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(54) **WEAR RESISTANT COATINGS CONTAINING PRECIPITATION-HARDENED ALLOY BODIES AND METHODS FOR THE FORMATION THEREOF**

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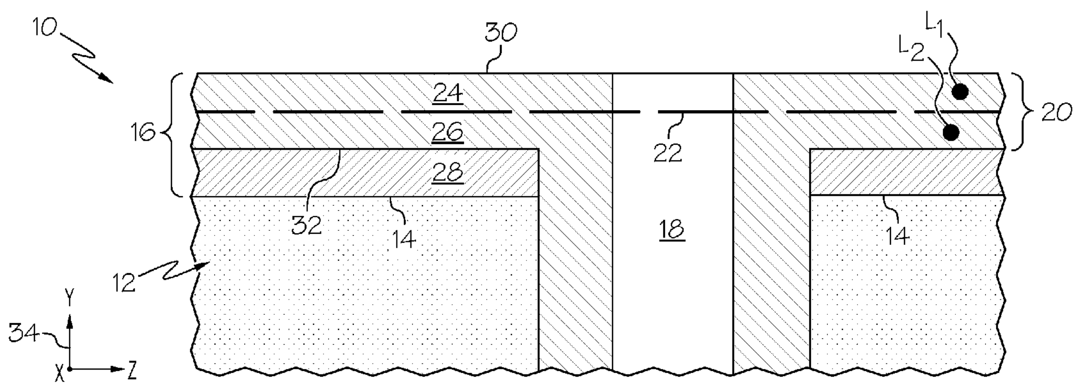
(57) **ABSTRACT**

Methods for producing a coated component are provided, as are coated components having wear resistant coatings. In embodiments, the method includes the step or process of fabricating, purchasing, or otherwise obtaining a component having a component surface. An XP alloy body is formed over the component surface to yield a coated component, wherein P is phosphorus and X is cobalt, nickel, or a combination thereof. After formation of the XP alloy body, the XP alloy body is machined; and, following machining, the coated component is heat treated to precipitate harden the XP alloy body. In certain embodiments, heat treatment may be conducted to concurrently anneal the underlying component in conjunction with precipitation hardening of the XP alloy body. In other instances, the method further includes the step of forming a barrier layer over the component surface prior to deposition of the XP alloy body.



