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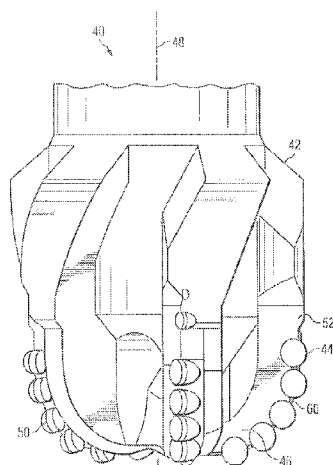


FIG. 3

(57) Abstract: Hardfacing material compositions comprise a plurality of hard material phases dispersed in a continuous metallic alloy binder phase, wherein the hard material phase comprises sintered carbide pellets and other carbide materials, wherein the pellets are encapsulated by thermally stable material layer formed from refractory metals or refractory carbides that that operate to insulate and protect the pellets from unwanted interdiffusion of constituent materials between the pellets and the metallic alloy binder phase during application of the hardfacing material composition onto a desired substrate to thereby retain a desired level of toughness and hardness to enhance operable service life.

HARDFACING MATERIAL COMPOSITIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 62/266485, filed 11 December 2015, which is incorporated by reference.

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BACKGROUND

Composite materials have been applied to the surfaces of downhole tools, in particular drill bits that are subjected to extreme wear. These composite or hard particle materials are often referred to as "hardfacing" materials and typically include at least one phase that exhibits relatively high hardness and another phase that exhibits relatively high fracture toughness. Thus, hardfacing materials are applied to drill bits as well as a variety of other tools such as downhole tools to improve wear resistance. Hardfacing may also be used in an effort to improve both the hardness and fracture toughness of the downhole tool. For example, typical hardfacing materials may include tungsten carbide particles substantially randomly dispersed throughout an iron-based matrix material. The tungsten carbide particles exhibit relatively high hardness and wear resistance, while the matrix material exhibits relatively high strength and fracture toughness.

An example of downhole tools which may have hardfacing compositions applied thereon are roller cone bits, which include a bit body having one or more roller cones rotatably mounted to the bit body. The bit body is typically formed from steel or another high strength material and includes a plurality of cutting elements disposed at selected positions about the cones. The cutting elements may be formed from the same base material as the cone. These bits are typically referred to as "milled tooth" bits. Milled tooth bits include one or more roller cones rotatably mounted to a bit body. The one or more roller cones are typically made from steel and include a plurality of teeth formed integrally with the material from which the roller cones are made. Typically, a hardfacing material is applied to the exterior surface of the teeth to improve the wear resistance of the teeth. The hardfacing material typically includes one or more metal carbides, which are bonded to the steel teeth by a metal binder alloy. Once applied, the carbide particles are in effect suspended in a matrix of metal forming a layer on the surface. The carbide particles give the hardfacing material hardness and wear resistance, while the matrix metal provides fracture toughness to the hardfacing.

Conventional hardfacing material compositions are known to provide properties of hardness and/or wear resistance that may be compromised as a result of particular material

constituents being used and/or the high temperature process that is used for applying the hardfacing material to the metallic bit surface. It is, therefore, desired that a hardfacing material composition be engineered in a manner that provides an improved degree of hardness and wear resistance that is not compromised when applied to a metallic bit surface, to thereby provide a drill bit displaying an enhanced degree of service life when compared to drill bits having surfaces comprising conventional hardfacing materials.

SUMMARY

Hardfacing material compositions as disclosed herein include a plurality of hard material phases dispersed in a continuous metallic alloy binder phase, wherein the hard material phase includes sintered WC-Co pellets. In an example, the continuous metallic alloy binder phase may include an iron-or nickel-based metal or alloy. A feature of such hardfacing composition is that the pellets are encapsulated by a thermally stable material layer that is interposed between and in contact with both the pellets and the continuous metallic alloy binder phase. In an example, the thermally stable material layer is formed from a material selected from a material having a melting point that exceeds the application temperature of the hardfacing, e.g., that has a melting temperature of greater than about 1,650°C, and greater than about 1,700°C.

Materials useful as the thermally stable layer may include refractory metals, carbides of refractory metals, and combinations thereof. Suitable refractory metals include Ti, V, Cr, Zr, Nb, Mo, Ru, Rh, Hf, Ta, W, Re, Os and Ir, and suitable carbides of refractory metals include Ti, V, Cr, Zr, Nb, Mo, Ru, Rh, Hf, Ta, W, Re, Os and Ir. In an example, the thermally stable material layer includes W. The thermally stable material layer may have a thickness that is between about 2 to 4 percent of the pellet diameter, or have a thickness of from 2 to 80 micrometers.

The hardfacing composition hard material phase includes other carbide materials in addition to the sintered WC-Co pellets, where such other carbide materials may or may not be encapsulate with the thermally stable material layer. In an example, the other carbide material may be spherical cast carbide. In an example, the hard material phase comprises from 55 to 90 percent by weight pellets and from about 10 to 45 percent by weight of the other carbide materials based on the total weight of the pellets and the carbide materials. In an example, the hardfacing material composition includes about 55 to 80 weight percent hard material phases and about 20 to 45 weight percent metallic binder alloy phase based on the total weight of the hardfacing composition.

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.

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BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of hardfacing material compositions and constructions comprising the same as disclosed herein will be appreciated as the same becomes better understood by reference to the following detailed description when considered in
10 connection with the accompanying drawings wherein:

FIG. 1 illustrates a perspective view of a milled tooth roller cone drill bit;

FIG. 2 illustrates a cross sectional view of a milled tooth comprising a layer of an example
15 hardfacing material composition as disclosed herein;

FIG. 3 illustrates a perspective view of a fixed cutter drill bit;

FIG. 4 is photomicrograph image of a conventional hardfacing material disposed on a metallic
20 surface of a drill bit; and

FIG. 5 is a photomicrograph image of a hardfacing material composition as disclosed herein disposed on a metallic surface of a drill bit, according to an embodiment of the invention.

25 FIG. 6A, 6B and 6C are photomicrographs of a cutting element in the form of a milled tooth comprising different hardfaced surfaces as disclosed herein.

DESCRIPTION

Hardfacing material constructions as disclosed herein comprise a plurality of hard
30 material phases that include hard materials in the form of relatively large sintered particles or pellets, according to embodiments described in greater detail below. Such hard material pellets are encapsulated by a layer of thermally stable material, and are combined with other hard material phases. The plurality of hard material phases are dispersed within a continuous metallic binder alloy phase or matrix. In an embodiment, the thermally stable material layer or shell

encapsulating the hard material pellet operates to provide a thermal barrier that protects the hard material pellet against constituents of the metallic binder alloy phase infiltrating into the hard material pellet during application of the hardfacing material composition while also protecting the metallic binder alloy phase from constituents of the hard material diffusing out of the pellet, i.e., it protects the pellet from unwanted interdiffusion that can operate to reduce the desired hardness and wear resistant properties of the hardfacing material.

Hardfacing material compositions or hardfacing as disclosed herein comprise a hard phase made up of sintered hard phase pellets and additional hard materials, wherein the hard phase, when applied onto a desired metallic substrate surface such as one on a downhole tool such as a drill bit, is dispersed in a metallic binder alloy phase or matrix to provide an enhanced degree of hardness and wear resistance to the tool.

