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(54) Title: METHOD OF SELECTIVELY ADAPTING MATERIAL PROPERTIES ACROSS A ROCK BIT CONE

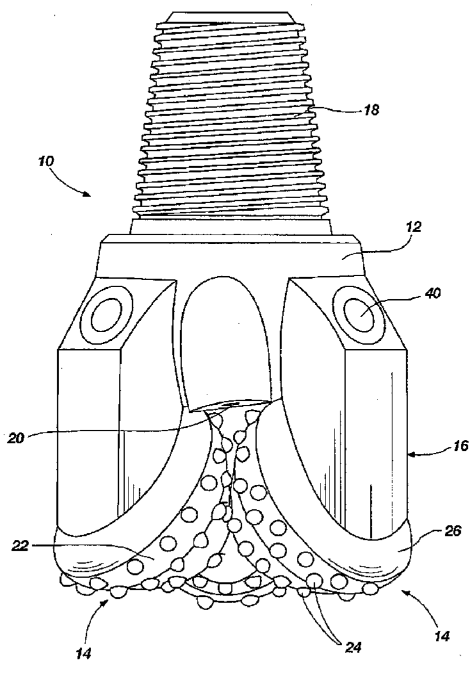

FIG. 1

(57) Abstract: Methods of forming cutter assemblies for use on earth-boring tools include sintering a cone structure to fuse one or more cutting elements thereto and having a hardened land area. In some embodiments, one or more green, brown, or fully sintered cutting elements may be positioned on a green or brown cone structure prior to sintering the cone structure to a final density. Cutter assemblies may be formed by such methods, and such cutter assemblies may be used in earth-boring tools such as, for example, earth-boring rotary drill bits and hole openers.

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TITLE OF THE INVENTION

METHOD OF SELECTIVELY ADAPTING MATERIAL PROPERTIES ACROSS A ROCK BIT CONE

PRIORITY CLAIM

This application claims the benefit of United States Application Serial No. 12/136,959, titled "METHOD OF SELECTIVELY ADAPTING MATERIAL PROPERTIES ACROSS A ROCK BIT CONE ", filed June 11, 2008, pending.

TECHNICAL FIELD

The present invention generally relates to earth-boring tools having one or more rotatable cones. More particularly, embodiments of the present invention relate to methods of forming cutter assemblies having a cone comprising a particle-matrix composite material for use in such earth-boring tools having variable properties across the cone, to cutter assemblies formed by such methods, and to earth-boring tools that include such cutter assemblies.

BACKGROUND

Earth-boring tools, including rotary drill bits, are commonly used for drilling boreholes or wells in earth formations. One type of rotary drill bit is the roller cone bit (often referred to as a "rock" bit), which typically includes a plurality of conical cutting elements (often referred to as "cones" or "cutters") secured to legs dependent from the bit body. For example, the bit body of a roller cone bit may have three depending legs each having a bearing pin. A rotatable cone may be mounted on each of the bearing pins. The bit body also may include a threaded upper end for connecting the drill bit to a drill string.

In some roller cone bits, the rotatable cones may include inserts or compacts that are formed from a particle-matrix composite material and secured within mating holes formed in an exterior surface of the cone body. The inserts protrude from the exterior surface of the cone body, such that the inserts engage and disintegrate an earth formation as the rotatable cone rolls across the surface of the earth formation in a well bore during a drilling operation. Such inserts may be formed by compacting a powder mixture in a die.

The powder mixture may include a plurality of hard particles (e.g., tungsten carbide) and a plurality of particles comprising a matrix material (e.g., a metal or metal alloy material). The compacted powder mixture then may be sintered to form an insert. In some roller cone bits, the body of the rotatable cones (or at least the outer shells of the rotatable cones) may be formed of steel. The particle-matrix composite material from which the inserts are formed may be relatively more resistant to abrasive wear than the body (or at least the outer shell) of the rotatable cones. During drilling operations, it is possible that a body of a rotatable cone may wear to the extent that one or more inserts may fall out from the hole in which it was secured due to excessive wear of the region of the cone body surrounding the hole.

In additional roller cone bits, the rotatable cones may include teeth that are milled or machined directly into an exterior surface of the cone body. After machining the teeth, hardfacing material may be applied to the teeth, gage, and other formation-engaging surfaces of the cone body in an effort to reduce wear of such formation-engaging surfaces. The hardfacing material typically includes a particle-matrix composite material. For example, the hardfacing material may include tungsten carbide granules or pellets embedded within a metal or metal alloy.

Various techniques known in the art may be used to apply a particle-matrix composite hardfacing material to a surface of a work piece, such as an earth-boring tool. For example, a hollow cylindrical tube may be formed from a matrix material, and the tube may be filled with hard particles (e.g., tungsten carbide). At least one end of the tube may be sealed and positioned near the surface of the work piece. The sealed end of the tube then may be melted using an arc or a torch. As the tube melts, the tungsten carbide particles within the hollow, cylindrical tube mix with the molten matrix material as it is deposited onto the work piece. In additional methods, a substantially solid rod comprising the particle-matrix composite hardfacing material may be used in place of a hollow tube comprising matrix material that is filled with hard particles.

Additional arc welding techniques also may be used to apply a hard-facing material to the exterior surface of the work piece. For example, a plasma-transferred arc may be established between an electrode and a region on the exterior surface of the work piece on which it is desired to apply a hard-facing material. A powder mixture including both hard particles and particles comprising matrix material then may be directed through or proximate the plasma-transferred arc onto the region of the exterior surface of the work piece. The heat generated by the arc melts at least the particles of matrix material to form a weld pool on the surface of the work piece, which subsequently solidifies to form the particle-matrix composite hardfacing material.

Hardfacing applications may be relatively labor intensive, and hardfacing thickness and uniformity of coverage may be difficult to control in a repeatable manner. Furthermore, application of hardfacing material to the teeth of a rotatable cone may reduce the sharpness of the cutting edges of the teeth. Some grinding of the hardfacing to desired shapes may be performed. U.S. Patent No. 6,766,870, discloses a method of shaping hardfaced teeth through a secondary machining operation. However, sharpening the hardfaced teeth by grinding adds another step and substantial labor and machining cost in a process for manufacturing a roller cone bit.

DISCLOSURE OF INVENTION

In some embodiments, the present invention includes methods of forming cutter assemblies for use on earth-boring tools. The methods include sintering a less than fully sintered cone structure to a desired final density to fuse at least one cutting element, also termed “inserts” herein, to the cone structure, and hard particles selectively located between rows of inserts in a matrix material.

In additional embodiments, the present invention includes cutter assemblies for use on an earth-boring tool having one or more cutting elements co-sintered and integral with a cone structure and hard particles selectively located between rows of cutting elements in a matrix material. The cone structure and the cutting elements each may comprise a particle-matrix composite material. The material composition of the cone structure may differ from the material composition of at least one of the cutting elements.

In yet further embodiments, the present invention includes earth-boring tools having at least one such cutter assembly rotatably mounted on a bearing pin.

BRIEF DESCRIPTION OF DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming that which is regarded as the present invention, the advantages of this invention may be more readily ascertained from the following description of the invention when read in conjunction with the accompanying drawings in which:

FIG. 1 is a side elevational view of an earth-boring drill bit according to an embodiment of the present invention;

FIG. 2 is a partial sectional view of one embodiment of a rotatable cutter assembly, including a cone, of the present invention and that may be used with the earth-boring drill bit shown in FIG. 1;

FIG. 3 is a schematic view illustrating one method that may be used to form a cone of a rotatable cutter assembly according to an embodiment of the present invention;

FIG. 4 is a schematic view illustrating another method that may be used to form a cone of a rotatable cutter assembly according to another embodiment of the present invention;

FIGS. 5A-5C illustrate one embodiment of a method that may be used to form a rotatable cutter assembly of the present invention, such as the rotatable cutter assembly shown in FIG. 2;

FIGS. 6A-6C illustrate another embodiment of a method that may be used to form a rotatable cutter assembly that embodies teachings of the present invention, such as the rotatable cutter assembly shown in FIG. 2;

FIG. 7 is a side elevational view of another embodiment of an earth-boring drill bit of the present invention;

FIG. 8 is a partial sectional view illustrating another embodiment of a rotatable cutter assembly, including a cone, of the present invention and that may be used with an earth-boring drill bit, such as the earth-boring drill bit shown in FIG. 7;

FIG. 8A is a partial sectional view of a portion of a cone illustrating lands between rows of teeth of a rotatable cutter assembly;

FIG. 8B is a perspective view of a portion of a cone illustrating the lands between the rows of teeth of the rotatable cutter assembly;

FIG. 8C is a perspective view of a portion of a cone illustrating the lands between the rows of teeth of the rotatable cutter assembly;

FIG. 9 is a partial cross-sectional view of one embodiment of a tooth structure that may be used to provide a rotatable cutter assembly of the present invention, such as the rotatable cutter assembly shown in FIG. 8; and

FIG. 10 is a partial cross-sectional view of another embodiment of a tooth structure that may be used to provide a rotatable cutter assembly of the present invention, such as the rotatable cutter assembly shown in FIG. 8.