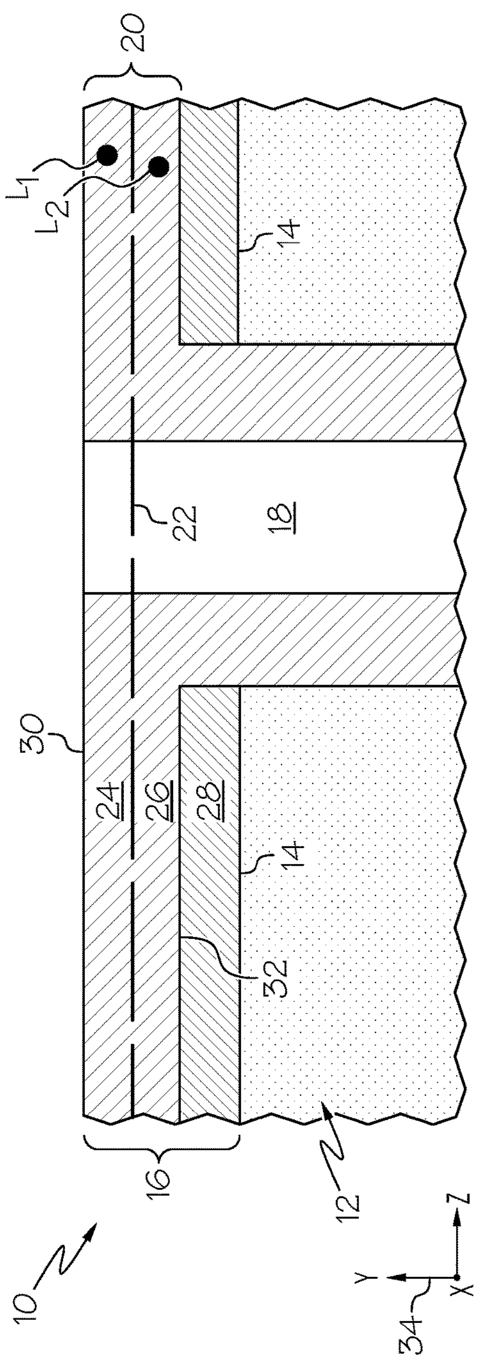


FIG. 1

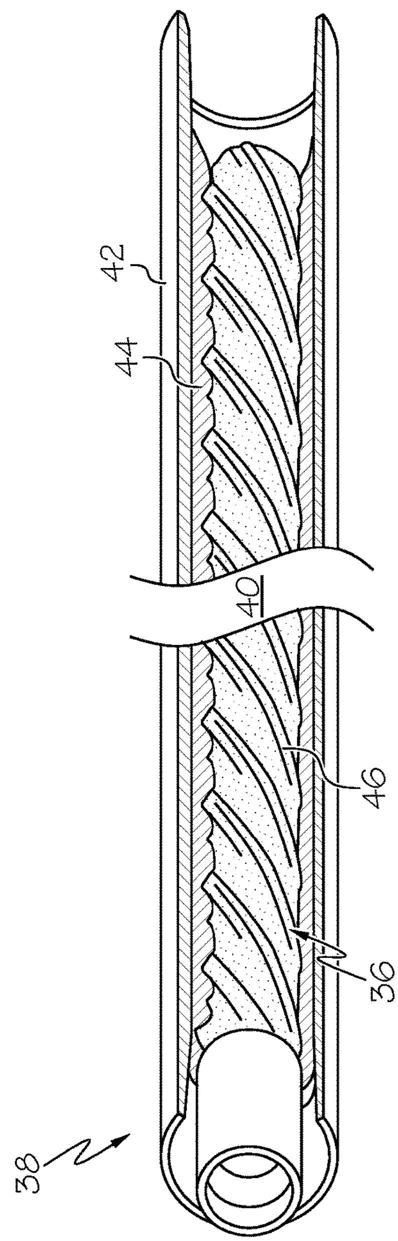


FIG. 2

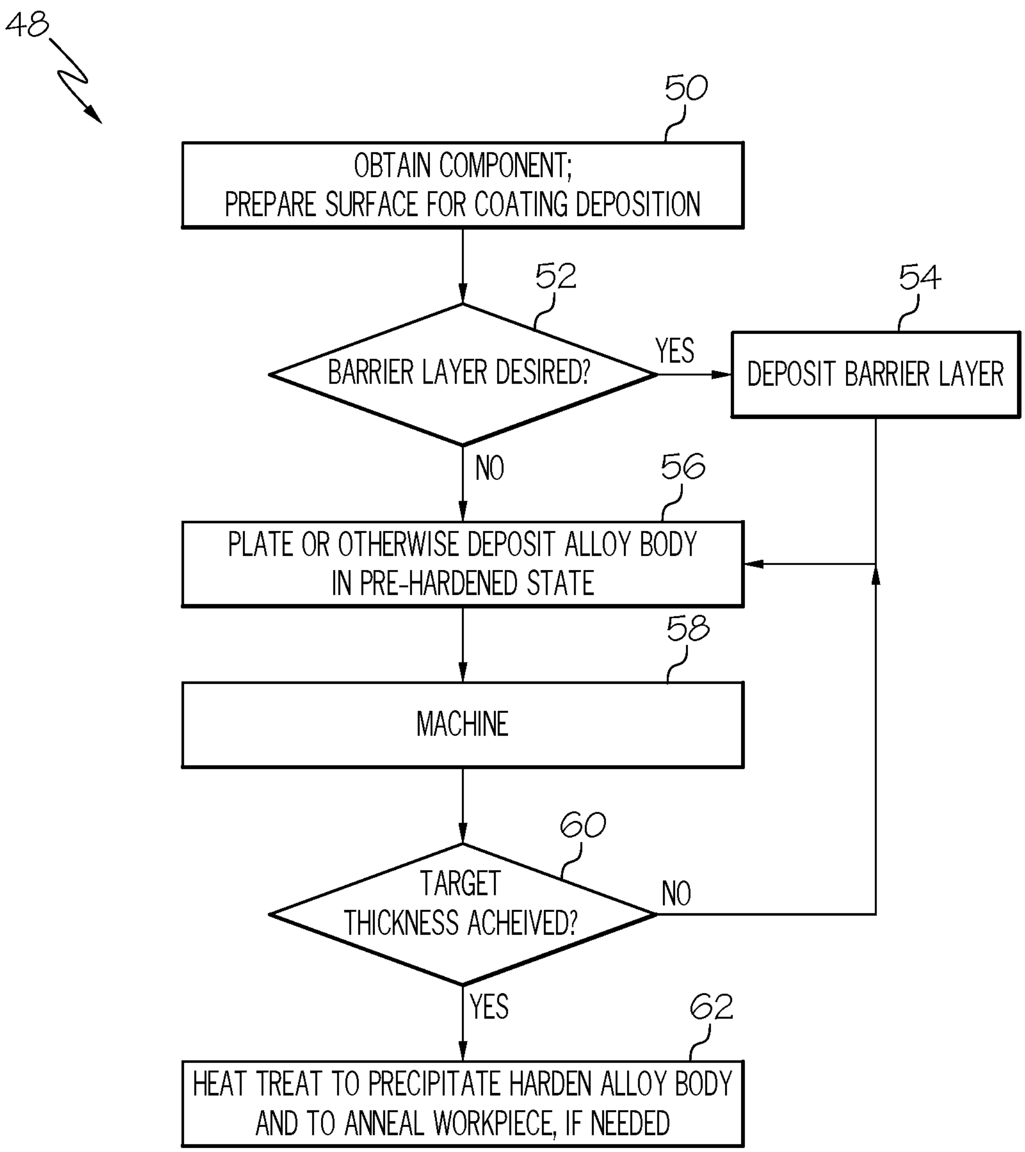

48
50
OBTAIN COMPONENT;
PREPARE SURFACE FOR COATING DEPOSITION
52
BARRIER LAYER DESIRED?
YES
54
DEPOSIT BARRIER LAYER
NO
56
PLATE OR OTHERWISE DEPOSIT ALLOY BODY
IN PRE-HARDENED STATE
58
MACHINE
60
TARGET
THICKNESS ACHEIVED?
NO
YES
62
HEAT TREAT TO PRECIPITATE HARDEN ALLOY BODY
AND TO ANNEAL WORKPIECE, IF NEEDED

FIG. 3

WEAR RESISTANT COATINGS CONTAINING PRECIPITATION-HARDENED ALLOY BODIES AND METHODS FOR THE FORMATION THEREOF

TECHNICAL FIELD

[0001] The following disclosure relates generally to wear resistant coatings and, more particularly, to wear resistant coatings containing precipitation-hardened alloy bodies, as well as to methods for the formation of such wear resistant coatings.

BACKGROUND

[0002] There is a need for low cost, high performance wear resistant coatings across various industries. In the oil and gas industry, for example, there exists a continued demand for wear resistant coatings suitable for deposition over components utilized in downhole drilling applications, such as lobed rotor shafts of the type found in the power section of steerable and non-steerable downhole mud rotors. Ideally, such wear resistant coatings are relatively durable and possess high hardness values exceeding, for example, 900 Vickers Pyramid Number (HV). It may also be desirable for such wear resistant coatings to serve as a barrier against undesired chemical reactions with environmental contaminants. For example, in the case of a downhill drilling applications, such wear resistant coatings beneficially shield the underlying substrate or component from exposure to environmental acids, sulfides, and salts, which could corrode or otherwise structurally degrade the underlying component.

