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(54) ARTICLE HAVING A SURFACE PROTECTED BY A SILICON-CONTAINING DIFFUSION COATING

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(57) **ABSTRACT**

A surface of an article is protected by coating the surface with a silicon-containing coating by preparing a coating mixture of silicon, a halide activator, and an oxide powder, positioning the surface of the article in gaseous communication with the coating mixture, and heating the surface of the article and the coating mixture to a coating temperature of from about 1150° F. to about 1500° F. The article is preferably a component of a gas turbine engine made of a nickel-base superalloy.

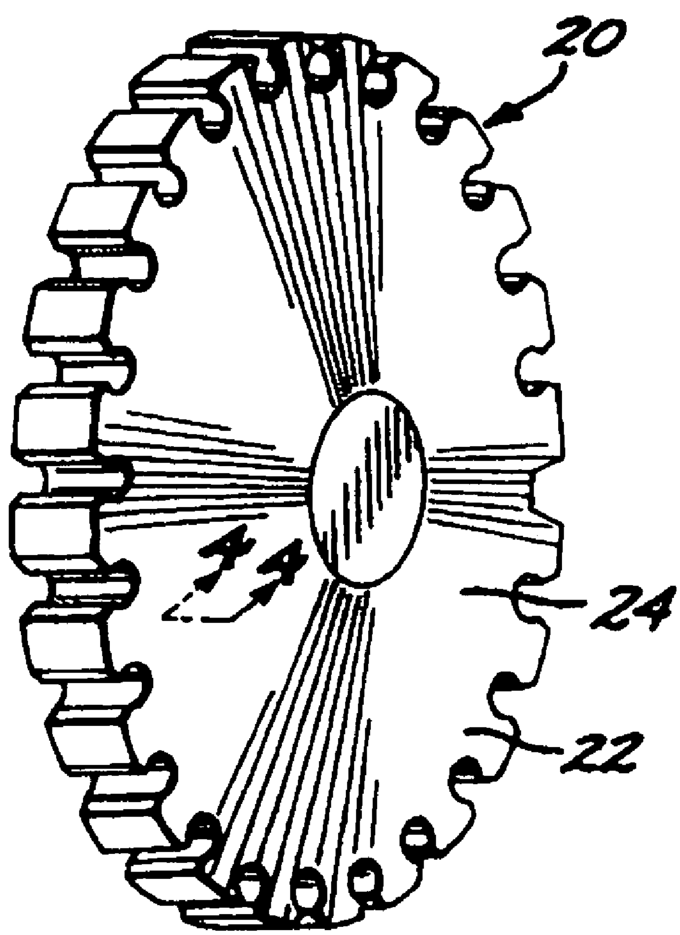


FIG. 1

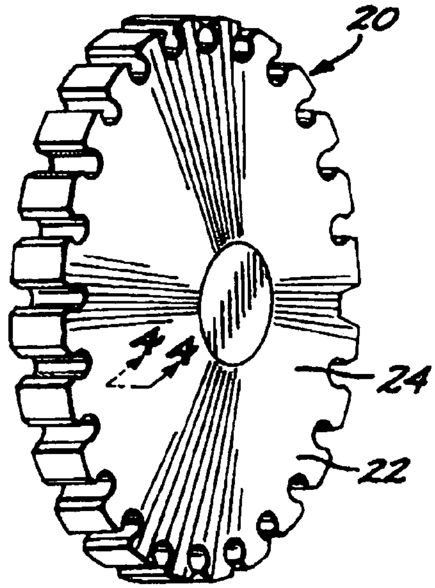
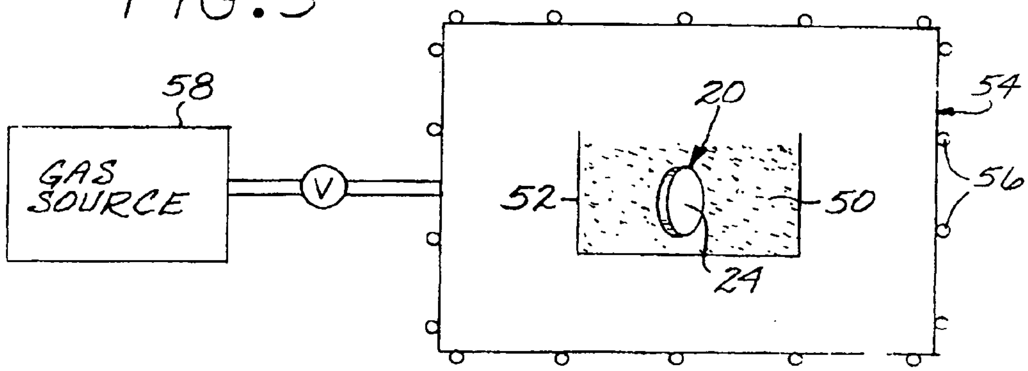


