ABSTRACT

Abrasion resistant coatings useful for improving abrasive wear and/or corrosion resistance in radial bearings and downhole tools exposed to drilling forces as well as abrasive and/or corrosive drilling fluids. An abrasion resistant coating is disposed on at least one surface of a component body to increase the resistance of the component to abrasive wear and corrosion. The abrasion resistant coating includes a plurality of spherical tungsten carbide particles and a plurality of tungsten carbide particles. At least 65% by volume of the spherical tungsten carbide particles have a diameter of less than about 25 microns.
WEAR RESISTANT COATINGS FOR RADIAL BEARINGS AND DOWNHOLE TOOLS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of related U.S. Provisional Application Ser. No. 61/794,091 filed on Mar. 15, 2013, titled, “Wear Resistant Coatings for Radial Bearings and Downhole Tools,” to Robert J. Ferguson and Peter T. Cariveau, the disclosure of which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] Directional drilling for the recovery of hydrocarbons or minerals from a subsurface formation may be carried out using a downhole motor (also commonly referred to as a “drilling motor” or “mud motor”), which is incorporated into the drill string above the drill bit. A downhole motor may include a drive shaft and a bearing assembly, among other components.

[0003] During operation of the downhole motor, high-pressure drilling fluid may be used to power the motor. In addition to powering the motor, the drilling fluid (or drilling mud) provides hydrostatic pressure to prevent formation fluids from entering the wellbore; cools and lubricates drill string components and the drill bit; and lifts cuttings away from the drill bit, among other functions. Various drilling muds may be used for specific purposes during drilling operations and often contain corrosive chemicals as well as various sized particles to perform their intended task(s).

[0004] In recent years, downhole motors have been introduced that generate very high-torque. These include “even-wall” stators such as the ERT series offered by Robbins & Myers and hard rubber (HR) stators such as those offered by Dyna-Drill. Higher torque results from the ability of these power sections to withstand higher operating pressures and pressure drops. The bearing(s) used in the universal joints as drive elements to transmit torque must endure high loads and a fretting motion, which create point contact and high Hertzian stresses that may cause the mating materials to yield or spall. Also, when used as thrust bearings, ball bearings and their mating thrust seats may suffer galling because the thrust balls must be relatively small, because they are positioned under, and in the same plane with, the drive elements. Spalling and galling are destructive occurrences that can lead to costly failure of the bearings, and thus, of the entire mud motor.

SUMMARY OF THE DISCLOSURE

[0005] Numerous components of a drill string including, but not limited to, e.g., bearings of universal joints, are exposed to high stress environments during drilling operations. Further, corrosive and abrasive chemicals may be contained in the drilling muds and other fluids present in, used in, or introduced into a well, wellbore or other subterranean bore during such drilling operations. The drill string components may be coated with an abrasive and corrosion resistant alloy to extend their useful lifetimes and minimize their failure under such conditions.

[0006] In one aspect, one or more embodiments disclosed herein relate to a downhole component having a component body with at least one surface. An abrasion resistant coating may be disposed on the at least one surface of the component body. The abrasion resistant coating may contain a plurality of spherical tungsten carbide particles and a plurality of tungsten carbide particles. In one or more embodiments, at least 65% by volume of the spherical tungsten carbide particles have a diameter of less than about 25 microns.

[0007] In another aspect, one or more embodiments disclosed herein relate to a radial bearing, e.g., for use in a downhole tool or motor. The radial bearing may have an abrasion resistant coating on a surface thereof. The abrasion resistant coating may be formed from a plurality of spherical tungsten carbide particles and a plurality of tungsten carbide particles. In one or more embodiments, at least 65% by volume of the spherical tungsten carbide particles have a diameter of less than about 25 microns.

[0008] In another aspect, one or more embodiments disclosed herein relate to a method of manufacturing a downhole component by applying a layer of an abrasion resistant composition to a metal surface of a substrate. The abrasion resistant composition may include a plurality of spherical tungsten carbide particles and a plurality of tungsten carbide particles. In one or more embodiments, at least 65% by volume of the spherical tungsten carbide particles have a diameter of less than about 25 microns.