BEST MODES FOR CARRYING OUT THE INVENTION

The illustrations presented herein are not meant to be actual views of any particular material, apparatus, system, or method, but are merely idealized representations which are employed to describe the present invention. Additionally, elements common between figures may retain the same numerical designation.

The term "green" as used herein means unsintered.

The term "green structure" as used herein means an unsintered structure comprising a plurality of discrete particles held together by a binder material.

The term "brown" as used herein means partially sintered.

The term "brown structure" as used herein means a partially sintered structure comprising a plurality of particles, at least some of which have partially grown together to provide at least partial bonding between adjacent particles. Brown structures may be formed by partially sintering a green structure.

The term "sintering" as used herein means densification of a particulate component involving removal of at least a portion of the pores between the starting particles (accompanied by shrinkage) combined with coalescence and bonding between adjacent particles.

As used herein, the term "[metal]-based alloy" (where [metal] is any metal) means commercially pure [metal] in addition to metal alloys wherein the weight percentage of [metal] in the alloy is greater than the weight percentage of any other component of the alloy.

As used herein, the term "material composition" means the chemical composition and microstructure of a material. In other words, materials having the same chemical composition but a different microstructure are considered to have different material compositions.

As used herein, the term "tungsten carbide" means any material composition that contains chemical compounds of tungsten and carbon, such as, for example, WC, W_2C, and combinations of WC and W_2C. Tungsten carbide includes, for example, cast tungsten carbide, sintered tungsten carbide, and macrocrystalline tungsten carbide.

The depth of well bores being drilled continues to increase as the number of shallow depth hydrocarbon-bearing earth formations continue to decrease. These increasing well bore depths are pressing conventional drill bits to their limits in terms of performance and durability. Several drill bits are often required to drill a single well bore, and changing a drill bit on a drill string can be expensive.

New particle-matrix composite materials are currently being investigated in an effort to improve the performance and durability of earth-boring rotary drill bits. By way of example and not limitation, bit bodies for fixed-cutter type earth-boring rotary drill bits that include such particle-matrix composite materials, and methods for forming such bit bodies, are disclosed in pending United States Patent Application Serial No. 11/271,153, filed November 10, 2005 and pending United States Patent Application Serial No. 11/272,439, also filed November 10, 2005. In addition, earth-boring rotary drill bits having rotatable cutter assemblies that comprise a cone formed from such particle-matrix composite materials, as well as methods for forming such cones, are disclosed in pending United States Patent Application Serial No. 11/487,890, filed July 17, 2006.

An earth-boring drill bit 10 according to an embodiment of the present invention is shown in FIG. 1. The earth-boring drill bit 10 includes a bit body 12 and a plurality of rotatable cutter assemblies 14. The bit body 12 may include a plurality of integrally formed bit legs 16, and threads 18 may be formed on the upper end of the bit body 12 for connection to a drill string (not shown). The bit body 12 may have nozzles 20 for discharging drilling fluid into a borehole, which may be returned along with cuttings up to the surface during a drilling operation. Each of the rotatable cutter assemblies 14 include a cone 22 comprising a particle-matrix composite material and a plurality of cutting elements, such as the cutting inserts 24 shown. Each cone 22 may include a conical gage surface 26. Additionally, each cone 22 may have a unique configuration of cutting inserts 24 or cutting elements, such that the cones 22 may rotate in close proximity to one another without mechanical interference.

FIG. 2 is a cross-sectional view illustrating one of the rotatable cutter assemblies 14 of the earth-boring drill bit 10 shown in FIG. 1. As shown, each bit leg 16 may include a bearing pin 28. The cone 22 may be supported by the bearing pin 28, and the cone 22 may be rotatable about the bearing pin 28. Each cone 22 may have a central cavity 30 that may be cylindrical and may form a journal bearing surface adjacent the bearing pin 28. The cavity 30 may have a flat thrust shoulder 32 for absorbing thrust imposed by the drill string on the cone 22. As illustrated in this example, the cone 22 may be retained on the bearing pin 28 by a plurality of locking balls 34 located in mating grooves formed in the surfaces of the cone cavity 30 and the bearing pin 28. Additionally, a seal assembly 36 may seal bearing spaces between the cone cavity30 and the bearing pin 28. The seal assembly 36 may be a metal face seal assembly, as shown, or may be a different type of seal assembly, such as an elastomer seal assembly.

Lubricant may be supplied to the bearing spaces between the cavity 30 and the bearing pin 28 by lubricant passages 38. The lubricant passages 38 may lead to a reservoir that includes a pressure compensator 40 (FIG. 1).

As previously mentioned, the cone 22 may comprise a sintered particle-matrix composite material that comprises a plurality of hard particles dispersed through a matrix material. In some embodiments, the cone 22 may be predominantly comprised of the particle-matrix composite material. The hard particles may comprise diamond or ceramic materials such as carbides, nitrides, oxides, and borides (including boron carbide (B_4C)). More specifically, the hard particles may comprise carbides and borides made from elements such as W, Ti, Mo, Nb, V, Hf, Ta, Cr, Zr, Al and Si. By way of example and not limitation, materials that may be used to form hard particles include tungsten carbide (WC, W_2C), titanium carbide (TiC), tantalum carbide (TaC), titanium diboride (TiB_2), chromium carbides, titanium nitride (TiN), vanadium carbide (VC), aluminum oxide (Al_2O_3), aluminum nitride (AlN), boron nitride (BN), and silicon carbide (SiC). Furthermore, combinations of different hard particles may be used to tailor the physical properties and characteristics of the particle-matrix composite material. The hard particles may be formed using techniques known to those of ordinary skill in the art. Most suitable materials for hard particles are commercially available and the formation of the remainder is within the ability of one of ordinary skill in the art.

The matrix material may include, for example, cobalt-based, iron-based, nickel-based, iron and nickel-based, cobalt and nickel-based, iron and cobalt-based, aluminum-based, copper-based, magnesium-based, and titanium-based alloys. The matrix material may also be selected from commercially pure elements such as cobalt, aluminum, copper, magnesium, titanium, iron, and nickel. By way of example and not limitation, the matrix material may include carbon steel, alloy steel, stainless steel, tool steel, nickel or cobalt superalloy material, and low thermal expansion iron or nickel-based alloys, such as INVAR®. As used herein, the term "superalloy" refers to iron, nickel, and cobalt based-alloys having at least 12% chromium by weight. Additional exemplary alloys that may be used as matrix material include austenitic steels, nickel-based superalloys such as INCONEL® 625M or Rene 95, and INVAR® type alloys having a coefficient of thermal expansion that more closely matches that of the hard particles used in the particular material. More closely matching the coefficient of thermal expansion of matrix material with that of the hard particles offers advantages such as reducing problems associated with residual stresses and thermal fatigue. Another exemplary matrix material is a Hadfield austenitic manganese steel (Fe with approximately 12% Mn by weight and 1.1% C by weight).

In one embodiment of the present invention, the sintered particle-matrix composite material may include a plurality of -400 ASTM (American Society for Testing and Materials) mesh tungsten carbide particles. For example, the tungsten carbide particles may be substantially composed of WC. As used herein, the phrase "-400 ASTM mesh particles" means particles that pass through an ASTM No. 400 mesh screen, as defined in ASTM specification E11-04 entitled Standard Specification for Wire Cloth and Sieves for Testing Purposes. Such tungsten carbide particles may have a diameter of less than about 38 microns. The matrix material may include a metal alloy comprising about 50% cobalt by weight and about 50% nickel by weight. The tungsten carbide particles may comprise between about 60% and about 95% by weight of the composite material, and the matrix material may comprise between about 5% and about 40% by weight of the composite material. More particularly, the tungsten carbide particles may comprise between about 70% and about 80% by weight of the composite material, and the matrix material may comprise between about 20% and about 30% by weight of the composite material.