FIG. 1 illustrates an example of a downhole tool in the form of a milled tooth roller cone drill bit. The milled tooth roller cone drill bit 30 includes a steel body 10 having a threaded coupling or 11 at one end for connection to a conventional drill string (not shown). At the opposite end of the drill bit body 10 there is a cutting structure comprising a roller cone 12, for drilling earthen formations to form an oil well or the like, e.g., a wellbore. Each roller cone 12 is rotatably mounted on a journal pin (not shown) extending inwardly on the bit leg 13 which extends downwardly from the bit body 10. Each bit leg 13 has a shirttail region 20. As the bit is rotated by the drill string (not shown) to which it is attached the roller cones 12 effectively roll on the bottom of the well bore being drilled. The roller cones 12 are shaped and mounted so that as they roll, teeth 14 on the cones 12 gouge, chip, crush, abrade, and/or erode the earthen formations (not shown) at the bottom of the wellbore. The teeth 14g in the row around the heel of the cone 12 are referred to as the gage row teeth that engage the bottom of the hole being drilled near its perimeter or gage. Fluid nozzles 15 direct drilling fluid ("mud") into the hole to carry away the particles of formation created by the drilling.

Such a roller cone drill bit as shown in FIG. 1 is conventional and is therefore merely one example of various arrangements that may be used in a drill bit which may comprise the hardfacing material composition as disclosed herein. For example, the roller cone drill bit illustrated in FIG. 1 has three roller cones. However, one, two and four roller cone drill bits are also known in the art. Therefore, the number of such roller cones on a drill bit is not intended to be a limitation on the scope of the present disclosure. The arrangement of the teeth 14 on the

cones 12 shown in FIG. 1 is just one of many possible variations. In fact, it is typical that the teeth on the three cones on a rock bit differ from each other so that different portions of the bottom of the hole are engaged by each of the three roller cones so that collectively the entire bottom of the hole is drilled. A broad variety of tooth and cone geometries are known and do not form a specific part of this invention, nor should the present disclosure be limited in scope by any such arrangement. The example teeth on the roller cones shown in FIG. 1 are generally triangular in a cross-section taken in a radial plane of the cone.

FIG. 2 illustrates a milled tooth 14 as comprising a leading flank 16 and a trailing flank 17 meeting in an elongated crest 18. The flanks and crest of the tooth 14 is covered with a layer 19 of the hardfacing material composition as disclosed herein. In an embodiment, the leading face of each such tooth 14 is covered with a hardfacing layer so that differential erosion between the wear-resistant steel on the trailing face of the tooth tends to keep the crest of the tooth relatively sharp for enhanced penetration of the rock being drilled. The leading flank of the tooth is the face of the tooth that leads the tooth relative to the direction of motion of the cone.

In an example embodiment, although not specifically illustrated herein, the crest of a tooth, that is, the portions facing in more or less an axial direction on the cone, may be the portion of the teeth provided with a layer of hardfacing. This may be particularly beneficial on the so-called gage row of the bit which is often provided with hardfacing. In an example embodiment, although not specifically illustrated herein, the hardfacing material composition as disclosed herein may be applied to one or more bit legs 13 (FIG. 1) to form a layer of hardfacing. The hardfacing may be applied on the shirttail region of the bit legs.

FIG. 3 illustrates another example of a downhole tool in the form of a fixed cutter drill bit. In this example, a fixed cutter drill bit 40 includes a bit body 42, which includes a cutting structure comprising at least one blade and at least one polycrystalline diamond (PCD) compact cutting element 44 disposed thereon. Typically, the bit body may be formed of steel or a matrix material. The matrix material may be formed from a powdered tungsten carbide infiltrated with a binder alloy within a suitable mold form. The bit body 42 is formed with at least one blade 46, which extends generally outward away from a central longitudinal axis 48 of the drill bit 40. In this example, the bit body may include one or more layers of hardfacing 60 for abrasion and/or erosion resistance. The cutting elements 44 are disposed on the blade 46, wherein the blade includes at least one pocket 50 adapted to receive the cutting element 44. The area of the blade

46 that contacts the wall of the wellbore (not shown separately) is the gage area 52. The number of blades 46 and/or cutting elements 44 are related, among other factors, to the type of formation to be drilled, and can thus be varied to meet particular drilling requirements. The one or more layers of hardfacing may be deposited on any exterior surface of the fixed cutter drill bit. In some example embodiments, the hardfacing may be deposited on at least a portion of a blade of the fixed cutter drill bit which may include at least a portion of the cutter pocket.

While the present disclosure has been described with respect to a limited number of embodiments, one of ordinary skill in the art would also recognize that any exterior surface of a downhole tools may be provided with a layer of the hardfacing material compositions as disclosed herein.

Hardfacing material compositions as disclosed herein comprise a hard phase that includes relatively large-sized hard materials in the form of sintered particles or pellets. In an example, the large-sized hard materials are sintered pellets comprising tungsten carbide. For example, the large-sized hard materials may comprise tungsten carbide in the form of WC-Co and/or WC-Ni, titanium carbide in the form of TiC-Co and/or TiC-Ni, borides such as tungsten borides, titanium borides, and ternary boride cermet. Ternary boride cermet materials useful for forming the sinter particles or pellet as used with hardfacing material compositions disclosed herein include those disclosed in US Published Patent Application No. 2014/0262542, which is incorporated by reference. The hard material pellets may be formed and sintered by conventional process known in the art. In an example, sintered cemented tungsten carbide (WC-Co) comprises small particles of tungsten carbide (e.g., 1 to 15 microns) bonded together with the metal binder cobalt (e.g., about 6 percent by weight). Sintered cemented tungsten carbide may be produced by mixing an organic wax, monotungsten carbide and the metal binder; pressing or pelletizing the mixture to form a green compact; sintering the green compact at temperatures near the melting point of the metal binder; and, in some cases, comminuting the resulting sintered compact to form pellets of the desired particle size and shape. In an example, the resultant hard material pellets may be spherical in shape to provide a uniform stress concentration along the entire surface of the pellet, thereby operating to provide an enhanced degree of impact resistance.

In an example, the hard material pellets may be sized to provide a desired degree of wear resistance in the hardfacing as called for by a particular end-use application. In an example where the end use application of the hardfacing is to provide a protective surface on a milled

tooth of a drill, the hard material pellets may have a particle diameter of greater than about 40 microns, from about 100 to 2,000 micrometers, or from about 80 to 1,200 micrometers.

It is to be understood that hardfacing material compositions as disclosed herein may include hard material pellets having a monomodal particle size distribution, or having a bi- or multi-modal particle size distribution. For example, the hard material pellets may include a combination of different average particle diameters, wherein such particle diameters are within at least one of the ranges provided above. For a particular hardfacing embodiment, it may be desired to use hard material pellets having a multimodal particle size distribution of two average particle sizes. Such an example may comprise: pellets having a first particle size distribution of characterized as 16/20, wherein 16/20 refers to US mesh size, and wherein pellets in this distribution have a particle diameter that passes through 16 mesh but not 20 mesh (i.e., pellets having a particle size of greater than about 840 micrometers up to about 1,190 micrometers); and having a second particle size distribution of hard material pellets characterized as 30/40, wherein 30/40 refers to US mesh size, and wherein pellets in this distribution have a particle diameter that passes through 30 mesh but not 40 mesh (i.e., pellets having a size of greater than about 400 micrometers up to about 595 micrometers).

As used herein, the term "mesh" refers to the size of the wire mesh used to screen the carbide particles. For example, "40 mesh" indicates a wire mesh screen with forty holes per linear inch, where the holes are defined by the crisscrossing strands of wire in the mesh. The hole size is determined by the number of meshes per inch and the wire size. The mesh sizes referred to herein are U.S. Standard Sieve Series mesh sizes, also described as ASTM E11.

It is to be understood that the above is just one example of a hard material pellet multimodal size distribution that may be used to make hardfacing material compositions as disclosed herein, and that such particle size distributions can and will vary depending on such factors as the type of material used to form the pellets, the particular end-use application, and the types/sizes of other materials used to make hardfacing material compositions as disclosed herein. Further, the particular amount or proportion of the differently-sized hard material pellets will also have an impact on the desired end use properties, such as hardness, wear resistance and toughness, of the hardfacing material containing the same.