[0003] Specialized coatings have been developed for usage in downhole drilling applications and other applications demanding high wear and corrosion resistance. Examples of such coatings include hard chrome platings and tungsten-carbide (WC) coatings. Such legacy wear resistant coatings are, however, typically limited in one or more respects. For example, the High Velocity Oxygen Fuel (HVOF) deposition processes utilized to deposit WC coatings are often costly to perform. Further, in the case of both hard chrome platings and WC coatings, such coatings are typically quite hard and brittle as initially deposited As a result, such legacy wear resistant coatings pose additional challenges when machining is desirably performed following coating deposition to define structural features, to satisfy dimensional tolerances, or meet surface finish requirements. Post-coating machining, such as grinding to satisfy surface finish requirements, is thus a costly and time consuming process, often requiring diamond cutting tools and specialized operations. Post-coating machining can also potentially result in damage, such as chipping or cracking, of the newly-deposited wear resistant coating. This may not only adversely impact the structural integrity of the wear resistant coating, but may also render the coating prone to the ingress of environmental contaminants as noted above.

[0004] There thus exists an ongoing demand for high performance, wear resistant coatings and methods for forming such wear resistant coatings, which can be performed in a relatively cost efficient, timely, and reliable manner. It would be particularly desirable for such coating formation methods to ease post-coating machining of the coating, while achieving finished coatings with relatively high hardness values and other desirable properties. It would also be desirable for embodiments of wear resistant coatings to serve as effective environmental barriers by deterring the penetration of environment contaminants through the coating thickness and to the underlying substrate or component. Other desirable features and characteristics of embodiments of the present invention will become apparent from the subsequent Detailed Description and the appended Claims, taken in conjunction with the accompanying drawings and the foregoing Background.

BRIEF SUMMARY

[0005] Methods for producing coated components are provided. In embodiments, the method includes the step or process of fabricating, purchasing, or otherwise obtaining a component having a component surface. An XP alloy body is formed over the component surface to yield a coated component, wherein P is phosphorus and X is cobalt, nickel, or a combination thereof. After formation of the XP alloy body, the XP alloy body is machined; and, following machining, the coated component is heat treated to precipitate harden the XP alloy body. In certain embodiments, heat treatment may be conducted to concurrently anneal the underlying component in conjunction with precipitation hardening of the XP alloy body. In other instances, the method further includes the step of forming a barrier layer over the component surface prior to deposition of the XP alloy body. The barrier layer may contain a greater amount of X and, perhaps, a lesser amount of P than does the XP alloy body; e.g., in certain implementations, the barrier layer may consist essentially of X. In other embodiments in which the component assumes the form of a mud rotor shaft having a lobed outer surface, the step of machining may entail polishing, grinding, or otherwise machining the mud rotor shaft to impart the lobed outer surface with an average roughness equal to or less than 1 micron.

[0006] In further embodiments, the method includes the step or process of obtaining a component having a component surface. A precipitation-hardened alloy body is formed over the component surface. The precipitation-hardened alloy body is formed by depositing at least one alloy layer in a pre-hardened or relatively soft state over the component surface to yield a coated component. The at least one alloy layer is then machined in the pre-hardened state. Afterwards, heat treatment is performed to anneal the component, while precipitate hardening the at least one alloy layer to thereby yield a precipitation-hardened alloy body. Following heat treatment, the precipitation-hardened alloy body may have a hardness at least twice that of the at least one alloy layer, as measured in the pre-hardened state. In certain implementations, the method further includes the step of forming a barrier layer over the component surface prior to deposition of the at least one alloy layer, while formulating the barrier layer to be less susceptible to precipitate hardening, when heat treated, than is the at least one alloy layer. In still other embodiments, the at least one alloy layer may be composed of an XP alloy, wherein P is phosphorus and X is cobalt, nickel, or a combination thereof. In such instances, the barrier layer may contain an increased amount of X and a decreased amount of P as compared to the at least one alloy layer.

[0007] Components protected by wear resistant coatings (herein, "coated components") are further provided. In embodiments, the coated component includes a base component having a component surface and a precipitation-hardened alloy body, which is formed over the component surface and which may or may not directly contact the component surface. The precipitation-hardened layer is composed of an XP alloy body wherein P is phosphorus and X is cobalt, nickel, or a combination thereof. In certain implementations, the coated component further includes a barrier layer disposed between the component surface and the precipitation-hardened alloy body, with the barrier layer containing X in a greater amount than does the XP alloy body. In other implementations, the XP alloy body may be composed of a majority X, by weight, and between about 5% to about 25% P, by weight. In still further implementations, the XP alloy body may have opposing inner and outer surfaces, with the inner surface located closer to the component than is the outer surface. In such implementations, the XP alloy body may further have a first P content adjacent the inner surface and a second P content adjacent the outer surface, with the second P content exceeding (e.g., at least twice) the first P content.

[0008] Various additional examples, aspects, and other useful features of embodiments of the present disclosure will also become apparent to one of ordinary skill in the relevant industry given the additional description provided below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] At least one example of the present invention will hereinafter be described in conjunction with the following figures, wherein like numerals denote like elements, and:

[0010] FIG. **1** is a cross-section of a limited region of coated component including a component body over which a wear resistant coating is formed, as illustrated in accordance with an exemplary embodiment of the present disclosure;

[0011] FIG. **2** is an isometric cutaway view of the power section of a downhole mud rotor, which contains a lobed rotor shaft protected by a wear resistant coating similar or identical to that shown in FIG. **1** and which is illustrated in accordance with an exemplary embodiment of the present disclosure; and

[0012] FIG. **3** is a flowchart setting-forth a method for forming a wear resistant coating over selected surfaces of an underlying component or substrate, as illustrated in accordance with an exemplary embodiment of the present disclosure.

[0013] For simplicity and clarity of illustration, descriptions and details of well-known features and techniques may be omitted to avoid unnecessarily obscuring the exemplary and non-limiting embodiments of the invention described in the subsequent Detailed Description. It should further be understood that features or elements appearing in the accompanying figures are not necessarily drawn to scale unless otherwise stated.