In another embodiment of the present invention, the sintered particle-matrix composite material may include a plurality of –635 ASTM mesh tungsten carbide particles. As used herein, the phrase "-635 ASTM mesh particles" means particles that pass through an ASTM No. 635 mesh screen as defined in ASTM specification E11-04 entitled Standard Specification for Wire Cloth and Sieves for Testing Purposes. Such tungsten carbide particles may have a diameter of less than about 20 microns. The matrix material may include a cobalt-based metal alloy comprising substantially commercially pure cobalt. For example, the matrix material may include greater than about 98% cobalt by weight. The tungsten carbide particles may comprise between about 60% and about 95% by weight of the composite material, and the matrix material may comprise between about 5% and about 40% by weight of the composite material. After forming, the cone 22 may exhibit a hardness in a range extending from about 75 to about 92 on the Rockwell A hardness scale.

FIGS. 3, 4, and 5A-5C illustrate embodiments of a method that may be used to form the cone 22 and the cutter assembly 14 shown in FIG. 2. In general, this method includes providing a powder mixture, pressing the powder mixture to form a billet, forming a green or brown cone structure from the billet, and sintering the green or brown cone structure to a desired final density.

FIG. 3 illustrates a method of pressing a powder mixture 42 to form a green billet that may be used to form the cone 22. As illustrated in FIG. 3, the powder mixture 42 may be pressed with substantially isostatic pressure within a mold or container 44. The powder mixture 42 may include a plurality of the previously described hard particles and a plurality of particles comprising a matrix material, as also previously described herein. Optionally, the powder mixture 42 may further include one or more additives such as, for example, binders (e.g., organic materials such as, for example, waxes) for providing structural strength to the pressed powder component, plasticizers for making the binder more pliable, and lubricants or compaction aids for reducing inter-particle friction and otherwise providing lubrication during pressing.

The container 44 may include a fluid-tight deformable member 46. For example, the deformable member 46 may be a substantially cylindrical bag comprising a deformable and impermeable polymeric material, which may be an elastomer such as rubber, neoprene, silicone, or polyurethane. The container 44 may further include a sealing plate 48, which may be substantially rigid. The deformable member 46 may be filled with a powder mixture 42 and optionally vibrated to provide a uniform distribution of the powder mixture 42 within the deformable member 46. The sealing plate 48 may be attached or bonded to the deformable member 46, which may provide a fluid-tight seal therebetween.

The container 44, with the powder mixture 42 therein, may be placed within a pressure chamber 50. A removable cover 52 may be used to provide access to the interior of the pressure chamber 50. A gas (such as, for example, air or nitrogen) or a fluid (such as, for example, water or oil), which may be substantially incompressible, is pumped into the pressure chamber 50 through a port 54 at high pressures using a pump (not shown). The high pressure of the fluid may cause the member 46 to deform, and the fluid pressure may be transmitted substantially uniformly to the powder mixture 42. The pressure within the pressure chamber 50 during isostatic pressing may be greater than about 35 megapascals (about 351.6 KG/CM^2). More particularly, the pressure within the pressure chamber 50 during isostatic pressing may be greater than about 138 megapascals (1406.5 KG/CM^2).

In additional methods, a vacuum may be provided within the container 44 and a pressure greater than about 0.1 megapascals (about 1.05 KG/CM^2) may be applied to the deformable member 46 of the container 44 (by, for example, the atmosphere) and may compact the powder mixture 42. Isostatic pressing of the powder mixture 42 may form a green billet, which may be removed from the pressure chamber 50 and the container 44 after pressing for machining. In some embodiments, the resulting billet may have a generally cylindrical configuration.

FIG. 4 illustrates an additional method of pressing a powder mixture 56 to form a green billet that may be used to form the cone 22 shown in FIG. 2. The method illustrated in FIG. 4 comprises forming a billet using a rigid die 58 having a cavity for receiving the powder mixture 56. The powder mixture 56 may be the same as the powder mixture 42 used in the method illustrated in FIG. 3. The cavity of the rigid die 58 may be generally conically-shaped, and may form an overall conical billet. Alternatively, the cavity may be cylindrical, and may form a cylindrical billet. A piston or ram 60 may sealingly engage the walls of the rigid die 58. A force may act on the piston 60 and may press the powder mixture 56 into a green billet with a coherent shape suitable for machining.

The green billet, whether formed by the method illustrated in FIG. 3 or FIG. 4, may be machined in the green state to form a green cone structure 22A shown in FIG. 5A. In additional methods, however, the green billet may be partially sintered to form a brown billet, and the brown billet then may be machined to form a brown cone structure (not shown). The brown billet may be less than fully dense to facilitate machining thereof. Green or brown structures, such as the green cone structure 22A, a brown cone structure, or a green or brown billet, may be machined in substantially the same manner as for steel cones known in the art. However, because shrinkage may occur during subsequent sintering processes, the dimensions of the green or brown structures may be over-sized to accommodate for shrinkage.

FIG. 5A illustrates a green cone structure 22A that may be used to form the cutter assembly 14 (FIGS. 1-2). As illustrated in FIG. 5A, in some embodiments, the green cone structure 22A may have an overall shape corresponding to the desired final shape of the cone 22, and may include various features such as a central cavity 30 for providing a journal bearing surface adjacent a bearing pin 28 (FIG. 2) and apertures 62 for receiving cutting inserts 24 therein (FIG. 2).

Optionally, displacement members 64 may be inserted into the apertures 62 for preserving a desired size, shape and orientation of each of the apertures 62 during a subsequent sintering process. The displacement members 64 may comprise dowels that are dimensioned to the desired final dimensions of the aperture 62 in the cone 22 to be formed for each cutting insert 24. The displacement members 64 may be formed of a material, such as a ceramic, that will remain solid and stable at the sintering temperature. Additionally, the displacement members 64 may be formed of a porous and/or hollow material to facilitate their removal from the resulting fully sintered cone 22 after the sintering process. The apertures 62 may be larger in diameter than the displacement members 64 before sintering, and may shrink during sintering to the diameters of the displacement members 64.

In some embodiments, the green cone structure 22A shown in FIG. 5A may be heated and sintered in a furnace (not shown) to a desired final density to form a fully sintered cone 22 shown in FIG. 5B. The fully sintered cone 22 is shown in FIG. 5B after the displacement members 64 (FIG. 5A) have been removed from the fully sintered cone 22.

In some embodiments, the furnace may comprise a vacuum furnace for providing a vacuum therein during the sintering process. In additional embodiments, the furnace may comprise a pressure chamber for pressurizing the cone therein as it is sintered. Furthermore, the furnace may be configured to provide a controlled atmosphere. For example, the furnace may be configured to provide an atmosphere that is substantially free of oxygen in which the cone 22 may be sintered.

As a non-limiting example, it may be desirable to provide a cone 22 comprising a sintered tungsten carbide material. To form such a cone, a green cone structure 22A may be formed that includes a plurality of particles comprising tungsten carbide and a plurality of particles comprising a cobalt-based matrix material, the particles being bound together by an organic binder material. In such methods, the green cone structure 22A may be sintered at a temperature of between about five hundred degrees Celsius (500° C) and about fifteen hundred degrees Celsius (1500° C).. The sintering temperature may differ between particular particle-matrix composite material compositions.

During the sintering process, the green cone structure 22A may undergo shrinkage and densification as it is sintered to a final density to form the cone 22. After sintering, the cone 22 may have the desired exterior configuration, which may include the apertures 62, and the central cavity 30. Limited or no further machining may be necessary for these surfaces. The cavity 30, or other surfaces, may be machined after sintering. For example, the bore surfaces of the cavity 30 may be ground and polished to achieve a desired surface finish.

As shown in FIG. 5C, after the cone 22 has been formed and the optional displacement members 64 removed, cutting inserts 24 may be secured within the apertures 62. The cutting inserts 24 may have a size and shape selected to provide a tight and secure press-fit between the cutting inserts 24 and the apertures 62. In additional embodiments, the cutting inserts 24 may be bonded within the apertures 62 using an adhesive. In yet other embodiments, the cutting inserts 24 may be secured within the apertures 62 using a soldering or brazing technique.

The central cavity 30 may be finished, machined and the cone 22 may be mounted to the bearing pin 28 in a conventional manner (FIG. 2). The cutting inserts 24 may be formed separately from the cone 22 in a manner similar to that in which the cone 22 is formed. Although the cutting inserts 24 may also be formed of a sintered particle-matrix composite material, the composition of the particle-matrix composite material of the cutting inserts 24 may differ from the composition of the particle-matrix composite material of the cone 22.