[0009] In another aspect, one or more embodiments disclosed herein relate to a method of forming an abrasive resistant coating. The method may comprise admixing a spherical tungsten carbide powder with a tungsten carbide powder to form a mixture, with the spherical tungsten carbide powder including at least 65% by volume of particles having a diameter of less than about 25 microns; puckling the mixture to form a puck; milling the puck to form a cloth; applying the cloth to a substrate; and vacuum brazing the cloth to the substrate.

[0010] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF DRAWINGS

[0011] The FIGURE is a chart illustrating a particle size distribution of an embodiment of the abrasion resistant coatings disclosed herein.

DETAILED DESCRIPTION

[0012] One or more embodiments disclosed herein relate to abrasion resistant coatings useful for improving abrasive wear and corrosion resistance for radial bearings, tools, and downhole components exposed to drilling forces and abrasive and corrosive drilling fluids.

[0013] Abrasion resistant coatings according to embodiments herein may be formed from a mixture of spherical tungsten carbide particles and tungsten carbide particles. The abrasion resistant coating may include a plurality of spherical tungsten carbide particles and a plurality of tungsten carbide particles. In some embodiments, the spherical tungsten carbide particles are spherically shaped plasma densified tungsten carbide particles. In forming the mixture, the plurality of particles used may be of varied sizes. For example, the particle size and/or the particle size distribution of the spherical tungsten carbide particles may be selected to result in coatings having excellent
abrasion resistance, e.g., from decreased oxygen content or decreased mean free path, as will be discussed further below. [0014] In one or more embodiments, at least 65% by volume of the spherical tungsten cobalt carbide particles have a diameter of less than about 25 microns. In some embodiments, greater than 67.5% by volume of the spherical tungsten cobalt carbide particles have a diameter of less than about 25 microns. Further, in some embodiments, greater than 70%, 72.5%, or 75% by volume of the spherical tungsten cobalt carbide particles have a diameter of less than about 25 microns.

[0018] The particle size distribution of the spherical tungsten cobalt carbide particles is less than about 1.5 in some embodiments; less than about 1.4 in other embodiments; less than about 1.3 in other embodiments; and less than about 1.2 in still other embodiments. In one or more other embodiments, the particle size distribution of the spherical tungsten cobalt carbide particles is less than about 1.1.

[0019] In some embodiments, the spherical tungsten cobalt carbide particles have a particle size distribution having a D_{50} (based on volume percent) in the range from about 12 to about 24 microns, such as a D_{50} in the range from about 13 to about 20 microns or a D_{50} in the range from about 14 to about 18 microns. In some embodiments, essentially no spherical tungsten cobalt carbide particles have a diameter of less than about 5 microns and essentially no spherical tungsten cobalt carbide particles have a diameter of greater than about 38 microns.

[0020] When forming the coatings, the spherical tungsten carbide particles and the plurality of tungsten carbide particles may be used at a weight ratio of the spherical tungsten carbide particles to the plurality of tungsten carbide particles in the range from about 50:50 to about 90:10. In other embodiments, the weight ratio of the spherical tungsten carbide particles to the plurality of tungsten carbide particles may be in the range from about 55:45 to 88:12; and yet in other embodiments, in the range from about 60:40, 65:35, or 70:30 to about 75:25 or 80:20.

[0021] By restricting the particle size of the spherical tungsten carbide particles as described above, the particles may have advantageously low initial oxygen content. In one or more embodiments, prior to formation of the abrasion resistant coating, the spherical tungsten carbide particles may have an oxygen content of less than about 300 ppm by weight; less than 250 ppm by weight; less than 225 ppm by weight; or even less than 200 ppm by weight. Excessive oxygen may cause bonding, for example, and may reduce the contact angle during the brazing process. For particle mixtures having high oxygen content, such as those having an oxygen content greater than 350 ppm or 400 ppm by weight, vacuum baking may be used to decrease the oxygen content to a more desirable range. Advantageously, selection of particle size distributions as detailed above may allow abrasion resistant coatings herein to be formed without a vacuum bakeout of the particles to decrease oxygen content, saving both time and operating expense. Further, elimination of a vacuum bakeout step may result in improved product consistency.

