turbine engine.

13. The component of one of claims 10 to 12 which is a turbine airfoil having an exterior surface having cooling holes and having said coating sprayed on said surface without closing said cooling holes.

14. The component of one of claims 10 to 13 wherein said coating has a surface roughness less than 300 micro-inch as measured by a profilometer.
FIG. 2

DEPOSITION EFFICIENCY (%) vs MEAN PARTICLE SIZE (MICRON)

- The graph shows a linear relationship between deposition efficiency and mean particle size.
- The efficiency decreases as the particle size increases.
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<th>Category</th>
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<th>CLASSIFICATION OF THE APPLICATION (W.I.P.)</th>
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<tr>
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<td>US 3 993 454 A (GIGGINS JR CHARLES STANLEY ET AL) 23 November 1976 (1976-11-23) * column 2, line 35-43; examples 1-3 *</td>
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The present search report has been drawn up for all claims.

Place of search: MUNICH
Date of completion of the search: 21 January 2004
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