In additional methods, rather than forming a green or brown billet comprising a sintered particle-matrix composite material and machining the green or brown billet to form a green or brown cone structure, a green billet may be sintered to a desired final density to provide a fully sintered billet. Such a fully sintered billet then may be machined to form the fully sintered cone 22 shown in FIG. 5B using traditional machining methods or ultrasonic machining methods. As such a fully sintered billet may be relatively difficult to machine, and the use of ultrasonic machining methods may facilitate the machining process. .For example, ultrasonic machining methods may include applying a high frequency vibratory motion to the machining tool, which may enhance removal of material from the fully sintered billet.

FIGS. 6A-6C illustrate an additional embodiment of a method that may be used to form a cutter assembly (such as the cutter assembly 14 shown in FIG. 2) of the present invention. As discussed in further detail below, the method generally includes providing a less than fully sintered green or brown cone structure comprising a plurality of apertures, inserting inserts into the apertures in the green or brown cone structures, and sintering the resulting structure to a desired final density to secure the inserts to the cone. In this manner, the inserts may be co-sintered and integral with the cone. In some embodiments, the inserts may comprise less than fully sintered green or brown inserts, and the green or brown inserts may be sintered to a desired final density simultaneously with the cone. In other embodiments, the inserts may be fully sintered when they are inserted into the corresponding apertures of the green or brown cone structure.

Furthermore, the inserts may have a composition gradient that varies from a region or regions proximate the interface between the inserts and the cone and a region or regions proximate the formation engaging surface or surfaces of the inserts. For example, the regions of the inserts proximate the interface between the inserts and the cone may have a material composition configured to facilitate or enhance bonding between the inserts and the cone, while the regions proximate the formation engaging surface or surfaces of the inserts may have a material composition configured to enhance one or more material properties or characteristics such as, for example, hardness, toughness, durability, and wear resistance. As one non-limiting example, the regions of the inserts proximate the interface between the inserts and the cone may have a first matrix material substantially similar to the matrix material of the cone, while the regions proximate the formation engaging surface or surfaces of the inserts may have a second matrix material selected to enhance one or more of the hardness, toughness, durability, and wear resistance of the inserts. In such embodiments, the concentrations of the first matrix material and the second matrix material in the inserts may vary either continuously or in a stepwise manner between the regions proximate the interface and the regions proximate the formation engaging surface.

Referring to FIG. 6A, a green cone structure 22A may be formed or otherwise provided as previously described in relation to FIG. 5A. A plurality of green cutting inserts 24A may be provided. Each of the green cutting inserts 24A may comprise a plurality of hard particles and a plurality of particles comprising a matrix material, and the particles may be held together by an organic binder material. As previously discussed, the composition of the green cutting inserts 24A may differ from the composition of the green cone structure 22A. Furthermore, the green cutting inserts 24A may have a composition gradient that varies from a region or regions proximate the interface between the inserts and the cone and a region or regions proximate the formation engaging surface or surfaces of the inserts, as previously mentioned. The green cone structure 22A further includes green lands 23A which comprise a matrix material of particles held together by an organic binder material having a composition harder than that of the composition of the green cone structure 22A, such as the composition of the green cutting inserts 24A.

In some methods, additional green elements or components other than the green cutting inserts 24A also may be secured to the green cone structure 22A prior to sintering. By way of example and not limitation, one or more green bearing structures 68A that are to define bearing surfaces of the cone 22 may be secured within the central cavity 30 of the green cone structure 22A. Similar to the green cutting inserts 24A, each of the green bearing structures 68A may comprise a plurality of hard particles and a plurality of particles comprising a matrix material, and the composition of the green bearing structures 68A may differ from the composition of the green cone structure 22A.

As illustrated in FIG. 6B, the green cutting inserts 24A may be provided within the apertures 62 of the green cone structure 22A, and the green bearing structures 68A may be secured at a selected location within the central cavity 30 of the green cone structure 22A.

By way of example and not limitation, the green cutting inserts 24A and the apertures 62 within the green cone structure 22A may be sized and shaped so as to provide an average clearance therebetween of between about .0254 mm and about .635 mm. Such clearances also may be provided between the green bearing structures 68A and the green cone structure 22A.

After assembling the various green components to form a structure similar to that shown in FIG. 6B, the structure may be sintered to a desired final density to form the fully sintered structure shown in FIG. 6C. During the sintering process of the cone 22, including the apertures 62 or other features, the cutting inserts 24 or other cutting elements, and the bearing structures 68 may undergo shrinkage and densification. Furthermore, the cutting inserts 24 and the bearing structures 68 may become fused and secured to the cone 22. In other words, after the sintering process, cutting inserts 24 and bearing structures 68 may be co-sintered and integral with the cone 22 to provide a substantially unitary cutter assembly 14′.

After the cutter assembly 14′ has been sintered to a desired final density, various features of the cutter assembly 14′ may be machined and polished, as necessary or desired. For example, bearing surfaces on the bearing structures 68 may be polished. Polishing the bearing surfaces of the bearing structures 68 may provide a relatively smoother surface finish and may reduce friction at the interface between the bearing structures 68 and the bearing pin 28 (FIG. 2). Furthermore, the sealing edge 72 of the bearing structures 68 also may be machined and/or polished to provide a shape and surface finish suitable for sealing against a metal or elastomer seal, or for sealing against a sealing surface located on the bit body 12 (FIG. 2).

The green cutting inserts 24A, the green lands 23A, and the green bearing structures 68A may be formed from particle-matrix composite materials in much the same way as the green cone structure 22A. The material composition of each of the green cutting inserts 24A, green lands 23A, green bearing structures 68A, and green cone structure 22A may be separately and individually selected to exhibit physical and/or chemical properties tailored to the operating conditions to be experienced by each of the respective components. By way of example and not limitation, the composition of the green cutting inserts 24A and the green lands 23A may be selected so as to form cutting inserts 24 comprising a particle-matrix composite material that exhibits a different hardness, wear resistance, and/or toughness different from that exhibited by the particle-matrix composite material of the cone 22.

The cutting inserts 24 and lands 23 may be formed from a variety of particle-matrix composite material compositions. The particular composition of any particular cutting insert 24 and the lands 23 may be selected to exhibit one or more physical and/or chemical properties tailored for a particular earth formation to be drilled using the drill bit 10 (FIG. 1). Additionally, cutting inserts 24 and lands 23 having different material compositions may be used on a single cone 22.

By way of example and not limitation, in some embodiments of the present invention, the cutting inserts 24 and the lands 23 may comprise a particle-matrix composite material that includes a plurality of hard particles that are harder than a plurality of hard particles of the particle-matrix composite material of the cone 22. As another non-limiting example, the concentration of the hard particles in the particle-matrix composite material of the cutting inserts 24 and the lands 23 may be greater than a concentration of hard particles in a particle-matrix composite material of the cone 22.

Although the cutter assembly 14' shown in FIG. 6C is illustrated as comprising the cone 22, the cutting inserts 24, lands 23 and the bearing structures 68, it is contemplated that in additional embodiments, the cutter assembly 14' may not be formed with separate green bearing structures 68A, as described herein. Furthermore, as described above, the cutter assembly 14' may be formed by combining a green cone structure 22A, green cutting inserts 24A, green lands 23A and green bearing structures 68A to form a green cutter assembly structure, and subsequently sintering the green cutter assembly to a desired final density. The present invention is not so limited, however, and methods according to further embodiments of the present invention may include assembling green structures, brown structures, fully sintered structures, or any combination thereof, and then sintering or reheating sintered components to the sintering temperature and causing the various components to fuse together to form a unitary, integral cutter assembly structure.

While the cutter assembly 14' previously described herein has a cone 22 that includes insert-type cutting structures, cutter assemblies having cones that include tooth-type cutting structures also may embody teachings of the present invention, and embodiments of methods of the present invention may be used to form cutter assemblies having cones that include such tooth-type cutting structures. For example, FIG. 7 illustrates another earth-boring drill bit 74 according to an embodiment of the present invention which comprises a plurality of cutter assemblies 80 each having a cone 88 that includes cutting teeth 104.

As shown in FIG. 7, the earth-boring drill bit 74 has a bit body 76 that may have threads 78 formed on its upper end for connection to a drill string (not shown). The bit body 76 may have three integrally formed bit legs 82, each supporting a bearing pin 84 (not shown). In some embodiments, the bit body 76 and the bearing pins 84 may be formed of a steel alloy in a conventional manner. Additionally, the bit body 76 may have nozzles 86 for discharging drilling fluid into the borehole, which may be returned along with cuttings up to the surface during a drilling operation.