FIG. 3



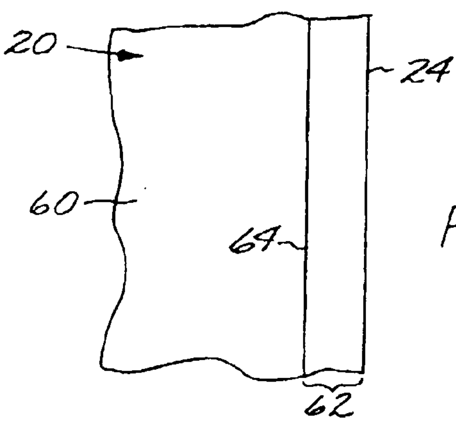


FIG. 4

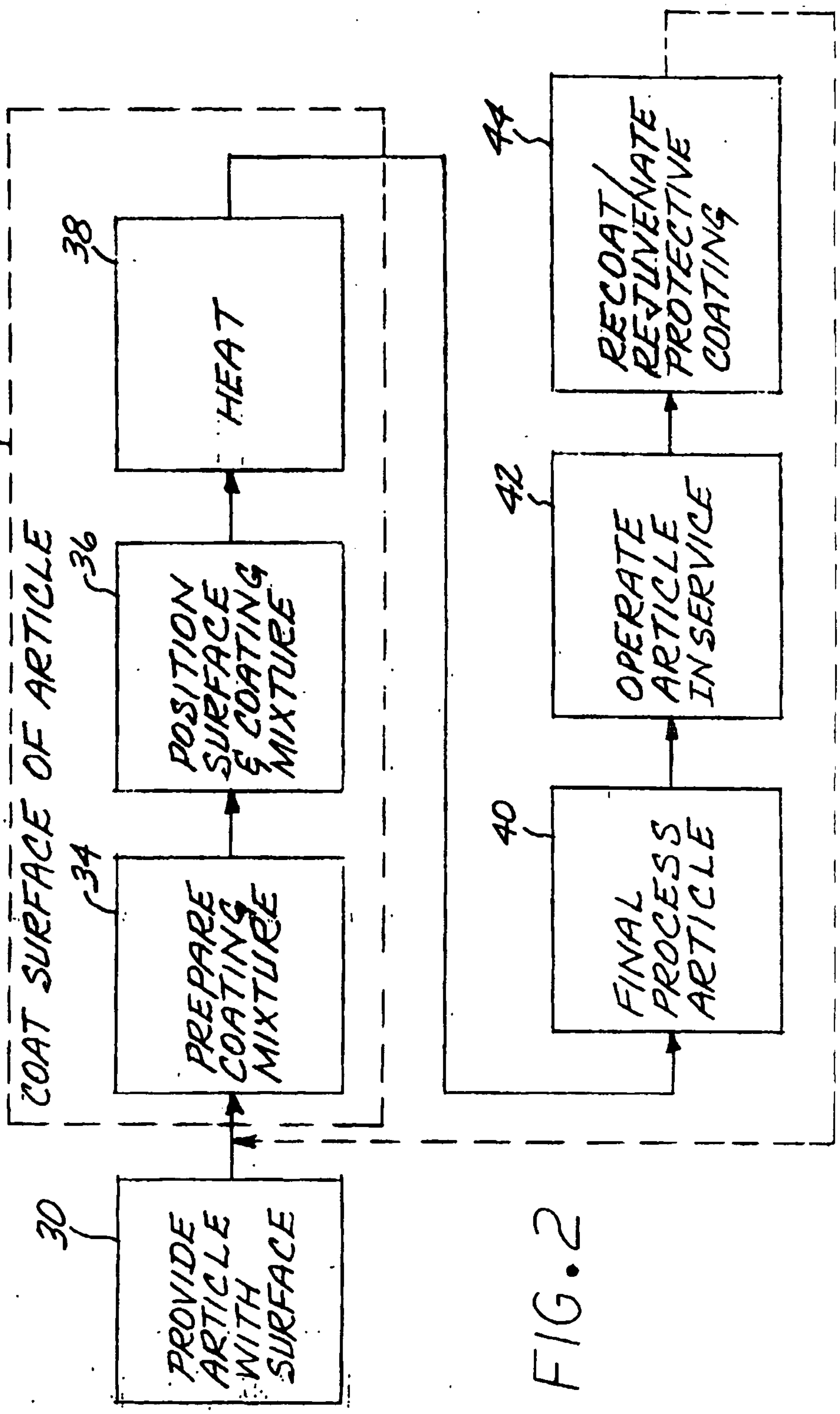

30
PROVIDE ARTICLE WITH SURFACE
32
COAT SURFACE OF ARTICLE
34
PREPARE COATING MIXTURE
36
POSITION SURFACE & COATING MIXTURE
38
HEAT
40
FINAL PROCESS ARTICLE
42
OPERATE ARTICLE IN SERVICE
44
RECOAT/REJUVENATE PROTECTIVE COATING

FIG. 2

ARTICLE HAVING A SURFACE PROTECTED BY A SILICON-CONTAINING DIFFUSION COATING

[0001] This invention relates to the protection of a surface with a coating, and more particularly to the protection of a nickel-base superalloy gas turbine component with a silicon-containing coating.

BACKGROUND OF THE INVENTION

[0002] In a basic form of an aircraft gas turbine (jet) engine, air is drawn into the front of the engine, compressed by a shaft-mounted compressor, and mixed with fuel. The mixture is burned, and the hot combustion gas is passed through a turbine mounted on the same shaft. The turbine includes a turbine disk (sometimes termed the "rotor"), upon which turbine blades are mounded. The flow of combustion gas turns the turbine by impingement against an airfoil section of the turbine blades, which turns the shaft and provides power to the compressor. Seals prevent the leakage of hot combustion gas around the turbine. After passing through the turbine, the hot combustion gas flows from the back of the engine, driving it and the aircraft forward.

[0003] In prior generations of aircraft gas turbine engines, the turbine disks and seal components operated at a sufficiently low temperature that hot corrosion was not a major concern. In current and advanced gas turbine engines, however, some of the components, such as the turbine disk and some of the seal components, are operated at a sufficiently high temperature that they are subjected to hot corrosion during operation. The corrodant is introduced into the turbine section of the engine in the hot combustion gases. The corrodant typically includes alkaline sulfate deposits that may have carbon as well.

[0004] Nickel-base superalloys are used as the materials of construction of some types of turbine disks and seal components. In service, the nickel-base superalloys are exposed to hot corrosion in the intermediate temperature range of about 1000° F. to about 1500° F. The compositions of the nickel-base superalloys are selected to achieve the required mechanical properties in service. However, the superalloys that have the desired mechanical properties are not sufficiently resistant to hot-corrosion damage. The hot-corrosion damage, if it becomes sufficiently severe, may cause the superalloy component to fail prematurely.

[0005] Environmentally resistant coatings are known for use with nickel-base superalloys operated at higher temperatures. Aluminum-containing diffusional and overlay coatings that oxidize to produce a protective aluminum oxide scale are widely used. However, these coatings are typically not suitable for use on wrought gas turbine components operated in the temperature range of about 1000° F. to about 1500° F., because they require higher deposition temperatures that adversely affect the mechanical properties of the heat-treated wrought nickel-base superalloys.

[0006] There is a need for an improved approach to the protection of nickel-base superalloys and other materials operated in a corrosive environment in the temperature range of about 1000° F. to about 1500° F. The new approach must be compatible with the processing of the component. The present invention fulfills this need, and further provides related advantages.