[0022] With regard to the tungsten carbide particles, the tungsten carbide particles may include at least one of monocristalline tungsten carbide, cast tungsten carbide, macrocristalline tungsten carbide, or a eutectic mixture of WC and W_{6}C_{5}. In some embodiments, the tungsten carbide particles are spherical. In other embodiments, the tungsten carbide particles are irregularly shaped, i.e., non-spherical.

[0023] An average particle size of the tungsten carbide particles is generally selected to be less than an average particle size of the spherical tungsten carbide particles. For example, the average particle size for the tungsten carbide particles may be in the range from about 0.1 to about 10 microns, such as in the range from a lower limit of about 0.5, 1, 1.5, 2, 2.5, or 3 microns to an upper limit of about 1.5, 2, 2.5, 3, 3.5, 4, or 5 microns. An average particles size D_{50} of the tungsten carbide particles may be less than about 10 microns in some embodiments, and the tungsten carbide particles may have an average particle size D_{50} in the range from about 1.2 to about 2.8 microns, such as in the range from about 1.4 to about 2 microns.
In one or more embodiments, a particle size distribution of a mixture of the tungsten carbide particles and the spherical tungsten carbide particles is bimodal. For example, in some embodiments the particle size distribution of the mixture of tungsten carbide particles and the spherical tungsten carbide particles may be similar to that as illustrated in the FIGURE. Overall, the mixture may be selected such that greater than about 95% of the particles have a particle size of less than about 35, 50, or 25 microns in various embodiments.

The spherical powders and the size ranges used in one or more embodiments disclosed herein may allow for improved flow and particle packing during packing and brazing processes. The bimodal particle size distributions in one or more embodiments disclosed herein may allow for the small irregular tungsten carbide particles to fill the large pores left by the larger spherical tungsten carbide particles. Limiting the maximum particle size may thus improve wear resistance by removing weak particles that may fracture and cause defects in the material. Further, limiting the large particles significantly improves the uniformity and packing of the particles and may allow a larger percentage of the tungsten carbide material to be added to the matrix mixture without disrupting the particle packing and wear resistance. Overall, this leads to a much higher density tungsten carbide reinforced material.

Restricting the particle size distribution and the maximum particle size of the spherical tungsten carbide particles may result in a decrease in the mean free path for the braze infiltrate as compared to mixtures including any significant quantity of particles greater than about 35 microns in size. In other words, the particle size selection may restrict the mean free path between carbide particles and sintered masses of carbide. The resulting reduction in mean free path, as compared to mixtures including larger particles, may result in improved abrasive resistance, thereby reducing the rate at which erosion and abrasive wear may occur. The presence of a larger mean free path and braze accumulation will result in erosion and abrasive wear at a much faster rate than adjacent carbide masses. Further, the use of spherical tungsten carbide particles may reduce the localized stress concentration at the surface of sintered masses. Thus, proper selection of particle size and particle size distribution according to one or more embodiments disclosed herein may provide for superior abrasion resistant coatings.

In some embodiments, the abrasion resistant coating has a mean free path, as measured using image analysis and Scanning Electron Microscopy (SEM), between spherical tungsten carbide particles of less than about 15 microns. In other embodiments, the abrasion resistant coating has a mean free path between spherical tungsten carbide particles of less than about 10 microns. In other embodiments, the abrasion resistant coating has a mean free path between spherical tungsten carbide particles of less than about 9 microns. In other embodiments, the abrasion resistant coating has a mean free path between spherical tungsten carbide particles of less than about 8 microns. In other embodiments, the abrasion resistant coating has a mean free path between spherical tungsten carbide particles of less than about 7 microns. In other embodiments, the abrasion resistant coating has a mean free path between spherical tungsten carbide particles of less than about 6 microns. In other embodiments, the abrasion resistant coating has a mean free path between spherical tungsten carbide particles of less than about 5 microns. In yet other embodiments, the abrasion resistant coating has a mean free path between spherical tungsten carbide particles of less than about 4, 3, or even 2 microns.