As shown in FIG. 7, each cone 88 may have a plurality of rows of cutting teeth 104. The teeth 104 may vary in number, have a variety of shapes, and the number of rows may vary. A conical gage surface 106 may surround the back face 102 of each cone 88 and define the outer diameter of the drill bit 74. As discussed in further detail below, one portion of each tooth 104 may be integrally formed with the body of each cone 88, and another portion of each tooth 104 may be formed using a separate green or brown cone structure that is fused to the cone 88 during a sintering process.

FIG. 8 is an enlarged partial cross-sectional view illustrating a portion of one of the cutter assemblies 80 mounted on a bearing pin 84, and shows each of the teeth 104 rotated about the cone 88 into the plane of the figure so as to illustrate the so-called "cutting profile" defined by the cutting surfaces of all the teeth 104 on the cone 88. As shown in FIG. 8, each bearing pin 84 of the drill bit 74 (see FIG. 7) may support one of the cutter assemblies 80. Each cone 88 of the cutter assemblies 80 may have a central cavity 90 that provides a journal bearing surface adjacent the bearing pin 84. The cone 88 may have a flat thrust shoulder 92 and may have a lock groove 94 formed within the central cavity 90. In such a configuration, a snap ring 96 may be located in the lock groove 94 and a mating groove may be formed on the bearing pin 84 for locking the cone 88 in position on the bearing pin 84. The cone 88 also may have a seal groove 98 for receiving a seal 100. The seal groove 98 may be located adjacent a back face 102 of the cone 88. By way of example and not limitation, the seal 100 may be an elastomeric ring. In some embodiments, the back face 102 of the cone 88 may comprise a substantially flat annular surface surrounding the entrance to the central cavity 90.

Lubricant may be supplied to spaces between the central cavity 90 of the cone 88 and the bearing pin 84 by lubricant passages 108. The lubricant passages 108 may lead to a reservoir that includes a pressure compensator 110 (FIG. 7).

The cone 88 may comprise a particle-matrix composite material as previously described in relation to the cone 22 shown in FIG. 2. Similarly, the cone 88 may be formed using methods substantially similar to those previously described in relation to the cone 22 with reference to FIGS. 3 and 4. In general, the cone 88 may be formed by green or brown billet, machining the green or brown billet to form a green or brown cone structure, and sintering the green or brown cone structure to a desired final density. The cone 88 includes lands 103 formed from a variety of particle-matrix composite material compositions. The particular composition of any particular land 103 may be selected to exhibit one or more physical and/or chemical properties tailored for a particular earth formation to be drilled using the drill bit 74 (FIG. 7). Additionally, lands 103 having different material compositions from each other may be used on a single cone 88.

By way of example and not limitation, in some embodiments of the present invention, the lands 103 may comprise a particle-matrix composite material that includes a plurality of hard particles that are harder than a plurality of hard particles of the particle-matrix composite material of the cone 88. As another non-limiting example, the concentration of the hard particles in the particle-matrix composite material of the lands 103 may be greater than a concentration of hard particles in a particle-matrix composite material of the cone 88.

A portion of the cone 88 is illustrated in FIG. 8A in cross-section showing the various rows of teeth 104 of the cone 88 and the lands 103 located therebetween.

In FIG. 8B a portion of a cone 88 is illustrated in perspective to show the rows of teeth 104 and the lands 103 located between the rows of teeth 104.

In FIG. 8C a portion of a cone 88 is illustrated in cross-section showing the various rows of teeth 104 and lands 103B located between the rows of teeth 104. As the lands 103B are recessed into the cone 88, a green insert 103C is inserted into the land 103B at a desired location. The green inserts 103C maybe of any desired length and size to fit into the lands 103.

In FIG. 8C illustrated is another embodiment of a method of the present invention and that may be used to form the cutter assembly 80 shown in FIGS. 7 and 8. The method is substantially similar to that previously described in relation to FIG. 8. A green cone structure 88B may be provided that is substantially similar to the green cone structure 88A shown in FIG. 9. The green cone structure 88B, however, may include a plurality of land base structures 103B. In this configuration, a green plug structure 103C may be provided within each of the apertures 103B. The green plug structures 103C may be formed from the same materials and in substantially the same manners previously described in relation to the green cutting inserts 24A (FIGS. 6A-6B). In some embodiments, the green plug structures 103C may be secured within the apertures 103B using an adhesive.

After assembling the green plug structures 103C and the green cone structures 88A, the resulting structure may be sintered to a desired final density to form the fully sintered cutter assembly 80 as shown in FIGS. 7 and 8.

FIG. 9 illustrates one embodiment of a method of the present invention and that may be used to form the cutter assembly 80 shown in FIGS. 7 and 8. As shown therein, in some methods that embody teachings of the present invention, a green cone structure 88A may be provided by machining a greet billet. The green cone structure 88A may include a plurality of tooth base structures 105A. A protruding feature 116 may be provided on each of the tooth base structures 105A, and a green cap structure 112 may be provided on each of the protruding features 116. The green cap structures 112 may be formed from the same materials and in substantially the same manners previously described in relation to the green cutting inserts 24A (FIGS. 6A-6B). In some embodiments, the green cap structures 112 may be secured to the protruding features 116 using an adhesive. The tooth base structures 105A, together with the green cap structures 112 thereon, define a plurality of green teeth structures 104A.

After assembling green caps structures 112 on the tooth base structures 105A to form the green teeth structures 104A, the resulting structure may be sintered to a desired final density to form the fully sintered cutter assembly 80 as shown in FIGS. 7 and 8.

The material composition of the green cap structures 112 and the green cone structure 88A may be separately and individually selected to exhibit physical and/or chemical properties tailored to the operating conditions to be experienced by each of the respective components. By way of example and not limitation, the composition of the green cap structures 112 may be selected so as to form, upon sintering the green cap structures 112, a particle-matrix composite material that exhibits a different hardness, wear resistance, and/or toughness different from that exhibited by the particle-matrix composite material of the cone 88 (FIGS. 7 and 8).

FIG. 10 illustrates another embodiment of a method of the present invention and that may be used to form the cutter assembly 80 shown in FIGS. 7 and 8. The method is substantially similar to that previously described in relation to FIG. 9. A green cone structure 88B may be provided that is substantially similar to the green cone structure 88A shown in FIG. 9. The green cone structure 88B, however, may include a plurality of tooth base structures 105B, each of which has an aperture 118 therein. In this configuration, a green plug structure 114 may be provided within each of the apertures 118. The green plug structures 114 may be formed from the same materials and in substantially the same manners previously described in relation to the green cutting inserts 24A (FIGS. 6A-6B) and the green cap structures 112 (FIG. 9). In some embodiments, the green plug structures 114 may be secured within the apertures 118 using an adhesive. The tooth base structures 105B, together with the green plug structures 114, may define a plurality of green teeth structures 104B.

After assembling green plug structures 114 on the tooth base structures 105B to form the green teeth structures 104B, the resulting structure may be sintered to a desired final density to form the fully sintered cutter assembly 80 as shown in FIGS. 7 and 8.

As described above, the cutter assembly 80 shown in FIGS. 7 and 8 may be formed by combining a green cone structure 88A, 88B with green cap structures 112 and/or green plug structures 114 to form a green cutter assembly, and subsequently sintering the green cutter assembly to a desired final density. The present invention is not so limited, however, and other embodiments of methods of the present invention may include assembling green structures, brown structures, fully sintered structures, or any combination thereof, and then sintering or reheating sintered components to the sintering temperature and causing the various components to fuse together to form a unitary, integral cutter assembly structure. By way of example and not limitation, the green cone structure 88A shown in FIG. 9 may be partially sintered to form a brown cone structure (not shown), and the green cap structures 112 may be assembled with the brown cone structure. The resulting structure then may be sintered to a final density to fuse the cap structures to the cone structure and form the teeth 104 (FIG. 7). As another non-limiting example, the green plug structures 114 shown in FIG. 10 may be partially sintered to form brown plug structures (not shown), and the brown plug structures may be assembled with the green cone structure 88B. The resulting structure then may be sintered to a final density to fuse the plug structures to the cone structure and form the teeth 104 (FIG. 7).

While teachings of the present invention are described herein in relation to embodiments of tri-cone rotary drill bits, other types of earth-boring drilling tools such as, for example hole openers, rotary drill bits, raise bores, fixed/rotary cutter hybrid drill bits, cylindrical cutters, mining cutters, and other such structures known in the art, may embody the present invention and may be formed by methods that embody the present invention. Furthermore, while the present invention has been described herein with respect to certain preferred embodiments, those of ordinary skill in the art will recognize and appreciate that it is not so limited. Rather, many additions, deletions and modifications to the described and illustrated embodiments may be made without departing from the scope of the invention as hereinafter claimed. In addition, features from one embodiment may be combined with features of another embodiment while still being encompassed within the scope of the invention as contemplated by the inventors.