BRIEF SUMMARY OF THE INVENTION

[0007] The present approach provides a method for protecting a surface of an article. It is particularly useful for protecting a component of a gas turbine engine that is operated in a temperature range of from about 1000°**20** F. to about 1500° F. and potentially subject to hot corrosion from the hot combustion gases, such as gas turbine disks and some seal components. The present approach protects the surface of the article, is compatible with the thermomechanical processing of wrought nickel-base superalloys used to manufacture the articles, and is compatible with achieving and maintaining the mechanical properties required in the article. The coating approach is not limited by line of sight access to the surface that is to be protected. It is also environmentally friendly and readily used in commercial operations.

[0008] A method for protecting a surface of an article comprises the steps of providing the article having the surface thereon, and thereafter coating the surface with a silicon-containing coating. The coating is accomplished by preparing a coating mixture having silicon, a halide activator, and an oxide powder, positioning the surface of the article in gaseous communication with the coating mixture, and heating the surface of the article and the coating mixture to a coating temperature of from about 1150° F. to about 1500° F., typically in an oven. Most preferably, the surface is contacted to the coating mixture, as by packing the coating mixture around and in contact with the surface.

[0009] The coating mixture preferably has from about 2 to about 10 percent by weight of silicon powder, from about 0.1 to about 0.5 percent by weight of a halide activator, and the balance aluminum oxide powder. The coating is preferably performed in an inert atmosphere or hydrogen. The heating time is determined by the desired thickness of the protective layer, but is typically on the order of from about 2 to about 8 hours.

[0010] The article is preferably made of a nickel-base superalloy, and most preferably a wrought nickel-base superalloy. Examples of such articles are components of a gas turbine engine, such as turbine disks and seals. The surface of the article may be mechanically worked before it is coated.

[0011] The resulting article is preferably a component of a gas turbine engine having a nickel-base superalloy substrate composition, with a protective layer at the surface of the component. The protective layer comprises a mixture of silicon and elements from the substrate composition interdiffused with the silicon. Most preferably, the protective layer consists essentially of a mixture of silicon and elements from the substrate composition interdiffused with the silicon.

[0012] The protected article is preferably operated in a gas turbine at an operating temperature of from about 1000° F. to about 1500° F. and contacted by hot combustion gas.

[0013] When the coating mixture is heated during the coating step, the chemical reaction between the silicon and the halide activator produces a silicon-containing gas. An example is silicon fluoride in the case of a fluoride-containing activator. The silicon-containing gas is transported to the component, which serves as a substrate for the deposition of the silicon-containing gas. Upon contacting the surface of the substrate, the silicon-containing gas decomposes to deposit silicon on the substrate. Because the reaction and the vapor-phase transport are performed at elevated temperatures, the silicon interdiffuses with elements from the substrate composition to produce a silicon-rich surface layer. The silicon-rich surface layer protects the article against corrosion by the corrosive components of the hot combustion gas.

[**0014**] The present protection approach, which does not require that the component be heated during processing to a temperature above its normal service operating temperature, is fully compatible with the thermomechanical and other processing treatments of wrought nickel-base superalloys that are used in the preferred components such as gas turbine disks and seals. Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention. The scope of the invention is not, however, limited to this preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0015**] **FIG. 1** is a perspective view of a protected component of a gas turbine engine;

[**0016**] **FIG. 2** is a block flow diagram of an approach for protecting the component;

[**0017**] **FIG. 3** is a schematic sectional view of a coating apparatus with the article packed in the coating mixture; and

[**0018**] **FIG. 4** is a schematic sectional view of the protected component of **FIG. 1**, taken on line **4-4**.

DETAILED DESCRIPTION OF THE INVENTION

[**0019**] The present approach may be used to process a wide variety of physical forms of workpieces to produce a wide variety of final articles **20**. Components of gas turbine engines are of particular interest. **FIG. 1** illustrates one such article **20**, a turbine disk **22** having an article surface **24**. Other components include, for example, seals and compressor components. The present approach is not limited to the production of these articles, however.

[**0020**] **FIG. 2** depicts a preferred approach for protecting the surface **24** of the article **20**. The article **20** having the article surface **24** thereon is provided, step **30**. The article **20** is furnished in substantially its final size and shape, and underlying base-metal composition. The surface protection treatment to be described subsequently alters the dimensions of the article only very slightly.