DETAILED DESCRIPTION

[0014] The following Detailed Description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. The term "exemplary," as appearing throughout this document, is synonymous with the term "example" and is utilized repeatedly below to emphasize that the description appearing in the following section merely provides multiple non-limiting examples of the invention and should not be construed to restrict the scope of the invention, as set-out in the Claims, in any respect. As further appearing herein, statements indicating that a first layer or first body of material is "deposited over," "deposited on," "formed over," or "formed on" a second layer, a second body of material, or a component does not require that that the first layer or body is deposited or formed directly on and intimately contacts the second layer, body, or component unless otherwise specifically stated.

[0015] Definitions

[0016] The following definitions apply throughout this document. Those terms not expressly defined here or elsewhere in this document are assigned their ordinary meaning in the relevant technical field.

[0017] Coating—One or more layers of material formed over a component surface.

[0018] Coated Component—A component having at least one surface over which a wear resistant coating is formed.

[0019] Cobalt-Phosphorous (CoP) Alloy—An alloy predominately composed of cobalt and phosphorus, by weight.

[0020] Component—Any article of manufacture over which a coating can be formed. This term is synonymous with or encompasses similar terms including "substrate," "part," and "workpiece."

[0021] Nickel-Phosphorous (NiP) Alloy—An alloy predominately composed of nickel and phosphorus, by weight.

[0022] XP Alloy—An alloy predominately composed of phosphorous and "X," by weight, wherein "X" is cobalt, nickel, or a combination thereof.

[0023] Overview

[0024] Embodiments of wear resistant coatings, coated components protected by wear resistant coatings, and methods for forming wear resistant coatings are disclosed. Embodiments of the wear resistant coatings contain precipitation-hardened alloy bodies, which are initially deposited in a pre-hardened and subsequently precipitation hardened to enhance the final hardness of the alloy bodies. In the pre-hardened state, the alloy bodies may be soft and ductile, in a relative sense, and therefore amenable to machining utilizing conventional tooling equipment and techniques. By initially depositing the alloy bodies in a pre-hardened state, performing the needed machining operations, and subsequently precipitate hardening the alloy bodies, wear resistant coatings can be fabricated having relatively high hardness values, while machining of the coating is eased. Depending upon alloy body composition and heat treatment parameters, the alloy bodies can achieve relatively high hardness values approaching or exceeding 950 Vickers Pyramid Number (HV) following precipitate hardening. Comparatively, a given alloy body may have a hardness value between 500 and 600 HV in its initially-deposited, pre-hardened state. Process efficiency can also be enhanced by precipitate hardening the alloy body, while concurrently annealing the underlying substrate or component utilizing a single heat treatment process in certain instances.

[0025] In accordance with embodiments of the present disclosure, a given alloy body may be electrodeposited over a component surface, whether as a single, continuous layer or as multiple, successively-deposited layers. If deposited in multiple layers, machining can be performed at suitable junctures between layer deposition to, for example, remove nodular growth from newly-deposited material layers, to define more detailed structural features, or the like. Generally, the precipitation-hardened alloy body may be composed of any material or combination of materials suitable for achieving the desired wear resistance functionality and other desired properties (e.g., high ductilities), while remaining capable of significant enhancement in hardness values via heat treatment and precipitate hardening; e.g., ideally, precipitation hardening results in an increase of at least 50% in hardness value, if not a doubling of the hardness value when transitioning from the pre-hardened to the post-hardened state of the alloy body. In implementations, the precipitation-hardened alloy body is composed of an XP alloy; that is, an alloy containing alloy predominately composed of phosphorous (P) and "X," by weight, wherein "X" is cobalt (Co), nickel (Ni), or a combination thereof. For example, in one embodiment, the XP alloy contains a majority X, by weight; a lesser amount of P, by weight; and any number (zero or more) additional constituents present in a lesser amount than P, by weight.

[0026] In embodiments, the wear resistant coating may consist solely of the precipitation-hardened alloy body, which is formed directly on and physically contacts the underlying substrate or component surface. Alternatively, the wear resistant coating may contain one or more additional layers, such as a bondcoat, formed between the precipitation-hardened alloy body and the underlying component. In this latter regard, when the wear resistant coating desirably provides environmental barrier protection, one or more barrier layers may be formed between the precipitation-hardened alloy body and the underlying component, with the barrier layer(s) composed of a material less susceptible to precipitate hardening than is the alloy body. As compared to the alloy body, the intervening barrier layer may remain relatively impermeable to contaminant penetration following heat treatment and precipitate hardening the alloy body, which may experience grain growth rendering the alloy body more susceptible to containment penetration. In further implementations, the wear resistant coating may lack any such barrier layer, and the precipitation-hardened alloy body may instead be deposited to undergo reduced (e.g., little to no) precipitation formation in one or more limited regions or bands. In embodiments in which the alloy body is composed of an XP alloy, the alloy body may be deposited to contain a lower (and possibly zero) P content adjacent its inner surface, while having a substantially higher (e.g., at least twice the) P content adjacent its outer surface. As still further possibility, a combination of the aforementioned approaches can be employed such that the wear resistant coating contains a barrier layer, while the alloy body is imparted with a varied P content through its thickness; e.g., a P content that decreases in a stepped or non-stepped (gradual) manner, as taken through the thickness of the alloy body moving toward the barrier layer. Exemplary embodiments of coated components having wear resistant coatings will now be discussed in conjunction with FIGS. **1-2**.

[0027] Examples of Coated Component Having Wear Resistant Coatings

[0028] FIG. **1** is a cross-sectional schematic of a coated component **10**, as illustrated in accordance with an exemplary embodiment of the present disclosure. Coated component **10** includes an underlying substrate or component body **12**, which has a principal component surface **14** over which a wear resistant coating **16** is formed. Only limited regions of wear resistant coating **16** and component body **12** are shown in FIG. **1** for clarity. Component body **12** can have any number and type of structural features, which may be present prior to formation of wear resistant coating **16** or which may be defined via machining operations carried-out during the below-described coating formation process. To further illustrate this point, the illustrated region of coated component **10** is depicted to include a cavity, bore, depression, or channel **18**, which is partially shown and which or may not penetrate fully through component body **12**. As generically illustrated in FIG. **1**, component body **12** can be any article of manufacture over which wear resistant coating **16** is usefully formed; e.g., in one embodiment, component body **12** may be a mud rotor shaft having a lobed outer surface, as described below in conjunction with FIG. **2**.