CLAIMS

What is claimed is:

1. A method of forming a cutter assembly for use on an earth-boring tool, the method characterized in that:

providing a less than fully sintered cone structure comprising first hard particles and a matrix material, the cone structure having positions for at least two rows of cutting elements to be located thereon and a land located between the at least two rows of cutting elements, the land comprising second hard particles and a matrix material; and

sintering the cone structure to a final density to fuse the at least one cutting element to the cone structure.

2. The method of claim 1, wherein providing a less than fully sintered cone structure is further characterized in that:

mixing the first hard particles and second hard particles with other particles comprising the matrix material to form a powder mixture; and

pressing the powder mixture to form the green cone structure.

3. The method of claim 2, further characterized in that:

selecting the first hard particles and the second hard particles from the group consisting of diamond, boron carbide, boron nitride, aluminum nitride, and carbides or borides of the group consisting of W, Ti, Mo, Nb, V, Hf, Ta, Cr, Zr, Al, and Si; and

selecting the matrix material from the group consisting of cobalt-based alloys, iron-based alloys, nickel-based alloys, cobalt and nickel-based alloys, iron and nickel-based alloys, iron and cobalt-based alloys, aluminum-based alloys, copper-based alloys, magnesium-based alloys, and titanium-based alloys.

4. The method of claim 1, further characterized in that machining at least one aperture in the less than fully sintered cone structure for positioning at least one cutting element on the less than fully sintered cone structure.

5. The method of claim 1, further characterized in that machining at least one protrusion on the less than fully sintered cone structure for positioning at least one cutting element on the less than fully sintered cone structure onto the at least one protrusion of the green cone structure.

6. The method of claim 1, further characterized in that positioning at least one cutting element on the less than fully sintered cone structure comprising third hard particles and a matrix material on the less than fully sintered cone structure.

7. The method of claim 1, further characterized in that:

positioning at least one bearing structure on the less than fully sintered cone structure; and

fusing the bearing structure to the less than fully sintered cone structure while sintering the cone structure to a final density.

8. The method of claim 1, further characterized in that mounting the cone structure on a bearing pin of an earth-boring tool.

9. An earth-boring tool characterized in that:

a bearing pin; and

a cutter assembly rotatably mounted on the bearing pin, the cutter assembly comprising:

a cone comprising a particle-matrix composite material having a first material composition and a second material composition in the land region thereof.

10. The earth-boring tool of claim 9, wherein the particle-matrix composite material of the cone of the first material composition and the second material composition are each characterized in that a plurality of hard particles dispersed throughout a matrix material, the hard particles comprising a material selected from diamond, boron carbide, boron nitride, aluminum nitride, and carbides or borides of the group consisting of W, Ti, Mo, Nb, V, Hf, Ta, Cr, Zr, Al, and Si, the matrix material selected from the group consisting of cobalt-based alloys, iron-based alloys, nickel-based alloys, cobalt and nickel-based alloys, iron and nickel-based alloys, iron and cobalt-based alloys, aluminum-based alloys, copper-based alloys, magnesium-based alloys, and titanium-based alloys.

11. The earth-boring tool of claim 9, further characterized in that at least one bearing structure co-sintered and integral with the cone.

12. The earth-boring tool of claim 9, wherein the at least one bearing structure is characterized in that a particle-matrix composite material.

13. The earth-boring tool of claim 9, further characterized in that at least one cutting element.

14. The earth-boring tool of claim 9, further characterized in that at least a portion of a cutting tooth structure.

15. The earth-boring tool of claim 9, wherein the at least one cutting element is characterized in that the at least one cutting element has a varying material composition between a first region proximate an interface between the at least one cutting element and the cone and a second region proximate a formation-engaging surface of the at least one cutting element.