As noted above, vacuum baking of the particles may be used to reduce average particle oxygen content. Heating of the particles during vacuum baking may result in sintering of some particles, which negatively impacts mean free path. Mean free path may thus advantageously be improved by proper selection of particle size and particle size distributions according to one or more embodiments herein.

The mixture of particles described above may be used to form abrasion resistant coatings having an abrasive resistance factor of at least 150. The abrasion resistance factor (ARF) may be determined by measuring the weight loss of the coating according to ASTM G65 method A, and the density of the coating according to ASTM B311. The weight loss is converted to a volume loss by dividing the weight loss by the density of the coating. This volume loss is adjusted to account for diameter change of the rubber wheel during the test. The abrasive resistance factor is then calculated by taking the inverse of the adjusted volume loss times 1000. Abrasion resistant coatings, according to one or more embodiments herein, may have an ARF of at least 160; an ARF of at least 170; an ARF of at least 180; an ARF of at least 190; or an ARF of at least 200. Abrasion resistant coatings, according to one or more embodiments herein, may have an ARF in the range from about 160 to about 220 or in the range from about 175 to about 200.

Production of spherical tungsten carbide particles may result in particles outside of the desired range of particles described above. In some embodiments, tungsten carbide particles may be sieved, ultrasonically sieved, or air classified to result in the desired particle size range and particle size distribution.

The abrasion resistant coatings described above may be applied to a drilling component, such as a radial bearing, to form a coated drilling component for use in drilling or other operations that may be performed downhole. For example, the abrasion resistant coatings described above may be applied to a wear surface of a radial bearing or other portions of a drilling component to provide a drilling component that has abrasion and wear resistance.

To facilitate application of the abrasion resistant coatings, the tungsten carbide particles and the spherical tungsten carbide particles may be pre-mixed and/or milled with a ball mill, TURBULA, or other means. The mixture of particles may then be joined together to form a puck; for example, the pucking process may include joining the particles together by a web-like structure formed by one or more polymeric materials, such as polytetrafluoroethylene (PTFE).

The resulting puck may then be milled into a thin flexible membrane or cloth. The thickness of the cloth selected may vary depending upon the underlying substrate, such as an iron metal or alloy, among others, as well as the depth of capillary action of the infiltrate to the selected underlying substrate. The flexible cloth may then be applied to a substrate and may readily conform to the shape of the substrate. The cloth may then be cut to shape and applied with a low temperature adhesive, if desired. Optionally, another cloth, such as a cloth containing a braze material powder, may
then be applied onto the layer of cloth formed according to one or more embodiments disclosed herein.

[0034] Once the cloth is applied, the temperature of the cloth layers and the surface of the substrate may be increased to brazing temperatures to effect the metallurgical bonding of the cloth layer(s) with the substrate material. The infiltration brazing process may be performed, for example, using a vacuum furnace with an inert gas atmosphere to preclude degradation of complex carbides at brazing temperatures, which may be in the range from about 500°C to about 1200°C. The brazed product may then be ground to produce a finished product without abuse of the abrasion resistant coating.

[0035] The brazing process may result in a change in physical properties of the underlying substrate. In some embodiments, the brazed product may be heat treated to restore the grain structure and mechanical properties of the substrate altered by the elevated temperatures during vacuum brazing.

[0036] As described above, abrasion resistant coatings according to one or more embodiments herein may be used to enhance the wear resistance of components that are used in drilling or downhole operations, where such components may be exposed to drilling muds and other fluids containing abrasive and corrosive constituents. In some embodiments, the abrasion resistant coatings as described above may be applied to radial bearings, thrust bearings, universal joints, and transmissions, among other such components.