[0029] Wear resistant coating **16** contains a precipitation-hardened alloy body **20**, which is produced over component surface **14** utilizing a combination of deposition, machining, and heat treatment processes. Wear resistant coating **16** may consist wholly or entirely of alloy body **20** in certain implementations. In other embodiments, wear resistant coating **16** may contain one or more additional material layers, such as a bondcoat or a barrier layer, which may be combined with alloy body **20** in a stacked relationship. In such embodiments, precipitation-hardened alloy body **20** will typically be the outermost layer or portion of wear resist coating **16** and may consequently be considered a topcoat; however, the possibility that another layer of material, such as a relatively thin, solid film lubricant layer, may be formed over alloy body **20** in alternative implementations of coating **16** is not precluded. Precipitation-hardened alloy body **20** may or may not directly contact component surface **14**, depending upon whether wear resistant coating **16** is produced to contain a bondcoat, barrier layer, or other material layer between coating **16** and component surface **14**. Wear resistant coating **16** may have an average thickness ranging from 2 to 10 microns (μm) in an embodiment. In other embodiments, coating **16** may be thicker or thinner than the aforementioned range.

[0030] Precipitation-hardened alloy body **20** may be composed of any material or combination of materials providing the desired wear resistance properties, while also being susceptible to precipitate hardening through heat treatment. As previously indicated, precipitation-hardened alloy body **20** is usefully composed of an XP alloy, with "X" representing Co, Ni, or a combination thereof. As a specific example, precipitation-hardened alloy body **20** may contain at least 50% X and between about 5% and about 25% P, by weight, in embodiments. In other implementations, precipitation-hardened alloy body **20** may be consist essentially of X and P; and, perhaps, may contain about 10% to about 15% P, by weight, with the remainder of alloy body **20** composed of X. The particular formulation or composition of precipitation-hardened alloy body **20** will vary among embodiments depending, at least in part, upon the desired properties of wear resistant coating **16**, the intended operational environment of coated component **10**, the technique utilized to deposit alloy body **20**, cost considerations, and other such factors. When precipitation-hardened alloy body **20** is composed of an XP alloy, Ni may be favored over Co for cost saving purposes, particularly when the pre-hardened alloy body is deposited utilizing an electroplating process. Accordingly, precipitation hardened alloy body **20** may be predominately composed of Ni, by weight, with the remainder of alloy body **20** composed of Co, P, or a combination thereof in embodiments. If desired, micro-size or nano-size particles may be embedded in precipitation-hardened alloy body **20** by, for example, co-deposition during plating to enhance or tailor certain properties of alloy body **20**. Again, as indicated above and described more fully below, precipitation-hardened alloy body **20** is suitably deposited utilizing an electroplating process; however, other deposition techniques can be equivalently utilized.

[0031] Precipitation-hardened alloy body **20** may be deposited as a single layer or as multiple layers. For example, as indicated in FIG. **1** by dashed line **22**, precipitation-hardened alloy body **20** may be deposited as a first XP alloy layer **24** and as second, subsequently-deposited XP alloy layer **26**. When so formed, XP alloy layers **24**, **26** may or may not have substantially equivalent thicknesses, morphologies, and/or formulations. In one approach, first XP alloy layer **24** is electrodeposited over component surface **14** utilizing a first plating bath chemistry; the partially-coated component is removed from the plating bath, machined, and returned to the same or a similar plating bath; and second XP alloy layer **26** is then electrodeposited over first XP alloy layer **24**. As discussed below in conjunction with FIG. **3**, such an approach may be useful when precipitation-hardened alloy body **20** is deposited at relatively high thicknesses and is prone to nodular growth. In this case, nodule growth can occur near edges, corners, and similar topological features of component surface **14** as the electroplating process progresses. Localized irregulates or nodular protuberances can consequently develop, grow, and potentially scavenge the plating current, obstruct features having smaller dimensions, and cause similar issues. As a more specific example, in an embodiment in which channel **18** exists prior to the coating formation process (as opposed to being formed after the coating formation process by drilling or other machining), localized growth can occur near the mouth of channel **18** and may potentially pinch-off or obstruct channel **18** if not removed. By temporarily halting the plating process, grinding or otherwise removing such regions of localized growth, and then resuming the plating process, this can be avoided. In other embodiments, alloy body **20** can be deposited in three or more layers, with any number and type of machining operations interspersed with the layer deposition steps.

[0032] Wear resistant coating **16** may be fabricated to contain one or more additional layers in addition to precipitation-hardened alloy body **20** in at least some embodiments of coated component **10**. This possibility is illustrated in FIG. **1**, which depicts wear resistant coating **16** as further containing a barrier layer **28** provided between alloy body **20** and component surface **20**. Barrier layer **28** is formulated to prevent or at least deter penetration of contaminants through the thickness of coating **16**; that is, along an axis orthogonal to outer surface **30** of wear resistant coating **16** corresponding to the Y-axis identified in FIG. **1** by coordinate legend **34**. In so doing, barrier layer **28** shields coated component **10** from exposure to such contaminants during usage to reduce corrosion or other degradation of underlying component body **12**. To enable barrier layer **28** to provide this function, barrier layer **28** is beneficially formulated to experience minimal or no precipitate hardening during the below-described heat treatment process.