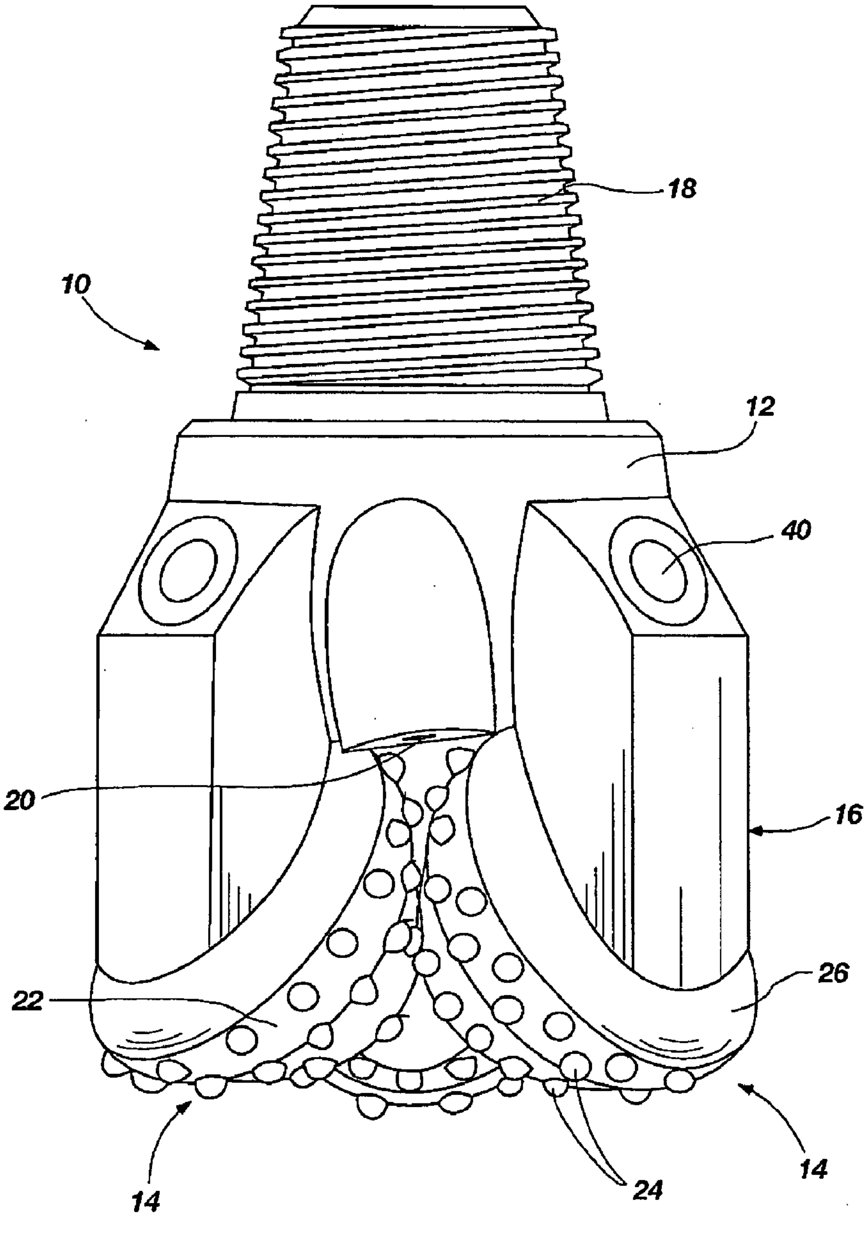

FIG. 1

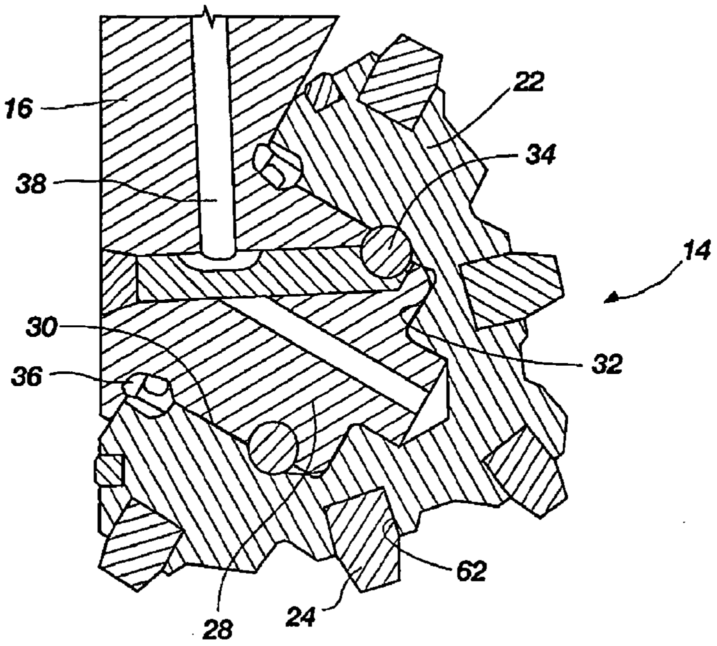

FIG. 2

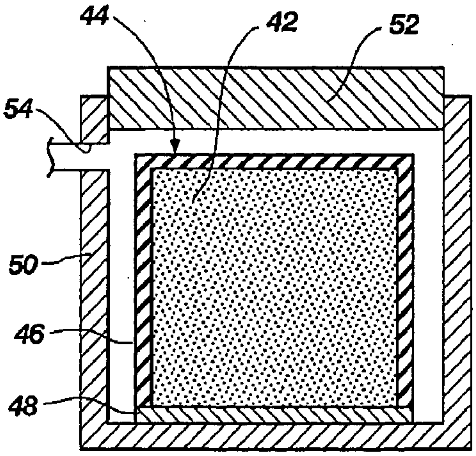

FIG. 3

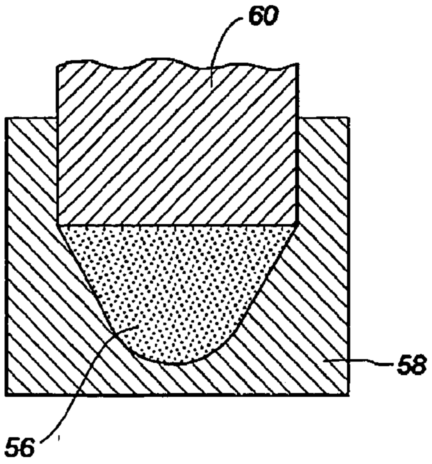

FIG. 4

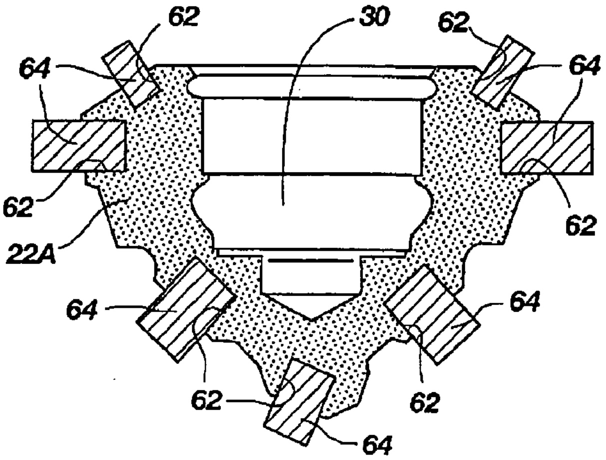

FIG. 5A

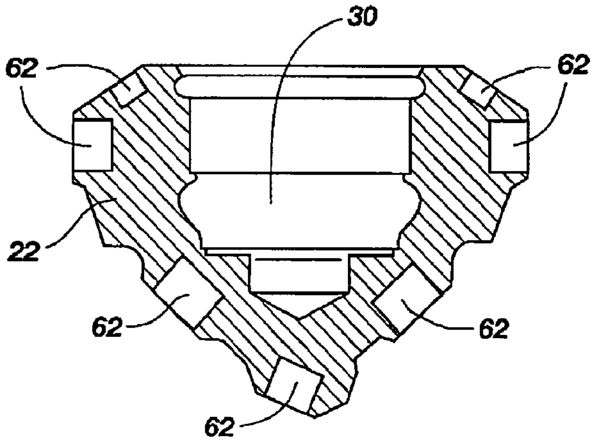

FIG. 5B

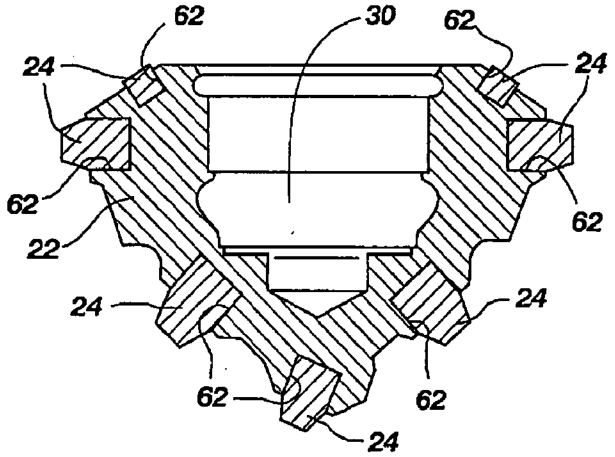

FIG. 5C

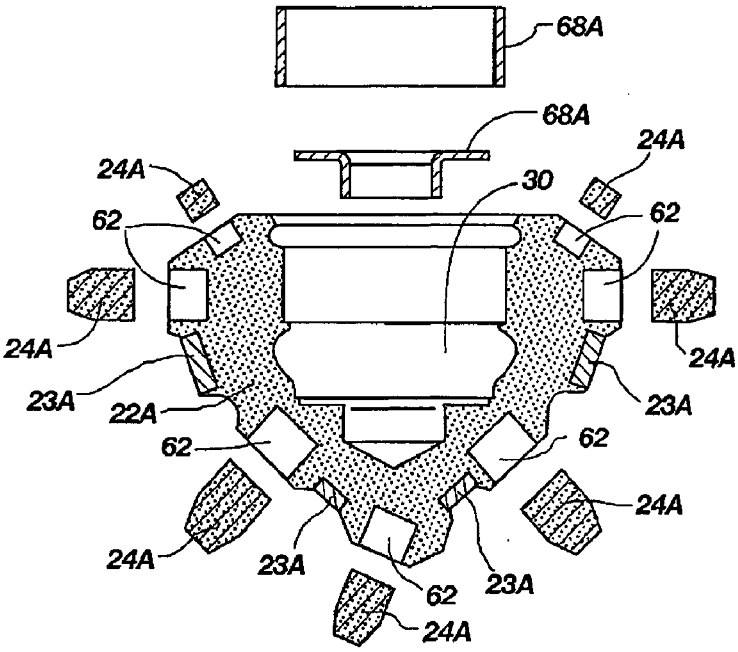

FIG. 6A

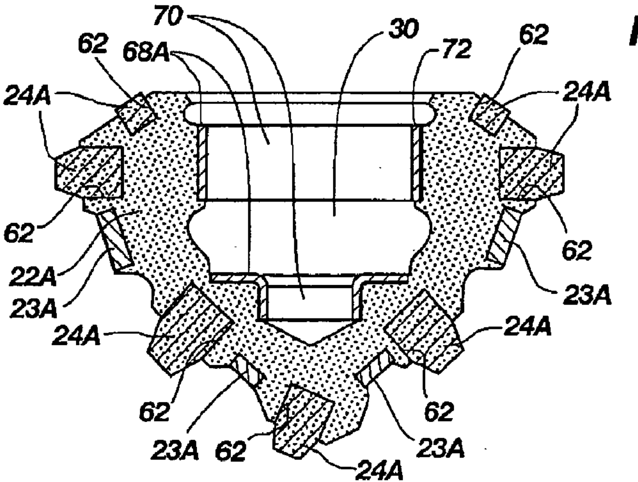