[**0021**] The article **20** is preferably made of a nickel-base alloy as the base metal, and is most preferably made of a nickel-base superalloy. A nickel-base alloy is a composition of matter having more nickel than any other element. A nickel-base superalloy is a nickel-base alloy that is hardenable by the precipitation of gamma prime or a related phase. A presently preferred nickel-base superalloy that is to be protected by the present approach is Rene™ 88DT, having a nominal composition, in weight percent, of 13 percent cobalt, 16 percent chromium, 4 percent molybdenum, 3.7 percent titanium, 2.1 percent aluminum, 4 percent tungsten, 0.75 percent niobium, 0.015 percent boron, 0.03 percent zirconium, and 0.03 percent carbon, up to about 0.5 percent iron, balance nickel and minor amounts of other elements. Another example is alloy ME3, having a nominal composition, in weight percent, of about 20.6 percent cobalt, about 13.0 percent chromium, about 3.4 percent aluminum, about 3.7 percent titanium, about 2.4 percent tantalum, about 0.90 percent niobium, about 2.10 percent tungsten, about 3.80 percent molybdenum, about 0.05 percent carbon, about 0.025 percent boron, about 0.05 percent zirconium, up to about 0.5 percent iron, balance nickel and minor amounts of other elements. These alloys are presented by way of example, and the use of the present invention is not so limited.

[**0022**] The nickel-base superalloy is desirably a wrought nickel-base superalloy, which is cast and then mechanically worked, usually by thermomechanical working at elevated temperature such as by forging, to reach the shape of the article **20**. It may also be heat treated prior to working, at intermediate points in the working process, and after working. The details of the working and heat treating are known in the art for each alloy.

[**0023**] The surface **24** of the article **20** may be mechanically worked or otherwise processed as a final stage of the providing step **30**. For example, the article surface **24** may be shot peened to induce a desired stress state into the article surface **24**. It may optionally be grit blasted or vapor honed.

[**0024**] The working, heat treating, mechanical working, and other processing produce a desired structure and stress state at the surface **24** and in the microstructure of the article **20**. This structure and stress state may not be disturbed or altered by heating the article **20** to a temperature of greater than about 1500° F. in subsequent processing, or the mechanical performance under service conditions of the article **20** will be adversely affected.

[**0025**] The article surface **24** is thereafter coated with a silicon-containing coating, step **32**. The coating operation **32** first includes preparing a coating mixture of silicon, a halide activator, and an oxide powder, step **34**. The silicon is preferably furnished as silicon powder of any operable size, most preferably −100 mesh. The halide activator is of any operable type. Operable halide activators include, for example, ammonium fluoride, ammonium chloride, sodium fluoride, sodium chloride, sodium bromide, sodium iodide, potassium fluoride, potassium chloride, potassium bromide, potassium iodide, aluminum fluoride, and aluminum chloride, or mixtures thereof. Most preferably, the halide activator is an ammonium halide or an aluminum halide. The oxide powder is inert in the coating operation and serves to slow the coating process and prevent agglomeration of the powders that would prevent access of the coating vapor to the surface **24**. The oxide powder is preferably aluminum oxide (alumina, or Al_2O_3). Any operable oxide powder size may be used, but a preferred size is −325 mesh.

[**0026**] A preferred composition of the coating mixture is from about 2 to about 10 percent by weight of silicon powder, from about 0.1 to about 0.5 percent by weight of a halide activator, and the balance aluminum oxide powder.

[**0027**] The surface **24** of the article **20** is positioned in gaseous communication with the coating mixture, step **36**. Any operable approach may be used, but the presently preferred approach, illustrated in **FIG. 3**, is to pack the coating mixture **50** in contact with the surface **24** of the article, as by packing the entire article **20** in the coating mixture **50**. For example and as illustrated, the article **20** may be placed into a container **52**, and the solid coating mixture **50** is poured into the container **52** to surround and immerse the article **20**.

[**0028**] The surface **24** of the article **20** and the coating mixture **50** are thereafter heated to a coating temperature of from about 1150° F. to about 1500° F., step **38**. If the coating temperature is lower than about 1150° F., the rate of coating is too slow to be commercially feasible. If the coating temperature is greater than about 1500° F., the stress state, structure, and/or microstructure of the underlying article **20** are adversely affected.

[**0029**] The preferred approach is to heat the surface **24** of the article **20** and the coating mixture **50** in an oven **54**, see **FIG. 3**. The oven **54** may be of any operable type, but is represented as an electrically heated oven with electrical heating coils **56**. The heating **38** is preferably performed in an inert-gas (e.g., argon) or hydrogen-reducing atmosphere, supplied by a gas source **58**.