For example, with reference to the bimodal pellet size example provided above, for a particular end-use application, it may be desired to use a larger amount of the 16/20 pellets than the 30/40 hard material pellets. In such an example, the increased amount of the of the larger-sized hard material pellets relative to the small-sized hard material pellets may operate to provide an increased degree of hardness and wear resistance, while also providing a desired packing density for the hard material pellets operating to thereby to improve the overall density or volume of the hard material pellets in the hard phase of the hardfacing material composition.

In an example, the hard material pellets comprise a desired weight percent of the total hard material phase. In an example, the total amount of the pellets (whether having a monomodal or multimodal size distribution) comprise a majority, i.e., greater than 50 percent of the weight percent of the total weight of the hard material phase. In an example, the pellets comprise between about 55 to 90 percent by weight, 65 to 80 percent by weight, or 70 to 75 percent by weight of the total weight of the hard material phases.

It is to be understood that the exact amount of the pellets that are used to make up the hard material phase will vary depending on a variety of factors. In a particular example, comprising pellets having the bimodal size distribution noted above, the total amount of the pellets are approximately 70 percent by weight of the of the hard material phase, wherein the pellets having the 16/20 mesh size distribution make up approximately 42 percent by weight of the total weight of the hard material phase, and the pellets having the 30/40 mesh size distribution make up approximately 29 percent by weight of the total weight of the hard material phase.

As noted above, a feature of hardfacing material compositions as disclosed herein is that such hard material pellets are coated or encapsulated with a thermally stable material. The thermally stable material is formed from materials capable of preventing both the unwanted diffusion of constituents within the hard material pellets, e.g., cobalt or the like, into the metallic binder alloy phase, and to prevent constituents of the metallic binder alloy phase from diffusing or infiltrating into the hard material pellets when exposed to high temperatures used for applying the hardfacing material composition onto a desired metallic surface and/or during use of the device upon which the hardfacing material composition is disposed thereon.

It has been discovered with conventional hardfacing materials that during application of the hardfacing by conventional high-temperature application methods, such as by oxyacetylene welding or the like, that binder materials in the metallic binder alloy phase such as iron and the like diffuse into the hard materials such as tungsten carbide. The diffused binder material operates to produce an eta phase along the outer perimeter of the hard material pellet and/or dispersed throughout the surrounding metallic binder alloy network. Such eta phase is brittle and operates to embrittle the hard materials as well as the continuous metallic binder alloy network or phase, making it vulnerable to cracking and failure during use and/or during heat cycles associated with repairs. Accordingly, the formation and presence of such eta phase operates to embrittle the metallic binder alloy, thereby reducing the desired combination of hardness and toughness in conventional hardfacing material. For this reason, such conventional hardfacing materials are vulnerable to premature breakage and failure that reduces the effective service life of the associated equipment upon which the conventional hardfacing material is applied to protect.

FIG. 4 is a photomicrograph illustrating a hardfacing layer 70 disposed on a milled tooth 72 of a drill bit (such as that illustrated in FIG. 2). The hardfacing layer 70 comprises sintered carbide pellets 74 that are not encapsulated to include a thermal barrier. Sintered carbide pellets 74 are shown to include a heat affected zone 76 that appears as a darkened zone surrounding the outside region of the pellets 74. Where the sintered full dense WC-Co structure loosens around the surface or perimeter, Co diffuses out into the metallic binder alloy and Fe from the alloy diffuses in. The formation of the heat affected zone 76 operates to both reduce the effective size and adversely impacts resulting properties of the pellets, e.g., the carbide pellets now have a reduced content of WC operating to reduce the hardness of the pellets in the hardfacing material. Additionally, when the dissolved carbide material, e.g., WC, from the pellets meets iron and Co diffusing from the metallic binder this combines to form an eta phase 79. In most instances, the eta phase 79 is formed and exists in a region along an outside edge of the pellet 74 in the metallic binder alloy 78. The formation and presence of the eta phase 79 causes the hardfacing to be embrittled. Thus, the combined formation of the heat affected zone 76 and the eta phase 79 that occurs during application of the hardfacing at elevated temperature, operates to cause the hardfacing 70 to be embrittled and not display a desired combination of toughness and hardness.

FIG. 5 is a photomicrograph illustrating a hardfacing layer 80 formed from the hardfacing material composition as disclosed herein disposed on a milled tooth 82 of a drill bit

(such as that illustrated in FIG. 2), according to an embodiment of the invention. The hardfacing layer 80 comprises sintered carbide pellets 84 as disclosed above that are encapsulated with the thermally stable material to provide a surrounding thermal barrier layer 86, according to an embodiment. As contrasted to the conventional hardfacing layer 70 illustrated in FIG. 4, the presence of the thermal barrier layer 86 in the hardfacing material composition disclosed herein is shown to operate to prevent the unwanted formation of the eta phase in the sintered carbide pellets 84 and the adjacent metallic binder alloy matrix 88 during application of the hardfacing at elevated temperature. In an embodiment, the hardfacing thus has enhanced hardness and toughness as compared to conventional hardfacing materials, which can provide an extended service life to abrasive surfaces.

Thermally stable materials useful for encapsulating the hard material pellets of hardfacing compositions disclosed herein include those that are functionally capable of providing a thermal barrier to mitigate interdiffusion between the hard material pellet and the metallic binder alloy phase. In an embodiment, the thermal barrier prevents interdiffusion. In another embodiment, the thermal barrier inhibits interdiffusion, though some small degree of interdiffusion may occur. Such thermally stable materials include those having melting points that are above the temperatures encountered during application of the hardfacing material, e.g., greater than about 1,650°C, and in some embodiments greater than about 1,700°C, and/or during use of the device that is hardfaced in a particular application, e.g., as a bit used for drilling subterranean formations. Example materials useful as the thermal barrier include refractory metals, carbides of refractory metals, and combinations thereof. Such refractory metals and/or carbides of the same may include Ti, V, Cr, Zr, Nb, Mo, Ru, Rh, Hf, Ta, W, Re, Os and Ir. In example embodiment, the thermal barrier material is one formed from tungsten (W) and tungsten carbide (WC). Accordingly, thermally stable materials used to form the thermally stable barrier are free of materials having a melting temperature below about 1,650°C, which includes but is not limited to such materials as Co, Ni, Fe, Cu, combinations thereof or the like.

In an embodiment, the entire hard material pellet is encapsulated by the thermally stable material to provide comprehensive surface protection against unwanted interdiffusion. The thermal barrier is thus provided in the form of a layer or shell disposed around and surrounding the outside surface of the hard material pellet. The layer thickness of the thermal barrier may vary, but ideally should be of sufficient dimension to give a mechanically/thermally/chemically stable structure capable of providing the desired thermal barrier to prevent unwanted

disassociation of the hard material pellets, dense enough to eliminate the diffusion path of materials such as Fe, Ni, Cu, and Co and the like in the metallic binder alloy phase, while not being so great so as to interfere with the desired hardness and wear resistant properties of the underlying hard material pellet. In an example, the thickness of the thermal barrier layer will
5 also be a function of the material used to form the pellet and its relative size, as well as the thermal conductivity and chemical affinity of the thermally stable material with the hard material pellet.

In an example, the thermal barrier layer may have a thickness that is about 2 to 4 percent
10 of that of the hard material pellet diameter. Thus, an example thermal layer as used herein may have a thickness of greater than 1 micrometer, in the range of from about 2 to 80 micrometers, from about 20 to 50 micrometers, or from about 10 to 30 micrometers. In certain applications such as that disclose above where the hard material pellet is 30/40 US mesh size, a thermal barrier thickness of about 10 micrometers may be sufficient, and where the hard material pellet is
15 16/20 US mesh size, a thermal barrier thickness of about 20 micrometers may be sufficient. These are but example thermal layer thicknesses and it is to be understood that other thickness within the ranges provided above may be used to provide a desired thermal barrier depending on the particular pellet material, thermally stable material, pellet size, composition of the metallic binder alloy phase, and end-use application. It should also be understood that in some
20 embodiments, a fraction of the pellets may have imperfections in the encapsulation, such as holes or thin areas, where interdiffusion is not wholly prevented.