FIG. 6B

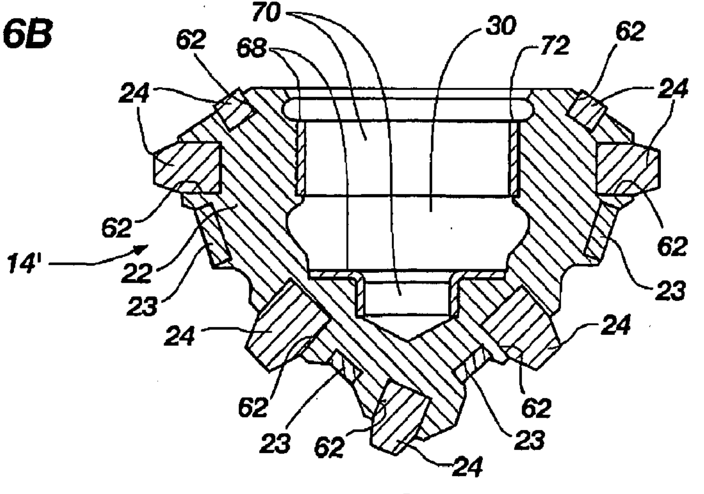

FIG. 6C

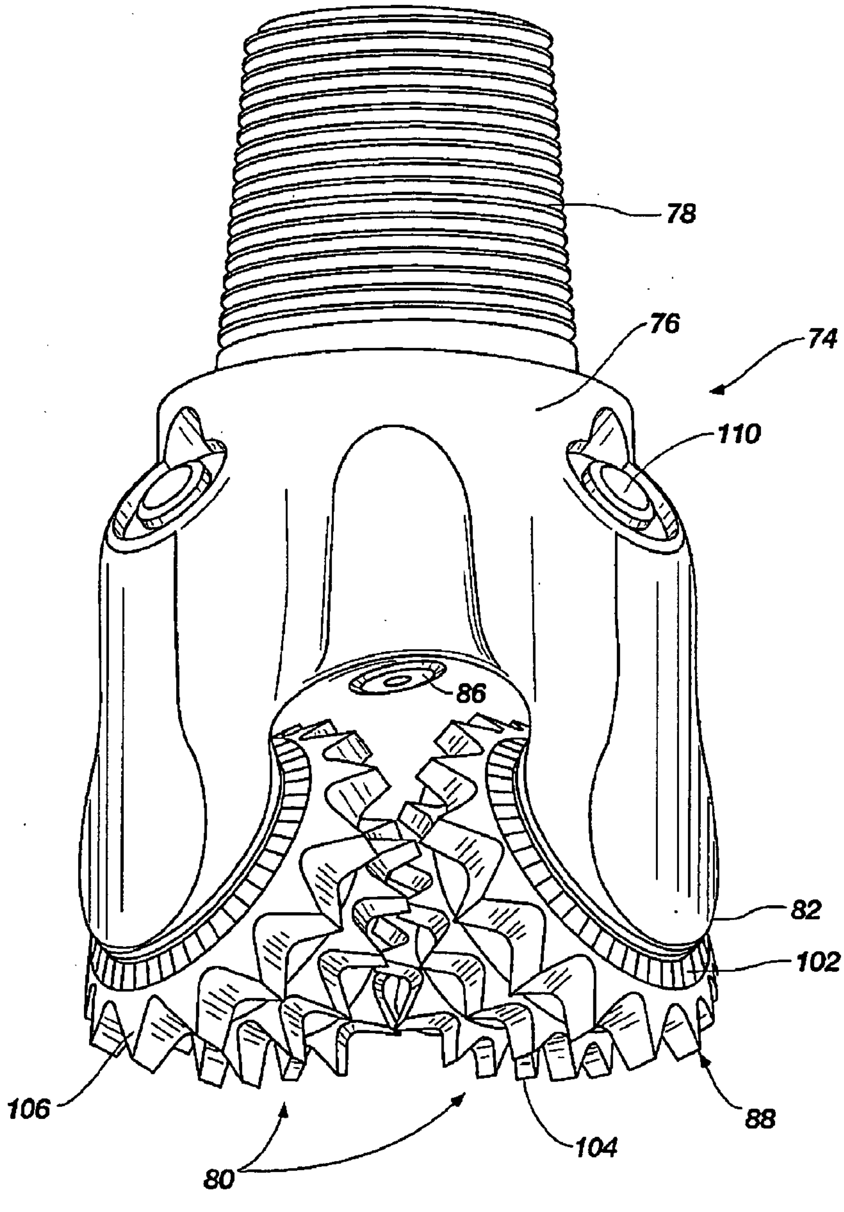

FIG. 7

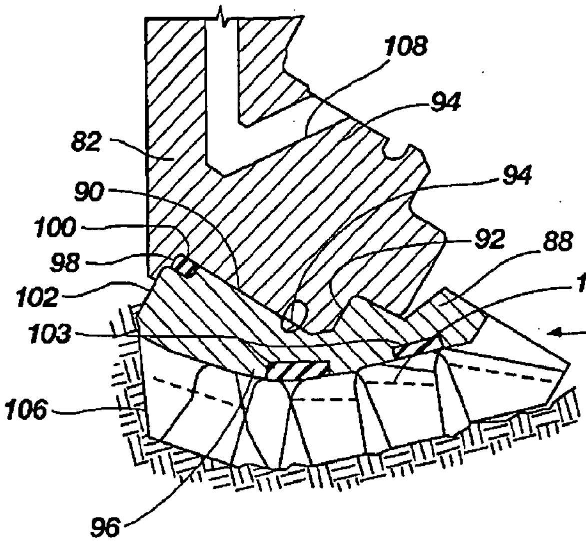

FIG. 8

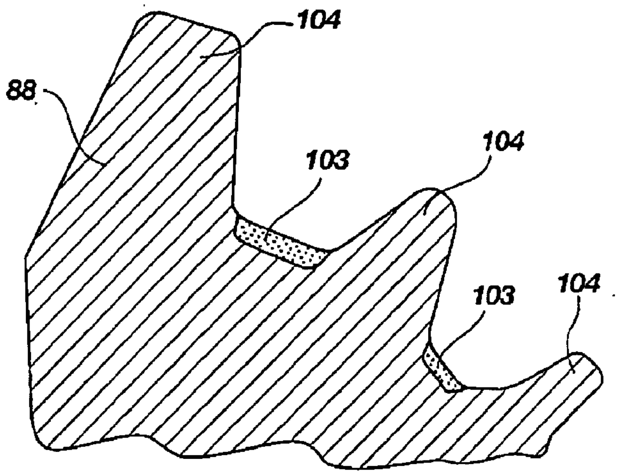

FIG. 8A

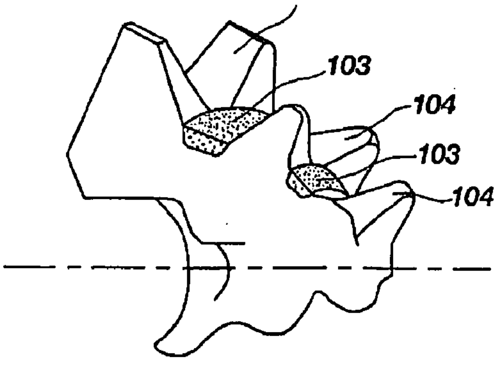

FIG. 8B

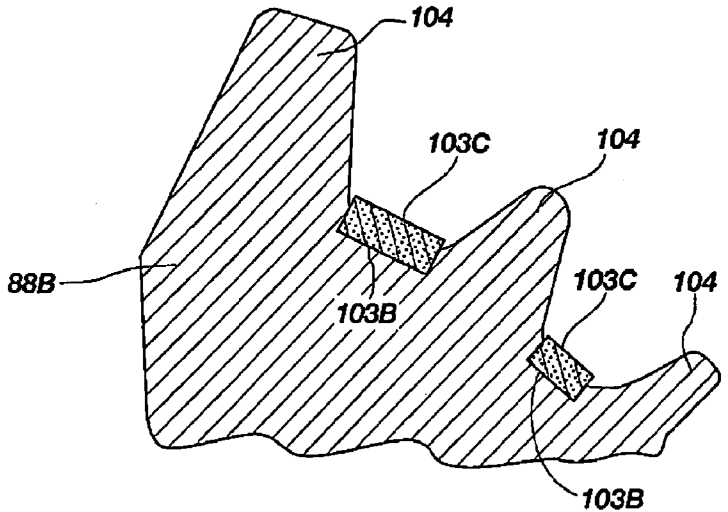

FIG. 8C

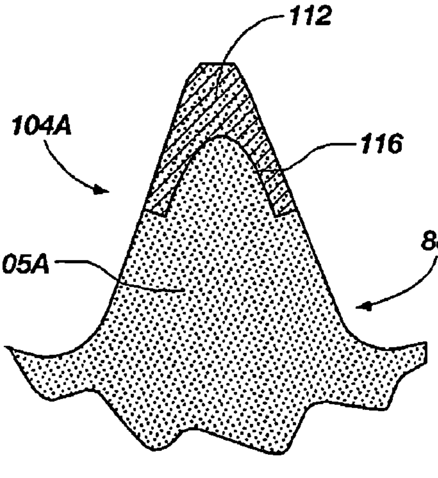

FIG. 9

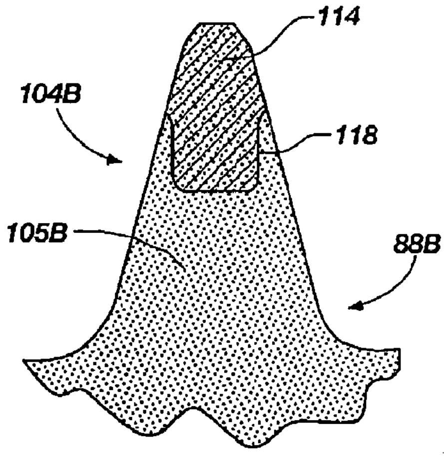

FIG. 10