[**0030**] The heating causes the halide activator to react with the silicon to produce a gaseous form. For example, if the halide activator is ammonium fluoride, the ammonium fluoride decomposes to produce fluoride ions. The fluoride ions react with the silicon to produce a silicon-bearing gas such as gaseous silicon fluoride (SiF_6 or a related form). The silicon-bearing gas diffuses to the surface **24** of the article **20**. Upon contacting the surface **24**, the silicon-bearing gas decomposes to deposit silicon upon the surface **24**.

[**0031**] The article **20** thereby serves as a substrate **60** for the deposition of the silicon and thence the protective coating **62**, as shown in **FIG. 4**. The silicon is initially deposited in elemental form. However, because the deposition is performed at elevated temperature, the deposited silicon interdiffuses with the base metal of the substrate composition, which is a nickel-base superalloy in the preferred embodiment. The protective coating **62** is therefore a diffusion coating whose composition is a gradient composition extending through the protective coating **62**. At the surface **24**, the protective coating **62** has its greatest percentage silicon content and lowest percentage content of base-metal elements from the substrate **60**. The portion of the protective coating **62** at and nearest the surface **24** may be substantially completely pure silicon, if the silicon deposition in step **38** is continued for a sufficiently long time. With increasing distance below the surface **24**, the percentage of silicon in the coating is reduced, and the percentage of the base-metal elements of the substrate **60** increases until it reaches 100 percent at the greatest depth **64** of the protective coating **62**. Optionally but not preferably at the present time, other elements may be co-deposited with the silicon to become part of the protective coating **62**.

[**0032**] The heating step **38** is continued for a time sufficient to produce the protective coating **62** of a desired thickness. A preferred coating temperature range of from about 1250° F. to about 1400° F. for a time of from about 2 to about 8 hours has been found sufficient for most applications of interest. For example, a heating step **38** of about 5 hours at a coating temperature of about 1400° F. produces a protective coating **62** about **0.0007** inch thick. The coating temperature may, however, range as low as 1150° F. and as high as 1500° F., as discussed earlier.

[**0033**] After the coating **32** is complete, the article **20** with the protective coating **62** thereon is final processed, step **40**. The final processing may include, for example, thermal treatments, final machining of uncoated portions, and cleaning.

[**0034**] The article **20** with the protective coating **62** in place is operated in service, step **42**. In the preferred application, the article **20** is operated at an operating temperature of from about 1000° F. to about 1500° F. and contacted by hot combustion gas for an extended period of time.

[**0035**] One of the advantages of the present approach is that, after service, the protective coating **62** may be restored and rejuvenated by recoating, step **44**. During service, it is expected that some of the protective coating **62** would be corroded or eroded away, or otherwise lost. To some extent the as-deposited protective coating **62** is "self-healing", as any excess silicon in the protective coating **62** may interdiffuse with the substrate **60** during service. Eventually, however, the protective coating **62** becomes thinner and in some places may be lost entirely. To perform the recoating, step **32** is repeated after the article **20** is cleaned, and all service-produced residue removed. Step **40** may optionally be repeated as necessary. The article **20** may then be returned to service, step **42**. Subsequent recoatings/rejuvenations are permissible.

[**0036**] The present approach has been reduced to practice. Flat panel specimens of Rene™ 88DT were coated by the preferred approach discussed above. The coated flat panel specimens and uncoated specimens of Rene™ 88DT were exposed at 1300° F. to a sodium sulfate corrodant mixture and periodically evaluated. The coated specimens had about three times the life of the uncoated specimens.

[**0037**] Although a particular embodiment of the invention has been described in detail for purposes of illustration, various modifications and enhancements may be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be limited except as by the appended claims.

1-17. (canceled)

18. An article comprising

a component of a gas turbine engine having a nickel-base superalloy substrate composition; and

a protective layer at a surface of the component, wherein the protective layer comprises a mixture of silicon and elements from the substrate composition interdiffused with the silicon.