[0033] In implementations in which precipitation-hardened alloy body **20** is composed of an XP alloy, barrier layer **28** may be composed of an alloy containing an increased amount of X and/or a lesser amount of P as compared to alloy body **20**. For example, in an embodiment in which precipitation-hardened alloy body **20** contains first amount of P and a first amount of Ni, barrier layer **28** may contain a second amount of P less than the first amount of P (and possibly being zero) and second amount of Ni exceeding the first amount of Ni. In at least some instances, barrier layer **28** may consist essentially of pure Ni; the term "consist essentially," as appearing herein, indicating that a named layer or body (here, barrier layer **28**) contains a minimum of 99% of a named constituent (here, Ni), by weight. Similarly, in embodiments in which precipitation-hardened alloy body **20** contains P and a first amount of Co, barrier layer **28** may contain a second amount of P less than the first amount of P (possibly 0% P, by weight) and a second amount of Co exceeding the first amount of Co; e.g., barrier layer **28** may consist essentially of pure Co. When provided, barrier layer **28** usefully, but non-essentially has a thickness equal to or less than that of precipitation-hardened alloy body **20**. For example, in one embodiment, a barrier layer **28** may be formed to have a global average thickness between 4 and about 8 μm, while alloy body **20** has a global average thickness greater than that of barrier layer **28**.

[0034] As noted above, wear resistant coating **16** need not contain a discrete or separately-formed barrier layer in all instances. Instead, in alternative embodiments, wear resistant coating **16** can be imparted with a barrier layer functionality by strategically varying the composition of precipitation-hardened alloy body **20** through its thickness; that is, as taken along an axis orthogonal to the outer surface of alloy body **20** corresponding to the Y-axis in coordinate legend **34** (FIG. **1**). This, in effect, may create certain bands or regions within precipitation-hardened alloy body **20**, which possess a reduced susceptibility to precipitate hardening and thus better retain the ability to act as a shield or sealant deterring the penetration of environmental contaminants through coating **16** and to component body **12**. For example, when composed of an XP alloy, precipitation-hardened alloy body **20** can be deposited to have a varied P content through its thickness, noting that the bands of alloy body **20** having a decreased P content will typically be more resistive to P-phase formation and grain growth induced by precipitate hardening. As a still further possibility, the above-described approaches can be combined such that wear resistant coating **16** contains a barrier layer, while precipitation-hardened alloy body **20** has a varied P content and thus selectively resists grain growth through its thickness.

[0035] In embodiments, precipitation-hardened alloy body **20** possesses a maximum P content at or adjacent outer surface **30** of alloy body **20**, which may correspond to location L_1 identified in FIG. **1**. When moving through alloy body **20** toward component body **12**, the P content of precipitation-hardened alloy body **20** may decrease in a gradual or stepped fashion to a minimum value or local minima. In at least some instances, this minimum value may be located at or adjacent inner surface **32** of alloy body **20**, which may correspond to location L_2 in FIG. **1**. For example, in an embodiment, the minimum P content at location L_2 may be at least one half the P content at location L_1, considered by weight percentage. Further, while the minimum P content at location L_2 will typically be greater than zero in such embodiments, the minimum P content at location L_2 may be closer to zero weight percentage than to the P content at location L_1. When an electroplating process is utilized to deposit alloy body **20**, such variations in P concentration, whether present in a gradual or more stepped distribution, can be created by adjusting process parameters, such as current density, in situ during the electroplating process. To provide a specific example, the current density may be first maintained at a relatively low level to deposit the initially-plated portion of alloy body **20** to contain a minimum P content. Afterwards, the current density may be boosted to deposit the remainder of precipitation-hardened alloy body **20** to contain an increased P content as alloy body **20** is gradually compiled or build-up over component surface **14** and barrier layer **28**, if present. In still further embodiments, the P content of precipitation-hardened alloy body **20** may vary in another manner (e.g., such that alloy body **20** has a minimum P content between locations L_1 and L_2 identified in FIG. **1**) or alloy body **20** may have a substantially uniform P content through its thickness.

[0036] In the embodiment shown in FIG. **1**, coated component **10** is illustrated in a highly generalized manner to emphasize that underlying component body **12** can assume virtually any desired shape or physical form. Similarly, wear resistant coating **16** can be formed over any type of component, regardless of application or usage. This notwithstanding, wear resistant coating **16** may be particularly beneficial when formed over components subject to high wear conditions or corrosive environments during usage. In this regard, FIG. **2** illustrates a coated component in the form of a mud rotor shaft **36**, which is contained in the power section of a downhole mud rotor **38** (partially shown). As indicated by gap **40**, mud rotor shaft **36** can have any desired length, which may approach or exceed **10** meters in implementations. Additionally, multiple mud rotor shafts **36** may be ganged together or joined in series to span the full depth of a given well. In addition to mud rotor shaft **36**, downhole mud rotor **38** further includes a tubular stator casing **42** and an inner tubular sleeve **44**, which may be composed of a rubber or another polymer. The interior of sleeve **44** is threaded or lobbed in a twisting or spiral pattern. The twisting, lobed interior geometry of sleeve **44** combines with the twisting, lobed outer geometry of mud rotor shaft **36** to form a sealed cavity, which varies in location as rotor shaft **36** rotates with respect to sleeve **44** and casing **42**. During operation of downhole mud rotor **38**, a pressurized liquid is delivered into the sealed cavity, which varies in shape and location as rotor shaft **36** rotates, to drive rotation of rotor shaft **36** and a non-illustrated bit in which mud rotor **38** terminates.