In an example, the thermal barrier material may be applied to the hard material pellet by methods that include but are not limited to electronic plating, electroless plating, chemical vapor
25 deposition (CVD) coating plasma vapor deposition (PVD) coating, plasma coating, mechanical alloying, and by reduction reaction. Prior to coating the hard material pellets it may be useful to clean or otherwise prepare the pellets for coating so as to ensure a strong adhesion therewith. In an example where the hard material pellets are sintered WC-Co, prior to applying the thermal barrier material, e.g., in the form of W, the pellets are cleaned to remove residues, oxides or
30 greases with an organic solvent, ultrasonic energy, combinations thereof and the like. In an example, a CVD process may be used to deposit or grow thin films of the thermal barrier coatings upon the hard material pellets. CVD systems operate by introducing a process gas or chemical vapor into a deposition chamber in which the substrate/hard material pellets to be processed have been placed. The gaseous source chemicals pass over the substrate, are adsorbed

and react on the surface of the substrate to deposit the film. Various inert carrier gases may also be used to carry a solid or liquid source into the deposition chamber in a vapor form. Typically, the substrate is heated from about 200 to 900°C, and in another example from about 600 to 800°C to initiate the reaction for a length of time calculated to achieve the desired thermal

5 barrier material layer thickness.

In addition to the coated sintered hard material pellets disclosed above, the hard phase of hardfacing material compositions as disclosed herein may also contain other hard materials other than the sintered pellets that may include carbides such as cast tungsten carbide, titanium
10 carbide, titanium boride, and tungsten boride and combinations thereof. Cast tungsten carbide is a eutectic mixture of the WC and W₂C compounds, as such the carbon content in cast carbide is sub-stoichiometric (i.e., it has less carbon than the monotungsten carbide). Cast tungsten carbide is typically made by resistance heating tungsten in contact with carbon in a graphite crucible having a hole through which the resultant eutectic mixture drips. The liquid is quenched in a
15 bath of oil and is subsequently comminuted to the desired particle size and shape. The cast tungsten carbide may be in the form of crushed or spherical particles.

In an example, the cast tungsten carbide used herein is in the form of spherical particles for the purpose of providing improved impact resistance by uniform stress distribution. In an
20 example, such additional hard material may have an average particle diameter of about 30 to 150 US mesh (90 to 600 micrometers), or from about 60 to 120 US mesh (125 to 250 micrometers). Such additional hard materials in the hard material phase may be provided having a monomodal or multimodal size distribution depending on the particular desired properties and end-use application. In an example, such as that disclosed above where the hard phase pellets are
25 provided having the multimodal size distribution of 16/20 US mesh and 30/40 US mesh, the additional hard materials in the form of spherical cast carbide have an average particle size of from about 60 to 120 US mesh (125 to 250 micrometers).

In an example, the amount of such additional hard materials used to form the hardfacing
30 hard phase is less than about 50 percent by weight of the total weight of the hard material phase, is from about 10 to 45 percent by weight, between about 20 to 35 percent by weight, or from 25 to 30 percent by weight of the total weight of the hard material phase (wherein the hard material phase is understood to be the hard pellets and the additional hard materials). In the particular example described above where the total amount of hard pellets is approximately 70 percent by

weight, the remaining hard materials comprise approximately 30 percent by weight of the total weight of the hard material phase.

In an example, such additional hard materials are not coated with the thermally stable material. In another embodiment, the additional hard materials may be coated with the thermally stable material. Generally, the presence of such additional hard materials is desired as such materials display increased properties of hardness and wear resistance when compared to the sintered hard material pellets. Additionally, such additional hard materials may operate to increase the packing density of the hard material phase in the hardfacing.

In an embodiment, the metallic binder alloy phase in the hardfacing composition may include steel materials similar to those used for the metallic binder alloy in conventional hardfacing materials. In an example, the metallic binder alloy may be an iron-based binder alloy or a nickel-based binder alloy that may additionally comprise such elements as Co, Ni, Mn, P, C, Cr, Si, S, and combinations thereof depending on the particular type of material selected. The metallic binder alloy may be an iron- or nickel-containing metal alloy having a melting point that is at least 1,300°C, and more suitably at least 1,400°C. Such metallic binder alloys may include, but are not limited to, soft steels. As used herein, the soft steels is meant to include steel materials having a low carbon content, for example steel having a carbon content of less than 0.15% by weight, based on the total weight of the steel (i.e., mild steel). Examples of mild steel include, but are not limited to, AISI (American Iron and Steel Institute) 1010 (0.1% w carbon), AISI 1008 (0.08% w carbon), and AISI 1006 (0.06% w carbon) grades of steel. Such steel materials comprise at least 95 percent by weight iron based on the total weight of the steel.

Hardfacing material compositions as disclosed herein generally comprise a hard or carbide phase including the coated hard material pellets and the additional hard materials, and a matrix phase including the metallic binder alloy, wherein the carbide phase is dispersed within the continuous matrix phase. As used herein, the term "hard or carbide phase", is meant to include the materials which may be placed within a welding tube or which may be placed upon a welding wire, i.e., the filler. As used herein, the term "metallic binder alloy" is meant to include the matrix material which includes materials other than those in the carbide phase as described above. A welding "rod" or stick may include a tube formed from the metallic binder alloy, e.g., of mild steel sheet, enclosing the carbide phase. The carbide phase may also include deoxidizer for the steel, flux, and a resin binder to retain the particles in the tube during welding. The

hardfacing is applied by melting the rod on the surface of the tool. The steel tube melts to weld to the surface and provides the matrix for the carbide phase in the hardfacing. During application, the deoxidizer alloys with the mild steel of the tube.

5 In an example, hardfacing compositions as disclosed herein comprise as combined with the hard material phase other materials such as a metal capable of forming a metal carbide, an oxidizer, and a resin binder. In such combination, the hard material in the form of the pellets and other hard materials comprise from about 90 to 98 percent by weight, 94 to 97 percent by weight, or from 95 to 96 percent by weight of the total combined composition of such materials. In a
10 particular example, wherein the hard pellets and remaining hard materials are in the forms and amounts disclosed above, the hard material phase comprises approximately 96 percent by weight of the total combined composition of the hard materials as combined with metal powder, deoxidizer, and binder resin.

15 In an example, the metal is provided in powder form and is used for the purpose of combining with the hard materials that are not the pellets to form desired metal carbides. Metals useful in this regard include niobium, tungsten, molybdenum, tantalum, chromium, and vanadium. In an example, the metal powder is niobium, and the amount of the metal powder used is from about 0.05 to 5 weight percent, 0.1 to 2, or from 0.2 to 0.5 percent by weight of the
20 total weight of the hard materials as combined with the metal powder, deoxidizer, and resin binder.

In an example, the deoxidizer may comprise a silicomanganese composition which may be obtained from Chemalloy Company, Inc. in Bryn Mawr, PA. A suitable silicomanganese
25 composition may contain 65 to 68 percent by weight manganese, 15 to 18 percent by weight silicon, a maximum of 2 percent by weight carbon, a maximum of 0.05 percent by weight sulfur, a maximum of 0.35 percent by weight phosphorus, and a balance comprising iron. The deoxidizer may be present in a quantity of at most about 5 percent by weight based on the total weight of the hard phase including the metal powder, oxidizer and resin binder.