19. The article of claim 18, wherein the substrate has a nominal composition, in weight percent, of 13 percent cobalt, 10 percent chromium, 4 percent molybdenum, 3.7 percent titanium, 2.1 percent aluminum, 4 percent tungsten. 0.75 percent niobium, 0.015 percent boron, 0.03 percent zirconium, and 0.03 percent carbon, up to about 0.5 percent iron, balance nickel arid minor amounts of other elements; or has a nominal composition, in weight percent, of about 20.6 percent cobalt, about 13.0 percent chromium, about 3.4 percent aluminum, about 3.7 percent titanium, about 2.4 percent tantalum, about 0.90 percent niobium, about 2.10

percent tungsten, about 3.80 percent molybdenum, about 0.05 percent carbon, about 0.025 percent boron, about 0.05 percent zirconium, up to about 0.5 percent iron, balance nickel and minor amounts of other elements.

20. The article of claim 18, wherein the protective layer consists essentially of a mixture of silicon and elements from the substrate composition interdiffused with the silicon.

21. (canceled)

22. The article of claim 18, wherein the component is in a cast-and-worked form.

23. The article of claim 18, wherein tile surface of the substrate component is mechanically worked.

24. (canceled)

25. The article of claim 18, wherein the article is a turbine disk, a seal, or a compressor component.

26. An article comprising

a component of a gas turbine engine having a nickel-base superalloy substrate composition In a cast-and-worked form; and

a protective layer at a surface of the component, wherein the protective layer comprises silicon.

27. The article of claim 26, wherein the substrate has a nominal composition, in weight percent, of 13 percent cobalt, 16 percent chromium, 4 percent molybdenum, 3.7 percent titanium, 2.1 percent aluminum, 4 percent tungsten, 0.75 percent niobium, 0.015 percent boron, 0.03 percent zirconium, and 0.03 percent carbon, up to about 0.5 percent iron, balance nickel and minor amounts of other elements; or has a nominal composition, in weight percent, of about 20.6 percent cobalt, about 13.0 percent chromium, about 3.4 percent aluminum, about 3.7 percent titanium, about 2.4 percent tantalum, about 0.90 percent niobium, about 2.10 percent tungsten, about 3.80 percent molybdenum, about 0.05 percent carbon, about 0.025 percent boron, about 0.05 percent zirconium, up to about 0.5 percent iron, balance nickel and minor amounts of other elements.

28. The article of claim 26, wherein the protective layer comprises a mixture of silicon and elements from the substrate composition interdiffused with the silicon.

29. (canceled)

30. The article of claim 18, wherein the protective layer is substantially pure silicon at the surface of the component.

31. The article of claim 26, wherein the protective layer is substantially pure silicon at the surface of the component.

32. An article comprising

a component having a nickel-base superalloy substrate composition; and

a protective layer at a surface of the component, wherein the protective layer comprises a mixture of silicon and elements from the substrate composition interdiffused with the silicon, and wherein the protective layer has a gradient composition with a greatest percentage of silicon at the surface of the component and a reduced percentage of silicon with increasing distance into the component from the surface of the component.

33. The article of claim 32, wherein the substrate has a nominal composition, in weight percent, of 13 percent cobalt, 16 percent chromium, 4 percent molybdenum, 3.7 percent titanium, 2.1 percent aluminum, 4 percent tungsten, 0.75 percent niobium, 0.015 percent boron, 0.03 percent zirconium, and 0.03 percent carbon, up to about 0.5 percent iron, balance nickel and minor amounts of other elements; or has a nominal composition, in weight percent, of about 20.6 percent cobalt, about 13.0 percent chromium, about 3.4 percent aluminum, about 3.7 percent titanium, about 2.4 percent tantalum, about 0.90 percent niobium, about 2.10 percent tungsten, about 3.80 percent molybdenum, about 0.05 percent carbon, about 0.025 percent boron, about 0.05 percent zirconium, up to about 0.5 percent iron, balance nickel and minor amounts of other elements.

34. The article of claim 32, wherein the protective layer consists essentially of a mixture of silicon and elements from the substrate composition interdiffused with the silicon.

35. The article of claim 32, wherein the component is in a cast-and-worked form.

36. The article of claim 32, wherein the surface of the component is mechanically worked.

37. The article of claim 32, wherein the article is a turbine disk, a seal, or a compressor component.

38. The article of claim 32, wherein the protective layer is substantially pure silicon at the surface of the component.

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