[0037] During mud rotor operation, relatively severe frictional forces or harsh abrasive forces may be exerted between the mating surfaces of mud rotor shaft **36** and sleeve **44**. To stave-off premature wear of rotor shaft **36** and sleeve **44**, a wear resistant coating **46** is formed over the outer lobed surface of rotor shaft **36**. As shown in FIG. **2**, wear resistant coating **46** may be considered analogous to wear resistant coating **16** described above in conjunction with FIG. **1**, and the combination of wear resistant coating **46** and rotor shaft **36** may be considered an example of a "coated component." Wear resistant coating **46** and, specifically, the precipitation-hardened alloy body contained in coating **46** (corresponding to alloy body **20** shown in FIG. **1**) can be imparted with a highly smooth surface finish by machining prior to precipitate hardening of the alloy body. For example, in an embodiment, grinding or polishing may be performed to impart coating **46** with a surface finish finer than 1 μm (approximately 40 μin) and, perhaps, a surface finish equivalent to or finer than 0.4 microns (approximately 15 μin). Such a highly smooth surface enhances the integrity of the seal formed between rotor shaft **36** and sleeve **44**, while concurrently minimizing abrasion of sleeve **44** during rotation of rotor shaft **36**. An exemplary method for forming wear resistant coating **46** shown in FIG. **2**, wear resistant coating **16** shown in FIG. **1**, or a similar wear resistant coating will now be described in conjunction with FIG. **3**.

[0038] Examples of a Method for Producing a Coated Component

[0039] FIG. **3** is a flowchart setting-forth an exemplary coating formation method **48**, which can be carried-out to form a wear resistant coating over selected surfaces of one or more components. In the illustrated example, coating formation method **48** includes a number of process steps identified as STEPS **50**, **52 54**, **56**, **58**, **60**, **62**. Depending upon the particular manner in which coating formation method **48** is implemented, each illustrated step (STEPS **50**, **52 54**, **56**, **58**, **60**, **62**) may entail a single process or multiple sub-processes. Further, the steps shown in FIG. **3** and described below are offered purely by way of non-limiting example. In alternative embodiments of coating formation method **48**, additional process steps may be performed, certain steps may be omitted, and/or the illustrated steps may be performed in alternative sequences. For ease of explanation, method **48** will be described with reference to coated component **10** shown in FIG. **1**.

[0040] Coating formation method **48** commences at STEP **50** during which the component or components to be coated are obtained by, for example, purchase from a third party supplier or by independent fabrication. Selected surfaces of the components are also prepared for deposition of the wear resistant coating. Surface preparation involve cleaning, such as treatment with acid to dissolve surface oxides or degreasing. Grinding may be performed to improve surface finish. Afterwards, a barrier layer (e.g., barrier layer **28** shown in FIG. **1**) can be plated or otherwise deposited over the component surfaces, if desired (STEPS **52**, **54**). For example, in embodiments in which the later-deposited alloy body precursor contains Ni, a barrier layer having a relatively high Ni content, and possibly consisting essentially of Ni, may be plated onto selected surfaces of the components. Conversely, in embodiments in which the subsequently-deposited alloy body precursor contains Co, a barrier layer having a relatively high Co content, if not consisting essentially of Co, may be plated onto selected component surfaces. In other embodiments, if a barrier layer is not desirably formed over the components, method **48** may advance directly to STEP **56**, as described below.

[0041] During STEP **56** of coating formation method **48**, the precipitation-hardened alloy body is electroplated or otherwise deposited over targeted surfaces of the processed component(s). When an electroplating process is employed, the particular parameters and plating bath chemistries of the electroplating process may vary among embodiments. However, as a non-limiting example in implementations in which the alloy body is desirably composed of an XP alloy, a liquid additive, a powder additive, and/or dissolvable anodes can be utilized to provide the source of X ions during the plating process. For example, in certain embodiments, Ni ions may be supplied in the form of a chemical additive (e.g., a Ni sulfate compound) introduced into the plating bath, in which case inert (e.g., platinum-plated titanium) anodes may be inserted into the NiW plating bath and energized to drive the electroplating process. In other implementations, the Ni ion source may be provided utilizing consumable or soluble Ni anodes, which are replenished as needed during the electroplating process. Comparatively, Co ions may be provided as a water-soluble additive, such as Co sulfate ($CoSO_4.7H_2O$). P ions can likewise be provided utilizing suitable chemical species and, in an embodiment, may be supplied by breakdown of phosphorous acid (H_3PO_3) added to plating bath solution. The plating bath chemistry may also be formulated to include other ingredients or constituents including pH balancing agents and/or chelating agents, such as organic acids. Other bath formulations are also possible, with fine tuning of other parameters (e.g., temperatures and agitation intensities) performed as appropriate for a particular plating bath operation.

[0042] Advancing next to STEP **58** of coating formation method **48**, machining of the newly-deposited alloy body or layer is conducted. Generally, conventional tooling and processes can be utilized to machine alloy body **20** in its pre-hardened or soft state in which alloy body **20** may have a relatively hardness value on the order of, for example, 500 to 600 HV. Such machining operations may be performed to define detailed structural features in alloy body **20** and component body **12**, as desired. For example, in an embodiment, mechanical drilling, laser drilling, water jetting, electro discharge machining, or the like may be performed to form channel **18** in bodies **12**, **20**, as shown in FIG. **1**. Additionally or alternatively, grinding or polishing may be performed to impart outer surface **30** with a highly smooth surface finish, such as a surface finish having an average roughness less than 0.4 microns (approximately 15 μin) RA. As further indicated in FIG. **3** by STEPS **56**, **58**, **60**, such process steps can be repeated, as appropriate, until a desired alloy body thickness is achieved.

[0043] After achieving the desired thickness, coating formation method **48** advances to STEP **62** and heat treatment is performed to precipitate harden alloy body **20**. In embodiments in which component body **12** is desirably annealed (e.g., as may be the case when component body **12** is composed of a cold-worked metal or alloy, such as steel), a single heat treatment process can be carried-out to precipitate harden alloy body **20**, while concurrently annealing component body **12**. The particular parameters of the heating schedule employed will vary depending upon the composition of alloy body **20** and whether component body **12** is desirably annealed. However, in at least some embodiments, heat treatment may be performed at peak temperature between 250 and 450 degrees Celsius for a time period ranging from 2 to 24 hours. After heat treatment and precipitate hardening, the hardness value of alloy body **20** beneficially exceeds 950 HV and, in certain instances, may have been increased by a factor of two or more. Coating formation method **48** concludes following STEP **62**, and can be repeated, as needed, to form additional wear resistant coatings over other components in the above-described manner.