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In an example, the resin binder may be in the form of a temporary resin binder such as a small amount of thermoset resin to partially hold the hard phase pellets and other hard materials in the hard material or carbide phase together so that they do not shift during application, e.g., welding. The resin binder may be present in a quantity of at most about 1 percent by weight

based on the total weight of the hard materials including the metal powder, deoxidizer, and resin binder.

Hardfacing material compositions as disclosed herein comprise the hard material phase (including the coated pellets and additional hard materials, metal powder, deoxidizer, and resin) as combined with the metallic binder alloy for applying to a desired metallic substrate.

Hardfacing material compositions as disclosed herein do not include polycrystalline diamond. In an example, such hard material phase comprises at least about 50 percent by weight, from about 55 to 80 percent by weight, or in some embodiments greater than about 65 percent by weight of the total weight of the hard material phase and the metallic binder alloy based on the total weight of the hard material phase and metallic binder alloy. In an embodiment, the metallic binder alloy is present in the remaining amount of less than about 50 percent by weight, from about 20 to 45 weight percent, or in some embodiments less than about 35 percent by weight. In a particular example, the hardfacing composition comprises approximately 67 percent by weight hard material phase, and approximately 33 percent by weight metallic binder alloy.

Hardfacing material compositions as disclosed herein may be applied as a hardfacing layer to the desired metallic substrate, e.g., a drill bit body, cone, and/or teeth, using processes well known in the art such as by atomic hydrogen welding. Another process is oxyacetylene welding. Other processes include plasma transferred arc ("PTA"), gas tungsten arc, shield metal arc processes, laser cladding, and other thermal deposition processes. In oxyacetylene welding, for example, the hardfacing material is typically supplied in the form of a tube or hollow rod ("a welding tube"), which is filled with hard phase composition and wherein the tube is often made of steel (iron) or similar metal (e.g., nickel and cobalt) which can act as a binder when the rod and its granular contents are heated.

The tube thickness is selected so that its metal forms a selected fraction of the total composition of the hardfacing material as applied to the metallic surface, e.g., drill bit and/or teeth. In another embodiment, the metallic binder alloy may be in the form of a wire, e.g., a welding wire and the hardfacing materials are coated on the wire using resin binders. In an embodiment, with a PTA welding process, the hardfacing materials may be supplied in the form of a powder. In other embodiments, the hardfacing materials may be supplied in the form of a welding tube or a welding wire.

Other methods and techniques for applying hardfacing material composition as disclosed are known in the art and are omitted here for the sake of clarity. It should be noted that while oxyacetylene welding is the method of applying hardfacing material compositions described herein for enablement purposes, other suitable methods may be employed.

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A feature of hardfacing material compositions as disclosed herein is the use of sintered hard material pellets and the encapsulation of the same by a thermally stable material that provides a surrounding thermal barrier thereon to protect such hard material pellets from the unwanted interdiffusion that is known to occur in conventional hardfacing materials at high
10 temperatures associated with application of the hardfacing, which interdiffusion otherwise operates to embrittle and reduce combined toughness and hardness properties of the hardfacing by the unwanted formation of a heat affected region and by the formation of an eta phase as discussed above. Accordingly, hardfacing material compositions as disclosed herein are specifically engineered to eliminate (or substantially reduce) such interdiffusion between the
15 hard phase pellets and surrounding metallic binder alloy, thereby ensuring that the desired level of toughness and hardness remains after the hardfacing is applied, thereby providing enhanced service life of the metallic surface provided by the composition once applied.

Hardfacing material compositions as disclosed herein (e.g., the hardfacing material
20 construction as disclosed above and illustrated in FIG. 5) were tested for wear resistance and impact strength against conventional hardfacing materials (e.g., with the hardfacing material discussed above and illustrated in FIG. 4), and the results were compared. Specifically, a high stress wear test was conducted in accordance with ASTM B611, and the test results demonstrated that the hardfacing material composition as disclosed herein provided a wear
25 number that was approximately 27 percent greater than that of the conventional hardfacing material. A low stress wear test was also conducted in accordance with ASTM G65, and the test results demonstrated that the hardfacing material composition as disclosed herein provided a volume loss that was approximately 9 percent less than that of the conventional hardfacing material. Finally, a combined wear and impact test was conducted, wherein the two different
30 hardfacing materials were subjected to both wear and impact conditions, for an accumulated period of time of 7 hours and the accumulated weight loss was measured every hour. The results demonstrated the following comparative weight loss differences: after 1 hour a 60 percent lower weight loss; after 2 hours a 71 percent lower weight loss; after 3 hours a 70 percent lower weight loss; after 4 hours a 76 percent lower weight loss; after 5 hours a 71 percent lower weight loss;

after 6 hours a 70 percent lower weight loss; and after 7 hours a 64 percent lower weight loss as compared to the conventional hardfacing materials. Accordingly, these test results operate to confirm that hardfacing material compositions as disclosed here provide improved properties of wear resistance/hardness and toughness (as measured in terms of wear number, weight loss, and cumulative weight loss) when compared to conventional hardfacing materials.

FIGS. 6A, 6B and 6C are photomicrographs different surfaces of a cutting element in the form of a milled tooth having hardfaced layers or surfaces formed from the premium hardfacing material and a different hardfacing material. FIG. 6A illustrates a hardfaced milled tooth 100, and more specifically a crest surface 102 of the milled tooth 104 comprising a hardfaced layer 106 disposed thereon that is formed from the premium hardfacing material described above and illustrated in FIG. 5. As illustrated, the hardfaced layer 106 comprises sintered carbide pellets 108 as disclosed above encapsulated with the thermally stable material to provide a surrounding thermal barrier layer 110. Also illustrated in FIG. 6A are flank surfaces 112 and 114 of the milled tooth 104 that extend from opposite sides of the 102 and that have a hardfaced layer 116 disposed thereon different from that of the crest, which is formed from a different hardfacing material having a reduced wear resistance as compared with the hardfaced layer 106.

FIGS. 6B and 6C illustrate different portions of the hardfaced milled tooth 100. FIG. 6B illustrates the flank surface 112, and FIG. 6C illustrates the flank surface 114 of the milled tooth 104 and the hardfaced layer 116 disposed thereon. The hardfaced layer 116 is not formed from the premium hardfacing material and comprises the features illustrated above in FIG. 4 such as the sintered carbide pellets 118 that are not encapsulated to include a thermal barrier and that are shown to include a heat affected zone 120 that appears as a darkened zone surrounding an outside region of the pellets 118 where the sintered full dense WC-Co structure is getting loose, Co diffuses out into the metallic binder alloy and Fe from the alloy diffuses in, ultimately resulting in the hardfaced layer having a reduced degree of wear resistance as compared to the hardfaced layer formed from the premium hardfacing material.

While hardfacing material compositions as disclosed herein have been described and illustrated as being used with a particular example device and tool, it is to be understood that hardfacing materials as disclosed here may be used in conjunction with any type of tool or equipment where improved properties of wear resistance, hardness and toughness are desired over that of the underlying substrate material is desired. Examples of such other types of tools

and equipment include and are no limited to blades or cutting faces of mills (e.g., lead mills, window mills, taper mills, dress mills, follow mills, watermelon mills, junk mills, section mills, and the like), hole openers, underreamers, and stabilizers. Hardfacing material composition as disclosed herein may also be applied to slips or gripping elements of tools such as anchors or downhole tractors. Hardfacing material constructions as disclosed herein may also be applied to tools used to re-grind downhole debris or internally on impact surfaces within various tools (e.g., jars, vibration tools, hammer bits, and the like). Hardfacing material compositions may be applied as hardbanding on tool joints or upsets of drill pipe, drill collars, transition or heavy weight drill pipe, stabilizers, underreamers, hole openers, milling tools, fishing tools, jars and impact tools, vibration tools, bypass valves, measurement-while-drilling tools, logging-while-drilling tools, circulation valves, release tools, among others. These are but a few examples of the types of tools and equipment that hardfacing material constructions may be used with and it is understood that all such uses are intended to be within the scope of this disclosure.