[0037] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from the disclosure. Accordingly, all such modifications are intended to be included within the scope of this disclosure. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke means-plus-function treatment for any limitations of any of the claims herein, except for those in which the claim expressly uses the words ‘means for’ together with an associated function.

What is claimed is:

1. A downhole component, comprising:
   a component body having at least one surface; and
   an abrasion resistant coating disposed on the at least one surface of the component body, the abrasion resistant coating including a plurality of spherical tungsten carbide particles and a plurality of tungsten carbide particles;
   wherein at least 65% by volume of the spherical tungsten carbide particles have a diameter of less than about 25 microns.

2. The downhole component of claim 1, wherein the spherical tungsten carbide particles in the abrasion resistant coating have a mean free path of less than about 15 microns, as measured using image analysis and Scanning Electron Microscopy (SEM).

3. The downhole component of claim 1, wherein the spherical tungsten carbide particles comprise less than 5% by volume of particles having a diameter of less than about 5 microns.

4. The downhole component of claim 3, wherein the spherical tungsten carbide particles comprise essentially no particles having a diameter of less than about 5 microns and essentially no particles having a diameter greater than about 38 microns.

5. The downhole component of claim 1, wherein the spherical tungsten carbide particles are spherically shaped plasma densified tungsten carbide particles.

6. The downhole component of claim 1, wherein the spherical tungsten carbide particles have a particle size average of less than about 24 microns.

7. The downhole component of claim 1, wherein the abrasion resistant coating has an abrasive resistance factor of at least 150.

8. The downhole component of claim 1, wherein a weight ratio of the spherical tungsten carbide particles to the plurality of tungsten carbide particles is in the range from about 50:50 to about 90:10.

9. The downhole component of claim 1, wherein the spherical tungsten carbide particles have an oxygen content of less than about 300 ppm by weight.

10. The downhole component of claim 1, wherein an average particle size of the tungsten carbide particles is less than about 10 microns.

11. The downhole component of claim 1, wherein the tungsten carbide particles comprise at least one of monocristalline tungsten carbide, cubed tungsten carbide, macocristalline tungsten carbide, or a eutectic mixture of WC and WC.

12. The downhole component of claim 1, wherein the tungsten carbide particles are spherical.

13. The downhole component of claim 1, wherein a particle size distribution of a mixture of the tungsten carbide particles and the spherical tungsten carbide particles is bimodal.

14. The downhole component of claim 1, wherein the downhole component is a radial bearing.

15. A method of manufacturing a downhole component, comprising:
   applying a layer of an abrasion resistant composition to a metal surface of a substrate, the abrasion resistant composition comprising:
   a plurality of spherical tungsten carbide particles and a plurality of tungsten carbide particles;
   wherein at least 65% by volume of the spherical tungsten carbide particles have a diameter of less than about 25 microns.

16. The method of claim 15, further comprising heating the abrasion resistant composition and at least the surface of the substrate to effect metallurgical bonding of the abrasion resistant composition with the substrate.

17. A method of forming an abrasive resistant coating, comprising:
   admixing a spherical tungsten carbide powder with a tungsten carbide powder to form a mixture, wherein the spherical tungsten carbide powder comprises at least 65% by volume of particles having a diameter of less than about 25 microns;
   puckering the mixture to form a puck;
   milling the puck to form a cloth;
   applying the cloth to a substrate; and
   vacuum brazing the cloth to the substrate.
18. The method of claim 17, further comprising at least one of:
ultrasonic sieving or air classifying a mixture of tungsten cobalt carbide particles to recover a fraction of tungsten cobalt carbide particles where at least 65% by volume of particles having a diameter of less than about 25 microns;
mixing the fraction of spherical tungsten cobalt carbide particles with tungsten carbide particles;
adhering the cloth to the substrate using an adhesive compound; or
applying a second cloth comprising a braze material powder to the cloth.
19. The method of claim 17, wherein the vacuum brazing is carried out under an inert atmosphere.
20. The method of claim 17, wherein the process does not include vacuum baking of the tungsten cobalt carbide particles to reduce an oxygen content thereof.