CONCLUSION

[0044] There has thus been provided embodiments of wear resistant coatings, coated components protected by wear resistant coatings, and methods for forming wear resistant coatings. The wear resistant coatings contain precipitation-hardened alloy bodies, which are initially deposited in a pre-hardened and subsequently precipitation hardened to greatly enhance the final hardness of the alloy bodies. By initially depositing the alloy bodies in a pre-hardened state, machining as appropriate, and subsequently precipitate hardening the alloy bodies, wear resistant coatings can be fabricated having relatively high hardness values, while facilitating the coating formation process; in particular, while facilitating machining of the coating to define refined structural features, to achieve highly smooth surface finishes, to satisfy stringent dimensional tolerances, or the like. Process efficiency can also be enhanced by precipitate hardening the alloy body, while concurrently annealing the underlying substrate or component utilizing a single heat treatment process in embodiments. The wear resistant coating may consist solely of the precipitation-hardened alloy body or, instead, may contain one or more additional layers, such as a barrier layer formed between the precipitation-hardened alloy body and the underlying component.

[0045] Terms such as "comprise," "include," "have," and variations thereof are utilized herein to denote non-exclusive inclusions. Such terms may thus be utilized in describing processes, articles, apparatuses, and the like that include one or more named steps or elements, but may further include additional unnamed steps or elements. While at least one exemplary embodiment has been presented in the foregoing Detailed Description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing Detailed Description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. Various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set-forth in the appended Claims.

What is claimed is:

1. A method for producing a coated component, comprising:

obtaining a component having a component surface;

forming an XP alloy body over the component surface to yield a coated component, wherein P is phosphorus and X is cobalt, nickel, or a combination thereof;

after forming the XP alloy body, machining the XP alloy body; and

after machining the XP alloy body, heat treating the coated component to precipitate harden the XP alloy body.

2. The method of claim **1** wherein heat treating comprises heat treating the coated component to anneal the component, while concurrently precipitate hardening the XP alloy body.

3. The method of claim **1** further comprising forming a barrier layer on the component surface prior to deposition of the XP alloy body, the barrier layer containing a greater amount of X than does the XP alloy body.

4. The method of claim **3** wherein the barrier layer consists essentially of X.

5. The method of claim **3** wherein depositing comprises electroplating the XP alloy body directly onto the barrier layer.

6. The method of claim **1** wherein the component comprises a mud rotor shaft having a lobed outer surface, and wherein machining comprises machining the mud rotor shaft to impart the lobed outer surface with an average roughness equal to or less than 1 micron.

7. The method of claim **1** further comprising formulating the XP alloy body to contain:

a majority X, by weight; and

about 5% to about 25% P, by weight.

8. The method of claim **1** further comprising formulating the XP alloy body to consist essentially of:

about 10% to about 15% P, by weight; and

the remainder X.

9. The method of claim **1** wherein the XP alloy body is formed by successively depositing at least a first XP alloy layer and a second XP alloy layer, and wherein the method further comprises:

depositing the first XP alloy layer;

machining the first XP alloy layer to remove areas of nodular growth therefrom; and

after machining the first XP alloy layer, depositing a second XP alloy layer over the first XP alloy layer.

10. The method of claim **1** wherein the XP alloy body comprises opposing inner and outer surfaces, the inner surface located closer to the component than is the outer surface; and

wherein forming comprises forming the XP alloy body to contain a first P content adjacent the inner surface and a second P content adjacent the outer surface, the second P content at least twice the first P content.

11. The method of claim **1** wherein forming the XP alloy body comprises:

depositing an XP alloy layer over the component surface utilizing an electroplating process; and

increasing a current density during the electroplating process to increase the P content of the XP alloy body as the XP alloy body is compiled over the component surface.

12. A method for producing a coated component, comprising:

obtaining a component having a component surface; and

forming a precipitation-hardened alloy body over the component surface, forming comprising:

electrodepositing at least one alloy layer in a pre-hardened state over the component surface to yield a coated component;

after electrodepositing, machining the at least one alloy layer in the pre-hardened state; and

heat treating the coated component to anneal the component, while precipitate hardening the at least one alloy layer to yield a precipitation-hardened alloy body having a hardness at least twice that of the one or more alloy layers in the pre-hardened state.

13. The method of claim **12** further comprising:

prior to electrodepositing the at least one alloy layer, forming a barrier layer over the component surface; and

formulating the barrier layer to be less susceptible to precipitate hardening than is the at least one alloy layer.

14. The method of claim **13** further comprising:

formulating the at least one alloy layer to be composed of an XP alloy, wherein P is phosphorus and X is cobalt, nickel, or a combination thereof; and

formulating the barrier layer to contain an increased amount of X and a decreased amount of P as compared to the at least one alloy layer.

15. The method of claim **12** wherein the one or more alloy layers comprise opposing inner and outer surfaces, the inner surface located closer to the component than is the outer surface; and

wherein the method further comprises electrodepositing the at least one alloy layer to have a P content, which decreases when moving from the outer surface toward the inner surface.

16. A coated component, comprising:

a component having a component surface; and

a precipitation-hardened alloy body overlying the component surface, the precipitation-hardened layer composed of an XP alloy body wherein P is phosphorus and X is cobalt, nickel, or a combination thereof.

17. The coated component of claim **16** further comprising a barrier layer disposed between the component surface and the precipitation-hardened alloy body, the barrier layer containing X in a greater amount than does the XP alloy body.

18. The coated component of claim **16** wherein the XP alloy body comprises:

a majority X, by weight; and

about 5% to about 25% P, by weight.

19. The coated component of claim **16** wherein the XP alloy body comprises:

opposing inner and outer surfaces, the inner surface located closer to the component than is the outer surface;

a first P content adjacent the inner surface; and

a second P content adjacent the outer surface and at least twice the first P content.

20. The coated component of claim **16** wherein the coated component comprises a mud rotor shaft having a lobed outer surface, and wherein the lobed outer surface has an average surface roughness equal to or less than 1 micron.

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