Although only a few example embodiments of hardfacing material compositions and devices comprising the same 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 concepts as disclosed herein. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims. 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 35 U.S.C. § 112, paragraph 6 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 hardfacing composition comprising:
a plurality of hard material phases dispersed in a continuous metallic alloy binder phase,
5 wherein the hard material phase comprises sintered WC-Co pellets, and wherein the continuous
metallic alloy binder phase comprises an iron-or nickel-based metal alloy; and
a thermally stable material layer encapsulating the pellets and interposed between and in
contact with both the pellets and the continuous metallic alloy binder phase, wherein the
thermally stable material layer is formed from a material selected from the group consisting of
10 refractory metals, carbides of refractory metals, and combinations thereof.
2. The hardfacing composition as recited in claim 1 wherein the refractory metals are
selected from the group consisting of Ti, V, Cr, Zr, Nb, Mo, Ru, Rh, Hf, Ta, W, Re, Os
and Ir.
15
3. The hardfacing composition as recited in claim 2 wherein the carbides of refractory
metals include those selected the group consisting of Ti, V, Cr, Zr, Nb, Mo, Ru, Rh, Hf,
Ta, W, Re, Os and Ir.
- 20 4. The hardfacing composition as recited in claim 2 wherein the thermally stable material
layer comprises W.
5. The hardfacing composition as recited in claim 1 wherein the material used to form the
thermally stable material layer has a melting temperature of greater than about 1,650°C.
25
6. The hardfacing composition as recited in claim 1 wherein the material used to form the
thermally stable material layer has a melting temperature of greater than about 1,700°C.
7. The hardfacing composition as recited in claim 1 wherein the hard material phase
30 comprise other carbide materials in addition to the sintered WC-Co pellets.
8. The hardfacing composition as recited in claim 7 wherein the other carbide materials are
encapsulated with the thermally stable material layer

9. The hardfacing composition as recited in claim 7 wherein the hard material phase comprises from 55 to 90 percent by weight pellets and from about 10 to 45 percent by weight of the other carbide materials based on the total weight of the pellets and the carbide materials.

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10. The hardfacing composition as recited in claim 1 wherein the other carbide materials are spherical cast carbide.

10

11. The hardfacing composition as recited in claim 1 wherein the thermally stable material layer has a thickness that is between about 2 to 4 percent of the pellet diameter.

12. The hardfacing composition as recited in claim 1 wherein the thermally stable material layer has a thickness of from 2 to 80 micrometers.

15

13. The hardfacing composition as recited in claim 1 wherein the hardfacing composition comprise about 55 to 80 weight percent hard material phases and 20 to 45 weight percent metallic binder alloy phase based on the total weight of the hardfacing composition.

20

14. A bit for drilling earthen formations comprising:

a body and a number of cones rotatably disposed on the body, the cones comprising a number of teeth projecting therefrom, wherein at least one of the both, cones, and teeth comprise a hardfacing composition disposed thereon, the hardfacing composition comprising:

- 25 a plurality of hard material phases dispersed in a continuous metallic binder alloy phase, wherein the hard material phases comprise sintered WC-Co pellets and other carbide material particles, wherein the metallic binder alloy material comprises an iron- or nickel-based metal; and

- 30 a thermally stable material layer encapsulating the WC-Co pellets and interposed between the pellets and in contact with both the hard-phase particles and the continuous metallic binder alloy phase, wherein the thermally stable material layer consists of material having a melting temperature greater than a melting temperature of the metallic binder alloy material.

15. The bit as recited in claim 14 wherein the thermally stable material layer has a thickness that is about 2 to 4 percent of a diameter of the sintered WC-Co pellets.

16. The bit as recited in claim 14 wherein the thermally stable material layer has a melting temperature of greater than about 1,650°C.
- 5 17. The bit as recited in claim 14 wherein the thermally stable material layer is formed from materials selected from the group consisting of refractory metals, carbides of refractory metals and combinations thereof.
- 10 18. The bit as recited in claim 14 wherein the thermally stable material is formed from a refractory metal or refractory metal carbide selected from the group consisting of Ti, V, Cr, Zr, Nb, Mo, Ru, Rh, Hf, Ta, W, Re, Os and Ir.
19. The bit as recited in claim 14 wherein the thermally stable material comprises W.
- 15 20. The bit as recited in claim 14 wherein the hardfacing material comprises about 55 to 90 percent by weight pellets and from about 10 to 45 percent by weight of another carbide material based on the total weight of the pellets and the other carbide materials.
- 20 21. The bit as recited in claim 20 wherein the other carbide materials comprise spherical cast carbide.
22. The bit as recited in claim 13 wherein the hardfacing composition comprise about 55 to 80 weight percent hard material phases and 20 to 45 weight percent metallic binder alloy phase based on the total weight of the hardfacing composition.
- 25 23. A method for making a hardfacing composition comprising:
encapsulating a plurality of hard particles in the form of sintered carbide pellets with a material that is thermally stable material at elevated temperatures used to apply the hardfacing material onto a metallic substrate; and
30 combining the encapsulated pellets with a metallic binder alloy and subjecting the same to elevated temperatures of greater than about 1,650°C to form a hardfacing composition on the substrate, wherein the plurality of encapsulated pellets are dispersed within a continuous phase of the metallic binder alloy material such that the thermally stable material contacts both the

pellets and the metallic binder alloy, wherein during the combining, the pellets do not melt and are protected by the thermally stable material from interdiffusion.

24. The method as recited in claim 23 wherein during the encapsulating, the thermally stable material is applied to have a thickness that is 2 to 4 percent of a diameter of the hard particle.

25. The method as recited in claim 23 wherein during the encapsulating, the thermally stable material is selected from the group refractory metals and carbides formed therefrom consisting of Ti, V, Cr, Zr, Nb, Mo, Ru, Rh, Hf, Ta, W, Re, Os and Ir.

26. The method as recited in claim 23 wherein the pellets are formed from sintered WC-Co, wherein the hardfacing further comprises other carbide materials including cast carbide, and wherein the pellets comprise a majority weight percent of the hard materials based on the total weight of the pellets and the other carbide materials.

27. The method as recited in claim 26 wherein the metallic binder alloy comprises steel.

28. The method as recited in claim 23 wherein the other carbide materials are not encapsulated by the thermally stable material.

29. The method as recited in claim 23 wherein during the encapsulating, the thermally stable material is W and is applied to the pellets by chemical vapor deposition, and wherein the thermally stable material has a layer thickness of from about 2 to 80 micrometers.

30. The method as recited in claim 23 wherein during the combining, the temperature is greater than about 1,700°C.

31. The method as recited in claim 23 wherein after the combining, hardfacing composition comprise about 55 to 80 weight percent hard material phases and 20 to 45 weight percent metallic binder alloy phase based on the total weight of the hardfacing composition.

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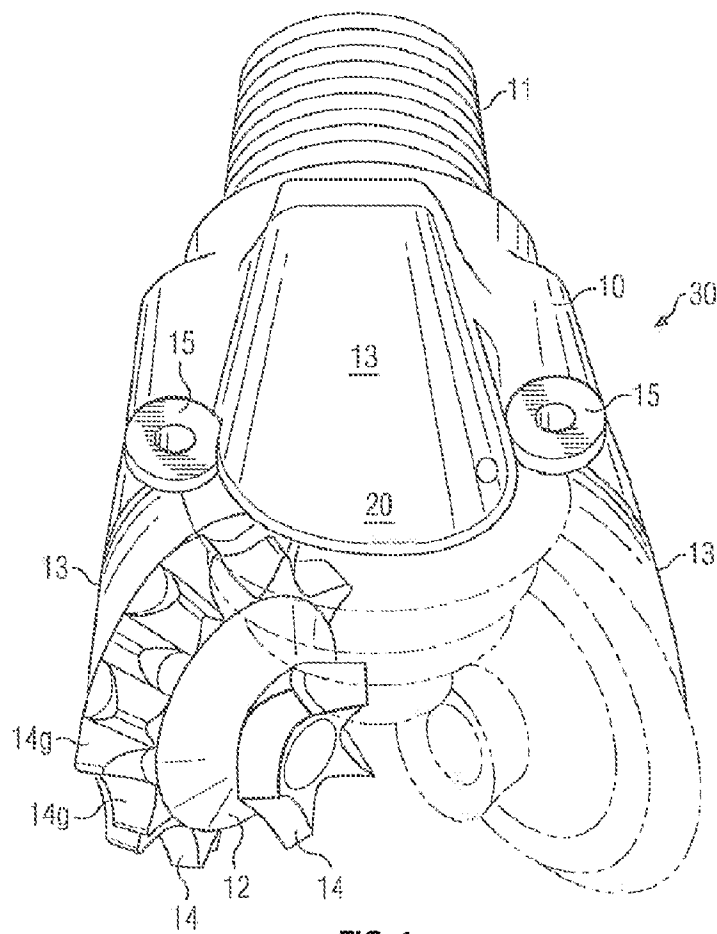


FIG. 1

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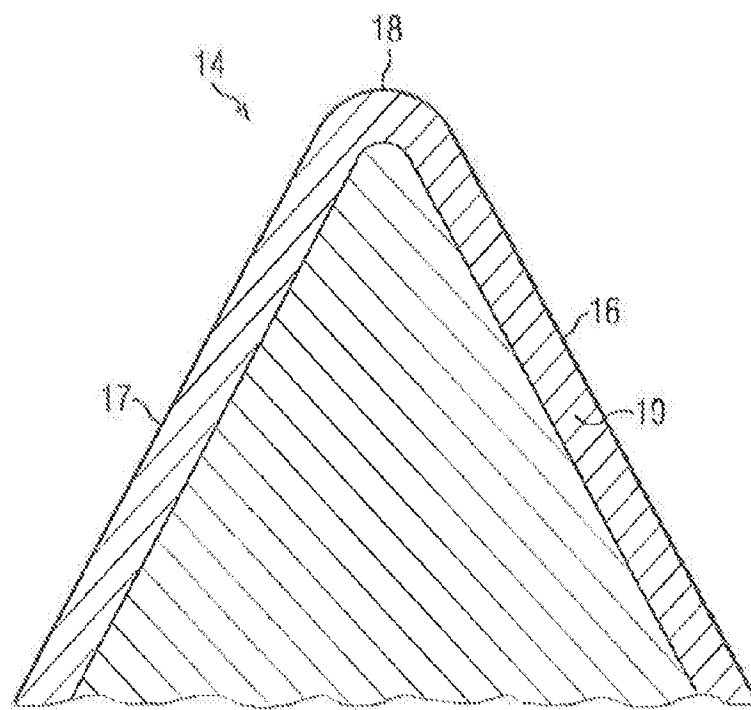


FIG. 2

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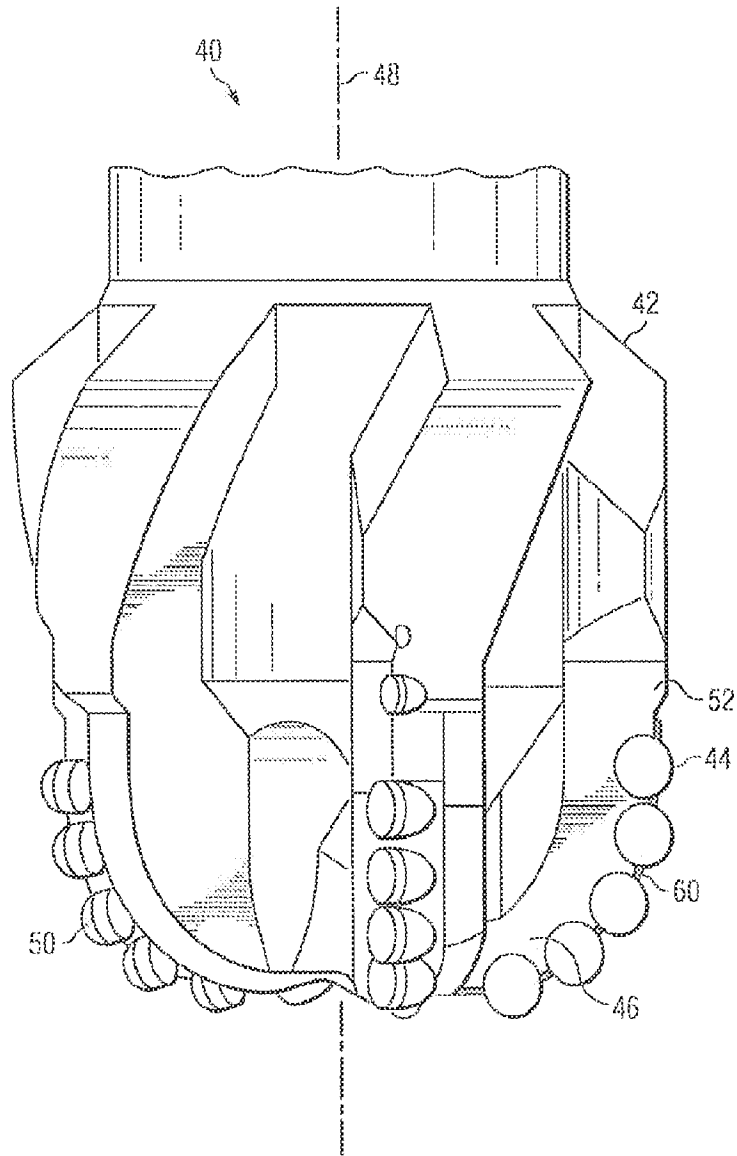
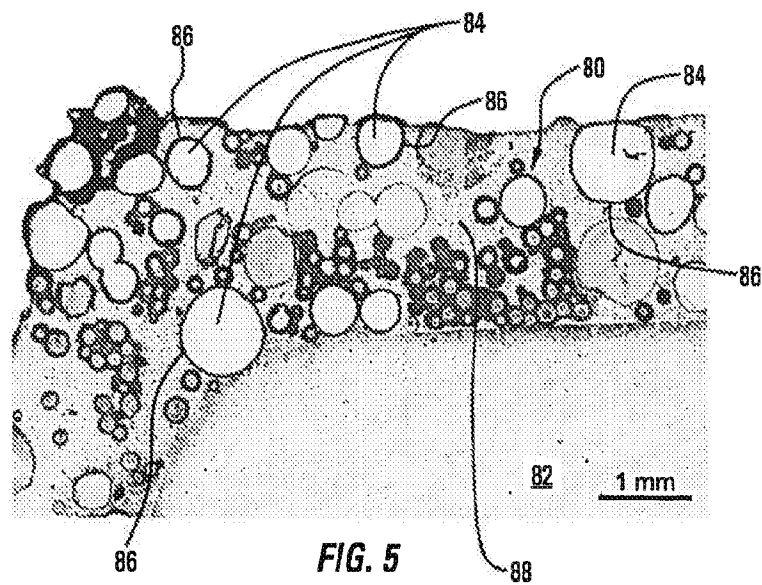
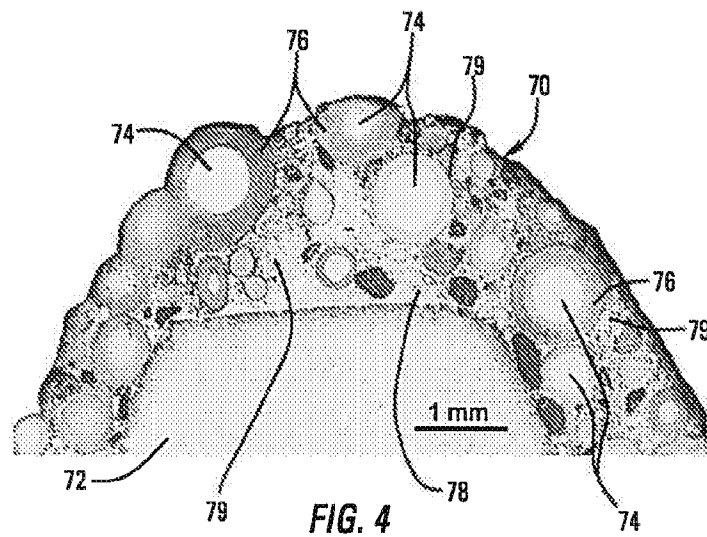


FIG. 3

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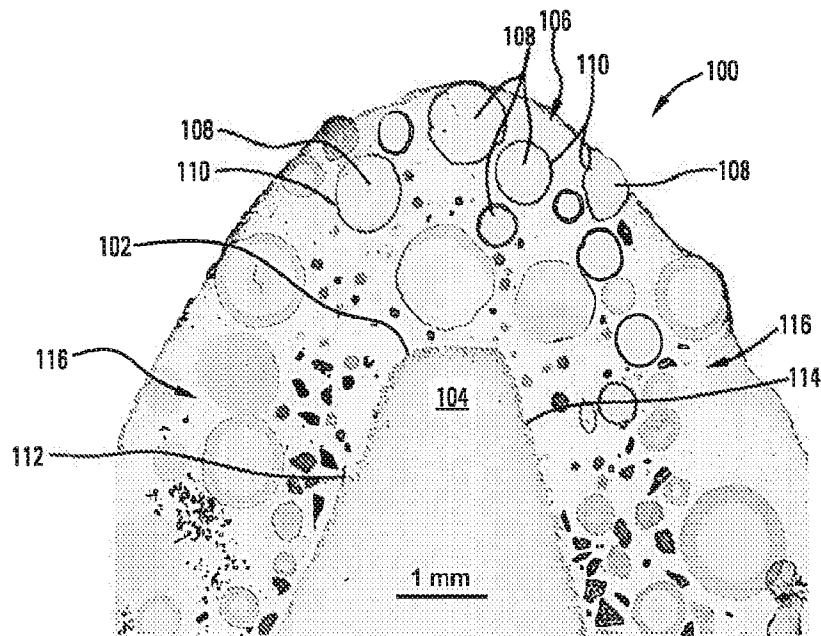


FIG. 6A

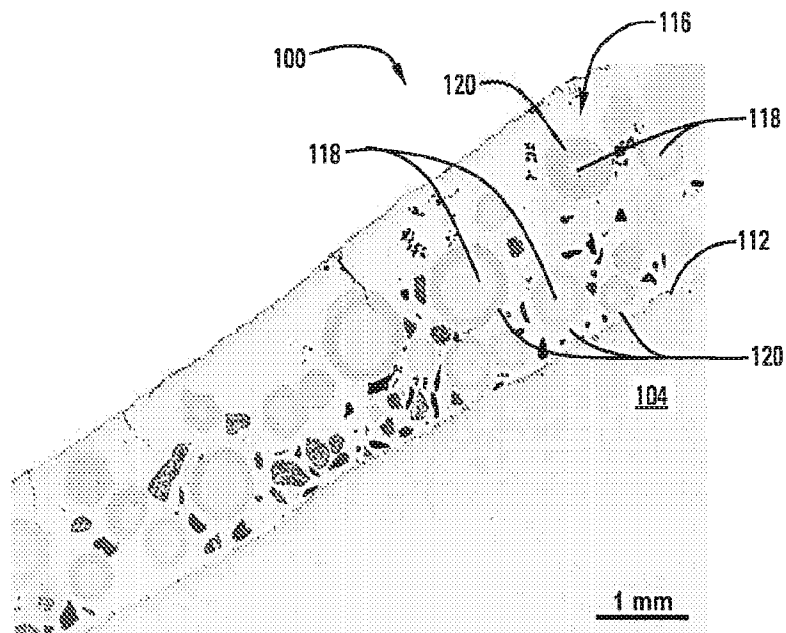


FIG. 6B

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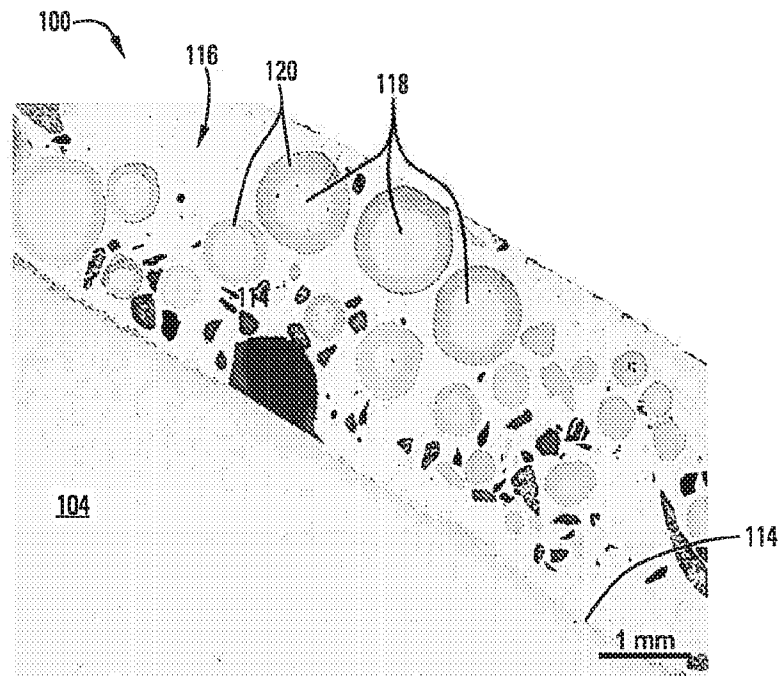


FIG. 6C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/066053**A. CLASSIFICATION OF SUBJECT MATTER****E21B 10/50(2006.01)i, E21B 10/54(2006.01)i, E21B 10/08(2006.01)i, E21B 10/42(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
E21B 10/50; E21B 10/36; E21B 10/46; B24B 1/00; E21B 10/54; E21B 10/08; E21B 10/42Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: bit, hard material, binder, thermally stable material, refractory metal, pellet, encapsulate**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010-0122853 A1 (SCOTT et al.) 20 May 2010 See paragraphs [0017], [0020]-[0021], [0025], [0028]-[0029], claims 1, 23, and figures 1-2.	23-25, 29-31
Y		1-22, 26-28
Y	US 2008-0017421 A1 (LOCKWOOD, GREGORY T.) 24 January 2008 See paragraphs [0049], [0051], [0053], [0080], claims 1-2, and figure 3.	1-22, 26-28
A	US 8220567 B2 (SCOTT et al.) 17 July 2012 See column 5, lines 36-39, column 6, lines 10-12 and figure 5.	1-31
A	US 2008-0282618 A1 (LOCKWOOD, GREGORY T.) 20 November 2008 See abstract, claim 1, and figure 3.	1-31
A	US 6170583 B1 (BOYCE, JAMES EDWARD) 09 January 2001 See abstract, claim 1, and figure 4.	1-31



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 March 2017 (24.03.2017)

Date of mailing of the international search report

24 March 2017 (24.03.2017)

Name and mailing address of the ISA/KR

International Application Division

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/066053

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